IMPORTANCE OF SHALLOW WATER, REEF-ALGAL HABITATS AS NURSERY AREAS FOR COMMERCIAL FISH FROM SOUTHEASTERN AUSTRALIA

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EXECUTIVE SUMMARY

Subtidal reefs and associated algae together with nearby unvegetated sand habitats in depths of 2 to 7 m were sampled at six sites in Port Phillip Bay with visual SCUBA transects, gill nets and fish traps from November 1992 to May 1994. Species richness and abundance of fishes was much higher on reef-algal habitat compared with unvegetated habitat. Commercial species were observed in low numbers and were found predominantly on reef, however, no direct recruitment of juveniles of commercial species to reefs was observed. Results were consistent with other studies that show that larval recruitment is generally to very shallow habitats with movement to deeper reefs occurring at an older stage.

Shallow (< 1m depth) subtidal reef-algal, seagrass and unvegetated habitats were sampled monthly with a seine net at three sites on the western coast of Port Phillip Bay from October 1993 to March 1994. Juveniles of a number of important commercial species, that had previously been found in seagrass, were also collected from shallow reefs. The most important commercial species collected, King George whiting, showed a change in habitat preference with growth. Larval settlement was initially to seagrass and reef-algae, after three to four months most were found on reef-algae, and after five to six months most were found on unvegetated sand. Overall, the results indicated that shallow reef-algae was at least as important as seagrass to juvenile commercial fish, and supported the idea that larvae initially recruit to very shallow habitats before moving deeper with age.

To extend the generality of results, the sampling techniques used in Port Phillip Bay were applied along the western coast of the Gulf St Vincent in December 1994, and in Jervis Bay, NSW, in February 1995. In Gulf St Vincent, two seagrass habitats, unvegetated sand, and intertidal reef-algae were sampled with a seine net at six sites. In Gulf St Vincent the fish species present, and associated patterns of habitat preference, were similar to Port Phillip Bay. Like Port Phillip Bay, the most important commercial species encountered as juveniles was the King George whiting. Most juvenile King George whiting were collected on reef-algal and unvegetated habitats, consistent with the results for Port Phillip Bay for this species at a similar stage of development.

In Jervis Bay, shallow (< 1 m depth) reef-algal, unvegetated sand and seagrass (tapeweed) habitats were sampled by seine net, and deeper (2 - 7 m depth) reefs were sampled by SCUBA transect at six sites. Juveniles of commercial species were primarily collected in shallow (< 1 m) unvegetated habitat. A number of commercial species were observed on deeper reef, however, these were mainly older juveniles and adults. This result was consistent with previous studies in NSW that show that larvae of commercial species tend to recruit to estuarine eelgrass habitats and move to deeper habitats such as reefs at a later stage. Thus, results from both interstate areas showed consistencies with results from Port Phillip Bay.

Moderately exposed sandy beaches of Port Phillip Bay were sampled with a seine net from June 1993 to May 1994. Three sites were sampled monthly and five sites were sampled quarterly. At each site two depth zones were sampled, one extending from the waters edge out 10 m and a second 50 m offshore. Juveniles of a number of commercial species were collected in this habitat, with yellow-eye mullet the most abundant. The strongest pattern found was in the differences between zones, with the majority of juvenile fishes occurring in the inshore zone. Results showed that moderately exposed sandy beaches are an important habitat for juvenile commercial fish in Port Phillip Bay, and that shallow water 'per se' may represent a distinct nursery habitat.

The recruitment of the most important commercial species collected in Port Phillip Bay, the King George whiting, was studied in relation to climatic data and patterns of water movement simulated with a computer model. Seining was conducted at three seagrass sites, spanning approximately 40 km from Port Phillip Heads to the inner bay. Sampling was conducted every three to four days through September and October. Most juveniles were collected at the intermediate site, juveniles at the site nearest the heads occurred in short-lived pulses, while few juveniles were collected at the site furthest into the bay. Arrival of King George whiting larvae was found to be correlated with high water levels in the bay, produced by westerly winds and low barometric pressure. Arrival of larvae was also strongly correlated with the arrival of passive particles in a computer model simulation of water circulation over the same period. The model output was consistent with low numbers of juveniles at the site furthest from the entrance because few larvae would reach this point. Low numbers of juveniles at the site nearest to the entrance was not predicted from the model as larval supply should have been high. The appearance of pulses of juveniles at the site near the entrance was correlated with calm conditions, indicating that this site is too exposed to wind and currents for longer-term recruitment of juveniles.

To further examine the importance of location relative to habitat structure in the utilisation of habitat by King George whiting, artificial plant beds were deployed at five locations of varying distance into Port Phillip Bay. Patterns of abundance with distance into the bay was consistent with previous studies; with one location showing consistently high recruitment mostly unrelated to habitat structure. Collection of pre-settlement larvae offshore, and post-settlement juveniles in seagrass beds, at nine sites spanning the same area of coast, showed that patterns were consistent with the supply of larvae with the exception of a site close to Port Phillip Heads. This site had high numbers of larvae but low numbers of juveniles, probably because the site was too exposed for juveniles to persist.

Major conclusions were that shallow reefs were at least as important as seagrass beds as nursery habitats for juvenile commercial fish, but deeper reefs were important for older stages. Sandy beaches were also an important habitat for other species of juvenile commercial fish, and in particular, shallow sandy habitats were more important than deeper, suggesting that shallow water in itself may form a nursery habitat. For King George whiting, as long as some form of structure was present, location of the habitat, in relation to currents bringing larvae and exposure to rough conditions, were much more important than characteristics of the habitat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BACKGROUND

Attempts to manage fish stocks on the premise that recruitment is a predictable function of parent stock have largely been unsuccessful due to high variability in recruitment, that is largely independent of stock size (Sissenwine 1984). Research has largely implicated the role of survival of larval and juvenile stages in determining the size of year classes entering an exploitable stock (Doherty and Williams 1988).

Understanding the factors influencing the survival of young stages of commercial fish is therefore critical. For many species, the presence of a suitable habitat for juveniles may be of vital importance. This is now widely recognised by industry, which has expressed concern about the effect of habitat deterioration or loss on the future of some fisheries.

The importance of a habitat to juvenile, commercial fish may not only depend on the quality of the habitat (cover, food production, etc.), but also the location of the habitat relative to hydrodynamic processes such as currents. Settlement to habitats may be greater where currents patterns provide a high supply of larvae compared with similar habitats in areas where larval supply is low (McShane *et al.* 1988; Black *et al.* 1990).

Our previous FRDC funded project on the role of seagrass beds as nursery habitats produced a number of important results (Jenkins *et al.* 1993). Apart from providing direct habitat for commercial species such as stranger, rock flathead and leatherjackets; abundances and growth rates of juveniles of a number of commercial fishes, such as King George whiting and flounders, were higher in seagrass areas, primarily through enhanced food production rather than the traditional concept of protection from predators. Furthermore, seagrass beds of similar habitat quality in Port Phillip Bay varied consistently in the number of juvenile fish they supported, apparently due to their location relative to major current systems. The results of this study has already had an important influence on the planning of developments that might have impinged on seagrass habitats of importance to commercial fisheries.

This work leads to a number of further questions relating to habitat preservation for commercial fishes. Our previous work on seagrass further confirmed the importance of seagrass habitat to young stages of commercial fishes and crustaceans in Australia (Bell and Pollard 1989). In contrast to this, the role of shallow, reef environments in the early life history of commercial fishes in temperate Australia is virtually unknown. Do commercial fishes which utilise seagrass habitats also use reef habitats? Are there important commercial species that do not utilise seagrass habitat but do use reef habitat?

Shallow reefs can provide a significant area of habitat in temperate, coastal systems. For example, in Port Phillip Bay, the area of shallow reef-habitat is similar to the area of seagrasses. Reef habitat can be very complex due to the growth of macroalgae that usually occurs. Anecdotal information from fisherman suggests that these reef habitats are important for sub-adults of species such as snapper and King George whiting, however quantitative information is lacking. The patterns of utilisation of reef-algal habitats by young juveniles of species such as these is unknown.

A further habitat that has received little attention is unvegetated, sandy habitats. Our previous study of seagrass habitats included consideration of unvegetated areas adjacent to seagrass (Jenkins *et al.* 1993). These areas have been shown to be important habitats to juvenile, commercial fish because seagrass detritus that accumulates in these habitats supports significant populations of small crustaceans, which are the major dietary item of juvenile fish (Shaw and Jenkins 1992). The proposed study, however, would also investigate, unvegetated, sandy habitats that are sufficiently distant from other habitats not to be influenced by them (Ferrell and Bell 1991). A major question that can be investigated in relation to unvegetated habitats is whether shallow water 'per se' can provide a nursery habitat for juvenile commercial fish.

A mentioned previously, our study of seagrass habitats suggested that for some species, the location of the habitat may be of much greater importance than the characteristics of the habitat (Jenkins *et al.* 1993; Jenkins *et al.* 1994; Jenkins *et al.* 1996). In the present study we investigate the role of habitat structure relative to location by using artificial habitats. We also use a hydrodynamic computer model to investigate the possible role of currents delivering larvae in determining important recruitment locations for juvenile commercial fish.

The significance of the proposed project lies firstly in its definition of the role of shallow, reef-algal habitats together with shallow unvegetated habitats as nurseries for commercial species, and secondly its definition of the relative importance of habitat structure relative to location with respect to factors such as exposure and currents delivering larvae. This information will be important, firstly to fisheries managers who require knowledge of the population dynamics of these apparently crucial early phases in the life histories of commercial species; and secondly, to coastal planners and managers who need to reconcile competing resource demands, and often lack information about the long-term ecological importance of such areas.

The results of the present project are presented as six individual research reports each with introductory information outlining the research problem and need, description and justification of research methods, detailed results with statistical analyses, and discussion of results. Chapter 1 describes a study of subtidal reef-algal habitats in depths of 2 to 7 m of Port Phillip Bay and a comparison with adjacent unvegetated habitats. Chapter 2 describes a study of shallow (< 1m) subtidal reef-algal habitats of Port Phillip Bay with a comparison of nearby seagrass and unvegetated habitat. Chapter 3 describes a study of reef-algal habitats of Gulf St Vincent, South Australia and Jervis Bay, NSW, utilising the same techniques used in Port Phillip Bay. Chapter 4 describes a study of moderately exposed beach habitats in Port Phillip Bay. Chapter 5 describes a study of the recruitment of King George whiting to seagrass beds in Port Phillip Bay and compares results with the predictions of hydrodynamic numerical models. Chapter 6 describes a study of the recruitment of king George whiting to artificial habitats in Port Phillip Bay to determine the importance of habitat location relative to structure.

OBJECTIVES

(1) To undertake a field program aimed at describing and quantifying patterns of utilisation of shallow-water, reef-algal and unvegetated habitats in southeastern Australia by juvenile fishes of commercial significance. The resulting data base will be interpreted so that clear statements can be made to industry groups and environmental managers about the apparent value (or otherwise) of reef-algal habitat as a nursery for commercially-important species of fish.

(2) To undertake a field program aimed at determining the relative importance of habitat structure compared with hydrodynamic processes in determining the distribution of juvenile fishes in marine habitats. The resulting data base will be interpreted so that clear statements can be made to industry groups and environmental managers about the effect of hydrodynamic processes on the value of shallow-coastal areas as nurseries for important commercial fish.

CHAPTER 1

LARGE-SCALE VARIATION IN THE COMMUNITY STRUCTURE AND RECRUITMENT OF FISHES ASSOCIATED WITH REEF-ALGAL AND UNVEGETATED SANDY HABITATS IN PORT PHILLIP BAY

1.1 INTRODUCTION

Unlike many fields of marine ecology, where most effort has been concentrated in temperate waters rather than tropical areas, our knowledge of the processes structuring reef fish communities comes mainly from tropical environments. Although tropical coral reefs have a much higher diversity of species than temperate reefs, the standing crops of temperate reef fishes are surprisingly similar to those recorded from coral reefs (Russell 1977).

Temperate rocky reefs differ from tropical coral reefs in that macroalgae forms a major source of structural habitat. The presence of macroalgae, together with topographic complexity, are important factors affecting the distribution and abundance of reef fishes at various scales (Leum and Choat 1980; Jones 1984c; Jones 1988). Macroalgae can provide fish with a variety of resources: refuge from predators (Ebeling and Laur 1985; Carr 1989), sources of food (Jones 1984b; Carr 1989) and nursery areas for juveniles (Jones 1984a; Ebeling and Laur 1985; Behrents 1987). Large canopy forming algae such as *Macrocystis angustifolia* and *Ecklonia radiata* can also modify reef areas by damping the effects of waves and surge (Russell 1977).

It has often been assumed that temperate fish, including those of commercial importance, do not settle directly on to reefs, but rather migrate to reefs from shallow water 'nursery areas', for example mangroves and seagrass beds, at a later stage (Leum and Choat 1980; Kingett and Choat 1981). Numerous authors have demonstrated that direct settlement to temperate rocky reefs does occur (Jones 1984b; Cowen 1985; Levin 1991; Lincoln Smith *et al.* 1991; Levin 1993). However, recruitment can be extremely patchy, and complicated by various factors including algal cover (Jones 1984b) and depth (Leum and Choat 1980).

The factors establishing and changing populations of temperate reef fish are of fundamental importance, and it is not yet possible to say whether recruitment or post-recruitment processes are more important. The population dynamics of coral reef fishes appears to be strongly influenced by fluctuations in recruitment (Doherty and Williams 1988; Milicich *et al.* 1992; Doherty and Fowler 1994). Recruitment has been shown to be highly variable both spatially and temporally for many temperate reef fish species

(Leum and Choat 1980; Jones 1984c; Jones 1988 and references therein; Lincoln Smith *et al.* 1991), and this variation probably makes a considerable contribution to determining the abundance and composition of temperate reef fish communities, particularly at scales greater than individual reefs (Doherty 1987). It is necessary to understand the natural levels of variation in reef fish populations for use as a baseline in monitoring the possible effects of human impact, such as the disposal of sewage and increased fishing pressure (Lincoln Smith *et al.* 1991).

