rock lobster and any ontogenetic, temporal and spatial shifts in its diets. The study will provide a sound basis for understanding trophic relations at higher levels and will lay the groundwork for understanding what, if any, are the direct and indirect effects of fishing on coastal ecosystems. Furthermore, in combination with the compilation of data from the other related projects within the program, this study will help establish baseline data on the biodiversity and ecology of Jurien Bay Marine Park. Such base-line data is essential for assessing whether the size of current management zones within the marine park are adequate, and for future assessment of the effectiveness of management zones in the newly established Jurien Bay Marine Park.

3.3.6 Ecophysiology of Benthic Primary Producers

Investigators / Institutions

Professor Paul Lavery	Centre for Ecosystem Management, Edith Cowan University
Dr Russ Babcock	Marine and Atmospheric Research, CSIRO
Dr Ray Masini	Department of Environment (WA)
Dr Kathryn McMahon	Centre for Ecosystem Management, Edith Cowan University

Executive Summary

Reduction in the availability of light, due to a range of anthropogenic activities, has been identified as a major cause of benthic habitat loss. Understanding the role of light as a driver of ecosystem integrity is fundamental to managing the State's benthic marine ecosystems. Such knowledge can underpin the development of environmental quality criteria and identify indicators of sub-lethal stress in marine ecosystems, permitting early management intervention. To help fill current knowledge gaps, this project aims to determine the effect of different intensities, durations and timing of light reductions on *Amphibolis* ecosystems and to determine the subsequent patterns of recovery. The project is in its second year, and is due to be completed in late 2007.

In a two-phase project the response of the meadow-forming seagrass *Amphibolis griffithii* (Black) den Hartog to light reduction was examined. The first phase examined severe (>90%) light reductions over a 3-month period and a subsequent one month recovery period. The second phase examined the effects of varying the intensity and duration of light reductions. Morphological and physiological variables were measured in meadows subjected to reduction in light and in control plots. In the first phase experiment, leaf biomass, leaf cluster density and the number of leaves per cluster all declined in shaded plots and after 3 months were about 30%, 50% and 60% of the controls, respectively. Leaf extension was one third that of the control plots. Epiphyte biomass in shaded plots was 44% of the controls after 6 weeks shading and 18% after 3 months shading. Leaf chlorophyll concentration was affected by shading, but only in the upper canopy: shaded leaves had 55% more chlorophyll than control leaves. Shading reduced the carbohydrate stored in the rhizomes of shaded plants: sugars declined rapidly and continuously and after 3 months were less than 20% of controls; a decline in starch concentrations lagged that of sugars. All variables showed a significant shift towards the values in control plots 42 days after removal of shading, indicating capacity for recovery, though in many cases these remained significantly lower than the controls.

In the subsequent, phase 2 experiment significant reductions in seagrass and algal biomass were observed following three, six and nine months of moderate and heavy light reduction in plots shaded at the end of summer, where the maximum carbohydrate reserves were expected. After nine months shading no leaves remained. The abundance of

macroinvertebrate fauna also reduced after 3 months of shading. In direct contrast to the phase 1 study, there was no recovery in the plots shaded for three and six months up to four months after shading was removed. Additional samples will be taken to determine when the shaded plots return to the same conditions as the control plots. There was some recovery in algal epiphyte biomass, though it did not return to control conditions. This implies that three months of continuous shading on *Amphibolis* meadows has a significant impact on the flora and fauna in the ecosystem and recovery will not occur in the short-term, though the basis of the contrast in Phase 1 and Phase 2 outcomes for seagrass recovery remains unclear and is being investigated further.

From our results, the minimum light requirements of *A. griffithii* are estimated at greater than 10% of surface irradiance. *A. griffithii*, its epiphytes and the associated fauna respond rapidly to severe, short-term reductions in light availability. Ongoing work will determine the longer-term recovery, if any, and apply the finding to the development of criteria for assessing the potential significance of light reduction in *A. griffithii* ecosystems.

Introduction

Light is probably the single most important environmental factor controlling coastal benthic primary productivity. A broad range of coastal and marine developments can lead to a reduction in PAR availability at the seabed. In this context, understanding of light and its co-variates as a driver of ecosystem structure is of fundamental importance for the management of the State's marine environment.

Robust and ecologically meaningful indicators of sub-lethal environmental stress must underpin such management. Sound science to inform the development of these indicators and their associated criteria is therefore critical to achieving sustainability in Western Australia. The objectives of this research program are to fill gaps in our understanding of how ecosystems respond to variation in light, in order to improve our ability to understand variations in habitat structure at the ecosystem level and to assess and manage impacts associated with human use of these systems.

Key benthic habitats along the central west coast for which scientific research is required are primarily seagrass meadows and macroalgal reefs. There are particular gaps in the understanding of the effects of light stress on *Amphibolis* species (*A. antarctica* and *A. griffithii*). In the context of allowing the correct balance to be struck between protecting the environment without unnecessarily constraining development, quantitative assessments of the degree of light reduction that can be sustained without irreversible or long-term damage are urgently required.

Only by conducting controlled field experiments that involve the manipulation of known factors are we able to limit the relative contribution of potentially confounding factors to the research outcomes. The research project involves the establishment of treatment and control sites to determine the effect of reduced PAR and the timing and duration of light reduction on *Amphibolis* ecosystems.

Aims/objectives

1. To determine the effect of different intensities, durations and timing of light reductions on *Amphibolis* ecosystems; and

2. To determine the subsequent patterns of recovery.

Methods

A two-stage approach was used to address the aims. In stage 1, a preliminary field experiment examined the effects of intensive, short-term shading on *Amphibolis griffithii*

meadows. This yielded important information on the response to light reductions and also clarified key variables to be measured in Stage 2.

Stage 2 comprised of a more extensive field experiment in which *A. griffithii* ecosystems were subjected to a range of intensities and durations of light reduction and with these treatments commencing at different times of year. Stage 2 commenced in March 2005 and is due to finish in November 2007. The results presented here are, therefore, interim.

