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Standing Crop and Nutrient Content of Macrophytes in Port Phillip Bay

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EXECUTIVE SUMMARY

The objectives of the investigation of benthic macroalgae of Port Phillip Bay were to determine the spatial and temporal variation in taxonomic composition and biomass of major macroalgal assemblages in the north part of the Bay, and to document the nitrogen content of abundant macroalgae in the north of the Bay. In addition to measurement of biomass and nutrient content, the relationship between macroalgal biomass and seabed cover was examined. The standing crop and associated nutrient pool of macroalgae in the north of Port Phillip Bay was estimated.

Macroalgal assemblages were surveyed at five locations in Port Phillip Bay on four occasions at 4, 6, 8 and 10 m depths from 1995 to 1996. The five locations were Kirk Point and Wedge Point adjacent to the Western Treatment Plant at Werribee, Altona Bay southwest of the mouth of the Yarra River, Green Point at Brighton, and Aspendale two kilometres southeast of Mordialloc Creek.

The investigations found large quantities of benthic macroalgae (seaweeds) growing on the sandy and silty seabeds in the north of Port Phillip Bay from 4 m to 10 m water depth. Macroalgae were particularly abundant along the northwest side of the Bay where predominantly unattached red algal species at times blanketed more than 90 percent of the soft seabed in patches 10s to 100s metres long. The biomass offshore from Altona and Werribee is often above 200 g/m^2 and exceeds 4,000 g/m^2 on occasion. Biomass was lower at Brighton and Aspendale where most macroalgae were attached to the cunjevoi, *Pyura stolonifera*, which grows in the sand and silt.

In the northern parts of the Bay from Werribee to Aspendale, the total standing stock of macroalgae during the four surveys was estimated as 110,000 tonnes, 120,000 tonnes, 130,000 tonnes and 240,000 tonnes. The corresponding range in nutrient content was 210 tonnes to 1,000 tonnes of nitrogen, and 10 tonnes to 144 tonnes of phosphorus. The distribution of high macroalgal biomass from Wedge Point to Altona correlates with the transport path of nutrients from the Western Treatment Plant, and Werribee River towards Altona in the Bay's clockwise water circulation pattern.

The thick macroalgal blankets are likely to have a significant influence on the cycling of nutrients between the water column and seabed. The macroalgal blankets may not only cover or exclude microphytobenthos, they may also incorporate nitrogen which would otherwise be used by the microphytobenthos. The nitrogen associated with the macroalgae may not be as readily incorporated into sediments as the nitrogen in plankton. Hence, denitrification may be reduced in areas of dense macroalgal growth.

Although relationship between macroalgal biomass and seabed cover was established, the relationship is asymptotic and accurate predictions of biomass at high macroalgal cover cannot be made. The relationship also varied between sites and surveys. These limitations on prediction of macroalgal biomass from cover mean that the standing crop of macroalgae in the Bay cannot be accurately estimated from macroalgal cover from remote sensing images. At this stage, therefore, standing crop and nutrient pools can only be estimated from physical sampling of macroalgal assemblages.

There is a substantial reduction in standing crop and a change in macroalgal assemblage composition southeast of the Yarra River. In contrast, diatom populations are considerably higher in abundance from the Yarra River mouth to the south east than they are from Altona to the Werribee region (Harris *et al* 1996). Silica, other micronutrients and turbidity in Yarra River may favour the growth of diatoms (which require silica for their skeleton) down the eastern side of the Bay rather than benthic macroalgae. Different wave climates on the east and west sides of the Bay may also be a factor influencing plant growth at shallow sites.

It is speculated that higher loads of nutrients may increase the standing crop and seabed cover of these red macroalgal assemblages. This in turn could decrease denitrification processes in the seabed resulting in higher nitrogen pools in the Bay. Increased macroalgal growth also could result in increased amounts of macroalgae on beaches, anaerobic seabed conditions, and significant changes to seabed ecology.

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1. INTRODUCTION

1.1. Background

A major objective of the Port Phillip Bay Environmental Study was to establish the status, fate and distribution of nutrients in the Bay (CSIRO 1992). Particular attention was to be given to the discharge of nutrients from the Western Treatment Plant and major freshwater inputs such as the Yarra River, Werribee River and Mordialloc Creek (Figure 1).

Human activities around Port Phillip Bay contribute substantial amounts of nutrients to the Bay, and nutrient inputs to the Bay are likely to increase as the population increases and the urban area expands. Increased nutrient loads may stimulate marine plant growth including both seaweeds and phytoplankton. Excessive growth of seaweeds (macroalgae) may cause accumulation of organic material on the seabed and beaches, and result in degradation of the Bay's environmental condition.

The Port Phillip Bay Environmental Study was planned to produce a series of numerical models to be used in Bay management. The proposed models culminate in an integrated ecological model concerned primarily with the mass fluxes of nitrogen in the Bay (Harris *et al* 1996).

The Bay's water column, phytoplankton, microphytobenthos and sediments were recognised early in the Study as significant pools and processors of organic and inorganic nutrients in the Bay (Skyring *et al* 1992). These components were the focus of intensive investigation during the four years of the Study. Benthic macroalgae (seaweeds) and seagrasses also were identified as possible significant pools of nutrients, and a comprehensive review of information on the benthic flora of Port Phillip Bay was undertaken (Light and Woelkerling 1992). While attached macroalgal communities were considered to be limited to small areas of reef (Skyring *et al* 1992), large quantities of unattached seaweeds had been reported in previous studies offshore from the Western Treatment Plant, Altona and north eastern Bay beaches (Brown *et al* 1980, Brown and Davies 1986, Spencer 1970 and 1972). However, the spatial extent, composition, biomass, productivity and nutrient content of these unattached assemblages was unknown. Hence, an investigation was required to provide data on the biomass and nutrient content of major macroalgal assemblages in the Bay for the Port Phillip Bay nutrient model.

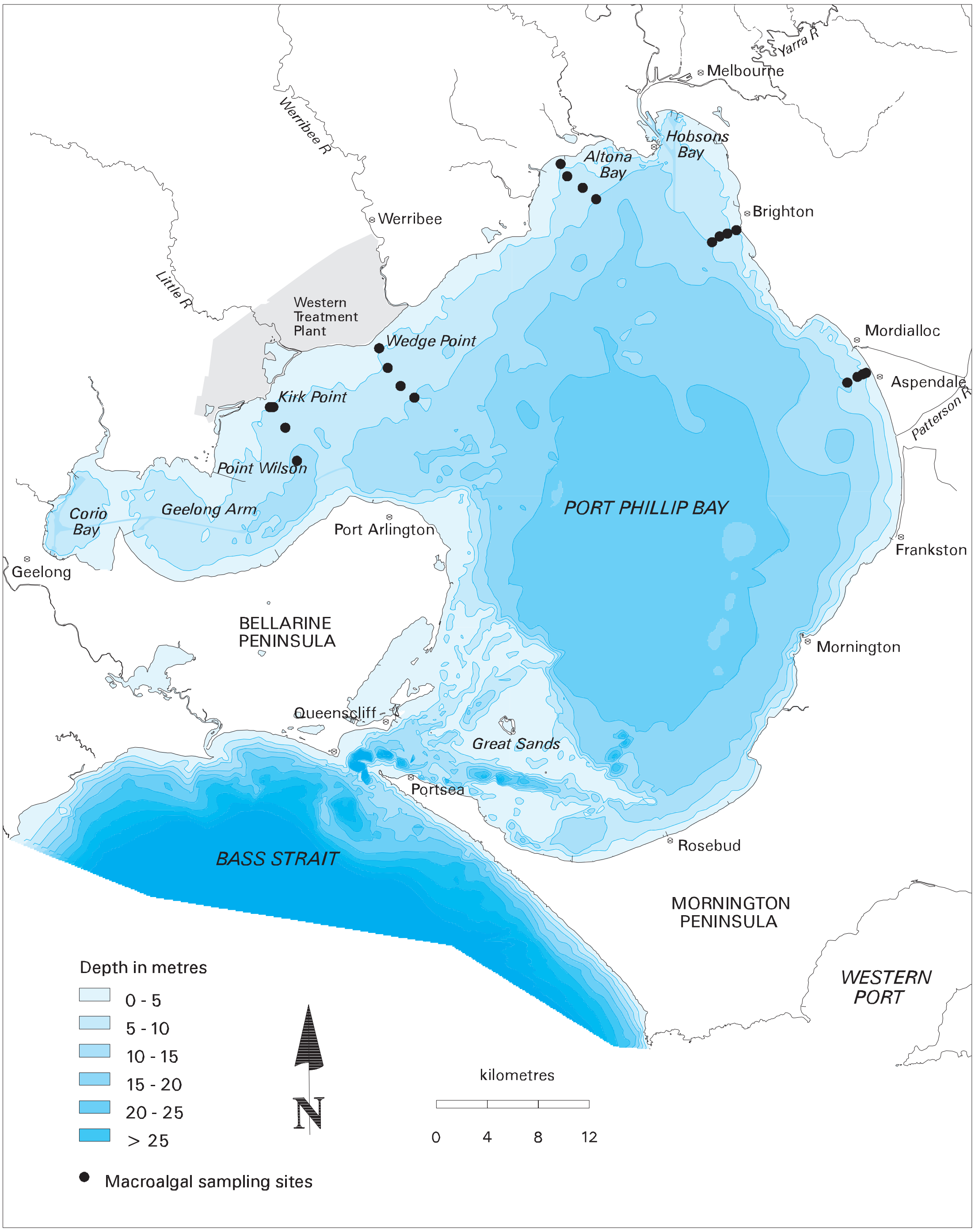


Figure 1: Port Phillip Bay locations and macroalgal sampling sites

1.2. Objectives

Consulting Environmental Engineers (CEE Pty Ltd) was commissioned by the Port Phillip Bay Environmental Study to carry out the investigation of benthic macroalgae. The purpose of the investigation was to provide information for direct input to the integrated ecological model, and further our understanding of macroalgal ecology in the Bay.

The objectives of the investigation were to determine:

- the spatial and temporal variation in composition and biomass of major macroalgal assemblages in the north of the Bay; and,
- the spatial and temporal variation in nitrogen content of abundant macroalgae in the north of the Bay.

1.3. Scope of Work

The scope of work for the investigation was to:

- document the general taxonomic composition of major macroalgal assemblages at four depths at five locations in the north of the Bay on four survey occasions;
- determine the mean biomass of the assemblages at each depth site on each survey;
- examine the spatial variability in biomass and composition of the assemblages;
- measure the nitrogen and phosphorus content of dominant components of the assemblages at each depth site on each survey;
- examine the relationship between macrophyte cover and biomass to facilitate assessment of standing crop by remote sensing;
- examine the relationship between biomass and nutrient pools; and
- determine the influence of assemblage structure, and the related factors of location, depth and time of year, on these relationships.

2. METHODS

2.1. Description of Study Sites

Only the major macroalgal assemblages of the Bay could be examined in the time available. They were those which may be influenced by the discharge from the Western Treatment Plant and major freshwater inputs such as the Yarra River, Werribee River and Mordialloc Creek (Figure 1). Five study locations selected for investigation were offshore from:

- Kirk Point - on the southwest coast of the Western Treatment Plant;
- Wedge Point - on the northeast coast of the Western Treatment Plant;
- Altona Bay - 18 km northeast of the Western Treatment Plant, 6 km southwest of the mouth of the Yarra River and adjacent to the Altona Treatment Plant;
- Green Point, Brighton - 6 km southeast of the mouth of the Yarra River and directly opposite Altona Bay; and
- Aspendale - 24 km southeast of the mouth of the Yarra River and 2 km southeast of Mordialloc Creek.

Four sites were sampled at each location, on the 4, 6, 8 and 10 depth contours (Fig. 1). The 12m depth was also examined at Wedge Point, Brighton and Aspendale during the first survey.

All sites, except the Kirk Point 4m depth, were composed of sand at the shallower sites grading to silt at the deeper sites. The Kirk Point 4m depth consisted of low relief basalt reef interspersed with patches of sand and shellgrit. Small outcrops of rock were also present at the Altona Bay 4m depth, but were sparsely distributed.

The solitary ascidian *Pyura stolonifera* was common at all sites, and was particularly abundant between the 6 and 8m depths. Scallops *Pecten fumatus* and clumps of mussels *Mytilus edulis planulatus* also were common. The introduced tube worm *Sabella spallanzanii* was common at Kirk Point, Wedge Point and Altona (west of the River Yarra), and was usually present in clumps attached to *P. stolonifera*, algae and pieces of shell. *Sabella spallanzanii* was not observed at the Aspendale sites, but several individuals were observed at the Brighton 6, 8 and 10m depths.

2.2. Field Sampling Methods

The sites were examined over four periods: March to June 1995; September to October 1995; December to January 1995/96; and March 1996 (Table 1). The sample times were limited by periods of poor weather and low underwater visibility. The Wedge Point 10m depth and all Kirk Point sites could not be sampled during the second survey period for these reasons.

Table 1. Macroalgal sampling dates

Location	Depth	Survey 1	Survey 2	Survey 3	Survey 4
Kirk Point	4 m	31-5-95	*	15-12-95	12-3-96
	6 m	23-5-95	*	15-12-95	12-3-96
	8 m	23-5-95	*	15-12-95	12-3-96
	10 m	23-5-95	*	15-12-95	12-3-96
Wedge Point	4 m	31-5-95	9-10-95	14-12-95	12-3-96
	6 m	16-3-95	9-10-95	14-12-95	12-3-96
	8 m	16-3-95	9-10-95	14-12-95	12-3-96
	10 m	17-3-95	*	14-12-95	12-3-96
	12 m	17-3-95			
Altona Bay	4 m	31-5-95	15-9-95	13-12-95	4-3-96
	6 m	11-5-95	12-9-95	13-12-95	4-3-96
	8 m	11-5-95	12-9-95	13-12-95	4-3-96
	10 m	11-5-95	12-9-95	13-12-95	4-3-96
Brighton	4 m	10-5-95	29-9-95	8-1-96	5-3-96
	6 m	10-5-95	29-9-95	8-1-96	5-3-96
	8 m	10-5-95	29-9-95	8-1-96	5-3-96
	10 m	9-5-95	29-9-95	8-1-96	5-3-96
	12 m	9-5-95			
Aspendale	6 m	2-6-95	27-9-95	9-1-96	5-3-96
	8 m	2-6-95	27-9-95	9-1-96	5-3-96
	10 m	2-6-95	27-9-95	9-1-96	5-3-96
	12 m	2-6-95			5-3-96

Note: An asterix denotes times not sampled because of poor weather and visibility.

At each site, a 100m transect was deployed on the seabed along the depth contour (parallel to the shore), and a video record of the macroalgae along the transect line was taken by divers. Point-intercept estimates of algal cover were made using a 3m long pole marked with 15 points at 20cm intervals. The pole was placed transversely across the transect at 5m intervals. The algal group or animal under each point was recorded.

A 1 m² quadrat frame was placed beside the transect line at 10 m intervals, and photographed. All algae within each quadrat were harvested and placed in mesh bags for subsequent weighing, taxonomic examination and nutrient content analysis.

The 35mm slides of photographed quadrats were provided to CSIRO at the completion of the task. These slides will be forwarded to the records officer at Melbourne Water's Western Treatment Plant for storage and future reference. CEE Pty Ltd holds the video records of each dive.

2.3. Laboratory Methods

The harvested samples were sorted to species (where possible), weighed and identified. In the case of larger samples, subsamples of approximately 300-500 g were taken for sorting. Many samples contained assemblages of highly entwined fine red algal species, and could not be fully sorted without the samples drying (and influencing the biomass estimates). The dominant species in these highly mixed samples were removed and weighed. The remaining mixture was then weighed as a whole and the species present were identified. These mixed assemblages are referred to as “mixed fine reds”.

Up to ten 50 g samples of the most abundant taxa were analysed for nitrogen and phosphorus content at each site. Samples were weighed before and after desiccation at 80º C for 48 hours. Dried samples were finely ground, and a 0.2 g subsample digested in sulphuric acid and hydrogen peroxide. Nitrogen and phosphorus content of the digest was measured using automated methods (Technicon Autoanalyzer II, Technicon Instruments 1977; Industrial Methods Number 329-74 W/B, Technicon Industrial Systems, Tarrytown, New York).

The cover of algae in each quadrat was estimated by projecting photographs onto a grid of approximately 120 equidistant points, and counting the points covered by algae. Each photograph was assessed at the same magnification. The proportion of cover was taken as the proportion of points covered by algae. This cover proportion was then compared with the harvested yield from the quadrat. Poor visibility from suspended particles and plankton blooms often reduced the quality of the photographs and different taxonomic groups were not easily identifiable. However, the photographs were adequate for the estimation of total macrophyte cover.

The sampling regime was reduced in the third and fourth surveys. Point-intercept and photoquadrat cover estimates, and detailed descriptions of taxonomic composition, were only made for the first two surveys. For the third and fourth surveys, total biomass measurements were taken for the 10 quadrats sampled at each site, but the macroalgal composition was only determined from a minimum of four quadrats (or more where the biomass was low).

3. RESULTS

3.1. Composition of Major Macroalgal Assemblages

Two major macroalgal assemblages were observed during the surveys. One consisted of unattached, predominantly red algal assemblages at sites to the west of the Yarra River, at Altona Bay, Wedge Point and Kirk Point. The other consisted of *Caulerpa* and filamentous red algal assemblages predominantly attached to *Pyura stolonifera*, but also to living mussels and shell debris at sites east of the Yarra River, at Brighton and Aspendale. The macroalgae at the Kirk Point 4m depth were mostly attached to rocks and mussels. The macroalgal assemblage structure was diverse at most sites, and 57 species from 47 genera were identified from the first two survey samples (Table 2).

The unattached algal assemblages at Altona and Wedge Point comprised a diverse, interwoven mixture of red algae, blanketing the substratum in patches that were highly variable in area and density. Large red algae were a prominent component, including *Botryocladia obovata*, *Jeannerettia pedicellata* and *Rhodymenia australis*. *Botryocladia* was a dominant component at deep sites at both locations. *Rhodymenia* was particularly prevalent on one occasion at Wedge Point. The assemblages at Altona Bay and Wedge Point also contained a high proportion of fine red algae, particularly *Polysiphonia* spp, *Laurencia filiformis*, *Brongniartella australis*, *Echinothamnion mallardiae* and *Ceramium* spp. Green algae, including *Caulerpa*, *Ulva*, *Cladophora* were also common but were generally only a small component of the assemblages.

The assemblages at Kirk Point were distinct from Altona and Wedge Point, and were dominated by fine red species such as *Ceramium*, *Polysiphonia* and *Gracilaria*. The green algae *Caulerpa* spp, *Ulva* and *Cladophora* were also common at Kirk Point.