In south eastern Australia, shallow reef-algal areas represent a major habitat with the potential to significantly influence the structure of coastal fish communities. This study was designed to investigate broad spatial variation in community structure and recruitment of fishes to subtidal reefs, and to determine the importance of these reefs as settlement sites for fishes in Port Phillip Bay. There is a considerable body of research that demonstrates that seagrass beds contain a higher diversity and abundance of fishes than nearby unvegetated habitats (Bell and Pollard 1989; Ferrell and Bell 1991; Connolly 1994b), however, similar comparisons have not been made for temperate reef-algal areas. Consequently, a further aim was to ascertain whether the reefs supported a higher diversity of fishes and increased densities compared to the surrounding unstructured/unvegetated areas. Finally, the importance of reef-algal habitats for commercial fish species, including recruits and young juveniles, was assessed.

1.2 METHODS

1.2.1 Study sites

Port Phillip Bay is a large marine bay, with a narrow entrance and a small tidal range (~1 m). Reefs were composed of either basalt or ironstone. Six sites around Port Phillip Bay were selected for sampling (Fig. 1.1). Most sites had a high diversity of red and brown algae including *Ecklonia radiata* and species from the genera *Caulerpa*, *Laurencia* , *Sargassum* and *Cystophora* . The green alga, *Ulva* sp., was very common, especially at Altona, but extremely seasonal. Queenscliff was unusual with the presence of the seagrass, *Amphibolus antarctica.* These sites were considered representative of reefs within the bay, and the habitat types were readily distinguishable (Table 1.1). Unvegetated areas consisted of course to fine grained sand.

Table 1.1 Habitat characteristics of the six reef-algal sites in Port Phillip Bay.

Site	Queenscliff	Grassy Point	Avalon
Habitat	Rock flats	Low-medium relief reef	Shallow rock boulders
Depth (m)	3.0-5.0	1.5-3.0	1.0-2.5

Site	Altona	Black Rock	Mornington
Habitat	Shallow rock boulders	Medium relief reef	High relief reef
Depth (m)	2.0-4.0	2.0-4.0	2.0-6.0

1.2.2 Visual transects

Data were collected during four surveys from November, 1992 to April, 1993, and two surveys in January and May, 1994. Additional small-scale surveys were conducted in February and March, 1993, at four sites around the Black Rock area (Fig. 1.1). At each site, four transects were laid haphazardly over the reef. Fish were counted within one metre either side of the transect line using two methods. Conspicuous water column fish were recorded by a single SCUBA diver swimming steadily along the entire 50 metre transect (approximately one minute per 10 metres, referred to as fast transects). Cryptic fishes were counted by two divers (one either side of the transect line) actively searching through the vegetation along only 30 metres at a slower swimming speed (approximately 7 minutes per 10 metres, referred to as slow transects). All fish encountered were recorded and recruits were distinguished by their size (<40 mm total length). This procedure was repeated for the unvegetated areas only in January, March and April, 1993 when four fast transects and three slow transects were conducted on both the reef and unvegetated areas. Unvegetated areas were located adjacent to the reefs. Only four fast transects on the reef were conducted for the Black Rock area surveys.

1.2.3 Gill nets and fish traps

Additional methods for sampling reef and unvegetated habitats were gill nets in January, 1993, and fish traps in March and April, 1993. These methods were settled upon after pilot studies showed the rotenone would not be effective due to cold water temperatures and wave exposure. Sampling was not conducted using these methods at the Queenscliff site due to strong tidal currents. Gill nets were 30 m in length and 3 m depth with a 10 mm stretch mesh. Fish traps were triangular in shape, 1 m in length and 0.8 m in width, with an aperture of 20 cm by 6 cm, and a mesh size of 25 mm. Three replicate gill nets were randomly placed in each habitat in January, while two replicate fish traps were placed in each habitat in March and April. Gill nets and fish traps were set in the same area as visual transects for a period of two hours.

1.2.4 Statistical procedures

Only reef transects were analysed statistically as there was insufficient data from unvegetated areas for valid analysis. Analyses were conducted separately for the fast and slow transects, as the sampling method allowed the possibility of recounting individual fish. The only exception to this was for total species number which was pooled across fast and slow transects. Data were pooled for both divers on the slow transects. For analyses of total abundance, abundance less Atherinidae was considered a more representative measure, as atherinids, although sighted infrequently, may be considered pelagic and occurred in extremely high numbers which could only be approximated.

Before any statistical analyses were attempted, all data sets were subject to box and residual plots to test for normality and homogeneity of variances. If necessary, data were log (x+1) transformed. All data sets were analysed with analyses of variance (ANOVA) and unplanned comparisons (Tukey HSD tests). Exact p values were reported except where $p<0.001$ and significance was taken as $p<0.05$. Separate analyses were conducted for the more abundant species that showed considerable recruitment. Two analyses were conducted: November 1992, January, March and April, 1993 to compare monthly variation, and January and April 1993, January and May, 1994 to compare variation between years. Mixed model ANOVAS were used to compare sites (random) and months (fixed) in the first analysis, and sites (random), months (fixed) and years (fixed) in the second analysis.

The relative contribution to the total variance of each factor in the ANOVA was calculated from the variance components (Sokal and Rohlf 1981). For species number and total abundance a coefficient of variation, CV (standard deviation/mean) was calculated for the six main sites and the Black Rock area sites. For total abundance separate coefficients of variation were calculated for the fast and slow transects. Where $CV \geq 1.0$, variability was considered high (Lincoln Smith *et al.* 1991).

For multivariate analyses the data were transformed by $x^{0.25}$ and the Bray-Curtis similarity coefficient was calculated to generate similarity matrices for replicate samples (Clarke 1993). A two-way crossed analysis of similarities (ANOSIM), an analogue of multivariate analysis of variance with a randomisation test for significance, was used to compare sites and months. Where significant differences occurred multidimensional scaling (MDS) was used to plot the relationships amongst sites for each month. Separate monthly plots were created for the fast and slow transects where possible. Analyses were conducted with the PRIMER set of programs from Plymouth Marine Laboratory, England.

1.3 RESULTS

In total, 75 species representing 36 families, and an additional three families where species could not be identified, were visually censused on the reef-algal and unvegetated areas (Table 1.2). Most species were recorded on the reefs, with only four species (*Platycephalus bassensis*, *Ammotretis rostratus*, *Rhombosolea tapirina* and *Lepidotrigla vanessa*) occurring exclusively on unvegetated sand. A small selection of fishes (*Upeneichthys vlamingii*, *Tetractenos glaber*, Arripidae, Rajidae and Gobiidae particularly *Favonigobius lateralis*) were recorded from both habitat types.

1.3.1 Community structure

There was considerable overlap in the dominant species at each site (Table 1.2). The weedfish *Heteroclinus adelaide* and *H. perspicillatus* were among the five most abundant species at Avalon, Altona, Black Rock and Grassy Point. *Neoodax balteatus* was very abundant at Avalon, Black Rock, Grassy Point and Mornington. *Vincentia conspersa* was one of the dominant species at Avalon, Altona and Mornington, while *Trachinops caudimaculatus* was dominant at Avalon, Black Rock and Mornington. The leatherjacket *Acanthaluteres spilomelanurus* was abundant at Grassy Point and Mornington and the wrasse *Notolabrus tetricus* at Mornington and Queenscliff. Aside from *N. tetricus*, the remaining dominant species at Queenscliff were not among the most abundant at any of the other sites. In contrast, the sites at the northern end of the bay (Altona, Avalon and Black Rock) shared many dominant species. The northern bay sites tended to be characterised by small cryptic species, such as Clinidae, Gobiidae and Callionymidae, Grassy Point and Mornington possessed a combination of water column and cryptic species, while Queenscliff was dominated by water column species (Table 1.2).

Table 1.2 The total number of individuals visually recorded across all sites, habitats and months sampled. Recruits in brackets, pl=post larval, *=estimated number. Alt=Altona, Ava=Avalon, BR=Black Rock, Q=Queenscliff, GP=Grassy Point, M=Mornington.

Species	Sites					
	Alt	Ava	BR	Q	GP	M
Parascyllidae						
Parascyllium variolatum	0	0	0	5	0	0
Rhinobatidae						
Trygonorrhina guanerius	0	0	0	0	2	0
Gobiesocidae						
Gobiesocidae	6(1)	1	4(1)	0	0	0
Aspasmogaster tasmaniensis	0	0	1	0	0	0
Moridae						
Pseudophycis barbata	0	1	0	0	0	0
Atherinidae						
Atherinidae *	820	3180	230	0	640	3
Kestratherina esox	0	15	0	0	0	0
Syngnathidae						
Hippocampus breviceps	0	19	1	0	0	0
Hippocampus abdominalis	2	1	1	0	0	0
Phyllopteryx taeniolatus	0	0	0	1	0	0
Stigmatopora argus	0	7	1	0	2	0
Stigmatopora nigra	0	0	0	0	1	0
Stigmatopora spp.	3	4	0	0	0	0
Vanacampus phillipi	0	1	0	0	2	0
Scorpaenidae						
Gymnapistes marmoratus	0	1	1	0	27	0
Triglidae						
Triglidae	0	0	0	0	1	0
Lepidotrigla vanessa	0	0	0	0	1	0
Aploactinidae						
Aploactisoma milesii	0(1)	0	0	0	1	0
Pataecidae						
Aetapcus maculatus	0	0	0	0	1	0
Platycephalidae						
Platycephalus bassensis	3	0	1	0	1	1
Platycephalus laevigatus	0	0	0	0	0	1
Serranidae						
Caesioperca rasor	0	0	0	0	0	1
Plesiopidae						
Trachinops caudimaculatus *	0	126	259	0	7	1430(9)

Table 1.2 (Cont.) The total number of individuals visually recorded across all sites, habitats and months sampled. Recruits in brackets, pl=post larval, *=estimated number. Alt=Altona, Ava=Avalon, BR=Black Rock, Q=Queenscliff, GP=Grassy Point, M=Mornington.

Species	**Sites**					
	Alt	**Ava**	**BR**	**Q**	**GP**	**M**
Apogonidae						
Vincentia conspersa	10(9)	105(89)	11(6)	3	22(7)	24(4)
Siphaemia cephalotes	3	2(5)	8(1)	220	8(10)	0(2)
Dinolestidae						
Dinolestes lewini	0	0	0	1	0	0
Sillaginidae						
Sillaginodes punctata	0	0	0	0	0	8
Gerreidae						
Parequula melbournensis	0	0	0	100	0	0
Mullidae						
Upeneichthys vlamingii	0	1	6	21	20	9
Girellidae						
Girella zebra	25	7	0	3	0	10
Scorpididae						
Atypichthys strigatus	0	0	0	2	0	0
Scorpis aequipinnis	0	0	0	2	0	2
Tilodon sexfasciatum	0	0	0	2	0	1
Enoplosidae						
Enoplosus armatus	0	0	4	18	12	6
Aplodactylidae						
Aplodactylus arctidens	0	0	0	1	0	0
Cheilodactylidae						
Dactylophora nigricans	3	7	2	3	7	1
Cheilodactylus nigripes	0	0	0	7	0	4
Pomacentridae						
Parma victoriae	0	27	1	12	1	7
Labridae						
Labridae	0	0	0	1(15)	0	1
Dotalabrus aurantiacus	0	0	0	4	0	1
Eupetrichthys angustipes	0	0	0	0	0	1
Notolabrus tetricus	0	1	0	152	5	37
Pictilabrus laticlavius	0	0	0	3	1	8
Pseudolabrus psittaculus	0	0	0	2	0	0
Odacidae						
Haletta semifasciata	0	0	0	1	0	0
Neoodax balteatus	2(6)	135(61)	53(2)	0	286(62)	311(184)
Odax cyanomelas	0	0	0	9	0	0
Bovichtidae						
Bovichtus angustifrons	1	0	1	0	0	2
Blennidae						
Blennidae	0	3	0	1	0	1
Parablennius tasmanianus	8(11)	4	2(2)	1	0	2
Tripterygiidae						
Tripterygiidae	6(1)	3	8(2)	5	0	12
Norfolkia clarkei	3(5)	0	16(5)	0	0	17

Table 1.2 (Cont.) The total number of individuals visually recorded across all sites, habitats and months sampled. Recruits in brackets, pl=post larval, *=estimated number. Alt=Altona, Ava=Avalon, BR=Black Rock, Q=Queenscliff, GP=Grassy Point, M=Mornington.