Study Site

Both stages of the project were conducted at Jurien Bay, a relatively pristine system on the central Western Australian coast. The Jurien Bay region is dominated by seagrass, patchy sand and macro-algal reef habitats. The study site was located on an extensive (> 6 ha) *Amphibolis griffithii* meadow, on level bathymetry with an approximate depth of 4.0–4.5 m, located 200-300 m NE of Boullanger Island (308402E 6645234N; WGS84 datum). The site was sheltered from the predominant south-westerly winds and swells.

Stage 1 Experiment – High Intensity, short duration Light Reduction

A Before After Control Impact Repeated measures (BACI-R) field experiment was conducted in late summer, the period when *Amphibolis griffithii* plants have their highest levels of carbohydrate storage reserves (Carruthers & Walker 1997) and, possibly, the greatest capacity to withstand reductions in light availability.

Replicate treatment plots (n=4) of *A. griffithii* meadow were subjected to 80% PAR attenuation by shade screens for 106 days, the intensity and duration reflecting those observed in areas adjacent to harbour dredging programmes in the region (Unpublished data, Geraldton Port Authority). Each experimental unit measured 4.5 m x 3.0 m and was covered by a shade screen suspended on metal pickets. Control plots were constructed as above but lacked the suspended shade cloth. Attempts to establish procedural controls, with monofilament net suspended from the pickets, proved useless; they fouled rapidly with epiphytic algae, resulting in a 20-30% reduction in PAR after a few days. Consequently, the procedural controls were abandoned. Previous attempts at maintaining procedural controls for shading have also appeared futile (Bulthius 1983; Collier unpubl).

To validate the reduction in light availability in the treatments, photosynthetic photon flux density (PPFD) was measured at the top of the seagrass canopy across the plot, using a Li-Cor™ quantum photometer. The final workable area used for experimental sampling was approximately 4.5m^2 in the centre of the plots.

Morphological and physiological variables were sampled just prior to imposing the treatments and after 42, 66 and 106 days. After 106 days the shade screens were removed from the treatment plots and all plots were re-sampled after a further 42 days to test for any evidence of recovery following removal of shading.

Differences within and between treatments over time were tested using repeated measures ANOVA, with treatment and time as fixed factors. Prior to conducting ANOVA, all data were tested for compliance with assumptions of homogeneity of variance and normality. Non-compliant data were transformed as per the recommendations of Fowler & Cohen (1990).

Stage 2 Experiment – Multiple intensities and durations and timing of light reductions

Following analysis of the Stage 1 experimental outcomes, a second BACI-style field experiment was established in the study area with three main effects: intensity (high, medium or none), duration (0, 3, 6 or 9 months) and timing (end of winter or summer, to coincide with minimum and maximum carbohydrate reserves) of PPFD reduction. The intensities and durations of shading reflect those typically resulting from dredging programmes in the region (Unpub, Geraldton Port Authority).

Experimental units were constructed as in Stage 1 but with either 80% or 50% light attenuating shade screens. Five replicate plots have been established for each intensity-duration-timing combination, yielding an orthogonal design with 120 plots. Morphological and physiological variables (Table 3.5) have been sampled prior to imposing the treatments (T_o) and after 3, 6 and 9 months of treatment. The plot is re-sampled 3 months after removing shading (recovery period).

Table 3.5. Variables collected in Stage 1 and 2 of the research project.

Variable

Collected in Stage 1 & 2	Collected in Stage 2 only
Above- & below-ground seagrass biomass (leaf, stem, root and rhizome)	Epiphytic and epibenthic faunal composition & biomass
Seagrass morphology (height; stem, cluster & leaf density, leaf length & width, Leaf Area index)	Benthic infauna composition & biomass
Algal epiphyte biomass and composition	MPB composition and relative biomass
Leaf extension rates	Sediment composition and chemistry
Pigment concentration (seagrass leaves and selected algal epiphytes)	C^{13}, N^{15} and fatty acid signatures of fauna and primary producers
Carbohydrate concentrations (seagrass leaves & rhizome)	

In addition to the variables sampled in Stage 1, Stage 2 involves the collection and analysis of fauna and microphytobenthos samples, to determine any consequences of light reduction or seagrass loss for these components of seagrass ecosystems.

Sampling Methods

Photosynthetic Photon Flux Density (PPFD)

PPFD (μmol photon $m^{-2} s^{-1}$) was measured at the top of the seagrass canopy in one randomly chosen control and treatment plot using 'Odyssey Dataflow' submersible incident light sensors with an automated wiper unit to keep the sensor clean. PPFD attenuation through the water column, shade screens and seagrass canopy was determined during and after shading using a Li-Cor™ LI1000 quantum photometer.

Meadow morphology and biomass

Stem density (m^{-2}), percentage cover and maximum and average canopy heights (cm) were measured non-destructively in permanent 0.04 m^2 quadrats in the centre of each experimental plot, as per Duarte & Kirkman (2001). Above-ground biomass was measured destructively from a 20 x 20cm (0.04 m^2) quadrat placed randomly in each plot and separated into leaf, stem and epiphyte components. A core sample (11cm i.d., 0.01 m^2, 20 cm deep) was collected from inside the same 0.04 m^2 quadrat to quantify below-ground biomass (g DW m^{-2} of root, rhizome and detritus).

Leaf productivity, pigments and carbohydrates

Leaf extension was measured over the 2 weeks preceding sampling events, using the procedures of Short & Duarte (2001). Leaf clusters were collected from both the top and bottom of the leaf canopy for pigment and carbohydrate analysis. A 30 mm section from the youngest mature leaf was analysed for chlorophyll following the methods described

by Granger & Iizumi (2001) and Longstaff & Dennison (1999). to ensure fully developed pigment characteristics (Hemminga & Duarte, 2000). Total soluble sugars and starch analyses were performed on ground, dry leaves and rhizomes twice extracted in hot 80% ethanol. Spectrophotometric concentrations were determined as per Dubois & Gilles (1956). Starch content of the remaining material was analysed according to Quarmby and Allen (1989).

Fauna

Epibenthic and epiphytic fauna are collected in calico bags lowered over 0.04 m^2 of seagrass canopy. Benthic infauna are collected by coring sods of sediment (11 cm diameter, 15 cm deep). Fauna are being separated into the size categories of Edgar (1990) to allow biomass and secondary production estimate to be made.