The assemblages at the two eastern locations generally were attached to *Pyura*, which grew in small clumps, approximately 0.3 m across and 1-2 m apart. The algae growing on these clumps comprised either *Caulerpa remotifolia, C. longifolia* or *C. brownii,* with a mixture of fine reds such as *Laurencia* spp, *Polysiphonia* spp, *Ceramium* spp, *Chondria* spp and *Gracilaria cliftoni*. *Botryocladia* was absent from the Brighton and Aspendale locations.

Table 2. Macroalgal taxa identified from first two surveys

Taxon Description	Species	Kirk Pt	Wedge Pt	Altona Bay	Brighton Bay	Aspendale
Seagrass	*Heterozostera tasmanica*	X	X	X	X	X
Green Algae	*Caulerpa brownii*		X	X	X	X
	Caulerpa flexilis		X			
	Caulerpa geminata		X			X
	Caulerpa longifolia	X			X	X
	Caulerpa remotifolia	X	X	X	X	X
	Caulerpa vesiculifera					X
	Ulva laculata		X			
	Ulva rigida		X			
	Ulva sp.	X	X	X		
	Codium herveyi					X
Filamentous Greens	*Chaetomorpha*			X		
	Cladophora bainesii			X		
	Cladophora coelthrix	X	X			X
	Cladophora sp.		X	X		X
	Enteromorpha flexuosa		X			
Kelps	*Ecklonia radiata*		X			
	Sargassum sp.		X	X		
Other Browns	*Dictyota dichotoma*		X	X		X
	Cutleria multifida		X			
Large Reds	*Botryocladia obovata*		X	X		
	Jeannerettia lobata			X		X
	Jeannerettia pedicellata	X	X	X	X	X
	Dictymenia harveyana			X		
	Rhodoglossum proliferum		X	X		
	Rhodymenia australis		X	X	X	X
	Gloiosaccion sp.		X			
	Gracilaria cliftoni		X		X	X
	Hypnea charoides					X
	Hypnea filiformis	X				
	Hypnea ramentacea			X		
	Hypnea valentiae			X		X
	Laurencia botryoides				X	X
	Laurencia filiformis	X	X	X	X	X
	Soliaria tenera		X			
	Soliaria sp.		X	X	X	
Fine Reds	*Acrosaurium venulosum*		X	X	X	X
	Anotrichium sp.		X	X	X	
	Antithamnion divergens	X	X	X	X	X
	Antithamnion gracilentum					X
	Brongniartella australis	X	X	X		X
	Callithamnion sp.			X		X
	Ceramium macilentum	X	X	X	X	X
	Ceramium rubrum		X	X	X	X
	Ceramium isogonium				X	
	Ceramium australe			X		
	Champia zostericola		X		X	X
	Chondria bullosa					X
	Chondria harveyana					X

Table 2 (cont.): Macroalgal taxa identified from first two surveys

Taxon Description	Species	Kirk Pt	Wedge Pt	Altona Bay	Brighton Bay	Aspendale
Fine Reds cont.	*Chondria sp.*		X	X	X	X
	Coeloclonium sp.				X	X
	Crouania shepleyana					X
	Daysia sp. A	X	X	X	X	X
	Daysia sp. B		X			
	Echinothamnion mallardiae		X		X	X
	Falkenbergia sp.		X			
	Gonatogenia subulata		X			
	Griffithsia sp.		X	X		
	Griffithsia teges		X			
	Herposiphonia secunda		X			
	Holotrichia sp.				X	
	Lobospira bicuspidata			X		X
	Lobospira sp.				X	
	Lophothallia verticillata		X			X
	Medeiothamnion protensum		X		X	
	Metathamnion sp.			X		X
	Plocamium coccineum		X	X	X	X
	Plocamium sp.				X	
	Polysiphonia decipiens	X	X	X	X	X
	Polysiphonia scopulorm		X			
	Polysiphonia subtilissima		X	X	X	X
	Polysiphonia teges	X				X
	Polysiphonia sp.		X			
	Pterosiphonia pennata		X	X	X	X
	Spyridia filamentosa					X

3.1.1. Depth Related Changes in Assemblage Composition

General depth-related changes in macroalgal composition were evident at each location. At Kirk Point, the algae at 8 and 10m depths were predominantly fine reds with a small proportion of *Caulerpa remotifolia*. The proportion of *C. remotifolia* was generally higher at the 6 m depth, where other algae such as *Ulva, Jeannerettia* and *Rhodoglossum* were also more prevalent (Fig. 2a). The 4m Kirk Point depth had a mixture of rocky and sandy substrata, and the flora consisted of *Ulva* attached to the rocks and fine algae such as *Polysiphonia* and *Anotrichium* attached to rocks, *Pyura* and the tubes of sabellid worms.

At both Wedge Point and Altona Bay, the 8 and 10m depths were generally dominated by *Botryocladia*. Mixed fine reds, *Jeannerettia* and *Caulerpa remotifolia* were also common at the deeper sites, but in relatively low densities. The proportion of *Botryocladia* tended to decline with decreased depth. Mixed fine reds, *Jeannerettia, Rhodymenia* and *Caulerpa remotifolia* were dominant in shallower water, depending on the site and survey time (Figs. 2b & 2c).

At Brighton and Aspendale, *Caulerpa remotifolia* was more common at the deeper sites and *Caulerpa brownii* more common at the shallower sites. Fine reds were a major component of the assemblage at all depths (Figs. 2d & 2e). Algae were absent at the Aspendale 4m depth during all surveys.

3.1.2. Temporal Changes in Assemblage Structure

Changes in composition were evident at most locations and depths between the four surveys. At Kirk Point, the assemblage changes were relatively small compared with the other four locations. These changes were mostly at the 4 and 6m depths with an increase in the proportion of *Ulva* and *Caulerpa remotifolia* during the third and fourth surveys (Fig. 2a).

At Wedge Point, the proportion of *Botryocladia* at the 8 m and 10 m depths was high during the first survey, reduced during the second and third surveys, and high again during the fourth survey (Fig. 2b). The relative decline in *Botryocladia* was accompanied by increased proportions of *Rhodymenia*, *Caulerpa* and *Jeannerettia*. *Botryocladia* was, however, a major component at the 4m depth during the third survey. The relative abundance of *Botryocladia* during the fourth survey (March) was similar to the first survey (March), suggesting a cyclical pattern in composition changes. This was not reflected in the compositions at the shallow sites with substantial differences between the first and fourth surveys. The proportions of *Caulerpa* and *Jeannerettia* were higher in the fourth survey compared to the first, and the proportion of fine reds was relatively lower (Figure 2b).

The proportions of *Botryocladia* at Altona Bay were generally similar over the four surveys, except for a decline at 6 and 8m during the second survey and an increase at 4m during the third survey. The remaining assemblage components generally varied in the relative proportions of *Jeannerettia* and fine reds. No patterns in these changes were evident (Fig. 2c).

Temporal changes were observed in the composition of the assemblages at Brighton and Aspendale. However, little can be inferred from these changes due to the very low densities (usually less than 100 g/m^2) and clumped distributions. At Brighton, the proportion of fine reds was highest during the second survey and lowest during the fourth survey. *Caulerpa remotifolia* was a major component at all depths during the first survey, but this component was generally replaced by *Caulerpa brownii* at the 4 and 6m depths during the third and fourth surveys (Fig. 2d). The proportion of fine reds was highest at Aspendale during the third survey, but few temporal changes were evident in the relative proportions of other algal components (Fig. 2e).

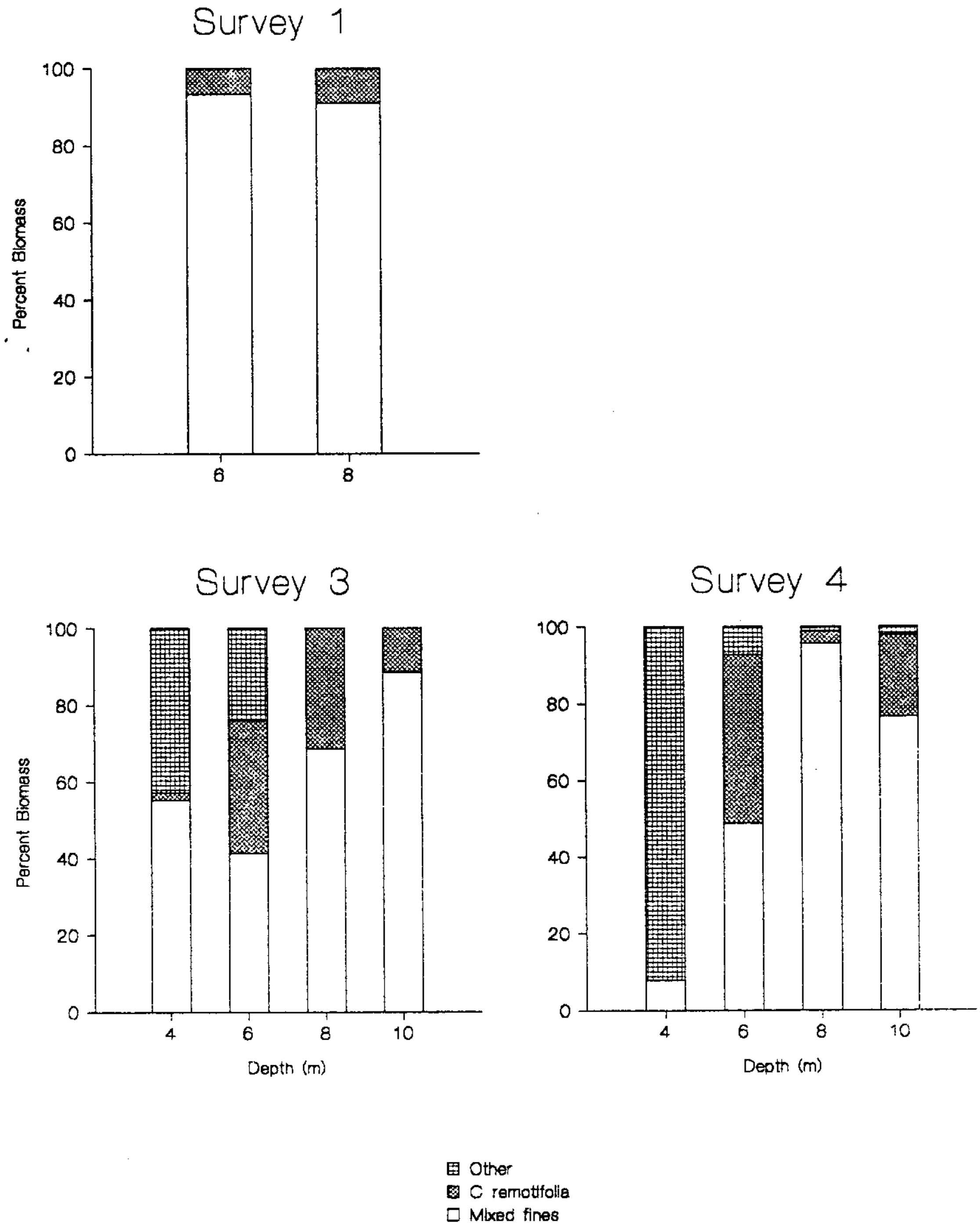


Figure 2a. Composition of macroalgae at Kirk Point

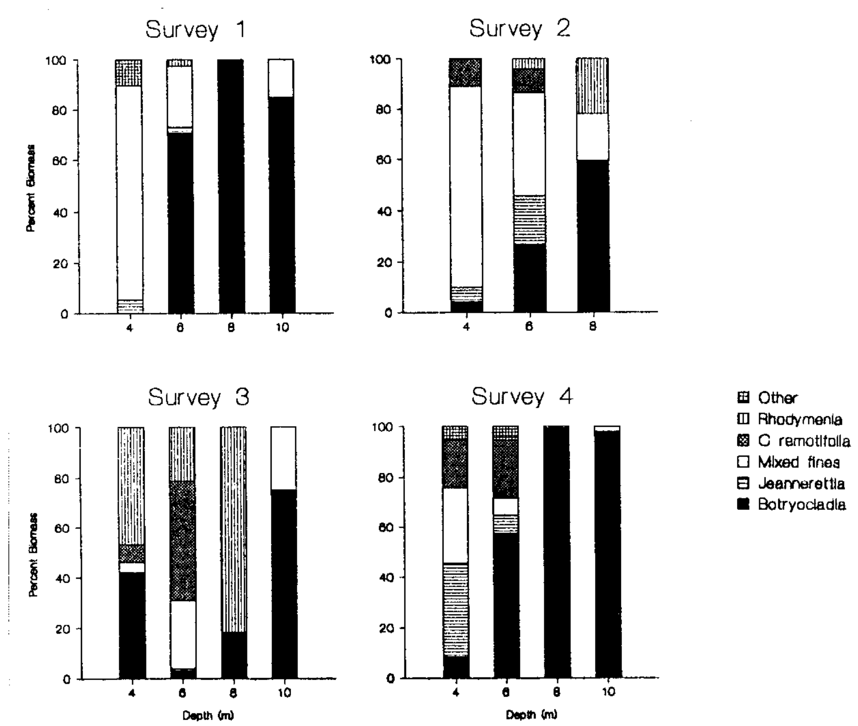


Figure 2b: Composition of macroalgae at Wedge Point

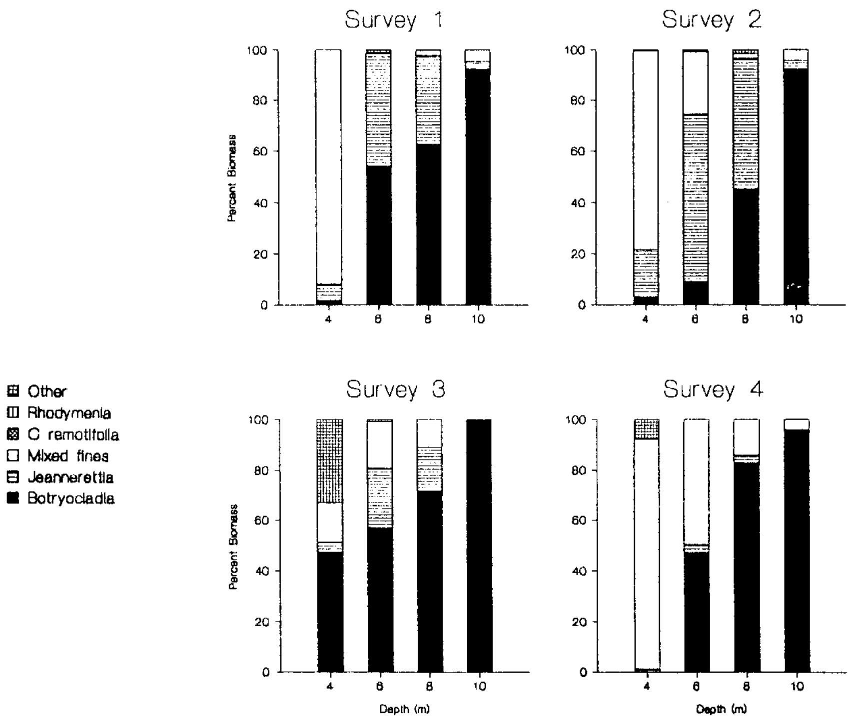


Figure 2c: Composition of macroalgae at Altona

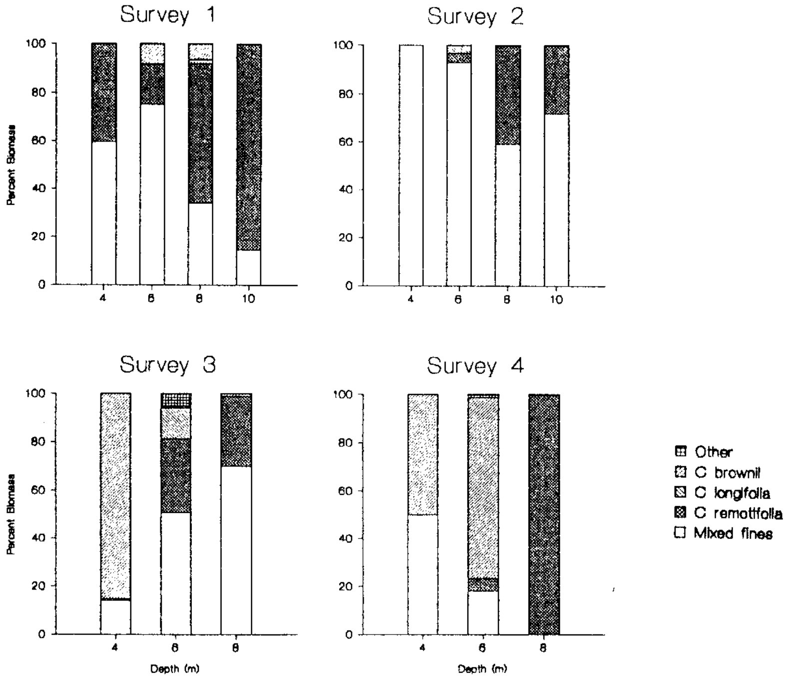


Figure 2d. Composition of macroalgal assemblages at Brighton

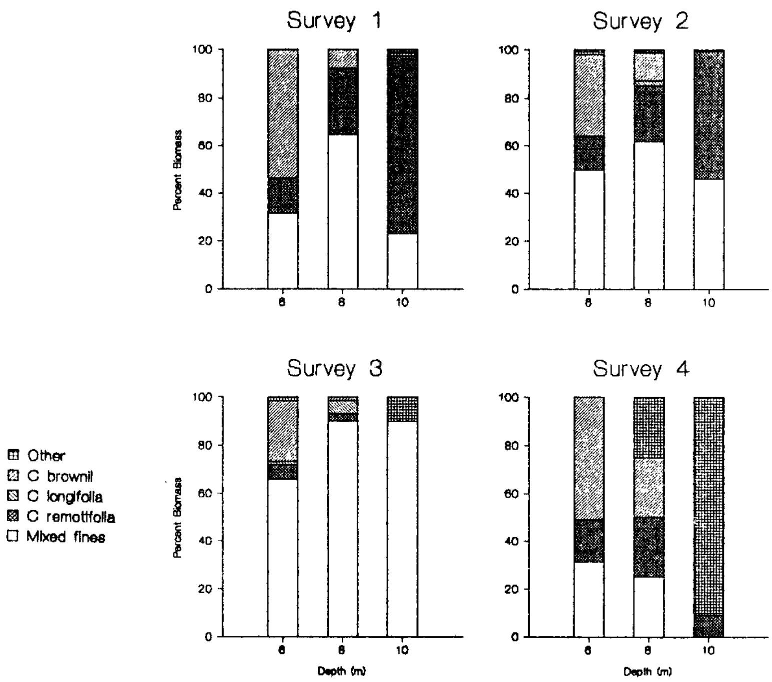


Figure 2e: Composition of macroalgal assemblages at Aspendale

3.2. Macroalgal Biomass

There were substantial differences in biomass between locations, depths and surveys. The standing crop of macrophytes was highest at Altona Bay and Wedge Point, with mean wet weight densities generally above 500 g/m^2 and 200 g/m^2 respectively (Table 3). The standing crops at Kirk Point, Brighton and Aspendale were comparatively low with mean densities usually below 100 g/m^2. The 8m depth at Kirk Point, however, had a wide range in biomass with a mean of 23 g/m^2 in the first survey increasing to 1103 g/m^2 and 952 g/m^2 in the third and fourth surveys respectively (Table 3).