Species			Sites			
	Alt	**Ava**	**BR**	**Q**	**GP**	**M**
Clinidae						
Clinidae	50(6)	32(1)	12(8)	9(1)	26(6)	10
Cristiceps aurantiacus	0	0	0	0	0	1
Cristiceps australis	12	9	5(1)	2(1)	14(2)	4(1)
Heteroclinus adelaide	66(28)	51(32)	33(10)	1	28(22)	0(2)
Heteroclinus heptaeolus	1	0	2	0	0	0
Heteroclinus johnstoni	0	4	0	1	1	3
Heteroclinus perspicillatus	119(14)	35(4)	33(9)	0	37(5)	14(3)
Heteroclinus tristis	0	0	0(2)	0	0	0
Heteroclinus wilsoni	0	0	3	1	0	0
Callionymidae						
Callionymidae	2(2)	1	18(3)	0	0	0
Eocallionymus papilio	0	1	6	0	0	0
Foetorepus calauropomus	2	1	18(1)	0	0	0
Gobiidae						
Gobiidae	62(1)	549(5) +288pl	17(1)	1	8(1)	0
Callogobius sp.	2	0	7	0	1	0
Favonigobius lateralis	0	0	0	0	2	6
Nesogobius pulchellus	16	37	2	0	24	0
Nesogobius sp.1	1	2	0	0	0	0
Nesogobius sp.2	0	1	0	0	6	0
Pleuronectidae						
Ammotretis rostratus	0	0	1	0	1	0
Rhombosolea tapirina	1	0	0	0	0	0
Monacanthidae						
Monacanthidae	0(13)	0	0(3)	2	0	1(1)
Acanthaluteres spilomelanurus	7(2)	1(3)	1	7	55(9)	273(14)
Acanthaluteres vittiger	0	0	1	4	16	1
Brachaluteres jacksonianus	4(1)	7(1)	13(1)	0	4(1)	15(3)
Meuschenia australis	0	0	0	2	0	2
Meuschenia flavolineata	0	0	1	5	0	1
Meuschenia freycineti	0	9	2	2	2	6
Meuschenia hippocrepis	0	0	0	0	0	2
Meuschenia scaber	0	0	0	3	0	0
Meuschenia trachylepis	0	0	0	0	1	0
Scobinichthys granulatus	0	2	3	1	11	3
Tetraodontidae						
Tetractenos glaber	8	0	3	1	0	2
Diodontidae						
Diodon nicthemerus	18	30	2	0	0	15
Other Families						
Rajidae	4	6	3	0	11	4
Ophichthidae	4	0	1	0	1	0
Arripidae	0	40	0	10	0	0

ANOSIM revealed a difference amongst the sites, for both the fast and slow transects. Monthly two dimensional MDS ordination plots tended to support the observation that the species composition at Queenscliff was quite different from the remaining sites (Figs 1.2 and 1.3). In some months, especially January 1993 (Fig. 1.3), Mornington also appears quite separate. These results support the contention that more water column species were recorded at Queenscliff than the northern bay sites, and an intermediate species composition, including both water column and cryptic species, was found at Mornington. There was a tendency for the site replicates to group together which supports these site differences (Figs 1.2 and 1.3).

1.3.2 Total species number

The total number of species was considerably and consistently higher on the reefs compared to the unvegetated habitats (Fig. 1.4). An analysis comparing species number on the reef habitat from November 1992 to April 1993 revealed significant effects of both site and month, and these factors accounted for 21.4% and 41.7% of the total variation respectively (Table 1.3). Avalon, Mornington and Black Rock recorded the highest numbers of species, significantly greater than Queenscliff and Altona (Fig. 1.4). Species number was significantly lower in November 1992 than the remaining months at all sites.

Table 1.3 ANOVA results for the comparisons between November 1992, January, March and April 1993 for species number (untransformed) and total abundance (log transformed).

Source	df	MS	F	p	% variance
Species Number					
Site	5	38.825	7.941	<0.001	21.4
Month	3	100.458	95.928	<0.001	41.7
Site*Month	15	1.047	0.214	0.999	0
Error	48	4.889			36.9
Total Abundance					
fast transects					
Site	5	14.090	18.754	<0.001	38.4
Month	3	12.446	10.102	<0.001	21.5
Site*Month	15	1.232	1.640	0.084	5.5
Error	72	0.751			34.6
slow transects					
Site	5	7.848	21.637	<0.001	50.8
Month	3	3.970	7.805	0.002	15.6
Site*Month	15	0.509	1.402	0.185	4
Error	48	0.363			29.6

An ANOVA comparing total species number in January and April 1993 with January and May 1994 revealed significant effects of site and year (Table 1.4). Significantly fewer species were recorded at Queenscliff and Altona than Grassy Point, Avalon and Mornington and the number of species recorded was significantly lower in 1994 (Fig. 1.4).

In the Black Rock area surveys the total species number varied significantly amongst sites only (Fig. 1.5A). The effect of site accounted for 21.1% of the total variation (Table 1.5). Species number at Red Bluff was significantly greater than Sandringham. Coefficients of variation for the six sites and the Black Rock area sites were 0.409 and 0.313 respectively, suggesting variation was low and bay-wide variation was not much greater than small-scale variation.

1.3.3 Total abundance

Total abundance was consistently higher on the reef-algal compared to unvegetated habitats and the results reported refer only to the reef transects (Fig. 1.6). Analyses comparing abundance from November 1992 to April 1993 revealed significant effects of site and month for both the fast and slow transects (Table 1.3). However, site accounted for a greater proportion of the total variation (Table 1.3). For the fast transects, total abundance at Altona was significantly lower than the remaining sites, while at Mornington abundance was significantly greater. For the slow transects, Queenscliff showed the lowest total abundance, significantly lower than the other sites. High abundances were recorded at Avalon and these were significantly higher than all sites except Mornington.

Analyses comparing total abundance in January and April 1993 with January and May 1994 revealed significant interactions between sites, months and years, for both the fast and slow transects; however, site accounted for 37% and 29.3% of the total variation respectively (Table 1.4). For the fast transects, Mornington and Grassy Point had the highest total abundances in both years, significantly greater than all sites except Queenscliff in 1994. In 1993 abundances at Altona were significantly lower than the other sites. For the slow transects, abundances were significantly lower at Queenscliff than all other sites in 1993, while there was no significant difference between the sites in 1994.

Table 1.4 ANOVA results comparing January and April, 1993 with January and May, 1994 for species number (untransformed) and total abundance (log transformed).

Source	df	MS	F	p	% variance
Species number					
Year	1	72.000	8.963	0.030	14.9
Month	1	34.722	3.659	0.114	5.9
Site	5	32.356	7.688	<0.001	19.7
Year*Month	1	26.889	5.860	0.060	10.4
Year*Site	5	8.033	1.909	0.110	5.3
Month*Site	5	9.489	2.255	0.064	7.4
Year*Month*Site	5	4.589	1.090	0.378	1.1
Error	48	4.208			35.3
Total abundance					
fast transects					
Year	1	6.637	1.475	0.279	1.8
Month	1	0.001	0.001	0.984	0
Site	5	15.201	23.489	<0.001	37
Year*Month	1	0.922	0.614	0.469	0
Year*Site	5	4.499	6.951	<0.001	19.6
Month*Site	5	1.923	2.972	0.017	6.5
Year*Month*Site	5	1.500	2.318	0.052	8.7
Error	72	0.647			26.4
slow transects					
Year	1	6.196	4.749	0.081	9.7
Month	1	9.442	19.182	0.007	17.7
Site	5	5.214	18.168	<0.001	29.3
Year*Month	1	1.746	4.166	0.097	5.2
Year*Site	5	1.305	4.546	0.002	12.1
Month*Site	5	0.492	1.715	0.149	2.4
Year*Month*Site	5	0.419	1.460	0.220	3.1
Error	48	0.287			20.5

In the Black Rock area surveys there was a significant effect of site only, which accounted for 45.9% of the total variation (Fig. 1.5B; Table 1.5). Red Bluff had total abundances significantly greater than the other sites, which were not significantly different. Coefficients of variation for the six main sites were 1.867 (fast) and 1.291 (slow) suggesting high variability in abundances between the sites. In contrast, the coefficient of variation for the Black Rock area sites was only 0.803.

Table 1.5 ANOVA results comparing total species number (untransformed) and total abundance less Atherinidae (log transformed).

Source	df	MS	F	p	% variance
Species number					
Site	3	4.865	3.134	0.044	21.1
Month	1	0.781	0.510	0.527	0
Site*Month	3	1.531	0.987	0.416	0
Error	24	1.552			78.9
Total abundance					
Site	3	3.315	10.796	p<0.001	45.9
Month	1	2.440	9.052	0.057	16.6
Site*Month	3	0.270	0.878	0.466	0
Error	24	0.307			37.5

1.3.4 Commercial species

Eight commercial species were encountered on the visual transects. The most common species, *Meuschenia freycineti*, *Scobinichthys granulatus* and *Upeneichthys vlamingii* were primarily recorded on the reef. *M. freycineti* individuals were recorded from all sites except Black Rock, predominantly from Avalon and Grassy Point, and *S. granulatus* from all sites except Altona, predominantly from Grassy Point (Table 1.2). *U. vlamingii* were reported from all sites except Altona, predominantly at Queenscliff and Grassy Point (Table 1.2), with all but three individuals occurring on the reef.

A number of commercial species were recorded less frequently. Forty Australian salmon, *Arripis* spp. were found on the reef at Altona in November 1992 and ten individuals were encountered on the unvegetated sand at Queenscliff. King George whiting, *Sillaginodes punctata*, were recorded on one occasion in January 1994 on the reef at Mornington. A single Greenback flounder, *Rhombosolea tapirina*, was recorded in March 1993 at Altona and two longsnout flounder, *Ammotretis rostratus*, were recorded in January 1993 at Grassy Point and Black Rock. Sand flathead, *Platycephalus bassensis*, were recorded at four sites (Mornington, Black Rock, Grassy Point and Altona). No recruits of commercial fish species were recorded.

Only three commercial species were sighted on the reef-algal visual transects in the Black Rock area. Two grass flathead, *Platycephalus laevigatus*, were observed at Red Bluff in February. In March, two *Scobinichthys granulatus* individuals were reported from Parkdale and Beaumaris, while red mullet, *Upeneichthys vlamingii*, were recorded at all four sites in both February and March.

Catches from gill nets and fish traps were dominated by leatherjackets (Monacanthidae), particularly from Grassy Point, Avalon and Mornington (Fig. 1.7).

Two commercial species, *Meuschenia freycineti* and *Scobinichthys granulatus*, were commonly collected in fish traps on reefs. Distribution of these species reflected that found with visual transects, *M. freycineti* were predominantly collected at Grassy Point and Avalon (Fig. 1.8) whilst *S. granulatus* were predominantly collected from Grassy Point (Fig. 1.9). Total lengths of leatherjackets ranged from 168 to 294 mm for *M. freycineti* and 110 to 267 mm for *S. granulatus*.

1.4 DISCUSSION

This study revealed increased species richness and abundances on the reefs compared to adjacent unvegetated-sandy areas at all sites examined. Howard (1989) found the overall abundance, number of species and biomass of fishes to be higher around limestone patch reefs than the surrounding sand/seagrass flats. Species number and fish biomass were significantly correlated with reef structure. Significant correlations between fish abundances and site variables were few, however, three of the five most abundant species showed significant relationships with reef structure, two species with seagrass and/or total macrophyte cover, while no species were correlated with unvegetated sand (Howard 1989). Comparisons between seagrass and unvegetated habitats have also yielded similar results (Heck Jr *et al.* 1989; Ferrell and Bell 1991; Connolly 1994a). Assemblages associated with seagrass tend to consist mainly of small, inconspicuous species and juveniles of larger species, whereas unvegetated areas are characterised by adults of large, mobile fish and species protected by either schooling behaviour or camouflage (Bell and Pollard 1989). A similar pattern was revealed for the unvegetated sand in this study, with families such as Platycephalidae, Pleuronectidae, Gobiidae (all protected by camouflage) and Arripidae (protected by schooling behaviour) recorded on the unvegetated habitat. In contrast to seagrass beds, individuals recorded on these reefs were not necessarily small and cryptic, or the juveniles of larger species.

Community structure showed wide variation amongst the reef sites, a common finding in reef fish studies from both temperate and tropical systems (Leum and Choat 1980; Kingett and Choat 1981; Choat and Ayling 1987; Choat *et al.* 1988). In general, lower numbers of species were recorded at Altona and Queenscliff compared to Avalon and Mornington. The community at Queenscliff was dominated by water column species that were conspicuous to divers, so this result is unlikely to be due to sampling biases. The transects at Queenscliff were, however, run over the reef flats, and therefore individuals hiding under the ledges, which were not sampled in this study, would not have been recorded. In contrast, the communities at Avalon, Black Rock and Altona were dominated by small cryptic families including the Blenniidae, Clinidae, Gobiidae and Apogonidae. Algal cover at Altona was quite low and this may explain the low number of species recorded, especially as many temperate reef fish rely on extensive cover (Ebeling and Laur 1985; Carr 1994).

Variation in species number was generally low, and was only marginally higher at the bay-wide scale compared with the smaller scale at Black Rock. In contrast, total abundance showed relatively higher variability, and the bay-wide scale showed considerably greater variation than the small scale. This high variability at the large spatial scale may be related to a number of factors including greater variability in habitat structure and recruitment at a broad scale (Bell *et al.* 1988; Carr 1989; Carr 1991; Carr 1994).

The total abundance of fish varied substantially between the sites. The fast transects, which recorded the larger water column species, showed higher abundances at Grassy Point and Mornington and low numbers at Altona. In contrast, the slow transects, which showed a bias towards the smaller cryptic species, recorded high abundances at Avalon and Mornington and very low abundances at Queenscliff. There are a number of possible reasons for the spatial differences in community structure and abundance between these reef-algal sites. Reef sites in Port Phillip Bay varied in bottom topography, algal assemblages and exposure to current and swell. Habitat type, in terms of bottom topography and macroalgal cover, has been shown to be important in influencing the distribution and abundance of many fish species (Connell and Jones 1991; Levin 1991; Carr 1994). Choat and Ayling (1987) found that reefs dominated by macroscopic algae supported large numbers of smaller fishes, mainly labrids, and concluded that reef type played an important role in determining the associated fish fauna. Larson and De Martini (1984) concluded from their study that kelp, *Macrocystis pyrifera*, enhanced the standing stock of fishes in areas of low-bottom relief on a southern California temperate reef.