Results

Response to high intensity, short duration light reduction

The seagrass canopy in the shaded treatment plots received 10% of the PPFD in control plots, indicating that the shade screens attenuated 90% of the incoming PPFD. At the end of the shading experiment, there were significant differences in the PPFD attenuated by the canopy in the shaded and control plots (LAC = 2.38 and 0.59 m^{-1}, respectively), representing almost two orders of magnitude difference in light penetration. Once shade screens were removed, the differences in canopy attenuation coefficients resulted in far greater penetration of PPFD through the previously shaded canopies, with 68 ± 7 µmol m^2 s^{-1} reaching the bottom of the previously shaded plots and 10 ± 1 µmol m^2 s^{-1} reaching the bottom of the control plots (Fig 3.34).
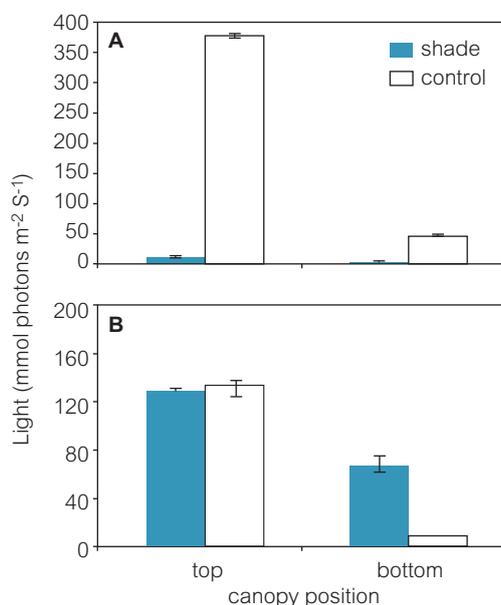

Figure 3.34: Light (PPFD) at the top and bottom of *Amphibolis griffithii* canopies that were subjected to shading (dark) or controls (open). A = during the shading period and B = immediately after removal of shading screens.

Above-ground morphology & biomass

The most obvious effect of shading was a dramatic reduction in the number of leaves and leaf biomass. Total leaf biomass displayed marginal increases over time in the control plots, but declined significantly in shaded plots (Fig 3.35; Table 3.5). After 106 days, the shaded plots had about one-third of the leaf biomass in unshaded plots (150 $\pm$ 38 g m^{-2} and 452 $\pm$ 103 g m^{-2}, respectively). Following removal of the shade screens, leaf biomass increased in the shaded plots and, after 42 days, was similar to the controls.

The reduction in leaf biomass in the shaded plots was due to a loss of leaves from each stem, in each cluster and from a reduction in the number of leaf clusters (Fig 3.35). Following removal of shading, the numbers of leaves per stem and the density of clusters in the shaded treatment increased and after 42 days were similar to the controls. The differences in the number of leaves per cluster persisted after shading treatment was removed.

Stem biomass and stem density in both treatment and control plots remained relatively stable and ranged from approximately 250 – 400 g DW m^{-2} and 250 – 400 stems m^{-2} throughout, respectively (Fig. 3.35), as did canopy heights (average heights ranging from 25 – 38 cm; Fig 3.35).

Epiphyte biomass followed a similar trend to leaf biomass, remaining relatively constant in the control plots but declining in the shaded plots (Fig 3.35). After 42 days of shading epiphyte biomass was less than half that in the control plots (211 $\pm$ 122 and 476 $\pm$ 200 g m^{-2}, respectively) and at the end of the shading period was less than 20% of that in the control (92 $\pm$ 82 and 500 $\pm$ 29 g m^{-2}, respectively). By the end of the recovery period, 42 days after shading had been removed, these differences were much reduced.

Root biomass, rhizome biomass and detrital biomass remained relatively stable throughout the study with little difference between treatments and control (Fig 3.36).

Physiological and growth responses

Leaf extension in control plots remained constant over the experimental period, at about 0.6 mm leaf^{-1} d^{-1} but in the treatment plots decreased to approximately one half and one third of this after 66 and 106 days of shading, respectively (Fig 3.37). In the recovery phase (after removal of shading), the differences between control and shaded plots persisted after the first 12 days but were not significant after 42 days. Areal leaf production (mm m^{-2} d^{-1}) followed similar patterns to leaf extension rates (Fig 3.37).

In the rhizomes, sugar concentrations declined sharply in the shaded treatments but remained relatively constant in the controls (Fig 3.38A). At the end of the shading period rhizome sugar concentrations in shaded treatments were 19% of the controls. Following removal of shading, rhizome sugar concentrations increased but were still significantly lower than the controls. Concentrations of starch in the rhizome declined significantly with shading, to 50% of the controls and showed only a minor increase 42 days after removal of shading (Fig 3.38B).