High quadrat yields (above 1000 g/m^2) were often collected from both Wedge Point and Altona Bay, particularly where *Botryocladia obovata* was present (the data are shown in Figures 3b & 3c). However, the mean biomass density was generally much lower because of patchy spatial distributions. The highest quadrat yield was 6700 g from the Wedge Point 8m depth and consisted entirely of *Botryocladia obovata*.

Considerable variation in biomass was observed between depths and surveys at each location. Few general trends were apparent from the variation, except that biomass was higher at the 6 and 8m depths. High algal biomass was recorded at Altona Bay 8m for all surveys, and 4 and 6m for the first and second survey; at Wedge Point 6 and 8m during the fourth survey; and at Kirk Point 8m during the third and fourth surveys (Figs. 3a to 3e; Table 3). The 10m depth at Altona had a high biomass during all surveys relative to other 10m depths.

Table 3. Mean total biomass for each depth and survey

		Mean total biomass, g/m^2				
Location	Depth	Survey 1 Mar-Jun 95	Survey 2 Sep-Oct 95	Survey 3 Dec-Jan 96	Survey 4 Mar 96	Maximum yield
Kirk Point	4 m	0		24	25	82
	6 m	89		6	50	426
	8 m	23		1103	952	3000
	10 m	0		16	19	53
Wedge Point	4 m	109	700	662	301	3853
	6 m	935	674	251	1722	4950
	8 m	826	644	142	4646	6700
	10 m	27		239	315	1022
	12 m	96				524
Altona Bay	4 m	999	1093	207	54	2045
	6 m	1200	1306	278	112	2153
	8 m	2846	2306	1753	2659	4566
	10 m	518	466	891	891	3228
Brighton	4 m	6	7	95	1	349
	6 m	50	26	41	39	143
	8 m	33	71	19	10	233
	10 m	7	5	6	0	27
	12 m	0				
Aspendale	4 m	0	0	0	0	
	6 m	65	194	459	11.3	1560
	8 m	21	56	276	7	1236
	10 m	16	20	39	4	138
	12 m	3				

Note: The maximum quadrat yield for each site is also shown. The variation between quadrats within sites is shown in Figures 3a to 3e.

Note: For Figures 3a to 3e the boxes mark the median and quartile ranges. The whiskers show the range of values that fall within 1.5 times the interquartile range from the upper and lower quartiles (approximately 90% of the data).

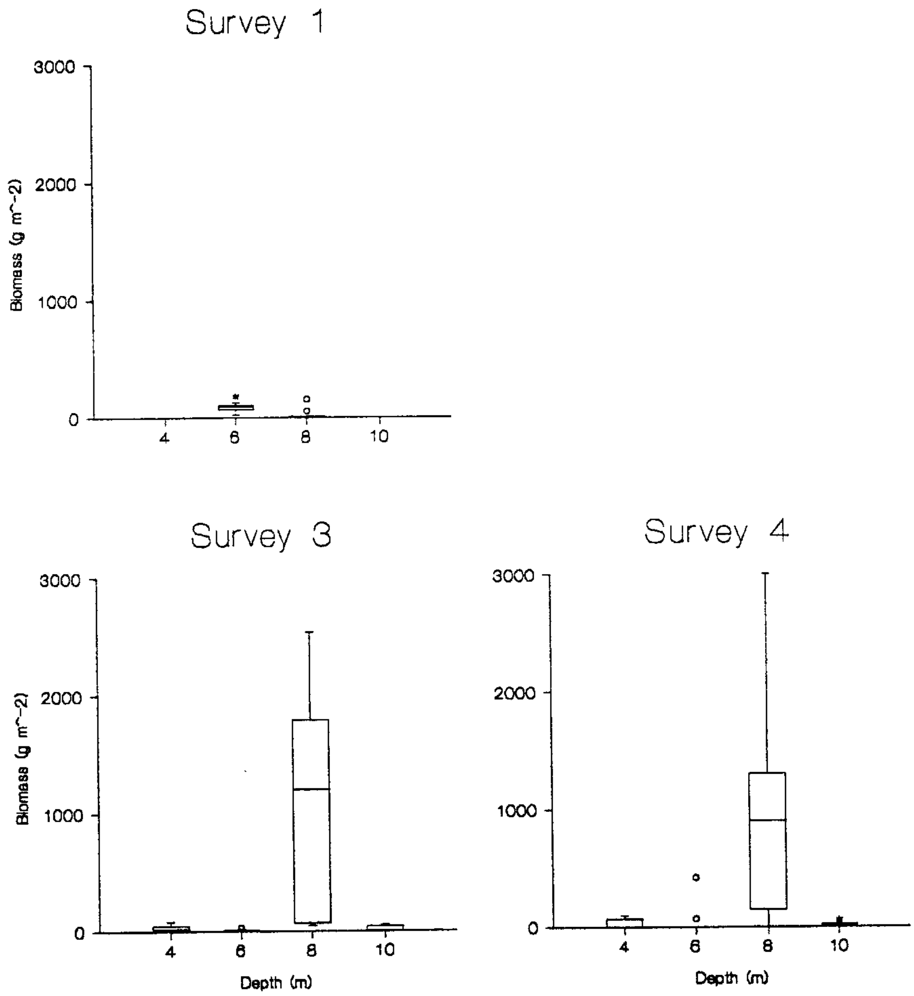


Figure 3a: Biomass of macroalgae at Kirk Point

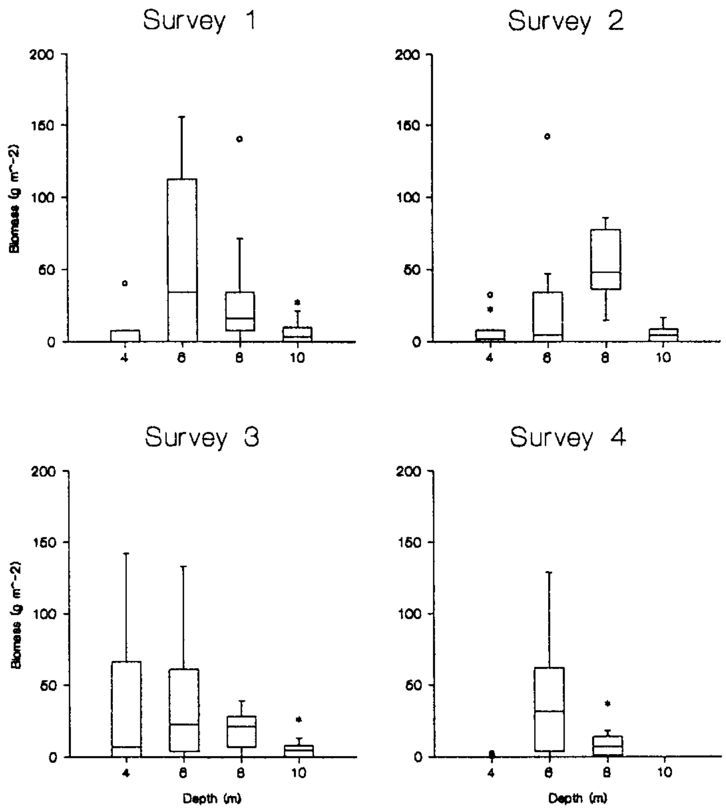


Figure 3b: Biomass of macroalgae at Wedge Point

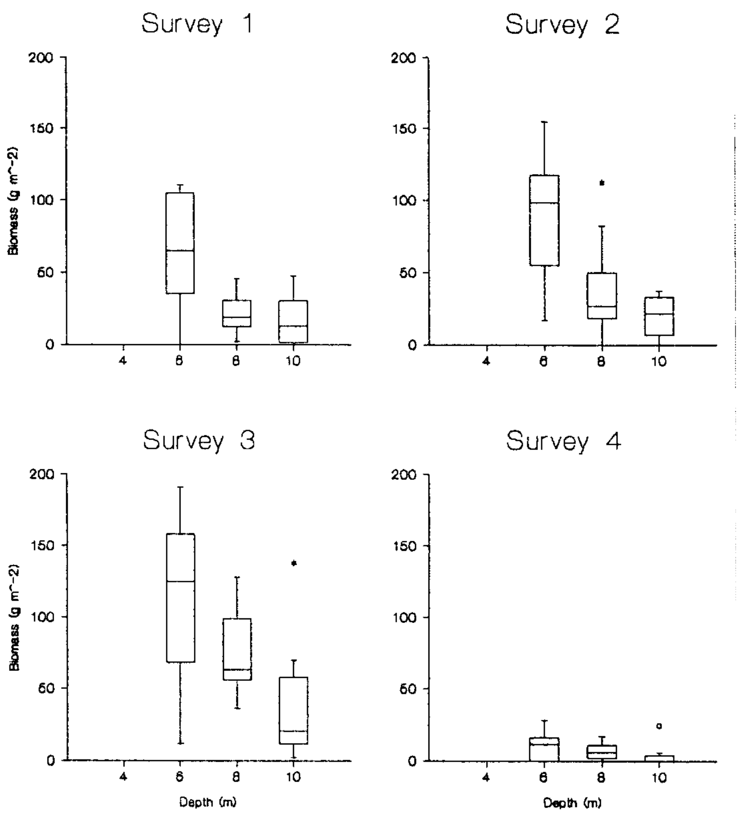


Figure 3c. Biomass of macroalgae at Altona

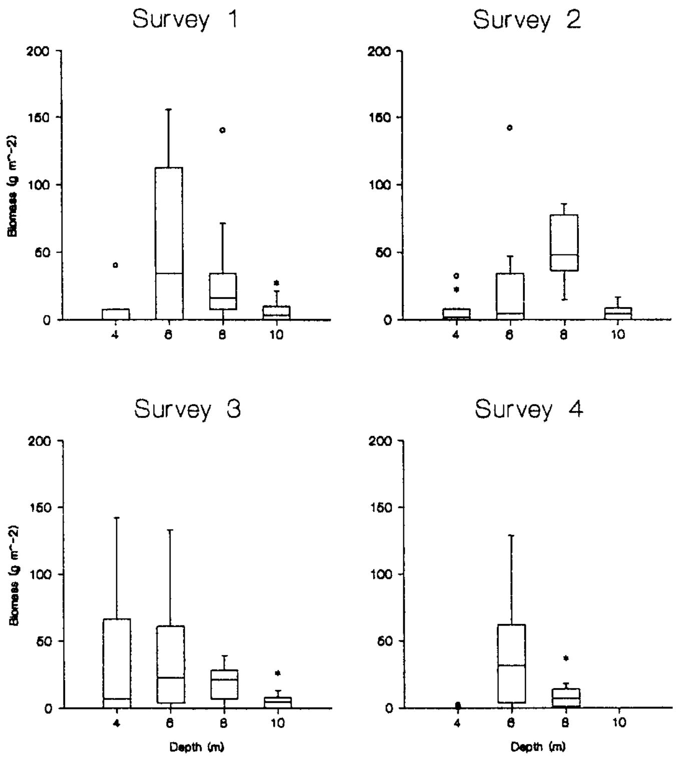


Figure 3d. Biomass of macroalgal assemblages at Brighton

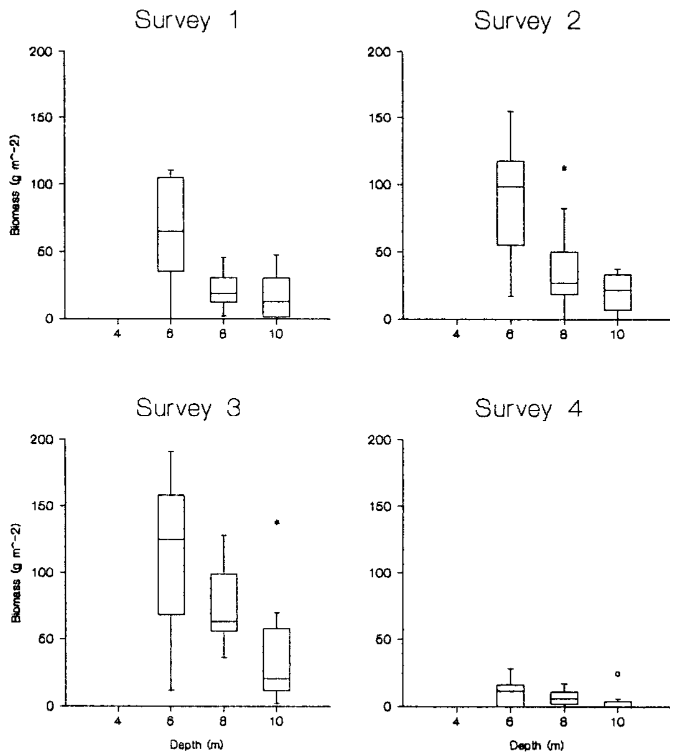


Figure 3e. Biomass of macroalgal assemblages at Aspendale

3.3. Small Scale Distribution and Substratum Cover

The total macroalgal cover was patchy at most sites, with the patch size varying between locations, depths, and survey times (Table 4; Figs. 4a to 4e). The unattached algae at the western sites occurred in patches of 10s to 100s of metres in size. Within these large scale patches, the algal layer varied in thickness, as well as in the number and size of bare areas within the algal patches. At the eastern sites, macroalgal cover was generally associated with small clumps of *Pyura* approximately 1m across and 2-3m apart.

Macrophyte cover was highest at Altona Bay. Over 90 percent of the seabed was covered by a blanket of seaweed at the 4 and 6m depths (first survey), and at the 8m depth (second survey). Cover at the 10m depth was lower than the shallower sites at Altona (21 and 24 percent), but was moderate compared with Wedge Point or eastern sites. Considerable changes in cover between surveys occurred at 4m with a reduction from 97% to 77%, and at 8m with an increase from 77% to 94% (Fig. 4c).

Wedge Point also had a high cover of algae. The proportion of substratum cover at Wedge Point during the first survey was less than 20% at 10 and 8m depth, 59% at 6m and 34 % at 4m depth. Cover was higher during the second survey, with 46%, 54% and 60% at the 8, 6 and 4m depths respectively (Figure 4b).

At Altona and Wedge Point, the macrophytes tended to occur in small discrete patches at the deeper sites, with the patch size increasing at shallower depths and the patches becoming more diffuse (less discrete).

At Kirk Point during the first survey, most of the algae cover occurred as a thin layer interspersed with many bare areas. The average cover was highest at 6m depth at 62%, with the algae at 8m depth covering 16% of the substratum (Table 4; Fig. 4a).

The cover at Brighton and Aspendale was low, usually less than 26%, with a slightly higher cover at Aspendale than Brighton. The 4 and 10m depths at Brighton had covers between 4% and 7%, while the cover at the intermediate 6 and 8m depths was 12% to 17% (Fig. 4d). The cover at Aspendale 10m ranged from 10% to 12% and cover at 8 and 6m ranged from 18% to 26% (Fig. 4e). Algae were always absent from the Aspendale 4m depth. There were no obvious changes in seabed cover between surveys at either Brighton or Aspendale (Table 4).

Table 4. Total percent cover of macrophytes using point-intercept method

Location	Depth	Survey 1 Mar-Jun 95	Survey 2 Sep-Oct 95
Kirk Point	4 m	0	
	6 m	62	
	8 m	16	
	10 m	0	
Wedge Point	4 m	34	60
	6 m	59	54
	8 m	20	46
	10 m	11	
	12 m	6	
Altona Bay	4 m	97	77
	6 m	90	84
	8 m	77	94
	10 m	24	21
Brighton	4 m	5	5
	6 m	14	12
	8 m	12	17
	10 m	4	7
Aspendale	4 m	0	0
	6 m	23	24
	8 m	26	18
	10 m	12	10

