A Quantitative Assessment of the Environmental Impacts of Mussel Aquaculture on Seagrasses

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Contents

ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
AEA	Aquaculture Extension Area
ANOVA	Analysis of Variance
ASIC	Australian Seafood Industry Council
AWMA	Albany Waterways Management Authority
DEP	Department of Environmental Protection
Df	Degrees of Freedom
DGPS	Differential Global Positioning System
DMSV	Digital Multispectral Video
F	F ratio
FRDC	Fisheries Research and Development Corporation
FWA	Fisheries WA (Fisheries Western Australia)
GCOM3D	Hydrodynamic Modelling software
GEMS	Global Environmental Modelling Systems
GPS	Global Positioning System
GSAA	Great Southern Aquaculture Association
IRC	International Risk Consultants
LAC	Light Attenuation Coefficient
MS	Mean Square Residual
NTF	National Tidal Facility
P	Probability value
SE	Standard Error
SEDMOD3D	Sediment transport model

1999/229	A quantitative assessment of the environmental impacts of mussel aquaculture on seagrass:

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OBJECTIVES

1. resolve environmental issues concerning the siting of longline bivalve culture over seagrass;
2. provide data that demonstrate that mussel farming can develop in an ecological sustainable manner;
3. provide a foundation of management practices for mussel farming over seagrass;
4. provide government agencies with the information that allows them to measure change to the seagrass environment relating to mussel culture;
5. provide a model that has application nationally to allow the needs and objectives of longline bivalve farming to be met in similar locations around Australia; and
6. provide a definitive tool that ensures agencies can make decisions on the acceptability of longline aquaculture located over seagrass.

NON-TECHNICAL SUMMARY

OUTCOMES ACHIEVED

- Clarification of the relative importance of specific environmental issues associated with mussel longline aquaculture practices over seagrass;
- Provision of information to assist government agencies in making decisions on the siting and management of mussel longline aquaculture in the vicinity of seagrass beds;
- The provision and application of a conceptual model for monitoring mussel farming impacts over seagrass; and
- The successful application of a numeric seagrass light-limitation model as an early warning monitoring method that will meet the needs and objectives of longline bivalve farming in similar conditions around the Australia.; and
- The provision of a definitive tool that ensures agencies can make decisions of the acceptability of longline aquaculture located over seagrass.

This project arose from a request by the developing mussel industry in Albany, Western Australia. Various government agencies including Fisheries WA, Department of Environmental Protection and the Albany Waterways Management Authority also expressed significant interest in the project's results in order to assess, as part of their management needs, environmental impacts of the mussel aquaculture of the fishery. It was concluded that there was a need to undertake research to:

- provide managers and regulators with appropriate data on the likely consequences of siting mussel leases on or near seagrass communities so they can make informed decisions;
- provide quantitative data on (a) physical changes and (b) biological changes to the seagrass habitat as a result of longline mussel aquaculture;
- provide recommendations on management options to minimise seagrass disturbance from longline aquaculture;
- provide data that allows mussel aquaculture to develop in an orderly and sustainable manner; and
- provide a tool for future management decisions on the interaction of aquaculture and seagrass.

The project was divided into six studies discussed below:

Mapping seagrass distribution

The main habitats in the Aquaculture Extension Area (AEA) comprise either seagrasses on sand, bare sand or communities of algae on rock. The AEA supports at least three large, perennial seagrasses and at least two smaller, more opportunistic seagrasses. Continuous beds of the seagrass *Posidonia sinuosa,* with high cover and high density, occur mainly in the areas immediately north, north-west and south-west of Mistaken Island. These areas include at least one of the existing lease sites located just north of Mistaken Island.

The deeper, offshore areas of the AEA, particularly in the southeast and also along the south-western shoreline, generally support seagrass with lower cover and density. The far north-western sector of the AEA comprises mainly unvegetated seabed.

Shading of seagrass by mussel longlines

Underwater light data were fitted to a model predicting long-term seagrass survival in response to light availability. This model by Masini et al (1995) was developed for *Posidonia* seagrasses and is applicable over the entire range of the species. It can provide either an early warning, or a confirmation, that seagrass can survive in the long-term at a particular water depth given the underwater light levels for that water depth.

The results during 2000 indicate that, in general, there was sufficient light for seagrasses to survive under mussel lines during the critical spring and summer periods where the plants must produce enough food to last them over the winter when light levels are too low.

However, the light levels measured during 2001 were lower at all sites than during 2000. The result between mussel lines and control sites was variable, suggesting the possibility that *Posidonia* seagrasses may not be receiving sufficient light. Light levels at sites under some mussel lines and at control sites had sufficient light levels, where at other sites under both mussel lines and control sites, the light levels were slightly lower. Although the light limitation model is applicable the variability in results between years indicates that a longer time series is needed in order to provide a more definitive assessment of shading effects of the seagrasses.

Seagrass health under mussel lines

Seagrass shoot density and leaf length are recognised indices for measuring seagrass health and are known to respond to the effect of shading. The results indicated that, in summer and spring 2000, there was no significant difference in seagrass shoot densities between mussel line and control sites. However, in winter 2000 and summer 2001 seagrass shoot densities under mussel lines were significantly less than at control sites.

Seagrass leaf length in summer 2000 was significantly greater in control sites compared with under mussel lines. However, in winter and spring 2000 and in summer 2001 there was no significant difference in leaf length between under mussel line and control sites.

Hydrodynamic patterns around the mussel longlines

Currents in the vicinity of Mistaken Island are weak with wind playing a dominant role in driving the circulation. Simulation of bio-deposition from the mussel lines using a particle tracking technique demonstrated that the majority of settling occurs within about 200 m of the lines, near to the northern side of Mistaken Island. Less than about 10% would be dispersed further and the location where this material was predicted to settle was dependent on the time of year and wind strength.

Organic Deposition

During February 2000, the percentage organic content of material collected in the sediment traps was significantly higher under mussel lines than at control sites whereas in August 2000 there was no significant difference.

When the organic content data were converted from a percentage value to grams dry weight the total deposition of organic matter was higher at the control sites than under the mussel lines at both sampling times. This increase in organic matter appeared to have a significant impact on seagrass health, as measured by the seagrass health indices discussed above.

Empty mussel shells were sometimes observed under the mussel lines although no clear trend was apparent.

Longline mooring devices

Scouring of the seabed due to the mooring structures occurred at some locations but not at others and the size of scoured areas changed over time at some mooring locations. Generally, the depth of the scouring was not sufficient to remove *P. sinuosa* rhizomes from the substrate.

Although monitoring of the size of scour could be continued, discussions in August 2001 with mussel farmers indicate that they will be replacing the existing mooring structures with “seagrass friendly” designs. Monitoring of seagrass shoot density and the area of scour around the new designs may be appropriate to assess the effectiveness of those designs.

Conclusions and Recommendations

Masini et al’s (1995) light limitation model is a robust and easily applied tool to determine whether shading effects will significantly impact *Posidonia* seagrass, which is a dominant and important seagrass species in the Aquaculture Extension Area.

The results to date, using this model, as well as other measurements such as seagrass health, indicate that there is no clear pattern to suggest that mussel lines are causing a significant deleterious impact on seagrass meadows. However, the variability in results indicates that a longer time series of data is needed to confirm that mussel longlines are not impacting the seagrass beds. Monitoring of a few key parameters over the next one to two spring/summer periods should provide enough data to determine whether any trends in light levels or with seagrass health indices are apparent.

As a bare minimum, the following parameters should be measured during spring and summer:

- light attenuation coefficients under mussel lines and control areas (for use in modelling seagrass survival from Masini et al’s (1995) model); and
- epiphyte biomass on seagrass leaves (for use in modelling seagrass survival from Masini et al’s (1995) model).

The following parameters could be monitored in summer:

- seagrass shoot density and leaf length as indices of seagrass health. This would provide a check of seagrass health independent of Masini et al’s (1995) model;
- longline anchor mooring scouring to confirm that the level of scouring has not become larger; and
- mussel shell deposits under the mussel lines to assess whether this has any impact on the surrounding seagrass.

KEY WORDS: Seagrass, mussels, aquaculture, longline.

1 ACKNOWLEDGEMENTS

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- Dr Ray Masini and Mr Craig Manning, DEP;
- Mr Simon Bennison ACWA;
- Mr Chris Gunby AWMA;
- Ms Tina Thorne, Dr Kirk Hahn, FWA;
- Mr Rob Lucas, Mr Scott Fisher, Mr Gareth James, GSAA

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- Albany City Council
- Albany Waterways Management Authority
- Aquaculture Development Council
- Fisheries Research and Development Corporation
- Great Southern Aquaculture Association
- Great Southern Development Commission
- International Risk Consultants

2 BACKGROUND

This project arose from a request by the developing mussel industry in Albany, Western Australia. Various government agencies including Fisheries WA (FWA), Department of Environmental Protection (DEP) and the Albany Waterways Management Authority (AWMA) also expressed significant interest in having this study carried out. Their interest stemmed from the fact that these organisations require information on the impact of mussel longlines on seagrass meadows in King George Sound, Western Australia, as part of their management needs.

Previously, the Albany Harbours (Western Australia) planning strategy identified a 138-hectare area around Mistaken Island in King George Sound as a possible aquaculture site. Earlier seagrass mapping indicated that the proposed site might include significant areas of seagrass cover (Evangelisti & Associates, 1999).

FWA granted aquaculture permits for two mussel farms prior to the DEP placing restrictions on aquaculture activities over seagrass meadows. Apart from the two existing licenses, there was the potential to accommodate many more leases and there was growing interest for aquaculture in the area.

Fisheries WA received a number of proposals to establish additional mussel leases. However, the DEP required additional information on the extent of seagrass in the proposed aquaculture extension area (AEA) before they would approve additional licences. It was highlighted that more information was also needed to assist Government regulators in assessing potential impacts on the marine ecosystem (in particular, seagrass meadows), both from individual leases and from cumulative impacts of multiple lease sites.

Locally, there is relatively limited research information on mussel line impacts over seagrass beds as the existing longer-term activities in Cockburn Sound have been conducted out of seagrass areas. Elsewhere in Australia, mussel longlining has generally been carried out in deep water away from seagrass meadows. However, as the popularity of this form of aquaculture increases, there will be increasing pressure to utilise areas where seagrasses occur.

Environmental issues associated with mussel aquaculture are described in several reports and articles (ASIC 1997; Nunes and Parsons 1998; Fisheries WA 1999; PIRSA 1999) as well as keynote scientific papers outlining the nature of seagrass beds and approaches to evaluating impacts of shellfish aquaculture on benthic communities (eg Grant, Hatcher, Scott and others 1995; Tregonning 1995; Lemmens et al 1996).

The main issues with respect to seagrasses are believed to include:

- possible effects of reduced light on seagrass productivity and function from shading by mussel lines and supporting infrastructure;

- possible physical removal of, or damage to, seagrasses from anchors of support vessels and tethered equipment;
- possible deleterious effects of sedimentation and biodeposition of pseudo faeces and faeces generated from the mussel farm site (depending upon the density of mussel lines and other factors such as local wave and current patterns);
- possible competition for available organic matter and nutrients between the seagrass assemblages (as a natural filter system) and the overlying mussel culture; and
- possible deleterious effects on seagrass fauna and seagrass function resulting from physico-chemical changes in sediments surrounding and under the mussel lines.

Knowledge of the relative importance of the above issues is limited and this lack of information was highlighted as a significant knowledge gap in the recent FRDC-sponsored review (Seagrass in Australia: Strategic Review and Development of an R&D Plan: FRDC Project 98/223).

Discussions with Australian fisheries scientists and managers indicated that, with existing scant information, scientific opinion of the importance of the above issues was diametrically opposed in some cases. For example, some scientists believed the role of sedimentation and biodeposition under the longlines in affecting seagrasses was relatively unimportant, whereas others cited overseas studies where bivalves only retained between 35-40% of material ingested (Nunes and Parsons 1998). These authors estimated that of 180 tonnes of organic matter that could be ingested by a raft of mussels, 100 tonnes would be returned as faecal and pseudofaecal material. They estimated that a typical oyster rack holding 420,000 oysters would generate 16 tonnes of faecal and pseudofaecal material over a 9 month growout season. The level of faecal and pseudofaecal material will be dependent upon a variety of conditions including the amount of sediment in the water column and water movement. As with many physical factors, the role of local conditions plays an important part in determining their relative importance (Butler and Jernakoff 1999). Similar divergent opinions were also apparent from Australian scientists as to the importance of other issues.

3 NEED

Apart from a growing interest in aquaculture activities in Australia, there is a need to identify the impacts associated with those activities, in order to protect the marine ecosystem. This is a high priority for Australian environmental regulators who are unlikely to allow additional aquaculture activities in the absence of knowledge about possible environmental impacts.

Gaps in our knowledge on the effects of aquaculture impacts on seagrasses and on ways to protect and restore seagrasses were highlighted in a review commissioned by FRDC (Butler and Jernakoff 1999). Potential impacts on seagrass meadows include the effects of reduced light and increased nutrient levels. Other issues of importance include the responses of seagrasses to perturbations and the time taken for them to recover from these impacts. Unless regulators can be confident that shellfish longline aquaculture does not significantly impact areas such as seagrass meadows, it is unlikely that the industry will be able to utilise these potentially suitable areas for expansion and development. Therefore, there is an urgent need to obtain this information.

Specific needs for the research are formed by the following questions:

- Can mussel farming be conducted over seagrass beds without impact?
- Are the impacts of mussel farming reversible over time if aquaculture activities cease in a particular area (e.g. through site rotation)?
- Is the extent of impact of mussel farming on seagrasses the same throughout the year (i.e. seasonal influences)?
- Are the rates of impact and recovery from potential impact from mussel farming compatible with available adaptive management options?

There is thus a need to undertake research to:

- provide managers and regulators with appropriate data on the likely consequences of siting mussel leases on or near seagrass communities so they can make informed decisions;
- provide quantitative data on the a) physical changes and b) biological changes to the seagrass habitat as a result of longline mussel aquaculture
- provide recommendations on management options to minimise seagrass disturbance from longline aquaculture;
- provide data that allows mussel aquaculture to develop in an orderly and sustainable manner; and
- provide a tool for future management decisions on the interaction of aquaculture and seagrass.

4 OBJECTIVES

The objectives of the project were to:

- resolve environmental issues concerning the sighting of longline bivalve culture over seagrass;
- provide data that demonstrate that mussel farming can develop in an ecological sustainable manner;
- provide a foundation of management practices for mussel farming over seagrass;
- provide government agencies with the information that allows them to measure change to the seagrass environment relating to mussel culture;
- provide a model that has application nationally to allow the needs and objectives of longline bivalve farming to be met in similar locations around Australia; and
- provide a definitive tool that ensures agencies can make decisions on the acceptability of longline aquaculture located over seagrass.

5 METHODS

Figure 4.1 shows the study area. The project was divided into six studies:

- mapping seagrass distribution in the aquaculture extension area;
- measuring the amount of light available to the seagrasses under the mussel longlines (water column light attenuation and light attenuation by periphyton);
- measurement of seagrass health under mussel longlines;
- modelling of the hydrodynamic patterns around the longlines;
- measurement of the amount of deposition under mussel longlines; and
- measuring the impact of mussel longline mooring devices on seagrasses.

The field studies focused on the larger, perennial seagrass species (mainly *Posidonia sinuosa*; Walker and Kirkman 1989) that dominate seagrass meadows in the study area rather than the smaller, more opportunistic species also occurring at the site and which are less susceptible to long term damage. The methods for each of these studies are discussed separately.

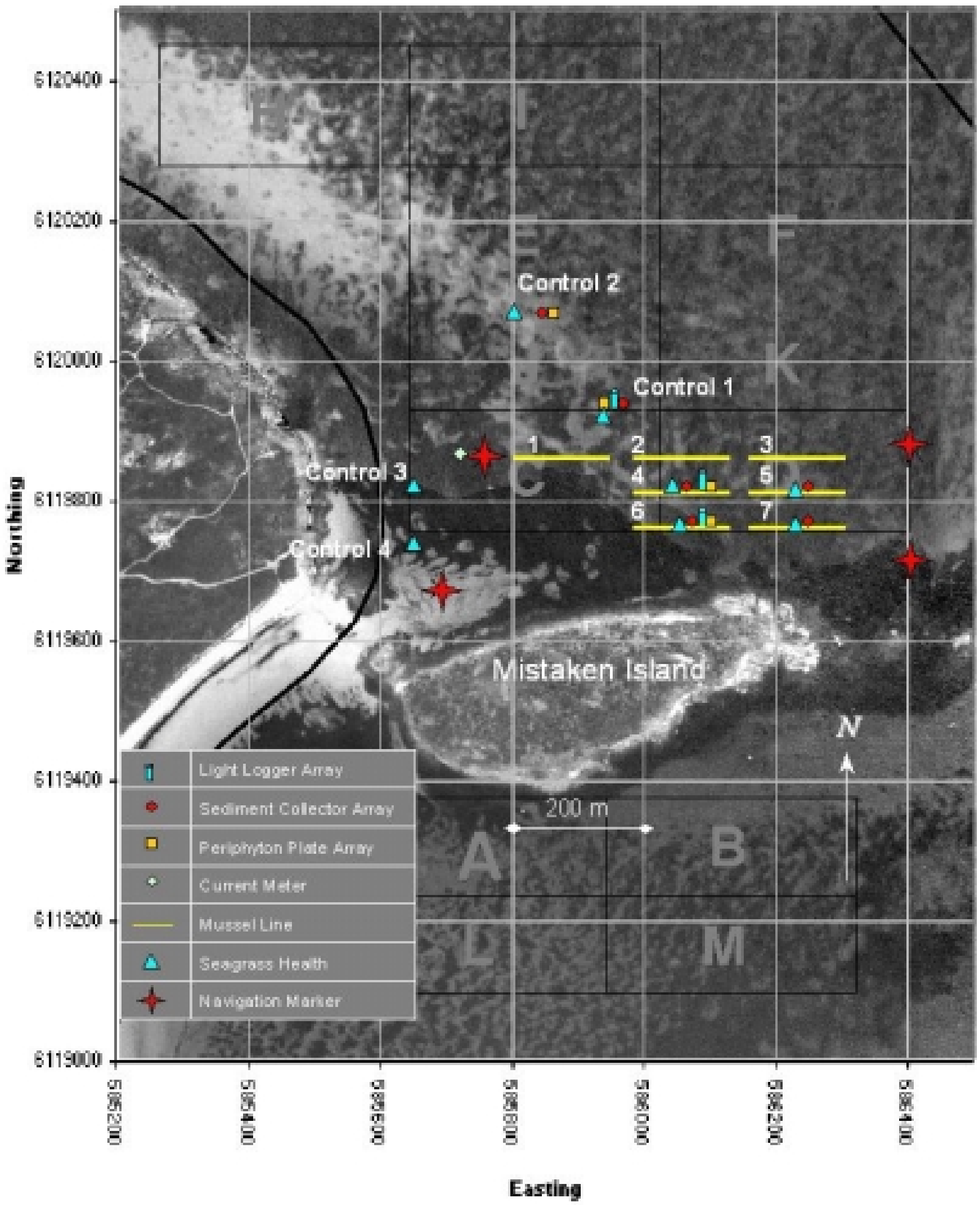


Figure 5.1 Mistaken Island area-map, showing location of mussel lines and experimental equipment deployed during FRDC study. Black rectangular boxes and grey letters on the map (A-M) refer to individual mussel lease sites allocated by FWA.

5.1 Mapping seagrass distribution in the aquaculture extension area

5.1.1 Aerial Imagery

Images obtained from aerial photography in October 1994, and from a survey by SpecTerra Systems Pty Ltd in May 1998 (Evangelisti & Associates 1999) using airborne DMSV, were used to generate a base map for the present survey (Figure 4.2). The images provided resolution of about 2-metres.

DMSV provided low cost, high spatial resolution imagery of the same scene captured simultaneously through four spectral channels (four narrow band-pass filters) and registered digitally as a single four band image "frame". Frames of imagery are acquired sequentially along GPS controlled flight paths, and written directly to a PC hard drive as individual files.

The narrow band-pass filters are easily interchanged for specific applications, however the four spectral bands typically utilised for vegetation mapping and monitoring are 25 nanometres wide and centred about the principal reflectance spectra features of vegetation.

The four bands used were:

- Band 1, the pigment absorption around 450 nm (best water penetration);
- Band 2, the relatively higher reflectance and transmission near 550 nm (some water penetration);
- Band 3, the strong chlorophyll absorption in the 650-670 nm range (minimal water penetration); and
- Band 4, the high infrared reflectance "plateau" beyond 750 nm (land-sea interface).

The aerial photography was rectified to the DMSV image using ER Mapper® software and selected ground control points, with DGPS derived coordinates used to confirm accuracy. Image-processing techniques can be used to enhance and discriminate subtle boundaries where there is the required amount of contrast between any of the bands of the scanned image. The DMSV and aerial photographic images were mosaiced into a single grey-scale image for use as a base map.

Maps were created from interpretations of the drop-down video data, using the digital and aerial photography as a background image (see below). The accuracy of the resulting maps of habitats is dependent on the quality of the contrast within the images in delineating real boundaries as well as the number of drop down video sites used to verify the map.

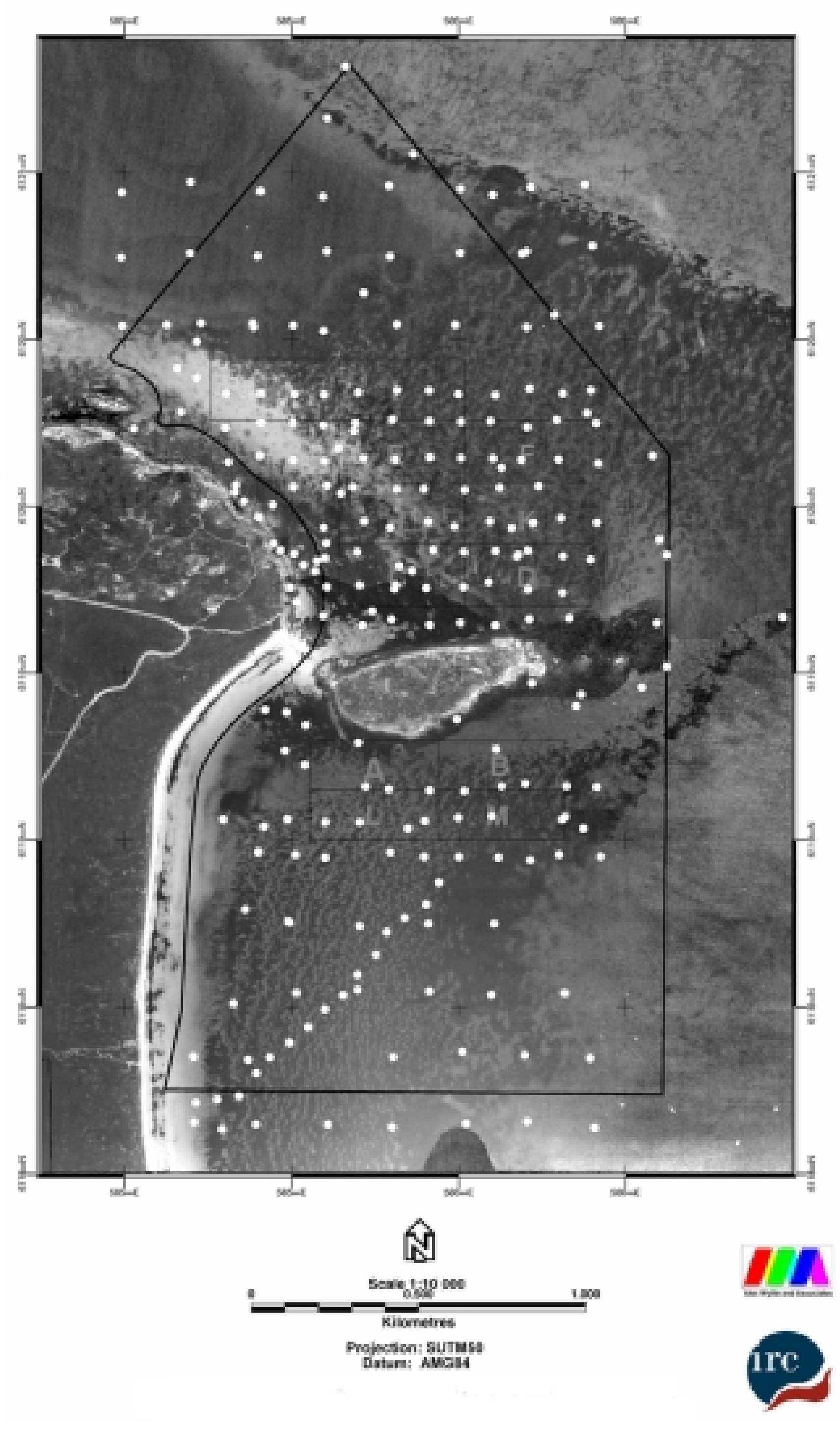


Figure 5.2 Base map of the study area, showing the Aquaculture Extension Area, proposed lease sites and seagrass mapping sites

5.1.2 Verification of seabed habitats

Field Survey

The field survey to map seagrasses within the AEA was conducted in October 1999. The original proposal to FWA was to establish a number of transects in 12 lease areas. This was subsequently revised to a programme involving the use of “drop-down” video photography of 240 sites across the AEA (Figure 4.2), with the video record for each site then linked back to a DGPS-fixed position. The DGPS coordinates are listed in Attachment 1. The drop-down video method allowed greater spatial coverage of the area in the available time than was possible with alternative methods. The field data were then used to verify seabed features apparent in multispectral photographs of the wider area (see below).

The drop-down video camera used to verify the seabed habitats was housed in a frame that provided a perpendicular view of the seabed from 40 cm above the seabed at a constant focal distance. The video was set to provide either a 0.5 m or 1 m field of view.

The camera and housing were lowered to the seabed at each sampling station then raised while the boat drifted a few metres. This procedure was repeated twice more at each site before the boat moved to the next sampling site. This procedure allowed small-scale patchiness (in the order of metres) and other seabed features such as sand ripples and wrack (dead and detached seagrass and algae) accumulations to be observed.

The DGPS position was recorded at the first of the three drop downs per site (Projection: SUTM50; Datum: AMG84). For each drop down, the main substrate and the dominant vegetation was described qualitatively. The vegetation was also recorded quantitatively as percentage cover.

Habitat and Vegetation Characteristics

The following categories were used to describe the key habitats and vegetation encountered in the AEA:

- Seagrass on sand;
- Algae on rock, sand or sandy pavement; and
- Bare sand.

The seagrass category was further divided into:

Larger seagrasses only:

- *Posidonia sinuosa;*
- *Posidonia ostenfeldii* complex spp.; and
- Mixed *Posidonia sinuosa* and *Amphibolis griffithii*

Smaller seagrasses only:

- *Halophila* spp.;
- *Heterozostera tasmanica*; and
- Mixed *Halophila* spp. and *H. tasmanica*

Mixed larger and smaller seagrasses:

- *Posidonia sinuosa* with *Halophila* spp.
- Mixed *P. sinuosa* and/or *A. griffithii* with *Halophila* spp. and/or *H. tasmanica* large and small seagrass assemblages; and
- *P. ostenfeldii* spp. complex with *Halophila* spp.

The vegetation recorded from sites in the AEA was identified using broad categories only. Algal communities were referred to collectively as algae. Seagrasses were identified to genus, and, where possible from inspection of the video photographs, to species.

Posidonia sinuosa and *Amphibolis griffithii* were readily identified to species from the video record. Similarly, *Posidonia* species from the "*ostenfeldii* species complex" could be identified collectively from the video record, although individual species were not readily identifiable on the basis of their external features.

The smaller seagrass, *Halophila,* was readily identified from the video record and is probably an annual, recruiting each year from seed. This genus is under revision and includes species with different leaf size and shape. It was identified as *Halophila* spp. in this study. The smaller seagrass *Heterozostera tasmanica*, which may be a perennial, was also identified from the video record.

Seagrass cover

Seagrasses within the AEA were separated into five areal cover categories based on the distribution of vegetation observed in the field of view of the video camera. The percent of the field of view covered by seagrass was recorded for each of three successive vertical drop-down video photographs of the seabed at each site. Cover values for the three drops at each site were then averaged and the resulting value assigned to one of the following broader categories:

- High cover (>75% cover);
- Moderate cover (50-75%);
- Low cover seagrass (25-50%);
- Sparse cover seagrass (5-25 %); and
- Trace (<5%).

Seagrass Density

Seagrass cover was further categorised according to the spatial arrangement (termed "density" in this report) of seagrasses apparent in the video field of view. At each site, density values were assigned to each of the three successive drop-down photographs of the seabed for which cover values were also recorded. These density values were averaged and the resulting value assigned to one of the following broader density categories:

- High density (>75%);
- Moderate density (50-75%);
- Low density (25-50%); and
- Very low density (<25%).

Seagrass density at each site was used in conjunction with the corresponding percentage cover values to identify those areas where seagrasses are most well developed within the AEA (see Section 5.1). Different cover and density values are illustrated by Figure 4.3 showing a hypothetical difference and Figure 4.4 showing actual video records.

Habitat mapping

Data describing seagrass composition, cover and density from the field survey were overlaid onto the rectified May 1998 multispectral image and the high definition October 1994 aerial photograph of the AEA. The boundaries of major habitats in the AEA were interpreted from tonal and textural differences apparent in the aerial images. The major habitats were then described based on the seagrass composition, cover and density observed in each habitat area.

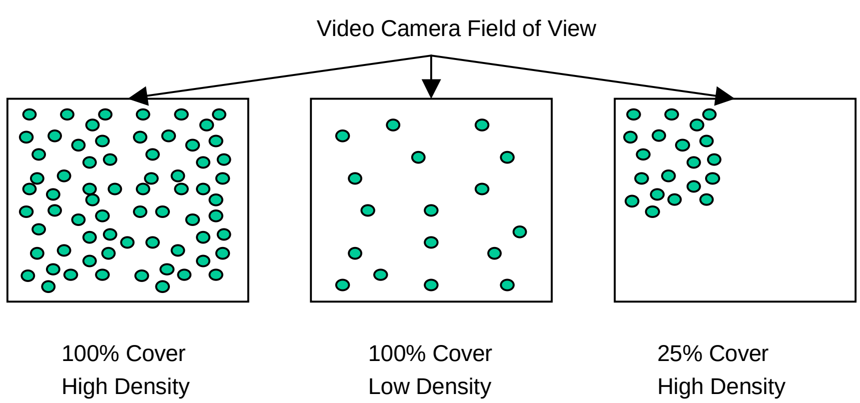
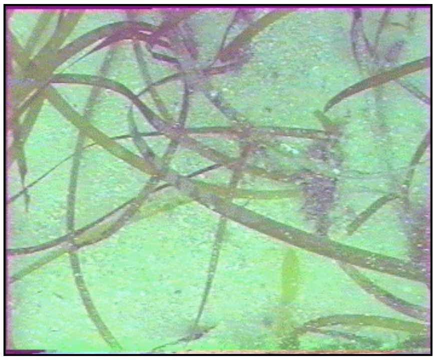
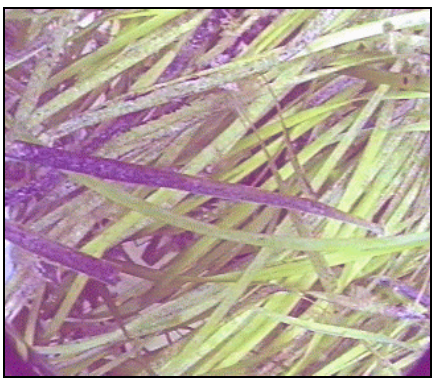


Figure 5.3 Hypothetical differences illustrating the difference between seagrass cover and density as defined in this report

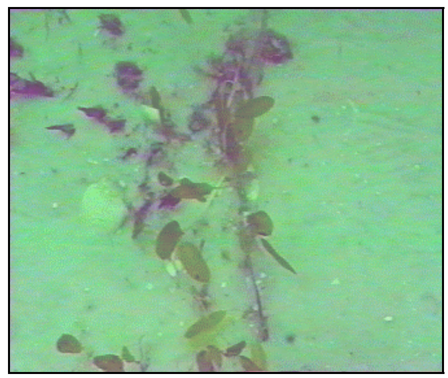


a *Posidonia sinuosa*: high cover / low density

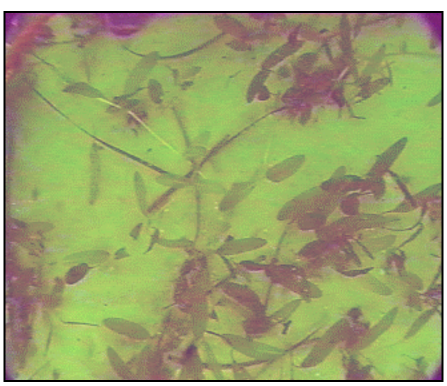
b *Posidonia sinuosa*: high cover / moderate density



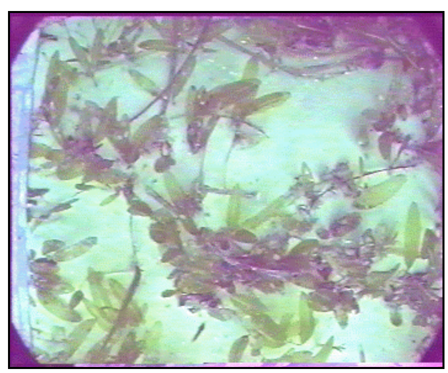
c *Posidonia sinuosa*: high cover / high density



d *Halophila* spp: moderate cover / very low density



e *Halophila* spp: high cover / low density



f *Halophila* spp: high cover / moderate density

Figure 5.4 Examples of seagrass total cover and density observed in seagrass habitats around Mistaken Island.

5.2 Light availability for seagrasses

The influence of mussel farming on the light available for seagrass photosynthesis was measured by both light attenuation by the mussel lines and light attenuation by periphyton (microscopic plants and algae) growing on the seagrass leaves. Comparing light levels under existing mussel longlines with light levels at a control site assessed light attenuation by the mussel lines. Light reduction at the seagrass leaf blade due to periphyton growth (periphyton consists of microalgae, bacteria and macro algal propagules) was assessed by measuring light absorbed by periphyton growing on clear acrylic sheets under mussel lines and at control sites.

The study of light availability is divided into the following tasks:

- measuring water column light attenuation;
- measuring periphyton light attenuation;
- estimating the minimum light requirements of the seagrass *Posidonia sinuosa* (the dominant seagrass at the study site); and
- examining the effect of mussel longline flotation gear that was originally used (square plastic drums) compared with a change in flotation required by FWA (12 inch black circular floats).

Seasonal light measurements were made in February, April, August, October 2000, January and April 2001 (Table 4.1).

5.2.1 Measuring water column light attenuation

Aim

To measure and compare light attenuation in the water column under mussel longlines and a control site.

Methods

Number of sampling sites

The impact of mussel lines on underwater light levels was investigated in February, April and August 2000 by placing automatic light loggers in areas under and away from the mussel lines. Aerial photographs and information from discussions with mussel farmers assisted in the selection of sampling sites. The number of sampling sites (ie, two mussel lines and one control site) was limited by the number (12) of light loggers available. However, it was possible to acquire an extra set of loggers so that an additional control site was measured from August 2000 onwards. Table 4.1 summarises the experimental design for the study. Sampling periods were 26 – 27 October 1999, 2 - 4 February 2000, 29 April - 1 May 2000 and 8 - 9 August 2000, 25 – 26 October 2000 and 31 January – 1 February 2001.

Table 5.1 Experimental design for the study of light attenuation by mussel lines

Factor	Description
Seasons	Spring 1999, summer 2000 autumn 2000, winter 2000, spring 2000, summer 2001
Sampling Areas	2 Mussel lines and 1 control until autumn 2000 then an addition control
Replicates	2 Replicate light loggers (under sea surface and above seabed) per sampling area

Deployment of light loggers

Each array deployed consisted of four light loggers (each made up of a Dataflow 392 Recorder and attached Dataflow Light Sensor), spaced 2 m apart in a line. Two light logger arrays were placed under existing mussel lines (Mussel Lines 4 & 6; see Figure 4.1), and 1 array was placed in a control area (Control 1; see Figure 4.1). At each array, two loggers were located 1 m above the seabed, and two were set within 3 m of the water surface. This depth, which protects the loggers from accidental entanglement with passing boat, is a similar depth to that used by Burt et al (1995) during their study of underwater light conditions.

Logger arrays were held in place by a ground line moored by two 25 kg weights. A 15 cm diameter surface float was used to mark their locations. DGPS coordinates of equipment in the lease area are presented in Attachment 1.

The choice of a control site was random but within limitations to minimise variability due to a spatial effect (eg sites that may experience different degrees of exposure the physical environment) or habitat effects (eg the control site had to be over *Posidonia sinuosa* meadows and not patches of bare sand).

An additional control site was added during the August 2000 (and subsequent sampling) as additional loggers became available.

In February 2001, using additional light loggers, the spatial variation in light attenuation of the AEA was measured simultaneously over 14 sites including the two control sites.

Estimation of light attenuation

Light attenuation through the water column was estimated by comparing light values from the surface and bottom loggers at each site. The loggers continuously recorded accumulated light (integrated irradiance) during contiguous 15 minute periods for several days.

The data were down-loaded from the loggers to determine:

1. Light Attenuation Coefficient m^{-1} (LAC). This was calculated using the formula: LAC = $(\log10\ Ii - \log10\ Iz) / z$; where Ii and Iz are the integrated irradiances for each 15 minute period for surface and bottom loggers respectively; and z is the vertical distance in metres between surface and bottom loggers.

2. Mean light reduction per 3 hour period. This was calculated as the percent reduction of the surface light levels; and
3. Differences in mean light reduction per day under mussel lines and the control site.

Data analyses

Data on light reduction (%) under mussel lines compared with control sites were analysed by ANOVA following transformation by arcsine to homogenise variances to satisfy variance and normality assumptions of the ANOVA. Analyses were one-way ANOVAs comparing light attenuation under mussel lines with the control. Data for each day were analysed separately.

5.2.2 Measuring periphyton light attenuation

Aim

To measure light attenuation by periphyton growing under mussel longlines and at control sites.

Methods

Twenty-four clear 12 cm x 12 cm acrylic plates ("periphyton collectors") were placed in areas of dense seagrass to the south of Mistaken Island for a period of 5 days for seeding by algal propagules. Arrays consisting of six periphyton collectors suspended at 1 m above the seabed were then positioned under four mussel lines and at two control sites (Figure 4.1) for one month. Periphyton collectors were placed in the field between 23 October and 26 November 1999 and from 1 February to 2 March 2000 (Table 4.1). Additional deployments will be made in autumn and winter 2000. Table 4.2 shows the experimental design used in the study.

Table 5.2 Experimental design used to measure light reduction due to periphyton growth.

Factor	Description
Seasons	Summer, autumn, winter spring 2000 and summer 2001
Sampling areas	4 mussel lines +2 controls
Replicates	6 replicate periphyton collectors per site

At the end of 1 month, the collectors were retrieved to measure the transmittance of light passing through the plates covered by periphyton. Light transmittance through each collector was measured for 60 seconds under direct sunlight. Light transmitted through the collectors was measured using a Dataflow 392 Datalogger and Light Sensor. The sensor was calibrated prior to recording light levels.

Light transmittance through a clear collector (no periphyton) was also measured to determine light attenuation due to periphyton. Light transmittance was measured alternately between periphyton and clear collectors to control for changes in light levels as the day progressed. Light reduction was calculated as % reduction (periphyton collector compared to the clear collector), with the value (x) transformed using *arcsine*$\sqrt{x}$ prior to statistical analysis. After recording light transmittance, the periphyton plates were sealed in plastic bags and frozen for further biomass analysis if required.

Light attenuation by periphyton was measured as the difference in light transmittance between collectors covered by periphyton and a clear collector (no periphyton). The influence of the mussel culture on periphyton growth was measured as the difference in periphyton biomass (estimated from light attenuation) between periphyton collectors positioned under mussel lines compared with those positioned at the two control sites.

To confirm that one month was a sufficient period of time for periphyton growth, periphyton plates were placed in the field in spring 2000 and harvested after one, two and three months duration in two control sites (Control Sites 1 & 2) and under two mussel longlines (Mussel Lines 4 & 6). Periphyton biomass and light attenuation were measured and compared.

5.2.3 Measuring epiphyte biomass on seagrass

During the second meeting of the project's Steering Group, Dr R Masini (DEP) suggested that measuring epiphyte biomass directly on the seagrass leaves would more accurately determine (compared with a visual estimate) which light attenuation curve (ie based on low, moderate or high epiphyte biomass) should be used in Section 5.2.4.

Aim

To determine the biomass of epiphytes growing on seagrass leaves in order to select which light attenuation curve (low, moderate, high epiphyte biomass) to use in Section 5.2.4.

Methods

Biomass measurements were made during winter and spring at the sampling sites used for seagrass health. These sites included Control Site 1 and Mussel Lines 4 and 6 that were also used to measure light attenuation. Ten seagrass leaves of similar size from each of four control sites and four sites under mussel lines were sampled to obtain scrapings of epiphytes from the leaves. The scrapings were dried and weighed to provide a biomass estimate in mg per g dry weight per cm^2 of seagrass leaf.

5.2.4 Estimating the minimum light requirements of the seagrass *Posidonia sinuosa*.

Aim

To determine the light attenuation-water depth relationship for the seagrass *Posidonia sinuosa* under mussel longlines and control areas.

Methods

Masini et al (1995) developed a model to determine the maximum theoretical water depth possible for *Posidonia sinuosa* survival, based on its minimum light requirements. Masini et al's model was derived from empirical field data collected from both the Perth and Albany regions. However, they also applied the results of other studies that investigated the relationship between photosynthesis and light availability. They found that their model was robust for Posidonia species and could be applied over the entire geographical range where *Posidonia* occurs. Their model can be used to predict the lower water depth limit at which seagrass can survive in the long term based on the light attenuation through the water column. If the theoretical water depth is less than the actual depth, *Posidonia* may not be able to survive at the particular depth in the long term. The amount of light available to seagrass will be dependent upon the time of year that the measurement takes place. Summer is the critical time when seagrass require light to produce food reserves to withstand the winter when light levels are insufficient to support self-sustaining photosynthesis (Masini and Van Senden 1995).

The data collected in Section 4.2.1 were integrated into Masini's model to determine the maximum water depth possible for *Posidonia* survival based on the light attenuation coefficient under mussel longlines and control sites. The water depth at the location of the mussel longlines and control sites averaged 12 m (range = 9.9 m - 13.0 m).

5.3 Seagrass health

Aim

To compare *Posidonia sinuosa* shoot density, and leaf length under mussel longline sites and at control sites.

Methods

IRC compared seagrass health (defined as either shoot density or leaf length) under existing mussel longlines and at control sites in January 2000, August 2000 and February 2001 (Table 4.3). Data were collected at the same locations as the light data described in Section 4.2 (see also Figure 4.1).

Seagrass health was measured under four mussel longlines and at four control sites. At each site, the leaf density in each of 20 randomly placed quadrats (20 cm x 20 cm) was counted by SCUBA divers, and recorded on underwater slates. In addition, a single shoot was taken from each of the 20 quadrats and placed in a calico bag. From the live samples, the number of leaves per shoot was counted, and leaf length measured within the quadrats. Shoot density in quadrats was estimated by dividing the number of leaves per quadrat by the number of leaves per shoot. The experimental design used in the study of seagrass health is shown in Table 4.3.

Table 5.3 Experimental design used to measure seagrass health.

Factor	Description
Seasons	Summer 2000, winter 2000 and summer 2001
Treatments	Mussel lines and Control sites
Number of sampling areas nested within each treatment	4
Number of replicate quadrats per sampling area	20

Data analyses

Data were analysed by nested ANOVA. Analyses were carried out on untransformed data for both seagrass shoot density (Bartlett's test for homogeneity of variances: P = 0.91) and shoot density (Bartlett's test: P = 0.64). Data on seagrass leaf length were transformed prior to analysis to satisfy the statistical assumptions of the ANOVA (Bartlett's test of transformed data = 0.24).

5.4 Hydrodynamic and biodeposition modelling

Hydrodynamic circulation is likely to be an important process affecting water quality and benthic conditions within the mussel leases located around Mistaken Island. The circulation patterns will bring planktonic food to the mussel longline sites and influence which areas any depositional material from the longlines may affect.

Aims

The major aims of the modelling study were to:

- describe flushing and circulation within the lease and surrounding areas under seasonal ambient conditions; and
- examine the potential for dispersion and accumulation of particulate material derived from the mussel lines.

Methods

Modelling was carried out using two integrated numerical models:

1. The GEMS three-dimensional Coastal Ocean Model, GCOM3D, was used to define hydrodynamic circulation in the area; and
2. The GEMS three-dimensional numerical sediment transport model, SEDMOD3D was used to define the behaviour of material released from the mussel lines under prevailing hydrodynamic conditions.

GCOM3D

GCOM3D is a three-dimensional, primitive equation, ocean model (Hubbert, 1991, 1993), which was developed by Global Environmental Modelling Systems (GEMS) to study and predict ocean currents on or near the continental shelf and in harbours and estuaries.