Commercial species were observed in low numbers and were found predominantly on reef. No larval recruitment of commercial species to reefs was observed. Seagrass beds immediately inshore of the reefs sampled at Grassy Point and Altona had large numbers of recruits of King George whiting, *Sillaginodes punctata*, and sixspine leatherjacket, *Meuschenia freycineti* (Jenkins *et al.* 1996). High abundances of post-settlement *S. punctata* have also been recorded on the shallow (<1 m) rubble reef off Grassy Point (Chapter 2). A study by Middleton *et al.* (1984) found that some fish species settled into *Zostera muelleri* during spring, and remained there for a period of about four months before moving to other habitats, specifically *Posidonia australis* seagrass beds, but also mangroves and rocky reefs. Weinstein and Heck (1979) found that juveniles of reef-associated predators were common in the seagrass beds along the coast of the Republic of Panamá. Links between shallow inshore habitats in estuaries and deeper coastal rocky reefs have also been shown for a variety of species in New South Wales (Bell and Worthington 1992; Gillanders and Kingsford 1992).

Inshore reefs such as those sampled in this study are targeted by recreational and commercial fisherman for subadult King George whiting, *Sillaginodes punctata*, and snapper, *Pagrus auratus*, in Port Phillip Bay. In our sampling we only encountered subadult *S. punctata* on one occasion, and no *P. auratus* were recorded. Our sampling methods may have biased against these species, which form schools, are highly mobile, and may be sensitive to disturbance by divers. Alternatively, our sampling may have been conducted during a period of poor juvenile recruitment. No larval recruitment of these species was recorded. As mentioned previously, larval *S. punctata* are known to recruit to very shallow (< 1 m) seagrass and reef-algal habitats (Chapter 2). Larval recruitment of snapper, however, has not been recorded in shallow habitats. It is possible that larval recruitment of snapper in Port Phillip Bay is similar to that in Japan (Azeta *et al.* 1980) and New Zealand (Francis *et al.* 1992) where the smallest individuals are collected from soft sediments in the deeper central areas of embayments.

1.5 CONCLUSIONS

A much higher diversity and abundance of fishes was recorded on the reefs compared to the unvegetated sand habitats. Major changes in community structure around the bay may be related to bottom topography and macroalgal cover, as these factors differed between the sites. Spear fishing is an important consideration, especially where sites were easily accessible to the general public. The northern bay sites tended to have fewer large water column species and were subject to extensive spear fishing activity. We observed minimal recruitment to the reefs sampled and no recruitment of commercial species. It is possible that many of the commercial species recruit to seagrass and shallower reef areas before migrating to deeper reefs at a later stage.

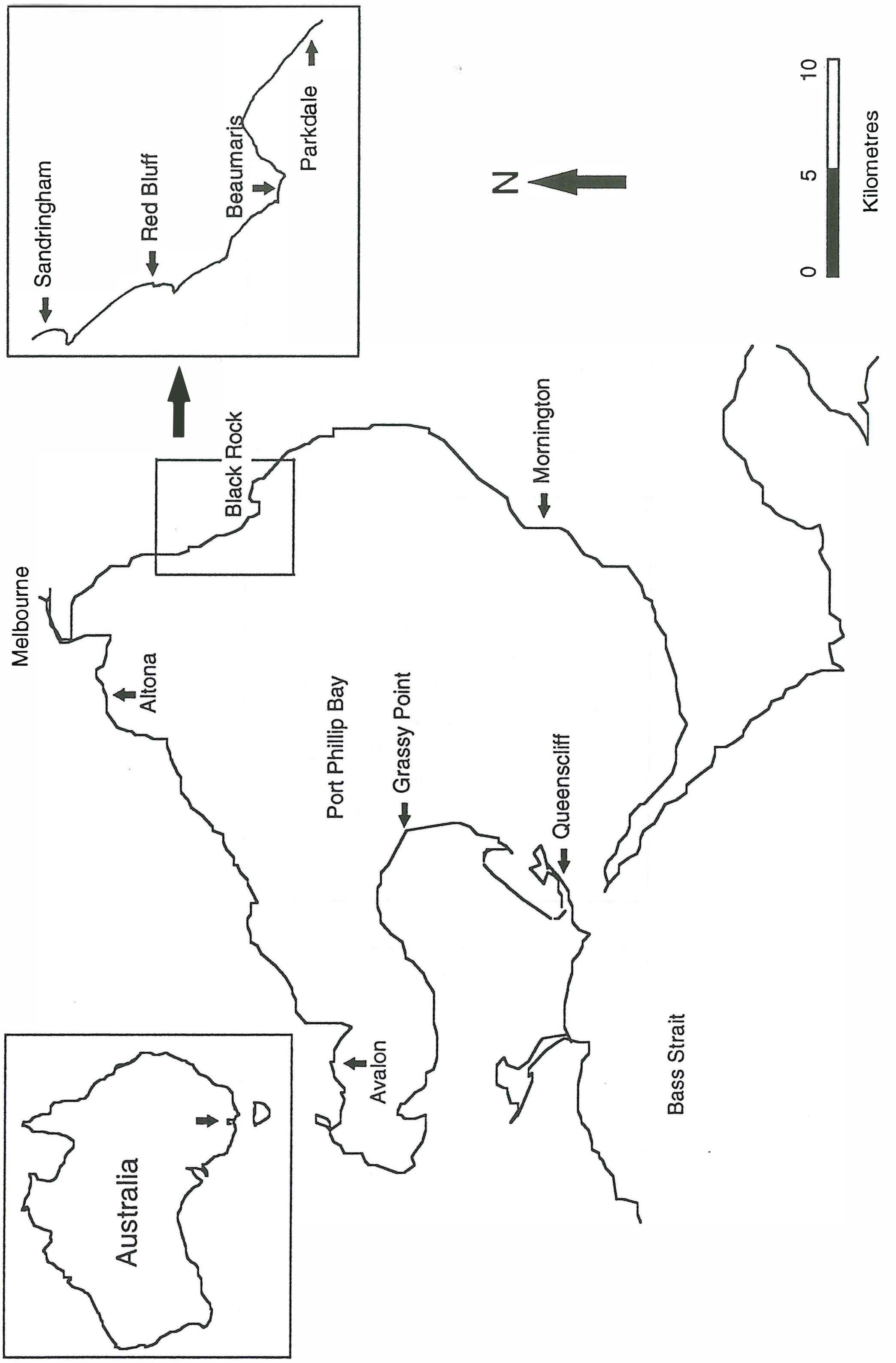

Fig. 1.1 Position of the study sites within Port Phillip Bay. Insets: Location of Port Phillip Bay on the Australian coast and the location of the four sites around the Black Rock area.

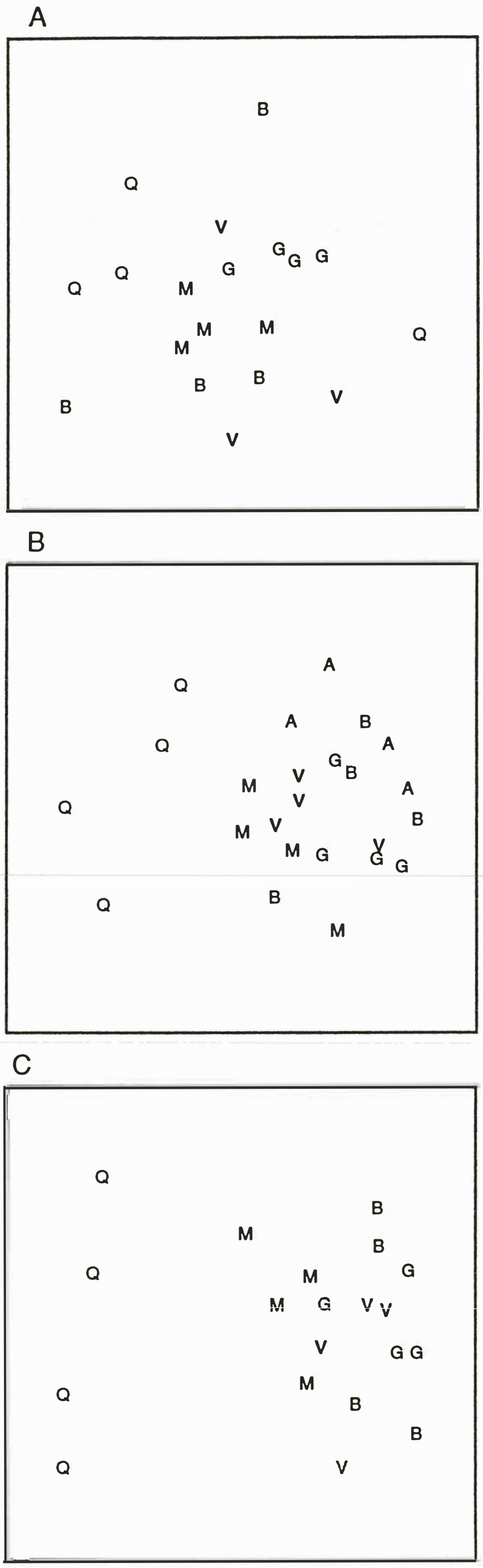

Fig. 1.2 Two dimensional MDS ordination plots of the fast transect fish assemblages showing site differences. A-January 1993 (stress 0.12), B-March, 1993 (stress-0.19) and C-April, 1993 (stress-0.10).

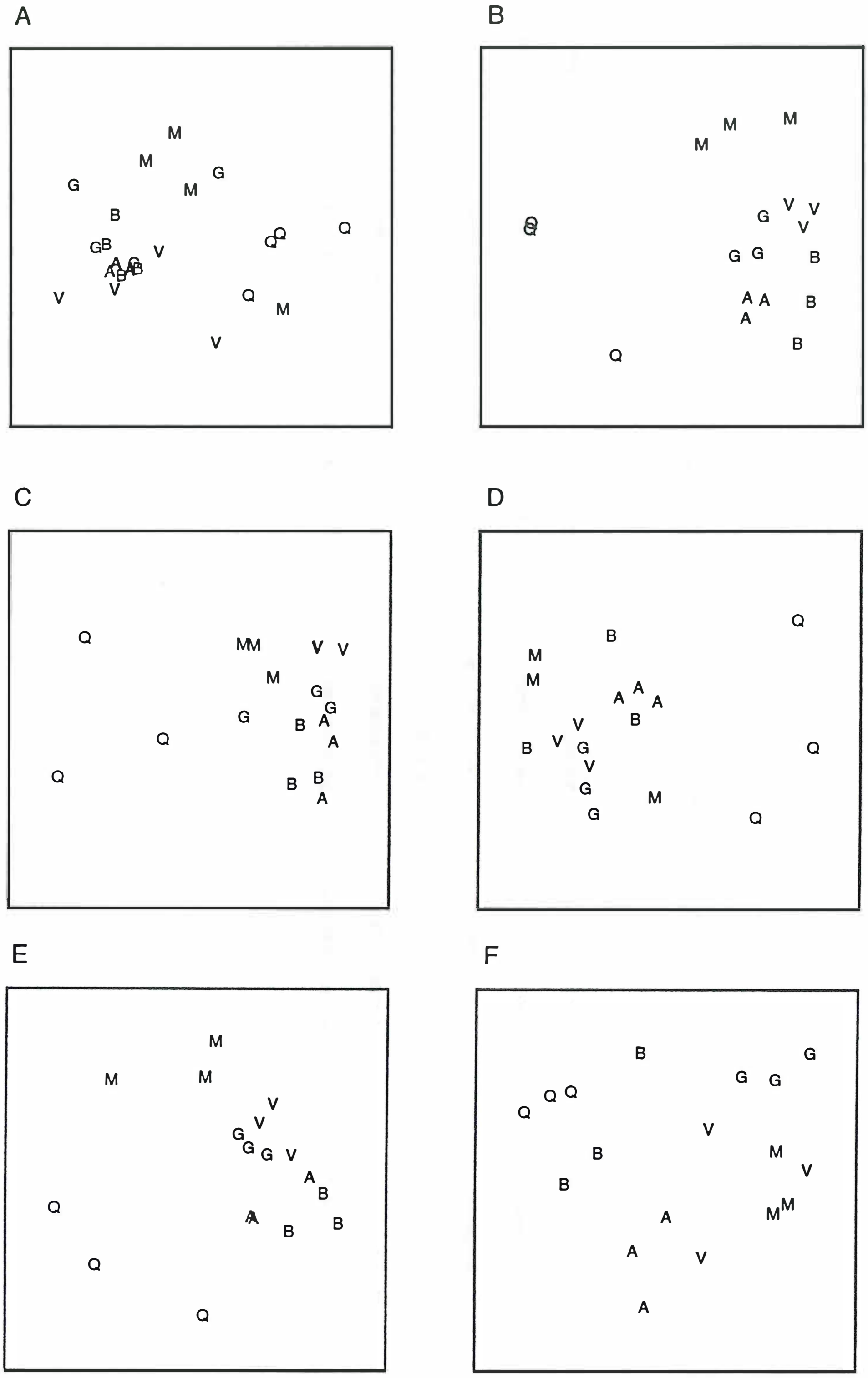

Fig. 1.3 Two dimensional MDS ordination plots of the slow transect fish assemblages showing site differences. A-November, 1992 (stress-0.16), B-January 1993 (stress-0.13), C-March, 1993 (stress-0.12), D-April, 1993 (stress-0.15), E-January, 1994 (stress-0.12) and F-May, 1994 (stress-0.15).