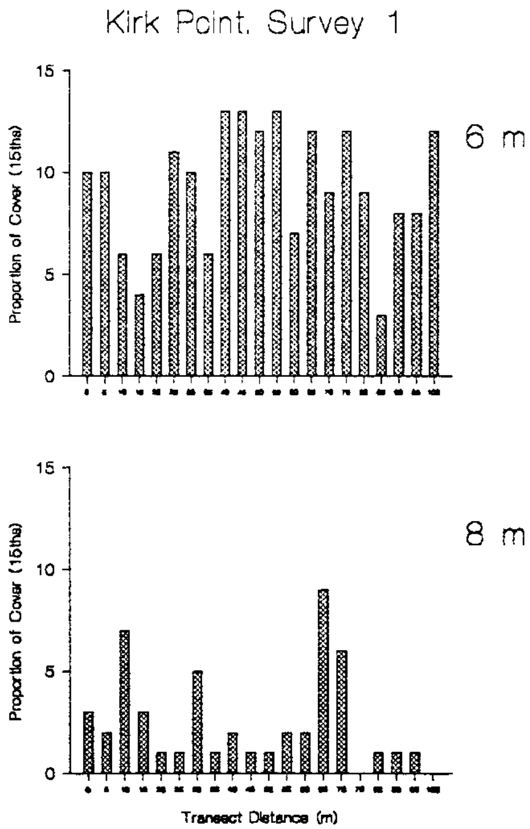


Figure 4a: Changes in macroalgal cover along 100 m transects at Kirk Point

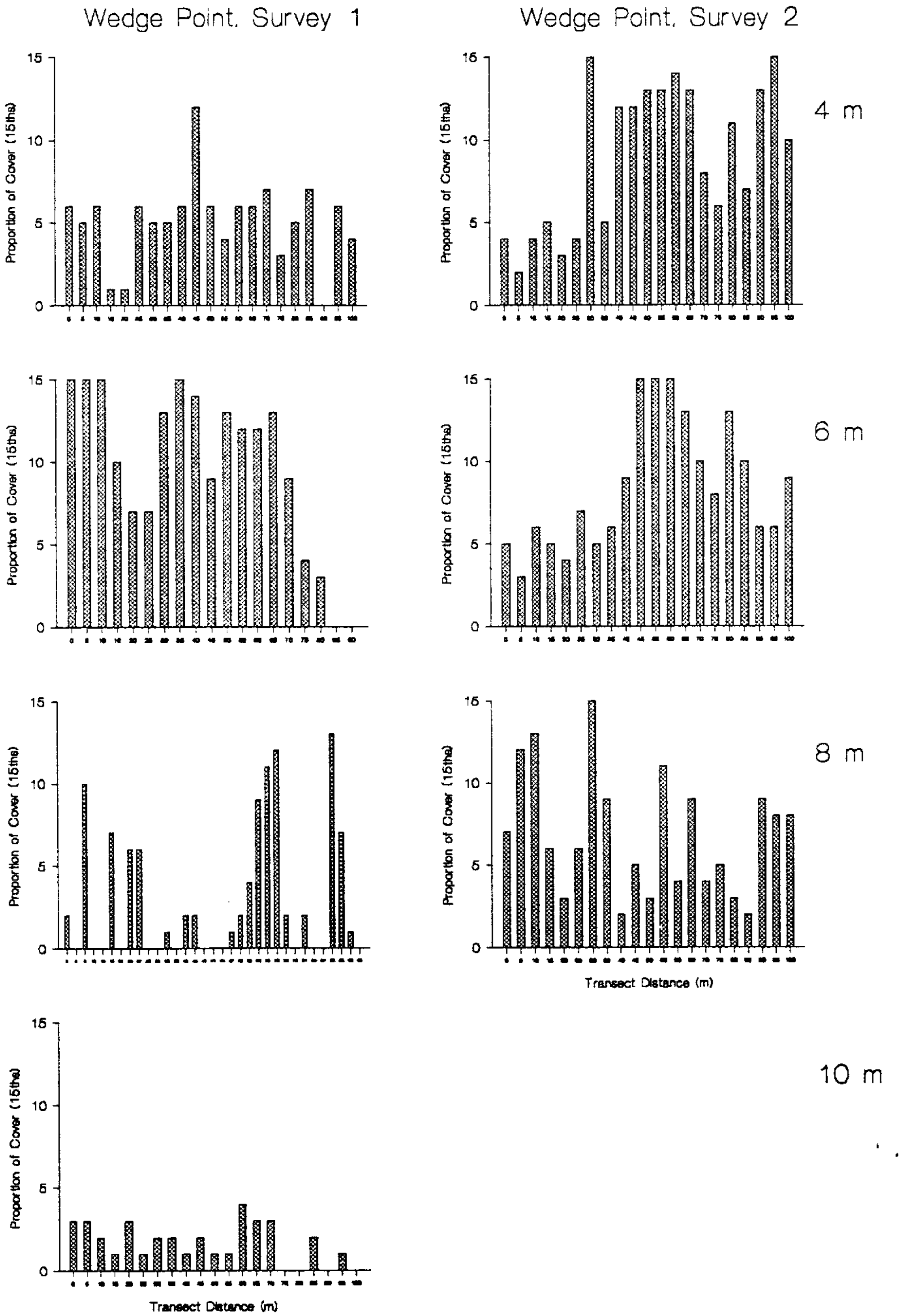


Figure 4b: Changes in macroalgal cover along 100 m transects at Wedge Point

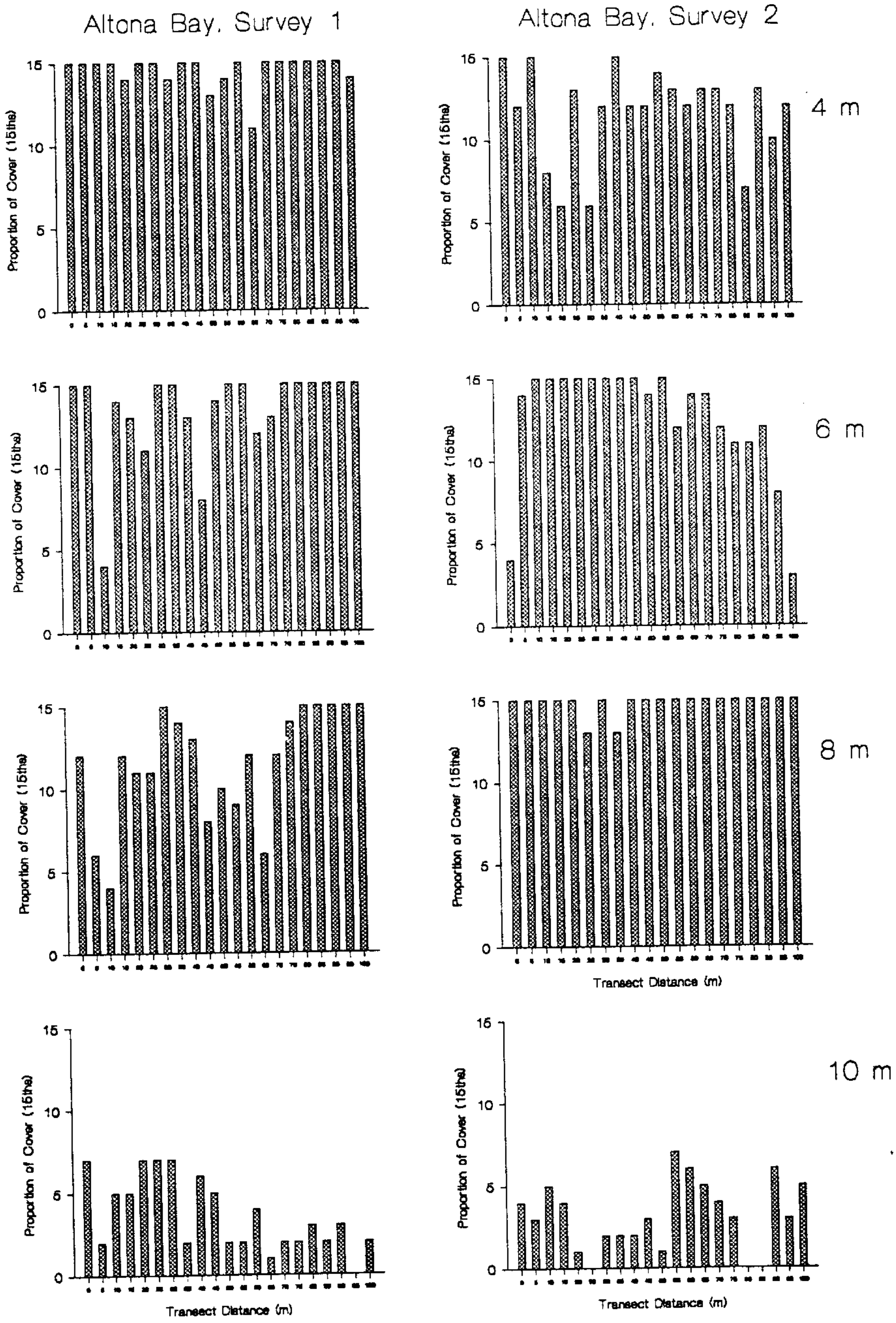


Figure 4c. Changes in macroalgal cover along 100 m transects at Altona

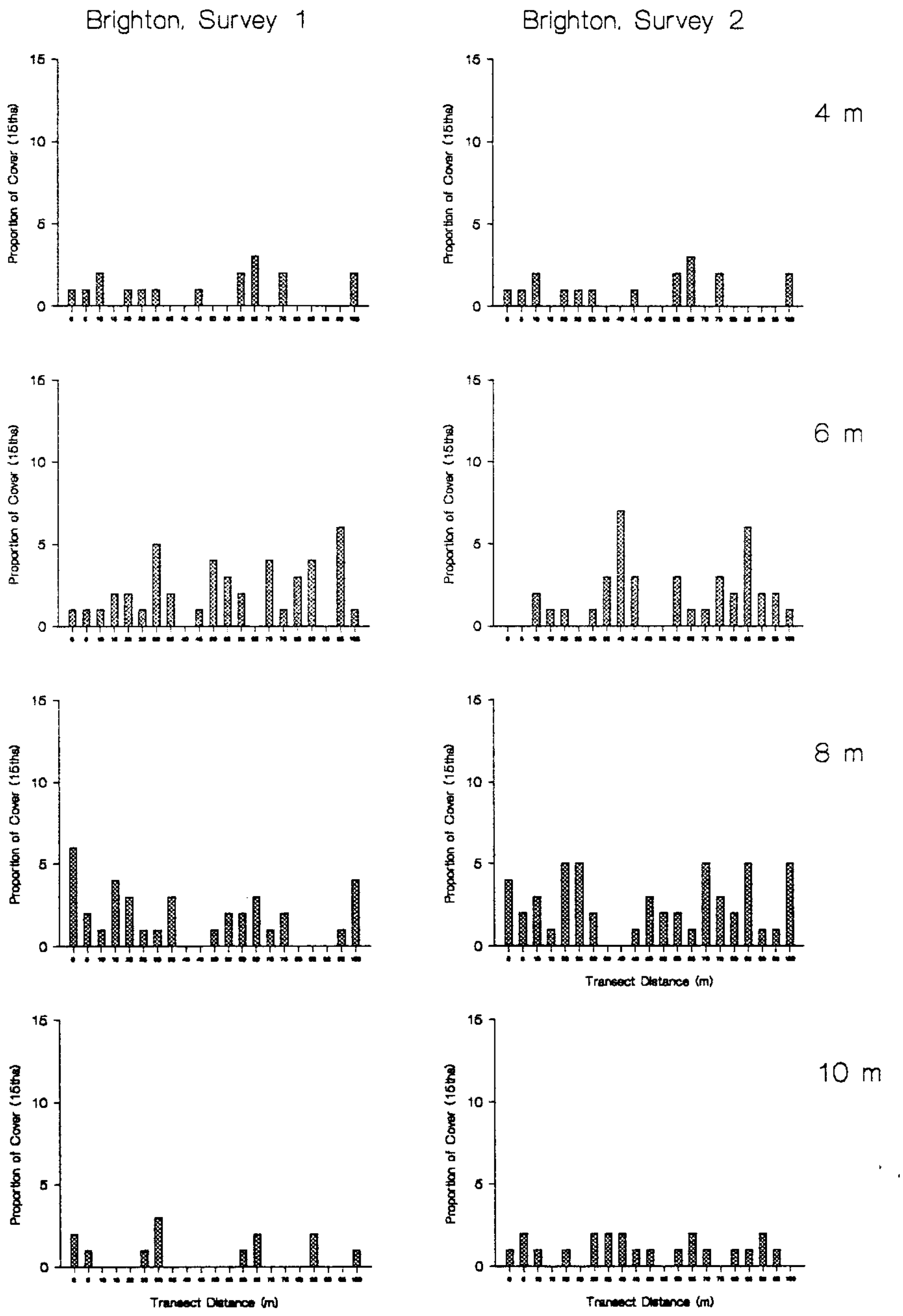


Figure 4d. Changes in macroalgal cover along 100 m transects at Brighton

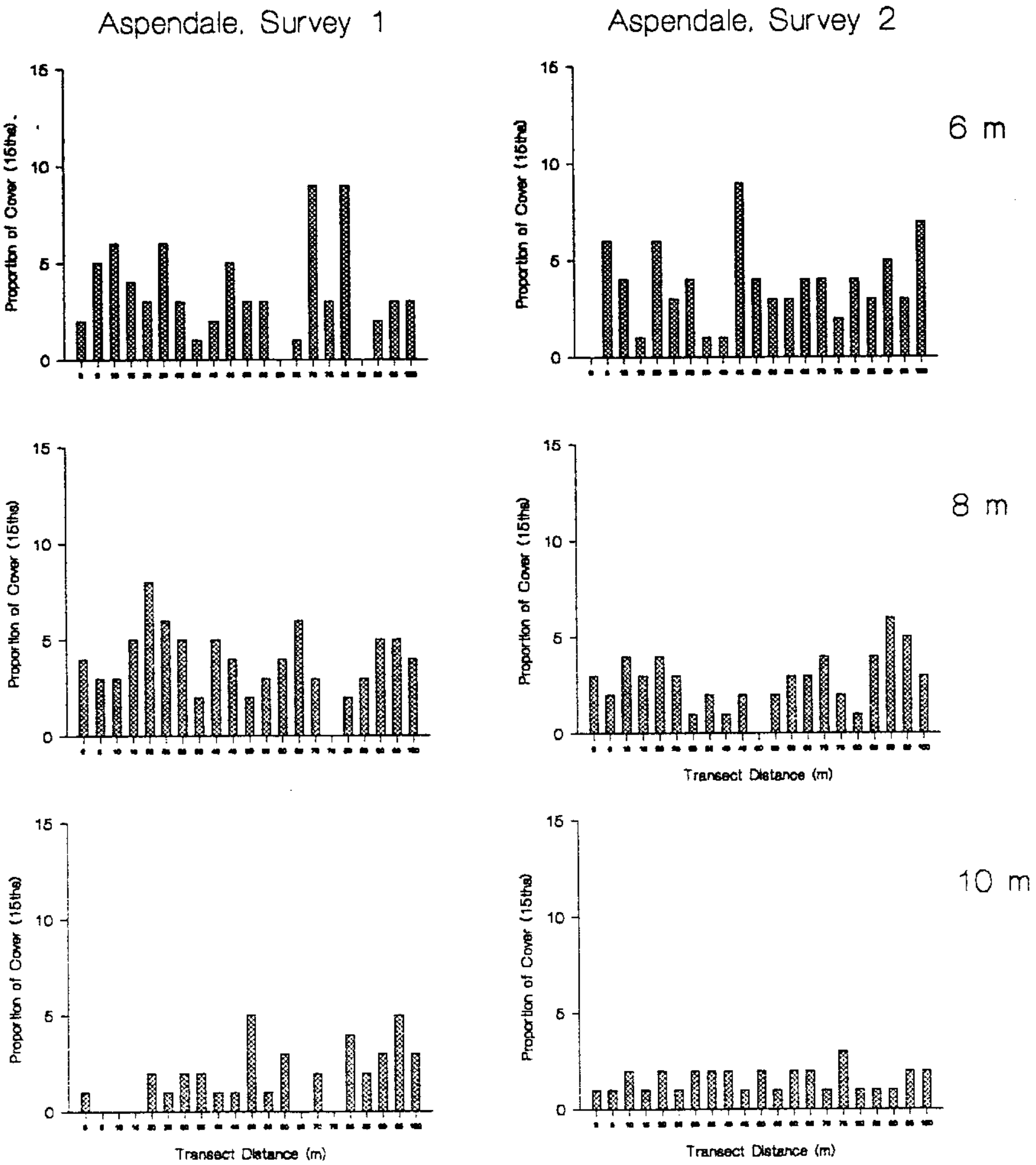


Figure 4e. Changes in macroalgal cover along 100 m transects at Aspendale

3.4. Relationships between Macroalgal Cover and Biomass

The area of substratum covered by macroalgae corresponded with the biomass present. This relationship could be described by the logistic function:

$$C = \beta W/(1 + \beta W) \qquad \text{(Equation 1)}$$

where *C* is the proportion of cover, *W* is the biomass and β is a coefficient. To compare the cover-biomass relationships between sites and times, the β coefficient was estimated using least-squares nonlinear regression (using the quasi-Newtonian method of Wilkinson *et al*. 1992), and curves were plotted for each data set (Figures 5a to 5e).

Significant regressions were obtained for all sites and times examined (Table 5). The coefficients of determination (r^2) show that the logistic models explained much of the variation in cover with biomass, with most values above 0.75 (Table 5). An exception was the Altona 10m depth for the second survey, with an r^2 of only 0.41.

Table 5. Significance of cover-biomass nonlinear regressions

Survey	Site	Regress MS	Residual MS	df	F		R^2 (cor)
Survey 1	Kirk 6	1.7921	0.0055	1, 9	328.1	**	0.74
	Kirk 8	0.1784	0.0011	1, 9	157.6	**	0.94
	Wedge 4	0.4947	0.0029	1, 9	168.7	**	0.48
	Wedge 6	3.6938	0.0035	1, 9	1048.8	**	0.95
	Wedge 8	0.8432	0.0125	1, 9	67.2	**	0.85
	Wedge 10	0.0266	0.0010	1, 9	26.3	**	0.20
	Wedge 12	0.0842	0.0011	1, 9	79.2	**	0.80
	Altona 4	9.5705	0.0008	1, 9	12349.0	**	1.00
	Altona 6	8.1398	0.0206	1, 9	359.6	**	0.24
	Altona 8	7.1762	0.0252	1, 9	284.5	**	0.58
	Altona 10	0.2518	0.0026	1, 9	96.4	**	0.84
	Brighton 4	0.0263	0.0002	1, 9	113.9	**	0.91
	Brighton 6	0.8666	0.6589	1, 9	59.1	**	0.67
	Brighton 8	0.0705	0.0009	1, 9	75.9	**	0.84
	Brighton 10						
	Aspendale 6	0.3422	0.0046	1, 9	75.0	**	0.67
	Aspendale 8	0.1069	0.0011	1, 9	101.4	**	0.74
	Aspendale 10	0.0397	0.0007	1, 9	59.7	**	0.79
Survey 2	Wedge 4	6.2255	0.0202	1, 9	308.9	**	0.69
	Wedge 6	3.4611	0.0485	1, 9	71.3	**	0.48
	Wedge 8	0.8244	0.0071	1, 8	116.7	**	0.82
	Altona 4	5.4073	0.0633	1, 9	85.4	**	0.34
	Altona 6	6.6704	0.0174	1, 9	383.5	**	0.71
	Altona 8	9.8010	0.0008	1, 9	11822.7	**	0.99
	Altona 10	0.1718	0.0228	1, 9	7.55	*	0.41
	Brighton 4	0.0169	0.0008	1, 6	22.1	**	0.51
	Brighton 6	0.0278	0.0013	1, 3	21.5	*	0.87
	Brighton 8	0.1968	0.0019	1, 8	102.5	**	0.78
	Brighton 10	0.0151	0.0004	1, 3	36.0	*	0.10
	Aspendale 6	0.3533	0.0085	1, 8	41.7	**	0.31
	Aspendale 8	0.2263	0.0029	1, 7	79.1	**	0.63
	Aspendale 10	0.0197	0.0003	1, 8	67.4	**	0.38

Note: * $p< 0.05$
** $p < 0.01$

Outlying and high leverage data points were evident in several instances, notably the Wedge Point 8m first and second surveys and the Altona 4m second survey (Figs. 5b and 5c). Such cases were not considered measurement errors and, even though they had a disproportionate influence on the regressions, the purposes of this investigation did not warrant their removal, especially given the small sample sizes.

There were considerable differences in the cover-biomass relationships between depths and locations. The β coefficients ranged from 0.26×10^{-3} to 45.9×10^{-3}, with most values between 1×10^{-3} and 10×10^{-3} (Table 6; see also Figure 5f for a comparison of different β curves). However, no general trends were evident in the β coefficients between depths at each location. At Wedge Point, the β coefficient tended to decrease with depth. At Altona, β was similar between the 4, 6 and 8m Altona depths, but was lower at the 10m depth. Lower β values were found for the intermediate, 6 and 8m depths at Brighton, and no differences with depth were apparent at Aspendale.