GCOM3D includes all non-linear advection terms and may be run in either barotropic mode, driven by wind stress, atmospheric pressure gradients, depth and terrain dependent bottom friction and astronomical tides, or in baroclinic mode, with the inclusion of ocean thermal structure. For high-resolution studies the system can be nested, whereby a model grid set up to cover an area of concern at fine spatial-resolution is provided with boundary data generated over a grid that has coarser spatial resolution, but wider geographic coverage. This nesting approach is used to reduce the uncertainties associated with the specification of conditions at open boundaries.

GCOM3D applies a split-explicit approach, to predict ocean circulation over a three-dimensional area. The first step calculates the effects of the gravity wave and Coriolis forces and solves a full continuity equation. Then follows the advective step, which accounts for the remaining non-linear terms. Finally, the "physics" step accounts for the effects of surface wind stress, atmospheric pressure gradients, bottom friction stress, and ocean thermodynamics (where relevant).

To set up GCOM3D to model over an area of interest, horizontal and vertical grids must first be defined. GCOM3D simulates the horizontal and vertical distribution of ocean currents by breaking the water column up into a regular grid structure. Horizontally, the model uses a defined number of regularly sized square cells in both the latitude and longitude. Vertically, the model operates over a specified number of layers, with breaks occurring at specified depths. The model allows for free-scalability of the horizontal grid so that model resolution can be optimised for the bathymetric complexity, and resulting complexity of water circulation, for an area under study. Variable spacing of the vertical layers is also supported so that resolution of depth-varying circulation can be adjusted to physical requirements. Much greater resolution is generally required in the vertical dimension than in the horizontal dimension. Thus, vertical layers are typically metres to tens of meters thick while horizontal grids are typically tens of metres to thousands of metres on a side.

After definition of the horizontal and vertical grid spacings, the model uses an automated gridding tool to read in bathymetric data and construct a three-dimensional representation of the water column covering the defined study area.

GCOM3D simulates tidal-forced flow in the region of interest by applying boundary forces calculated from measured or modelled tidal constituents. Tidal constituents describe the amplitude (i.e. magnitude) and phase (i.e. return period) of individual tidal waveforms that combine to make up the observed tides in an area. The model is set up to access databases of tidal constituents with global, regional or local coverage. Any number of tidal constituents may be used, but usually at least the seven constituents with the greatest magnitudes are used (usually M2, S2, N2, K2, O1, K1 and P1).

GCOM3D predicts wind forcing on circulation from either the surface-level of a mesoscale atmospheric model (e.g. Hubbert, 1991), or from point source observations. Data is input as a time-series of wind speed and direction and wind stress is calculated for each grid cell in the domain at each time step of the model.

In some locations, the thermodynamic structure of the ocean induces significant density currents and stratification can allow internal tides to propagate. For these locations, spatial variation in temperature and salinity can be used to calculate density currents.

SEDMOD3D

SEDMOD3D is a three-dimensional numerical sediment transport model, which uses ocean-circulation data generated by GCOM3D to predict the motion of particulate material released into coastal oceans or rivers. SEDMOD3D includes the following capabilities:

- Specification of up to 500 different particle sizes with associated settling rates and resuspension properties
- Continuous or episodic release of sediments into the water column at specified locations (e.g. for river outflows or dredge-spoil dumping)
- Resuspension of bottom sediments by seabed currents that exceed critical threshold speeds.
- Tracking of each sediment particle over time, with generation of hourly logs of sediment fates enabling the assessment of sediment accumulation or depletion over time.
- An emulsification algorithm (for fine sediments that interact with water)
- Visual display of currents and sediment transport

SEDMOD3D may be set up over a finer grid than that used by GCOM3D to simulate circulation data to allow for very high resolution of particle behaviour.

5.4.1 Set-up of the model grids for this study

GCOM3D was set up to operate over two model domains, which were linked by one-way nesting (Figure 4.5). The first grid (Grid A) covered Princess Royal Harbour, King George Sound and the Southern Ocean approaches to King George Sound (southern boundary from 35.25^o S 117.75^o W to 35.25^o S 118.5^o W). This domain was set up at a horizontal scale of 300 m and was used to generate boundary conditions for the second grid (Grid B), which was set up over Princess Royal Harbour and the western section of King George Sound at a horizontal scale of 100 m. This latter grid was used to generate the simulations of currents for input to SEDMOD3D.

SEDMOD3D was set up at a horizontal scale of 50 m covering the eastern section of Grid B and extending part way into Princess Royal Harbour (Grid C; Figure 4.6).

Bathymetric data used to generate the three-dimensional shape of these grids were compiled from digitised readings from hydrodynamic charts for the area (AUS 109, 110, 118) and from field measurements taken around the lease areas by IRC. The bathymetric model for the study area is shown in Figure 4.6.

Previous oceanographic studies in the region (Pattiaratchi *et. al.* 1991, Mills & D'Adamo 1993) have reported that density gradients do not play a significant role in circulation patterns within King George Sound and that meteorological and tidal forces principally drive the circulation. For this reason, GCOM3D was set up to run in barotropic mode, with forcing by winds and tides alone.

5.4.2 Calculation of tidal forcing

Tidal forcing within the region was measured in the field by placing two tidal gauges (Richard Brancker Research Ltd model 205) on the seabed for 1 month (22/10/1999 to 22/11/99). The gauges were positioned to the east and west of Mistaken Island to determine whether there was significant variation in the propagation of the tides around the Island. Measurements were also used to test for significant variation in tidal magnitude and timing between the lease areas and the National Tidal Facility (NTF) tide gauge position within Princess Royal Harbour.

Fourier analysis was used to define the magnitude and phase of tidal constants at each gauging site, and to remove residuals introduced by meteorological and other forcing. Predictions for tides based on calculated tidal constituents at the two measurement stations were then compared with predictions for the NTF gauge position. Results indicated that there were no significant differences in the timing or magnitude of tides among the three positions (Figure 4.7). This conclusion supports earlier observations for the study area (Mills & D'Adamo 1993).

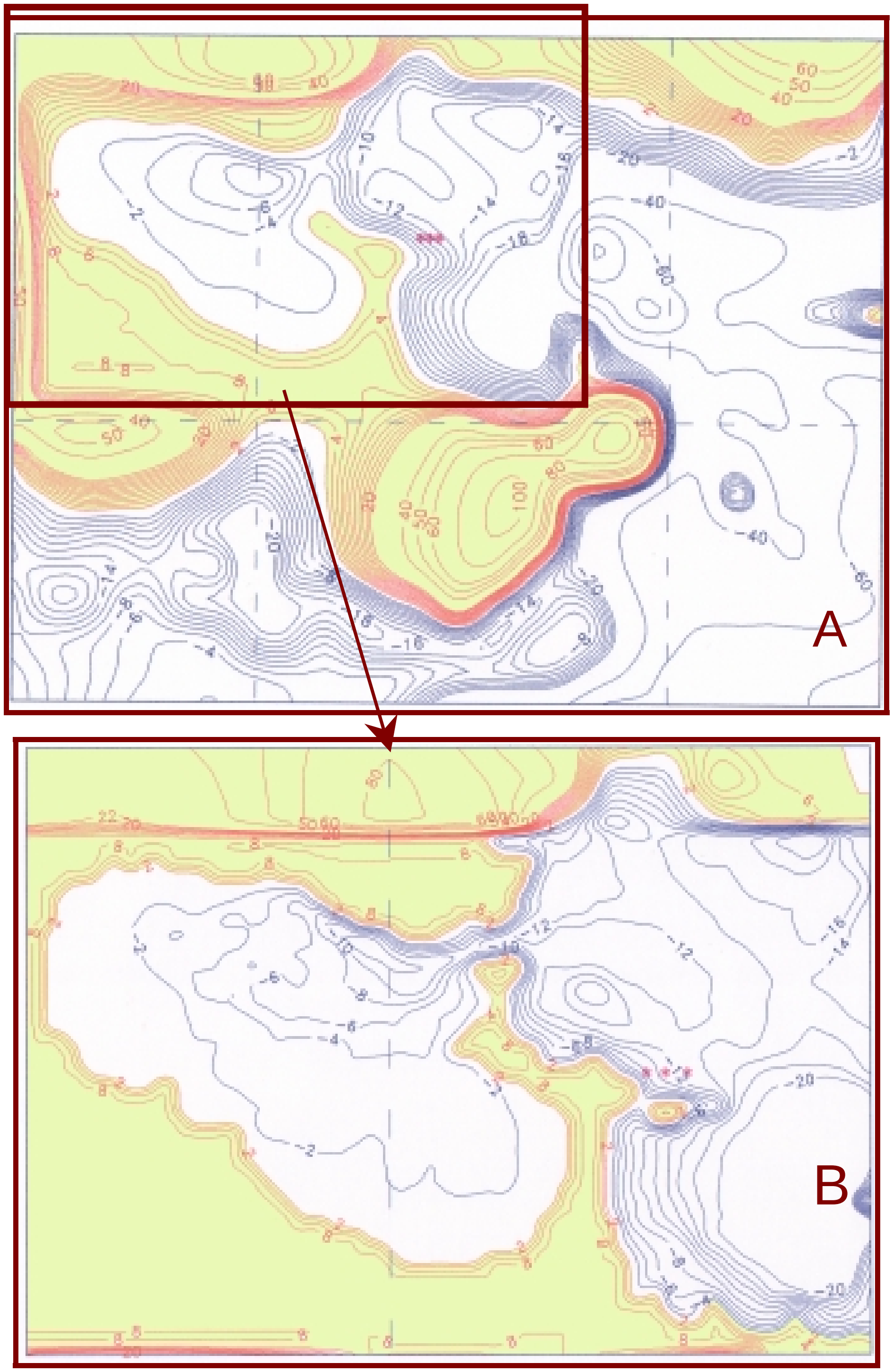


Figure 5.5 Model domains used for hydrodynamic modelling, showing the bathymetric models defined at 300 m resolution (grid A) and 100 m resolution (grid B). Inset to grid A shows the nested placement of grid B. Stars indicate the assumed positions of sediment release points.

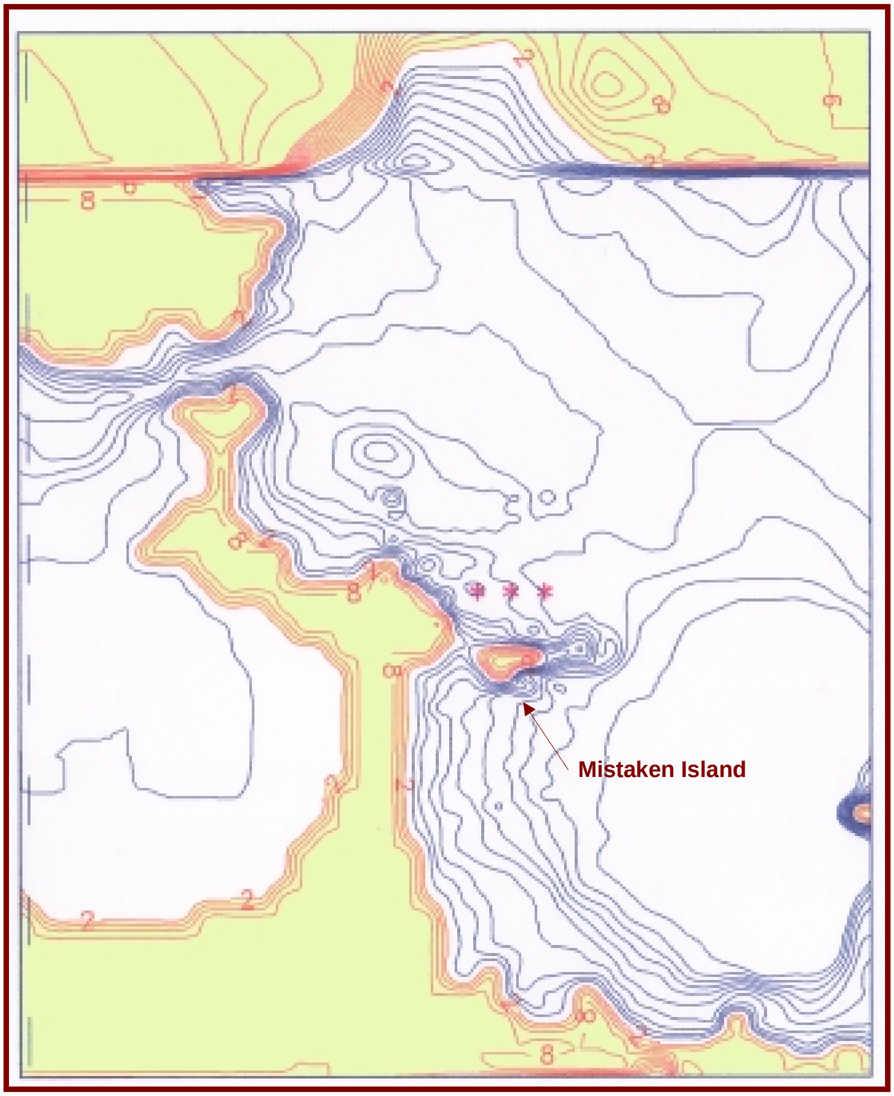


Figure 5.6 Model domain used for sediment transport modelling using SEDMOD3D showing the bathymetric model defined at 50 m resolution. The three red asterixis indicate location of the particle releases for the modelling.

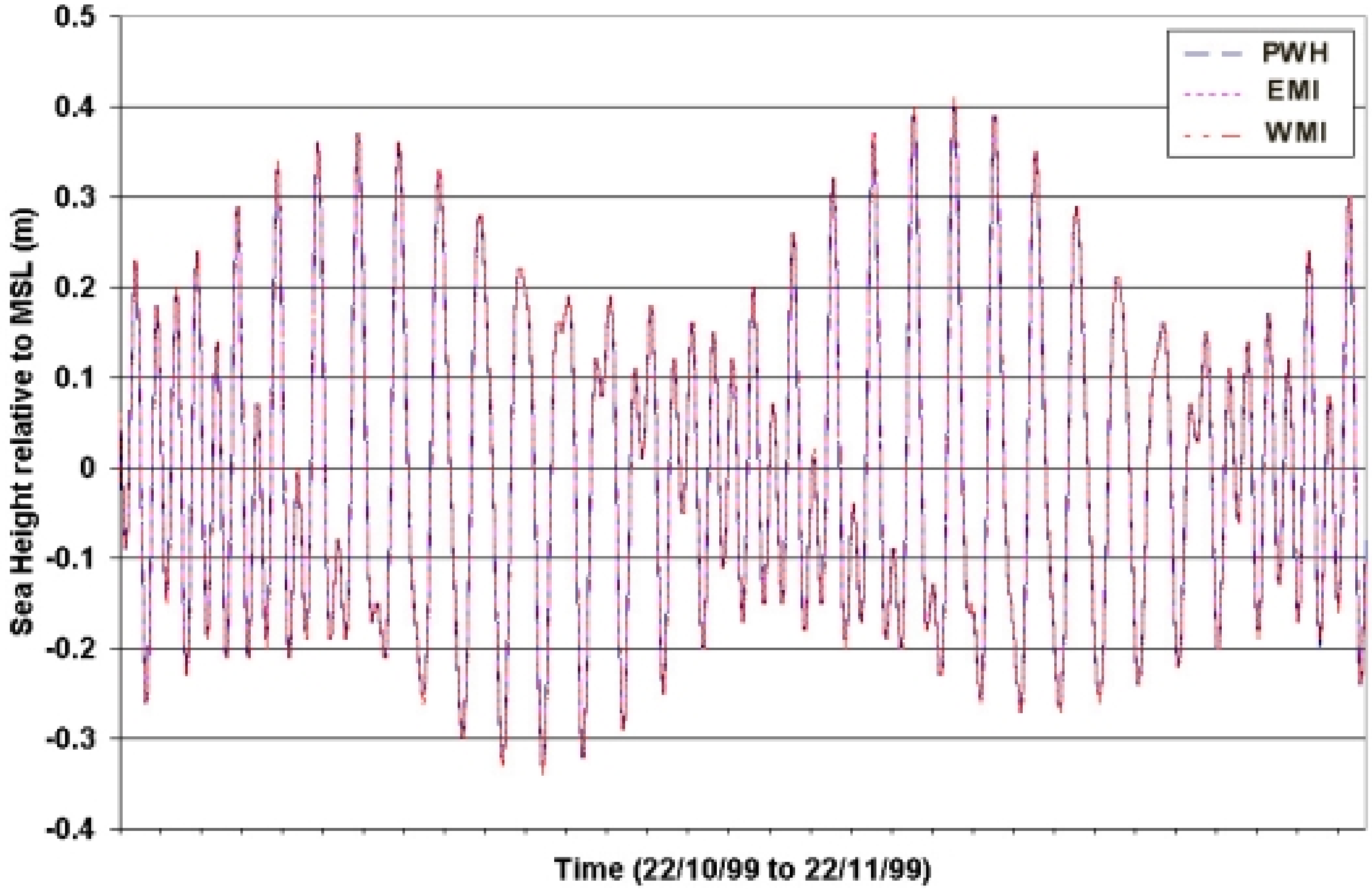


Figure 5.7 Comparison of tides predicted from tidal constituents measured at three locations: PWH=Princess Royal Harbour (source: National Tidal Facility); EMI = East side of Mistaken Island; WMI = West side of Mistaken Island (source: Tidal gauging for this study).

Measurements also confirmed earlier reports (Pattiaratchi *et. al.* 1991, Mills & D'Adamo 1993), that tidal forcing is relatively weak within most of King George Sound. The predicted tidal range is relatively small at approximately 0.70 m within a tidal change during spring tides and 0.28 m within a tidal change during Neap tides. These changes occur over approximately a 12-hour cycle. Raw measurements of sea-heights at the site are strongly modified by residuals (Figure 4.8), which can be attributed to meteorological forces.

Tidal forcing was input to the model by calculating variation in sea-height over time both along the open water boundary of each grid, and at the points of tidal measurement (NTF tidal station within Princess Royal Harbour and the two points of measurement from this study). Variation in sea-heights along the open boundaries of Grid A were calculated from a gridded set of modelled tidal constituents with a spatial resolution of approximately 5 km. Variation in sea-heights along the open boundaries of Grid B were predictions generated from Grid A for this boundary. All sea-height predictions were time-linked so that they could be defined for specific points in time, allowing hind-casting of circulation patterns when combined with time-linked wind observations.

5.4.3 Calculation of wind forcing

In contrast to tidal forcing, wind forcing is known to be a significant contributor to local circulation patterns (Pattiaratchi *et. al.* 1991). Thus, local wind patterns were important inputs to the modelling study.

Situated on the southwest corner of the continent, Albany is subject to a seasonal mid-latitude climate. In the winter months, the belt of high pressure known as the "sub-tropical ridge" typically lies over the cold land. During this period, the synoptic cycle results in the periodic passage of strong cold fronts originating in the Indian Ocean. Typically, the passage of a front will cause strengthening northwest winds followed by a shift in wind direction to the southwest with the frontal passage. Wind strength will then usually moderate as high pressure rises in the wake of the front.

In the summer months, the warming continent causes the sub-tropical ride to migrate southwards and northward penetration of Indian Ocean cold fronts is much more limited. With the mean position of the ridge to the south, the winds at Albany have an easterly bias, partly as a result of pressure gradient influences but also resulting from the summer sea breeze effect. Hot inland temperatures and cold southern ocean temperatures enhance the sea breeze along the south coast. During the warm months, the weather in the southwest of Western Australia is often dominated by the development of a heat trough on the west coast. This feature may be quite persistent, causing a northeast pressure gradient over the study area. The diurnal cycle then results in lighter northeasterly quarter winds overnight and in the morning hours with vigorous sea breezes developing in the afternoons. Periodically the approach of a southern front will cause the trough to move inland producing a southerly change on the south coast. Usually, a new high-pressure system will follow the front-trough system and winds back rapidly towards the east, renewing the heat trough.

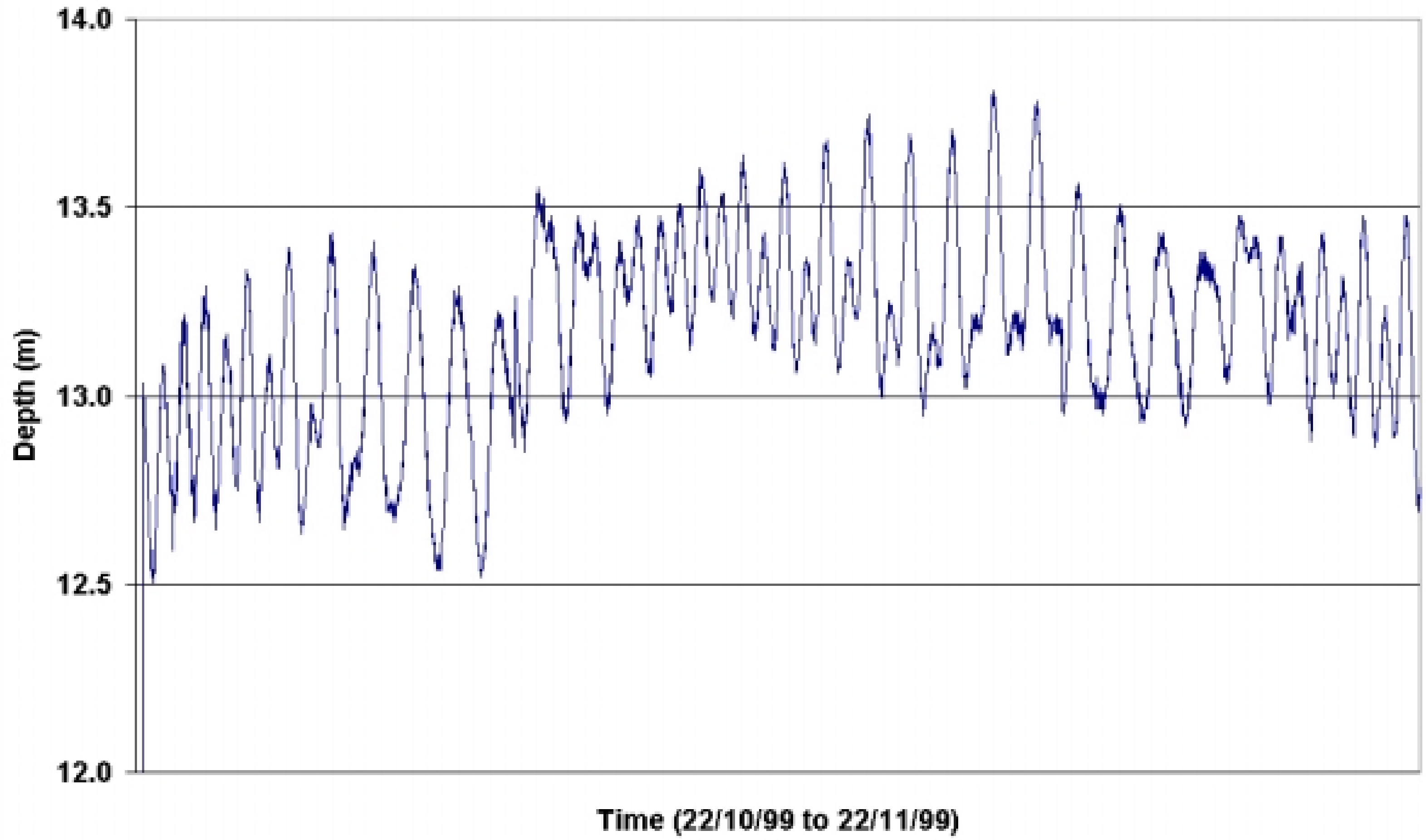


Figure 5.8 Variation in sea height measured at a site on the east side of Mistaken Island (EMI in Figure 4.7), showing the combined effects of astronomical tides, Meteorological forcing and other forces.

Long-run wind observations have not previously been recorded for the immediate area of the mussel leases. The nearest point of such measurements (1993 to current) is at the Bureau of Meteorology weather station placed at Albany Airport, which is located on an escarpment approximately 17 km to the northwest. As there may have been significant differences between wind patterns at the lease area and airport, a wind station was established on Mistaken Island to collect a sample of local wind conditions.

The wind station (Monitor Datalogger with digital anemometer and wind vane) was placed on an exposed rise at the top of Mistaken Island and set to record wind speed and direction at hourly intervals (10-minute averaged). The meter recorded wind conditions for a six-week period (2/6/2000 to 17/7/2000). Wind data obtained from Mistaken Island were then compared with concurrent observations made at Albany Airport.

The first part of the analysis compared the winds at the anemometer site with the airport to determine whether topographic or diurnal influences would prevent use of the longer data set from the airport being used to represent conditions at the study area.

Figure 4.9 shows a plot of the winds at the two recording sites for the period during which observations were available from both. Inspection of the plot shows that the observations are generally well correlated.

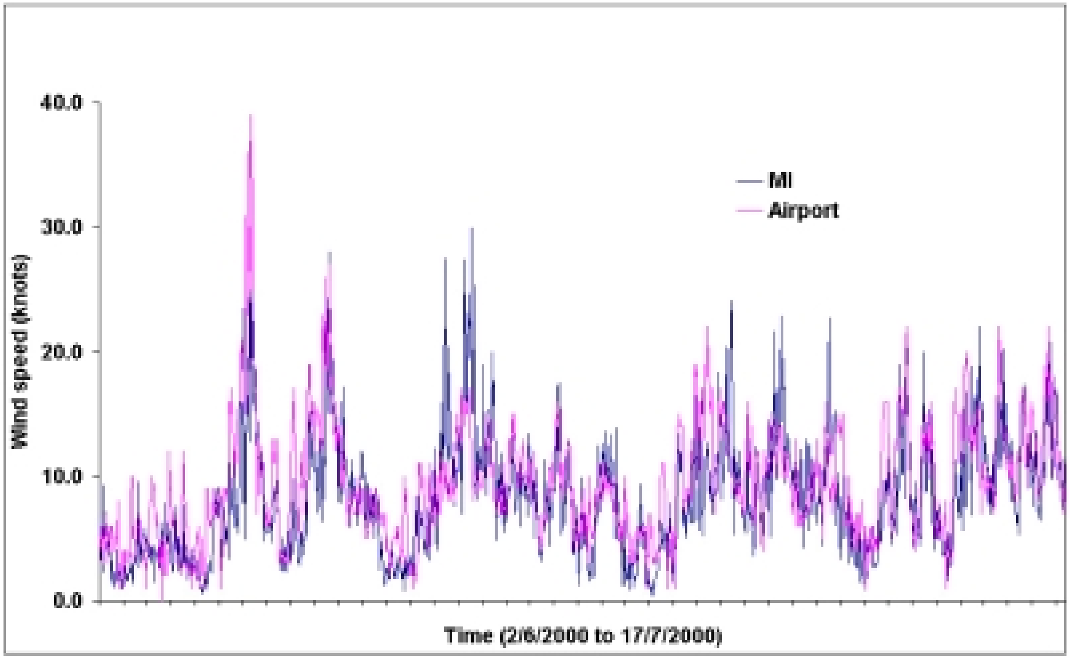
To compare wind observations statistically, each speed and direction value was converted into linear values for magnitude toward the east-west (u component) and north-south (v component). The u and v components were then correlated separately. For these correlations, the wind data were grouped by direction in order to test for dependency on synoptic pattern. The analysis supported the observation that winds at the two locations were well correlated (Figure 4.10).

It was concluded that the airport winds could be used to represent winds over the study region without correction. It was considered that differences between observations at the airport and the study site were just as likely to result from local topographic and terrain influences at the observation sites as gross differences between the two areas.

Having established that the airport data could reasonably be used to represent winds over the study area, the next requirement was to establish typical temporal patterns in the wind records. This was achieved by undertaking a similarity analysis of winds recorded over the longer term (1993-2000) broken up by monthly records (96 in all spanning 8 years).

The similarity analysis was achieved by resolving each hourly wind observation into the magnitude of its u-v components. This converted the angular data (i.e. constrained to 0-360 degrees for direction) into two-dimensional linear data from which a two-dimensional frequency array of u-v magnitudes was constructed. The frequency distribution of u-v magnitudes during any month was then compared with each other month and a root mean square difference of frequencies was calculated across the array. Referred to as the “similarity parameter”, this value is calculated for each pair combination. By applying threshold values to the similarity parameter, monthly records were grouped by similarity.

(a)



(b)

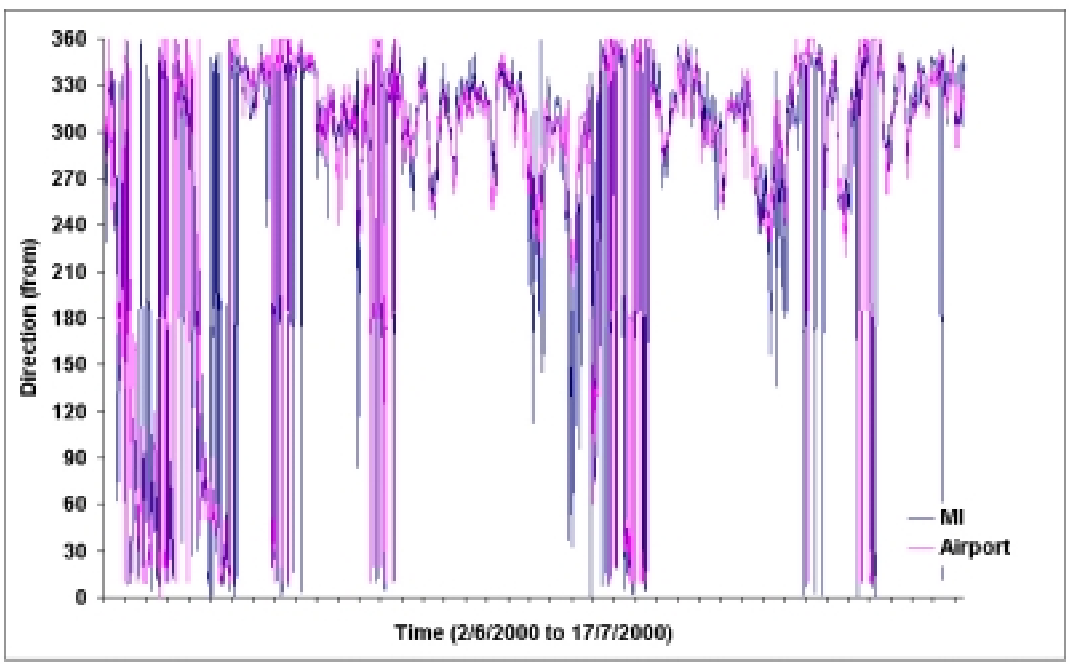
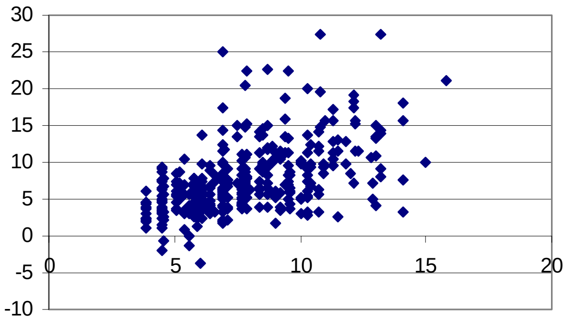
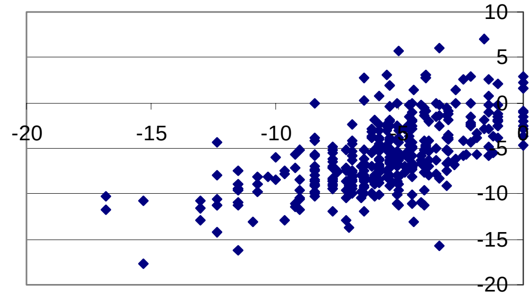


Figure 5.9 Comparison of wind speed (a) and wind direction (b) recorded at Albany airport and at Mistaken Island during a six-week sampling period (2/6/2000 to 17/7/2000).

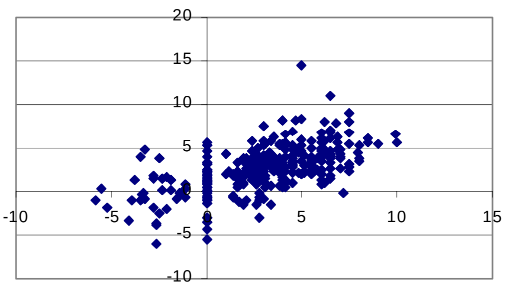
Ucomp > 5knots/270-330 degrees



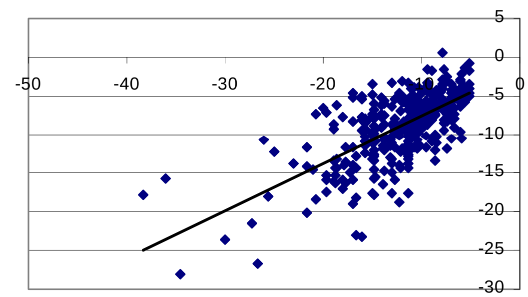
Ucomp > 5knots/270-330 degrees



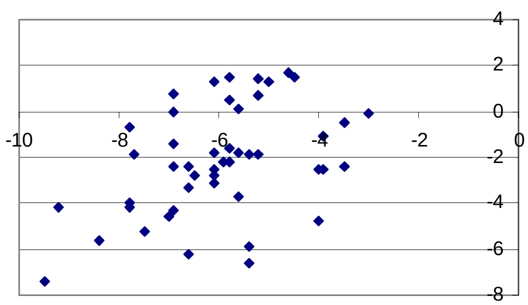
Ucomp > 5knots/330-030 degrees



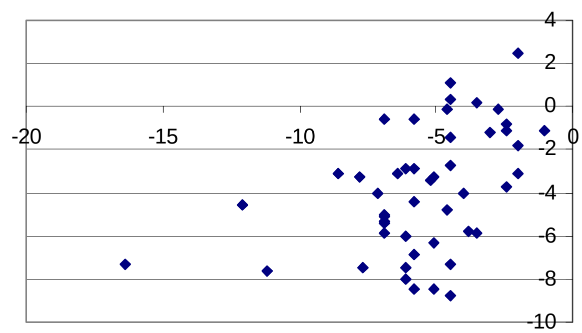
Vcomp >5 knots/ 330-030 degrees



Ucomp > 5knots/030-090 degrees



Vcomp > 5knots/030-090 degrees



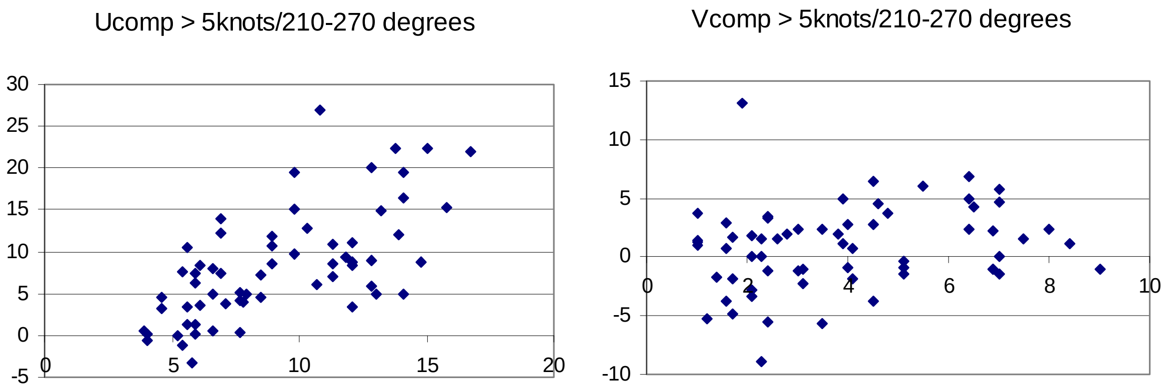


Figure 5.10 Correlation of u and v components of wind speed recorded at Albany airport and at Mistaken Island.

Table 5.4 Summary of coefficients for correlation of u and v components of wind speed recorded at Albany airport and at Mistaken Island.

Correlation Description	Correlation Coefficient
u component - Direction 270/330 deg	0.53
v component - Direction 270/330 deg	0.61
u component - Direction 330/030 deg	0.60
v component - Direction 330/030 deg	0.67
u component - Direction 030/90 deg	0.45
v component - Direction 030/90 deg	0.51
u component - Direction 210/270 deg	0.66
v component - Direction 210/270 deg	0.22

The most commonly occurring wind regimes fell into four primary groups, which coincide with major synoptic wind patterns. These are:

Group 1: Summer – non-easterlies. Occurs when a very strong and persistent high-pressure system develops to the south of Western Australia.

Group 2: Transition season. A wide range of wind directions reflect greater synoptic variability during transition from summer to winter in autumn and vice versa in the spring months.

Group 3: Winter. A preponderance of westerly quarter winds reflects the position of the subtropical ridge over the continent during the colder months. Winds typically shift between northwest and southwest with each frontal passage.

Group 4: Summer – easterlies. When a ridge to the south of the continent has abnormally high pressure causing easterly pressure gradients to persist over the southwest of the continent. In these situations, the passage of a southern front may break down the ridge temporarily, but it will tend to quickly reform.

To illustrate the mean configuration of winds in these groups, wind roses were constructed for each group based on their aggregated winds and these are shown in Figures 4.10 - 4.13.

To serve as an example of each wind pattern during modelling, a monthly record was selected from each of the above groups, as follows:

Group 1. February 1994;

Group 2. April 1995;

Group 3. June 1997;

Group 4. December 1994;

Plots of the time-varying winds during these periods are shown in Attachment 2. It should be understood that these records are illustrative of major wind patterns over the study area, but are not definitive of all wind conditions that could occur.

5.4.4 Validation of current predictions

To validate predictions of GCOM3D using wind and tidal forcing defined for the study area, water currents were measured over short periods (24 hours) at two locations within the lease area (Figure 4.1) between 31st January and 5th February 2000. Currents were measured by a seabed-mounted acoustic doppler current-profiler (Workhorse ADCP). This device measures currents at intervals through the water column by tracking the movement of suspended particles. GCOM3D was run using the set-up details described previously and with wind forcing calculated from measurements at Albany Airport over the period of current measurement. Predictions from GCOM3D for the sampling locations were then compared directly with field measurements.

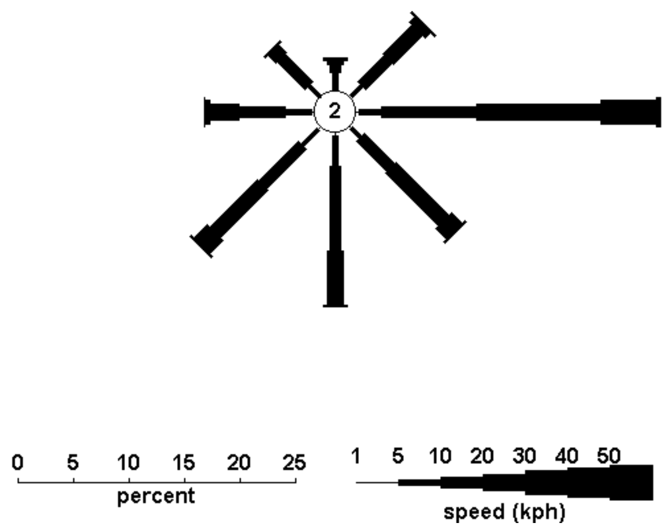


Figure 5.10 Windrose showing the distribution of wind speed and direction during Group 1 months. Plot is defined from all records from group 1 months.

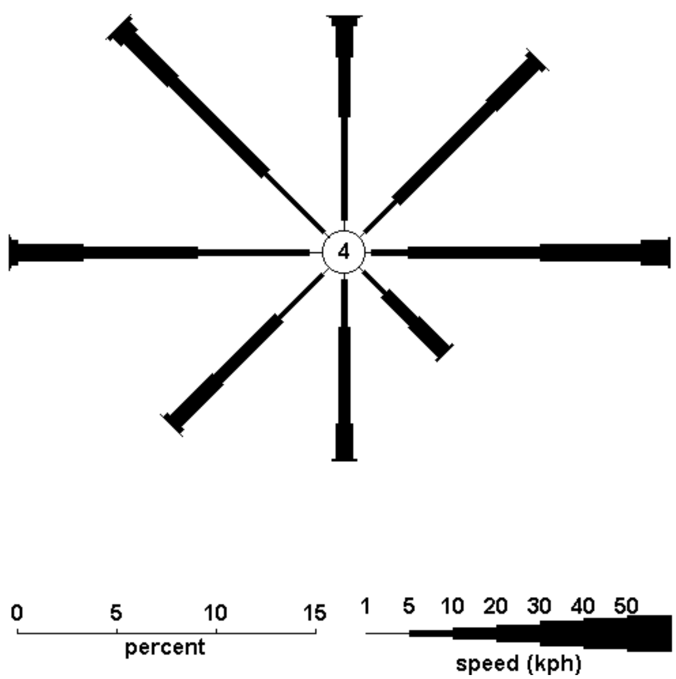


Figure 5.11 Windrose showing the distribution of wind speed and direction during Group 2 months. Plot is defined from all records from group 2 months.

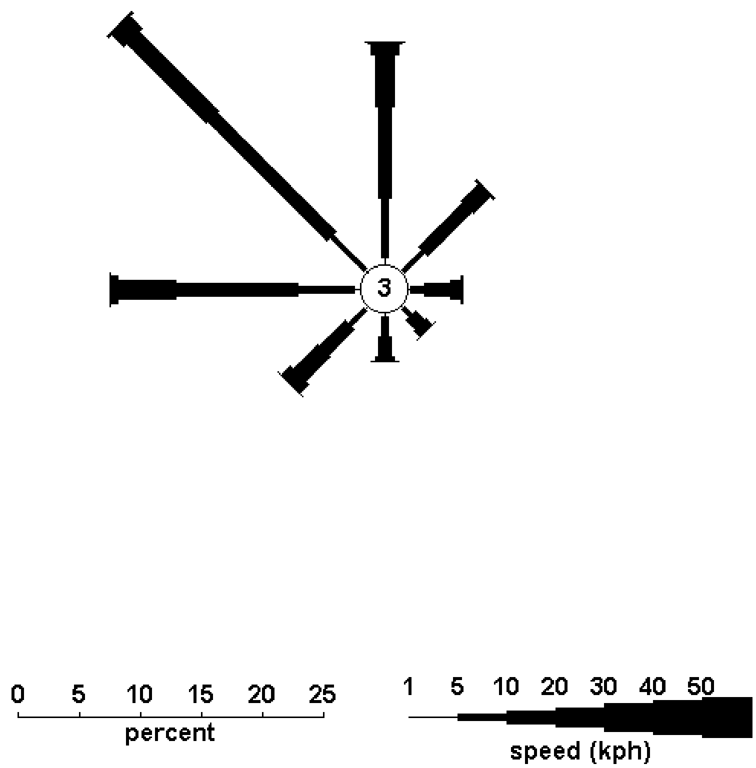


Figure 5.12 Windrose showing the distribution of wind speed and direction during Group 3 months. Plot is defined from all records from group 3 months.

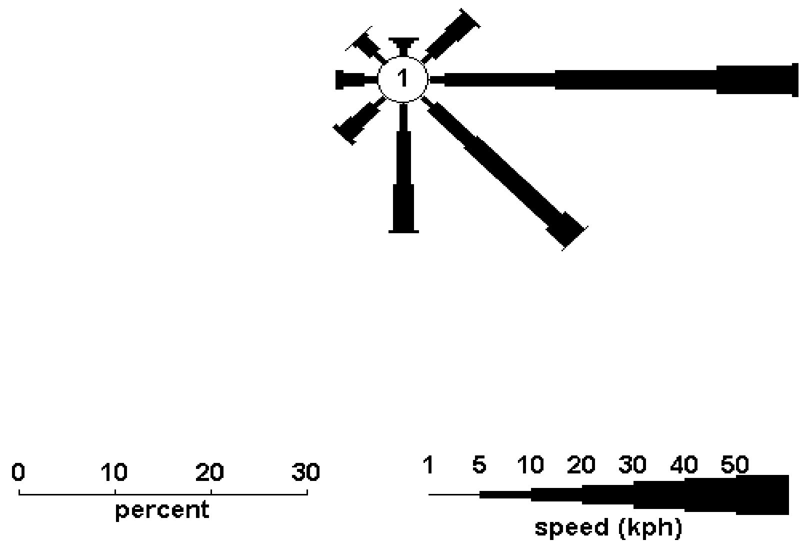


Figure 5.13 Windrose showing the distribution of wind speed and direction during Group 4 months. Plot is defined from all records from group 4 months.

Comparisons show a good agreement between the observed and predicted currents at the two locations, both in terms of the overall speed and direction of currents and the variation in currents with depth (Figures 4.14 - 4.17).

During the sampling period, current speed at Site 1, which was on the southern end of the lease area, and east of Mistaken Island, peaked at approximately 0.35 m s^{-1} near the surface and 0.12 m s^{-1} at mid-water depth (Figures 4.14 & 4.15). This result indicates a significant contribution by surface wind shear. Model predictions were usually within 0.025 m s-1 of observations and most peaks and troughs in current speed were predicted. Current direction varied around the compass over the sampling period and peak speeds were toward the north to north west (360 ^{o} – 300 ^{o}) and north to north east (0 ^{o} -120 ^{o}). Variation in current direction was well predicted, with only small and inconsistent errors in the timing of direction changes (< 2hours).