In the leaves, total soluble sugar concentration was significantly affected by shading but not starch concentrations (Fig 3.38C,D). After 38 days, the sugar concentrations in the shaded treatments were 47% of that in the control plants. For the remainder of the shading period, the concentration of sugars in the shaded leaves remained constant while in the controls it fell, so that by the end of the shading period, and throughout the recovery period there were no significant differences between the two. Concentrations of starch in the leaves at the start of the experiment were significantly higher in the treatment plots than controls, making control vs impact comparisons difficult.
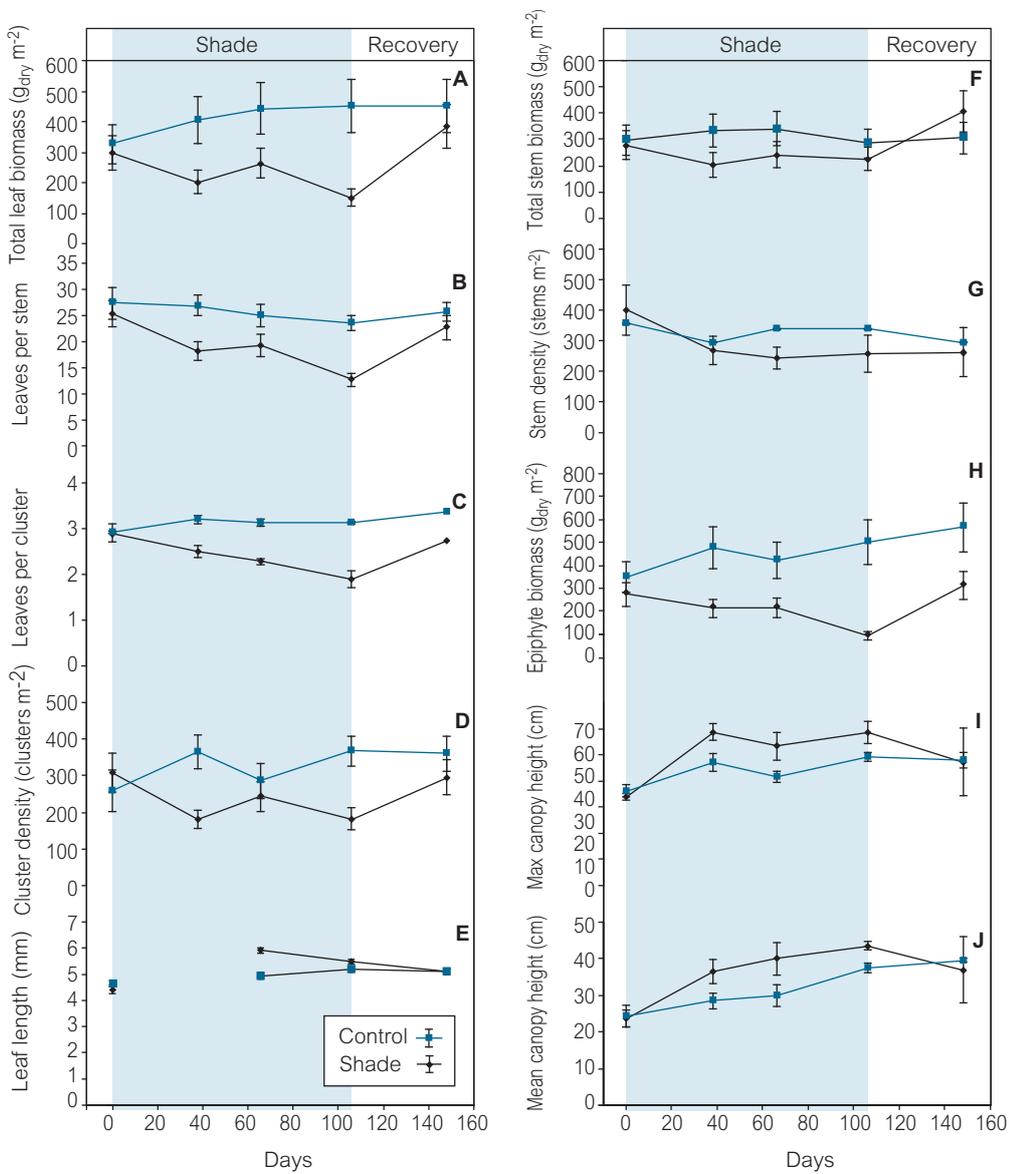
Figure 3.35: Above ground shoot and meadow characteristics of *Amphibolis griffithii* meadow meadows during shading and subsequent recovery periods in shaded (black) and control (grey) plots. A) leaf biomass, B) leaves stem[-1], C) leaves cluster[-1], D) cluster density, E) leaf length, F) stem biomass, G) stem density, H) epiphytic algae biomass, I) maximum canopy height, J) mean canopy height. Data are means (n=4) ± SE.