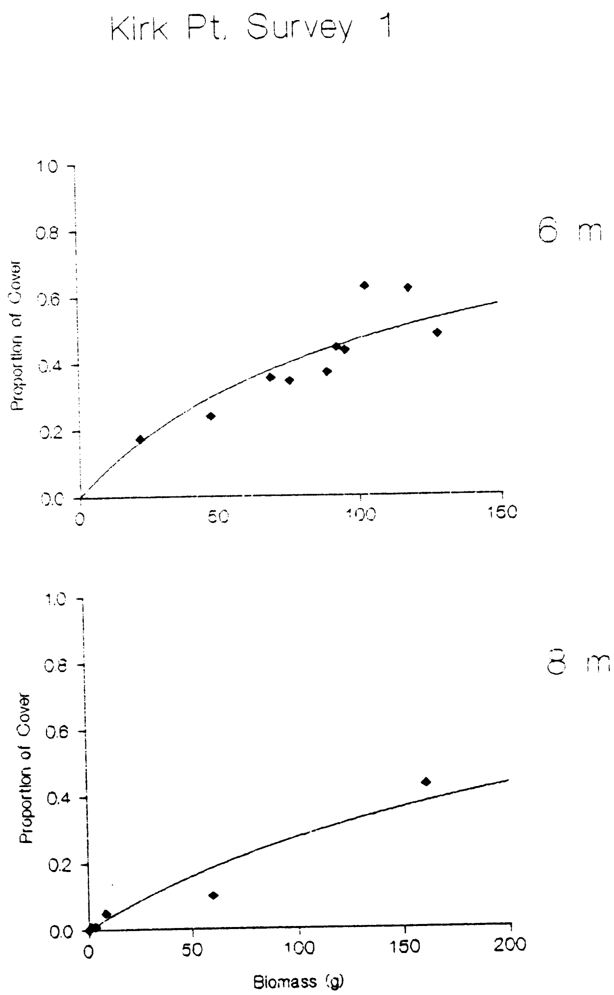


Figure 5a: Cover-biomass relationship for Kirk Point

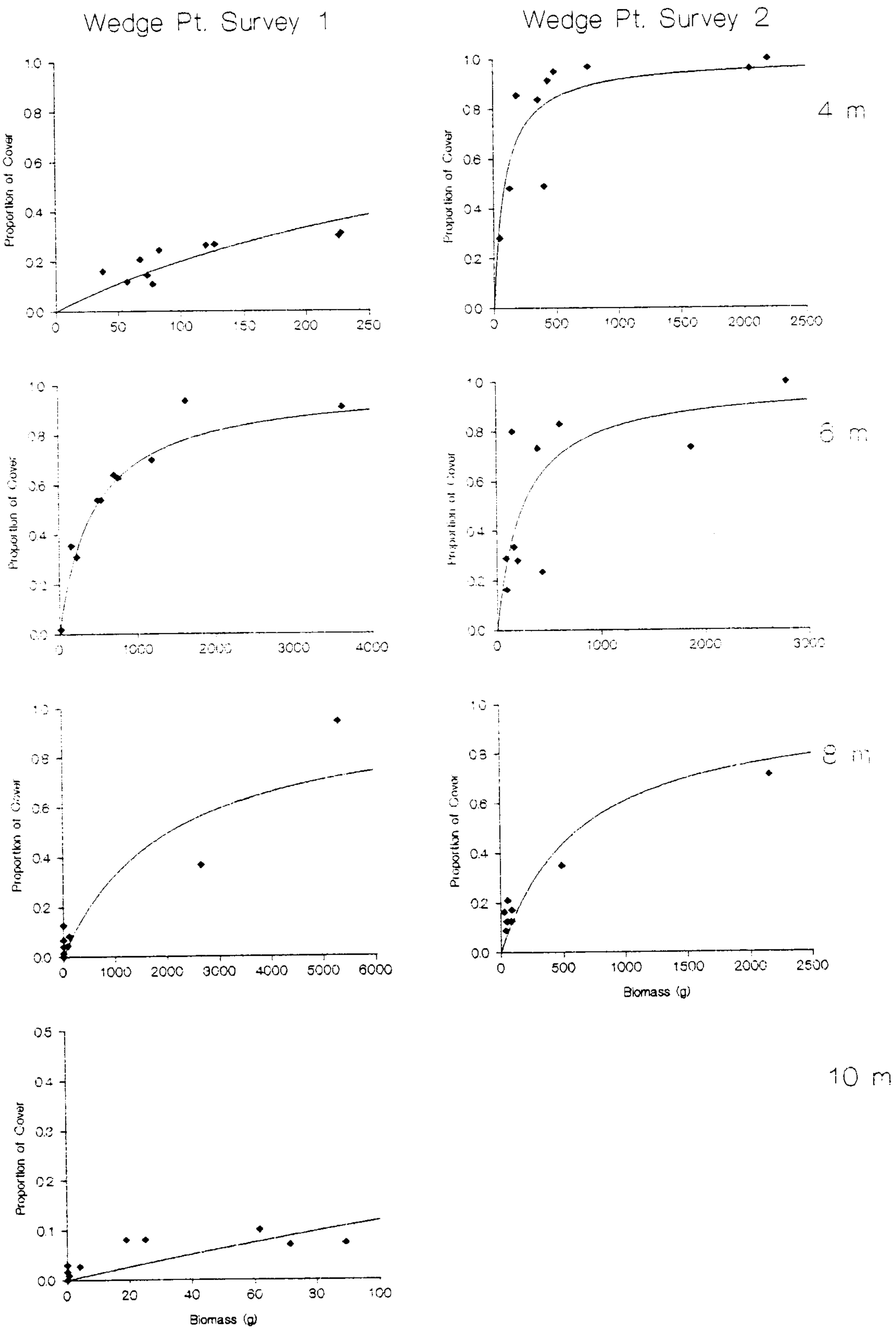


Figure 5b: Cover-biomass relationship for Wedge Point

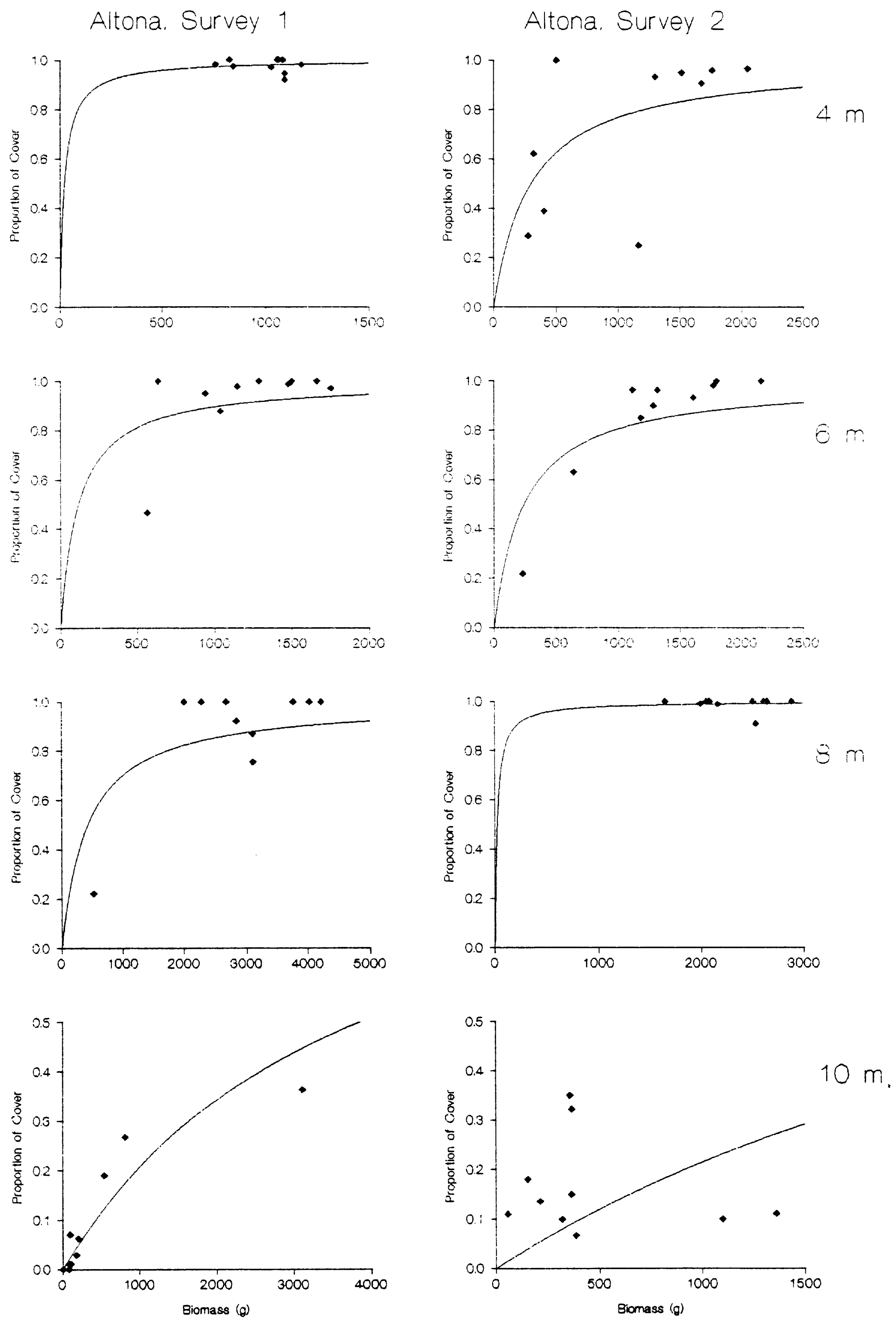


Figure 5c: Cover-biomass relationship for Altona

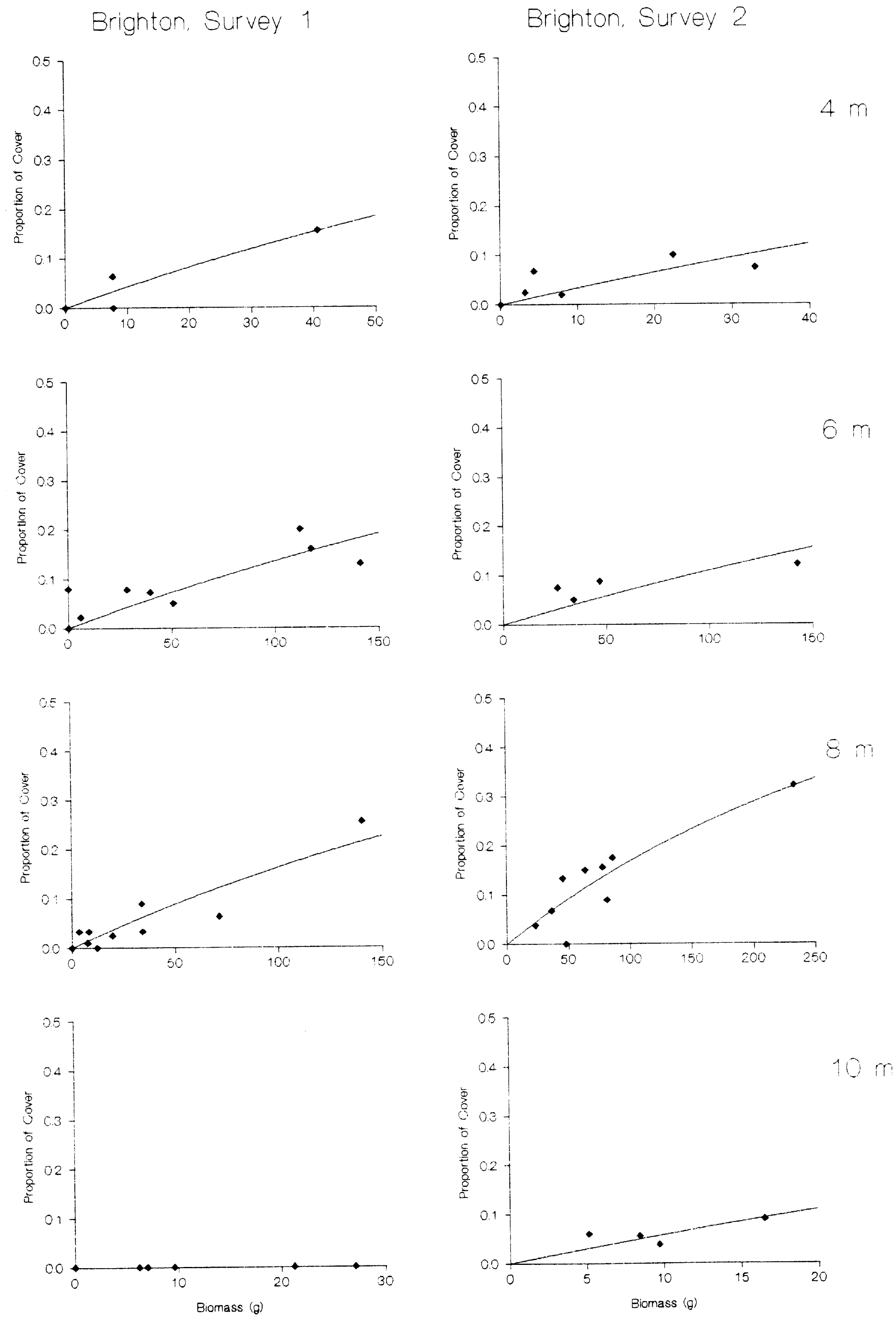


Figure 5d: Cover-biomass relationship for Brighton

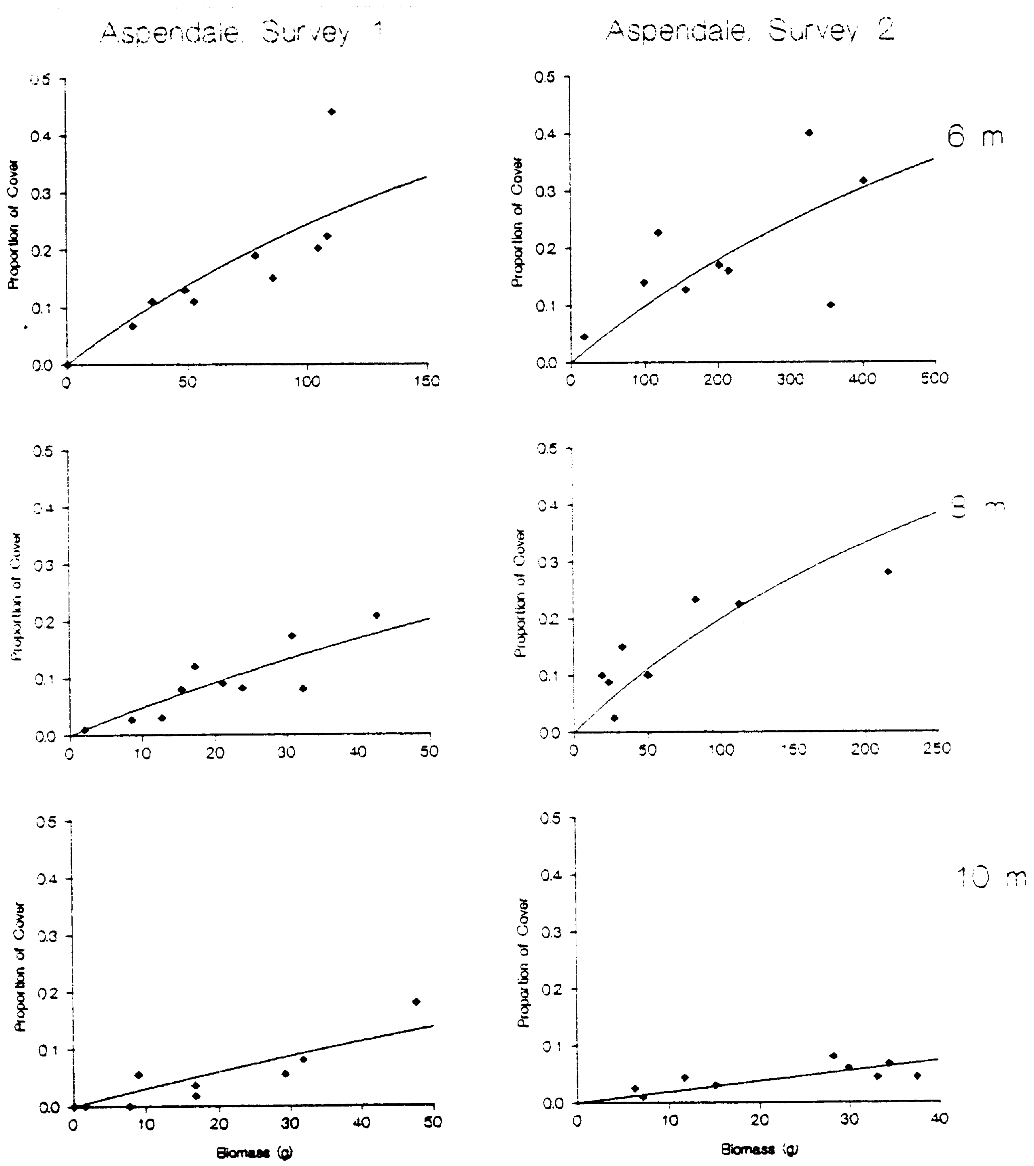


Figure 5e. Cover-biomass relationship for Aspendale

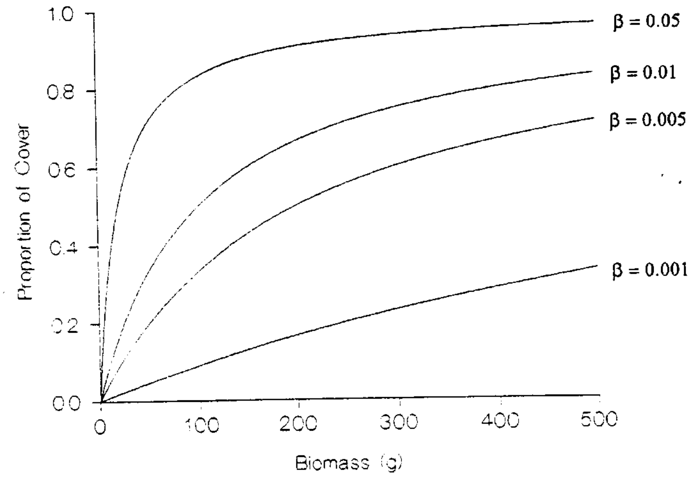


Figure 5f. Logistic curves relating cover to biomass with different β coefficients

Table 6. Estimates of β coefficients and confidence intervals (all values x10^{-3})

Survey	Site	b	SE_b	Lower 95% CL	Upper 95% CL
Survey 1	Kirk 6	8.859	0.867	6.898	10.820
	Kirk 8	3.779	0.420	2.829	4.729
	Wedge 4	2.499	0.251	1.931	3.066
	Wedge 6	2.192	0.157	2.136	2.849
	Wedge 8	0.486	0.278	-0.142	1.115
	Wedge 10	1.342	0.282	0.703	1.981
	Wedge 12	0.659	0.034	0.582	0.737
	Altona 4	45.938	18.828	3.345	88.531
	Altona 6	8.594	3.852	-0.120	17.308
	Altona 8	2.341	0.345	1.561	3.122
	Altona 10	0.260	0.009	0.239	0.281
	Brighton 4	4.515	0.491	3.404	5.625
	Brighton 6	1.572	0.229	1.055	2.089
	Brighton 8	1.939	0.251	1.370	2.507
	Brighton 10				
	Aspendale 6	3.223	0.462	2.179	4.267
	Aspendale 8	5.065	0.575	3.765	6.365
	Aspendale 10	3.194	0.452	2.171	4.216
Survey 2	Wedge 4	11.123	2.981	4.379	17.868
	Wedge 6	3.922	1.244	1.108	6.738
	Wedge 8	1.562	0.014	1.530	1.594
	Altona 4	3.342	1.086	0.885	5.799
	Altona 6	4.164	0.859	2.220	6.108
	Altona 8	44.061	39.926	-46.258	134.380
	Altona 10	0.274	0.085	0.082	0.466
	Brighton 4	3.494	0.819	1.489	5.499
	Brighton 6	1.228	0.288	0.313	2.144
	Brighton 8	2.021	0.236	1.477	2.565
	Brighton 10	6.173	1.113	2.632	9.714
	Aspendale 6	1.095	0.161	0.725	1.466
	Aspendale 8	2.493	0.364	1.632	3.355
	Aspendale 10	1.958	0.252	1.376	2.540

Similarly, there were no general trends in β coefficients between survey times. The β coefficients increased at Wedge Point between the first and second surveys, while β decreased at Aspendale. Beta declined at the Altona 4 m depth and increased at the 8m depth, with no apparent change at the 6 and 10m depths, or at any of the Brighton sites.