Current speeds at Site 2, which was on the eastern side of the channel separating Mistaken Island from the mainland, peaked at approximately 0.35 m s at the surface and 0.2 m s at mid-water depth (Figures 4.16 & 4.17). Thus surface wind shear was similarly expressed at this site. Model predictions showed good agreement with observations throughout the record. The peak in current speeds corresponding to a modification of current direction toward the west (240 to 270) at the end of the record indicates that water was being funnelled through the channel by winds from the east. The model was able to reproduce this pattern well using wind observations from Albany Airport. This supports the use of Albany Airport wind data and demonstrates that the model was resolving flow through the channel.

Modelling of currents

The four wind samples selected to represent major wind patterns were used as input to GCOM3D to simulate circulation over the study area, via the one-way nesting of Grids A and B. The outcome of this modelling were hourly logs defining three-dimensional current fields within Grid B over the period of each wind sample, at a spatial resolution of 50 m. This data was used as input to the particle transport modelling described in Section 4.5.

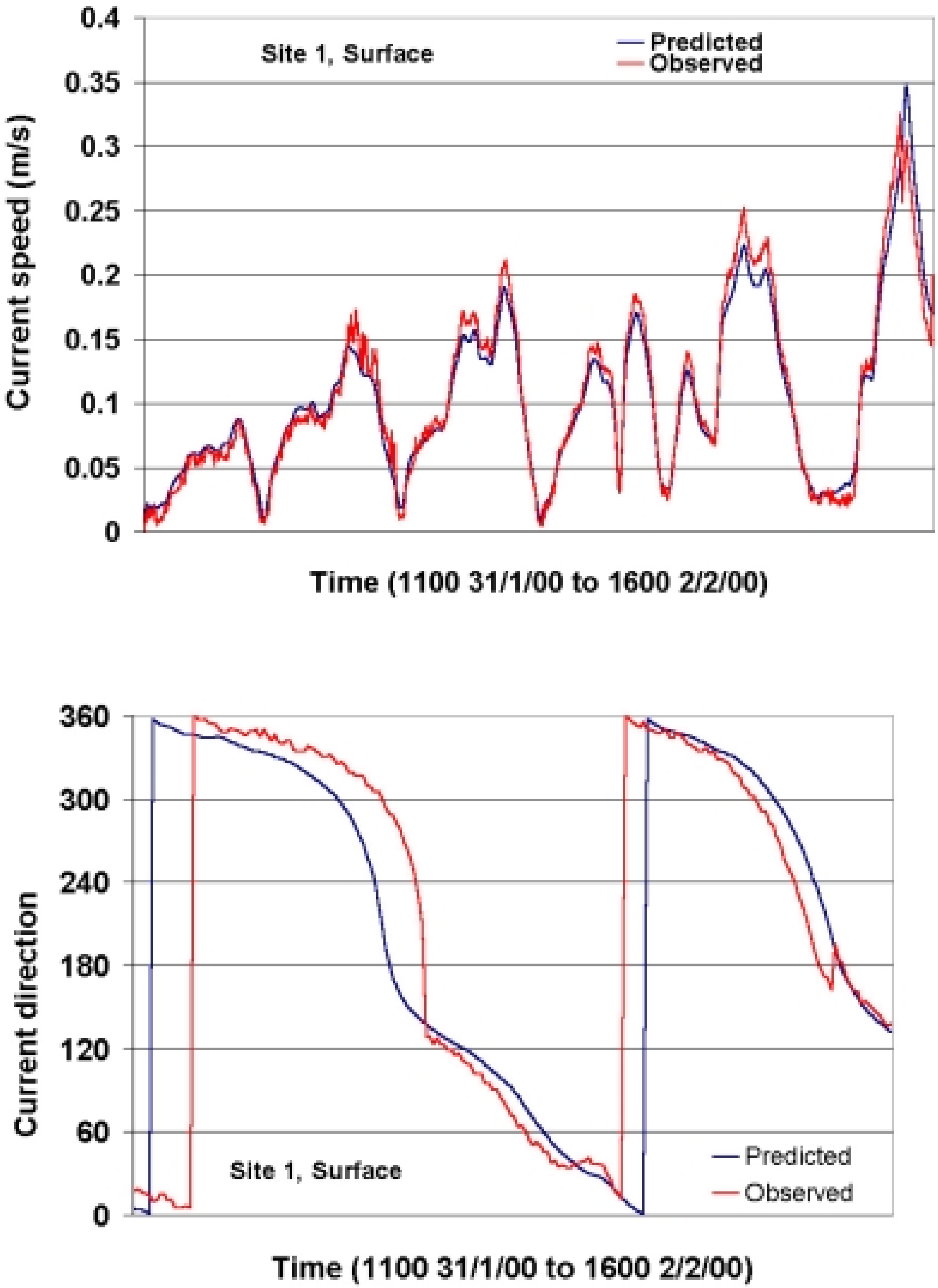


Figure 5.14 Comparison of predicted and observed currents at the surface layer (1m depth) at measurement Site 1.

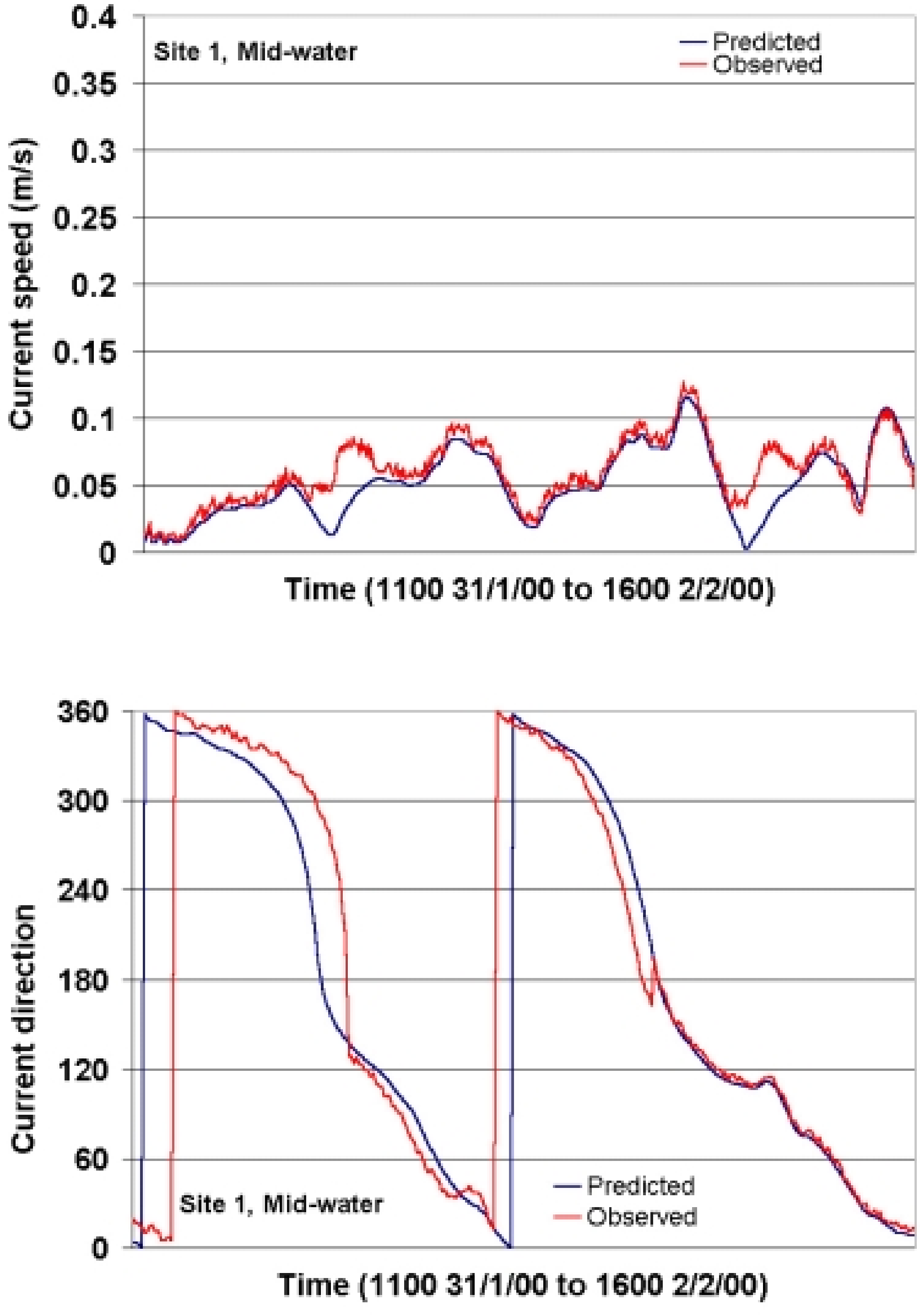


Figure 5.15 Comparison of predicted and observed currents at the mid-water layer (5 m depth) at measurement Site 1.

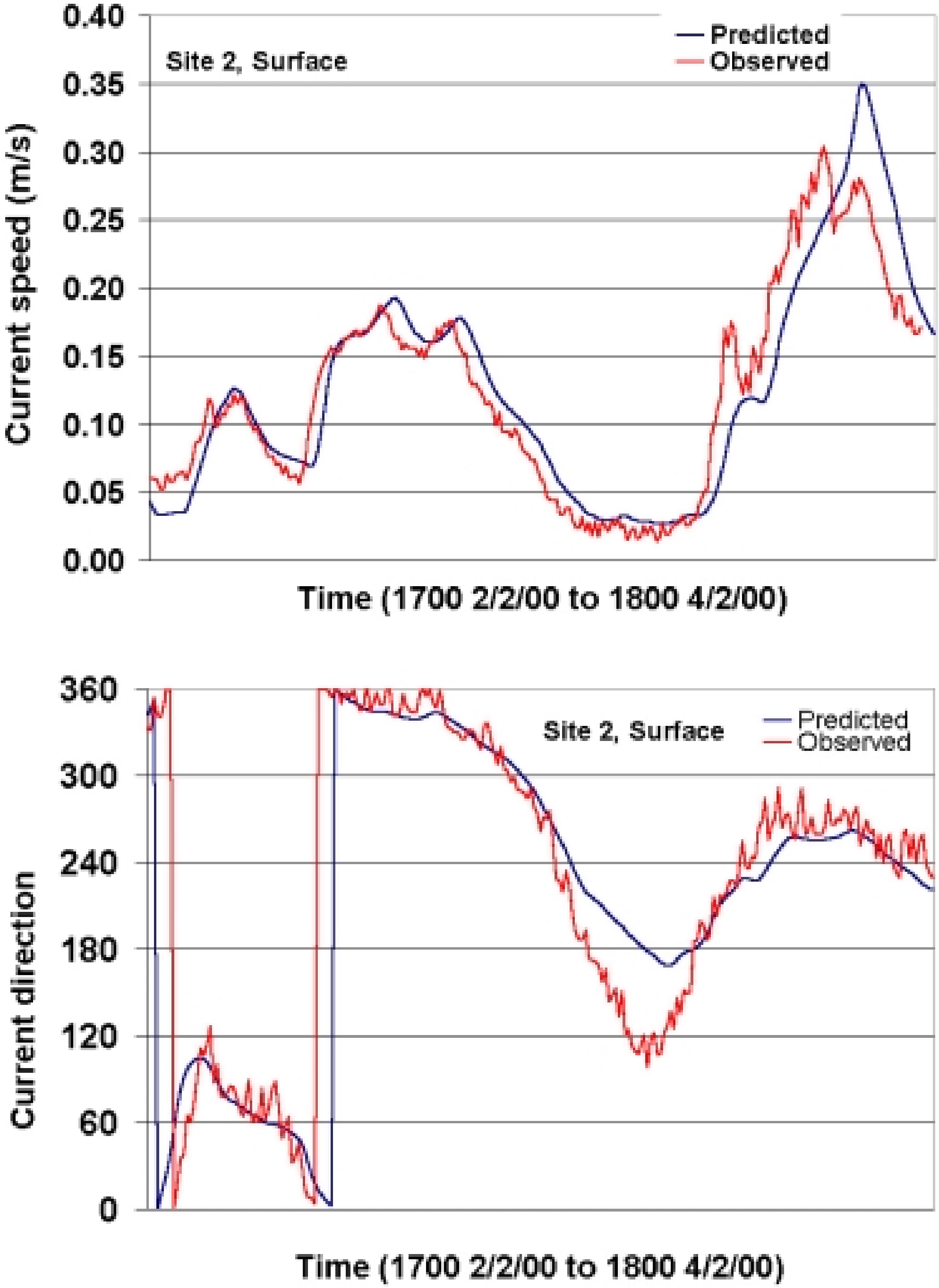


Figure 5.16 Comparison of predicted and observed currents at the surface layer (1m depth) at measurement Site 2.

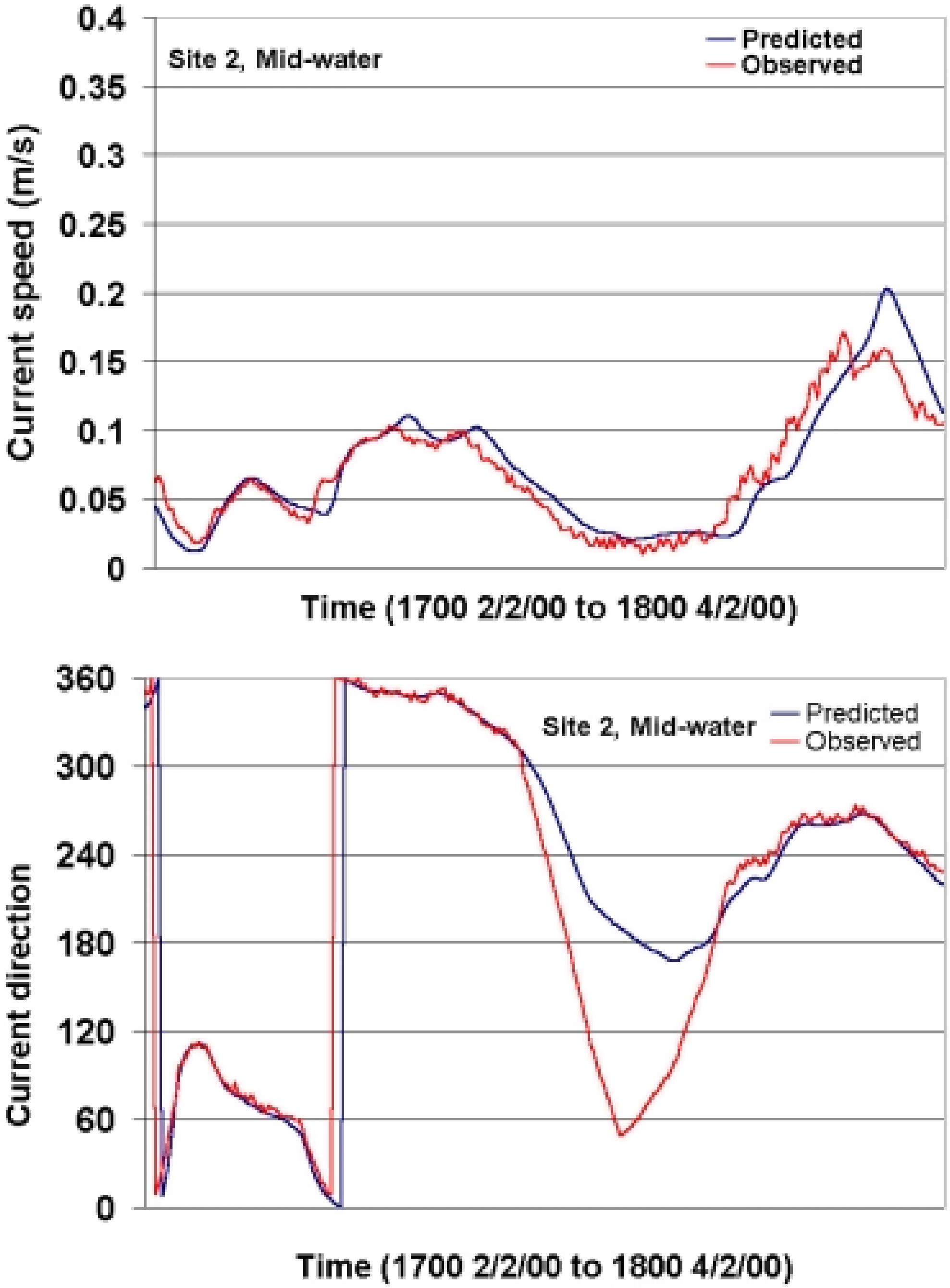


Figure 5.17 Comparison of predicted and observed currents at the Mid-water layer (5 m depth) at measurement Site 2

5.5 Modelling of particles released at mussel lines

The objective of modelling to define the transport of particles was to predict the fate of organic material released from the mussel lines. Sources of organic material contributed by the mussel farms could include faeces and pseudofaeces (material rejected by suspension feeders or deposit feeders as potential food before entering the gut) released by the mussels as well as similar material from other fouling organisms that grow upon the anchoring lines and fixtures (Grant *et. al.* 1995).

Particle transport modelling required the following inputs:

- The size and density of the particles, from which sinking rates were calculated against current speed;
- The rate of release of particles;
- The period and timing of releases; and
- The location of releases.

No data were available to define the size or density of organic material released from the mussel lines within the study area. For the purpose of modelling, It was assumed that these particles would have a size range of approximately 3-5 µm, which has been reported to be consumed by mussels (Lesser et al 1992). Sinking rates for decaying organic material have been reported as ranging from 0.1 to 10 m day^{-1} (Metcalf & Eddy 1991), these rates being considerably slower (~ 10 times) than for inorganic particles of the same size. We assumed a distribution over this range, as follows:

- 70% with sinking rates of 0.1 m day^{-1};
- 10% with sinking rates of 1.7 m day^{-1};
- 10% with sinking rates of 4.3 m day^{-1}; and
- 10% with sinking rates of 9.5 m day^{-1}.

Similarly, no data were available to define the rate of discharge, and variation in this rate, from the mussel lines within the study area. Field sampling that attempted to detect elevations in organic loading around the mussel lines with sediment traps proved inconclusive because there was no evidence for consistently greater deposition rates within traps placed under the lines relative to more distant sites **(**Section 4.7). As the rate of release of material could not be quantified (as mass over time), a nominal rate of discharge was defined and results were calculated as a proportion of the total number of particles (rather than mass) that had been released. Material was assumed to release continuously from the mussel lines, at a constant rate of 600 particles per hour.

Particles were released from three locations spaced over 700 m to represent the approximate position of the existing mussel culture lines, which are located on the eastern side of Mistaken Island.

Separate runs were modelled using wind data, and hind-cast tidal conditions, from the four example periods of wind data defined previously (Section 4.4.3). It should be noted that wind patterns varied both among and within these wind samples. Thus, the magnitude and direction of resulting water currents varied both among and within these sample periods.

SEDMOD3D calculated the effect of depth-varying currents on both the settlement of particles sinking through the water column, and the subsequent retransport of particles that had previously settled. Retransport was calculated where seabed currents exceeded a defined threshold speed. The threshold speed for organic particles was assumed to be an order of magnitude lower than those reported for fine inorganic particles lying on a flat sand bed (Soulsby 1997). A value of 0.03 m s^{-1} was applied.

At each (12 minute) time step, SEDMOD3D calculated the movement (by latitude, longitude and depth) of every particle that had been released up to that time. Hourly summaries of this data were stored from each run.

The hourly summary data were converted into gridded data files reporting the proportion of total particles that were settled on the seabed within each grid cell. This data was calculated for a 25 m x 25 m grid using the longitude and latitude address of each particle.

5.6 Organic deposition

Aim

To compare organic deposition from the water column under mussel longlines and control sites.

Methods

Sediment traps to collect particulate matter from the water column were deployed in summer (February 2000) and in winter (July 2000; Table 4.5). Sediment traps were deployed in an array consisting of eight traps spaced at 1 m intervals and suspended 1 m above the seabed (Figure 4.18). Each trap consisted of a 30 cm long PVC tube with a 5.5 cm internal diameter. The traps were tethered to a ground line moored by two 25 kg weights and marked by a small, submerged float. Four arrays were positioned under mussel lines and two were positioned at control sites. Table 4.5 shows the experimental design used to study organic deposition.

Table 5.5 Experimental design used to measure organic deposition.

Factor	Description
Seasons	Summer and winter
Sampling areas	4 mussel lines + 2 controls
Replicates	8 Replicates per site

The sediment traps were left for one month to provide a relatively long term, integrated measure of organic deposition. At the end of one month, divers capped each trap before bringing them to the surface, where the trap contents were decanted into 1 L plastic bottles and frozen prior to laboratory analysis. The particulate material in each sample was dried at 50°C for 24 hours and then weighed to 0.001g using a Sartorius 1518 balance. The material from sediment traps for February 2000 was also analysed for organic content.

Figure 5.18 Sediment traps used for the study of organic deposition

Data analyses

Data were originally analysed by 2-factor unbalanced ANOVA (factors being: "Treatments" - mussel lines and controls and "Sampling Areas"). Despite transforming the data it was not possible to satisfy assumptions the ANOVA (Bartlett's test $P < 0.001$). The analysis was therefore carried out in its simplest form: 1-factor ANOVA on untransformed data. Similarly, the organic content (% Loss on Ignition) data could not be transformed to satisfy the assumptions of ANOVA so were analysed by a simple one-way ANOVA.

5.7 Mussel longline mooring structures

Aim

- To measure the degree of movement, if any, of mussel longline mooring structures on the seabed; and
- to monitor for any damage to adjacent seagrass from mussel longline mooring lines or structures.

Methods

Monitoring the effects of mussel longline mooring structures on seagrass were undertaken during summer (February 2000 and 2001) and in winter (July 2000). Mooring structure effects were assessed by measuring the movement of either mooring anchors or mooring chains in relation to a star-picket hammered into the seabed. The chain is marked by rope tied through the link closest to each star-picket. Movement of a mooring will be apparent if the link has shifted relative to the picket. The rate and direction of movement was measured.

The aerial extent of scoured seabed surrounding each of the mooring chains and structures was estimated by SCUBA divers during each sampling period. Changes in the area of scoured seabed was measured by divers and also documented on video. The seagrass density scale developed in Section 4.1 was used to describe the seagrass in the vicinity of mussel line moorings (ie High cover >75%, Moderate cover 50-75%, Low cover 25-50% and Very Low cover <25%).

6 RESULTS

6.1 Mapping seagrass distribution in the aquaculture extension area

Information on seabed habitats is presented below at three scales:

- Regional-scale (King George Sound);
- Project-scale (Aquaculture Extension Area); and
- Local-scale (within individual mussel-culture lease areas).

Regional-scale information on habitats is available from the results of the 1998 survey of King George Sound (Evangelisti & Associates 1999). More detailed information on habitats within the boundaries of the Aquaculture Extension Area and within existing defined lease areas located north and south of Mistaken Island is presented in this report.

6.1.1 King George Sound

The broad habitat maps generated from the 1998 survey of King George Sound show that seagrass composition and cover differs markedly depending on location in the Sound. Along the south-western and southern sector of the Sound, in Frenchman's Bay, seagrasses appear to be dominated by the perennial *Posidonia sinuosa* and smaller, more opportunistic seagrass genera such as *Halophila* spp. and *Heterozostera tasmanica*. In contrast, seagrass beds to the north and north-east of the AEA, and those occurring in deeper water to the east of the AEA, and also inshore and north of Michaelmas Island, are predominantly species of the "*Posidonia ostenfeldii* species complex". This seagrass "complex" includes a number of related species separated taxonomically from *Posidonia sinuosa* by a number of common features. These features include anatomical differences such as narrower, tougher and biconvex leaves and a generally more resilient habit associated with deeper-rooting characteristics. This "complex' includes seagrasses such as *Posidonia coriaceae* recorded near the entrance to Oyster Harbour.

6.1.2 Aquaculture Extension Area

The key habitats and vegetation recorded in the AEA are described in detail below. The key habitat types and associated vegetation recorded at each field site using drop-down video photography is shown in Figure 5.1. Seagrass cover and density observed within the camera field-of-view at each field site is shown in Figures 5.2 and 5.3 respectively.

The habitat map of the AEA is an interpretation of the information in Figures 5.1, 5.2 and 5.3 and is shown in Figure 5.4. This map indicates that the major sub-tidal habitats in this area comprise seagrass on sandy seafloor.

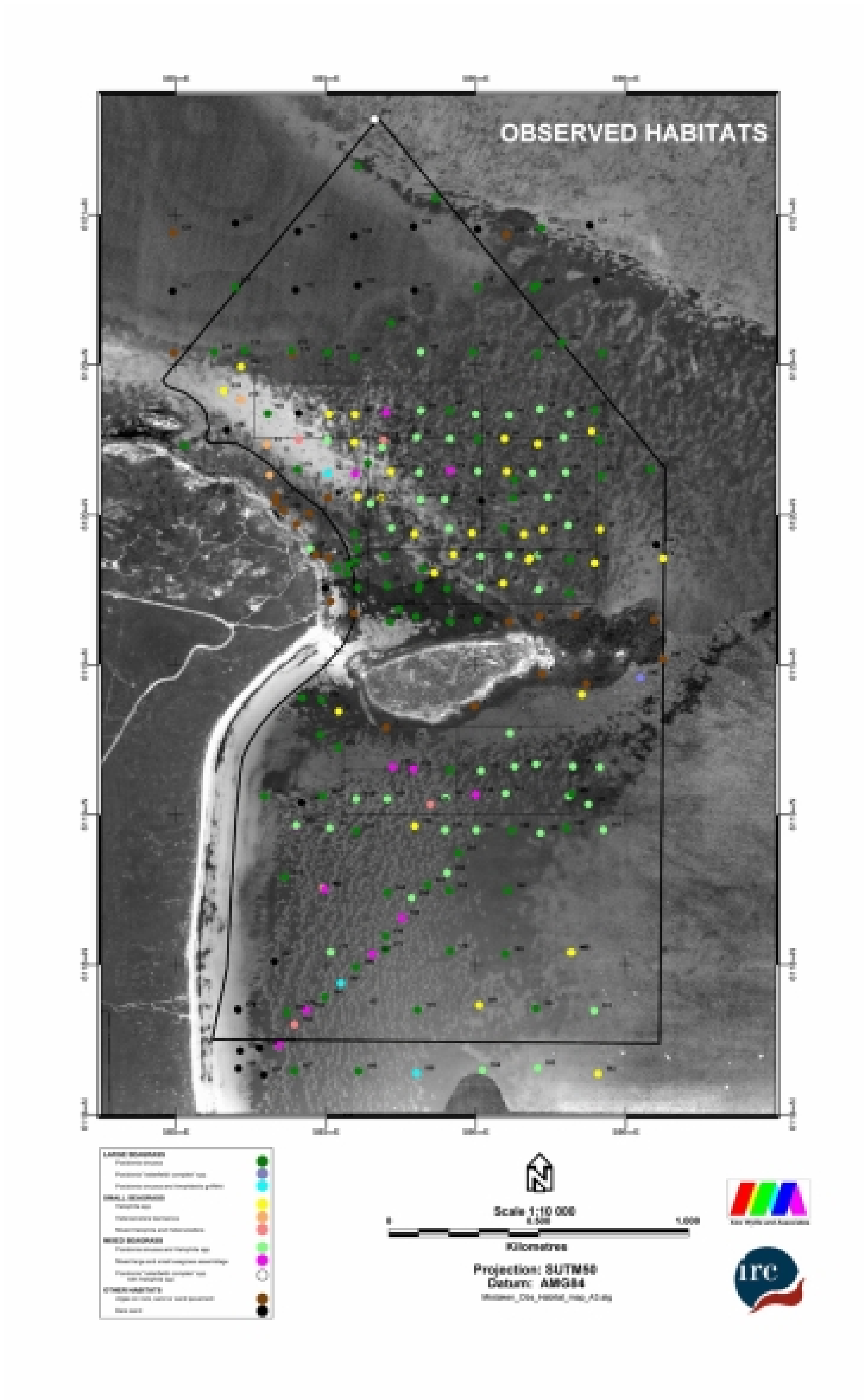


Figure 6.1 Observed habitats in the Aquaculture Extension Area

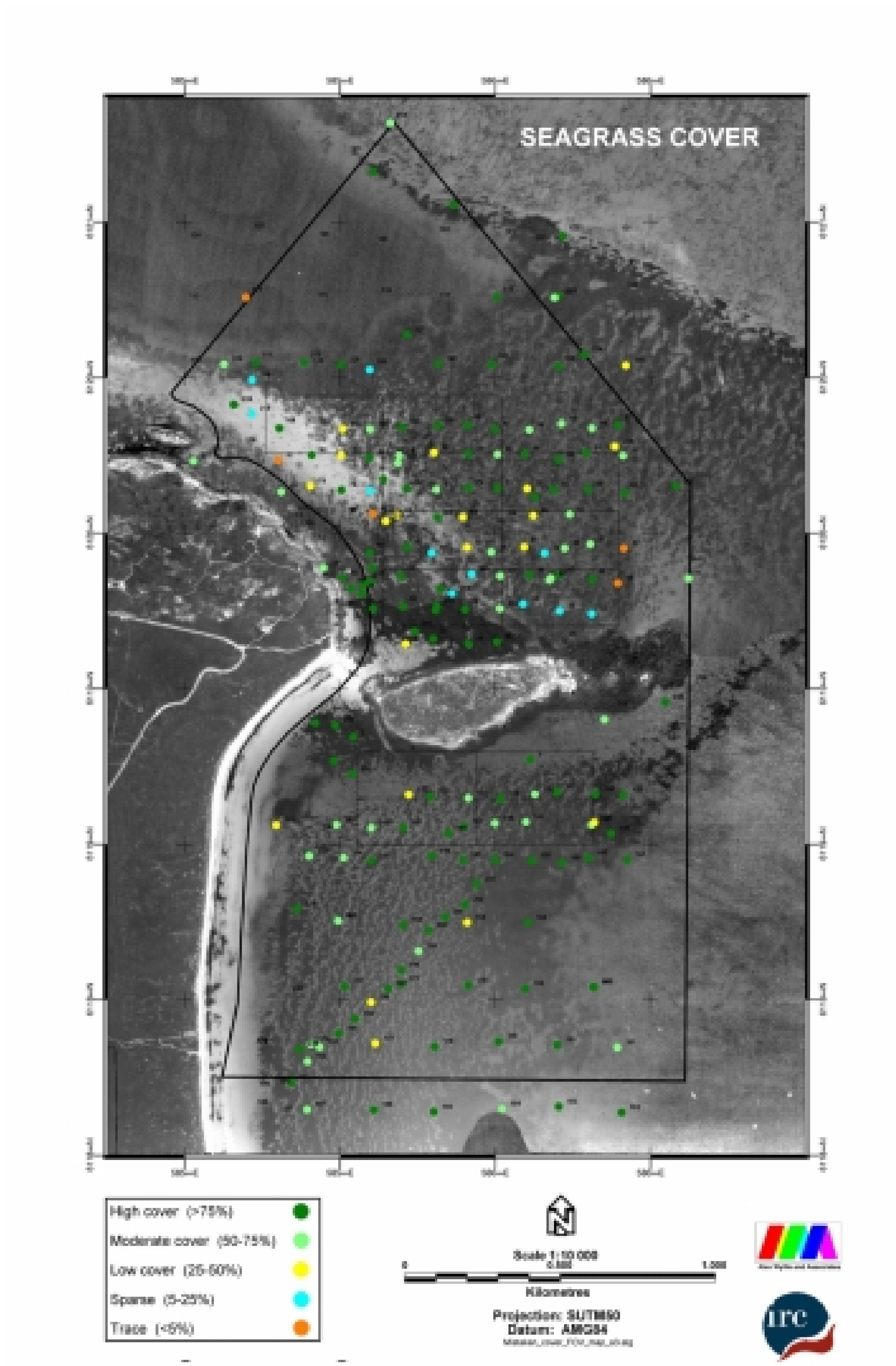


Figure 6.2 Seagrass cover in the field of view

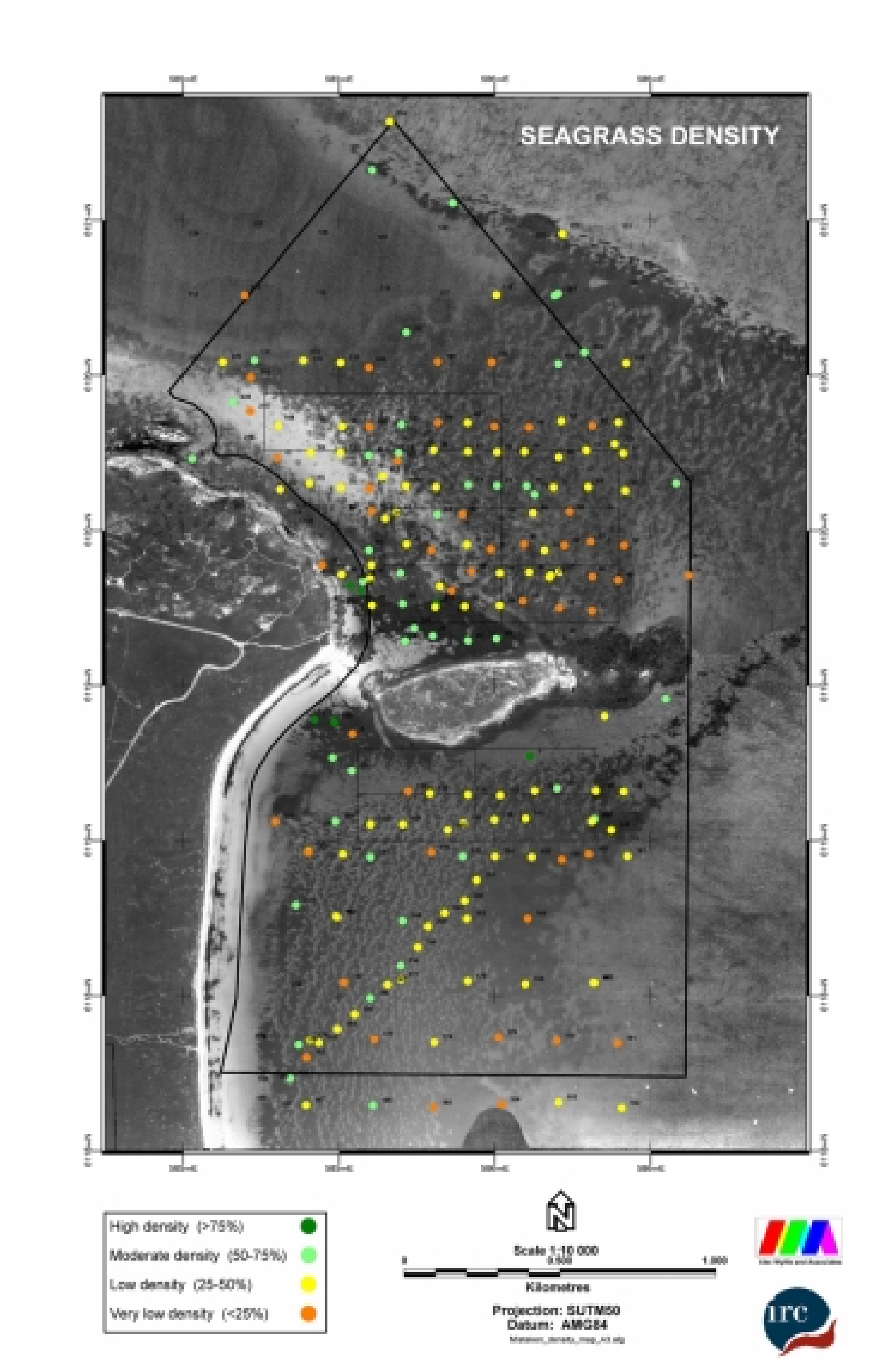


Figure 6.3 Seagrass density in the field of view

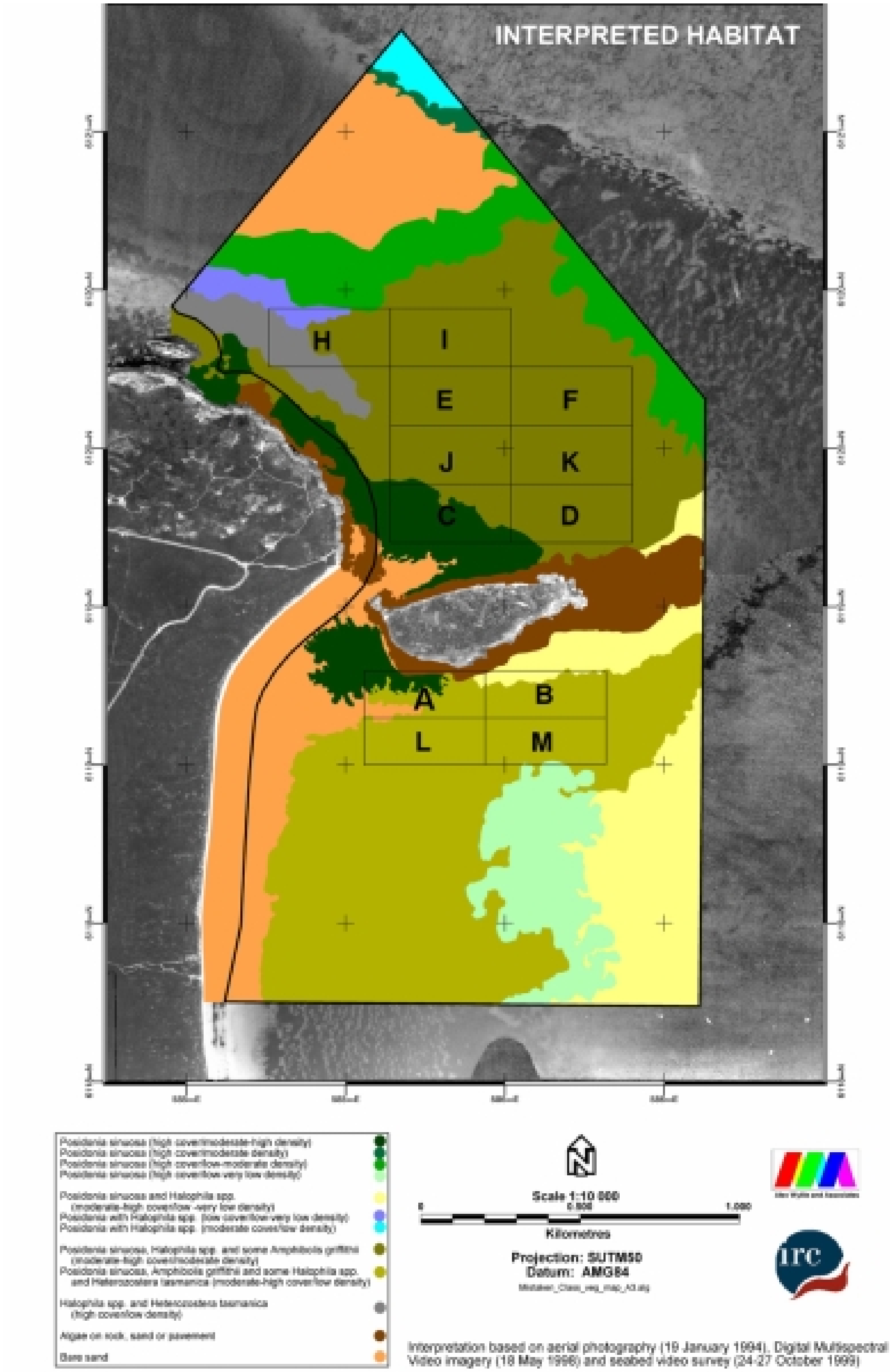


Figure 6.4 Habitat map

The main seagrass habitats distinguished on the basis of aerial photographs and field data are shown in Table 5.1 below:

Table 6.1 Main seagrass habitats

***Posidonia* beds with high cover and variable density:**
• *Posidonia sinuosa* (high cover / moderate—high density); • *Posidonia sinuosa* (high cover / moderate density); • *Posidonia sinuosa* (high cover / low—moderate density); and • *Posidonia sinuosa* (high cover / low—very low density).
***Posidonia* and *Halophila* spp. with variable cover and low density:**
• *Posidonia sinuosa* and *Halophila* spp. (moderate—high cover / low—very low density); • *Posidonia sinuosa* and *Halophila* spp. (low cover / low—very low density); and • *Posidonia ostenfeldii* "complex" with *Halophila* spp. (moderate cover / low density).
Mixed assemblages (typically 3 or more species) consisting of larger and smaller seagrasses with moderate—high cover and variable density:
• *Posidonia sinuosa*, *Halophila* spp., and some *Amphibolis griffithii* (moderate—high cover / moderate—high density); and • *Posidonia sinuosa*, *Amphibolis griffithii* and some *Halophila* spp. and *Heterozostera tasmanica* (moderate—high cover / low density).
Smaller seagrasses
• *Halophila* spp. and *Heterozostera tasmanica* (high cover / low density).
Algae on rock, sand or pavement
Bare sand

The main large, perennial seagrass in the AEA is *Posidonia sinuosa*. This seagrass was observed either alone, or mixed with other larger and smaller seagrasses. Locations that support well-established beds of *Posidonia sinuosa* with high cover and high density were observed to the north, north-west and south-west of Mistaken Island (Figure 5.4).

The presence of *Posidonia* species from the "*P. ostenfeldii* species complex" appeared to be restricted inside the AEA. This seagrass was observed in the most northerly sector of the AEA and at a site south-east of Mistaken Island. Mapping from the 1998 aerial photograph (Evangelisti & Associates 1999) suggests that this seagrass complex is better represented to the north-east of the AEA and in other parts of the Sound.

Most of the seagrass in the central sector of the AEA, including lease areas north of Mistaken Island, comprised largely mixed patches or beds of *Posidonia sinuosa* and *Halophila* spp. South of the Island, the seagrass composition included mixed assemblages of large and small seagrasses comprised of *Posidonia sinuosa* or *Amphibolis griffithii* with *Halophila* spp. or *Heterozostera tasmanica* (Figure 5.4). *Halophila* appeared to be represented less in locations south of Mistaken Island compared with north of the Island (Figure 5.1).

Seagrass cover and density were highly variable across the AEA. The areas of highest seagrass cover and density were the *Posidonia* beds located directly north, north-west and west of Mistaken Island. In the central area of the AEA to the north of Mistaken Island, patches of mixed *Posidonia* and *Halophila* with moderate-high cover and low-moderate density were widespread. In the central area of the AEA to the south of Mistaken Island, similar patches of mixed larger and smaller seagrasses, though with moderate-high cover and low density, were common over a large area of seabed. The seagrass *Amphibolis griffithii* was more common in this southern area.

An area of high cover of small seagrasses, corresponding with the large, light phototone area on the aerial photographs, was observed to the north-west of Mistaken Island. The smaller seagrasses occurring in this area occurred at low to very low density. Very low cover and density seagrass areas were evident in deeper offshore sectors such as in the south-east of the AEA and along the south-western margin of the AEA. Seagrass was largely absent in the north-western and south-western sectors of the AEA.

Other habitats observed in the AEA included algal communities growing on rock or sand. The algae were most widespread on littoral and sub-littoral rocky substrata, particularly in the shallow areas around islands. Algae also occurred as assemblages on sub-tidal sandy pavement. Wrack was also observed in several areas, including inshore areas along the western boundary of the AEA. The wrack is mobile and can move under the influence of wind and currents.

6.1.3 Aquaculture Leases

Seagrass composition, cover and density varies from one lease site to the next, depending on their location in relation to the seabed features evident as phototones on the aerial photographs. Some sites, such as Lease Area A, support several species but the overall cover is highly variable across the lease. Other sites, such as Lease Area C appear to have fewer seagrass species but display well-developed beds of *Posidonia sinuosa* with high and relatively uniform cover. Other sites, such as Lease Area H, are dominated by smaller seagrasses; cover is highly variable across that site, evidenced by the contrasting phototones present in the aerial photograph of that part of the AEA. Table 5.2 compares the composition, cover and density of seagrasses within the 12 aquaculture leases north and south of Mistaken Island.

Table 6.2 Summary of seagrass features recorded in aquaculture lease sites near Mistaken Island

Lease site	Seagrass composition	Seagrass cover**	Seagrass density**
A	• mainly *Posidonia sinuosa*; • some *Amphibolis griffithii* mixed with smaller seagrasses; • bare sand in the south-west.	• high cover of larger seagrasses in the north-west; • high cover of mixed large and small seagrasses in the south-east; • bare sand in the south-west.	• moderate to high density of larger seagrasses in the northwest; • low to very low density of mixed seagrasses in the south-east.
B	• mainly *P. sinuosa* and *Halophila* spp.	• mostly moderate or high cover; • better developed in the western sector, reducing in the deeper south-eastern sector.	• low density at sites across lease.
C	• large beds of *Posidonia sinuosa* across the south-western part of the lease; • *P. sinuosa* mixed with *Halophila* spp. in the north-east.	• moderate to high cover in the south-west; • low to moderate cover in the north-east.	• moderate to high density in the south-west; • low to very low density in the north-east.
D	• *P. sinuosa* in the south-west corner; • mixed P. sinuosa and *Halophila* spp. or *Halophila* spp. alone across the remainder of the lease.	• moderate to high cover across the northern sector of the lease; • sparse cover across the southern sector.	• low density in the north-west; • very low density in the southern and eastern parts of the lease.
E	• mixed *P. sinuosa* and *Halophila* spp. in the east; • predominantly mixed *Halophila* spp., and *H. tasmanica* in the west.	• low to moderate cover despite changes in seagrass species composition across lease.	• low density in western sector; • moderate density in the eastern sector.
F	• *P. sinuosa* alone in the south; • mixed *P. sinuosa* and *Halophila* spp., in the east; • *Halophila* spp. in the north-west.	• moderate cover across most of the lease area.	• low to moderate density across the lease area.