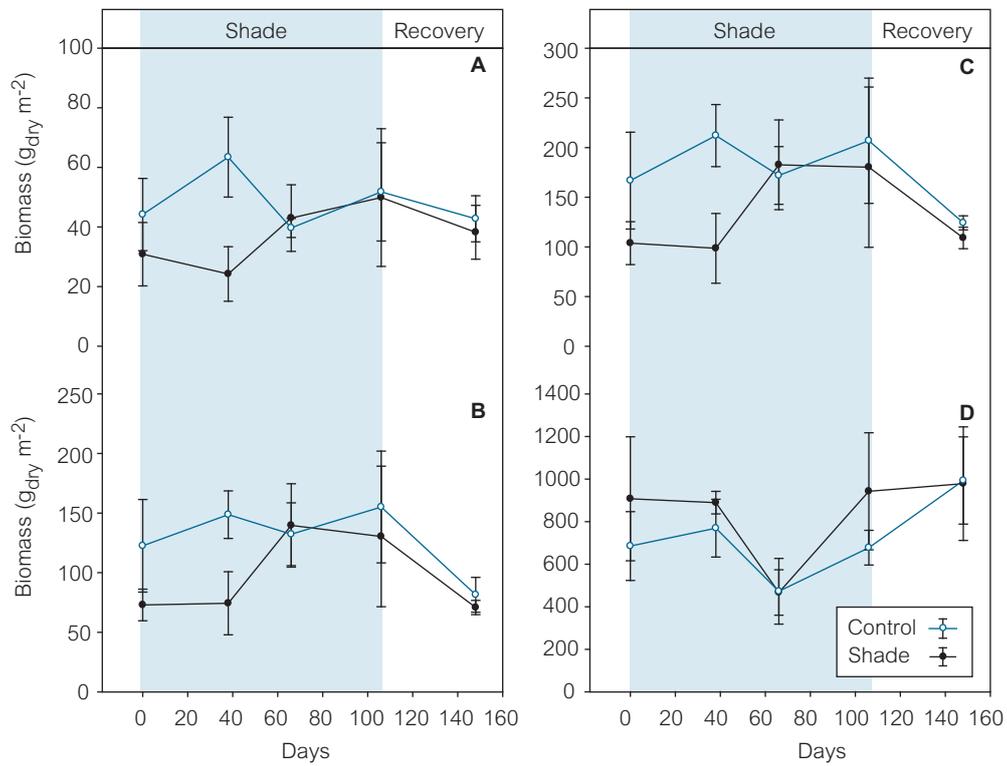
Figure 3.36: Below-ground biomass characteristics of *Amphibolis griffithii* meadow during shading and subsequent recovery periods in shaded (black) and control (grey) plots. A) Total below-ground biomass (rhizome + root + detritus), B) rhizome biomass, C) root biomass, D) detritus biomass. Data are means (n=4) ± SE.
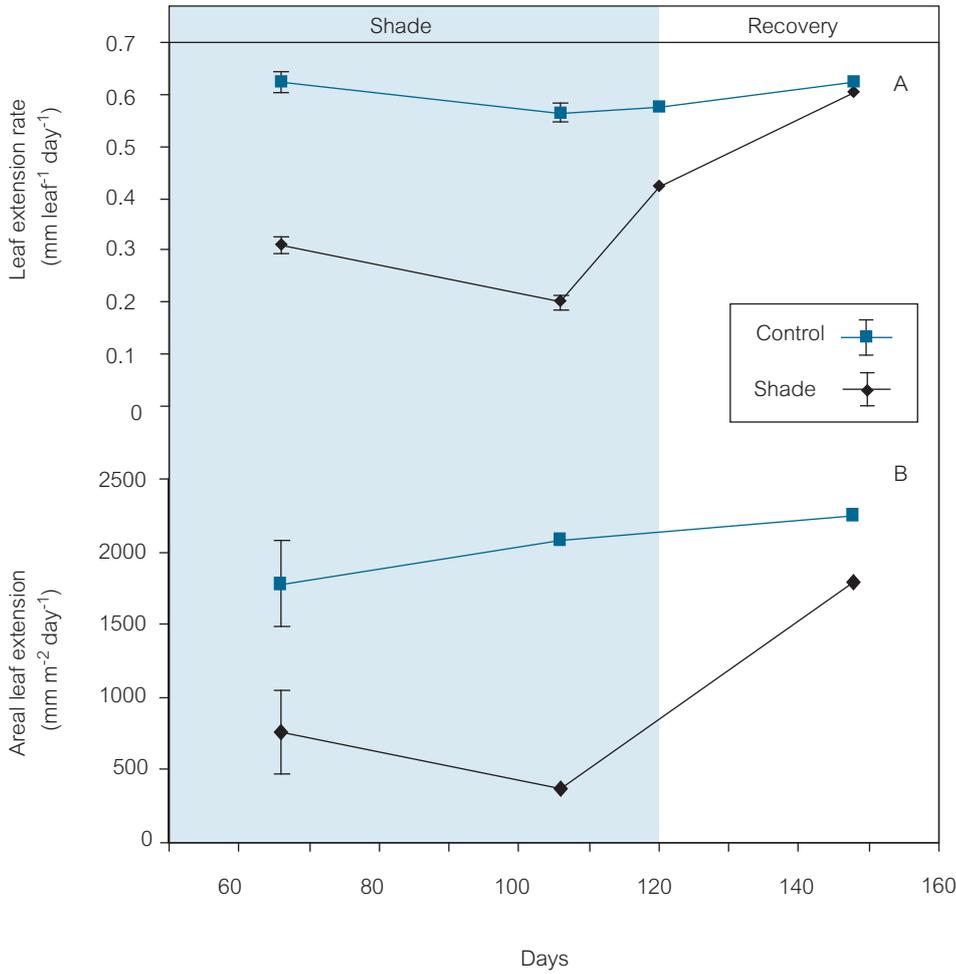
Figure 3.37: Leaf extention rates (A) and aerial leaf extension rates (B) in *Amphibolis griffithii* meadow during shading and subsequent recovery periods in shaded (black) and control (grey) plots. Data are means (n=4) ± SE.
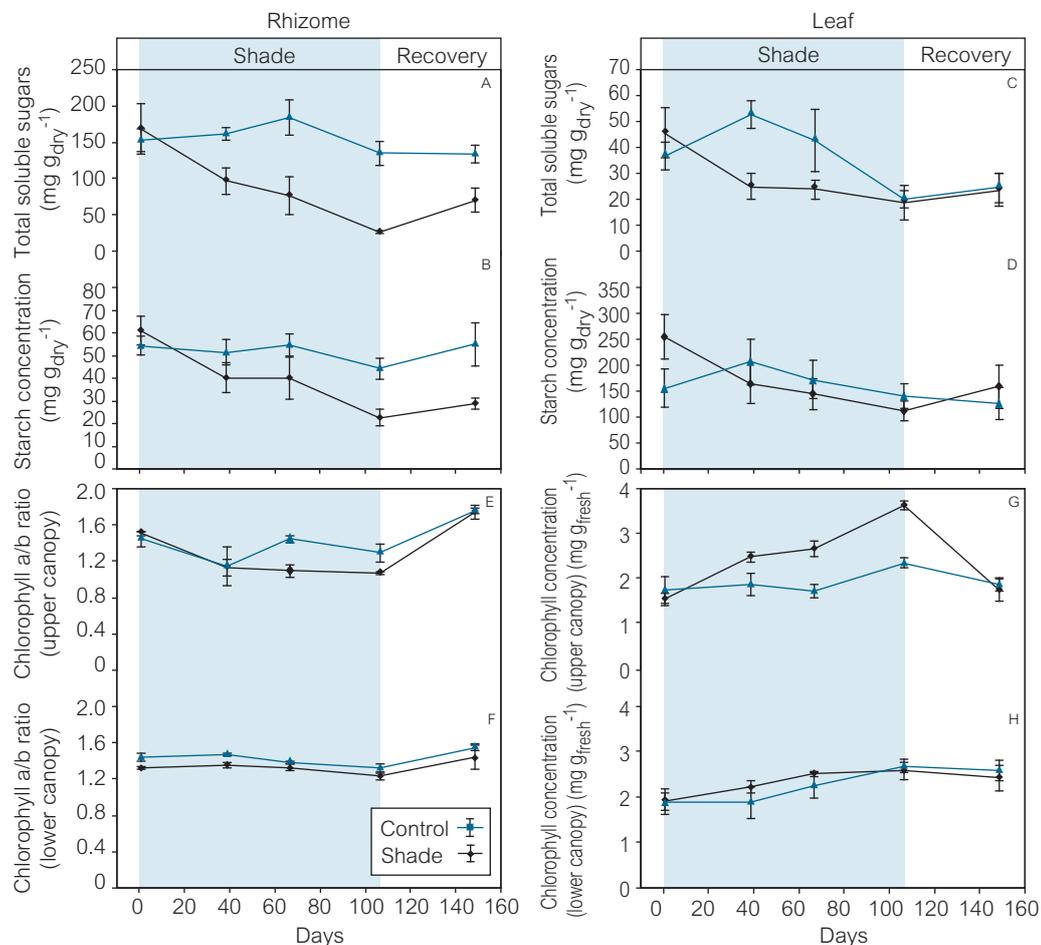
Figure 3.38: Carbohydrate and chlorophyll characteristics of *Amphibolis griffithii* meadow during shading and subsequent recovery periods in shaded (black) and control (grey) plots. A) soluble sugars in the rhizome, B) starch in the rhizome, C) soluble sugar in leaves, D) starch in leaves, E) chl *a/b* in upper canopy leaves, F) chl *a/b* in lower canopy leaves, G) chl (*a+b)* in upper canopy leaves, F) chl (*a+b)* in lower canopy leaves. Data are means (n=4) ± SE.