Although there were no consistent trends in β between depths and times for each location, β correlated with differences in macrophyte structure at Wedge Point and Altona Bay. At both these locations, β was significantly negatively correlated with the relative abundance (by biomass) of *Botryocladia* (Table 7). At Wedge Point, β was also positively correlated with the relative abundance of *Jeannerettia* and fine red algae. No correlations were found between β and the relative abundances *of Caulerpa remotifolia* and fine red algae at Brighton and Aspendale (Table 7).

Table 7. Spearman rank correlations (r_e) of β with proportion of biomass of dominant taxa

Location	Taxon	r_s	Significance
Wedge Point (n = 8; $r_{s\,(0.05)}$ = 0.738)	*Botryocladia*	-0.881	**
	Jeannerettia	0.913	**
	Fine reds	0.786	*
Altona Bay (n = 8; $r_{s\,(0.05)}$ = 0.738)	*Botryocladia*	-0.778	*
	Jeannerettia	0.548	
	Fine reds	0.143	
Brighton (n = 7; $r_{s\,(0.05)}$ = 0.786)	*C. remotifolia*	0.143	
	Fine reds	-0.143	
Aspendale (n = 6; $r_{s\,(0.05)}$ = 0.886)	*C. remotifolia*	0.257	
	Fine reds	-0.029	

Note: * significant at a = 0.05 ** significant at a = 0.01

The asymptotic relationship between cover and biomass means that, at near total cover, the biomass density is generally defined by a minimum value, and can range widely above this value. This was illustrated at Wedge Point and Altona Bay, where biomass varied by up to 2200 g/m^2 or more at covers above 90% (Figs. 5b & 5c).

3.5. Nutrient content of macroalgal species

Differences in the total nitrogen (as N) and total phosphorus (as P) content of macroalgae were detected between common species in Port Phillip Bay. Nitrogen was highest in *Caulerpa brownii* and *Rhodymenia* with concentrations between 0.3% and 0.6% wet weight (Table 8). The nitrogen content of other algae was generally higher in the larger species, with concentrations generally between 0.2% and 0.4% for

Botryocladia, *Jeannerettia*, *Ulva* and *C. remotifolia*. Fine red algal species with similar nitrogen content to these larger algae included *Ceramium*, *Echinothamnion* and *Polysiphonia*. The nitrogen content ranged between 0.1% and 0.2% (wet weight) for the fine red algae *Gracilaria*, *Laurencia*, *Hypnea* and *Champia* (Table 8).

Table 8. Nitrogen concentration of common macrophytes in Port Phillip Bay

	Nitrogen content, % of wet weight; median and range			
Taxon	Survey 1	Survey 2	Survey 3	Survey 4
C. brownii	0.56 (0.45-0.75)	0.33 (0.21-0.42)	0.20 (0.13-0.55)	0.66 (0.11-1.18)
C. longifolia			0.12 (0.08-0.18)	
C. remotifolia	0.29 (0.21-0.65)	0.26 (0.12-0.48)	0.18 (0.10-0.46)	0.39 (0.25-0.46)
Ulva	0.37 (0.30-0.41)		0.08 (0.07-0.09)	0.22 (0.12-0.27)
Cladophora		0.32 (0.20-0.45)	0.10 (0.04-0.13)	
Cutleria		0.25 (0.16-0.29)		
Botryocladia	0.27 (0.18-0.56)	0.33 (0.23-0.57)	0.25 (0.17-0.31)	0.42 (0.27-0.62)
Jeannerettia	0.24 (0.17-0.69)	0.22 (0.03-0.31)	0.18 (0.12-0.26)	0.41 (0.18-0.71)
Rhodymenia		0.64 (0.51-0.74)	0.31 (0.26-0.39)	
Mixed fines	0.45 (0.21-0.67)	0.18 (0.05-0.39)	0.13 (0.07-0.23)	0.43 (0.30-0.96)
Gloiosaccion	0.21			
Gracilaria	0.15	0.14	0.14 (0.06-0.17)	0.25
Hypnea	0.19 (0.16-0.23)			
Laurencia		0.15 (0.12-0.19)	0.09 (0.06-0.19)	
Solieria	0.96			
Brongniartella		0.33		
Ceramium	0.30 (0.29-0.34)	0.26 (0.14-0.47)	0.23	
Champia	0.22 (0.18-0.25)	0.10		
Echinothamnion	0.50		0.32	
Griffithsia		0.20		
Polysiphonia	0.26 (0.17-0.40)			

Note: The data were pooled over all locations and depths.

The phosphorus content of macroalgae was generally correlated with nitrogen content. Phosphorus in most large species ranged from 0.01 - 0.05% (as P, wet weight, Table 9) including *C.brownii*, *Botryocladia*, *Jeannerettia*, *Ulva*, *C. remotifolia*, *Ceramium*, *Echinothamnion* and *Polysiphonia*. *Rhodymenia* had a slightly higher range (0.02% to 0.06%), while the phosphorus concentration in *Gracilaria*, *Laurencia*, *Hypnea* and *Champia* was generally lowest being between 0.004% and 0.03% (Table 9).

The content of nitrogen in *C. remotifolia* appeared to be different between locations and depths. Nitrogen content was generally highest at Brighton, lower at Altona Bay, Aspendale and Wedge Point and lowest at Kirk Point (Fig. 6). The nitrogen content also appeared to be higher in shallow water specimens, although the content was low in samples from the Altona Bay and Wedge Point 4m depths. The phosphorus concentration of *C. remotifolia* was generally higher at Altona Bay and Wedge Point and there were no apparent trends with depth (Fig. 6a).

Table 9. Phosphorus concentration of common macrophytes in Port Phillip Bay

	Phosphorus content, % ($x10^{-3}$) wet weight; median and range			
Taxon	Survey 1	Survey 2	Survey 3	Survey 4
C. brownii	19 (16-25)	9 (6-12)	7 (2-14)	62 (21-97)
C. longifolia			5 (4-9)	
C. remotifolia	20 (15-47)	17 (8-30)	10 (7-23)	48 (33-61)
Ulva	25 (24-30)		10 (8-12)	32 (14-46)
Cladophora		24 (16-32)	4 (2-9)	
Cutleria		54 (13-69)		
Botryocladia	41 (26-51)	24 (16-48)	18 (9-27)	64 (46-89)
Jeannerettia	22 (19-82)	10 (2-20)	8 (6-11)	34 (26-98)
Rhodymenia		63 (34-73)	25 (16-37)	
Mixed fines	33 (17-63)	13 (3-26)	1 (0.4-3.0)	47 (33-86)
Gloiosaccion	4			
Gracilaria	8	12	6 (5-12)	31
Hypnea	12 (8-14)			
Laurencia		15 (12-20)	12 (10-29)	
Solieria	10			
Brongniartella		19		
Ceramium	39 (16-66)	15 (11-43)	14	
Champia	12 (11-14)	7		
Echinothamnion	35		14	
Griffithsia		9		
Polysiphonia	32 (15-48)			

Note: The data were pooled over all locations and depths.

There were no apparent differences in the nitrogen and phosphorus content of *Botryocladia* between the Altona Bay and Wedge Point sites (Fig. 6b). However, the concentration of nitrogen and phosphorus was more variable at Altona Bay.

The nutrient content of *Jeannerettia* was variable between locations and depths and there were no discernible patterns in these differences (Fig. 6c). Nitrogen and phosphorus content was highest and more variable at Altona Bay and Wedge Point.

The nitrogen content of fine red algal mixtures had similar ranges at all sites, but phosphorus tended to be higher and more variable at Brighton and Wedge Point (Fig. 6d).

The nutrient content of *C. remotifolia*, *Botryocladia*, *Jeannerettia* and mixed fine reds all followed a similar trend between surveys. Nitrogen and phosphorus content decreased between surveys 1, 2 and 3, and increased between surveys 3 and 4 to similar or higher than survey 1 (Figs. 7a & 7b).

The relative proportions of nitrogen and phosphorus in the Port Phillip Bay algae (indicated by N to P ratios) were generally similar between most species with median values between 9 and 12 (Fig. 8). Ratios were higher in *Caulerpa remotifolia*, *Ceramium*, *Hypnea* and *Gracilaria* with median ratios of 15, 16, 19 and 20, respectively. *Caulerpa brownii* had the highest median N:P ratio of 33 with a wide range in values around the median (Fig. 8).

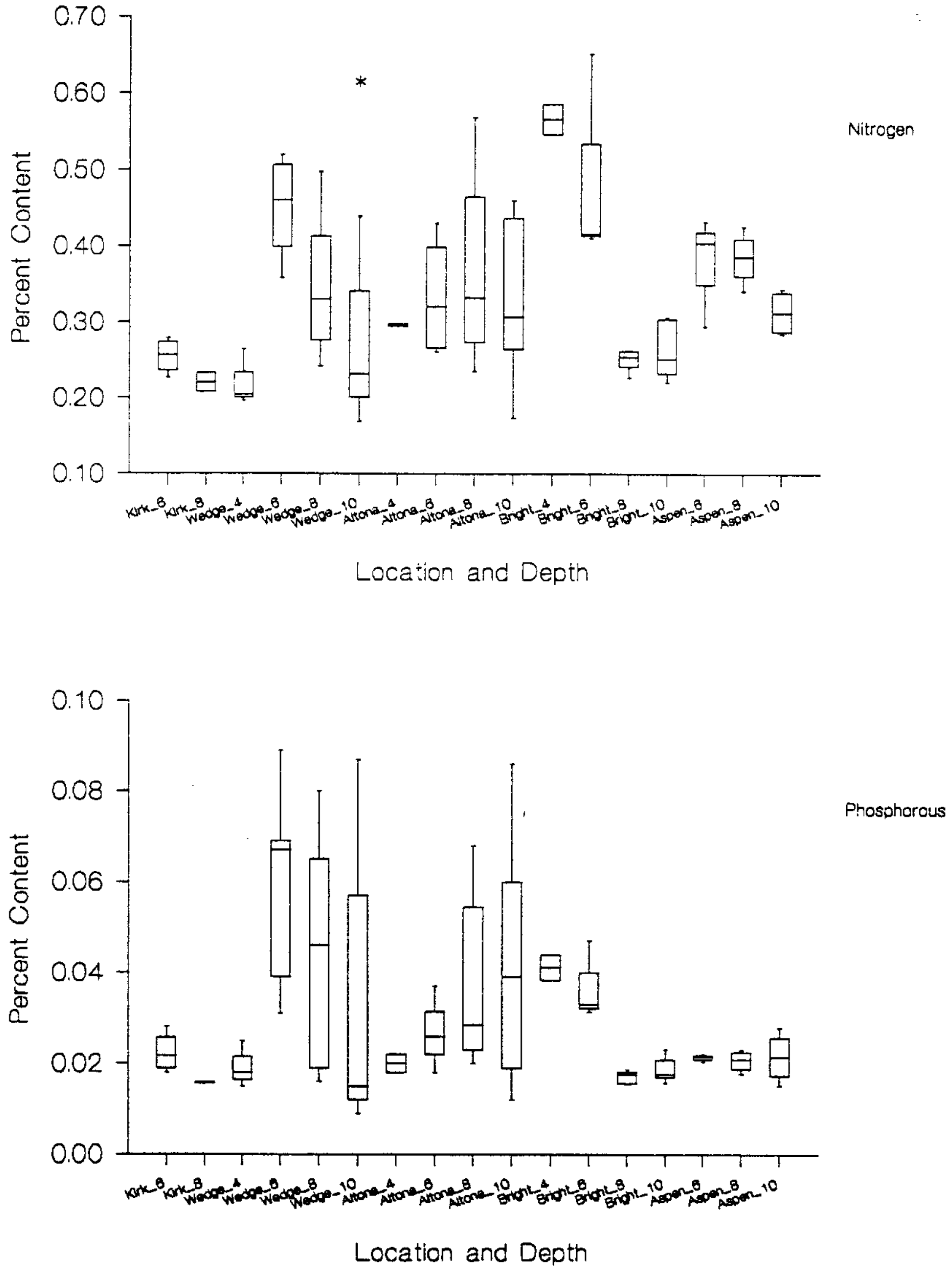
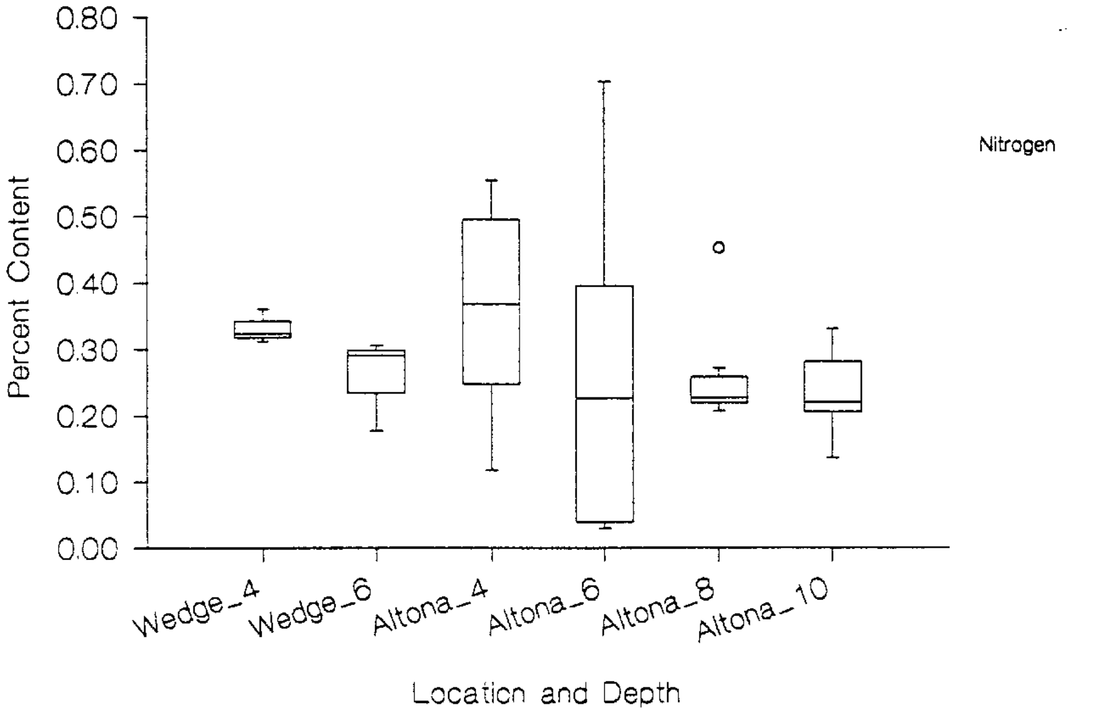


Figure 6a: Nitrogen and phosphorus content of *Caulerpa remotifolia*
Data are pooled over the 4 surveys



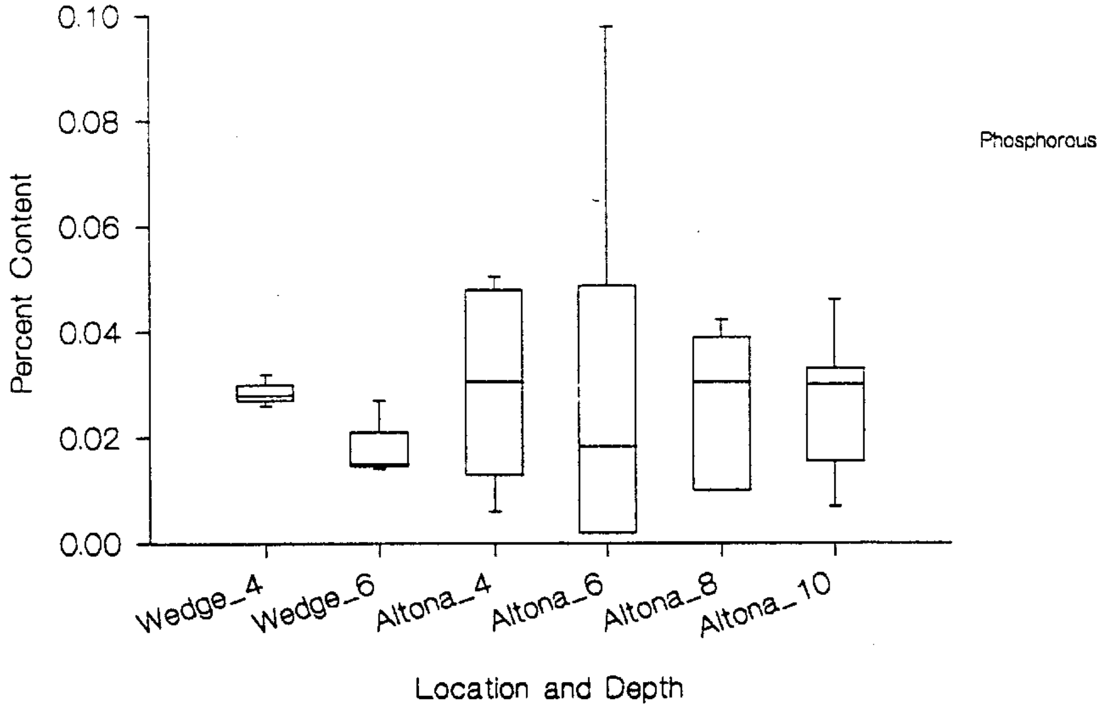


Figure 6b: Nitrogen and phosphorus content of *Botryocladia obovata*
Data are pooled over the 4 surveys