Table 6.2 continued

Lease site	Seagrass composition	Seagrass cover**	Seagrass density**
H	• mixed *P. sinuosa* and *Halophila* spp., in the north-west; • *Halophila* spp. in the east; • mixed *Halophila* spp. and *Heterozostera tasmanica* in the west.	• low to moderate cover across the lease area.	• low density across the lease area.
I	• mixed *P. sinuosa* and *Halophila* spp.	• moderate to high cover, particularly in eastern sector.	• very low to low density across the lease area.
J	• mixed *P. sinuosa* with *Halophila* spp. or *Halophila* spp alone.	• variable cover from traces through to moderate or high cover; • most seagrass in south-west sector.	• low to moderate density in western sector; • low to very low density in eastern sector.
K	• *P. sinuosa* in the north-west; • mixed *P. sinuosa* and *Halophila* in north-east; • *Halophila* spp. in the southern area of the lease.	• low in western sector and moderate in eastern sector.	• very low density across lease area.
L	• *P. sinuosa* or *A. griffithii* mixed with smaller seagrasses.	• high cover in eastern sector; • moderate cover in western sector.	• low density across lease area.
M	• *P. sinuosa* or *A. griffithii* mixed with smaller seagrasses.	• moderate cover across lease.	• Low density across lease.

**Halophila spp.* not differentiated into species; ** refer to percentage categories in text.

6.2 Light availability for seagrasses

6.2.1 Water column light attenuation

Daylight hours vary with season. During February 2000, light data were gathered between 0600-1800 hrs (ie, 12 hr duration) and between 0700-1715 hrs (ie, 10.15 hr duration) in April 2000, 0730-1630 hrs (ie 9 hr duration) in August 2000, 0545-1745 hrs (ie 12 hr duration) in October 2000 and 0545-1745 hrs (ie 12 hr duration) in January/February 2001.

February 2000

During the period 2 - 4 February 2000, light reduction in the water column, measured as the difference in light levels near the water surface and the seabed, was highest at the control site, and least at one of the two mussel lines. The percentage light reduction ranged between 64.9% and 74.6% at the two mussel lines, compared with a range of 64.1% to 73.8% at the control site (Figure 5.5). On all three days the degree of light reduction was significantly less at Mussel Line 6 than at both Mussel Line 4 and the Control site (Table 5.3). On Day 3 all sites were significantly different to each other, with highest light reduction at the control site, and lowest reduction at Mussel Line 6.

During the sampling period, the LAC ranged from 0.057 m^{-1} at Mussel Line 6, to 0.091 m^{-1} at Mussel Line 4. LAC was generally higher at the Control site during the first half of each day, and higher at Mussel Line 4 in the latter half of each day (ie, before and after 12:00 hrs respectively; Figure 5.6). LAC was lowest on all 3 days at Mussel line 6.

Table 6.3 Summarised data from ANOVA and Tukey's multiple range tests on the percent light reduction under mussel lines and control areas during 2 - 4 of February 2000

Date	Results of ANOVA and Tukey's multiple range tests		
	Order of light attenuation	Df MS numerator, Df MS denominator	P value
Day 1: 2/2/00	Mussel Line 4 = Control > Mussel Line 6	2,144	0.004
Day 2: 3/2/00	Mussel Line 4 = Control > Mussel Line 6	2,141	<0.001
Day 3: 4/2/00	Control > Mussel Line 4 > Mussel Line 6	2,141	<0.001

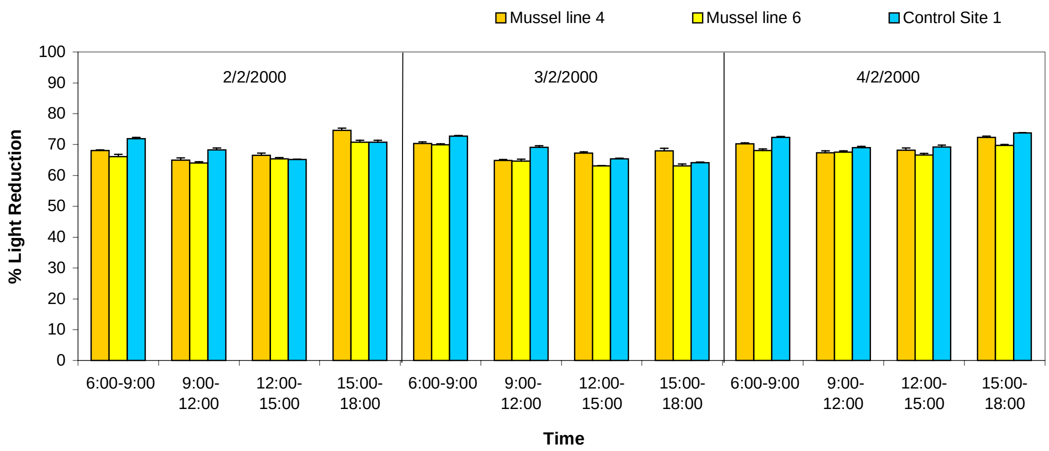


Figure 6.5 Percent water column light reduction at mussel line and control sites during February 2000 (mean ± SE) of twelve 15-minute integrated light recordings for each 3 hour period between 0600 and 1800 hrs

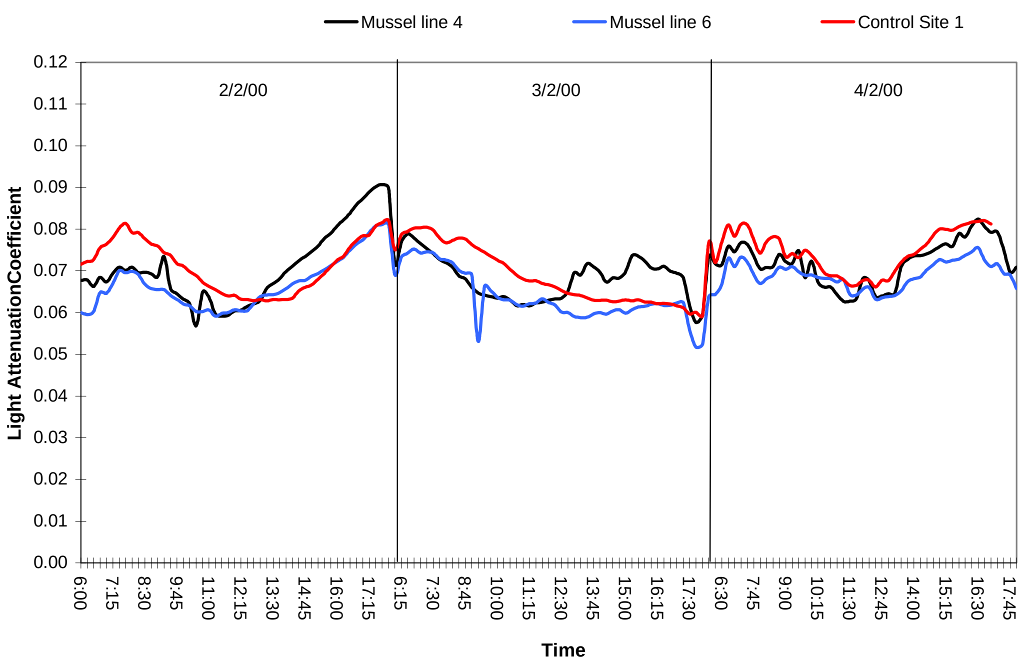


Figure 6.6 Light Attenuation Coefficient (LAC) for 3 days in February 2000 at mussel longline and control sites

April 2000

The degree of light reduction in the water column during April was generally greater than that measured during February. The reduction in light was highest at the control site (93.2%) and least at Mussel Line 6 (65.5%; Table 5.4, Figure 5.7). Attenuation was significantly higher at the control site than at both mussel line sites during the two days that light data were collected (Table 5.4).

Light Attenuation Coefficient (LAC) ranged from 0.064 m^{-1} under Mussel Line 6 on Day 2, to 0.163 m^{-1} under the Control site also on Day 2 (Figure 5.8). At all times during both days of light recording, LAC was higher under the Control site than both mussel line sites.

Table 6.4 Summarised data and results of analysis from sampling underwater light data during 29-30 April 2000.

Date	Results of ANOVA and Tukey's multiple range tests		
	Order of light attenuation	Df MS numerator, MS denominator	P value
Day 1: 29/4/00	Control > Mussel Line 4 = Mussel Line 6	2, 126	<0.001
Day 2: 30/4/00	Control > Mussel Line 4 = Mussel Line 6	2, 126	<0.001

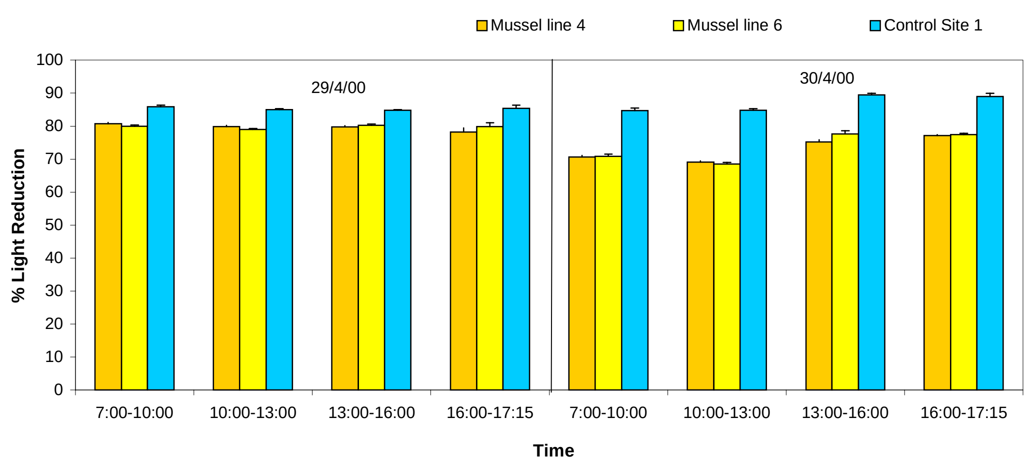


Figure 6.7 Percent water column light reduction at mussel line and control sites during April 2000 (mean ± SE) of twelve 15-minute integrated light recordings for each 3 hour period between 0700 and 1715 hrs

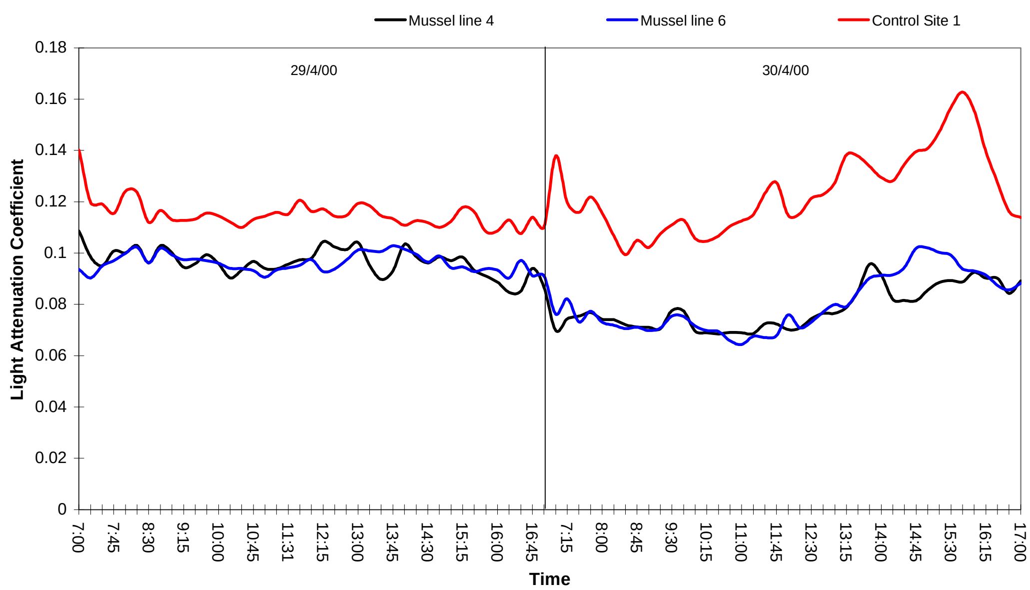


Figure 6.8 Light Attenuation Coefficient for 2 days in April 2000 at mussel longline and control sites

August 2000

During the period 9-10 August 2000, light reduction in the water column, measured as the difference in light levels near the water surface and the seabed, was lowest at Mussel Line 4 (69.9%) and highest at Control Site 5 (86.96%: Figure 5.9). The light reduction was significant higher at both control sites and Mussel Line 6 compared with Mussel Line 4 for both days (Table 5.5).

During the sampling period, the LAC ranged from 0.125 m^{-1} at Control Site 5, to 0.070 m^{-1} at Mussel Line 4. There was no clear separation of the LAC between mussel lines and control sites (Figure 5.10).

Table 6.5 Summarised data from ANOVA and Tukey's multiple range tests on the percent light reduction under mussel lines and control sites during 9 - 10 of August 2000

Date	Results of ANOVA and Tukey's multiple range tests		
	Order of light attenuation	Df MS numerator, MS denominator	P value
9/8/00	Control site 1 = Control site 5 = Mussel line 6 > Mussel line 4	3,152	<0.001
10/8/00	Control site 1 = Control site 5 = Mussel line 6 > Mussel line 4	3,152	<0.001

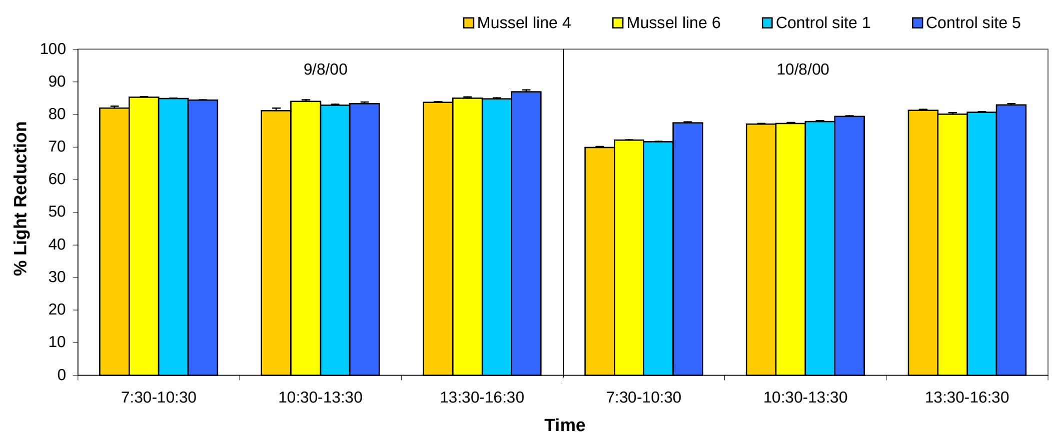


Figure 6.9 Percent water column light reduction at mussel line and control sites during August 2000 (mean + SE) of twelve 15-minute integrated light recordings for each 3 hour period between 0730 and 1630 hrs

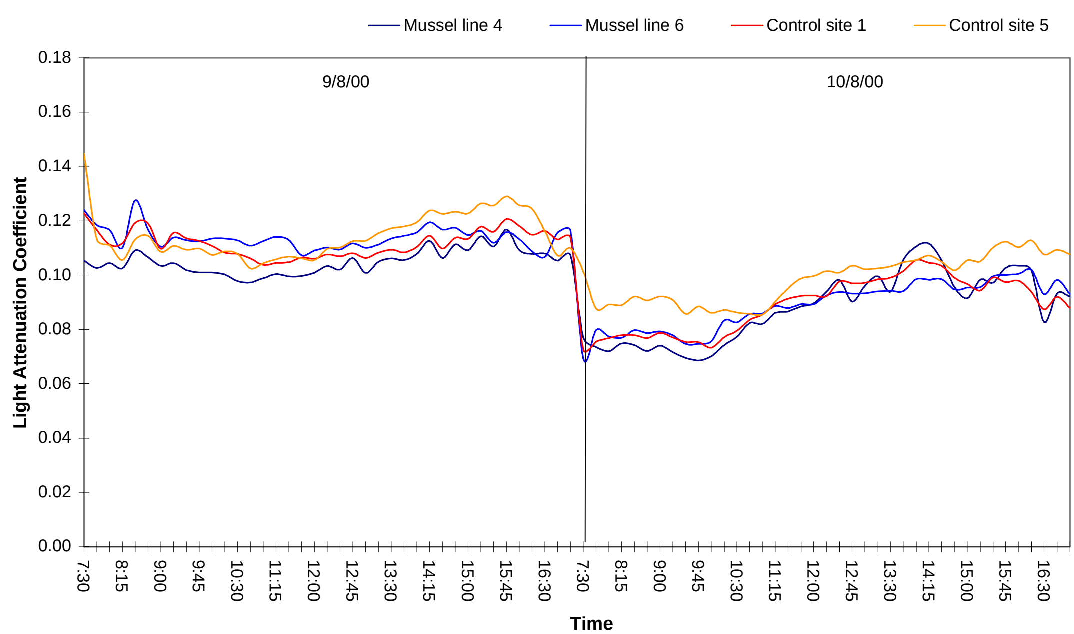


Figure 6.10 Light Attenuation Coefficient (LAC) for August 2000 under mussel longlines and control sites

October 2000

The degree of light reduction in the water column during October 2000 was less than that measured during August 2000. The maximum reduction in light occurred d under Mussel Line 4 (67.7%) and the minimum occurred under Mussel line 6 (79.0%: Figure 5.11). During both sampling days, the light reduction was similar for Control Site 1 and Mussel Line 4, and was significantly less than the reduction at Control Site 5 and Mussel Line 6 (Table 5.6).

Light Attenuation Coefficient (LAC) trends were similar to the light reduction on day 1 (Figure 5.11). At all times on day two and most times of light recording, LAC was higher under the Control Site 5 and Mussel Line 6 compared with Control Site 1 and Mussel Line 4.

Table 6.6 Summarised data from ANOVA and Tukey's multiple range tests on the percent light reduction under mussel lines and control sites during 25 - 26 of October 2000

Date	Results of ANOVA and Tukey's multiple range tests		
	Order of light reduction	Df MS numerator, Df MS denominator	P value
25/10/00	Control site 5 = Mussel line 6 > Mussel line 4 = Control site 1	3,188	<0.001
26/10/00	Control site 5 = Mussel line 6 > Mussel line 4 = Control site 1	3,188	<0.001

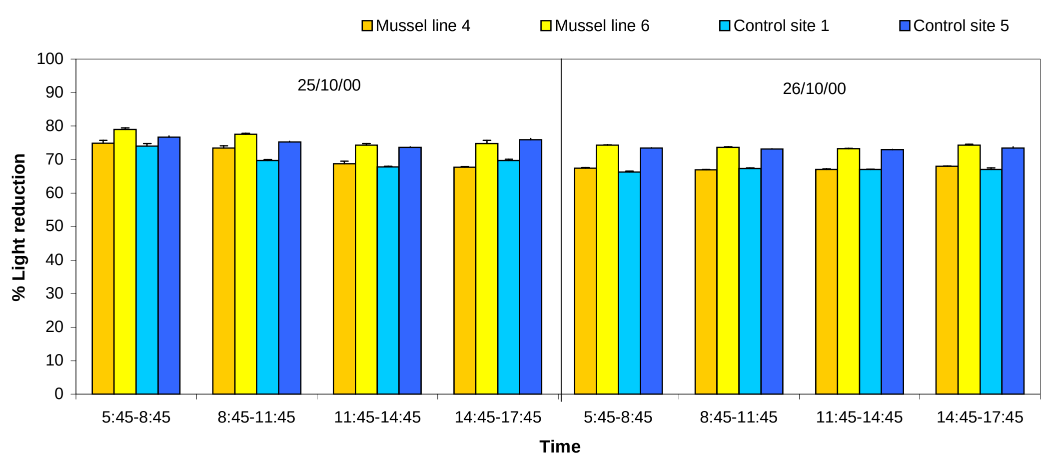


Figure 6.11 Percent water column light reduction at mussel line and control sites during October 2000 (mean ± SE) of twelve 15-minute integrated light recordings for each 3 hour periods

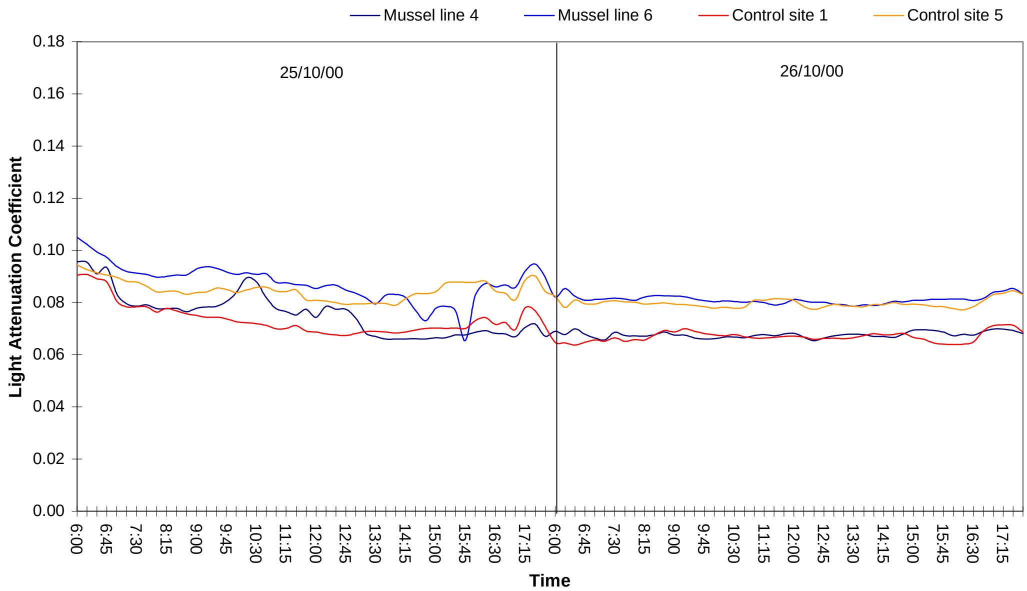


Figure 6.12 Light Attenuation Coefficient (LAC) for October 2000 under mussel longlines and control sites

January-February 2001

The maximum reduction in light under water occurred at Control Site 1 (82.5%) and the minimum reduction was at Control Site 5 (67.8%; Figure 5.13). Light reduction on 31 January 2001 was similar for Mussel Line 6 and Control Site 5 which was less than Mussel Line 4 which was similar to Control Site 1 (Table 5.7). On 1 February light reduction was greatest at Control Site 1. Mussel Line 6 had the next greatest reduction in light which was greater than Mussel Line 4. The least reduction in light occurred at Control Site 5 (Table 5.7).

Table 6.7 Summarised data from ANOVA and Tukey's multiple range tests on the percent light reduction under mussel lines and control sites during 31 January - 1 of February 2001)

Date	Results of ANOVA and Tukey's multiple range tests		
	Order of light reduction	Df MS numerator, Df MS denominator	P value
31/1/01	Control Site 1 = Mussel Line 4 > Mussel Line 6 = Control Site 5	3,188	<0.001
1/2/01	Control Site 1 > Mussel Line 4 > Mussel Line 6 > Control Site 5	3,188	<0.001

Light attenuation coefficients were greater on 1 February 2001 than on 31 January 2001. Attenuation coefficients appeared to be more ordered on 1 February compared with the mixed pattern exhibited on 31 January (Figure 5.13).

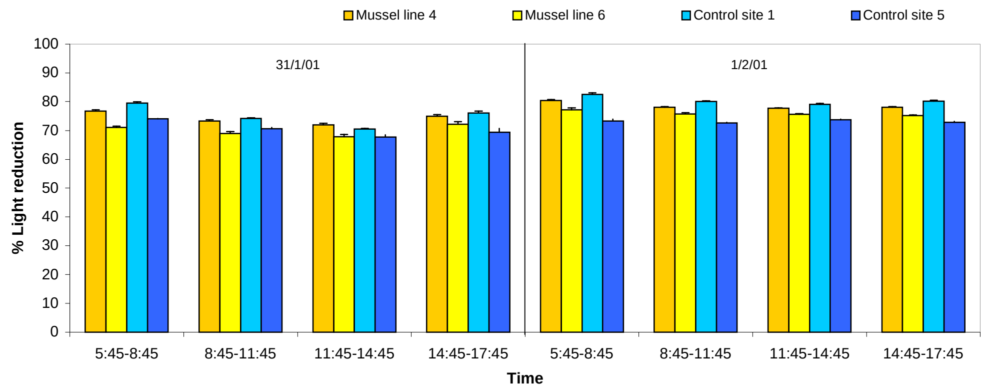


Figure 6.13 Percent water column light reduction at mussel line and control sites during January - February 2001 (mean ± SE) of twelve 15-minute integrated light recordings for each 3 hour periods between 0545 and 1745 hrs

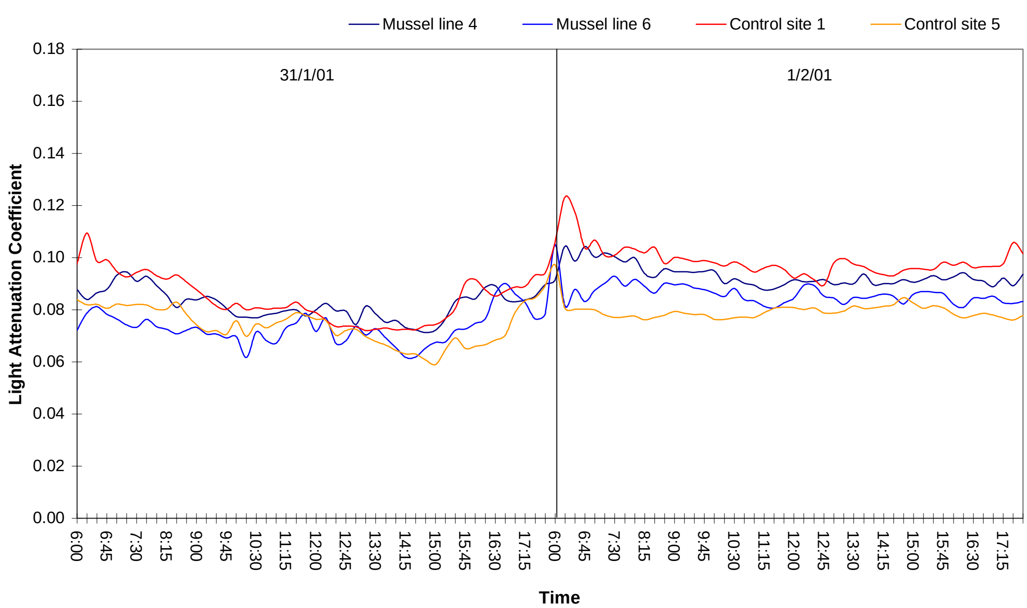


Figure 6.14 Light Attenuation Coefficient (LAC) for January-February 2001 under mussel longlines and control sites

Between year comparison of light attenuation (Summer 2000 and Summer 2001)

Data from 1st February 2000 and 2nd February 2001 were compared by 2 factor ANOVA (factors being mussel lines & control sites and years).

The results of the ANOVA on transformed data indicated that LAC was significantly less under mussel lines (69.9% ± 0.3%) than in control sites (71.5% ± 0.4%) (df = 1, 335: P = 0.023) and was significantly less in 2001 (68.2% ± 0.3%) compared with 2000 (72.4% ± 0.3%) (df = 1, 335; P < 0.001). There was no significant interaction between treatments (df = 1,335; P = 0.502).

Spatial comparison of light attenuation during February 2001

Of the 13 sites simultaneously measured, it was not possible to obtain information from one site, Control Site 5 due to a leaking light logger. Figure 15.15 shows the spatial arrangement of the area sampled including the location (eastings and northings), site identification, water depth and LAC. Water depth varied between 9.7 m and 13.0 metres across the study site. Light attenuation levels varied by up to 75% (compare Site 4 with Control Site 1) for a similar depth.

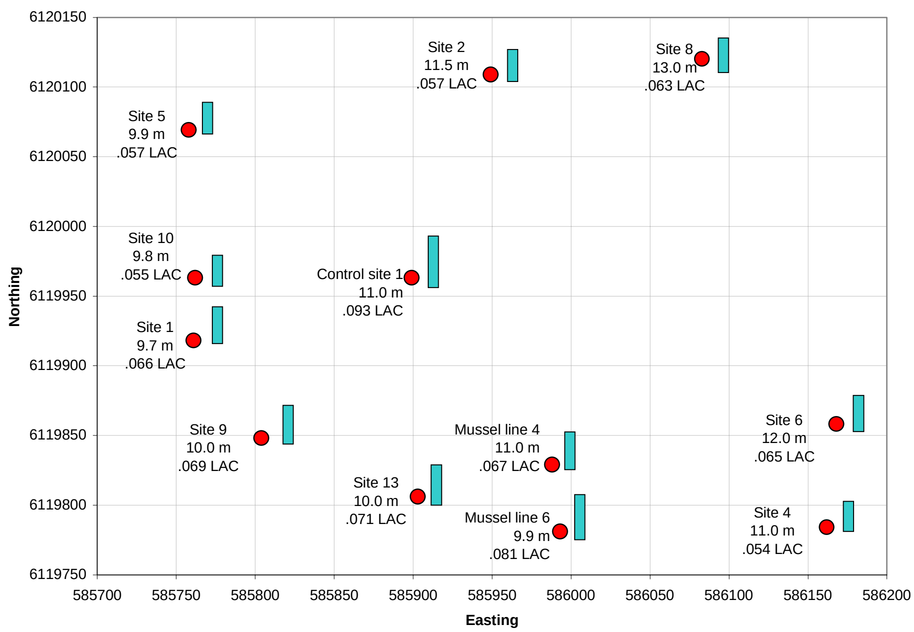


Figure 6.15 Spatial comparison of light attenuation coefficients measured simultaneously on 2 February 2001 in the Aquaculture Extension Area.

6.2.2 Periphyton light attenuation

Light reduction resulting from periphyton growth during October - November 1999 was significantly higher at mussel line 4 compared to both control sites 1 & 2 (df = 3, 20, P = 0.002). At mussel line 4 there was 49.6% light reduction due to periphyton growth, compared with 30.7% and 31.2% at control site 2 and 1 respectively (Figure 5.5).

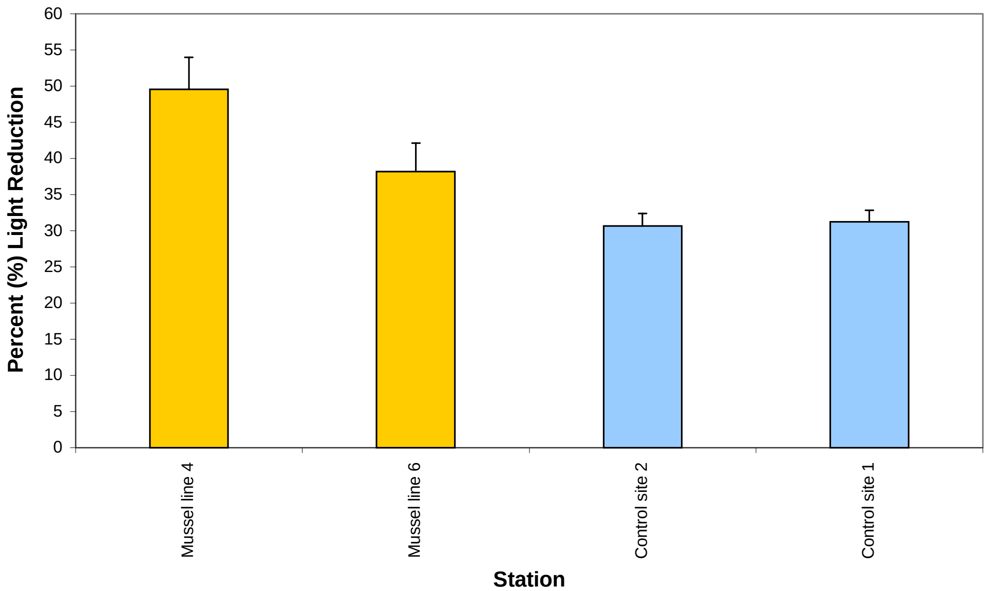


Figure 6.16 Light reduction resulting from periphyton growth during October-November 1999 (displaying means ± SE for 6 replicate periphyton plates)

Light attenuation by periphyton was less in February 2000 (summer) than in October 1999 (spring) for all sites. The light reduction for spring ranged between 30.7 - 49.6% and for summer between 12.6 - 37.7%.

In February, variability in light attenuation due to periphyton was significantly different between the two control stations (df = 3, 20; *P*=0.009) ie, 12.6% at Control site 1 and 34.7% at Control site 2 (Figure 5.17). For this period, light reduction was highest (37.7%) at mussel line 4. This level was significantly higher than that of Control site 1 (df = 3, 20; *P*=0.009).

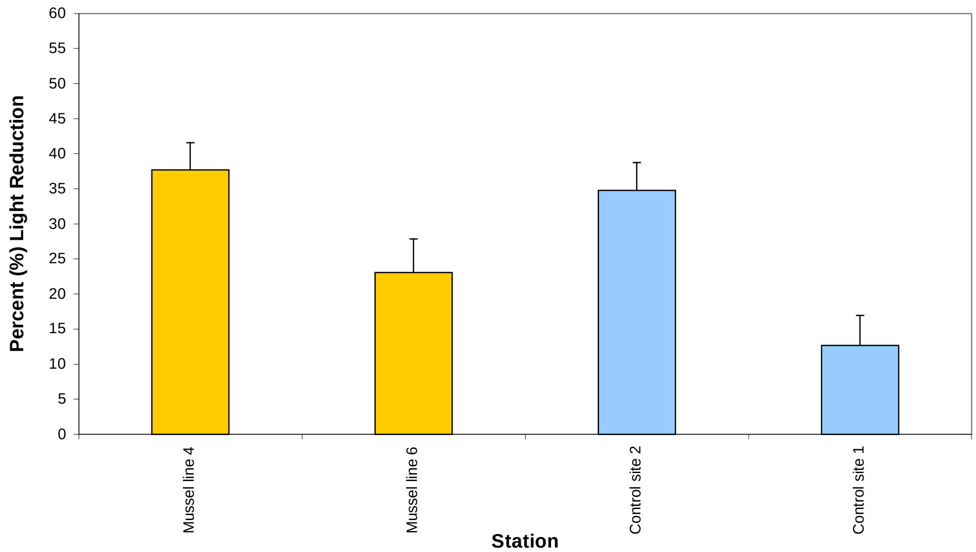


Figure 6.17 Light reduction resulting from periphyton growth during February 2000 (displaying means ± SE for 6 replicate periphyton plates)

May-June 2000

Analysis of light reduction resulting from periphyton growth during May - June 2000 indicated a significant difference (df = 3, 20; P = 0.38) although Tukey's multiple range test was unable to distinguish which values were significantly different (P = 0.05).

A one factor ANOVA testing mussel lines versus control sites indicated that there was significantly greater light reduction due to periphyton under mussel lines compared with control sites during May – June 2000 (df = 1,22: P = 0.04). This difference appeared to be due to a lower light reduction in the Control Site 2 (11.46% ± 1.75%). The level of light reduction due to periphyton at the Control Site 1 (18.23% ± 2.73%) was similar to that found at the Mussel line 4 (20.00% ± 2.75%) and Mussel line 6 (19.70% ± 1.71%; Figure 5.18).

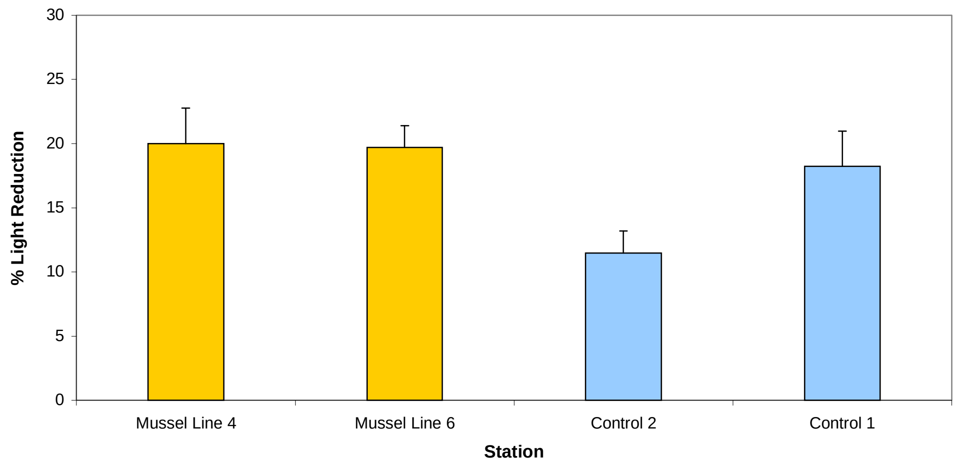


Figure 6.18 Light reduction resulting from periphyton growth during May-June 2000 (displaying means ± SE for 6 replicate periphyton plates)

October-November 2000

Data from October-November 2000 only used two replicates because the other replicate plates were left in the field for longer periods (see next section). The results indicated that the percentage of light reduction for Mussel Lines 4 and 6 and Control site 2 were similar. The level of light reduction between the two replicates at Control site 2 was identical (zero standard error (see Figure 5.19) where as the highest level of light reduction, and greatest variability between the two replicates occurred at Control Site 1.

Time series test: Light reduction from November 2000 – February 2001

Figure 5.20 shows the level of light reduction between November 2000 and February 2001. There is a similar pattern at each sampling station over the three time periods. In addition the reduction in light was greatest during November for all of the sample periods. The data suggest that a one month period for leaving settlement plates in the field is sufficient for obtaining a representative level of light reduction compared to a three month period.

Between year comparison of light attenuation (October-November 1999 and October-November 2000)

Comparison of Figures 5.16 and 5.19 indicate that the level of light reduction due to periphyton between October – November was much higher in 1999 compared with 2000. Although light reduction was greatest in periphyton under mussel lines in 1999, it was highest in control sites in 2000.

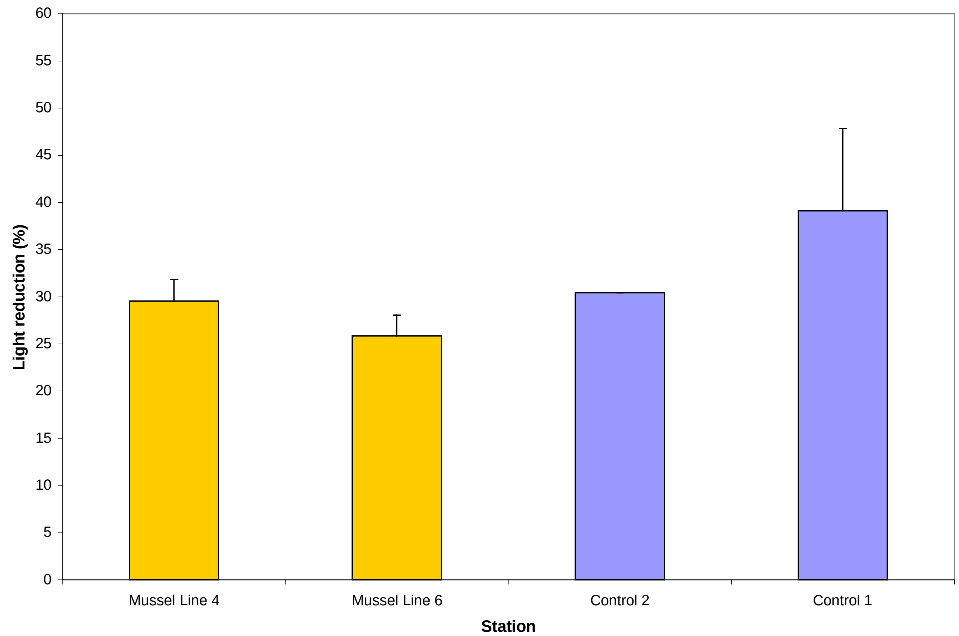


Figure 6.19 Light reduction resulting from periphyton growth during October-November 2000 (displaying means ± SE for 2 replicate periphyton plates)

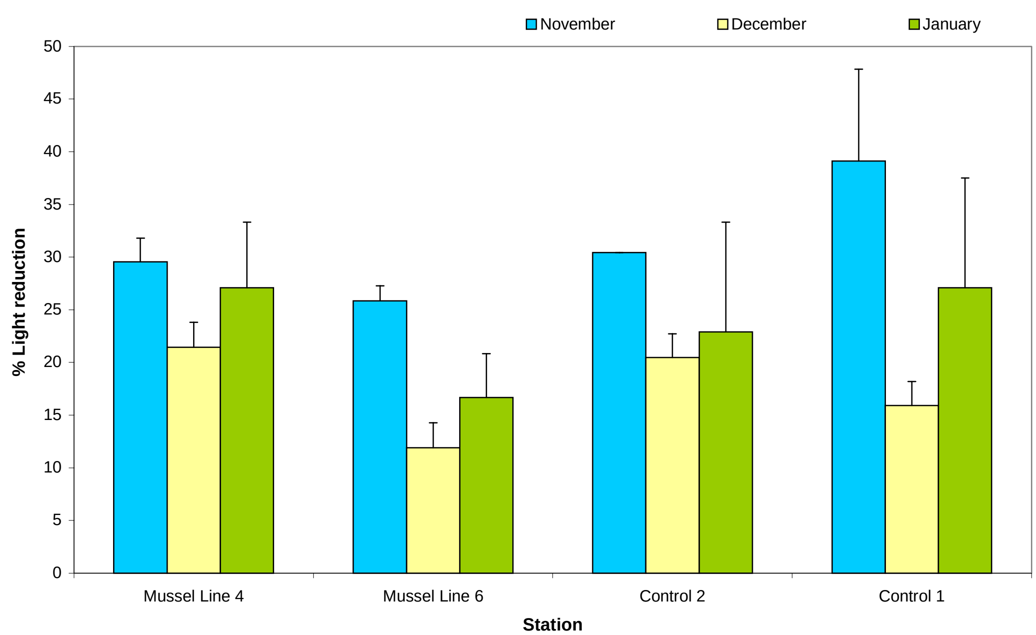


Figure 6.20 Light reduction resulting from periphyton growth during October 2000-February 2001 (displaying means ± SE for 2 replicate periphyton plates)

6.2.3 Measuring epiphyte biomass on seagrass

August-September 2000

The data indicated that seagrass leaves had low epiphyte biomass at most sampling sites. Mussel Line 6 and Control Site 4 had moderate levels of epiphyte biomass whereas Control Site 1 had high epiphyte biomass in winter (Figure 5.21).

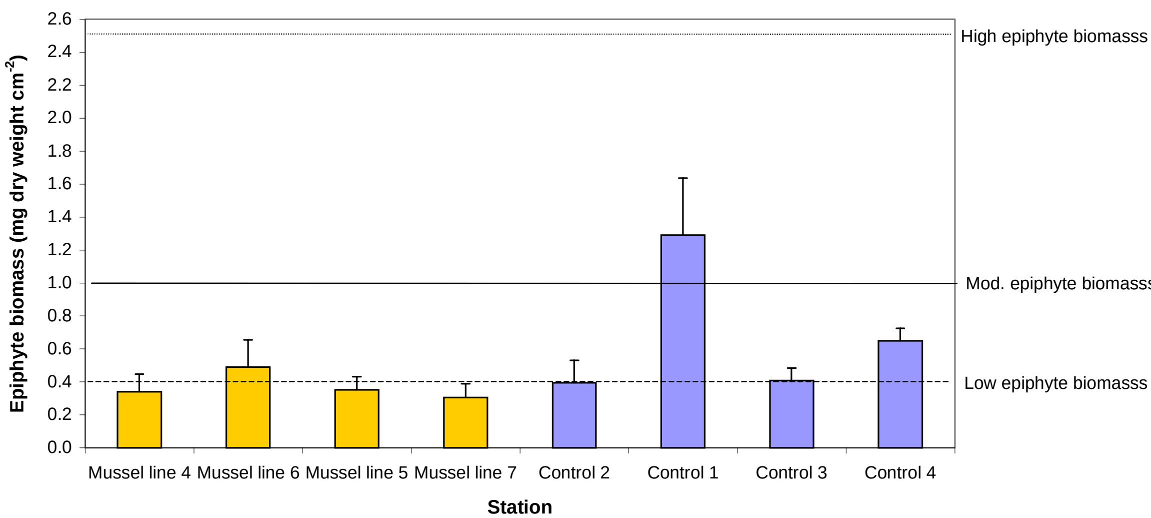


Figure 6.21 Periphyton biomass sampled from seagrass leaves during August 2000 (displaying means ± SE for 6 replicate periphyton plates). Low, moderate and high epiphyte biomass lines on Y axis are taken from Masini et al (1995) for *Posidonia* epiphytes

October-November 2000

During spring there was low epiphyte biomass on seagrass leaves at most sites (Masini et al 1995) with the exception of Control Sites 1 and 3 and Mussel Line 5 (Figure 5.22).