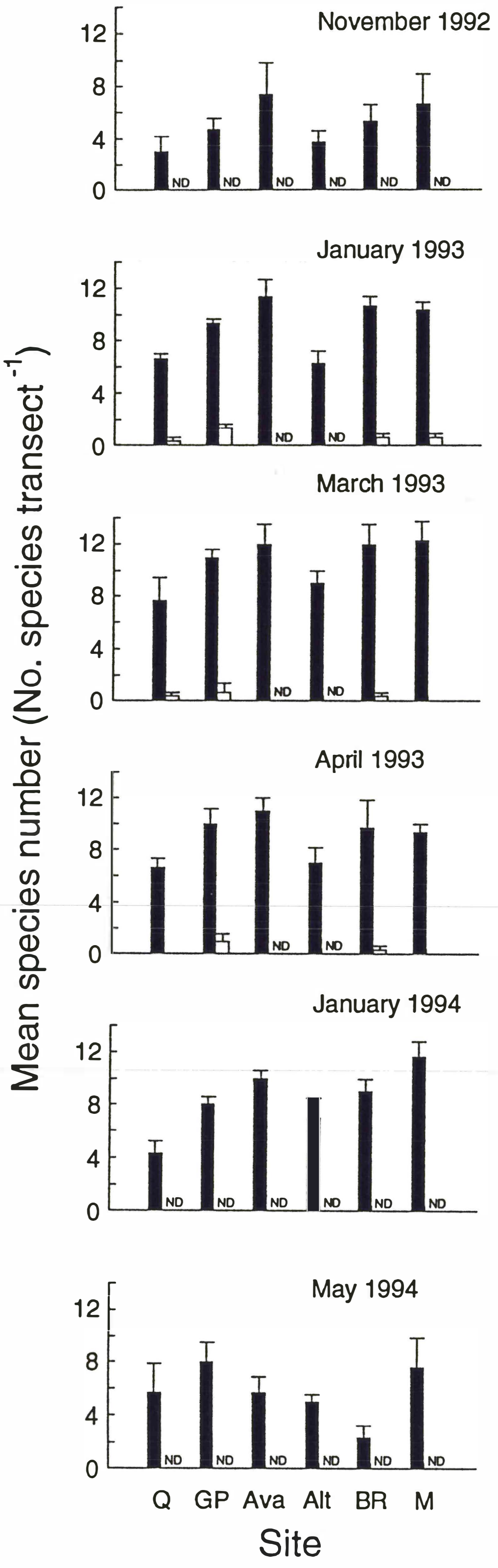

Fig. 1.4 Number of different species recorded at the six sites over all months sampled. Results for the fast and slow transects were pooled. Closed histograms-reef-algae, open histograms-unvegetated sand. Sites: Q=Queenscliff, GP=Grassy Point, Ava=Avalon, Alt=Altona, BR=Black Rock and M=Mornington. ND=no data. Error bars are standard error.

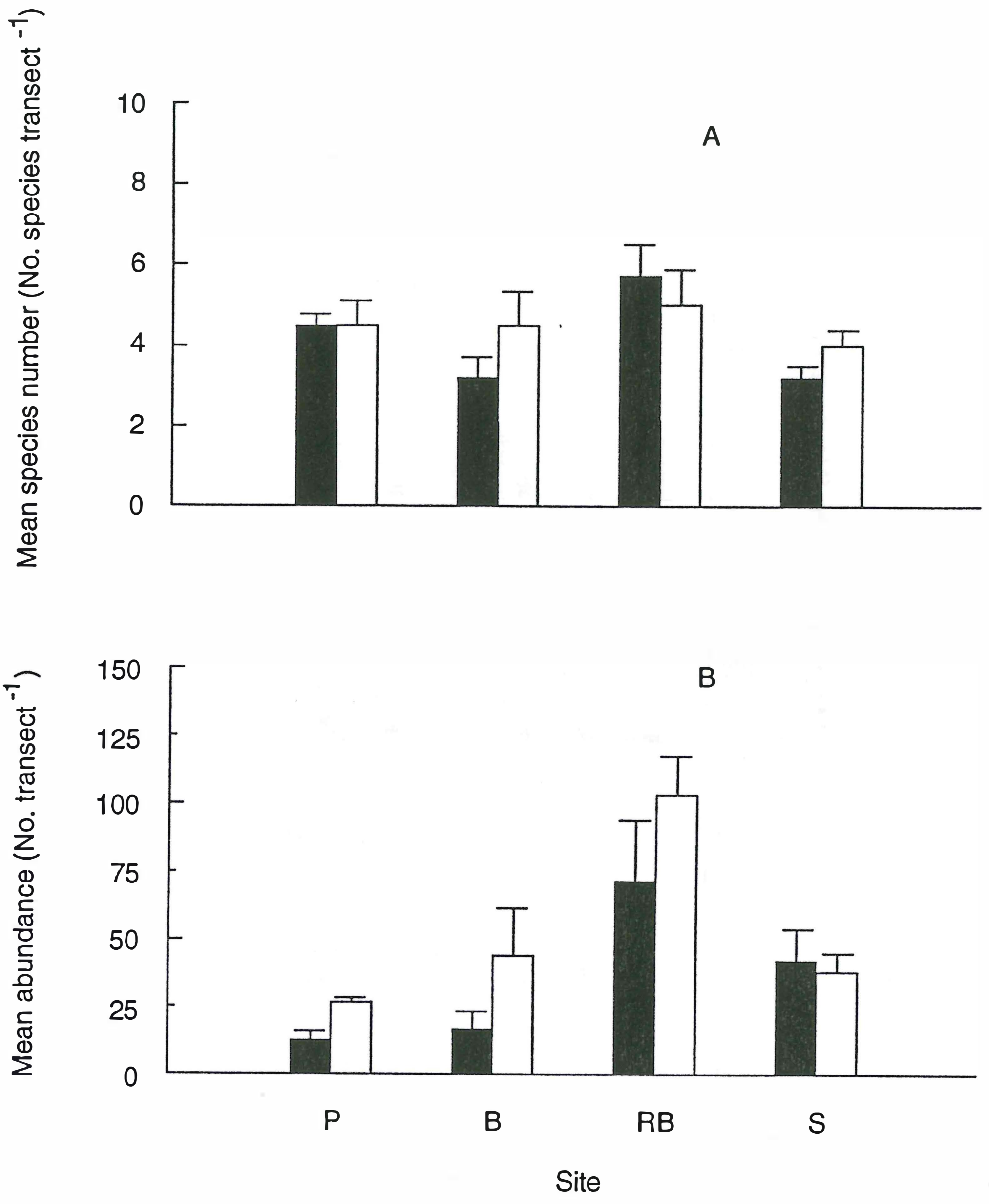

Fig. 1.5 Results for the Black Rock area surveys conducted in February 1993 and March 1993. A-mean species number (February-closed histograms, March-open histograms), B-mean abundance of total fish less Atherinidae (legend as for A). Sites: P=Parkdale, B=Beaumaris, RB=Red Bluff and S=Sandringham. Error bars are standard error.

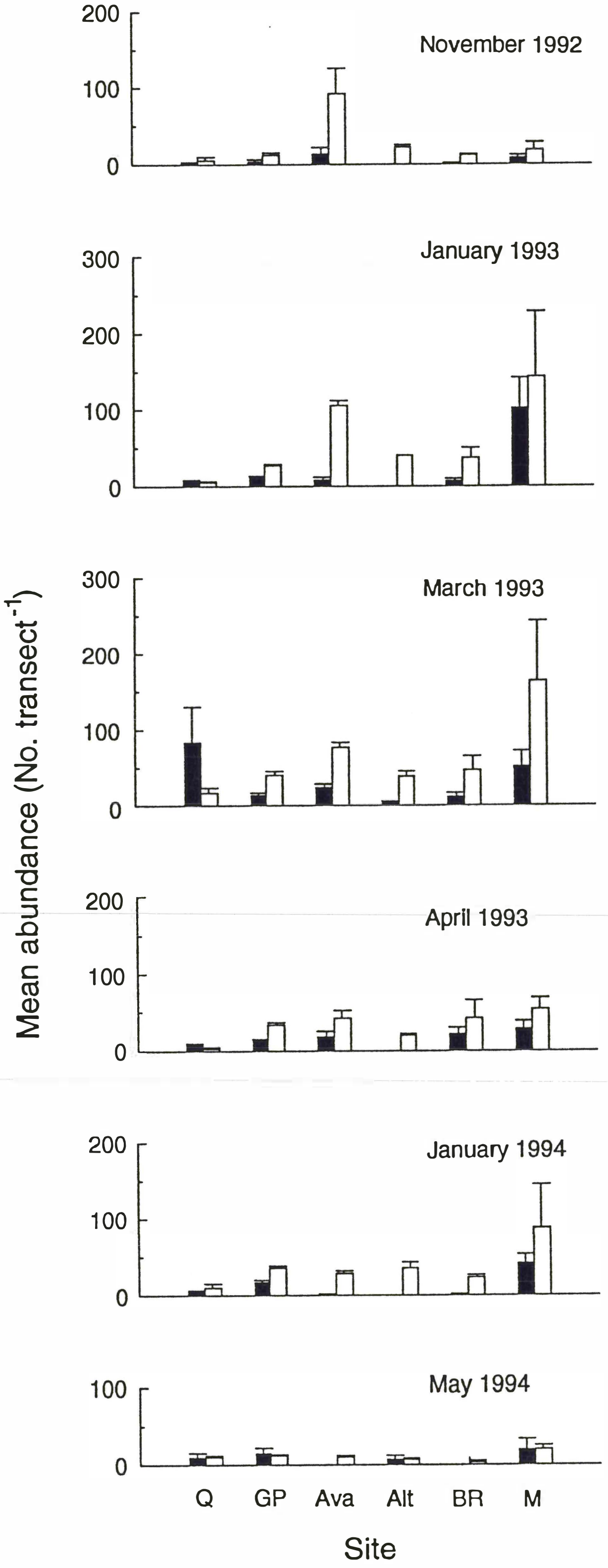

Fig. 1.6 Mean abundance of total fish less Atherinidae recorded over reef-algal areas at the six sites on all sampling dates. Closed histograms-fast transects, open histograms-slow transects. Sites: Q=Queenscliff, GP=Grassy Point, Ava=Avalon, Alt=Altona, BR=Black Rock and M=Mornington. Error bars are standard error.

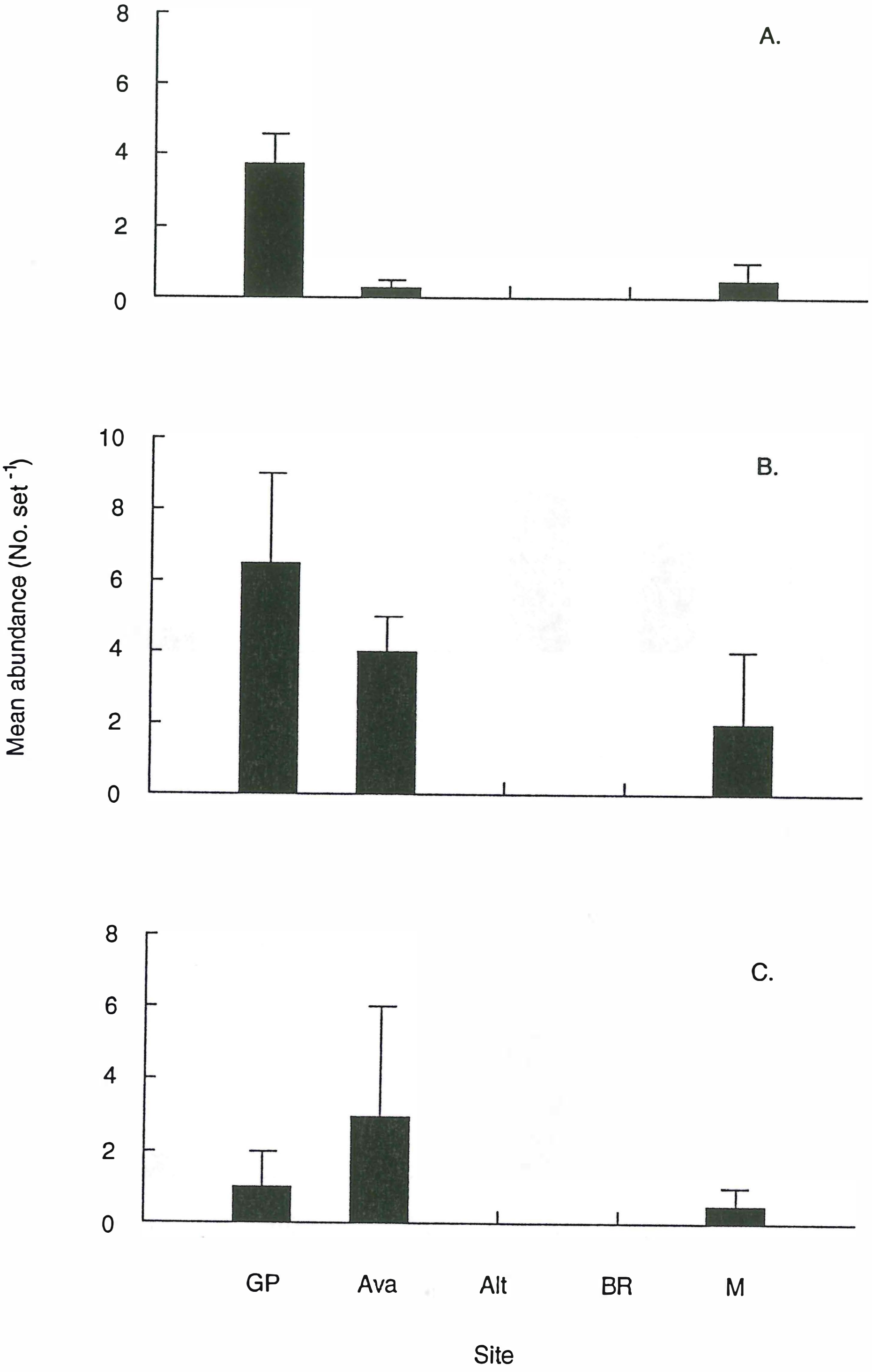

Fig. 1.7 Mean abundance of leatherjackets (Monacanthidae) collected in (A) gill nets in January 1993, (B) fish traps in March 1993 and (C) fish traps in April 1993. GP=Grassy Point, Ava=Avalon, Alt=Altona, BR=Black Rock and M=Mornington. Error bars are standard error.