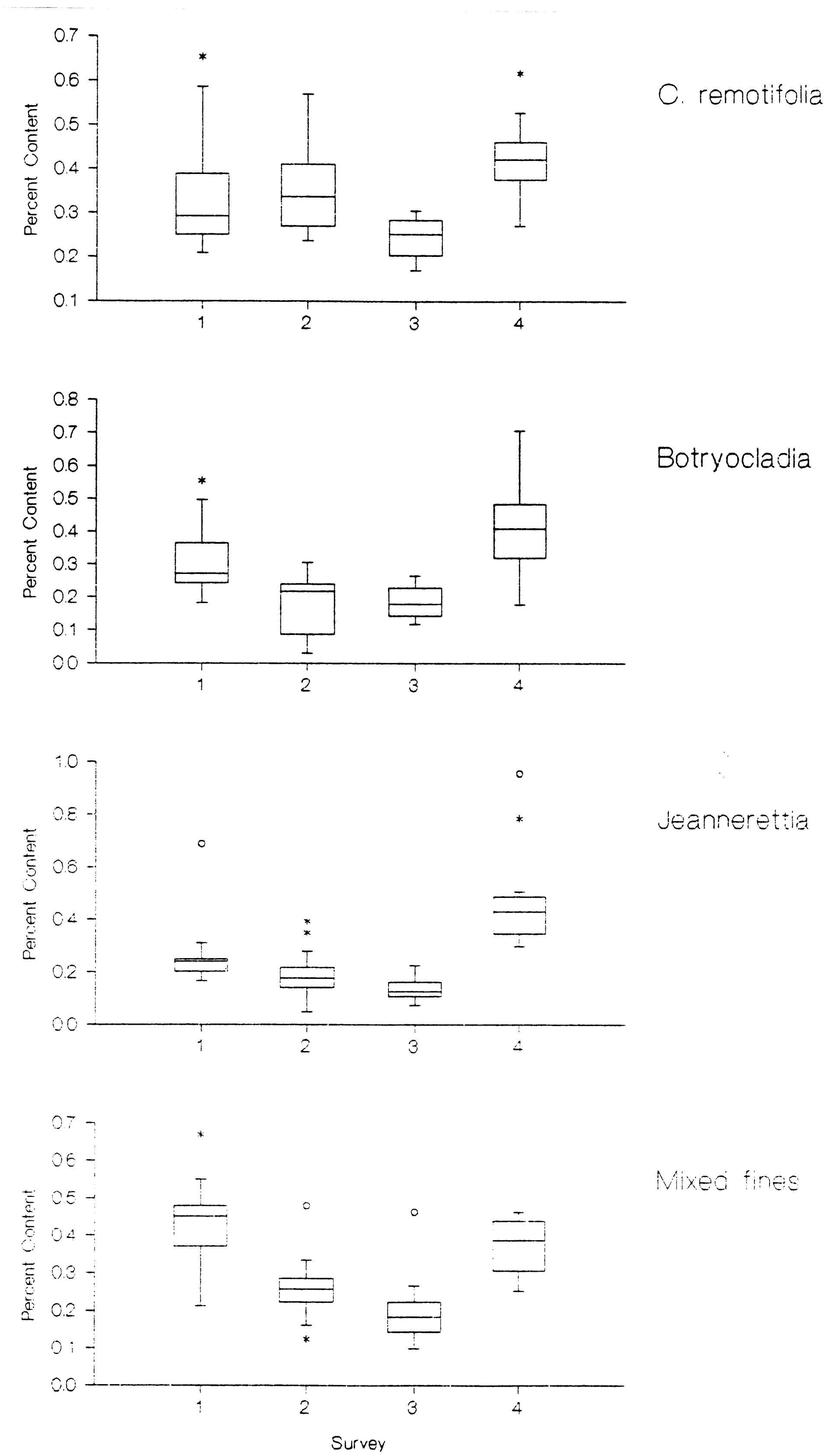


Figure 7a: Nitrogen content of common taxa for each survey
Data are pooled over all sites for each survey

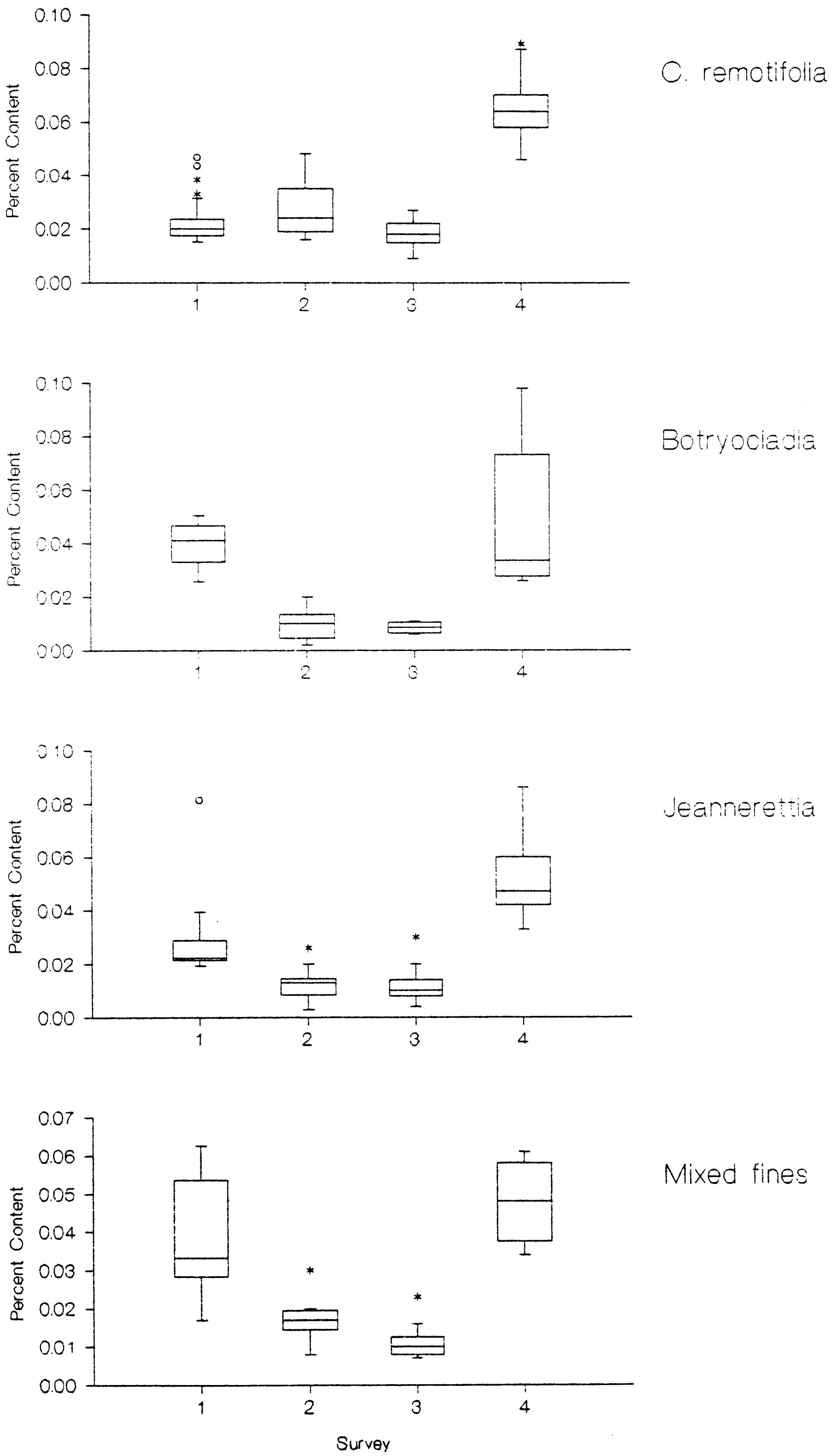


Figure 7b. Phosphorus content of common taxa for each survey
Data are pooled over all sites for each survey

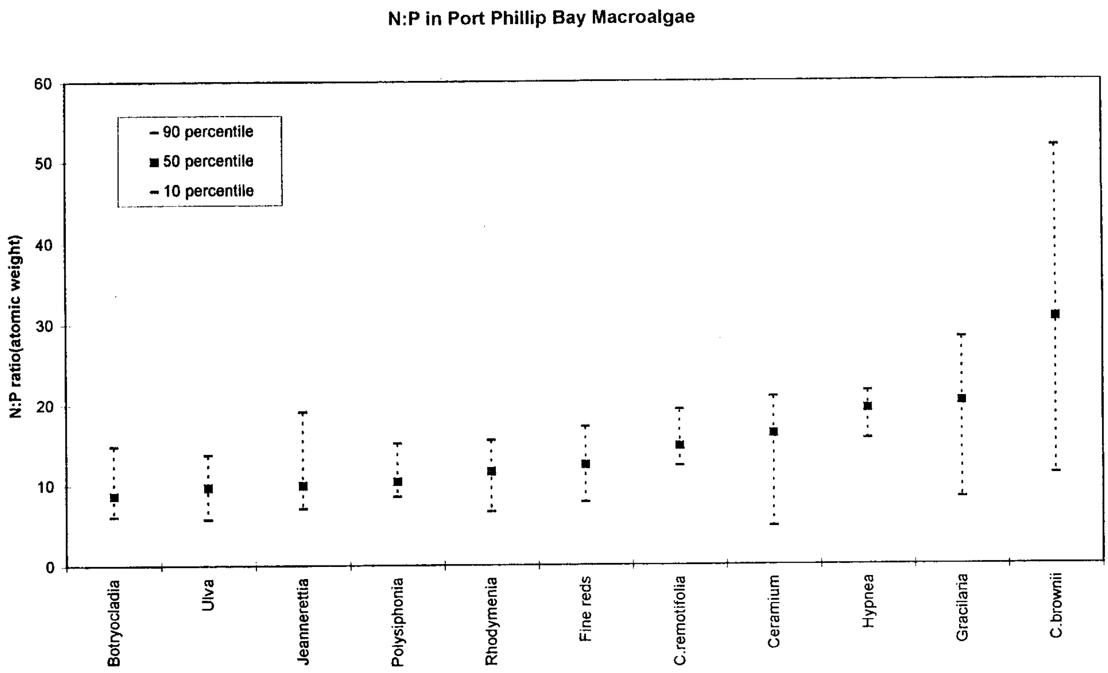


Figure 8: N:P in Port Phillip Bay macroalgae

3.6. Nutrient Content of Assemblages

The mean nitrogen and phosphorus content for the total assemblage at each site was calculated for each survey. The assemblage content was calculated using biomass for *Botryocladia*, *Jeannerettia*, *Caulerpa remotifolia* and the remaining taxa at each depth and time, and the median nutrient concentration for each of these taxa at each location (all depths were pooled) and time. The estimates for 'remaining taxa' were calculated using the nutrient content for mixed fine reds. The estimates for each taxa were then added together to provide an estimate of nitrogen and phosphorus content per square metre for the total assemblage (Tables 10 and 11).

The estimated nutrient content for the assemblages reflected differences between biomass between depths and times. The nitrogen and phosphorus content of assemblages at Wedge Point and Altona were generally one to two orders of magnitude higher than at Brighton and Aspendale, with intermediate values at Kirk Point (Tables 10 and 11). Although the nutrient content of the assemblages was largely a function of biomass, taxonomic differences were also influential at sites where biomass was high. For example, although the mean biomass was higher at the Altona 6m depth than the 4m depth in the first survey, the nitrogen content of the assemblage was greater at the 4m depth due to a higher proportion of taxa with high nitrogen concentrations (Table 10).

Table 10. Estimates of macrophyte nitrogen pools

		Nitrogen pool, mg/m^2			
Location	Depth	Survey 1	Survey 2	Survey 3	Survey 4
Kirk Point	4 m	0		33	108
	6 m	394		10	207
	8 m	102		1608	4077
	10 m	0		22	78
Wedge Point	4 m	423	1381	1218	1248
	6 m	2969	1588	396	7121
	8 m	2230	1733	216	19517
	10 m	80		527	1323
Altona Bay	4 m	4332	2101	393	232
	6 m	3088	2873	585	474
	8 m	7495	6190	3939	11197
	10 m	1437	1492	2227	3745
Brighton	4 m	22	13	123	2
	6 m	210	47	60	165
	8 m	118	151	28	38
	10 m	22	10	8	0
Aspendale	4 m	0	0	0	0
	6 m	278	372	611	49
	8 m	84	112	363	29
	10 m	52	45	51	15

Table 11. Estimates of macrophyte phosphorus pools

		Phosphorus pool, mg/m^2			
Location	Depth	Survey 1	Survey 2	Survey 3	Survey 4
Kirk Point	4 m	0		0.5	11.8
	6 m	28.8		0.2	23.8
	8 m	7.4		32.0	445.8
	10 m	0		0.3	8.7
Wedge Point	4 m	30.9	96.1	56.8	132.0
	6 m	359.0	106.3	11.2	965.2
	8 m	338.7	125.8	5.9	2967.5
	10 m	10.8		33.0	200.5
Altona Bay	4 m	324.3	139.9	19.5	25.2
	6 m	387.9	157.3	34.3	61.0
	8 m	971.3	379.1	252.3	1614.5
	10 m	207.9	107.6	160.3	564.1
Brighton	4 m	1.6	0.9	1.0	0.2
	6 m	15.3	3.4	1.2	18.2
	8 m	8.4	10.4	0.5	4.7
	10 m	1.6	0.7	0.1	0
Aspendale	4 m	0	0	0	0
	6 m	20.2	26.3	6.3	5.3
	8 m	6.1	7.8	3.2	3.3
	10 m	3.6	3.1	0.4	1.7

3.7. Macroalgal Standing Stocks and Nutrient Pools in Port Phillip Bay

The macroalgal standing stocks and nutrient pools were estimated using the mean biomass and assemblage nutrient content and the estimated area of each depth zone (3 to 5m, 5 to 7m, 7 to 9m, and 9 to 11m) within each of the five regions studied.

The total standing stock (wet weight) of macroalgae along the north coast of Port Phillip Bay from Kirk Point to Aspendale ranged from 100,000 to 240,000 tonnes (Table 12). The Wedge Point and Altona regions accounted for between 74 percent to 97 percent of the total standing stock of macroalgae.

The total macroalgal nitrogen pool was estimated to be between 200 tonnes and 1000 tonnes (Table 13). The phosphorus pool was between 10 tonnes and 144 tonnes (Table 14).

Table 12. Estimated macroalgal standing stocks in Port Phillip Bay

Location	Area ($\times 10^6$ m^2)	Standing stock estimate, tonnes Survey 1	Survey 2	Survey 3	Survey 4
Kirk Point	39.71	1520		17940	1611
Wedge Point	96.06	46444	45543	29206	159343
Altona Bay	55.76	79044	70732	52096	64437
Brighton	56.94	1381	1571	2188	719
Aspendale	43.97	1122	2859	8432	255
Total	292.44	129511	120705	109862	240865

Table 13. Estimated nitrogen pool in macroalgae in Port Phillip Bay

Location	Area ($\times 10^6$ m^2)	Nitrogen pool estimate, tonnes Survey 1	Survey 2	Survey 3	Survey 4
Kirk Point	39.71	7		25	69
Wedge Point	96.06	141	105	50	666
Altona Bay	55.76	225	180	120	271
Brighton	56.94	5	3	3	3
Aspendale	43.97	4	6	11	1
Total	292.44	382	294	209	1010

Table 14. Estimated phosphorus pool in macroalgae in Port Phillip Bay

Location	Area ($\times 10^6$ m^2)	Survey 1	Survey 2	Survey 3	Survey 4
Kirk Point	39.71	0.49		0.52	0.76
Wedge Point	96.07	18.09	7.42	2.44	96.80
Altona Bay	55.76	27.25	11.35	7.99	39.45
Brighton	56.94	0.39	0.22	0.04	0.33
Aspendale	43.97	0.32	0.40	0.11	0.12
Total	292.44	46.21	18.99	10.99	144.13

4. DISCUSSION

This study found a high biomass of unattached and attached algae in the north of Port Phillip Bay from 4 to 10m water depth. Macroalgae were particularly abundant along the northwest side of the Bay where predominantly unattached red algal species may blanket more than 90 percent of the seabed in patches of 10s to 100s of metres in size. The biomass offshore from Altona and Werribee is often above 200 g/m^2 and exceeds 4,000 g/m^2 on occasion.

In the northern parts of the Bay from Werribee to Aspendale, the total standing stock of macroalgae may be up to 240,000 tonnes and contain up to 1,000 tonnes of nitrogen and 144 tonnes of phosphorus at any one time. By comparison, the nitrogen pool in the phytoplankton of the Bay is estimated at 210 tonnes, and the microphytobenthos at 400 tonnes (Harris *et al.* 1996). Most of the algal biomass and nutrient pools are contained in the assemblages on the western side of the Bay.

4.1. Distribution of macroalgal assemblages

The macroalgal assemblages west of the Yarra River were distinct from those east of the river. Most algae from 4 to 10m depth at Altona, Wedge Point and Kirk Point were unattached red algal assemblages. Those at the Brighton and Aspendale locations were attached to solitary ascidians, mussels and shell fragments, and comprised mostly filamentous red algal species and various species of the green alga *Caulerpa*.

Predominant components of the assemblages differed between the locations east and west of the Yarra River. At Altona and Wedge Point the red alga *Botryocladia obovata* and other red algal species such as *Jeannerettia* and *Rhodymenia* were predominant. At Brighton and Aspendale, *Jeannerettia* and *Rhodymenia* were present in very low proportion and *Botryocladia* was absent. A variety of species were common to assemblages east and west of the Yarra River, although the proportions of these species varied substantially from site to site. These included *Caulerpa remotifolia*, *C. brownii* and various species of fine or filamentous red algae such as *Polysiphonia*, *Ceramium*, *Brongniartella*, and *Anotrichium*.