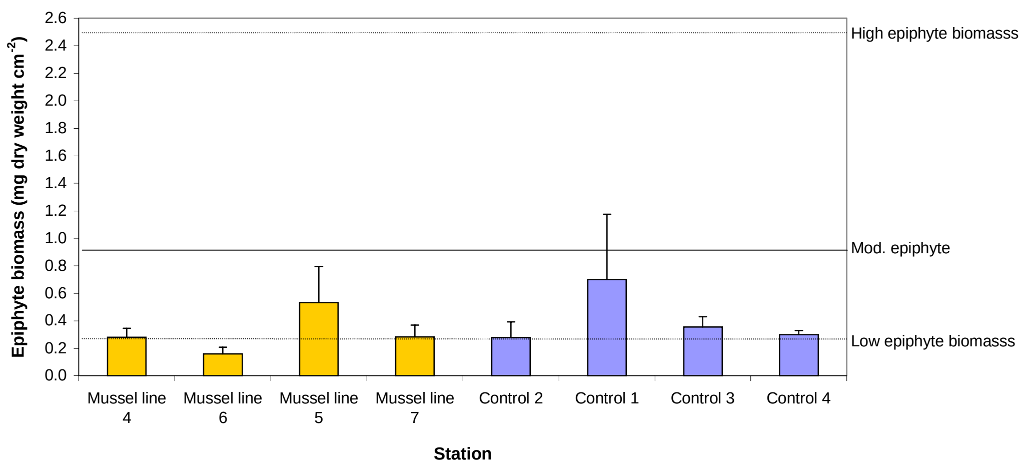


Figure 6.22 Periphyton biomass sampled from seagrass leaves during October-November 2000 (displaying means ± SE for 6 replicate periphyton plates). Low, moderate and high epiphyte biomass lines on Y axis are taken from Masini et al (1995) for *Posidonia* epiphytes

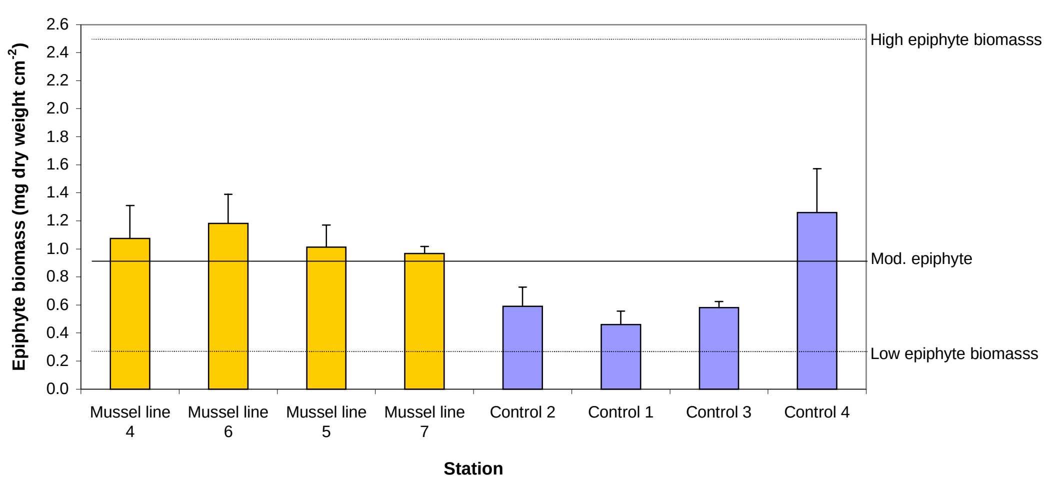


Figure 6.23 Periphyton biomass sampled from seagrass leaves during January 2001 (displaying means ± SE for 6 replicate periphyton plates). Low, moderate and high epiphyte biomass lines on Y axis are taken from Masini et al (1995) for *Posidonia* epiphytes

In January 2001, all seagrass leaves under mussel lines had a high level of epiphyte biomass compared with only one control site (Figure 5.23). The other three control sites had a moderate epiphyte biomass level. A one factor ANOVA on transformed data indicated that the level of epiphyte biomass was significantly greater on seagrass leaves under mussel lines compared with control sites (df = 1,77; P = 0.001).

6.2.4 Minimum light requirements of the seagrass *Posidonia sinuosa*

Figures 5.24-5.28 show the light attenuation coefficient data from Section 5.21 applied to Masini et al's (1995) model. The model is derived from empirical data to formulate the relationship between water column vertical light attenuation coefficient, epiphyte biomass and maximum depth of seagrass survival.

Posidonia sinuosa were observed by divers at the study site generally to have a low cover of epiphytes and data during summer and autumn 2000 were fitted to the "low epiphyte biomass" curve (Figures 5.24 and 5.25). Epiphyte biomass sampling during winter and spring 2000 permitted light attenuation curves to be fitted to the appropriate light attenuation curve (Figures 5.26 and 5.27).

The results indicate that during February 2000 and at the sampling sites (12 m depth) there was sufficient light reaching the seagrass leaves (maximum theoretical depth for the amount of light that would support seagrasses was between 15 m to 17 m).

Light attenuation data during April indicated that there was a sufficient light at 12 m depth for year round seagrass survival was one of the replicates from Mussel Lines 4 and 6 and at 11 m for the other replicates. Light attenuation coefficients at the control sites could only support seagrasses to about 10 m (Figure 5.21).

Light attenuation data during October 2000 indicated that all sites had sufficient light to support seagrass to a water depth of 12 m (Figure 5.27). However, light attenuation from the February 2001 indicated that only one replicate from Mussel Line 6 and the two replicates from Control Site 5 had sufficient light to sustain light levels at a depth of 12 m (Figure 5.28). The data indicated that seagrass could survive between 9.1 m and 13.3 m, which is within the range of depths found at the sampling sites).

When comparing the LAC curves for Summer between years (2000 and 2001) it is apparent that the light attenuation at all samples (under mussel lines and control sites) was greater in 2001 (Figure 5.28) compared with 2000 (Figure 5.24).

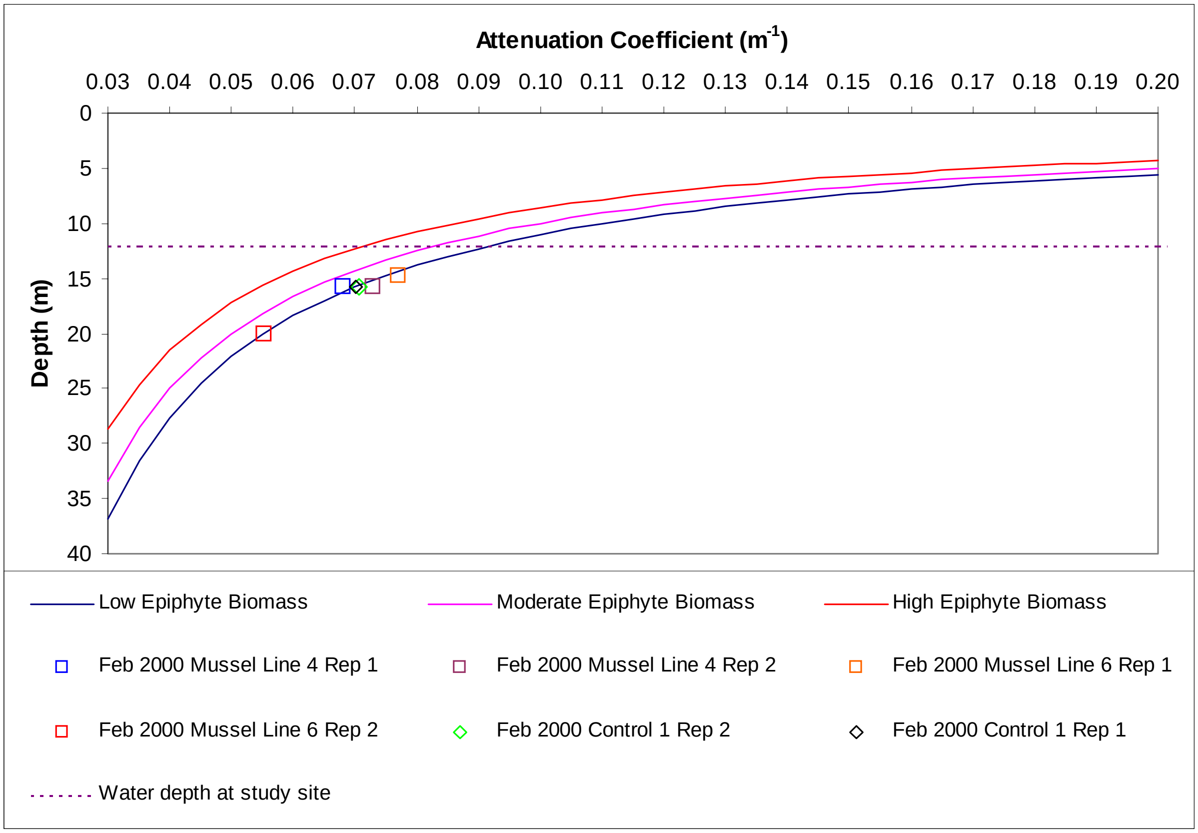


Figure 6.24 Light attenuation coefficient data applied to Masini et al's (1995) model for *Posidonia sinuosa* during summer 2000. Data fitted to low epiphyte curve.

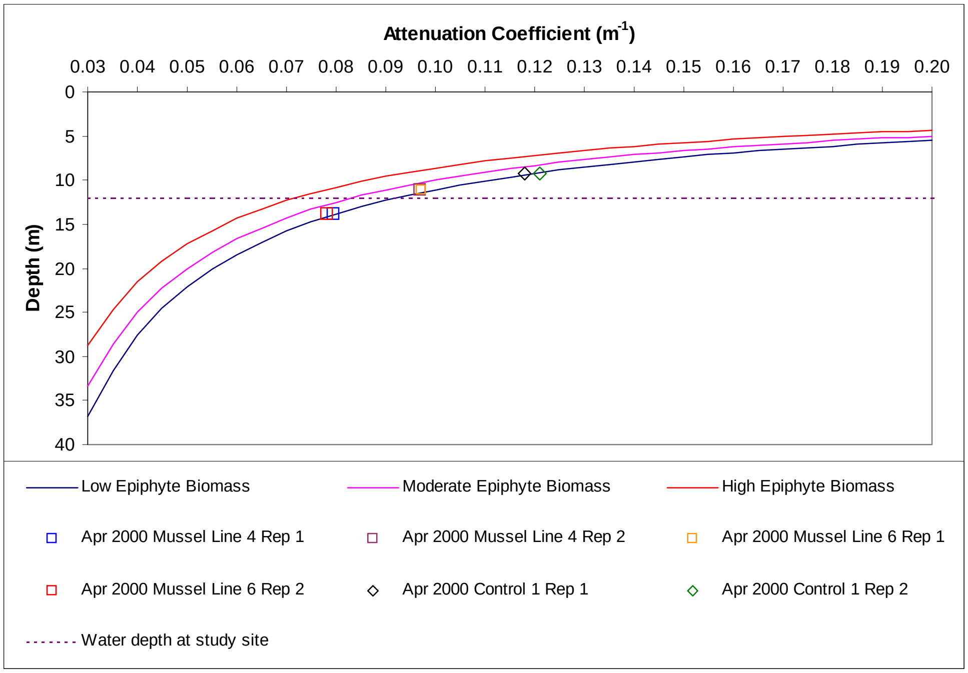


Figure 6.25 Light attenuation coefficient data applied to Masini et al's (1995) model for *Posidonia sinuosa* during autumn 2000. Data fitted to low epiphyte curve.

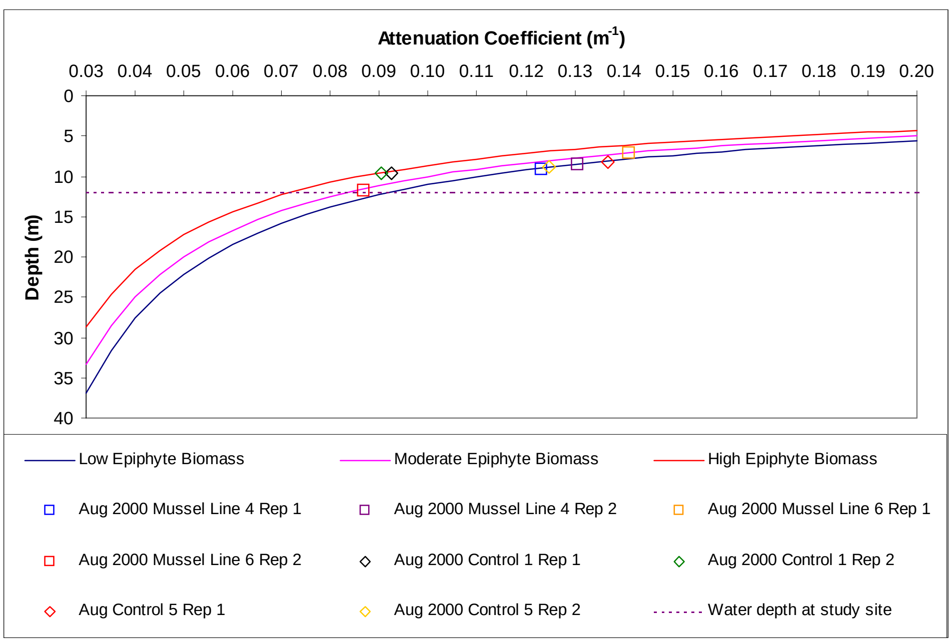


Figure 6.26 Light attenuation coefficient data applied to Masini et al's (1995) model for *Posidonia sinuosa* during winter 2000. Data are fitted to the low epiphyte curve except for those of Control Site 1-1 and 1-2 (fitted to the high epiphyte curve and Mussel Line 4 to the moderate epiphyte curve; see Figure 5.21)

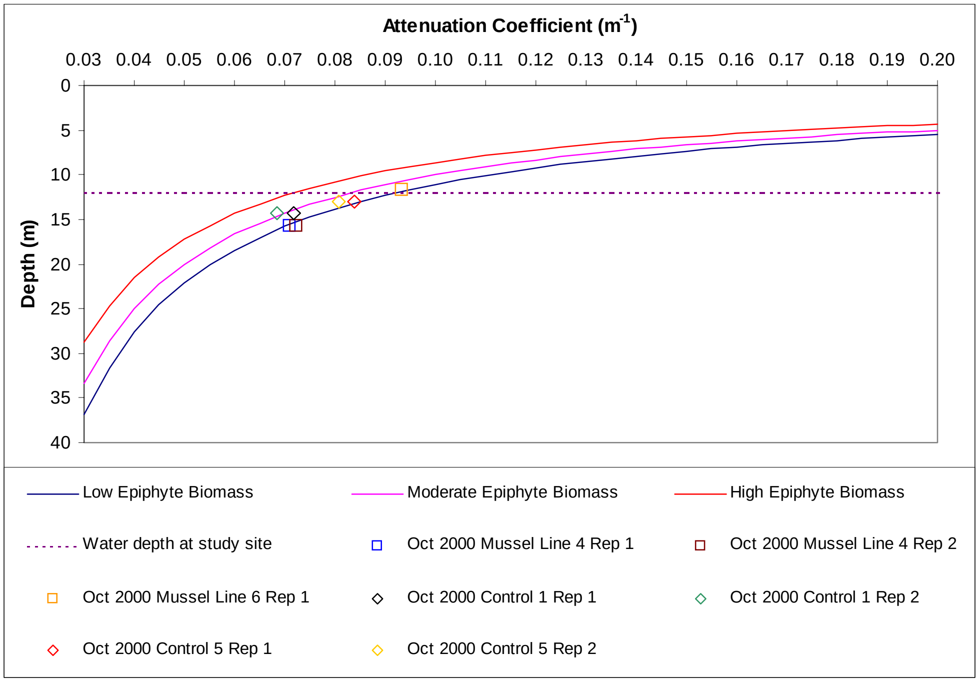


Figure 6.27 Light attenuation coefficient data applied to Masini et al's (1995) model for *Posidonia sinuosa* during spring 2000. Data fitted to low epiphyte curve except for those of Control Site 1 (fitted to moderate epiphyte curve; see Figure 5.22)

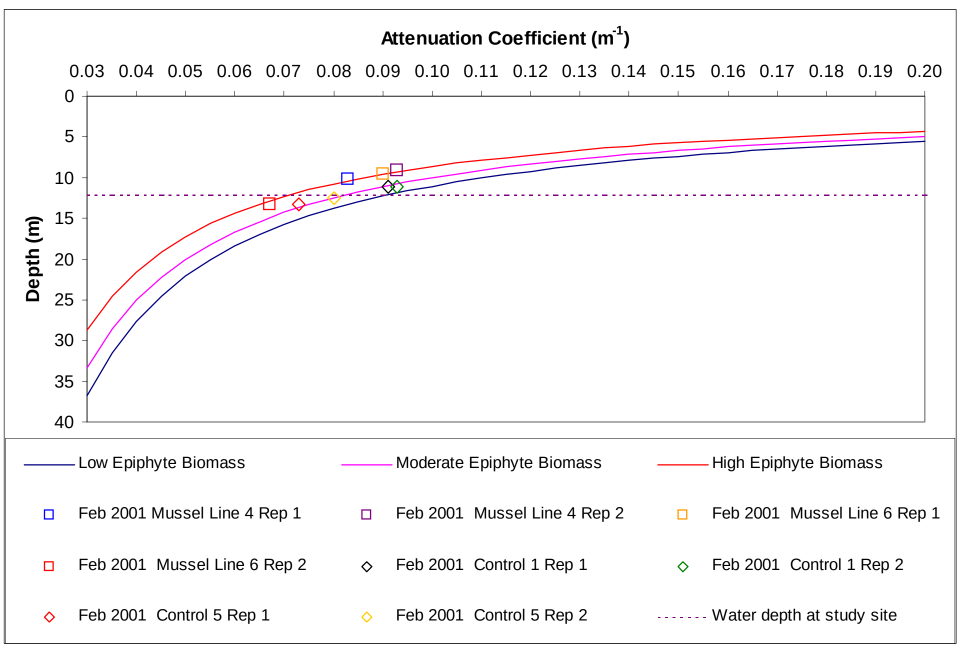


Figure 6.28 Light attenuation coefficient data applied to Masini et al's (1995) model for *Posidonia sinuosa* during summer 2001. Data fitted to epiphyte curves as for Figure 5.23.

Impact of changing mussel floats on light measurements

During the study, the float design was changed on Mussel line 4 (northwest Mussel line). Figures 5.24 – 5.28 indicate that attenuation coefficients under this line showed a similar response to that from the other sampling stations under mussel lines.

6.3 Seagrass Health

February 2000

The results of the nested ANOVA indicated that there was no significant difference in seagrass shoot densities between mussel line and control sites (df = 1,6; P = 0.98) or between sampling areas nested within treatments (df = 6,145; P = 0.55: Figure 5.29 shows *Posidonia* shoot density for each of the sampling sites under mussel lines and control sites.

The analysis of transformed seagrass leaf length data indicated that leaf length was significantly greater in control sites compared with under mussel lines (df = 1,6: P = 0.03). The mean leaf length in under mussel lines was 521.6 ± 15.9 mm (mean ± SE) compared with 573.4 ± 22.6 mm in control sites). There was no significant difference in leaf length between sampling sites nested within treatments (df = 6, 145; P = 0.89: Figure 5.30).

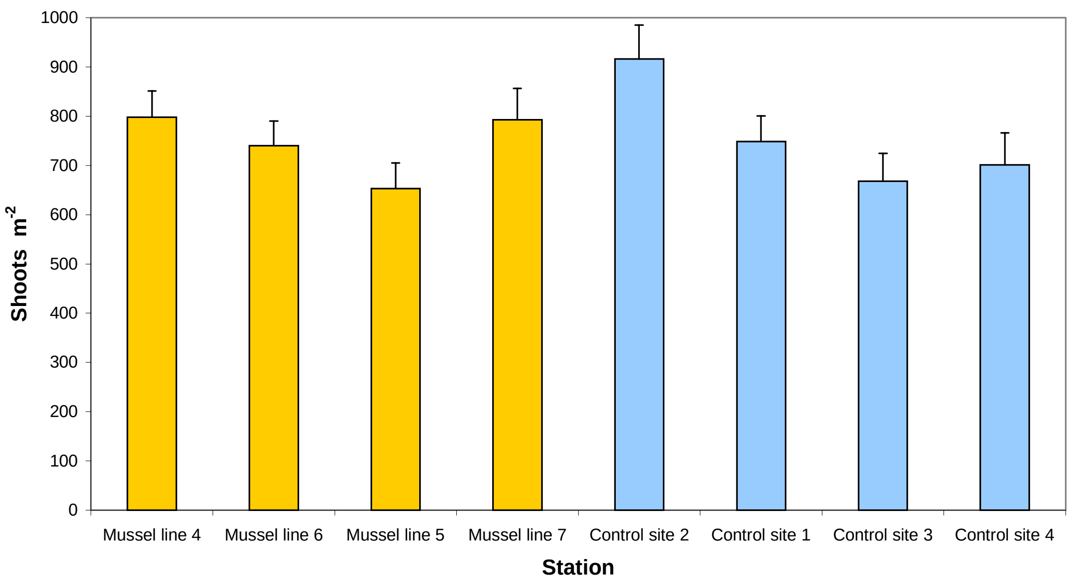


Figure 6.29 Posidonia sinuosa shoot density at mussel line and control sites during February 2000 (displaying means ± SE for 20 replicate quadrats)

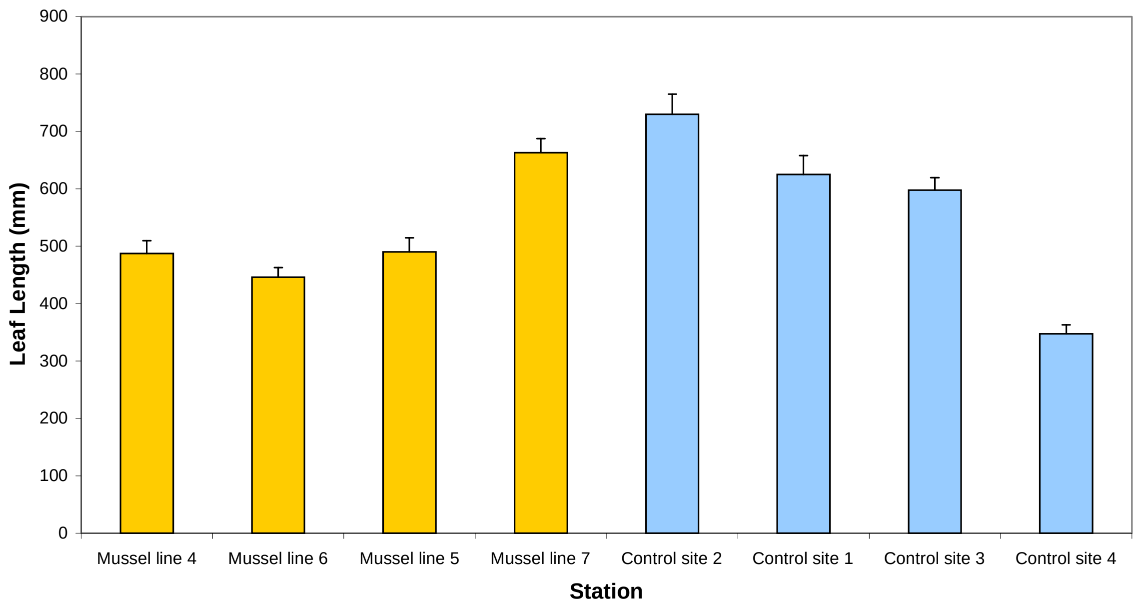


Figure 6.30 *Posidonia sinuosa* leaf lengths at mussel line and control site stations during February 2000 (displaying means ± SE for 20 replicate quadrats)

August 2000

The results of the nested ANOVA on transformed data indicated that seagrass shoot densities under mussel lines (870.2 ± 49.8) were significantly less than at control sites (1034.3 ± 36.0) (df = 1,6; P = 0.01). There was no significant difference between sampling sites nested within treatments (df = 6,145; P = 0.14; Figure 5.31).

The nested ANOVA of transformed leaf length data indicated that there was no significant difference in leaf length between under mussel line and control sites (df = 1, 6; P = 0.38). Although the ANOVA indicated that the sampling sites nested within treatments were significantly different (df = 6, 150; P = 0.001) Tukey's multiple range test was unable to clearly distinguish any differences between the means (P=0.05). Figure 5.32 shows leaf lengths for each sampling site.

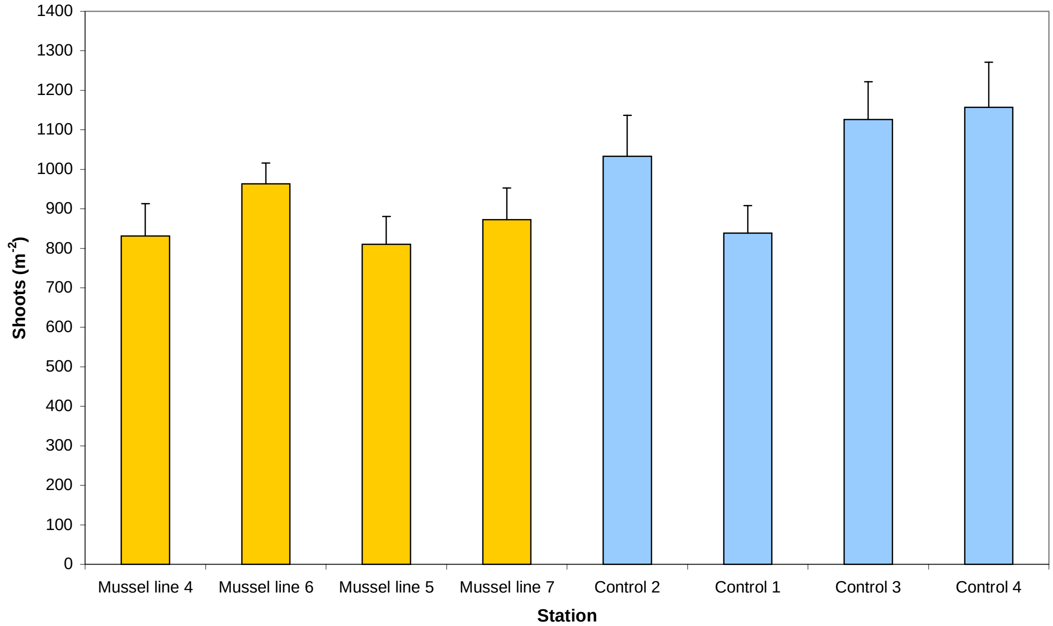


Figure 6.31 *Posidonia sinuosa* shoot density at mussel line and control sites during August 2000 (displaying means ± SE for 20 replicate quadrats)

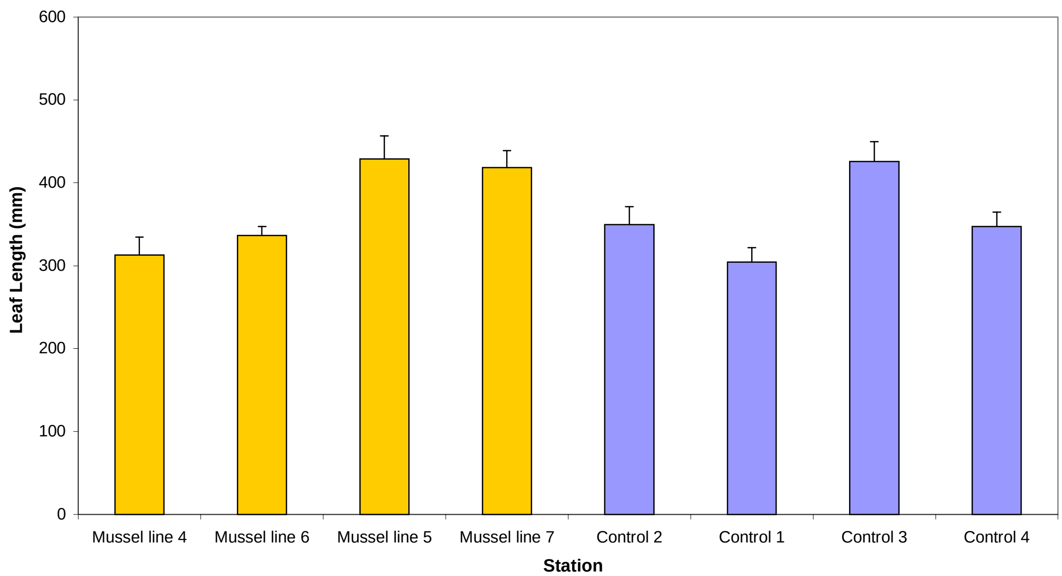


Figure 6.32 *Posidonia sinuosa* leaf length at mussel line and control sites during August 2000 (displaying means ± SE for 20 replicate quadrats)

October 2000

The results of the nested ANOVA on transformed data indicated that seagrass shoot density under mussel lines (829.4 ± 32.2) was not significantly different than at control sites (941.2 ± 46.2) (df = 1,6; P = 0.06). There was a significant difference between sampling sites nested within treatments (df = 6,151; P = 0.005; Figure 5.33).

The nested ANOVA of transformed leaf length data indicated that there was no significant difference in leaf length between under mussel lines (402.2 ± 14.8) and control sites (419.8 ± 14.8) (df = 1, 6; P = 0.59). The ANOVA indicated that the sampling sites nested within treatments were significantly different (df = 6, 152; P = 0.001). Tukey's multiple range test indicated that the leaf lengths under Mussel Line 6 and Control Site 4 (that were similar) were significantly different from the leaf lengths at other sampling sites (P=0.05). Figure 5.34 shows leaf lengths for each sampling site.

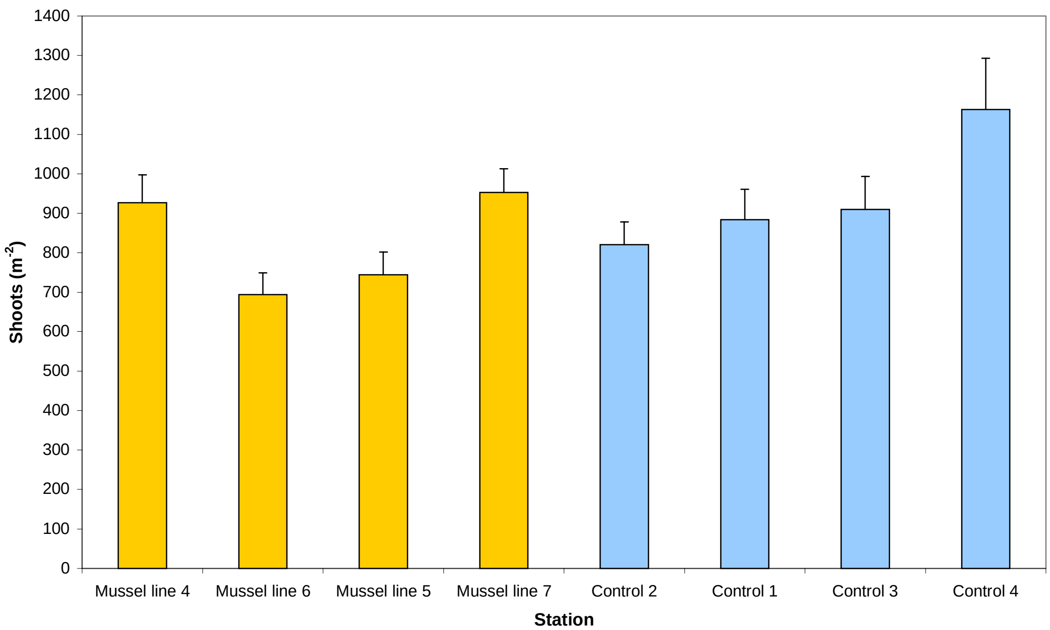


Figure 6.33 *Posidonia sinuosa* shoot density at mussel line and control sites during October 2000 (displaying means ± SE for 20 replicate quadrats)

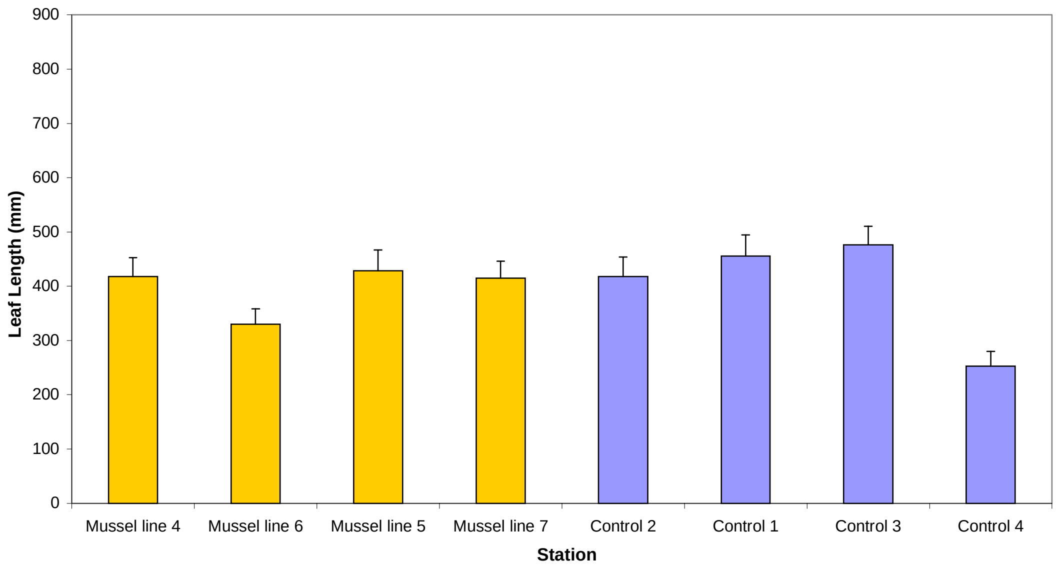


Figure 6.34 ***Posidonia sinuosa*** **leaf length at mussel line and control sites during October 2000 (displaying means ± SE for 20 replicate quadrats)**

February 2001

The results of the nested ANOVA on transformed data indicated that seagrass shoot densities under mussel lines (818.8 ± 31.8) were significantly less than at control sites (1010.6 ± 48.7) (df = 1, 6; P = 0.001). There was a significant difference between sampling sites nested within treatments (df = 6, 151; P = 0.001: Figure 5.35).

The nested ANOVA of transformed leaf length data indicated that there was no significant difference in leaf length between under mussel line (433.8 ± 12.1) and control sites (470.9± 12.1) (df = 1, 6; P = 0.12). The ANOVA indicated that the sampling sites nested within treatments were not significantly different (df = 6, 151; P = 0.18). Figure 5.36 shows leaf lengths for each sampling site.

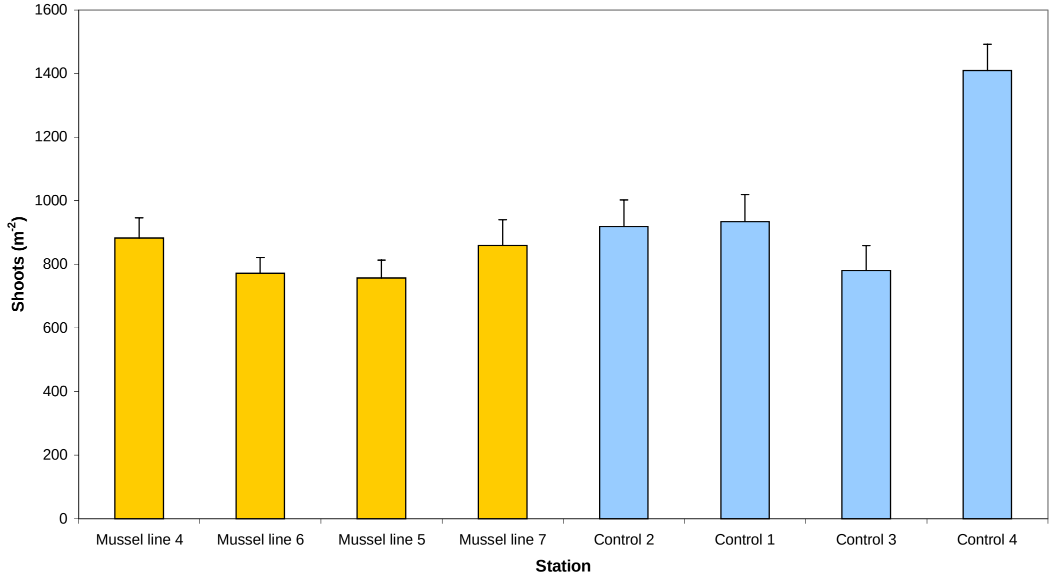


Figure 6.35 *Posidonia sinuosa* shoot density at mussel line and control sites during February 2001 (displaying means ± SE for 20 replicate quadrats)

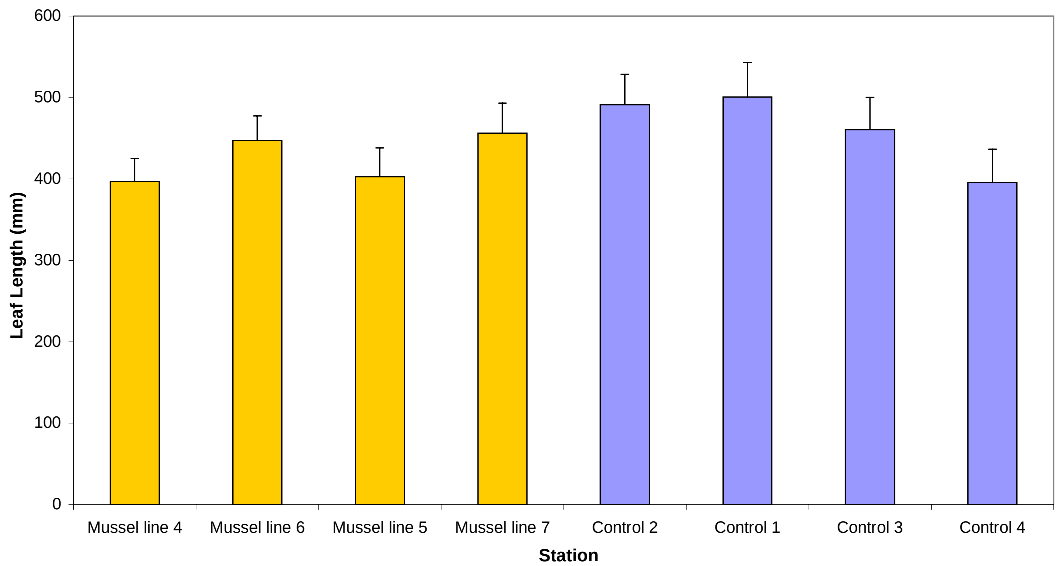


Figure 6.36 *Posidonia sinuosa* leaf length at mussel line and control sites during February 2001 (displaying means ± SE for 20 replicate quadrats)

6.4 Mussel Line Flotation

At the beginning of this study mussel line flotation consisted on PVC food drums. Since that time Fisheries WA have instituted a system of regulation/standardisation of flotation equipment and there has been some debate about the merits of these changes. During August 2000 there was an opportunity to video the performance of some of the mussel line flotation under a load of mussels. Figure 5.37 shows the mussel line float (PVC food drum) that is submerged under the sea surface and compressed so that it is unable to keep the vertical drop lines off the seabed (Figures 5.37 – 5.40). When the floats are on the surface, the bottom of the mussel drop lines are usually five or six metres off the seabed. Regardless of float design it will be important to ensure that drop lines and mussel lines are adequately supported so that when they are heavy with mussels, the drop lines are kept away from the seabed and any seagrasses.

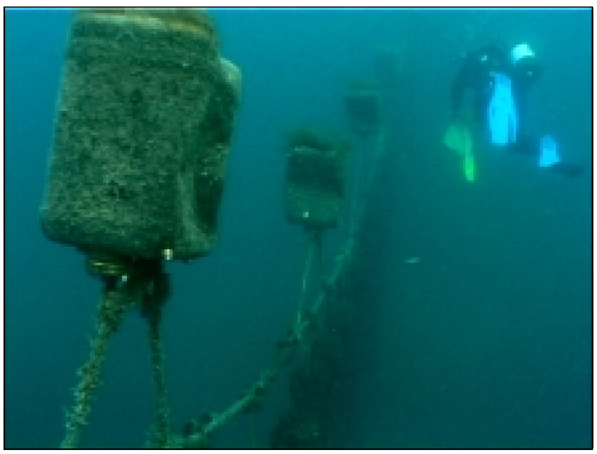


Figure 6.37 Mussel line floats at Mussel Line 4 showing their performance when supporting a full mussel line. Note compression of the floats.

Figure 6.38 Mussel lines from Mussel Line 4 lying on the seabed (sand) due to inadequate flotation.

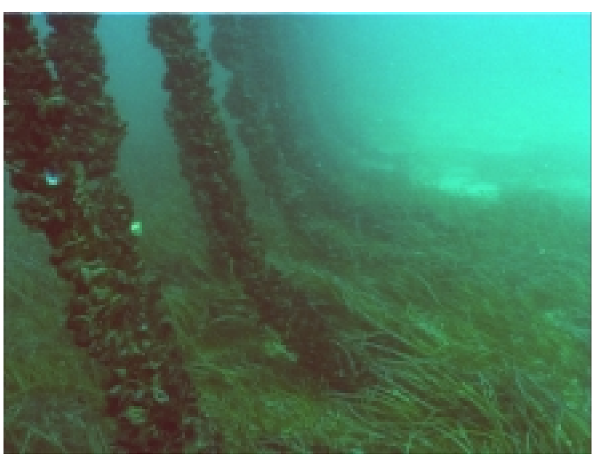


Figure 6.39 Mussel lines from Mussel Line 4 lying on the *Posidonia* seagrass due to inadequate flotation.

Figure 6.40 Mussel lines from Mussel Line 4 lying on *Heterozostera/Halophila* seagrass due to inadequate flotation

6.5 Mussel Shell Debris under Mussel Lines

During the study, divers found some occurrences under mussel lines of mussel shell on the seabed (Figure 5.41). Mussel shells were only found under mussel lines (ie not in control sites; Figures 5.42 – 5.44). The density of dead shells was always greater that the density of live shells (Figures 5.42 – 5.44). A one factor ANOVA on transformed data (log (x+1)) indicate that there was no significant difference in the density of live mussels on the seabed under mussel lines between summer 2000 and 2001 (df = 2, 237; P = 0.36). However, there was a significant difference for dead mussel shells with the density in summer 2001 being much less than that in summer 2000 (Figures 5.42 – 5.44).(df = 2, 237; P = 0.016)

It appeared that these shells were displaced from the mussel lines during harvesting and during storms (Gareth James, personal communication). The impact of these shells on the seabed and on the seagrasses is unknown, however no obvious negative effect of the shells was observed during the current project.