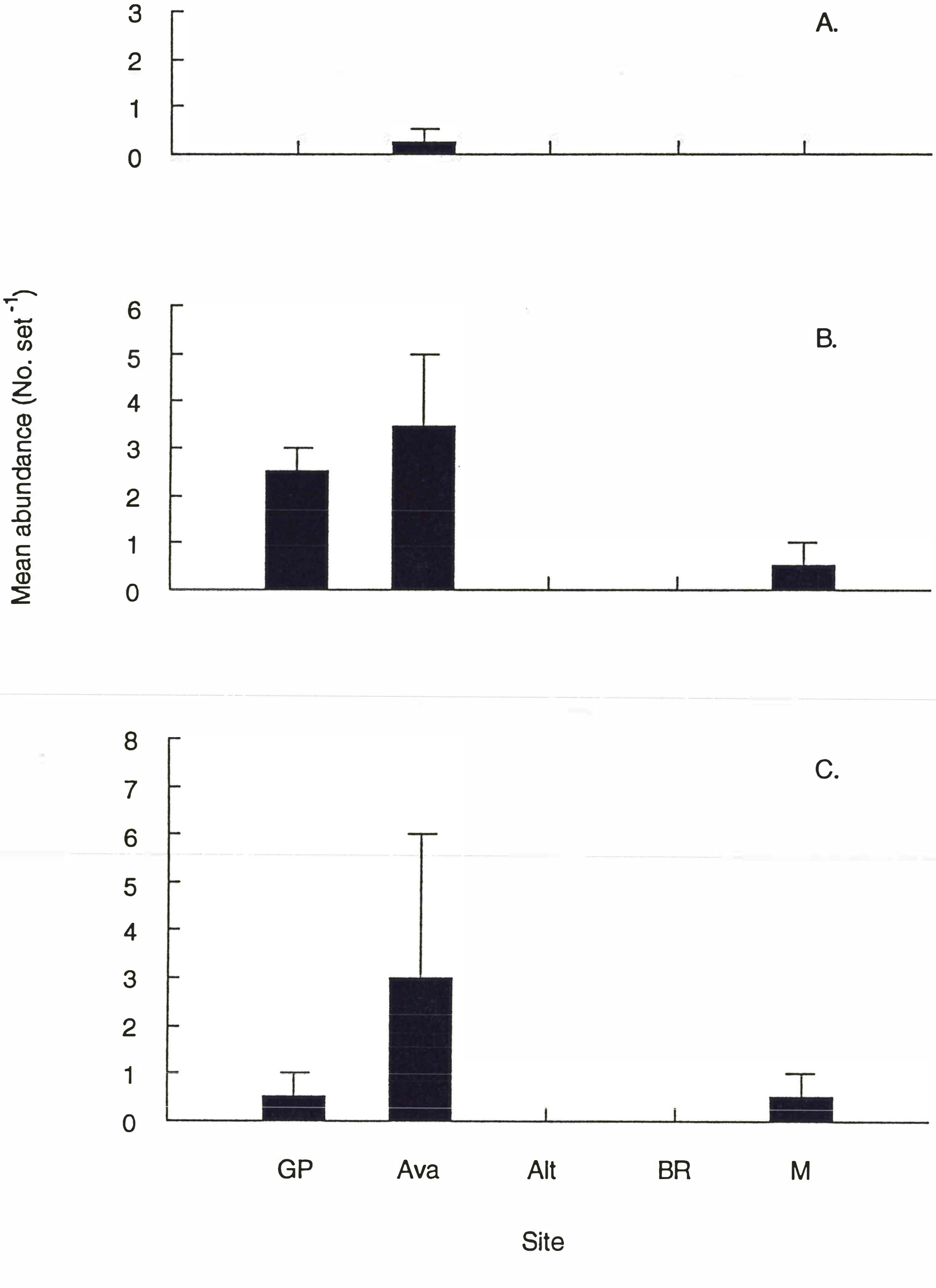

Fig. 1.8 Mean abundance of six-spine leatherjackets, *Meuschenia freycinetia*, collected in (A) gill nets in January 1993, (B) fish traps in March 1993 and (C) fish traps in April 1993. GP=Grassy Point, Ava=Avalon, Alt=Altona, BR=Black Rock and M=Mornington. Error bars are standard error.

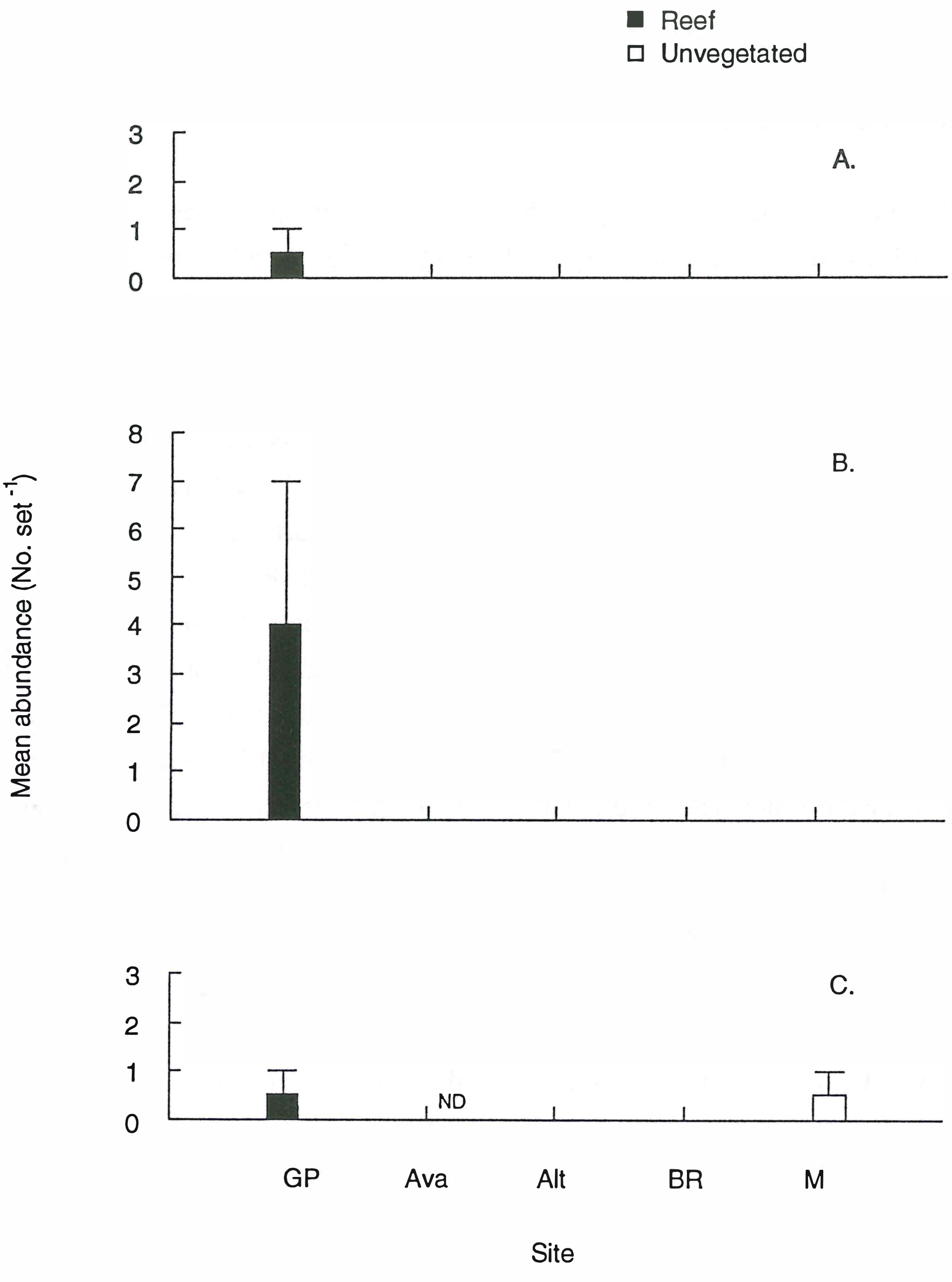

Fig. 1.9 Mean abundance of rough leatherjackets, *Scobinichthys granulatus*, collected in (A) gill nets in January 1993, (B) fish traps in March 1993 and (C) fish traps in April 1993. GP=Grassy Point, Ava=Avalon, Alt=Altona, BR=Black Rock and M=Mornington. Error bars are standard error.

CHAPTER 2

IMPORTANCE OF SHALLOW SEAGRASS, REEF-ALGAL, AND UNVEGETATED SAND HABITATS TO JUVENILE FISHES, WITH EMPHASIS ON COMMERCIAL SPECIES, IN A SOUTHERN AUSTRALIAN EMBAYMENT

2.1 INTRODUCTION

There is wide acceptance that seagrass beds are important 'nursery' areas for fishes (Pollard 1984; Bell and Pollard 1989), although there are exceptions where seagrasses do not appear to act as nursery areas (Bell and Harmelin-Vivien 1982; Heck Jr and Thoman 1984). Reefs and associated algae, and unvegetated sediments, have also been reported as important nursery areas, albeit much less frequently than is the case with seagrass. In the Mediterranean, juvenile fish were mainly associated with shallow, sublittoral reefs, rather than deeper seagrass (*Posidonia*) beds (Bell and Harmelin-Vivien 1982). Macrophyte (algae and seagrass) debris in surf zones apparently forms an important nursery habitat for fishes in Western Australia (Robertson and Lenanton 1984). Moderately exposed beaches in South Africa may provide a nursery habitat as important as estuaries (Bennett 1989). Finally, unvegetated sediment adjacent to seagrass, in contrast to the same habitat some distance (greater than 100 m) from seagrass, was an important habitat for juveniles of a number of important commercial species in New South Wales (Ferrell and Bell 1991). Thus, it is possible that the importance of seagrasses may have been over emphasised relative to other habitats in terms of their nursery function.

Experimental evidence suggests that rather than specific selection for seagrass, larvae of many species seek shelter of any form that is available at the time of settlement (Bell *et al.* 1987). The assumption that some species depend on seagrass may only have arisen from the fact that seagrass is the most common form of shelter in settlement areas (Bell *et al.* 1987). The present study compares the diversity and abundance of fishes, including the recruits and juveniles of commercial species, amongst shallow (< 1 m) reef-algae, seagrass and unvegetated sand habitats in Port Phillip Bay. The study was conducted at locations known to span a wide range of fish recruitment levels, and over the time period of highest fish recruitment (Jenkins *et al.* 1993)

2.2 METHODS

2.2.1 Study area

Port Phillip Bay is a large, semi-enclosed, predominantly tidal embayment linked to the ocean of Bass Strait by a narrow entrance (Fig. 2.1). The hydrodynamics are characterised by: an entrance region, where fast (3 $m.sec^{-1}$) ebb and flood jets dominate the circulation; a large flood-tidal delta, known as the Sands region, where strong currents occur in the major channels; and an "inner" zone, where tidal currents are weak (Black *et al.* 1993). On the western side of Port Phillip Bay, tidal currents drop to below 10 $cm.sec^{-1}$ at about the entrance to the Geelong arm. Tidal range inside the bay is less than one metre.

Seagrass around the Bellarine Peninsula area of Port Phillip Bay generally consists of narrow (20 m wide) bands of the subtidal seagrass, *Heterozostera tasmanica*, running parallel to the shoreline. Towards Corio Bay within the Geelong Arm, however, seagrass beds become more widespread due to protection from the predominant south-westerly wind experienced in the region. This pattern reflects the distribution of sediment grain size that becomes progressively finer from the Sands region around the Bellarine Peninsula and into the Geelong Arm (Anon. 1973).

Shallow, subtidal reefs in the region tend to be of low relief, and are usually either basalt or ironstone. A wide diversity of algae occurred on the reefs sampled, including representatives of the chlorophyte genera *Ulva*, *Cladophora*, *Caulerpa* and *Codium*; the phaeophyte genera *Cystophora*, *Caulocystis*, *Sargassum*, *Zonaria* and *Ecklonia*; and the rhodophyte genera *Heterosiphonia*, *Echinothamnion*, *Laurencia*, *Ptilota*, *Centroceras*, *Dictymenia* and *Jeannerettia*.

2.2.2 Field sampling

Sampling was conducted at three locations on the Bellarine Peninsula (Fig. 2.1). At each location, *Heterozostera* beds, reef-algal beds, and unvegetated sand, averaging approximately 0.5 m below MLWS, were sampled. Samples were taken from four replicate patches of each habitat, interspersed as thoroughly as possible along approximately 2 km of coastline. Samples were collected 2 h each side of low tide so that it was necessary to sample each location on a separate day. Sampling was conducted, on consecutive days where possible, from 15 October, 16 November and 15 December 1993, and 17 January, 11 February and 15 March 1994.

Fishes were sampled with a seine net of 20 metres length, a 2 metre drop, and a mesh of approximately 1 mm^2. A cod-end bag of 0.5 m depth was sewn into the centre of the net. The seine was set from a boat by walking it in a circle and returning to the boat. Two people in the boat would then retrieve the net. Occasionally, on reef-algal habitats, it was necessary for the person setting the net to release the bottom of the net from snags during retrieval. Once the net was retrieved into the boat, post-larvae and juveniles were sorted, anaesthetised in benzocaine, and preserved in 95% ethanol.

To determine plant biomass from seagrass or reef-algal habitats, replicate samples of plant material were collected in each of four patches of each habitat type at each of the three locations. Three replicate samples were collected from each habitat patch using a 25 cm quadrat. Plant material within the quadrat was cut at the level of the substratum with scissors, placed in a plastic bag, and preserved in 95% ethanol. Sampling was conducted 2h each side of day-time low tide from 16 to 18 March, 1994.