Shading had a significant effect on the chlorophyll concentration of leaves but only in the upper canopy (Table 3.5 & Fig 3.38F). At the start of the shading period shaded and control plants had similar concentrations of chlorophyll in upper canopy leaves (about 1600 ug chl g^{-1}) but after 66 days the mean concentration was higher in control leaves and after 106 days had increased to 3.6 ± 0.1 mg chl g^{-1} in shaded plants, 55% greater than control plants (2.3 ± 0.1 ug chl g^{-1}). Once shading was removed, the chlorophyll concentration of the upper leaves in the shaded treatments fell and after 42 days were similar to those of the controls.

Response to differing intensities and durations and timing of light reduction

The Stage 2 experimental study extended on the Stage 1 project to examine the effects of differing intensities and longer durations of light reduction, and any effect the timing of light reductions. At this stage, preliminary results are available for different intensities and durations of shading commenced in summer.

The stage 2 results extended the observations from Stage 1 to 6 and 9 months of shading. As in the Stage 1 studies, significant reductions in seagrass and algal biomass were observed after three months of light reduction at the end of summer. After 3 months of shading, above ground biomass had declined to 50% of the controls in the moderate and highly shaded

treatments (Fig 3.39). After 9 months, however, no leaves remained in either the moderate or heavily shaded treatments and the above ground seagrass biomass comprised of stems only, being about 40% of controls in moderately shaded plots and 25% in the heavily shaded plots.
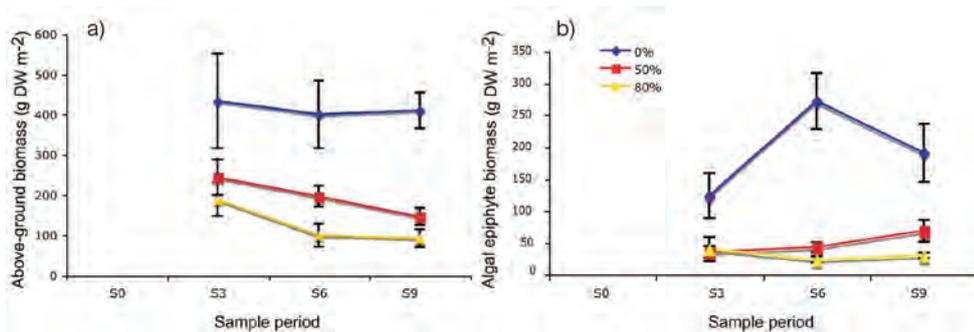

Figure 3.39: Total above-ground biomass (a) of, and algal epiphyte biomass (b) on *A. griffithii* in plots shaded at the end of summer for 3, 6 and 9 months with moderate and high light reduction.

Leaf productivity was significantly lower in the shaded treatments after 3 and 6 months of shading, being about 30% (0.25 mm d^{-1} m^{-2}) and 19% (0.16 mm d^{-1} m^{-2}) of that in the controls, respectively. This reduction was not evenly distributed across all clusters. For example, after 3 months of shading 40% of clusters in moderate shading and 34% in heavily shaded plots showed no growth, while the remainder showed some leaf extension.

The loss of seagrass biomass was paralleled with a loss of epiphyte biomass (Fig 3.39). As in the stage 1 studies, epiphyte biomass fell dramatically in the first 3 months of shading, to about 20% of the controls. This loss was similar under both moderate and heavy shading. After 9 months of shading, the epiphyte biomass was about 28% and 12% of that in controls for moderately and heavily shaded treatments, respectively.

Four months after shading ceased, there was no recovery of above-ground seagrass in the plots shaded for three and six months (Fig 3.40). There was some recovery in algal epiphyte biomass, though it did not return to control conditions.
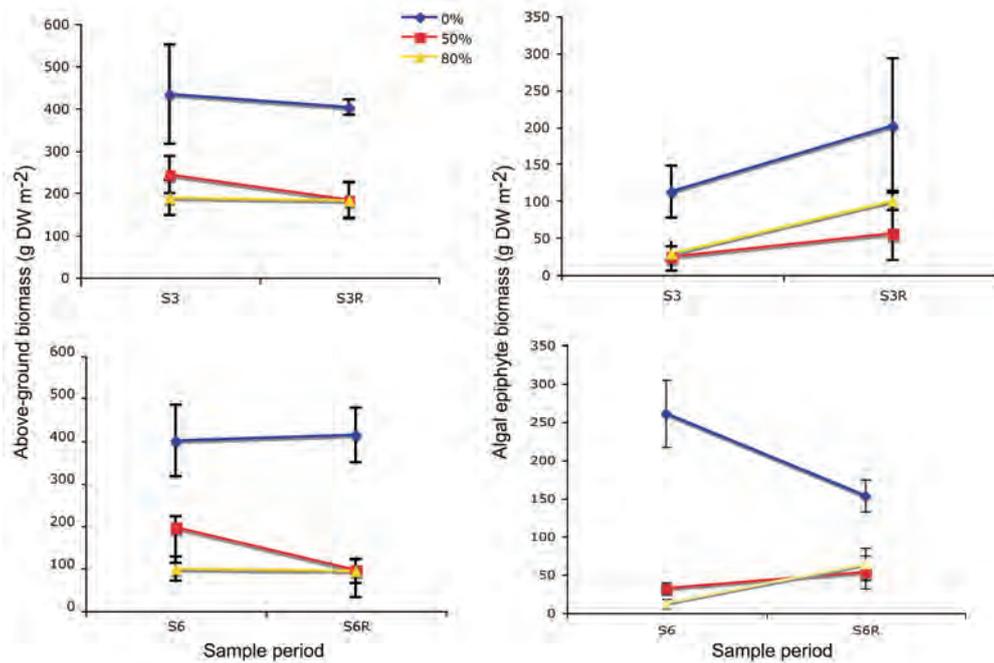
Figure 3.40: Above-ground biomass of and algal epiphyte biomass on *A. griffithii* in plots shaded at the end of summer for 3 and 6 months with moderate and high light reduction, and the recovery of these shading durations.