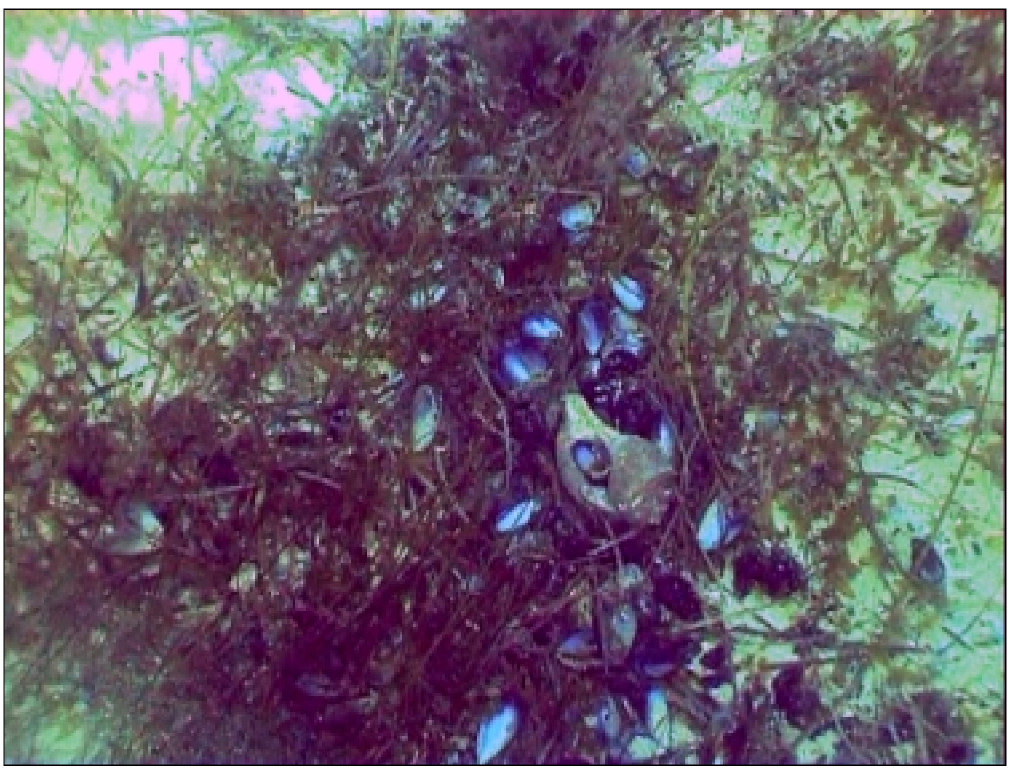


Figure 6.41 Mussel shells lying under Mussel Line 4

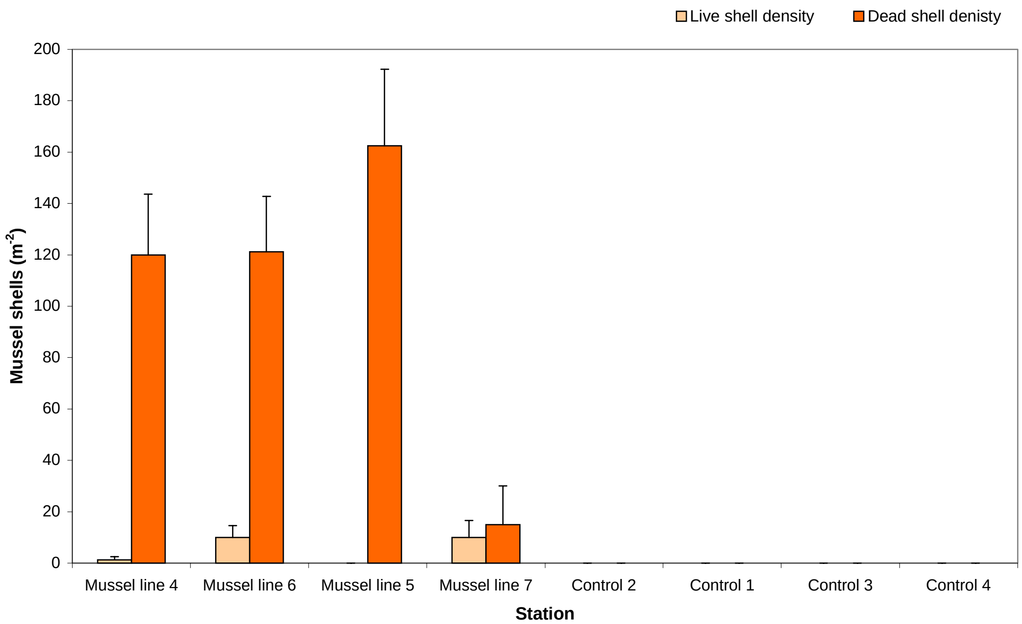


Figure 6.42 Density of mussel shells on the seabed in summer 2000

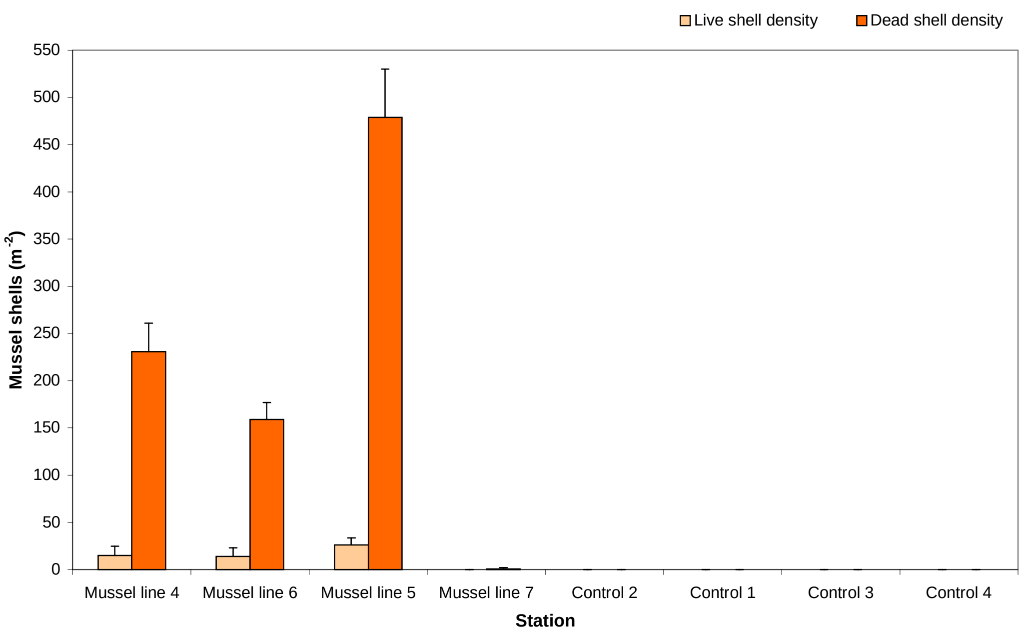


Figure 6.43 Density of mussel shells on the seabed in winter 2000

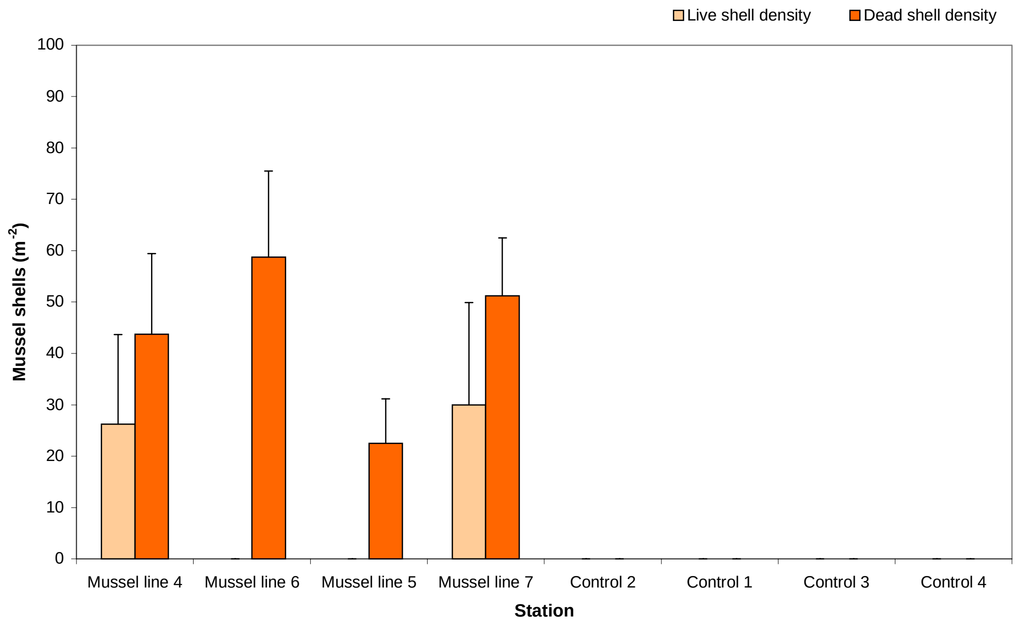


Figure 6.44 Density of mussel shells on the seabed in summer 2001

6.6 Hydrodynamic patterns

Results to date indicate that barotropic forces adequately simulate local circulation. There were no indications of baroclinic currents within the current measurements made at Mistaken Island during January. This is consistent with Pattiaratchi et al's (1991) findings which measured water currents over the northern section of the study domain for a 6-month period. Pattiarachi et al (1991) concluded that the water column was well mixed and that density-induced currents were insignificant over this period of measurement.

Tidal measurements for Mistaken Island indicate that there is only a small tidal range (approximately 0.75 m) and that there is no variation in the timing or magnitude of tide levels either side of Mistaken Island. This indicates that the local bathymetry (Figure 5.45) does not influence the tides. Modelling of circulation due to tides indicates that tidal flows are weak near Mistaken Island but get stronger towards the entrance to Princess Royal Harbour. Both measured and predicted current speeds near the island were less than 0.015 m s^{-1}.

Wind measurements taken over 12 weeks at Mistaken Island correlated closely with data collected over the same period from Albany airport. Hence it was possible to use long term wind data from the airport to model wind patterns at Mistaken Island to determine hydrodynamic circulation (see Figure 5.46).

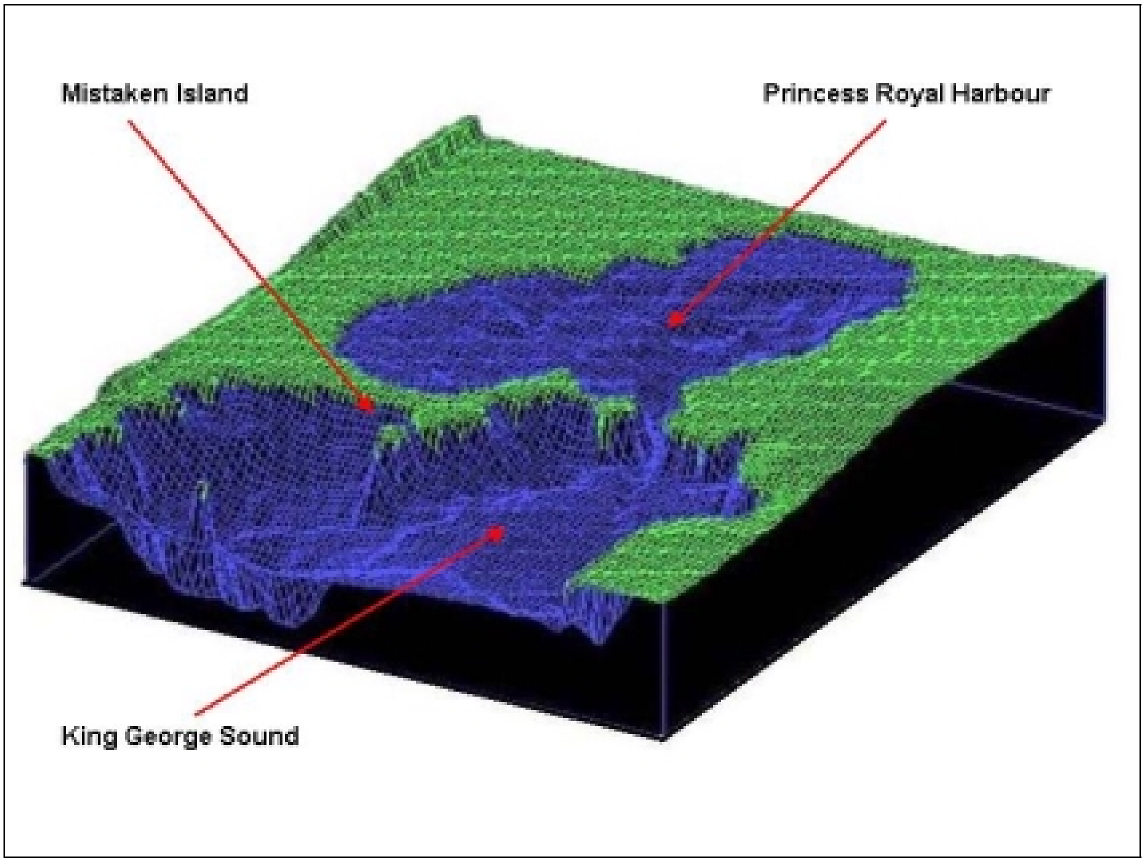


Figure 6.45 3D representation of bathymetry in the region of King George Sound that was used to model currents and sediment deposition.

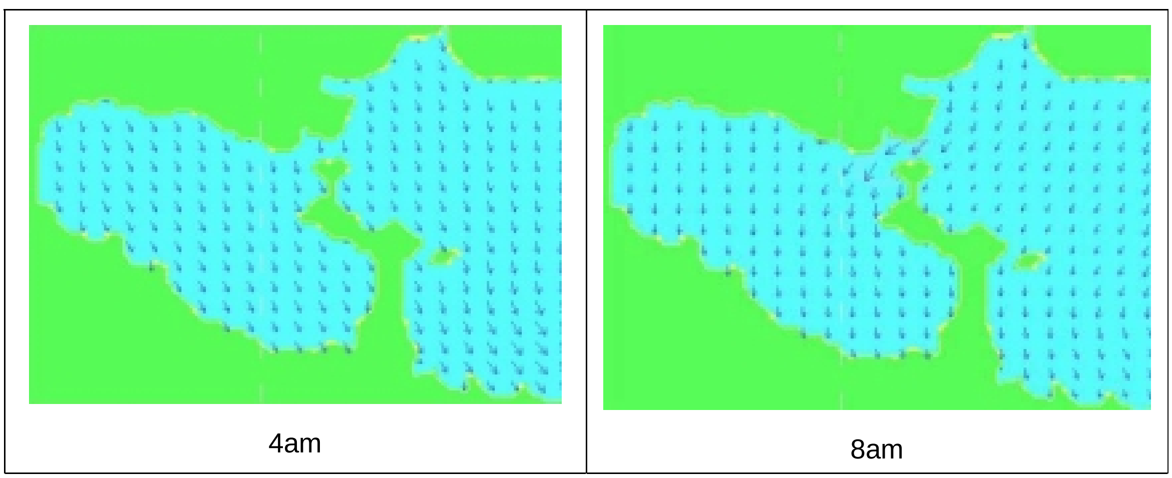


Figure 6.46 Predicted current strength (shown by the length of the arrows) and current direction in Princess Royal Harbour and King George Sound for two times on 4 June 2000.

Hydrodynamic and sediment transport modelling used SEDMOD3D (the sediment transport version of GCOM3D) over a 50 m x 50 m bathymetric grid. Forcing was derived for winds and tides.

Modelling of sediment transport, settlement and re-transport (ie. later movement of settled particles when seabed currents exceeded required thresholds) was carried out using sink rates reported for particles of the size range (3-5 micron) which is the range of food sizes eaten by mussels.

Discharge was from three points in a line, representing the existing mussel lines on the east side of Mistaken Island. Discharge was at a nominal continuous rate of 600 particles per hour and the model was run continuously for 365 hours (15 days).

Separate runs were modelled using wind data, and corresponding tidal conditions, from 4 example periods:

- February 1994
- April 1995
- June 1995
- December 1994

The model tracked the position (by latitude, longitude and depth) of every particle released during a run. Hourly summaries were stored for each run.

Hourly summary data were then converted to gridded data files reporting the percentage of total particles that were settled on the seabed within each grid cell. This data was calculated for a 25 m x 25 m grid using the longitude & latitude address of each particle.

In all cases the majority of deposition was confined to near the mussel lines. However, approximately 10% of the deposition was predicted to move away from the lines. During the February simulation, this material moved to the west until it contacted the shore. During April, it moved to the north east of King George Sound whereas during the June simulation, the material moved to the north, northwest and west. In the December simulation there was less material and it concentrated in the northwest and west parts of King George Sound.

6.7 Results of sediment modelling

Particle transport modelling indicated that organic material would tend be most concentrated on the northern side of Mistaken Island (Figures 5.47 – 5.50), however, low concentrations would be widely broadcast from the immediate location of the mussel leases under most weather conditions. In addition, results indicated that particles of the assumed size and density would be readily redistributed over time if they settled on the seabed.

The distribution of settled particles was predicted to vary with wind conditions both among and within each example run (Figures 5.47 – 5.50). For example, the February 1994 wind set commenced with strong winds from the northwest that backed around over a period of 3 days through south to the northeast (Attachment 2; Figure A2.1). Particles were initially predicted to mostly settle out at low concentrations extending towards the northeast (Figure 5.47; 40 hours). This was redistributed and pushed north and west during the southerly winds (Figure 5.47; 80 hours) and then to the southeast (Figure 5.47; 120 hours) and then to the northwest (Figure 5.47; 220 hours). The distribution pattern of particulate organic material from the mussel lines varied between times of the year (compare Figures 4.47 – 5.50).

In general, particles were predicted to mostly accumulate along the inshore waters of the northern and northwestern section of King George Sound. This result indicates that SEDMOD3D has calculated a reduction in current speeds along the shorelines to below threshold speeds for retransport of the defined particles, due to increased seabed friction. As modelling did not account for the transport of particles by wave action, which would be enhanced along some of these shores, it is possible that these accumulations are over-predicted. In any case, the amount of material predicted to settle in most shoreline locations was generally very low.

During all example simulations, the model predicted that the greatest concentrations of settled particles would occur along the northern side of Mistaken Island, immediately south of the points of discharge. More than 50% of material was accumulated in this area at most time steps of the model runs, and under some conditions the load rose to over 80% of the particles that had been released. This result suggests that current patterns in the area may trap material that is released from the mussel lines. If so, other naturally occurring organic material would also be expected to accumulate in this area. The habitat of this area next to Mistaken Island consists of algae on sand, rock and pavement (Figure 5.4) although seagrass occurs further to the north.

Overall, results indicated that concentrations of organic material contributed by the existing mussel farm would be low and transitory over most of the seagrasses areas to the north and south of Mistaken Island. The exposure of the seabed in these areas to wind and tide-induced currents was predicted to enhance dispersion of the material throughout King George Sound, and to retransport material that did accumulate in these areas. However, the consistent prediction of accumulation along the northern side of Mistaken Island suggests that this may be an area of interest if future monitoring of either organic accumulation or seagrass health were to be carried out.

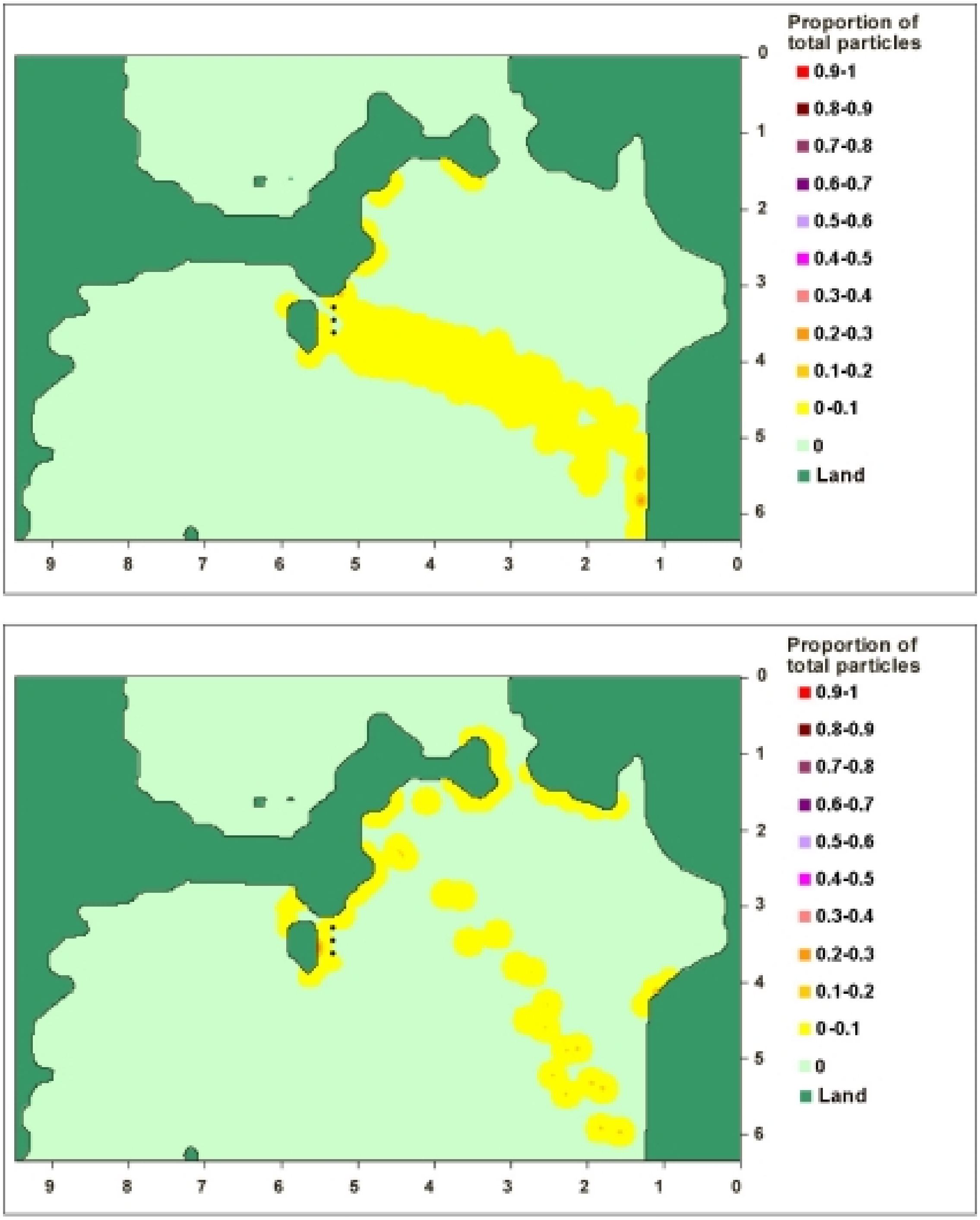
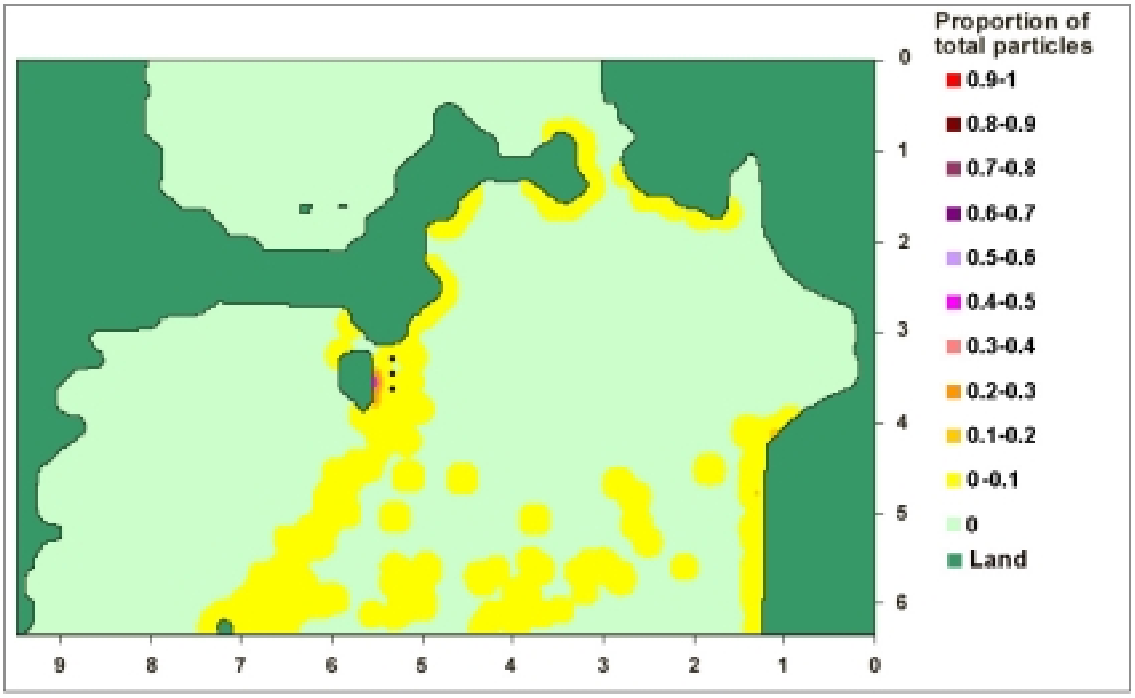


Figure 6.47 Predictions for the seabed distribution of particles released from the eastern side of Mistaken Island (black dots) during wind and tide conditions from February 1994. Top figure = after 40 hrs, bottom figure = after 80 hrs. Grid marks indicate distances in km.



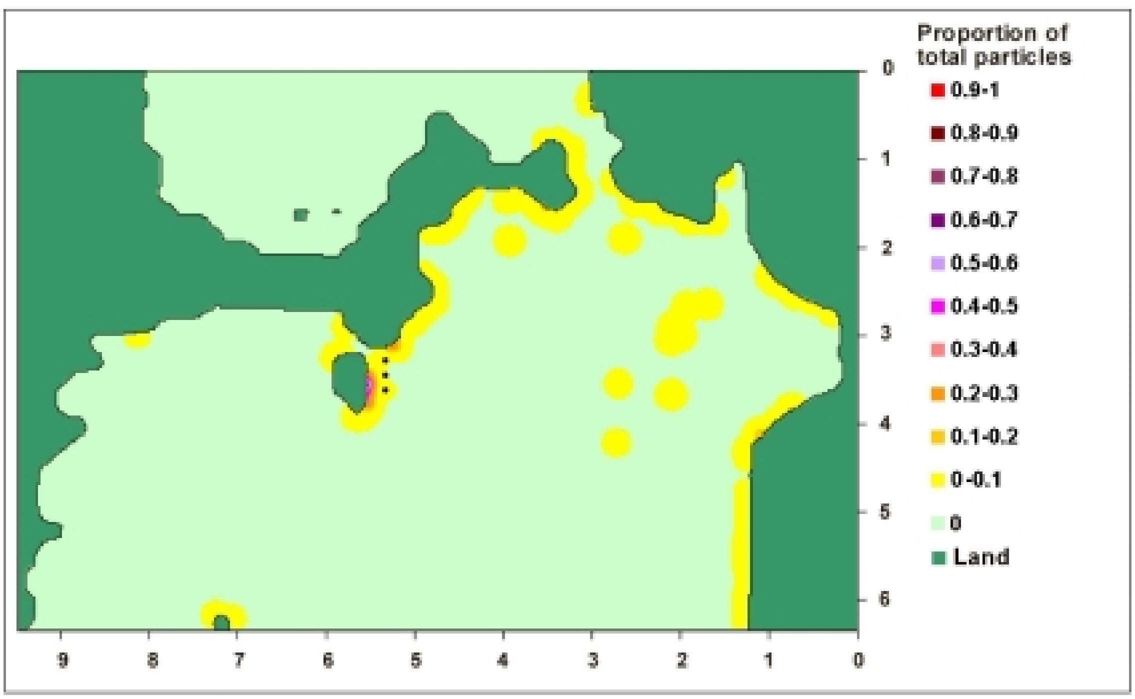
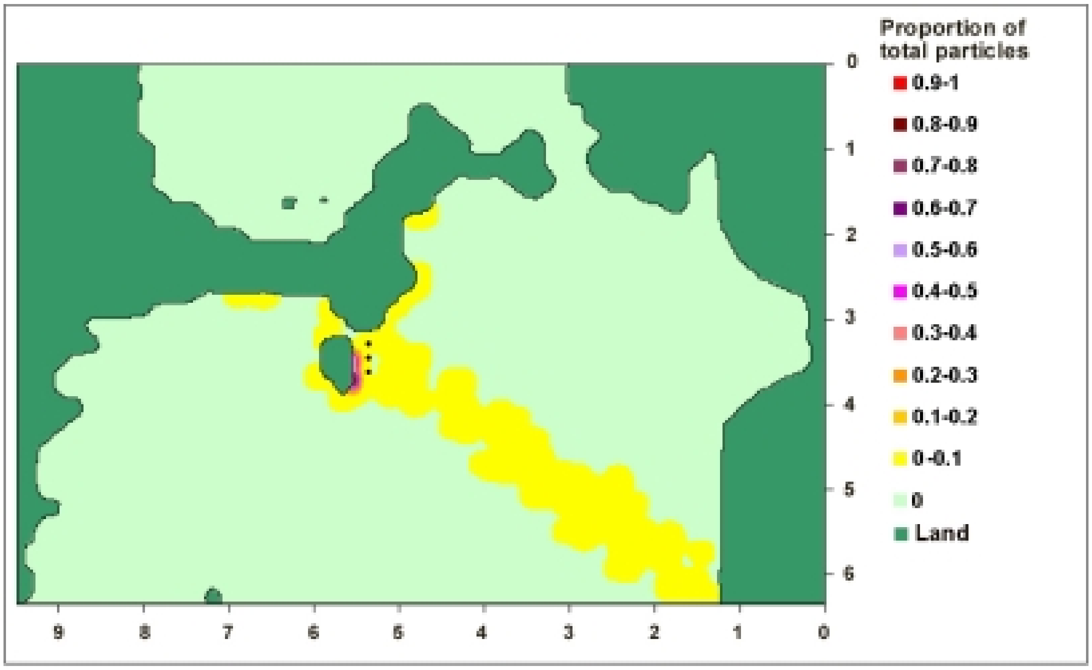


Figure 5.47 (Continued). Top figure = after 120 hrs, bottom figure = after 220 hrs.



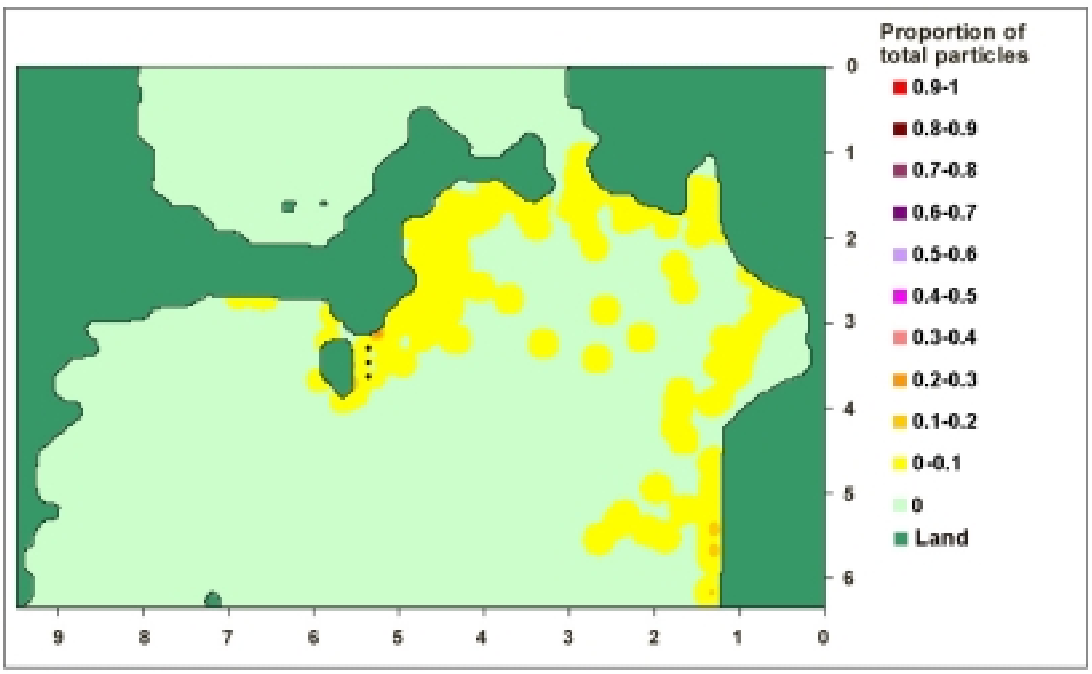
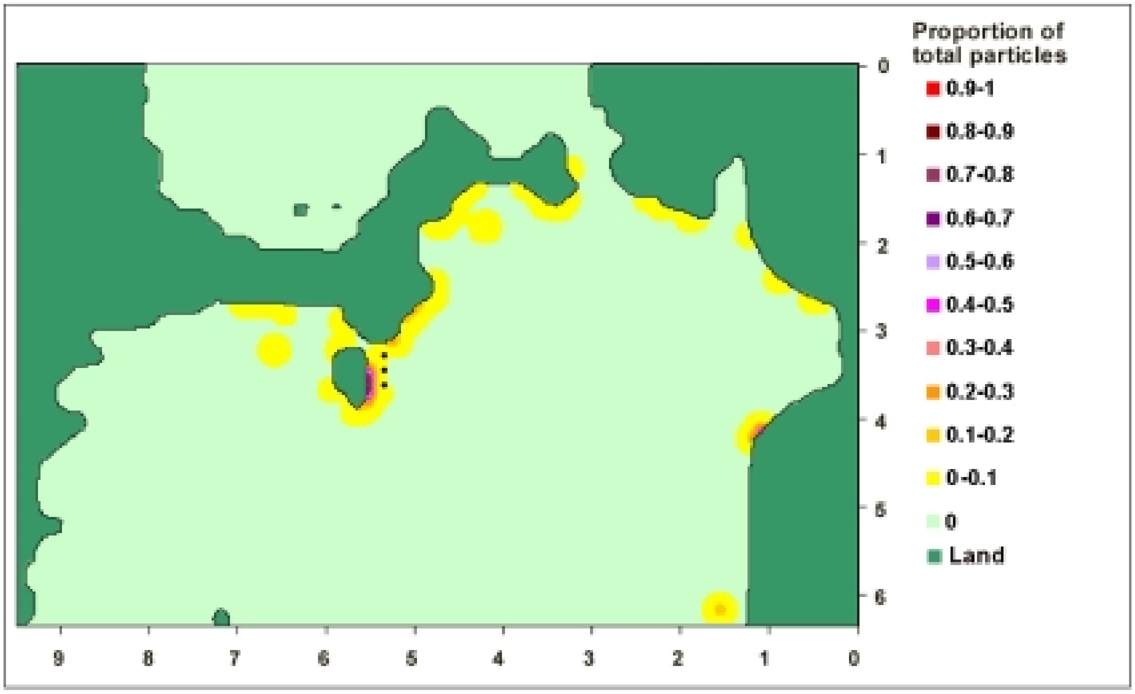


Figure 6.48 Predictions for the seabed distribution of particles released from the eastern side of Mistaken Island (black dots) during wind and tide conditions from April 1995. Top figure = after 40 hrs, bottom figure = after 80 hrs. Grid marks indicate distances in km.



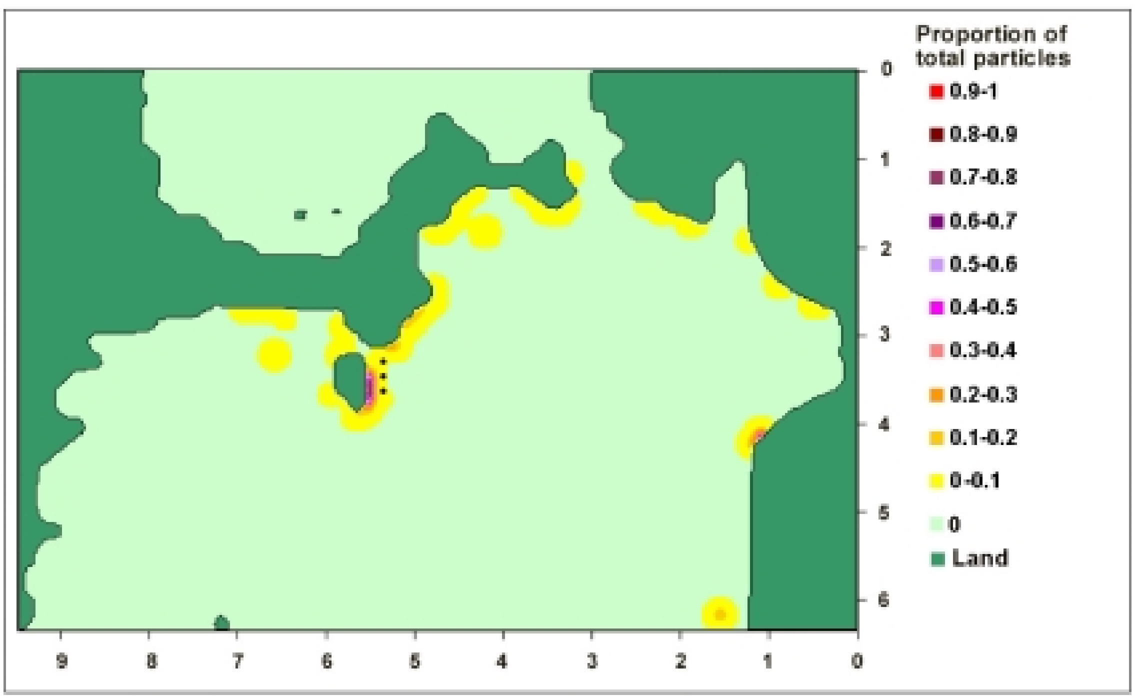
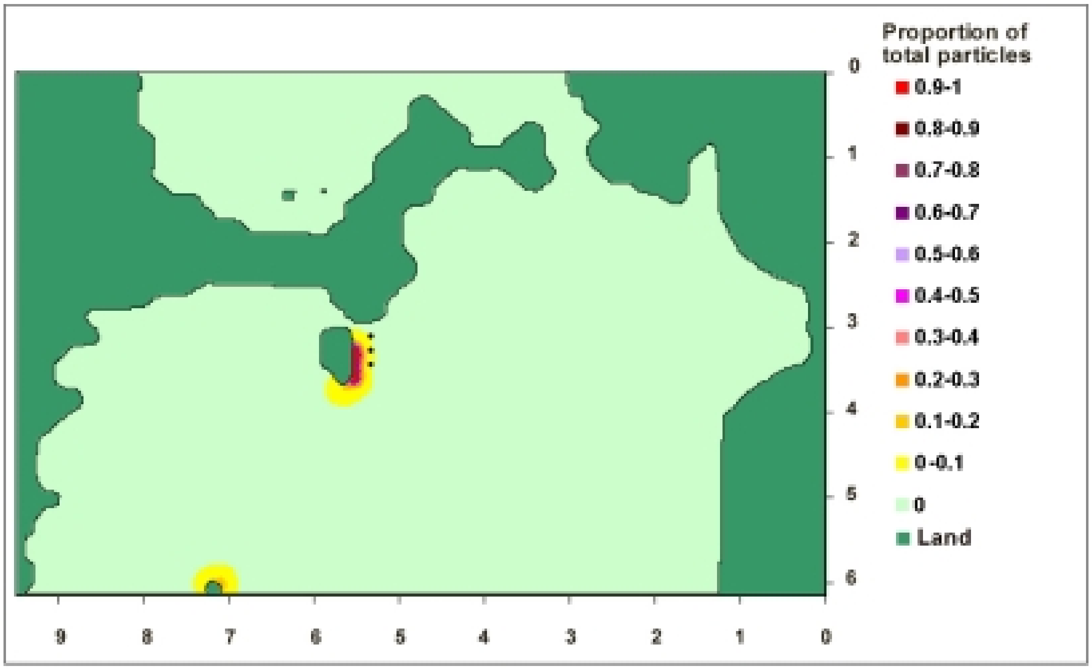


Figure 5.48 (Continued). Top figure = after 120 hrs, bottom figure = after 220 hrs.



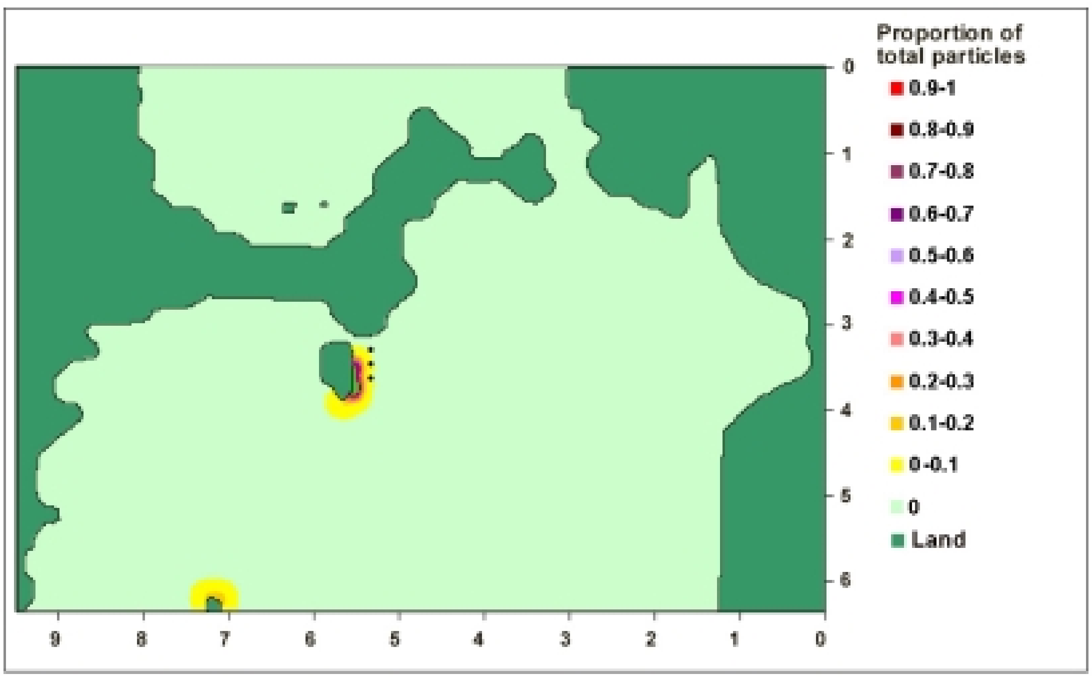
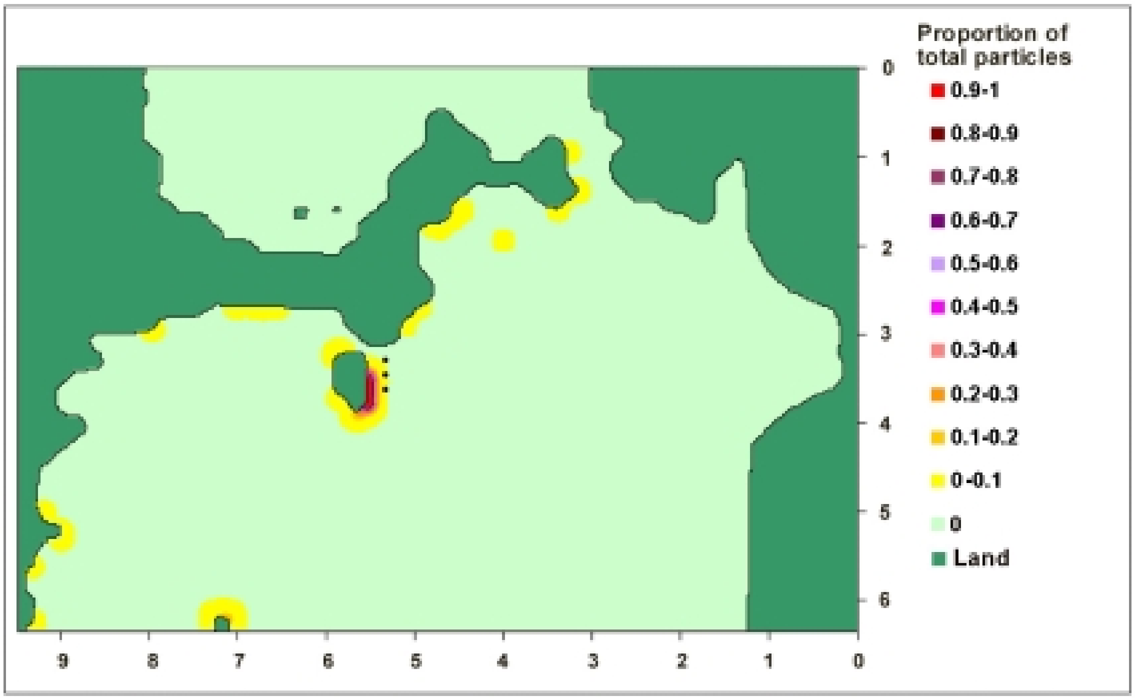


Figure 6.49 Predictions for the seabed distribution of particles released from the eastern side of Mistaken Island (black dots) during wind and tide conditions from June 1997. Top figure = after 40 hrs, bottom figure = after 80 hrs. Grid marks indicate distances in km.



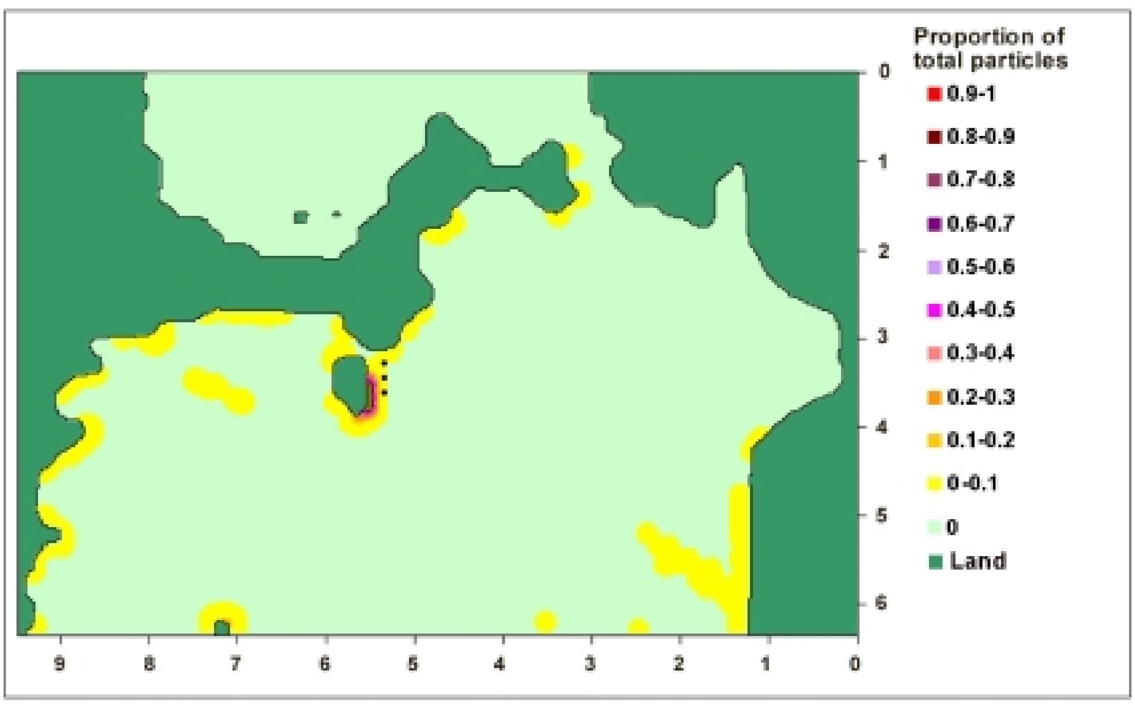


Figure 5.49 (Continued). Top figure = after 120 hrs, bottom figure = after 220 hrs.