The characteristics of seabed by macroalgae was also different east and west of the Yarra River. At Altona, Wedge Point and Kirk Point the assemblages were distributed predominantly as unattached blankets of macroalgae interspersed with patches of bare sandy or silty seabed. Previous studies (Spencer 1970, Brown and Davies 1991) also found unattached, or “drift”, red algal assemblages including *Botryocladia*, *Jeannerettia* and *Rhodymenia* at Kirk Point, Wedge Point, offshore from the Werribee River and at Altona. The assemblages at Brighton and Aspendale were attached to the solitary ascidian *Pyura stolonifera*, which had a clumped distribution on the seabed. *Pyura* assemblages also have been observed by the authors at Sandringham, Mordialloc, Carrum, Seaford and Frankston.

The macroalgal assemblage composition changed with depth at the western sites. Depth related changes were not as distinct at Brighton and Aspendale where most macroalgal biomass was between 6 and 8m, with very little algal biomass outside this range of depths.

At the western locations, *Botryocladia* was dominant at the 8 and 10m depths. Other red algae (*Polysiphonia*, *Jeannerettia*, *Rhodymenia*, *Ceramium*) became dominant as depth reduced from 8 to 4m. This pattern is similar to those observed in the 1960's, late 1970's and early 1980's (Spencer 1970, Brown *et al* 1980, Brown and Davies 1986). *Botryocladia* was the predominant component of assemblages at 8 to 10m depths offshore from Wedge Point to the Werribee River in the late 1960's (Spencer 1970). *Polysiphonia*, *Jeannerettia*, *Rhodymenia, Ceramium* were observed to be predominant at 6m depth offshore from Wedge Point and the Werribee River in the late 1970's and early 1980's (Brown *et al* 1980, Brown and Davies 1986).

The green algae *Ulva* and *Cladophora* were minor components of the assemblages at the sites surveyed in this study, but, when present, they were most common at the 4m depths. This contrasts with shallower waters (< 2m) offshore from Kirk Point, Wedge Point and the Werribee River, where *Ulva*, *Cladophora* and *Caulerpa* were described as major components of the macroalgal assemblages (Spencer 1970, Brown *et al* 1980). The predominance and abundance of *Ulva* and *Caulerpa* in shallow water (< 4m) at Kirk Point and Wedge Point and episodic blooms of *Cladophora* were ascribed to the discharge of nutrients in effluent from the Western Treatment Plant (Spencer 1970, (Brown *et al* 1980). Their absence from deeper sites is probably due to light limitation.

A map of the distribution of "Caulerpa spp" (sic) was compiled during surveys of Port Phillip Bay from 1957-1963 (MacPherson 1966). The map shows "Caulerpa spp" distributed as a wide band from Kirk Point to Williamstown, with other areas on the Bellarine Peninsula, Ricketts Point and Frankston. Brown *et al* (1980) found that *Caulerpa* species dominated the nearshore soft seabed macroalgal assemblages (< 2m) near the Western Treatment Plant. Spencer (1972) found predominantly red algal assemblages offshore (> 4m) with *Caulerpa* as a minor component as was found in this study. Hence, it appears that the generalised distribution of *Caulerpa* beds along the western side of the Bay in the past (MacPherson 1966) was an incorrect extrapolation of shallow water observations into deeper water.

The results from our surveys (1995/96) and those from the 1960s, 70s and 80s indicate that the composition of the macroalgal assemblages along the northwest part of the Bay changes from predominantly green algae such as *Caulerpa* and *Ulva* in depths less than 4 m, to fine filamentous and sheet red algae in depths between 4 and 8m, to predominantly *Botryocladia* and filamentous red algae from 8m and beyond. The macroalgal assemblages and depth related changes offshore from the WTP appear to have been a feature of the area over the past 30 years.

The unattached nature, relatively high biomass and species composition of the macroalgal assemblages along the western side of the Bay from Kirk Point to Altona, contrasts with the *Pyura*-attached, relatively sparse *Caulerpa* and filamentous red algal assemblages along the eastern side of the Bay from Brighton to Aspendale. It appears that the Yarra River marks a distribution boundary between major macroalgal communities east and west of the river mouth, and may also mark a boundary between phytoplankton communities (Harris *et al.* 1996).

4.2. Biomass and productivity

This study provides the first documentation of macroalgal biomass and its variability in time for large areas of the Bay. Previous investigations of macroalgal biomass were limited to nearshore reefs adjacent to the Western Treatment Plant and Altona (O'Brien 1975, Brown *et al* 1980). Previous biomass investigations of unattached macroalgal assemblages were restricted to within patch measurements and did not provide data for standing crop estimates (Brown and Davies 1986). Other biomass data collected at Werribee, Altona and Carrum in the late 1960's cannot be located (Spencer 1970).

Macroalgal biomass measured on nearshore basalt reefs near the Western Treatment Plant outfalls during 1978-79 (Brown *et al.* 1980) ranged from 90 to 312 g/m^2 (dry weight). This is equivalent to a wet weight biomass range of 500 to 1,700 g/m^2 using the average wet/dry weight factor of 5.5 from samples collected during this 95/96 study. From this study, the mean macroalgal biomass at the 6 and 8m depths at Wedge Point of 900 and 1,500 g/m^2, respectively and Altona of 700 and 2,300 g/m^2, respectively, indicate that the macroalgal biomass at offshore sites on the western side of the Bay is much greater than the shallow water (< 4m) assemblages near the Western Treatment Plant.

Although our investigation does not directly provide data on productivity, the substantial variation in composition and biomass of the assemblages between surveys suggests the turnover rate of macroalgae is shorter than the period between surveys (3 to 4 months). Given the high biomass at the 6 and 8m depths on the western side of the Bay, the productivity of these assemblages may be substantial. Further investigation of the productivity of macroalgal assemblages is required to compare nutrient fluxes in major ecosystem components such as phytoplankton, microphytobenthos and benthic fauna.

4.3. Extent of assemblages and calculation of standing crop

The biomass associated with macroalgal assemblages on soft seabeds in the Bay is substantial. While the extent of these assemblages has not yet been mapped, the results of this investigation and other studies provide evidence that the macroalgal assemblages are widespread along the northwest coast of Port Phillip Bay.

Parry (Marine and Freshwater Resources Institute) advised that fish monitoring trawls at 7 and 12m depth offshore from the Werribee River (5 km northeast of Wedge Point and 15 km southwest of Altona Bay) often contain substantial quantities of red algae. However algae are relatively scarce in trawls east of the Yarra River, and in the southern parts of the Bay. In the late 1960's, Spencer (1970) observed "vast" quantities of *Botryocladia* at 8m depth extending at least 10 km from 1 km south of Wedge Point to past Werribee River but not at sites offshore from Little River (4 km west of Wedge Point) or at Kirk Point (consistent with our findings). Red algal cover were also observed in abundance at Altona (Spencer 1970, 1972). Large quantities of unattached macrophytes (red algae e.g., *Jeanerettia*) were found on the seabed offshore from the Werribee River and Point Cook 1983 to 1987 (Brown and Davies 1991).

From this evidence, it is apparent that unattached red algal assemblages are widespread for several kilometre offshore and extend from southwest of Wedge Point (but not as far as Kirk Point) to Altona Bay as shown in Figure 9. The high biomass measured at Wedge Point and Altona appears permanent feature of the northwest part of the Bay which has persisted from at least the late 1960's.

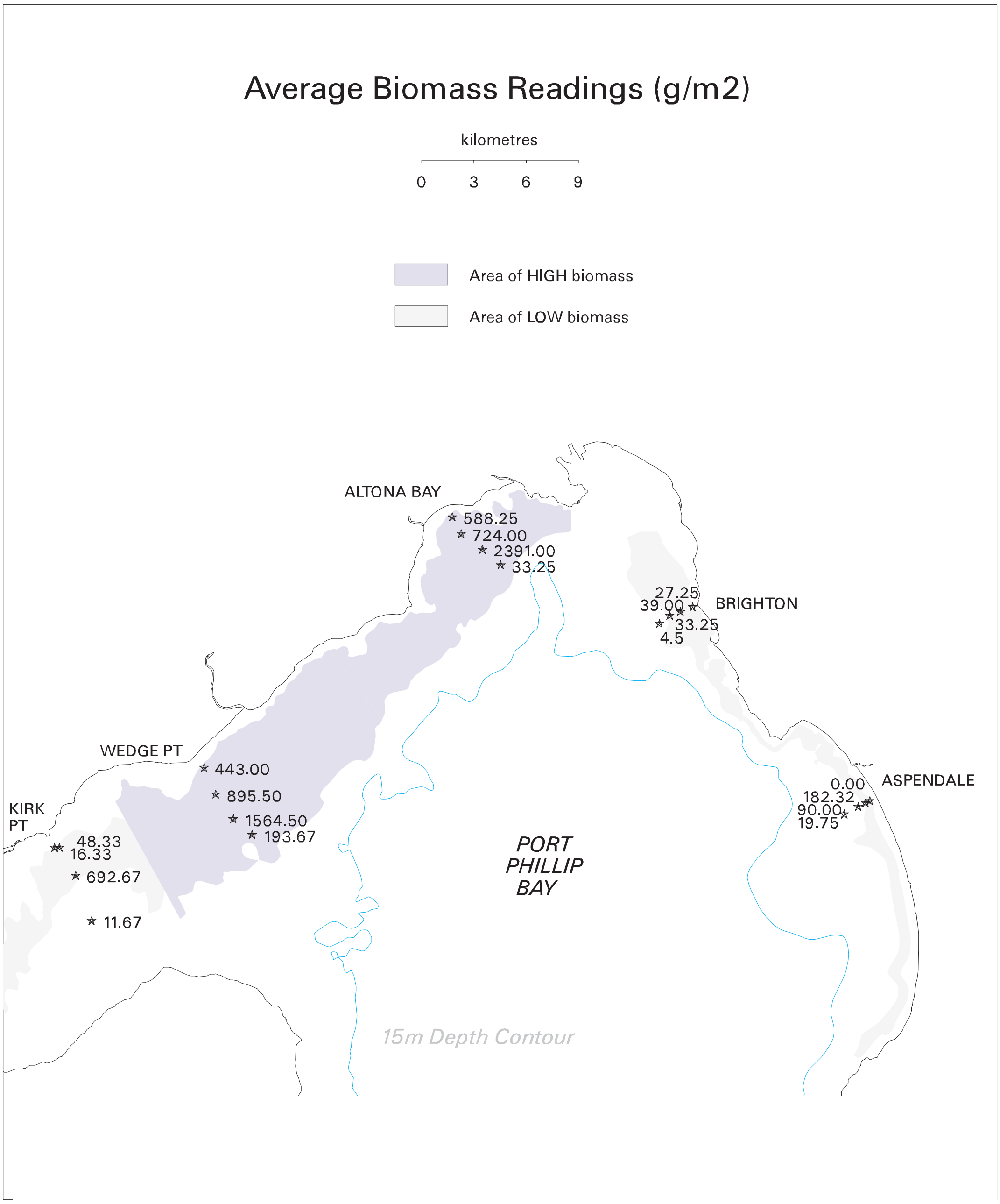


Figure 9: Probable distribution of high biomass macroalgal assemblages in the Bay

We estimate that standing crop of macroalgae in the north of Port Phillip Bay ranged from 110,000 tonnes to 240,000 tonnes. Our standing crop estimates are based on extrapolation of biomass along depth bands within regional zones and assume that the small scale patchiness in distribution is similar over the whole depth band. Most of the standing crop occurred between Wedge Point and Altona. If the Wedge Point and Altona Bay sites are typical of these regions, then our estimates are reasonable. However, if the Wedge Point and Altona sites had unusually high biomass compared to intermediate locations, then our standing crop for the Bay is an overestimate. Standing crop estimates for the Bay may be refined by measurements at more sites between Wedge Point and Altona, or mapping the extent of assemblages from validated remote sensing images.

4.4. Cover as an indicator of biomass and standing crop

Cover-biomass relationships are required to determine the standing crop of large areas of vegetation cover from remote sensing images (aerial photographs, satellite images, underwater video). The relationship between the percent cover and the biomass of algae was reasonably well described by a logistic function. Although this suggests that cover estimates may be used to monitor the biomass and associated nutrients pools of macrophytes in Port Phillip Bay, major limitations were found in the cover-biomass relationship.

One limitation is that the cover-biomass relationship represented by the β coefficient varied substantially between depths, locations and sampling times. No general trends were evident in relating β to location, depth or time, although β was related to algal composition at Altona and Wedge Point. Additional information is required, therefore, to determine the function coefficient and/or the assemblage structure of the algae each time the function coefficient is calculated so that biomass can be predicted from cover estimates.

A second limitation is the asymptotic nature of the relationship between cover and biomass. This means that when algal cover is high, biomass may vary by kilograms per square metre for the same algal cover value. This precludes accurate use of cover-biomass relationships at Altona and Wedge Point where the algae generally cover a high proportion of the seabed.

Because of these limitations, biomass assessments should continue to use physical collection methods (such as trawling or diver collection). However, this study was only over one year and it is possible that the β values are consistent from year to year. Hence, β values should continue to be examined to assess the ability of standing crop estimation using remote sensing techniques.

4.5. Macroalgae, water circulation and nutrient inputs

Water in the north of Port Phillip Bay generally circulates in a clockwise direction (Harris *et al* 1996). Hence, nutrient inputs to the Bay from the Western Treatment Plant, Werribee River and Little River tend to travel northeast from Werribee towards Altona and the Yarra River. Elevated concentrations of water column nutrients (e.g., ammonia-N) extend offshore and northeast of the Western Treatment Plant and Werribee River towards the Yarra River. Outputs from the Yarra River tend to travel down the southeast side of the Bay under the same clockwise water movement pattern. Elevated silica concentrations extend south from the Yarra River (Harris *et al* 1996).

The distribution of high macroalgal biomass from Wedge Point to Altona correlates with the transport path in the Bay's net clockwise water currents of nutrients from the Western Treatment Plant, and Werribee River towards Altona and the Yarra River.

There is a substantial reduction in standing crop and a change in macroalgal assemblage composition southeast of the Yarra River. In contrast, diatom populations are considerably higher in abundance from the Yarra River mouth to the south east than they are from Altona to the Werribee region (Harris *et al* 1996). Silica, other micronutrients and turbidity in Yarra River may favour the growth of diatoms (which require silica for their skeleton) down the eastern side of the Bay rather than benthic macroalgae. Different wave climates on the east and west sides of the Bay may also be a factor influencing plant growth at shallow sites.

4.6. Nitrogen pools and cycling

The range of estimates for the total nitrogen pool in benthic macroalgae in the northern part of the Bay is 200 to 1000 tonnes. This is substantially greater than the average nitrogen pool estimated for phytoplankton of 210 tonnes and for microphytobenthos of 380 tonnes, but is considerably less than the average nitrogen pool in benthic fauna of 3,000 tonnes (Harris *et al* 1996). The estimation of total nitrogen pool in macroalgae is largely dependant on the estimation of standing crop and is therefore subject to the limitations described for biomass estimations. However, our study indicates that the nitrogen contained in macrophytes at any one time is the major pool of plant nitrogen in the Bay.

The macroalgal assemblages in the western part of the Bay can form extensive blankets over the seabed. These thick macroalgal blankets are likely to have a significant influence on the cycling of nutrients between the water column and seabed. It is known that the exchange of nitrogen between the water column and seabed via phytoplankton and microphytobenthos is an important mechanism in nitrogen cycling and denitrification in the sediments of Port Phillip Bay (Harris *et al* 1996). The macroalgal blankets on the western side of the Bay may act as physical and biological barrier to this process. The macroalgal blankets may not only exclude microphytobenthos, but may also incorporate nitrogen that would otherwise be used by the microphytobenthos. The nitrogen in the macroalgae may not be as readily incorporated into sediments as plankton. Hence, denitrification may be reduced in areas of dense macroalgal growth.

4.7. Macroalgal distribution and nutrient enrichment

High abundances of macrophytes in the nearshore region of the Western Treatment Plant have been attributed to nutrient discharges from WTP drains at Murtcaim, Borrie, 145W and 15E. In particular, blooms of attached and drifting *Ulva* and *Cladophora* nearshore (< 2m water depth) from Kirk Point to 2 km east of Wedge Point are likely to be a direct response to nutrient enrichment (Brown *et al* 1980, Spencer 1970, Spencer 1972). Blooms of *Ulva* and *Cladophora* are often considered to be indicators of nutrient enrichment (e.g. Brown *et al.* 1980, Fairweather 1990, Dodds and Gudder 1992, Chidgey *et al.* 1994).

The high biomass and cover of red algal assemblages offshore from the Western Treatment Plant and Altona could be interpreted as bloom conditions. We suggest that the red algae comprising these assemblages are better adapted than the green algal species *Ulva* and *Cladophora* to use nutrients at depths between 4 and 10m. The distribution and abundance of the red assemblages offshore may be a response to nutrient discharges in the region of the Western Treatment Plant in the same way as the nearshore green algae.

It is speculated that higher loads of nutrients may increase the standing crop and seabed cover of these red macroalgal assemblages. This in turn could decrease denitrification processes in the seabed resulting in higher nitrogen pools in the Bay. Increased macroalgal growth also could result in increased amounts of macroalgae on beaches, anaerobic seabed conditions, and significant changes to seabed ecology.

4.8. Monitoring

A major outcome of the Port Phillip Bay Environmental Study has been a recommendation to reduce nitrogen loads on the Bay and to monitor trends in important components of nutrient cycling in the Bay (Harris *et al.* 1996). We have found that the high standing crop of macroalgae on the western side of Port Phillip Bay is a major pool of nitrogen in Port Phillip Bay and that the dense growth of macroalgae also may be an important influence on nitrogen cycling. The high macroalgal biomass offshore from the north-western coast of the Bay appear to be an indicator of elevated nitrogen loads in that region. Therefore, monitoring trends in the extent and biomass of macroalgae (and hence nutrient pool and extent of impact) on the western side of Port Phillip Bay should be a component of the Baywide nutrient monitoring program.

5. CONCLUSIONS

This study revealed important aspects of macrophytes in Port Phillip Bay:

- The soft sediments of Port Phillip Bay between 4 and 10m are a significant habitat for macroalgae;
- There is an extensive standing crop of macroalgae on the western side of the Bay which may extend up to 5 km offshore from the Western Treatment Plant to Altona;
- The macroalgal assemblages are variable in biomass and composition over a year and are therefore cycling nutrients;
- The macroalgal assemblages in north-western Port Phillip Bay can blanket the sediments and microphytobenthos, and may therefore be an important component of the water column/seabed nutrient flux pathway; and
- Regular surveys of macrophytes should be undertaken to document short term and long term changes in relation to nutrient inputs to the Bay.

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