2.2.3 Laboratory analysis

In the laboratory, fishes were identified and enumerated, and juvenile King George whiting, *Sillaginodes punctata*, were measured. For samples with more than 20 *S. punctata*, a random sub-sample of 20 individuals was taken for measurement. The standard length (SL; tip of the snout to the tip of the caudal peduncle) of specimens was measured under a dissecting microscope fitted with an ocular micrometer. Larger individuals were measured with vernier callipers. Samples of plant material were dried in an oven at 60°C for 48 h and weighed.

2.2.4 Data analysis

Assumptions of analysis of variance were examined using box and residual plots. Habitat, month and locality were considered to be fixed factors. For analysis of plant biomass, sites (habitat patches) were nested within each combination of habitat and location. With the exception of species richness, transformation to log(x+1) was necessary to produce acceptable homogeneity of variances and distribution of residuals. Tukey's test was used for post-hoc comparisons after ANOVA. Statistical analyses were carried out with the 'SYSTAT' computer program (Wilkinson *et al.* 1992).

For multivariate analyses the data were transformed by $x^{0.25}$ and the Bray-Curtis similarity coefficient was calculated to generate similarity matrices for replicate samples (Clarke 1993). For each date an analogue of multivariate analysis of variance with a randomisation test for significance (ANOSIM) was used to compare sites with habitats pooled and habitats with sites pooled. Multiple comparisons after the test were subjected to the Bonferroni adjustment. Where significant differences occurred multidimensional scaling (MDS) was used to plot the relationships amongst sites and habitats for each month with replicates pooled. All multivariate analyses were conducted using the PRIMER set of programs from Plymouth Marine Laboratory, England.

2.3 RESULTS

2.3.1 Fish assemblages

Differences were apparent in the assemblages associated with each habitat (Table 2.1). At all sites the pipefishes of the genus *Stigmatopora* were most abundant in seagrass habitat, although *Stigmatopora* recruits were evenly distributed across habitats at St Leonards. A number of groups such as odacids, clinids, and monacanthids were common on both reef-algae and seagrass but not on unvegetated sand. In contrast, pleuronectids and leptoscopids were restricted to unvegetated sand habitats. Some groups, such as atherinids, were ubiquitous on all habitats. The King George whiting, *Sillaginodes punctata*, was found on all habitats except in the case of Clifton Springs, where it was primarily collected on unvegetated sand. Site differences were also apparent, for example, atherinids were much more abundant at Clifton Springs than at the other sites.

For each sampling month, the assemblages at each site and in each habitat were compared using a two-way crossed ANOSIM with site and habitat as factors. In all months both sites and habitats showed significant differences ($P<0.05$). Pairwise comparisons with a Bonferroni adjustment (alpha=0.17) showed that while site and habitat differences varied amongst months, the most common pattern was for unvegetated habitat to be significantly different from seagrass and reef-algal habitats, but for the latter two habitats not to be significantly different (November, December, March), and in all months unvegetated was significantly different from seagrass. Differences between sites also varied, however, in all months St Leonards was significantly different from Clifton Springs. These relationships are presented graphically using multidimensional scaling (Fig. 2.2).

Table 2.1 The mean number of individuals and percentage of the total individuals for fish taxa collected from sites at St Leonards, Grassy Point and Clifton Springs from October 1993 to March 1994.

			St.Leonards			
Species	Bare		Seagrass		Reef	
	mean haul^{-1}	%	mean haul^{-1}	%	mean haul^{-1}	%
Squatinidae						
Squatina australis	0.04	0.74	0	0	0	0
Urolophidae						
Unidentified Urolophidae	0.08	1.47	0	0	0	0
Clupeidae						
Hyperlophus vittatus	0	0	0.29	0.65	1.83	9.44
Spratelloides robustus	0	0	0	0	0.29	1.50
Galaxiidae						
Galaxias maculatus	0	0	0	0	0.21	1.07
Gobiesocidae						
Parvicrepis sp.	0	0	0.04	0.09	0	0
Atherinidae						
Atherinosoma microstoma	0.33	5.88	0.54	1.20	0.21	1.07
Kestratherina brevirostris	0	0	0.08	0.18	0.21	1.07
Kestratherina esox	0	0	0.25	0.55	0	0
Leptatherina presbyteroides	0	0	0.04	0.09	0.08	0.43
Unidentified Atherinidae	0	0	0	0	0.63	3.22
Syngnathidae						
Stigmatopora argus	0.25	4.41	10.46	23.20	1.83	9.44
Stigmatopora nigra	0.08	1.47	11.46	25.42	0.63	3.22
Stigmatopora recruits	1.00	17.65	10.29	22.83	3.54	18.24
Hypselognathus rostratus	0.04	0.74	0.08	0.18	0.04	0.21
Vanacampus phillipi	0	0	0.04	0.09	0	0
Hippocampus breviceps	0	0	0	0	0.04	0.21
Scorpaenidae						
Gymnapistes marmoratus	0	0	0.08	0.18	0	0
Platycephalidae						
Platycephalus speculator	0.04	0.74	0	0	0	0
Apogonidae						
Siphaemia cephalotes	0	0	3.29	7.30	0.08	0.43
Sillaginidae						
Sillaginodes punctata	1.25	22.06	2.83	6.28	3.63	18.67
Arripidae						
Arripis truttacea	0.04	0.74	0.13	0.28	0	0
Arripis trutta	0.63	11.03	0	0	0	0
Enoplosidae						
Enoplosus armatus	0	0	0.25	0.55	0.04	0.21
Mugilidae						
Aldrichetta forsteri	0	0	2.25	4.99	0.58	3.00

Table 2.1 (Cont). The mean number of individuals and percentage of the total individuals for fish taxa collected from sites at St Leonards, Grassy Point and Clifton Springs from October 1993 to March 1994.

Species	St Leonards					
	Bare		Seagrass		Reef	
	mean $haul^{-1}$	%	mean $haul^{-1}$	%	mean $haul^{-1}$	%
Odacidae						
Neoodax balteatus	0	0	0.25	0.55	0.04	0.21
Odax cyanomelas	0	0	0.04	0.09	0	0
Haletta semifasciata	0	0	0.13	0.28	0.04	0.21
Leptoscopidae						
Lesueurina platycephala	0.33	5.88	0	0	0	0
Blenniidae						
Parablennius tasmanianus	0	0	0	0	0.08	0.43
Clinidae						
Heteroclinus adelaide	0	0	0	0	0.04	0.21
Heteroclinus perspicillatus	0	0	0.08	0.18	0.29	1.50
Heteroclinus wilsoni	0	0	0	0	0.04	0.21
Cristiceps australis	0.04	0.74	0.04	0.09	0.04	0.21
Gobiidae						
Nesogobius sp.*1*	0.08	1.47	0	0	0.04	0.21
Pleuronectidae						
Rhombosolea tapirina	0.17	2.94	0	0	0	0
Ammotretis elongatus	0.17	2.94	0	0	0	0
Monacanthidae						
Meuschenia freycineti	0	0	0.25	0.55	0.25	1.29
Acanthaluteres spilomelanurus	0.17	2.94	0.67	1.48	1.54	7.94
Acanthaluteres vittiger	0.08	1.47	0.13	0.28	0.21	1.07
Balistes jacksonianus	0	0	0	0	0.17	0.86
Tetraodontidae						
Contusus brevicaudatus	0.63	11.03	0.54	1.20	1.38	7.08
Tetractenos glaber	0.04	0.74	0.50	1.11	1.04	5.36
Diodon nicthemerus	0	0	0.04	0.09	0.33	1.72
Mean number of fish $haul^{-1}$	5.67		45.08		19.42	
Number of species	20		28		31	

Table 2.1 (Cont). The mean number of individuals and percentage of the total individuals for fish taxa collected from sites at St Leonards, Grassy Point and Clifton Springs from October 1993 to March 1994.

	Grassy Point					
Species	Bare		Seagrass		Reef	
	mean $haul^{-1}$	%	mean $haul^{-1}$	%	mean $haul^{-1}$	%
Rhinobatidae						
Trygonorrhina guanerius	0	0	0.04	0.08	0.08	0.24
Urolophidae						
Unidentified Urolophidae	0	0	0.04	0.08	0	0
Clupeidae						
Hyperlophus vittatus	0	0	0.25	0.48	0.25	0.71
Spratelloides robustus	0	0	0.04	0.08	0	0
Galaxiidae						
Galaxias maculatus	0	0	0.13	0.24	0	0
Atherinidae						
Atherinosoma microstoma	0.50	2.44	0.33	0.64	0.58	1.65
Kestratherina brevirostris	0	0	0.58	1.13	0.08	0.24
Kestratherina esox	0	0	0.46	0.88	0.63	1.77
Leptatherina presbyteroides	0.13	0.61	0	0	0.08	0.24
Hemiramphidae						
Hyporhamphus melanochir	0	0	0.38	0.72	0	0
Syngnathidae						
Stigmatopora argus	0.08	0.41	17.92	34.57	2.25	6.36
Stigmatopora nigra	0.13	0.61	5.67	10.93	0.33	0.94
Stigmatopora recruits	2.04	9.98	11.75	22.67	3.83	10.84
Vanacampus phillipi	0	0	0.04	0.08	0.04	0.12
Scorpaenidae						
Gymnapistes marmoratus	0	0	0.04	0.08	0.08	0.24
Platycephalidae						
Platycephalus speculator	0.13	0.61	0	0	0.04	0.12
Apogonidae						
Siphaemia cephalotes	0	0	0.08	0.16	0	0
Sillaginidae						
Sillaginodes punctata	14.96	73.12	8.83	17.04	24.33	68.79
Enoplosidae						
Enoplosus armatus	0	0	0.33	0.64	0.21	0.59
Cheilodactylidae						
Dactylophora nigricans	0	0	0.04	0.08	0	0
Mugilidae						
Aldrichetta forsteri	0.38	1.83	1.67	3.22	0	0
Odacidae						
Neoodax balteatus	0	0	0.75	1.45	0.29	0.82
Haletta semifasciata	0	0	0.13	0.24	0	0
Leptoscopidae						
Lesueurina platycephala	0.04	0.20	0	0	0	0

Table 2.1 (Cont). The mean number of individuals and percentage of the total individuals for fish taxa collected from sites at St Leonards, Grassy Point and Clifton Springs from October 1993 to March 1994.

	Grassy Point					
Species	Bare		Seagrass		Reef	
	mean haul^{-1}	%	mean haul^{-1}	%	mean haul^{-1}	%
Clinidae						
Heteroclinus perspicillatus	0.04	0.20	0.17	0.32	0.25	0.71
Heteroclinus wilsoni	0	0	0	0	0.04	0.12
Cristiceps australis	0	0	0.04	0.08	0.04	0.12
Gobiidae						
Nesogobius sp.*1*	0.04	0.20	0	0	0	0
Favonigobius lateralis	0.04	0.20	0	0	0	0
Gobiidae recruits	0.04	0.20	0.04	0.08	0.08	0.24
Pleuronectidae						
Rhombosolea tapirina	1.04	5.09	0	0	0	0
Ammotretis elongatus	0.42	2.04	0	0	0	0
Monacanthidae						
Meuschenia freycineti	0	0	0.75	1.45	0.29	0.82
Acanthaluteres spilomelanurus	0	0	0.58	1.13	0.17	0.47
Acanthaluteres vittiger	0	0	0.08	0.16	0.08	0.24
Balistes jacksonianus	0	0	0	0	0.25	0.71
Tetraodontidae						
Contusus brevicaudatus	0.42	2.04	0.04	0.08	0.46	1.30
Contusus richei	0	0	0	0	0.04	0.12
Tetractenos glaber	0.04	0.20	0.46	0.88	0.46	1.30
Diodon nicthemerus	0	0	0.13	0.24	0.08	0.24
Mean number of fish haul^{-1}	20.46		51.83		35.38	
Number of species	17		30		27	

Table 2.1 (Cont). The mean number of individuals and percentage of the total individuals for fish taxa collected from sites at St Leonards, Grassy Point and Clifton Springs from October 1993 to March 1994.

	Clifton Springs					
Species	Bare		Seagrass		Reef	
	mean haul-1	%	mean haul-1	%	mean haul-1	%
Atherinidae						
Atherinosoma microstoma	2.25	11.09	1.17	4.15	2.96	12.57
Kestratherina brevirostris	0	0	0	0	0.04	0.18
Kestratherina esox	0.17	0.82	2.33	8.30	1.21	5.13
Leptatherina presbyteroides	0.21	1.03	0.21	0.74	0.63	2.65
Unidentified Atherinidae	8.29	40.86	2.13	7.56	14.33	60.88
Syngnathidae						
Stigmatopora argus	0.04	0.21	7.96	28.30	1.63	6.90
Stigmatopora nigra	0	0	0.13	0.44	0.08	0.35
Stigmatopora recruits	0.21	1.03	10.25	36.44	0.38	1.59
Urocampus carinirostris	0	0	0.13	0.44	0	0
Hypselognathus rostratus	0.04	0.21	0.33	1.19	0	0
Vanacampus phillipi	0	0	0.29	1.04	0	0
Scorpaenidae						
Gymnapistes marmoratus	0	0	0.04	0.15	0	0
Platycephalidae						
Platycephalus speculator	0.08	0.41	0	0	0	0
Apogonidae						
Siphaemia cephalotes	0	0	0.13	0.44	0.17	0.71
Sillaginidae						
Sillaginodes punctata	6.38	31.42	0.71	2.52	0.58	2.48
Mugilidae						
Aldrichetta forsteri	0	0	0.17	0.59	0	0
Odacidae						
Neoodax balteatus	0	0	0.08	0.30	0.21	0.88
Clinidae						
Heteroclinus perspicillatus	0	0	0.04	0.15	0.08	0.35
Cristiceps australis	0	0	0	0	0.04	0.18
Gobiidae						
Favonigobius lateralis	0.17	0.82	0	0	0	0
Favonigobius tamarensis	0	0	0.04	0.15	0	0
Pleuronectidae						
Rhombosolea tapirina	1.08	5.34	0	0	0	0
Monacanthidae						
Meuschenia freycineti	0	0	0.13	0.44	0.38	1.59
Acanthaluteres spilomelanurus	0	0	0.25	0.89	0.17	0.71
Acanthaluteres vittiger	0	0	0	0	0.04	0.18
Tetraodontidae						
Contusus brevicaudatus	1.13	5.54	0.46	1.63	0	0
Tetractenos glaber	0.25	1.23	1.00	3.56	0.13	0.53
Diodon nicthemerus	0	0	0.17	0.59	0.50	2.12
Mean number of fish haul^{-1}	20.29		28.13		23.54	
Number of species	13		22		18	

2.3.2 Species richness and abundance

Species richness varied significantly amongst habitats and there was also a significant interaction between sites and dates (Table 2.2, Fig. 2.3). Post-hoc tests showed that overall, species richness was significantly higher in seagrass than in reef-algal habitat, which in turn was significantly higher than in unvegetated sand. No clear pattern was apparent in variation in species richness amongst sites on each date. In October, January and March there was no significant difference between sites.