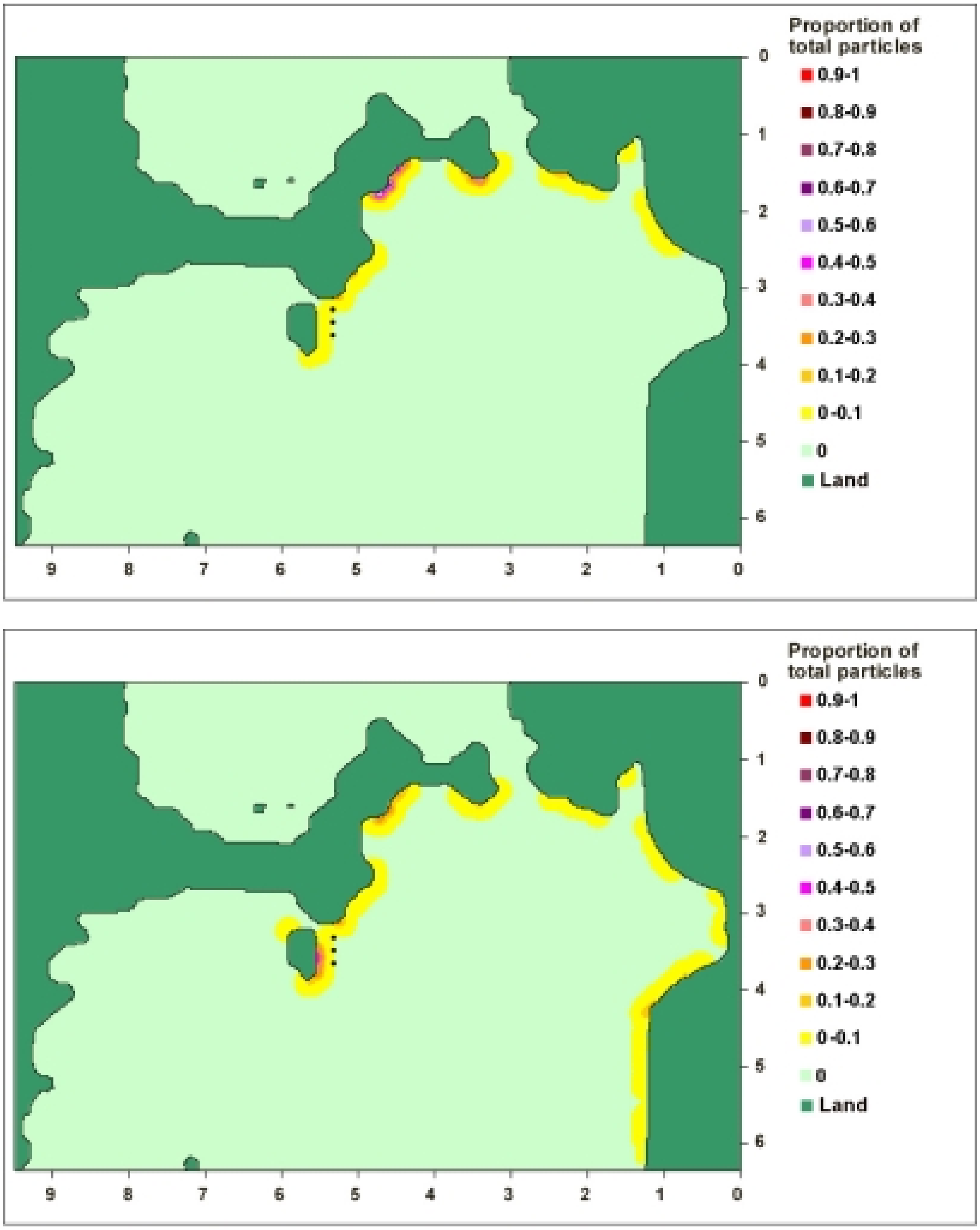


Figure 6.50 Predictions for the seabed distribution of particles released from the eastern side of Mistaken Island (black dots) during wind and tide conditions from December 1994. Top figure = after 40 hrs, bottom figure = after 80 hrs. Grid marks indicate distances in km.

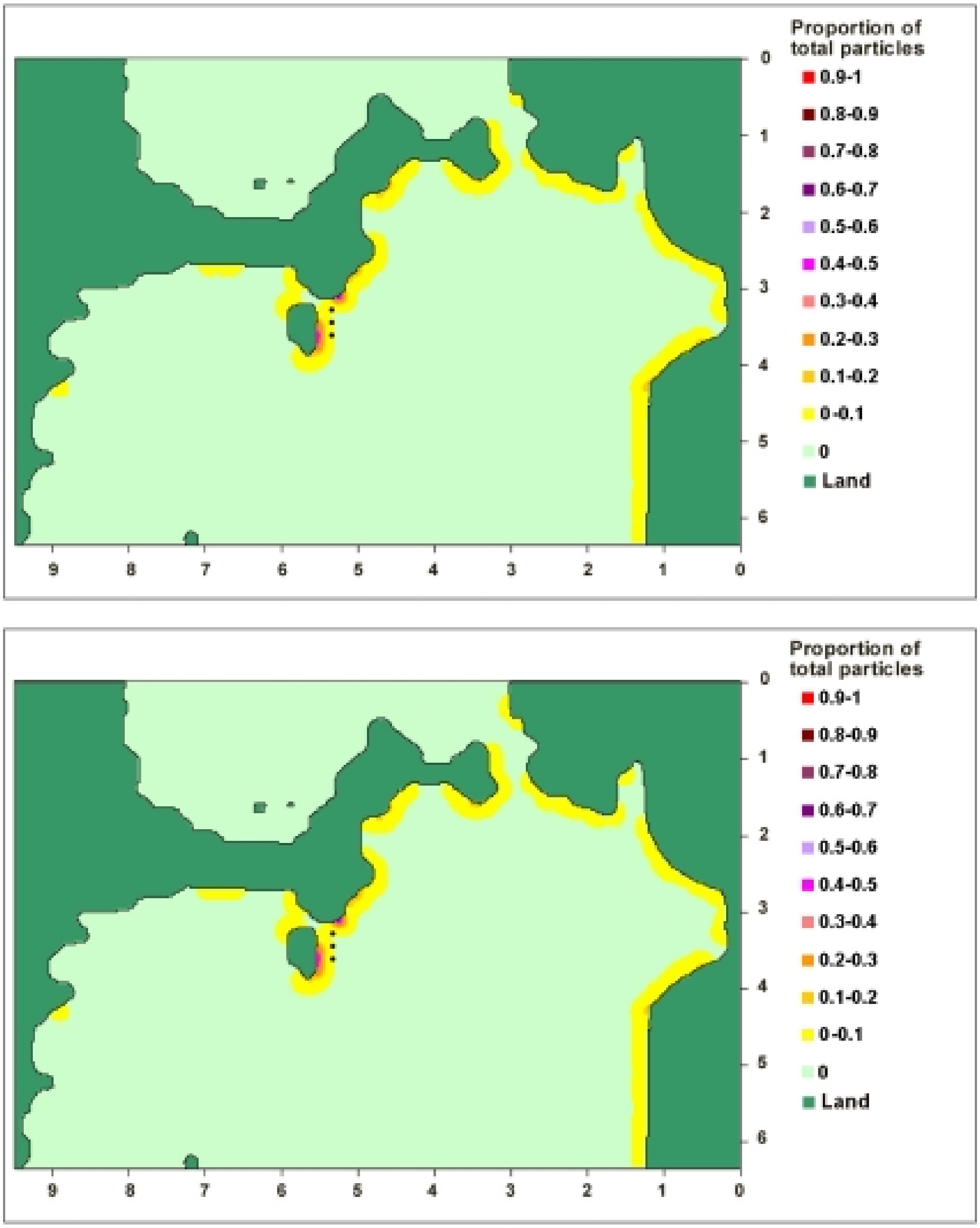


Figure 5.50 (Continued). Top figure = after 120 hrs, bottom figure = after 220 hrs.

6.8 Organic deposition

6.8.1 Total Sediment Deposition during February 2000

The amount of material deposited into sediment traps during February 2000 ranged from 1.83 (± 0.05) g under Mussel Line 6 to 3.61 (± 0.47) g at Control Site 2 (Figure 5.51). Analyses of variance indicated that there was a significant difference in sediment dry weight between the treatments (df = 1, 44; P < 0.001). The dry weight of material in control areas (3.20g ± 0.34g mean ± SE) was significantly greater than under mussel lines (2.17 ± 0.09). Sediment material deposited at Control Site 2 was significantly higher than at Mussel Lines 6, 4, and 5 (df = 5, 43; P = 0.001). Sediment deposition at the Control Site 1 was also comparatively high, at 2.93 g, however the amount was not significantly higher than at mussel lines.

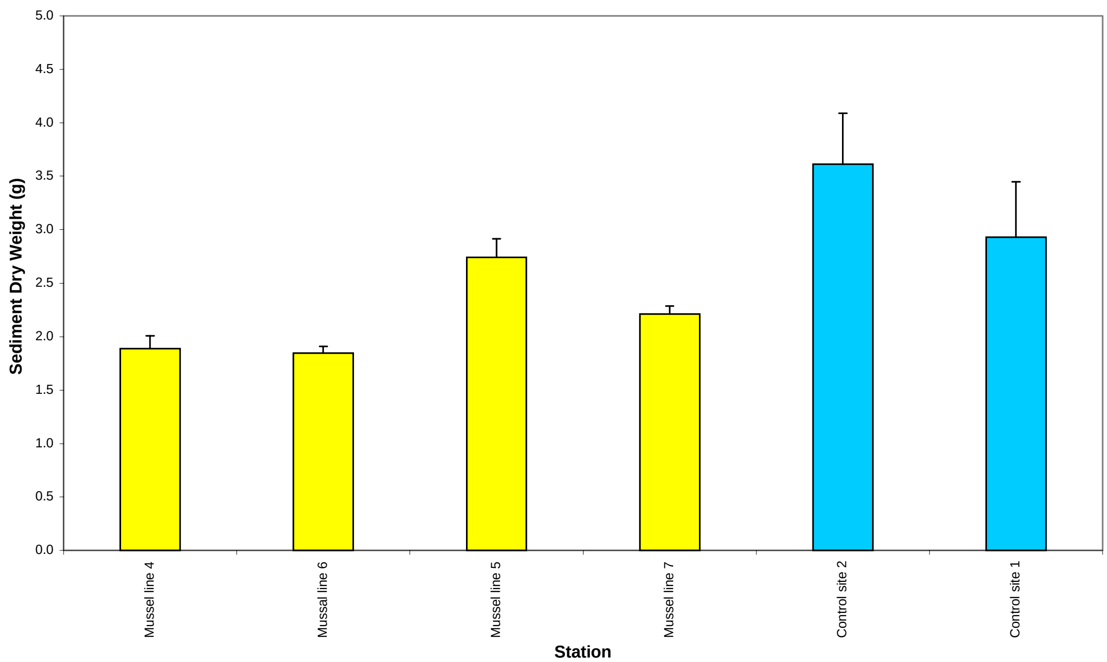


Figure 6.51 Sediment deposition under mussel lines and at control stations for February 2000 (displaying means ± SE for 8 replicate sediment traps)

6.8.2 Organic Deposition during February 2000

The mean (± SE) organic content ranged from 26.3% ± 0.3% under Mussel Line 4 through to 17.4% ±1.5% at Control Site 2 (Figure 5.52). The mean percentage of organic material was 20.2% ± 1.0% in control sites compared with 24.4% ± 0.5%. The ANOVA indicated that the organic content of material collected in the sediment traps was significantly higher under mussel lines than in control sites (df = 1,47; $P < 0.001$).

However, when the organic content data were converted from a percentage value to grams dry weight (Figure 5.53), the ANOVA showed that the total deposition of organic matter was higher at the control sites than under the mussel lines (df = 1,47; $P = 0.03$). The mass of organic matter ranged between 0.62 ± 0.06 g dry wt in control sites compared with 0.52 ± 0.01 g under mussel lines.

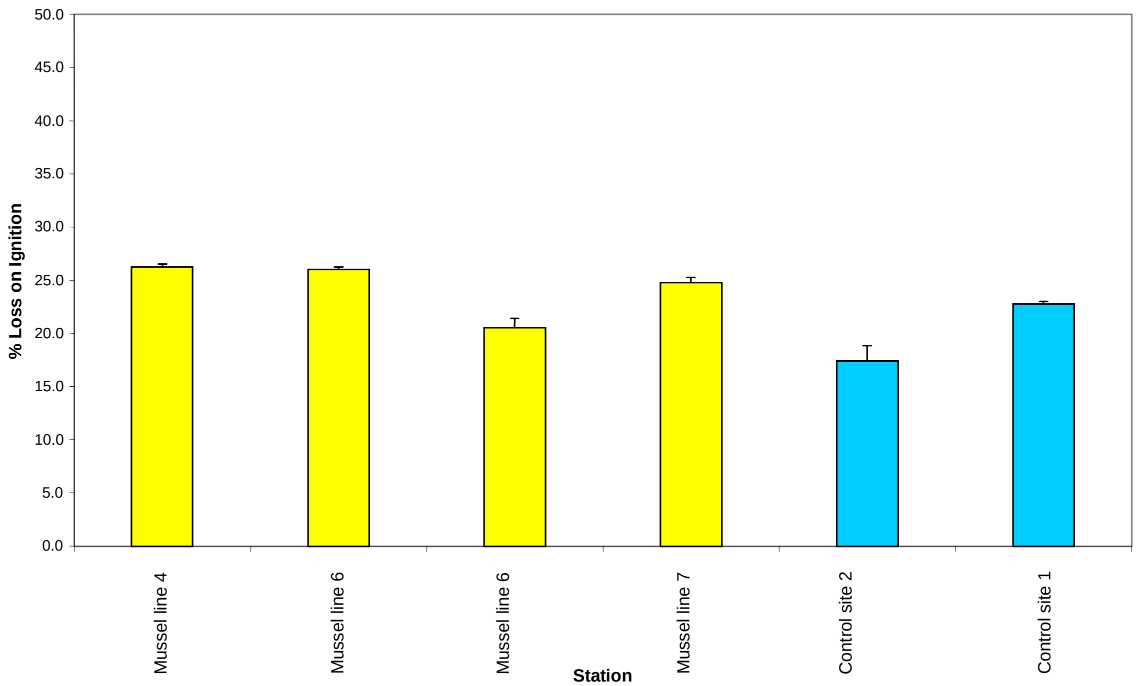


Figure 6.52 Mean percentage (± SE) loss of ignition of material from sediment samples during February 2000

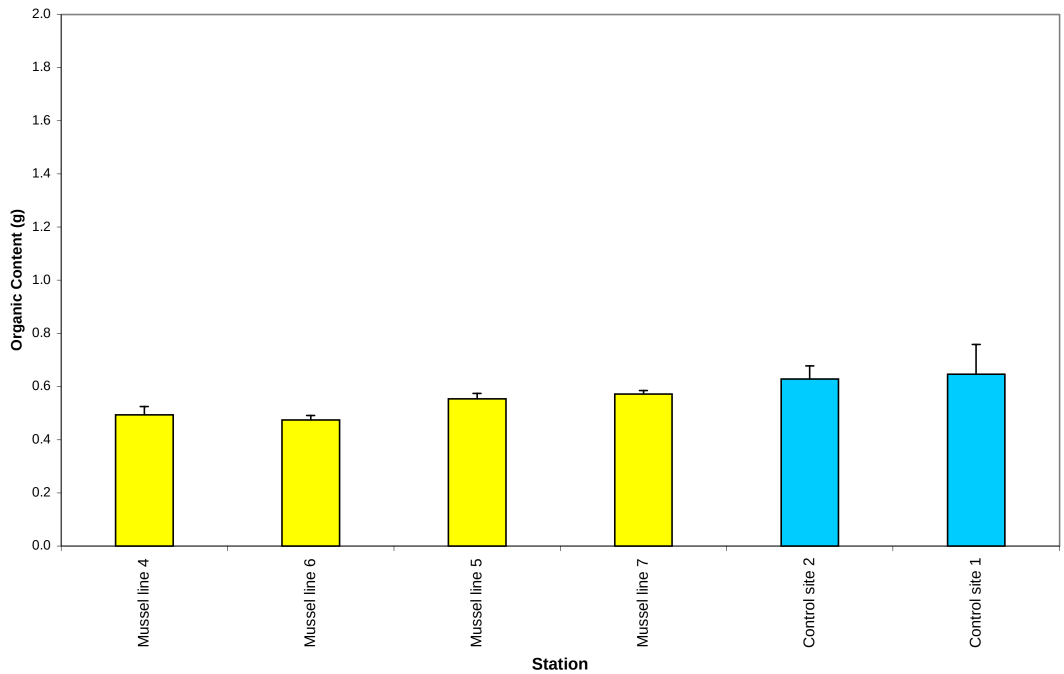


Figure 6.53 Weight of organic material found in sediment collectors during February 2000

6.8.3 Total Sediment Deposition during August 2000

The amount of material deposited into sediment traps during August 2000 ranged from 51.6 (± 15.5) g under Control Site 1 to 3.01 (± 0.21) g at Mussel Line 6 (Figure 5.54). Analyses of variance indicated that there was a significant difference in sediment dry weight between the treatments (df = 1, 45; P = 0.048). The dry weight of material in control sites 29.9 (± 10.2) g was significantly greater than under mussel lines 8.72 (± 1.03) g although this was due to the large amount of material at Control Site 1 (Figure 5.54). Sediment material deposited at Control Site 1 was significantly higher than at Mussel Lines 4, 6, and 7 (df = 5, 41; P = 0.001). Sediment deposition at the Control station was similar to that found at the mussel line sites.

6.8.4 Organic Deposition during August 2000

The mean organic content (± SE) ranged from 22.8% (± 0.9%) under Mussel line 6 through to 5.2% (±0.7%) at Control Site 1 (Figure 5.55). The mean percentage of organic material was 13.1% (± 2.6%) in control sites compared with 16.5% (± 1.2%) under mussel lines. The ANOVA indicated that there was no significant difference in organic content of material collected in the sediment traps under mussel lines and in control sites (df = 1,45; P = 0.39).

However, when the organic content data were converted from a percentage value to grams dry weight (Figure 5.56), the ANOVA on transformed data showed that the total deposition of organic matter was higher at the control sites than under the mussel lines (df = 1,45; P =

0.04). The mass of organic matter ranged between 1.53 (± 0.31) g dry wt in control sites compared with 0.95 (± 0.07) g under mussel lines.

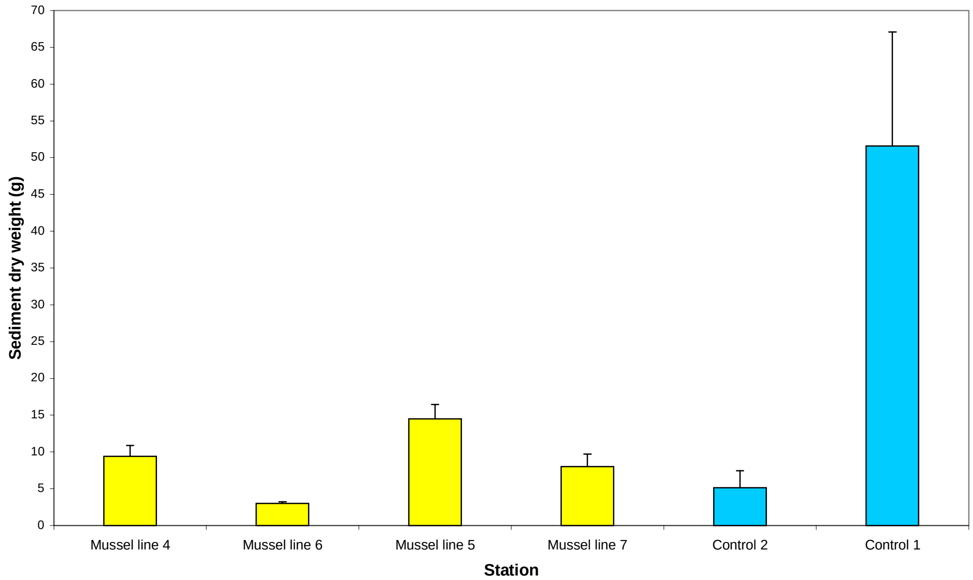


Figure 6.54 Sediment deposition under mussel lines and at control stations for August 2000 (displaying means ± SE for 8 replicate sediment traps)

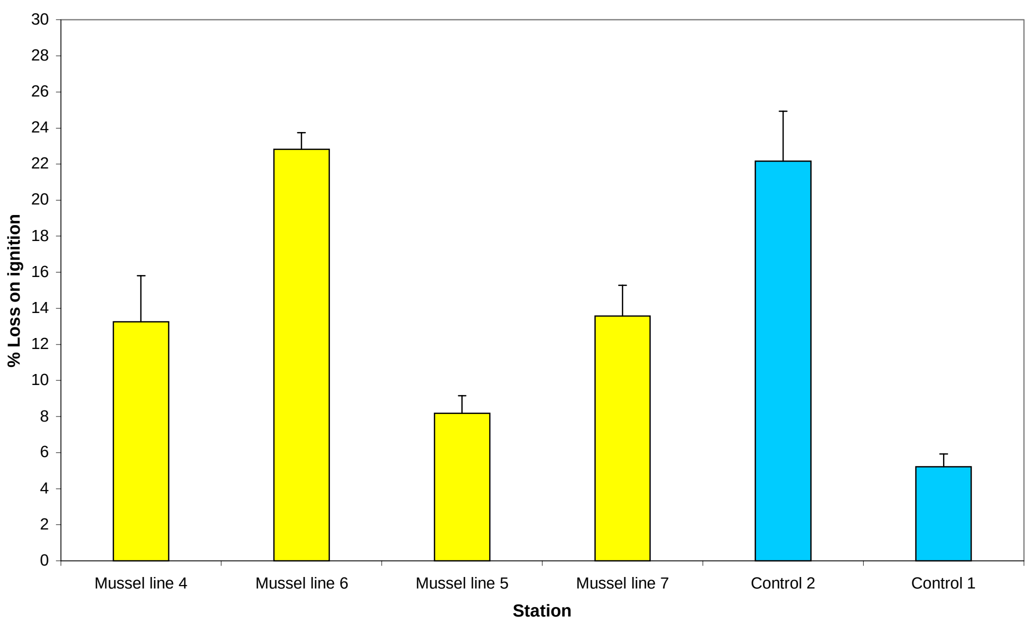


Figure 6.55 Loss on ignition of material from sediment samples collected under mussel lines and at control sites during August 2000 (displaying means + SE for 8 replicate sediment traps).

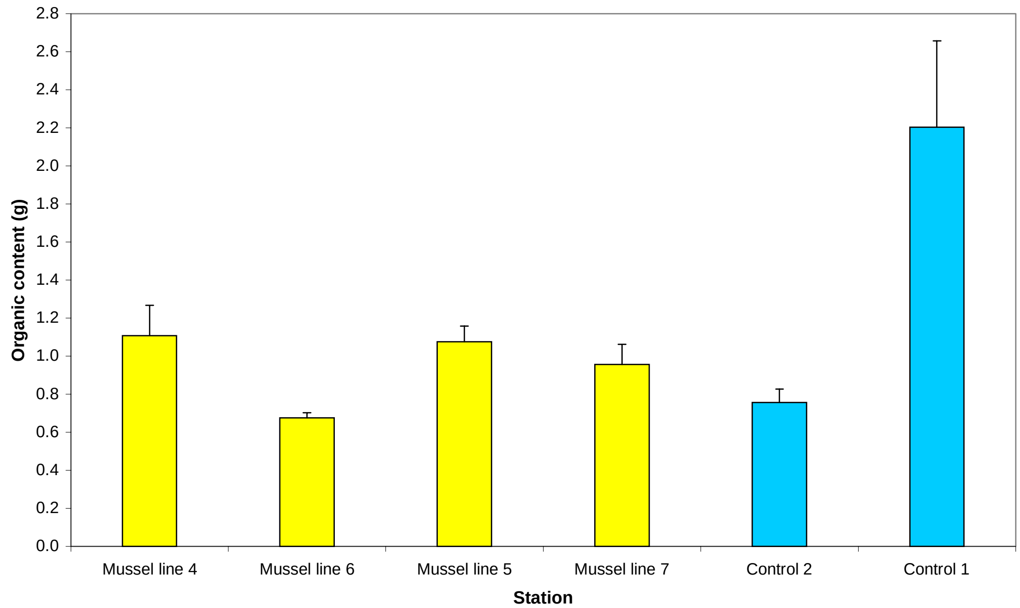


Figure 6.56 Weight of organic material from sediment samples collected under mussel lines and at control sites during August 2000 (displaying means + SE for 8 replicate sediment traps).

6.9 Mussel longline mooring structures

Anchoring devices for longline mooring structures are admiralty pattern anchors or steel cylinders, approximately 50 cm in diameter, sunken into the seabed. Some moorings were not visible as they were below the seabed, and sometimes covered by seagrass. Divers did not observe any apparent movement of the moorings (ie no drag marks or other seabed damage).

Mooring structures currently holding mussel longlines in place near Mistaken Island are positioned over a variety of seagrass habitats, ranging from bare sand to high-density *P. sinuosa* meadows (Table 5.9). Moorings were positioned over bare sand or sand with sparse H. ovalis meadows at the eastern end of Mussel Line 2, the western end of Mussel line 3 and at both ends of Mussel Line 7. At the western end of Mussel line 2, and at both ends of Mussel Lines 4, 5 and 8 moorings were positioned over high-density P. sinuosa.

Scouring of the seabed was recorded at 11 out of 16 moorings during the survey period, and in February 2001 a total of approximately 50 m^2 of seagrass was subjected to scouring. The estimated size of scours ranged from approximately 1.8 m^2 at the eastern end of Mussel Line 5 in February 2001, to 28.0 m^2 at the eastern end of Mussel Line 1 in September 2000.

The size of scoured areas changed over time at some mooring locations. Decreases in scour areas were noted at both ends of Mussel Line 1 from September 2000 to February

2001, whilst increases were recorded at both ends of Mussel Line 4 from February 2000 to February 2001, and the eastern end of Mussel Line 7 from September 2000 to February 2001.

Generally, the depth of the scouring was not sufficient to remove *P. sinuosa* rhizomes from the substrate, however at the eastern end of Mussel Line 4 there was complete removal of rhizomes due to scouring. There was evidence of recolonisation of scoured areas by H. ovalis and *H. tasmanica*, at the eastern ends of Mussel Lines 4 and 8, and at the western end of Mussel Line 5.

Anchoring devices remained static during the one-year monitoring period, meaning that dragging did not occur. A photographic time series of the seabed at selected mooring locations appears in Figures 5.57 to 5.65, and may be cross-referenced against the data in Table 5.9.

Table 6.8 Seabed scouring characteristics recorded at mussel longline moorings from February 2000 to February 2001

Mussel Line-End	Estimated Area of Seabed Scouring (m^2)			Rhizome Loss			Surrounding meadow description		
	Feb-00	Sep-00	Feb-01	Feb-00	Sep-00	Feb-01	Feb-00	Sep-00	Feb-01
1-West	-	14.0	3.0	-	None	None	-	Low to moderate density *P. sinuosa*, *H. ovalis*, *H. tasmanica* and *H ovalis* patches	Very low density *P. sinuosa*, and some *H ovalis* patches
1-East	-	28.0	6.0	-	None	None	-	Moderate density *P. sinuosa*, *H. ovalis, H. tasmanica* and *H ovalis* patches	Moderate to high density *P. sinuosa*, *H. ovalis*, and sand patches
2-West	2.0	2.0	3.0	-	None	None	High density *P. sinuosa*	High density *P. sinuosa*	High density *P. sinuosa*
2-East	0.0	-	0.0	-	-	-	Moderate density *P. sinuosa* and *H. ovalis*	-	*H. ovalis* and sand
3-West	-	-	2.8	-	-	None	-	-	*H. ovalis*
3-East	0.0	0.0	0.0	-	None	None	Moderate density *P. sinuosa* and *H. ovalis*	Sand, low density *H. ovalis* and *H. tasmanica*	Low density *P. sinuosa*, *H. ovalis*, sand. Some removal of *P. sinuosa*

Mussel Line-End	**Estimated Area of Seabed Scouring (m^2)**			**Rhizome Loss**			**Surrounding meadow description**		
	Feb-00	Sep-00	Feb-01	Feb-00	Sep-00	Feb-01	Feb-00	Sep-00	Feb-01
4-West	3.0	7.5	6.6	-	None	None	High density *P. sinuosa*	High density *P. sinuosa*	High density *P. sinuosa*, and some *Heterozostera* sp. in scour
4-East	5.5	18.0	19.0	-	All	All	High density *P. sinuosa*	Moderate density *P. sinuosa*	High density *P. sinuosa*, *H. ovalis* and sand patches. *H. ovalis* recolonisation in scour
5-West	-	-	3.7	-	-	None	-	-	High density *P. sinuosa*, and *H. ovalis* recolonisation of scour
5-East	-	2.5	1.8	-	None	None	-	Moderate density *P. sinuosa*	High density *P. sinuosa*
6-West	0.0	0.0	0.0	-	None	None	Moderate density *P. sinuosa*, *H. ovalis*, wrack and sand	Sand build up and consolidation with *H. ovalis*	Mixed *P. sinuosa*, *H. ovalis* and *Heterozostera* sp. meadow, with interspersed sand and wrack

Mussel Line-End	Estimated Area of Seabed Scouring (m^2)			Rhizome Loss			Surrounding meadow description		
	Feb-00	Sep-00	Feb-01	Feb-00	Sep-00	Feb-01	Feb-00	Sep-00	Feb-01
6-East	2.5	2.0	0.0	-	Partial	None	High density *P. sinuosa* interspersed with bare sand	On edge of moderate density *P. sinuosa*	Moderate density *P. sinuosa* with *H. ovalis* patches
	Feb-00	Sep-00	Feb-01	Feb-00	Sep-00	Feb-01	Feb-00	Sep-00	Feb-01
7-West	-	-	0.0	-	-	na	-	-	Sand and wrack
7-East	-	0.0	2.6	-	None	None	-	Sand and low density *H. ovalis*	Sand and low density *H. ovalis*. Feint scour in *H. ovalis*
8-West	-	-	0.0	-	-	None	-	-	High density *P. sinuosa*
8-East	-	-	3.3	-	-	None	-	-	High density *P. sinuosa*, and *H. ovalis* recolonisation of scour

September 2000

February 2001

Figure 6.57 Mussel Line 1 west - mooring chain scour

September 2000

February 2001

Figure 6.58 Mussel Line 1 east - mooring chain scour

February 2000

September 2000

February 2001

Figure 6.59 Mussel Line 2 West – Mooring chain scour.

February 2000

February 2001

Figure 6.60 Mussel Line 2 east - mooring chain on sparse meadow

February 2000

September 2000

February 2001

Figure 6.61 Mussel line 3 east - mooring chain scour

February 2000

September 2000

February 2001

Figure 6.62 Mussel line 4 west - mooring chain scour

February 2000

September 2000

February 2001

Figure 6.63 Mussel line 4 east - mooring chain scour

September 2000

February 2001

Figure 6.64 Mussel line 5 east - mooring chain scour

February 2000

September 2000

February 2001

Figure 6.65 Mussel line 6 east - mooring chain scour

7 DISCUSSION

This section includes:

- A discussion of the components measured in the project;
  - Habitats;
  - Light and seagrasses;
  - Seagrass health;
  - Sediment dispersion patterns;
  - Organic deposition;
  - Mussel floatation gear; and
  - Mussel longline mooring structures;
- Synthesis of the findings as a whole;
- Answers to questions raised in Section 2 regarding impacts of mussel longlines over seagrasses; and
- Assessment of the project against its objectives.

7.1 Habitats

The habitat maps produced using drop down video photography of 240 sites across the project area, and interpretation from aerial photography and rectified multispectral seabed images, show that the main benthic habitats of the AEA are:

- seagrass on sand;
- algae on rock; and
- bare sand.

Seagrass on sand was the most common habitat while algae were most common on rocks in the vicinity of islands. Seagrass composition and cover varied considerably across the AEA. This area supports at least three large, perennial seagrasses and at least two smaller, opportunistic seagrasses.

Seagrasses are best developed as uniform, high cover beds of *Posidonia sinuosa* in areas immediately north, north-west and south-west of Mistaken Island. Much of the central sector of the AEA comprises mixed patches of large and small seagrasses interspersed with bare sand. The predominant seagrasses are the perennial *Posidonia sinuosa* and the small seagrass *Halophila*. Small seagrasses with high cover predominate in the area north-west of

Mistaken Island that corresponds to the large, light phototone area on the aerial photographs. The northern and inshore south-western sectors include extensive areas largely devoid of seagrass.

The existing lease sites have variable seagrass composition and cover. Some lease sites overlap with the well-developed beds of *Posidonia* whist others overlap with more patchy seagrass while some are dominated by the smaller seagrasses.

Implications of this variability for management of any impacts of aquaculture over the entire AEA are not great from a practical sense because the entire area includes *Posidonia* and management of impacts could be uniformly regulated to Pprotect this species.

7.2 Light and seagrasses

7.2.1 Spatial variation in water column light levels

The study of spatial variation in light attenuation during February 2001 indicated that light reduction could vary by up to 41% for the same water depth and time within the AEA. This variability adds a level of certainty in predicting the impact of shading on seagrasses based on a few sample locations. For example, Control Site 1 had a higher underwater light reduction, at times, compared with under Mussel lines. Control Site 1 also appeared to have a higher underwater light reduction than other sites measured away from mussel lines during February 2001.

Reviewing trends over time (ie using a time series approach) is a way to reduce the influence of spatial variability in underwater light reduction in predicting the impact of shading on seagrasses by mussel longlines.

7.2.2 Temporal variation in water column light levels

Underwater light levels varied with seasons within a year. However, light attenuation during the same time of year (February) was found to be greater between years (greater in 2001 compared to 2000). The reduction in light levels in at least one control area as well as under mussel lines indicates a possible natural level of variability in light levels. This natural temporal variability at the study site negates making definitive statements on temporal trends in light levels based on a 2 year data set. Additional information will be required to establish the existence of any temporal trends in light levels (see Section 6.2.5). Based on the present results, however, light levels under mussel lines and control sites showed similar patterns with presumably similar effects on the seagrass beds.

7.2.3 Periphyton light attenuation

Studies of leaving periphyton plates in the field for up to 3 months provided similar levels of light reduction levels compared with settlement plates that had been left for one month. This information validated the use of using periphyton on plates left in the field for a single month.

The results indicate that light attenuation by periphyton was lower at all stations in summer than in spring. This result is expected because there is a seasonal decline in periphyton growth at this time of year (the minima for periphyton biomass on *Posidonia* seagrasses in temperate coastal waters is generally in late summer; Burt et al 1995).

The light attenuation data indicate that during some periods (October-November 1999 and May–June 2000) periphyton biomass growing on collectors in was higher under mussel lines than at control sites. At other times (February 2000 and October-November- 2000) no such difference could be distinguished.

No clear trend was apparent in measuring light reduction by this method. Although it is possible to relate the amount of light attenuation on the seagrass leaf to periphyton biomass, it is easier to measure periphyton directly for use in Masini et al's (1995) light limitation mode. Consequently, there would be little point in monitoring light reduction by periphyton on seagrass leaves or on artificial settlement plates in order to estimate its impact on seagrasses under mussel lines.

7.2.4 Measurements of epiphyte biomass on seagrass

Measurements of epiphyte biomass growing on seagrass leaves during winter and spring 2000 indicated that, in general, there was low epiphyte biomass on seagrass leaves in the AEA for these seasons. These data support the visual estimates initially used by divers to select the low epiphyte biomass light attenuation curve (Masini et al 1995; see Section 5.24). However, based on advice from the Project's Steering Group (R Masini pers comm.) light attenuation modelled from August-September 2000 onwards relied on actual measured periphyton biomass rather than visual estimates. These measurements were easy to undertake and should be included for any future monitoring of light level data that will include the use of Masini et al's (1995) model of seagrass light relationships.

7.2.5 Minimum light requirements of *Posidonia sinuosa*

Masini et al (1995) reported that "*Posidonia* can withstand acute shading for months" and can recover as long as it has been able to store sufficient energy reserves prior to shading. They suggest that seasonal differences in day length, water clarity and photosynthetically active radiation (PAR) will strongly influence the amount of time that light levels are sufficient to allow the production of energy stores. They report that *Posidonia* was found in positive carbon balance in summer and negative carbon balance in winter (Masini and van Senden 1995). This suggests that if *Posidonia* receives sufficient light levels during summer to allow production and storage of reserves it should be able to withstand suboptimal light levels during other times of the year (eg winter).

Masini et al (1995) applied empirical data from a number of studies including those from Simpson and Masini (1990) who studied light relationships for *Posidonia* spp in Princess Royal Harbour. Based on the good agreements of the available data and the predicted model output they concluded that their light attenuation model for *Posidonia sinuosa* was applicable across the entire range of the seagrass in Western Australia.

Results from the present study during the first year of measurements (summer 2000 through to spring 2001) indicated a relationship typical to that described in the preceding paragraphs; ie, there was sufficient light during summer and spring to allow the seagrasses under mussel lines and in control areas to survive and produce sufficient food. In autumn and winter, the light levels were low regardless of whether seagrasses were under mussel lines or control areas.

During the second summer of sampling (2001), the results are not as clear-cut. Based on those data, the model predicts that some of the seagrass sites did not receive sufficient light levels (at least during the period of sampling) to survive year round. However, some of these samples were in a control area. This indicates that it is not a clear-cut case of mussel lines reducing light levels; in fact, light levels under some mussel lines and controls were behaving if a similar way. Some measurements under mussel lines received sufficient light to survive. These results indicate that it would be prudent to continue to monitor light levels under mussel lines and control areas during Summer periods for a longer time period to establish if any trends in light levels are occurring.

7.2.6 Impact of changing mussel design floats on light measurements

During the study there was a change in mussel line float design. Floats originally used consisted of black 30 litre PVC drums (see Figure 5.37). The new gear that is being implemented as industry standard black 12 inch diameter circular floats. A comparison of light data pre and post float design indicated no discernible effect of the change in design on light levels measured during the study.

7.3 Seagrass health

Wood and Lavery (unpubl manuscript) reviewed monitoring indices used to assess seagrass health. These indices included shoot density, canopy cover, leaf area index and leaf length. They found that only one index, seagrass leaf length, showed a consistent pattern where healthy meadows had longer leaves, regardless of season, than meadows perceived subjectively by seagrass researchers to be unhealthy. Other indices such as shoot density showed a difference between healthy and unhealthy meadows in some seasons but not others (ie in summer but not in winter).

In the present study we measured seagrass leaf length and shoot density. Unfortunately our results were not clear-cut. For example there was only one sampling period where both leaf length and shoot density data indicated the same result (no difference between under mussel lines and control areas: August 2000). Leaf lengths were similar between treatments on three on 75% of sampling times where as shoot densities were similar between treatments on 50% of occasions. At the final sampling time (February 2001) leaf lengths were similar between seagrasses under mussel lines and control areas whereas shoot densities were less under mussel lines (on the previous occasion they were equal). These results indicate that it is premature to draw any definitive conclusion at the current time and additional monitoring of both parameters at least once per year, at the same time of year, should be carried out if a monitoring program was to be established.

7.4 Sediment dispersion patterns

Despite the wealth of information on the size of food eaten by bivalves (eg Wisely and Reid 1978, Bayne et al 1987) no information was found on the size of particles excreted (including literature searches by Fisheries WA: Sasha Brand-Gardner, pers. comm.). Pseudofaeces from bivalves can vary in size and shape and can be covered by a mucus layer (K Hahn WA fisheries pers comm.). For the purpose of modelling the biodeposition from the mussel lines, it was assumed that the particles were of similar size and density to those ingested. This is an important assumption to consider when interpreting the model results. Model simulations for different times of the year suggest that the majority of deposition will fall near to the lines on the northern side of Mistaken Island. Other areas will generally receive less than 10% of the fallout, if the model assumptions are correct. The distribution pattern varied with the time of year. The model simulations can at best be considered indicative, given the assumptions that have been made during model data input. However, the model does provide an indication of the likely sites to monitor for changes due to organic deposition from mussel longlines.

7.5 Organic deposition

Grant et al (1995) reported higher sedimentation rates (g dry wt of material) under mussel lines than in control sites in Nova Scotia. Similarly Nunes and Parsons (1998) produced a generalised bivalve model and reported that the deposition of material from bivalves such as oysters can be significant over time.

Given the inability of the data in our study to accommodate statistical assumptions of the ANOVA, our results should be interpreted with caution. Like Grant et al's (1965) results, the present study found that the percentage of organic matter in sediment traps was higher under mussel lines than in control areas. However, in contrast with Grant et al (1965) the weight of organic matter in sediment traps was greater at control sites. This appears to be due to a greater amount of total sediment load measured at control sites during February 2000 and at Control Site 1 during August 2000. These results indicate that site specific factors and variability may reduce the usefulness of predictions from generalised models. .

Based on information on hydrodynamic patterns and predicted dispersion locations (Section 5.7) we conclude that natural variability in sedimentation patterns within the aquaculture extension area and perhaps the choice of sampling sites makes meaningful interpretation of sedimentation data from the mussel lines difficult. We would not, therefore, recommend future measuring of sedimentation patterns to detect mussel line impacts.

Modelling results indicate that if sampling of organic material were to be carried out in the future, the most likely area to detect an elevated level of particulate organics would be directly to the east of Mistaken Island. However, any deleterious effect of the sedimentation on seagrass beds from the mussel lines would, be expected to manifest itself through a decline in seagrass health. This would be an easier parameter to measure.

7.6 Mussel flotation gear

A discussion on the use of black PVC drums as mussel line floats is most likely irrelevant given that there has been a change in gear regulations. However regardless of flotation gear used, it will be essential to make sure that mussel lines, even when fully laden with mussels, are kept away from physical contact with seagrasses. Figures 5.38-5.40 clearly show heavily encrusted mussel lines in contact with the seabed and seagrass. The potential to damage the seagrass by abrasion from the mussel encrusted mussel lines is very great and should be avoided if at all possible.

7.7 Mussel longline mooring structures

Removal of seagrass occurred at most moorings positioned over seagrass meadows. The most likely cause for this appeared to be to the movement of the mussel longline mooring chain across the seabed. The degree of scouring differed between moorings, ranging from small areas with only partial seagrass removal, to larger areas where rhizome removal occurred. Scouring was most severe at Mussel Line 4, particularly at the eastern end where rhizomes were completely removed. In areas where rhizomes were removed, recolonisation by *P. sinuosa* is likely to take longer compared to in areas where rhizomes remained intact. *P. sinuosa* is able to regenerate leaves from rhizomes relatively quickly, with leaf turnover time ranging from 84-108 days (Jernakoff et. al. 1996), however lateral growth (vegetative extension) of rhizomes may occur slowly. For example, in the closely related *P. australis* rhizome extension of rhizomes of mature plants is approximately 10-20 cm yr^{-1} (Larkum et. al. 1989). There is however evidence of recolonisation of scoured areas by more rapidly growing species.

Observed changes in scour sizes over time at some moorings may be due to several factors, including: seasonal differences in *P. sinuosa* leaf growth, recolonisation by other seagrass species and mussel growth on the longlines. As longlines become heavier due to increased mussel biomass they tend to float lower in the water, resulting in a greater length of chain on the seabed and increased scouring. Modifications to floatation devices and mooring systems may alleviate this problem.

8 BENEFITS

The mussel farming sector of the industry will benefit the most by this research. The information provided in this report will assist government agencies in deciding whether to allow additional sites in the aquaculture extension area to be farmed. To date, these agencies, have not been able to provide additional permits to farm mussels within the aquaculture extension area due to a lack of information on mussel longlining impacts. The direct benefit to the mussel farmers will therefore be an increase in the number of leases permitted in the seagrass extension area at around Mistaken Island.