The abundance of macroinvertebrate fauna in the seagrass canopy also reduced after 3 months of shading (Fig 3.41). This decline was consistent across all three groups of fauna examined, crustacea, molluscs and polychaetes, but was more severe in the heavily shaded treatment than the moderate.
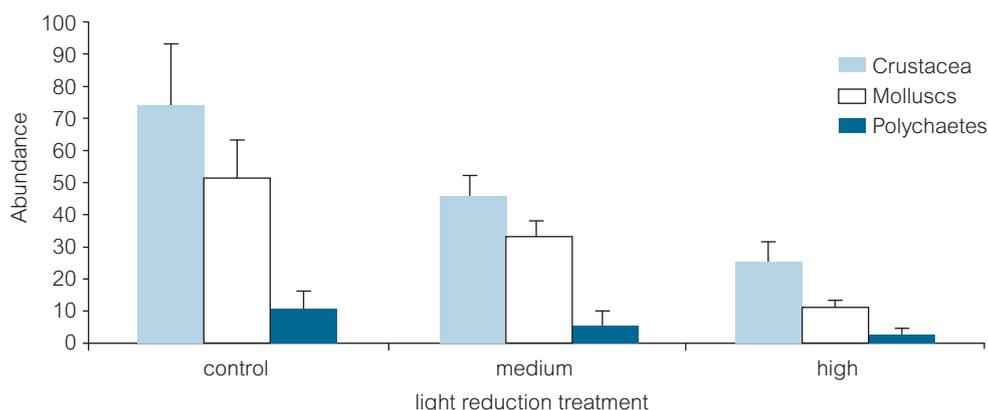

Figure 3.41: Faunal abundance in three taxonomic groupings, crustaceans, molluscs and polychaetes after 3 months shading with moderate and high light reduction.

Discussion

The morphological changes we observed were mainly in the canopy and were consistent with a strategy to reduce carbon-demand of the plants and increase light availability to the leaves that were retained. At the individual stem and shoot level, plants shed leaves from all clusters and stems. Leaves can have respiratory loads up to six times that of below-ground material (Masini et al. 1995) and the above-ground to below-ground biomass ratio in the genus

Amphibolis is approximately 6 (Paling & McComb 2000). Therefore, the dramatic reduction in above-ground tissue that we noted would have the effect of reducing the total plant respiratory load and allow the plant to meet more of its carbon demand from that fixed in the reduced light climate.

The reduction in above-ground biomass at the individual stem and shoot level also had the effect of thinning the seagrass canopy at the meadow-scale and reducing the degree of self-shading, as evident in the lower light attenuation coefficients of treatment canopies after shading. This response has been noted for other seagrasses (Via et al. 1998; Peralta et al. 2005) and may assist in recovery of the remaining leaves once light conditions improve (Carruthers & Walker, 1997).

Presumably, shedding leaves, which have a high-respiratory cost (Masini et al. 1995) was not sufficient to balance the plants' carbon budgets in this experiment, since carbohydrate reserves in the rhizome were simultaneously depleted. In shaded plots, leaf sugars initially declined rapidly following reductions in light, then stabilised. Rhizome sugar concentrations also declined following shading, though this decline continued through the shading period, possibly reflecting ongoing translocation to the leaves. Starch concentrations in the rhizome also declined, but much later than rhizome sugars. The lag in the rate of rhizome starch decline relative to rhizome sugars is indicative of a physiological reallocation of resources (Touchette & Burkholder 2000) found in other seagrasses and probably reflects a reallocation of rhizome sugars and, later, starches to the leaves.

The combined morphological and physiological responses displayed by *A. griffithii* to the reduction in light availability allowed some plants to survive, in a reduced biomass state, for at least 3-6 months of severe reduction in light and 6-8 months of moderate light reduction. While the plants remained functional, they were clearly demonstrating a carbon deficit, and they had lost all their photosynthetic tissue by about 6 months under heavy shading and between 6 and 9 months under moderate shading. Given this, it appears as though the minimum light requirements of *A. griffithii* are probably significantly greater than the global seagrass average of 11% of sub-surface light reported by (Duarte 1991).

Recovery

The majority of variables measured in the stage 1 experiment showed substantial recovery within 42 days. The number of leaves per stem, leaf extension, leaf cluster density, total leaf and total epiphyte biomass and the upper canopy total leaf chlorophyll all displayed full recovery. However, the recovery of seagrass above-ground biomass was not noted in the stage 2 experiment, despite both experiments occurring at the same time of year. The extent and rate of the recovery in the stage 1 experiments suggests *Amphibolis griffithii* is, at times, able to withstand a single episode of high intensity PAR reduction over the timescale of this study (3 months) but the stage 2 results suggest that this is not a consistent capacity. The factors influencing the ability to recover are not clear and are currently being examined. The carbohydrate stores at the commencement of a shading period may be crucial in determining the capacity and rate of recovery and this is being investigated.