9 FURTHER DEVELOPMENT

The results of the study have been presented to the Great Southern Aquaculture Association of Western Australia and to government agencies making up the Steering Committee for the project. The results have been presented to the 2001 Annual General Meeting of the Aquaculture Council of Western Australia (ACWA) and a summary of the report's findings will be published in the ACWA newsletter.

Knowledge from the study's research can be applied to assist the mussel farming industry through the application of a monitoring program that will be able to detect impacts on seagrass at an early stage. A suggested monitoring program is discussed in Section 9.1. These monitoring techniques could be used for other bivalve longline aquaculture where the major impact is expected to result from shading by the longlines.

9.1 Recommendations for monitoring

Monitoring to detect the impacts of continual anthropogenic activities is a recognised safeguard to minimise the risk of irreversible environmental impacts. There may be other ways to predict and monitor for seagrass decline in addition to those discussed and recommended in the present study. The recommendations below are designed to be as practical as reasonably possible for measurements made in the field. We believe that monitoring a few key parameters over the next one to two spring/summer periods would provide sufficient data to determine whether any trends in light levels or with seagrass health indices are apparent.

At a bare minimum, the following parameters should be measured during spring and summer.

- Light attenuation coefficients under mussel lines and control areas (for use in modelling seagrass survival from Masini et al's (1995) model).
- Epiphyte biomass on seagrass leaves (for use in modelling seagrass survival from Masini et al's (1995) model).

The following parameters could be monitored in summer:

- Seagrass shoot density and leaf length. This would provide a check of seagrass health independent of Masini et al's (1995) model. Seagrass in the area immediately to the north of Mistaken Island where the model predicted a possible build up of organic material should be one of the sites monitored.
- Longline anchor mooring scouring to confirm that the level of scouring has not become larger.
- Mussel shell deposits under the mussel lines to assess whether this has any impact on the surrounding seagrass.

10 PLANNED OUTCOMES

The project's outputs have led to a number of outcomes (see dot points below). Outputs have included a map showing the seagrass distribution and diversity of within the Aquaculture Extension Area. The information that this map contained was required by government agencies to make decisions on expanding the number of mussel farmers that could operate within the aquaculture extension area. Seminars provided to mussel farmers and government organisations have ensured that all parties have a common understanding of the important environmental issues concerning mussel longline farming over seagrass meadows. Results and conclusions from this final report will be used to further assist both government and industry to manage in a sustainable manner, mussel longline farming over seagrass meadows in the aquaculture extension area. Planned project outcomes are therefore:

- Clarification of the relative importance of specific environmental issues associated with mussel longline aquaculture practices over seagrass;
- Provision of information to assist government agencies in making decisions on the siting and management of mussel longline aquaculture in the vicinity of seagrass beds;
- The provision and application of a conceptual model for monitoring mussel farming impacts over seagrass; and
- The successful application of a numeric seagrass light-limitation model as an early warning monitoring method that will meet the needs and objectives of longline bivalve farming in similar conditions around the Australia; and
- The provision of a definitive tool that ensures agencies can make decisions of the acceptability of longline aquaculture located over seagrass.

11 CONCLUSIONS

The habitat within the Aquaculture Extension Area is comprised predominantly of seagrass beds. Seagrasses are susceptible to reductions in light levels that could be brought about through shading by mussel longlines. At the start of the study, light levels under mussel lines and control sites, based on Masini et al's (1995) model, were predicted to be sufficiently high. However, there was evidence from the final sampling period to suggest that levels might be changing to a point where seagrass could be affected. Alternatively, it may simply have been due to natural variability within the study area at the time of sampling. This may be the reason why some of the control and mussel line sites had lower light levels for the required water depth, whilst other sited did not.

Measurements of seagrass health also provided a variable result and it is not possible, based on the small temporal data set (only two summers), to conclude whether shading from mussel longlines are having a deleterious effect on seagrasses. .

Deposition of organic matter does not appear to be a problem at the present time. Moreover, the potential impact of live mussels and mussel shells being dislodged from the mussel lines and building up on the seabed does not appear to be having significant effect at the present time. However, a longer term outcome is not known.

The greatest impact to date on seagrass meadows appears to be from the anchoring systems that have been used to secure the longlines. If anchoring systems that do not drag over the seagrasses could be used, the greatest immediate threat to the seagrasses will be avoided.

11.1 Answers to questions raised in Section 2

Can mussel farming be conducted over seagrass beds without impact?

- The real issue is whether or not the impact is significant. The significance of impacts is likely to be site-specific. For example, wave and current movement may affect water turbidity and therefore light levels. This may have been the case where even at one of the control sites, the amount of light at times was not sufficient for long-term seagrass survival. At the present time, it is not possible to conclusively say that mussel farming over seagrasses has a significant impact or not. A larger time series to determine trends in seagrass response to the farming is needed if farming is to continue for any length of time.

Are the impacts of mussel farming reversible over time if aquaculture activities cease in a particular area (e.g. through site rotation)?

- This question was not directly tested during the study. However, the main causes of impact during the study appeared to be mooring damage. As long as the duration of any impact was kept to a minimum, it should be possible to rotate mussel lines before irreversible damage occurs. This may also involve removal of dropped shells in case there was any long term effects that caused a change in sediment chemistry.

Is the extent of impact of mussel farming on seagrasses the same throughout the year (i.e. seasonal influences)?

- The impact of shading on seagrasses is much more critical during spring and summer compared to autumn and winter. This study showed that light conditions in spring and summer were sufficient for seagrass survival. Low light levels (below critical levels for survival) were observed at both controls and under mussel lines indicating that it was not a mussel line impact. It was not possible to distinguish the extent of differences in seasonal impact of other factors.

Are the rates of impact and recovery from potential impact from mussel farming compatible with available adaptive management options?

Addressing the impact of shading is within available adaptive management options of continued monitoring, seasonal movement of mussel lines and placement of lines away from seagrass beds. Better designs of mooring devices will minimise any impact of longline anchors.

11.2 Addressing of project objectives in Section 3

Resolve environmental issues concerning the siting of longline bivalve culture over seagrass.

The main environmental issue for longline bivalve culture over seagrasses was expected to be the effect of shading. The light limitation model by Masini et al (1995) clearly predicts when seagrass cannot survive in the long term as a result of reduced light availability. Results of the present study suggest that the amount of shading by longlines may increase over time (perhaps as the lines become established and the mussels get larger). However, at the present time there is no clear evidence to indicate that mussel longlines, compared to control sites, are causing sufficient shading to result in a decline of seagrass within the AEA. A longer time series is needed to confirm this initial finding. If longlines are going to be placed over seagrass meadows, it will be important to monitor the light levels especially in spring and summer as an early warning indicator for future seagrass survival.

Provide data that demonstrate that mussel farming can develop in an ecological sustainable manner

The study has provided several sources of important data including:

- Habitat data that could be used to identify seagrass and non-seagrass areas. Positioning mussel longlines away from seagrass areas would avoid current issues of the impact of mussel aquaculture on seagrass survival;
- Data on underwater light levels can be integrated into a seagrass light limitation model to determine whether seagrass can survive shading by mussel lines;
- Data on periphyton levels was used to contribute to the seagrass light limitation model;

- Sedimentation data, which showed that the natural levels of variation in sediment deposition and movement was at least as great if not greater than sedimentation due to mussels;
- Modelling hydrodynamic and organic depositional data, which indicated the most likely depositional areas. These areas vary seasonally according to changing hydrodynamic patterns.
- Data on the impact of longline anchors that showed that the impact on seagrasses varied greatly. However, in general, chain from the longline anchors appeared to abrade the seagrasses resulting in clearings within the seagrass beds. The data indicate that more environmentally friendly mooring devices would minimise the level of seagrass damage;

The study provided data that can be used to manage the impacts of mussel lines to ensure that farming has the potential to develop in an ecologically sustainable manner so long as it is supported by a monitoring program that provides early warning if significant ecological impacts start to occur.

Provide a foundation of management practices for mussel farming over seagrass.

Management practices could include the following requirements for mussel farming over seagrasses:

- Identifying where seagrass occurs within aquaculture areas.
- Monitoring light levels under mussel lines during spring and summer to determine whether minimum light levels for seagrass survival are achieved.
- Monitoring of epiphyte biomass on seagrass leaves for input into the light limitation model. These data can be collected at the same time as seagrass health is monitored.
- Monitoring seagrass health at least once per year through shoot density and leaf length.
- Monitoring for other potential impact factors such as mussel lines dragging on the seabed and mussel shells building up on the seabed in areas of seagrasses.
- Ensuring “seagrass friendly” anchoring devices are used for mooring longlines in seagrass meadows.

Provide government agencies with the information that allows them to measure change to the seagrass environment relating to mussel culture.

Government agencies not only need information that allows them to measure changes in the seagrass environment, they also require information that gives them advanced warning. The information on light attenuation coefficients and epiphyte biomass when incorporated into seagrass light limitation models (Masini et al 1995) can provide this predictive capacity. Measurement of change in underwater light levels will provide a measure of change to the seagrass environment relating to mussel culture.

Information on seagrass shoot density and leaf length under mussel lines and at control sites will also allow government agencies to measure change to the seagrass environment relating to mussel culture.

Provide a model that has application nationally to allow the needs and objectives of longline bivalve farming to be met in similar locations around Australia.

A model that would have application nationally would be to combine predictions of the minimum light required by seagrasses (ie their lower depth limit) with supporting monitoring of seagrass health.

The present study has shown that the light limitation model by Masini et al (1995) can be applied effectively to determine in advance whether longline bivalve farming has the potential to impact seagrass areas. Other species of seagrass would require similar data on their photosynthetic rates. Data are for some species eg *Amphibolis antarctica* have already been determined (Masini and Manning; 1995). The direct applicability of the model will therefore depend on whether species specific data are available for use.

The seagrass health model is based on measuring changes in shoot density and leaf length under mussel longlines compared to areas away from the longlines. Any changes in shoot density and leaf length are indicative of changes to seagrass heath and longer-term survival.

Provide a definitive tool that ensures agencies can make decisions on the acceptability of longline aquaculture located over seagrass.

By knowing the depth of water where aquaculture is proposed, and the ambient light attenuation levels, agencies have a definitive tool in the seagrass light limitation model in making decisions on the acceptability of longline aquaculture over seagrass where shading is an issue. As discussed above, agencies may need to determine species specific irradiance relationships to apply in the model although *Posidonia* is found through out temperate Australia (Larkum et al 1989) and the model would have immediate application if required. Agencies can measure light reduction by the longlines in spring and summer to determine if seagrasses are potentially threatened.

Measuring indices of seagrass health is another tool to assist agencies in making decisions on the acceptability of longline aquaculture.

Although it may be possible to build a more complex decision support system that incorporate many factors into a single tool, experience on large environmental projects involving seagrass (eg Perth Coastal Waters) indicate that due to the complexity of biological systems, several simple models are more likely to be effective in accurately predicting impacts on seagrasses than large complex decision support systems.

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ATTACHMENTS

Attachment 1
Mapping site DGPS coordinates and habitat data

Table A1 Mapping site DGPS coordinates and habitat data

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
1	24-Oct-1999	585421	6119390	5.0	*Posidonia sinuosa*	High (75-100%)	High (75-100%)
2	24-Oct-1999	585542	6119344	7.2	*Halophila* spp.	High (75-100%)	Very low (< 25%)
3	24-Oct-1999	585700	6119291	4.1	Algae	not applicable	not applicable
4	24-Oct-1999	585995	6119361	12.0	Algae	not applicable	not applicable
5	24-Oct-1999	586113	6119272	15.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	High (75-100%)
6	24-Oct-1999	586220	6119469	6.0	Algae	not applicable	not applicable
7	24-Oct-1999	586352	6119401	16.0	*Halophila* spp.	Moderate (50-75%)	Low (25-50%)
8	24-Oct-1999	586593	6119649	13.0	Algae	not applicable	not applicable
9	24-Oct-1999	586623	6119854	16.0	*Halophila* spp.	Moderate (50-75%)	Low (25-50%)
10	24-Oct-1999	586159	6119935	14.0	*Halophila* spp.	Sparse (5-25%)	Low (25-50%)
11	24-Oct-1999	586175	6119849	14.0	*Halophila* spp.	Moderate (50-75%)	Low (25-50%)
12	24-Oct-1999	586179	6119855	14.0	*Halophila* spp.	Moderate (50-75%)	Low (25-50%)
13	25-Oct-1999	585402	6119968	4.6	Algae	not applicable	not applicable
14	25-Oct-1999	585331	6120042	8.9	Algae	not applicable	not applicable
15	25-Oct-1999	585467	6119867	5.7	Algae	not applicable	not applicable
16	25-Oct-1999	585536	6119823	5.3	*Posidonia sinuosa*	High (75-100%)	High (75-100%)
17	25-Oct-1999	585604	6119888	9.8	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
18	25-Oct-1999	585576	6119835	7.1	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
19	25-Oct-1999	585570	6119805	6.0	*Posidonia sinuosa*	High (75-100%)	High (75-100%)
20	25-Oct-1999	585515	6119712	2.6	Algae	not applicable	not applicable
21	25-Oct-1999	585497	6119756	3.3	Bare sand	not applicable	not applicable

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
22	25-Oct-1999	585594	6119671	2.9	Algae	not applicable	not applicable
23	25-Oct-1999	585712	6119643	5.0	*Posidonia sinuosa*	Low (25-50%)	Moderate (50-75%)
24	25-Oct-1999	585800	6119660	5.7	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
25	25-Oct-1999	585913	6119644	5.8	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
26	25-Oct-1999	586005	6119650	8.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
27	25-Oct-1999	586110	6119643	12.0	Algae	not applicable	not applicable
28	25-Oct-1999	586212	6119661	10.0	Algae	not applicable	not applicable
29	25-Oct-1999	586332	6119664	12.0	Algae	not applicable	not applicable
32	25-Oct-1999	586311	6119740	14.0	*Posidonia sinuosa*	Sparse (5-25%)	Very low (< 25%)
33	25-Oct-1999	586208	6119750	13.0	*Posidonia sinuosa* and *Halophila* spp.	Sparse (5-25%)	Low (25-50%)
34	25-Oct-1999	586090	6119772	12.5	*Halophila* spp.	Sparse (5-25%)	Low (25-50%)
35	25-Oct-1999	586015	6119757	12.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)
36	25-Oct-1999	585903	6119754	8.2	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
37	25-Oct-1999	585808	6119752	8.2	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
38	25-Oct-1999	585704	6119763	6.5	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
39	25-Oct-1999	585606	6119758	5.3	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
40	25-Oct-1999	585508	6119857	5.2	Algae	not applicable	not applicable
41	25-Oct-1999	585600	6119844	8.4	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
42	25-Oct-1999	585697	6119862	10.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
43	25-Oct-1999	585823	6119820	11.5	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
44	25-Oct-1999	585924	6119868	12.0	*Halophila* spp.	Low (25-50%)	Very low (< 25%)
45	25-Oct-1999	586016	6119862	11.5	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
46	25-Oct-1999	586111	6119865	13.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
47	25-Oct-1999	586207	6119866	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
48	25-Oct-1999	586312	6119850	14.5	*Posidonia sinuosa*	High (75-100%)	Very low (< 25%)
49	25-Oct-1999	586395	6119839	15.0	*Halophila* spp.	Trace (< 5%)	Very low (< 25%)
50	25-Oct-1999	586414	6119951	16.0	*Halophila* spp.	Trace (< 5%)	Very low (< 25%)
51	25-Oct-1999	586307	6119964	15.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Very low (< 25%)
52	25-Oct-1999	586224	6119951	14.0	*Halophila* spp.	Moderate (50-75%)	Low (25-50%)
53	25-Oct-1999	586094	6119955	14.0	*Posidonia sinuosa*	Low (25-50%)	Very low (< 25%)
54	25-Oct-1999	585987	6119939	13.0	*Halophila* spp.	Moderate (50-75%)	Very low (< 25%)
55	25-Oct-1999	585910	6119954	12.0	*Posidonia sinuosa* and *Halophila* spp.	Low (25-50%)	Low (25-50%)
56	25-Oct-1999	585795	6119936	11.0	*Halophila* spp.	Sparse (5-25%)	Very low (< 25%)
57	25-Oct-1999	585717	6119955	12.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
58	25-Oct-1999	585596	6119936	12.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
59	25-Oct-1999	585506	6120058	7.7	Algae	not applicable	not applicable
60	25-Oct-1999	585505	6120057	11.0	Bare sand	not applicable	not applicable
61	25-Oct-1999	585606	6120062	10.0	*Halophila* spp.	Trace (< 5%)	Very low (< 25%)
62	25-Oct-1999	585684	6120057	10.0	*Halophila* spp.	Low (25-50%)	Low (25-50%)
63	25-Oct-1999	585815	6120050	10.5	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Moderate (50-75%)
64	25-Oct-1999	585896	6120051	12.0	*Posidonia sinuosa* and *Halophila* spp.	Low (25-50%)	Low (25-50%)
65	25-Oct-1999	586018	6120048	13.0	Bare sand	not applicable	not applicable
66	25-Oct-1999	586123	6120056	14.0	*Posidonia sinuosa*	Low (25-50%)	Low (25-50%)
67	25-Oct-1999	586240	6120060	15.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Very low (< 25%)

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
68	26-Oct-1999	586418	6120128	15.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
69	26-Oct-1999	586299	6120140	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Moderate (50-75%)
70	26-Oct-1999	586188	6120139	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Moderate (50-75%)
71	26-Oct-1999	586103	6120143	14.0	*Halophila* spp.	Low (25-50%)	Moderate (50-75%)
72	26-Oct-1999	586128	6120116	13.5	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
73	26-Oct-1999	586007	6120144	12.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
74	26-Oct-1999	585914	6120146	11.0	Mixed large and small seagrass assemblage	High (75-100%)	Moderate (50-75%)
75	26-Oct-1999	585811	6120140	10.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)
76	26-Oct-1999	585715	6120143	9.7	*Halophila* spp.	High (75-100%)	Low (25-50%)
77	26-Oct-1999	585598	6120136	9.5	Mixed large and small seagrass assemblage	Sparse (5-25%)	Very low (< 25%)
78	26-Oct-1999	585505	6120138	10.5	Mixed large and small seagrass assemblage	High (75-100%)	Low (25-50%)
79	26-Oct-1999	585405	6120151	11.0	*Posidonia sinuosa*	Low (25-50%)	Low (25-50%)
80	26-Oct-1999	585311	6120132	10.0	*Heterozostera tasmanica*	Moderate (50-75%)	Low (25-50%)
81	26-Oct-1999	585302	6120234	9.5	*Heterozostera tasmanica*	Trace (< 5%)	Very low (< 25%)
82	26-Oct-1999	585409	6120250	9.5	Mixed *Halophila* spp. and *Heterozostera tasmanica*	High (75-100%)	Moderate (50-75%)
83	26-Oct-1999	585504	6120250	9.5	*Posidonia sinuosa* and *Halophila* spp.	Low (25-50%)	Low (25-50%)
84	26-Oct-1999	585595	6120242	11.0	*Halophila* spp.	High (75-100%)	Low (25-50%)
85	26-Oct-1999	585691	6120249	13.0	Mixed *Halophila* spp. and *Heterozostera tasmanica*	Moderate (50-75%)	Moderate (50-75%)
86	26-Oct-1999	585803	6120259	13.5	*Posidonia sinuosa* and *Halophila* spp.	Low (25-50%)	Low (25-50%)

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
87	26-Oct-1999	585913	6120254	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
88	26-Oct-1999	586007	6120252	14.0	*Posidonia sinuosa*	Moderate (50-75%)	Low (25-50%)
89	26-Oct-1999	586095	6120254	15.0	*Halophila* spp.	High (75-100%)	Low (25-50%)
90	26-Oct-1999	586205	6120236	14.5	*Halophila* spp.	High (75-100%)	Low (25-50%)
91	26-Oct-1999	586293	6120258	15.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
92	26-Oct-1999	586412	6120248	15.0	*Posidonia sinuosa*	Moderate (50-75%)	Low (25-50%)
93	26-Oct-1999	586396	6120348	14.5	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
94	26-Oct-1999	586312	6120337	14.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Very low (< 25%)
95	26-Oct-1999	586213	6120352	14.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)
96	26-Oct-1999	586110	6120332	14.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Very low (< 25%)
97	26-Oct-1999	585999	6120335	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
98	26-Oct-1999	585912	6120347	13.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
99	26-Oct-1999	585816	6120347	12.5	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
100	26-Oct-1999	585700	6120341	10.0	Mixed large and small seagrass assemblage	High (75-100%)	Moderate (50-75%)
101	26-Oct-1999	585597	6120334	9.5	*Halophila* spp.	Moderate (50-75%)	Very low (< 25%)
102	26-Oct-1999	585510	6120335	9.5	*Halophila* spp.	Low (25-50%)	Low (25-50%)
103	26-Oct-1999	585409	6120338	9.5	Bare sand	not applicable	not applicable
104	26-Oct-1999	585305	6120337	15.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
105	26-Oct-1999	586421	6120539	14.0	*Posidonia sinuosa*	Low (25-50%)	Low (25-50%)
106	26-Oct-1999	586204	6120536	14.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
107	26-Oct-1999	585990	6120543	14.0	*Posidonia sinuosa*	High (75-100%)	Very low (< 25%)

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
108	26-Oct-1999	585816	6120544	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Very low (< 25%)
109	26-Oct-1999	585596	6120525	14.0	*Posidonia sinuosa*	Sparse (5-25%)	Very low (< 25%)
110	26-Oct-1999	585388	6120537	13.5	Algae	not applicable	not applicable
111	26-Oct-1999	585229	6120548	10.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
112	26-Oct-1999	584993	6120540	15.0	Algae	not applicable	not applicable
113	26-Oct-1999	584989	6120745	15.0	Bare sand	not applicable	not applicable
114	26-Oct-1999	585197	6120758	15.0	*Posidonia sinuosa*	Trace (< 5%)	Very low (< 25%)
115	26-Oct-1999	585399	6120749	15.0	Bare sand	not applicable	not applicable
116	26-Oct-1999	585606	6120764	15.0	Bare sand	not applicable	not applicable
117	26-Oct-1999	585795	6120748	15.0	Bare sand	not applicable	not applicable
118	26-Oct-1999	586005	6120759	15.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
119	26-Oct-1999	586191	6120757	13.0	*Posidonia sinuosa*	Moderate (50-75%)	Low (25-50%)
120	26-Oct-1999	586401	6120780	13.0	Bare sand	not applicable	not applicable
121	26-Oct-1999	586379	6120964	13.0	Bare sand	not applicable	not applicable
122	26-Oct-1999	586217	6120955	14.0	*Posidonia sinuosa*	High (75-100%)	Very low (< 25%)
123	26-Oct-1999	586006	6120951	15.0	Bare sand	not applicable	not applicable
124	26-Oct-1999	585792	6120960	15.0	Bare sand	not applicable	not applicable
125	26-Oct-1999	585594	6120928	15.0	Bare sand	not applicable	not applicable
126	26-Oct-1999	585407	6120944	15.0	Bare sand	not applicable	not applicable
127	26-Oct-1999	585198	6120971	16.0	Bare sand	not applicable	not applicable
128	26-Oct-1999	584991	6120940	5.2	Algae	not applicable	not applicable
129	26-Oct-1999	585334	6120063	3.0	Algae	not applicable	not applicable
130	26-Oct-1999	585358	6120015	3.2	Algae	not applicable	not applicable

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
131	26-Oct-1999	585447	6119888	11.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Very low (< 25%)
132	26-Oct-1999	585722	6119159	11.0	Mixed large and small seagrass assemblage	Low (25-50%)	Very low (< 25%)
133	26-Oct-1999	585791	6119152	12.5	Mixed large and small seagrass assemblage	High (75-100%)	Low (25-50%)
134	26-Oct-1999	585913	6119148	15.0	*Posidonia sinuosa*	Moderate (50-75%)	Low (25-50%)
135	26-Oct-1999	586017	6119146	15.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
136	26-Oct-1999	586128	6119160	17.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)
137	26-Oct-1999	586200	6119168	18.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Moderate (50-75%)
138	26-Oct-1999	586323	6119160	18.5	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
139	26-Oct-1999	586413	6119158	18.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
140	26-Oct-1999	586374	6119034	18.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Moderate (50-75%)
141	26-Oct-1999	586311	6119062	18.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)
142	26-Oct-1999	586319	6119069	16.0	*Posidonia sinuosa*	Low (25-50%)	Moderate (50-75%)
143	26-Oct-1999	586099	6119071	14.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)
144	26-Oct-1999	585999	6119067	12.0	Mixed large and small seagrass assemblage	Moderate (50-75%)	Low (25-50%)
145	26-Oct-1999	585899	6119056	12.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
146	26-Oct-1999	585849	6119034	12.0	Mixed *Halophila* spp. and *Heterozostera tasmanica*	High (75-100%)	Low (25-50%)
147	26-Oct-1999	585704	6119052	10.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Moderate (50-75%)
148	26-Oct-1999	585601	6119052	9.7	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)
149	26-Oct-1999	585488	6119062	8.8	*Posidonia sinuosa*	Moderate (50-75%)	Moderate (50-75%)

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
150	26-Oct-1999	585418	6119040	7.5	Bare sand	not applicable	not applicable
151	26-Oct-1999	585295	6119061	7.0	*Posidonia sinuosa*	Low (25-50%)	Low (25-50%)
152	26-Oct-1999	585401	6118962	9.3	Mixed large and small seagrass assemblage	Moderate (50-75%)	Low (25-50%)
153	26-Oct-1999	585401	6118965	10.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Moderate (50-75%)
154	26-Oct-1999	585512	6118956	10.0	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)
155	26-Oct-1999	585601	6118946	12.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
156	26-Oct-1999	585796	6118962	13.5	*Halophila* spp.	High (75-100%)	Low (25-50%)
157	26-Oct-1999	585897	6118949	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Moderate (50-75%)
158	27-Oct-1999	586119	6118947	17.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
159	27-Oct-1999	586215	6118939	17.5	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
160	27-Oct-1999	586301	6118956	18.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
161	27-Oct-1999	586425	6118950	19.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
162	27-Oct-1999	585494	6118753	8.0	Mixed large and small seagrass assemblage	Moderate (50-75%)	Low (25-50%)
163	27-Oct-1999	585491	6118755	9.3	*Halophila* spp.	High (75-100%)	Low (25-50%)
164	27-Oct-1999	585704	6118741	11.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
165	27-Oct-1999	585910	6118748	14.0	*Posidonia sinuosa*	Low (25-50%)	Low (25-50%)
166	27-Oct-1999	586106	6118748	17.0	*Posidonia sinuosa*	High (75-100%)	Very low (< 25%)
167	27-Oct-1999	586316	6118541	19.5	*Halophila* spp.	High (75-100%)	Low (25-50%)
168	27-Oct-1999	586319	6118541	20.0	*Halophila* spp.	High (75-100%)	Low (25-50%)
169	27-Oct-1999	586098	6118536	18.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
170	27-Oct-1999	585913	6118546	15.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
171	27-Oct-1999	585698	6118551	11.5	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
172	27-Oct-1999	585515	6118542	9.8	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Very low (< 25%)
173	27-Oct-1999	585206	6118351	8.3	Bare sand	not applicable	not applicable
174	27-Oct-1999	585207	6118350	6.1	Bare sand	not applicable	not applicable
175	27-Oct-1999	585207	6118349	5.4	Bare sand	not applicable	not applicable
176	27-Oct-1999	585406	6118356	8.4	Mixed large and small seagrass assemblage	Moderate (50-75%)	Low (25-50%)
177	27-Oct-1999	585614	6118359	11.5	Mixed large and small seagrass assemblage	Low (25-50%)	Very low (< 25%)
178	27-Oct-1999	585805	6118349	14.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
179	27-Oct-1999	586011	6118365	17.0	*Halophila* spp.	High (75-100%)	Very low (< 25%)
180	27-Oct-1999	586199	6118354	18.5	*Posidonia sinuosa*	High (75-100%)	Very low (< 25%)
181	27-Oct-1999	586394	6118346	20.5	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Very low (< 25%)
182	27-Oct-1999	586407	6118137	20.0	*Halophila* spp.	High (75-100%)	Low (25-50%)
183	27-Oct-1999	586205	6118156	19.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
184	27-Oct-1999	586022	6118149	17.5	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Very low (< 25%)
185	27-Oct-1999	585802	6118139	15.0	Mixed large and small seagrass assemblage	High (75-100%)	Very low (< 25%)
186	27-Oct-1999	585609	6118146	12.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
187	27-Oct-1999	585394	6118147	8.7	*Posidonia sinuosa*	Moderate (50-75%)	Low (25-50%)
188	27-Oct-1999	585208	6118154	6.3	Bare sand	not applicable	not applicable
189	27-Oct-1999	585214	6118213	6.3	Bare sand	not applicable	not applicable
190	27-Oct-1999	585278	6118222	7.2	Bare sand	not applicable	not applicable

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
191	27-Oct-1999	585343	6118233	8.1	Mixed large and small seagrass assemblage	High (75-100%)	Moderate (50-75%)
192	27-Oct-1999	585395	6118301	9.2	Mixed *Halophila* spp. and *Heterozostera tasmanica*	Moderate (50-75%)	Low (25-50%)
193	27-Oct-1999	585435	6118348	9.9	Mixed large and small seagrass assemblage	Moderate (50-75%)	Low (25-50%)
194	27-Oct-1999	585495	6118392	9.8	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
195	27-Oct-1999	585549	6118439	11.0	Mixed large and small seagrass assemblage	High (75-100%)	Low (25-50%)
196	27-Oct-1999	585600	6118492	12.0	*Posidonia sinuosa*	Low (25-50%)	Moderate (50-75%)
197	27-Oct-1999	585655	6118535	11.5	Mixed large and small seagrass assemblage	High (75-100%)	Low (25-50%)
198	27-Oct-1999	585698	6118596	12.5	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
199	27-Oct-1999	585753	6118656	12.5	Mixed large and small seagrass assemblage	Moderate (50-75%)	Low (25-50%)
200	27-Oct-1999	585785	6118723	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
201	27-Oct-1999	585839	6118766	14.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
202	27-Oct-1999	585903	6118806	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
203	27-Oct-1999	585941	6118872	14.0	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
204	27-Oct-1999	586001	6118949	14.0	*Posidonia sinuosa* and *Halophila* spp.	High (75-100%)	Low (25-50%)
205	27-Oct-1999	586367	6119436	11.0	Algae	not applicable	not applicable
206	27-Oct-1999	586623	6119519	15.0	Algae	not applicable	not applicable
207	27-Oct-1999	586970	6119667	20.0	Bare sand	not applicable	not applicable
208	27-Oct-1999	585742	6119685	5.2	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
209	27-Oct-1999	585861	6119806	9.6	*Halophila* spp.	Sparse (5-25%)	Very low (< 25%)
210	27-Oct-1999	585648	6120038	10.0	*Posidonia sinuosa* and *Halophila* spp.	Low (25-50%)	Low (25-50%)
211	27-Oct-1999	585640	6120173	9.8	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
212	27-Oct-1999	585687	6120225	10.5	*Posidonia sinuosa* and *Halophila* spp.	Moderate (50-75%)	Very low (< 25%)
213	27-Oct-1999	585385	6120548	13.0	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
214	27-Oct-1999	585217	6120493	11.0	*Halophila* spp.	Sparse (5-25%)	Very low (< 25%)
215	27-Oct-1999	585216	6120384	10.0	*Heterozostera tasmanica*	Sparse (5-25%)	Very low (< 25%)
216	27-Oct-1999	585169	6120282	11.0	Bare sand	not applicable	not applicable
217	27-Oct-1999	585028	6120231	7.5	*Posidonia sinuosa*	Moderate (50-75%)	Moderate (50-75%)
218	4-Feb-2000	585662	6121318	not recorded	*Posidonia ostenfeldii* group and *Halophila* spp.	Moderate (50-75%)	Low (25-50%)
219	4-Feb-2000	585607	6121162	not recorded	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
220	4-Feb-2000	585865	6121055	not recorded	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
222	4-Feb-2000	586102	6120933	not recorded	Algae	not applicable	not applicable
223	4-Feb-2000	586203	6120763	not recorded	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
224	4-Feb-2000	586287	6120574	not recorded	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
225	4-Feb-2000	586385	6120278	not recorded	*Halophila* spp.	Moderate (50-75%)	Low (25-50%)
226	4-Feb-2000	585505	6120541	not recorded	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
227	4-Feb-2000	585716	6120639	not recorded	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
228	4-Feb-2000	585158	6120413	not recorded	*Halophila* spp.	High (75-100%)	Moderate (50-75%)
229	4-Feb-2000	585127	6120543	not recorded	*Posidonia sinuosa*	Moderate (50-75%)	Low (25-50%)
230	4-Feb-2000	585444	6120003	not recorded	Algae	not applicable	not applicable
231	4-Feb-2000	585812	6119764	not recorded	*Posidonia sinuosa*	High (75-100%)	High (75-100%)

Station	Date	Easting	Northing	Depth	Habitat Category	Seagrass cover class (%)	Seagrass density class (%)
233	4-Feb-2000	585485	6119382	not recorded	*Posidonia sinuosa*	High (75-100%)	High (75-100%)
234	4-Feb-2000	585540	6119225	not recorded	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
235	4-Feb-2000	585362	6118792	not recorded	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
236	4-Feb-2000	585327	6118510	not recorded	Bare sand	not applicable	not applicable
237	4-Feb-2000	585292	6118133	not recorded	Bare sand	not applicable	not applicable
238	4-Feb-2000	585370	6118341	not recorded	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
239	4-Feb-2000	585248	6117940	not recorded	Bare sand	not applicable	not applicable
240	4-Feb-2000	585531	6117979	not recorded	*Posidonia sinuosa*	High (75-100%)	Moderate (50-75%)
243	4-Feb-2000	586581	6120151	not recorded	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)
244	4-Feb-2000	586601	6119900	not recorded	Bare sand	not applicable	not applicable
245	4-Feb-2000	586548	6119457	not recorded	*Posidonia* ostenfeldii complex	High (75-100%)	Low (25-50%)
246	4-Feb-2000	585480	6119267	not recorded	*Posidonia sinuosa*	High (75-100%)	Low (25-50%)

Attachment 2
Sample wind files used to represent each of the major synoptic wind patterns

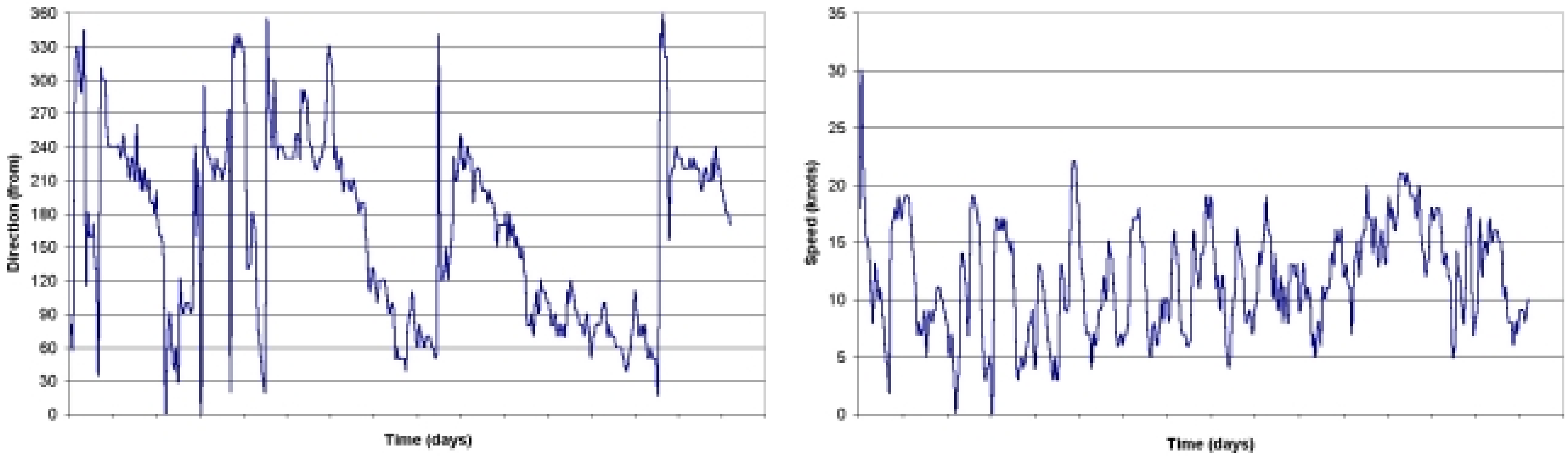
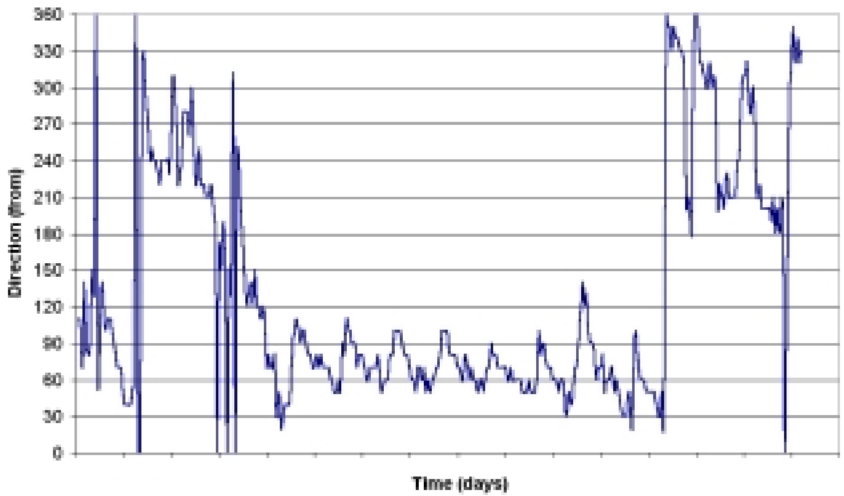


Figure A2.1: Variation in the speed and direction of winds during February 1994, used to represent a Group 1 wind pattern



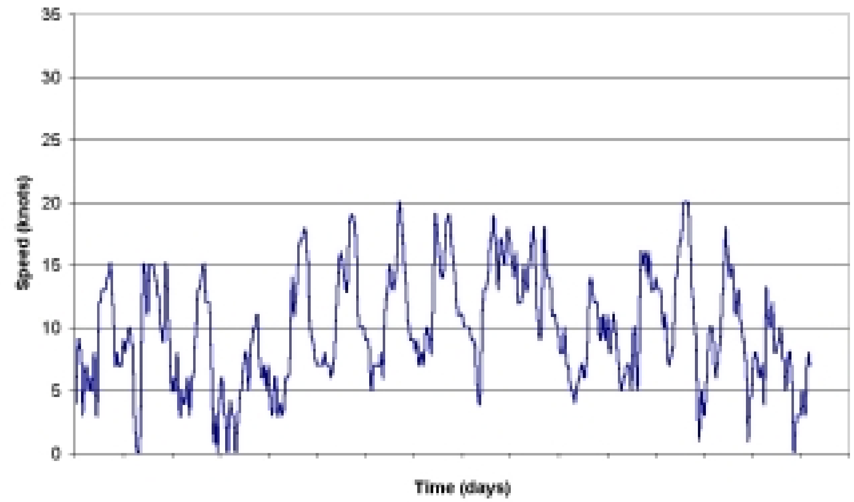


Figure A2.2: Variation in the speed and direction of winds during April 1995, used to represent a Group 2 wind pattern

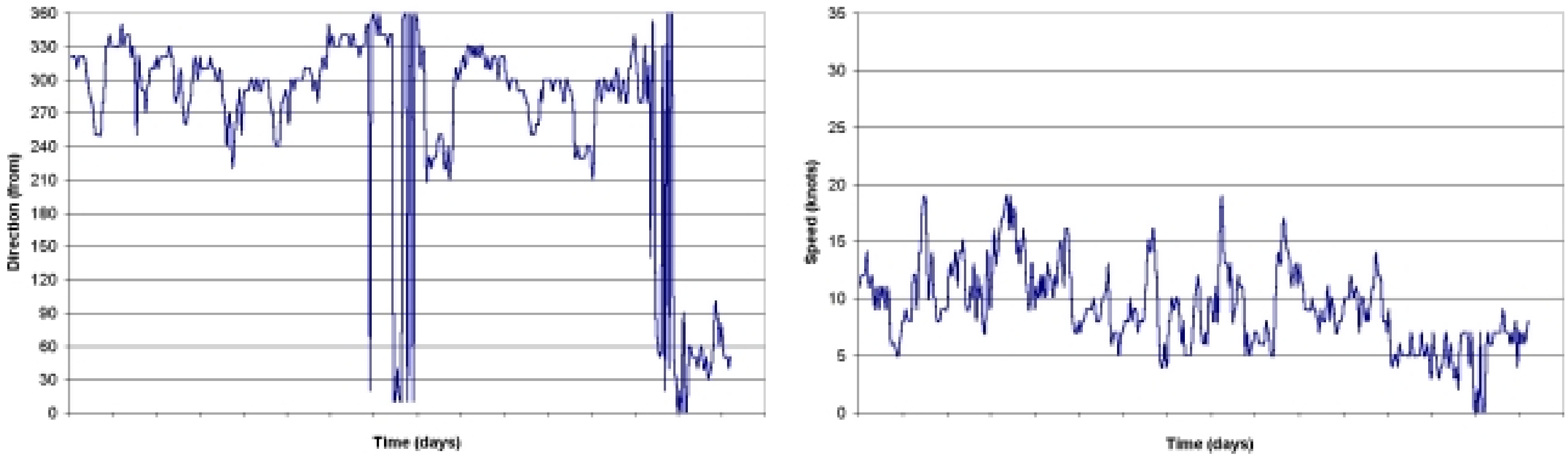
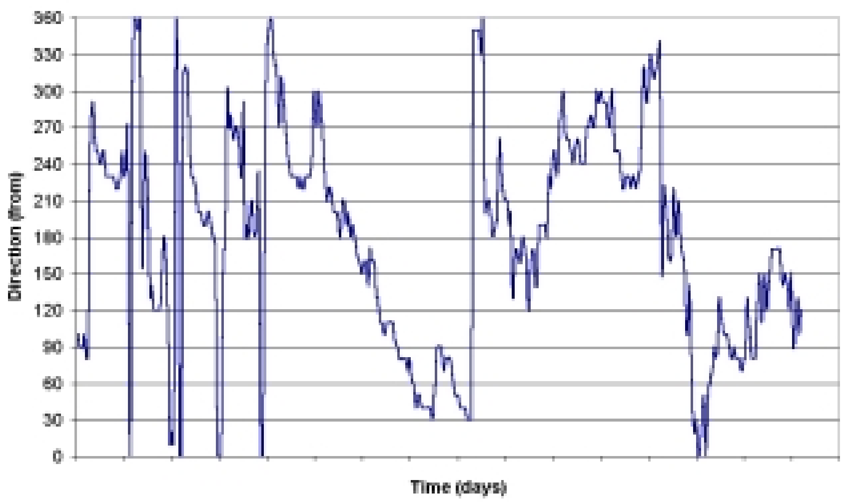


Figure A2.3: Variation in the speed and direction of winds during June 1997, used to represent a Group 3 wind pattern



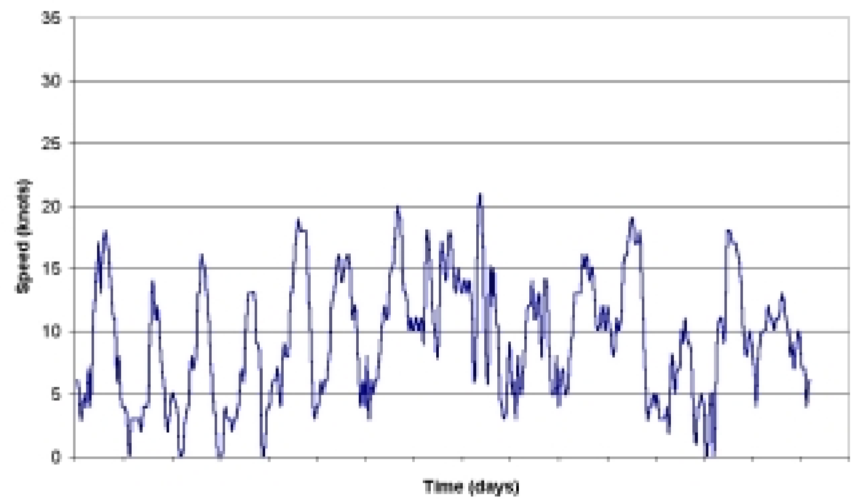


Figure A2.4: Variation in the speed and direction of winds during December 1994, used to represent a Group 4 wind pattern

APPENDICES

Appendix 1 Intellectual Property

Intellectual Property = Nil

Appendix 2: Staff

STAFF

Bastyan, Geoff

Black, Anthony

Brookes, Kim

Chaplin, Shane

Gordon, David

Hubbard, Graham

Jernakoff, Peter

Jolly, Peter

Langtry, Scott

Nielsen, John

Phillips, Rob

Wyllie, Alex