Trophic implications

Ecologically, one of the most significant responses noted in the experiment was the rapid decline in epiphyte biomass. The loss of macroalgae in shaded conditions may reflect their limited capacity to store reserves. Alternatively it may have been associated with a shift in top-down control mechanisms induced by the experiment, though we did not monitor herbivore density in the treatments and controls. If the loss of epiphytes was due to light-limitation, it has potentially profound trophic implications. Seagrass epiphytes are an important food source for a range of vertebrate and invertebrate grazers (Nielsen & Lethbridge, 1989; Heck et al., 2000), presumably due to palatability and nutritional value (Klumpp et al. 1992). While it is difficult to extrapolate small-scale experimental results to whole ecosystem consequences,

it is clear that if the decline in epiphyte biomass noted here were replicated over large spatial scales then, even ignoring any negative consequences of seagrass loss, the trophic implications of epiphyte loss would be significant, as would the flow-on effects for biodiversity functions of seagrass meadows. The significantly lower abundances of epibenthic fauna after 3 months of shading is further evidence that shading of seagrasses may have profound trophic consequences. The precise mechanism of the decline is unclear, and is the subject of ongoing studies. However, the changes in seagrass that we have observed would affect the quality of the habitat as both a food resource (reduced algal biomass) and shelter (reduced leaf biomass and leaf area index).

In summary, at this point of the project it is necessary to be cautious about over-extrapolating the results. However, it is clear that moderate and severe shading in the order of three months can cause dramatic losses of photosynthetic tissue in *Amphibolis griffithii*, and after 6-8 months almost complete loss. The data on the capacity for recovery are inconsistent, but in some cases we observed no recovery of seagrass biomass up to 4 months after a 3 month shading period. Earlier experiments yield contrasting outcomes, with significant recovery within a month of shading being removed. Clearly, this variability in recovery has important implications in terms of developing management criteria and gaining a better understanding of what drives the highly variable responses will be a priority for the remainder of the project. Ongoing work will also explore in more detail the trophic implications of seagrass loss.

Acknowledgements

References

Bulthius DA (1983) Effects of *in situ* light reduction on density and growth of the seagrass *Heterozostera tasmanica* (Martens ex Aschers.) den Hartog in Western Port, Victoria, Australia. J Exp Mar Biol Ecol 67:91-103

Carruthers TJB & Walker DI (1997) Light climate and energy flow in the seagrass canopy of *Amphibolis griffithii* (J.M. Black) den Hartog. *Oecologia* 109:335-341

Duarte C (1991) Seagrass depth limits. Aq Bot 40:363-77.

Duarte CM (2002). The future of seagrass meadows. Environ Conserv 29:192-206

Duarte CM & Kirkman H (2001) Methods for the measurement of seagrass abundance and depth distribution. In *Global Seagrass Research Methods* Short FT & Coles RG (eds.) Elsevier Science BV, Amsterdam

Dubois M & Gilles KA (1956) Colorimetric method for the determination of sugars and related substances. Anal Chem 28:350-356

Fowler J, Cohen L & Jarvis P (1998) Practical statistics for field biology. Wiley Publ. Chichester; New York

Granger S & Lizumi H (2001) Water quality measurement methods for seagrass habitat. In *Global Seagrass Research Methods.* Short FT & Coles RG (eds.) Elsevier Science BV, Amsterdam

Heck KL, Pennock JR, Valentine JF, Coen LD & Sklenar SA (2000) Effects of nutrient enrichment and small predator density on seagrass ecosystems: An experimental assessment. Limnol Oceanogr 45:1041-1057

Hemminga MA & Duarte CM (2000) *Seagrass Ecology.* Cambridge University Press, Cambridge

Klumpp DW, Salitaespinosa JS & Fortes MD (1992) The role of epiphytic periphyton and macro-invertebrate grazers in the trophic flux of a tropical seagrass community. Aq Bot 43:327-349

Lavery PS & Vanderklift MA (2002) A comparison of spatial and temporal patterns in epiphytic macroalgal assemblages of the seagrasses *Amphibolis griffithii* and *Posidonia coriacea*. Mar Ecol Progr Ser 236:99-112

Longstaff BJ, Loneragan NR, O'Donohue MJ, Dennison WC (1999) Effects of light deprivation on the survival and recovery of the seagrass *Halophila ovalis* (R Br) Hook. J Exp Mar Biol Ecol 234:1-27

Longstaff BJ & Dennison WC (1999) Seagrass survival during pulsed turbidity events: the effects of light deprivation on the seagrasses *Halodule pinifolia* and *Halophila ovalis*. Aq Bot 65:105-121

Masini RJ, Cary JL, Simpson CJ & McComb AJ (1995) Effects of light and temperature on the photosynthesis of temperate meadow-forming seagrasses in Western Australia. Aq Bot 49:239-254

Nielsen J & Lethbridge R (1989) Feeding and the epiphyte food resource of gastropods living on the leaves of the seagrass *Amphibolis griffithii* in southwestern Australia. J. Malacol Soc Aust 10:47-58.

Paling EI & McComb AJ (1994) Nitrogen and phosphorus uptake in seedlings of the seagrass *Amphibolis antarctica* in Western Australia. Hydrobiologia 294:1-4

Peralta G, Brun FG, Hernandez I, Vergara JJ, Perez-Llorens JL (2005) Morphometric variations as acclimation mechanisms in *Zostera noltii* beds. Est Coast Shelf Sci 64:347-356

Peralta G, Perez-Llorens J, Hernandez I & Vergara J (2002) Effects of light availability on growth, architecture and nutrient content of the seagrass *Zostera noltii* Hornem. J Exp Mar Biol Ecol 269:9-26.

Short FT & Duarte C (2001) Methods for the measurement of seagrass growth and production. In *Global Seagrass Research Methods.* Short FT & Coles RG (eds.) Elsevier Science BV, Amsterdam

Touchette BW & Burkholder JM (2000) Overview of the physiological ecology of carbon metabolism in seagrasses. J Exp Mar Biol Ecol 250:169-205

Via J, Sturmbauer C, Schőnweger G, Sőtz E, Mathekowitsch S, Stifter M & Rieger R (1998) Light gradients and meadow structure in *Posidonia oceanica*: ecomorphological and functional correlates. Mar Ecol Progr Ser 163:267-278

Conference attendance and presentations

6th International Seagrass Biology Workshop, Townsville, QLD: November 2004.

SFRME Mini Symposium – Benthic Ecology of the mid-west coast; April 2005.

Stockholm University – Botany Institute: The effects of light reduction on seagrass ecosystems and the trophic implications.

Publications and/or outcomes to date

Mackey, P., Collier, C. and Lavery P.S. (in review, MEPS). The effects of reduced light availability in *Amphibolis griffithii* ecosystems.