Table 2.2 Analysis of variance of species richness in seagrass, reef-algal and unvegetated sand habitats at three sites over six months.

Source	DF	MS	F	P
Month	5	5.474	1.696	0.138
Site	2	47.241	14.633	0.000
Habitat	2	79.310	24.566	0.000
Month*Site	10	9.863	3.055	0.001
Month*Habitat	10	3.932	1.218	0.283
Site*Habitat	4	5.782	1.791	0.133
Month*Site*Habitat	20	3.605	1.117	0.337
Error	162	3.228		

Abundance of fishes showed significant interactions between habitat and month, and habitat and site (Table 2.3, Fig. 2.4). Post-hoc tests indicated that in terms of sites, the major pattern was that seagrass and reef-algae were higher than unvegetated sand at St Leonards and Grassy Point, whilst at Clifton Springs, seagrass was significantly higher than reef-algae and unvegetated sand, whilst the latter two habitats were not significantly different. In terms of month, the major pattern was that seagrass and reef-algae were significantly higher than unvegetated habitat from October to January, whilst in February and March seagrass was significantly higher than reef-algae and unvegetated sand, whilst the latter two habitats were not significantly different.

Table 2.3 Analysis of variance of log(x+1) transformed abundance (not including atherinid and clupeid post-larvae) in seagrass, reef-algal and unvegetated sand habitats at three sites over six months.

Source	DF	MS	F	P
Month	5	1.132	1.186	0.318
Site	2	28.086	29.426	0.000
Habitat	2	39.785	41.683	0.000
Month*Site	10	1.320	1.383	0.192
Month*Habitat	10	2.672	2.800	0.003
Site*Habitat	4	3.632	3.805	0.006
Month*Site*Habitat	20	1.560	1.635	0.050
Error	162	0.954		

2.3.3 Commercial species

The most abundant commercial species, and one of the most abundant species overall, was the King George whiting, *Sillaginodes punctata* (Table 2.1). The abundance of juvenile *S. punctata*, with respect to location and habitat, varied markedly over the sampling period (Fig. 2.5). Abundances at St Leonards declined from October to November and were extremely low thereafter. In October, when significant numbers occurred at St Leonards, most individuals were on reef or seagrass. Abundances were consistently highest at Grassy Point with the exception of the March sampling. The pattern of habitat usage was similar to St Leonards in October, however, from November to January there was an increasing proportion found on reef relative to seagrass at this location, whilst in February and March most occurred on sand. *S. punctata* were rare at Clifton Springs until February and March, when most individuals were collected on sand.

This variation must be considered in the context of juvenile growth and movement, with the October samples including newly settled individuals of approximately 20 mm in length, and later samples containing increasingly larger individuals (Fig. 2.6). There was little change in the size distribution from October to November at St Leonards. The size distribution at Grassy Point increased rapidly between the November and December samples. In December there had been an apparent immigration of individuals to Clifton Springs. The size distribution at Clifton Springs was generally biased to the upper end of the size distribution at Grassy Point at the same time.

To examine the habitat preference of newly settled individuals, abundances on habitats at St Leonards and Grassy Point in October and November were compared using 3-factor ANOVA. Main effects were significant, as was the interaction between habitat and location (Table 2.4). When habitat use was compared for locations, with months pooled, abundances were significantly higher on reef compared with unvegetated sand at St Leonards, and both reef and seagrass were significantly higher than unvegetated sand at Grassy Point (Tukey's test, P<0.05).

Recruits of other commercial species occurred in lower abundances. The yellow-eye mullet, *Aldrichetta forsteri*, occurred sporadically over the sampling period, and was most frequently collected over seagrass (Fig. 2.7). Recruits of the six spine leatherjacket, *Meuschenia freycineti*, were collected in low but consistent numbers over the sampling period (Fig. 2.8). Recruitment to seagrass and reef-algae was similar, and no recruitment was recorded on unvegetated habitats (Fig. 2.8). Juvenile greenback flounder, *Rhombosolea tapirina*, were only found on unvegetated sand (Fig. 2.9).

Table 2.4. Three factor analysis of variance of ln(x+1) transformed abundances of post-settlement *Sillaginodes punctata*. ns=not significant, *=P<0.05, **=P<0.001.

Source	DF	MS	F
Month	1	1.454	15.657 **
Location	1	1.066	11.476 *
Habitat	2	3.325	35.808 **
Month * Location	1	0.317	3.412 ns
Month * Habitat	2	0.258	2.780 ns
Location * Habitat	2	0.852	9.179 **
Month * Location * Habitat	2	0.003	0.028 ns
Error	36	0.093	

Post-hoc comparison of Location * Habitat interaction:

St Leonards U SG RA Grassy Point U SG RA

2.3.4 Plant biomass

The mean biomass of algae collected from each locality ranged from approximately 50 $g.m^{-2}$ to 110 $g.m^{-2}$, the mean biomass of seagrass was very similar amongst localities at approximately 75 $g.m^{-2}$ (Fig. 2.10). The majority of the variation in plant biomass occurred amongst sites within habitats and localities, differences between habitats and amongst localities were not significant (Table 2.5).

Table 2.5. Analysis of variance of log(x+1) transformed plant biomass from seagrass and reef-algal biomass in March 1994. ns=not significant, *=$P<0.05$, **=$P<0.001$.

Source	DF	MS	F
Habitat	1	0.81	0.89 ns
Locality	2	1.00	0.99 ns
Habitat*Locality	2	0.91	0.90 ns
Site(Habitat*Locality)	18	1.02	4.61 **
Error	48	0.22	

2.4 DISCUSSION

Fish assemblages were similar between seagrass and reef-algal habitat with the exception of the abundant pipefishes of the genus *Stigmatopora.* Artificial macrophyte experiments comparing a thin, strap-like morphology similar to *Heterozostera* with a wide-thallus morphology similar to many algae showed that *Stigmatopora* have a clear preference for simulated *Heterozostera* (Sutherland 1994). The feeding behaviour of *Stigmatopora*, where individuals grasp onto a seagrass blade by the tail while feeding on mobile animals such as harpacticoids (Howard and Koehn 1985), may not be possible on many algal morphologies and therefore may explain this preference. Furthermore, the colour and morphology of *Stigmatopora* tends to mimic *Heterozostera* blades. Alternatively, higher numbers of potential prey in the more complex artificial macrophyte habitat may suggest a corresponding increase in the abundance of prey between seagrass and reef-algal habitats (Sutherland 1994).

A number of species previously found in subtidal seagrass, including leatherjackets (Monacanthidae), rock whitings (Odacidae) and weedfishes (Clinidae) (Jenkins *et al.*

1993) were also common on reef-algae in this study. The greatest difference amongst fish assemblages was between the unstructured sand habitat and the structured habitat. This observation supports the contention that fishes tend to respond to the presence of structure *per se* rather than a particular type of habitat (Bell *et al.* 1987). Some fishes such as pleuronectids and leptoscopids are specifically adapted to living on sedimentary habitats and will obviously show a preference against structure.

Although exceptions occur, seagrass habitats are typically found to have a greater diversity and abundance of fishes than nearby unvegetated habitats (Bell and Pollard 1989). Species richness in the present study followed a hierarchy where seagrass was higher than reef-algae which in turn was higher than unvegetated sand. Abundance of fishes in seagrass and reef-algae was higher than unvegetated sand at St Leonards and Grassy Point, and also from October to January. Sogard and Able (1991) found a similar pattern for estuarine fish where densities were higher in seagrass and macroalgal beds compared with unvegetated areas. Seagrass abundances were always higher than the other habitats in our study, mainly due to large numbers of the pipefish, *Stigmatopora.*

The King George whiting, *Sillaginodes punctata*, a dominant species in this study, showed a complex relationship with habitat, and this had a major influence on the overall abundance patterns. Larvae of *S. punctata* enter Port Phillip Bay at an advanced stage of development (approximately 15 to 20 mm length) from September to November (Jenkins and May 1994). Immediately after settlement in October, *S. punctata* were associated with both *Heterozostera* and reef-algal habitats but not unvegetated habitats. With growth, however, an increasing preference was shown for reef-algal habitat over *Heterozostera* habitat at Grassy Point. After January, unvegetated sand was preferred over either of the structured habitats at this site. Like the present study, Robertson (1977), in nearby Western Port, found initial settlement of *S. punctata* to *Heterozostera* in September but an ontogenetic shift to unvegetated mud habitat occurred in December. In contrast to these locations, however, post-settlement *S. punctata* in Swan Bay, a small bay connected to Port Phillip Bay, were mainly associated with unvegetated sand patches within large, dense beds of *Heterozostera* (Jenkins *et al.* 1993). Unlike Victorian results, post-settlement *S. punctata* in Barker Inlet, South Australia, continue to be associated with intertidal seagrass, *Zostera*, habitat, rather than unvegetated habitat, with growth (Connolly 1994a). Habitat usage by post-settlement *S. punctata*, therefore, appears to show great variation depending on the location studied.

Site differences were apparent amongst fish assemblages, particularly between St Leonards and Clifton Springs. The physical environment varied greatly amongst sites, with St Leonards relatively exposed to wave action and with strong tidal currents offshore, whilst Clifton Springs was relatively protected from wave action and tidal currents. Also, sediments tend to become progressively finer with distance into the bay. Habitat variation in terms of plant biomass was much greater within sites than between sites in our study, suggesting that broad-scale habitat differences would not explain differences in fish assemblages.

Differences in assemblages of fish in seagrass over broad spatial scales have been intensively studied by Bell and co-workers (Bell and Westoby 1986c; Bell *et al.* 1988) where habitat variation was shown to be unimportant, and variation in larval recruitment was hypothesised to be a major factor. Variability in recruitment of *Sillaginodes punctata* to locations was at least as great as variation amongst habitats within locations. The consistency of habitats across sites adds to other evidence based on natural (Jenkins *et al.* 1996) and artificial (Chapter 6) seagrass that broad-scale variability in recruitment of *S. punctata* to Port Phillip Bay is not related to broad-scale habitat variation. Temporal variation in recruitment of *S. punctata* is largely determined by hydrodynamic processes delivering larvae (Jenkins and Black 1994). It may be reasonable to expect that broad-scale spatial variation in recruitment of *S. punctata* to Port Phillip Bay habitats may also be largely determined by hydrodynamics (Chapter 5,6). Later in the juvenile stage apparent migration of individuals further into the bay also had a major effect on abundance patterns. Migration of juvenile fishes may be a very important factor in the variation in fish assemblages over a broad-scale (Sogard 1989).

Results of this study must be considered in light of potential biases in the sampling method. A seine net has been shown to be an efficient sampler of post-settlement *S. punctata* in seagrass habitat (Connolly 1994c). This efficiency can be attributed to the fact that post-settlement *S. punctata* tend to position themselves near the top or above the seagrass canopy (Connolly 1994c). Small, sediment associated gobiids, however, were much less efficiently sampled (Connolly 1994c). Sutherland (1994) examined the efficiency of a seine net in collecting four species of fish in artificial seagrass habitat. The pipefish, *Stigmatopora* spp., and the leatherjacket, *Acanthaluteres* spp. were collected with high efficiency while the odacid, *Neoodax balteatus*, and the clinid, *Cristiceps australis* were collected with low efficiency. These differences are probably attributable to the normal position of the species in the water column, with the first two species associated with the top of the seagrass canopy while the second two species occur deeper within the canopy. The finding that *Stigmatopora* spp. and *Sillaginodes* *punctata* were dominant species would be partially attributable to sampling bias. Sampling efficiency in unvegetated sand habitat might be expected to be higher than in structured habitats although this may not be the case with groups such as pleuronectids and gobiids which can bury themselves.

2.5 CONCLUSIONS

In conclusion, seagrass and reef-algal habitats had similar assemblages of fish with the exception of pipefish, *Stigmatopora*, which were dominant in seagrass. Unvegetated sand habitats, however, had quite a different assemblage from the structured habitats. Species richness and abundance of fishes was generally higher in the structured habitat relative to the unvegetated sand. Superimposed on variability due to habitat was broad-scale spatial variability not related to habitat. The major commercial species sampled was the King George whiting, *Sillaginodes punctata*. Spatial variation in abundance of post-settlement *S. punctata* was related to habitat, with reef-algal and seagrass habitats most important immediately after settlement. There was increasing importance of reef-algal habitat over seagrass in the months after settlement, and finally a shift in habitat to unvegetated sand approximately four months after settlement. While most emphasis in the past has been placed on seagrass beds as nursery areas for juvenile commercial fish, this study shows that when reef-algal and seagrass habitats both occur in high recruitment locations, the reef-algal habitat may be at least as important.

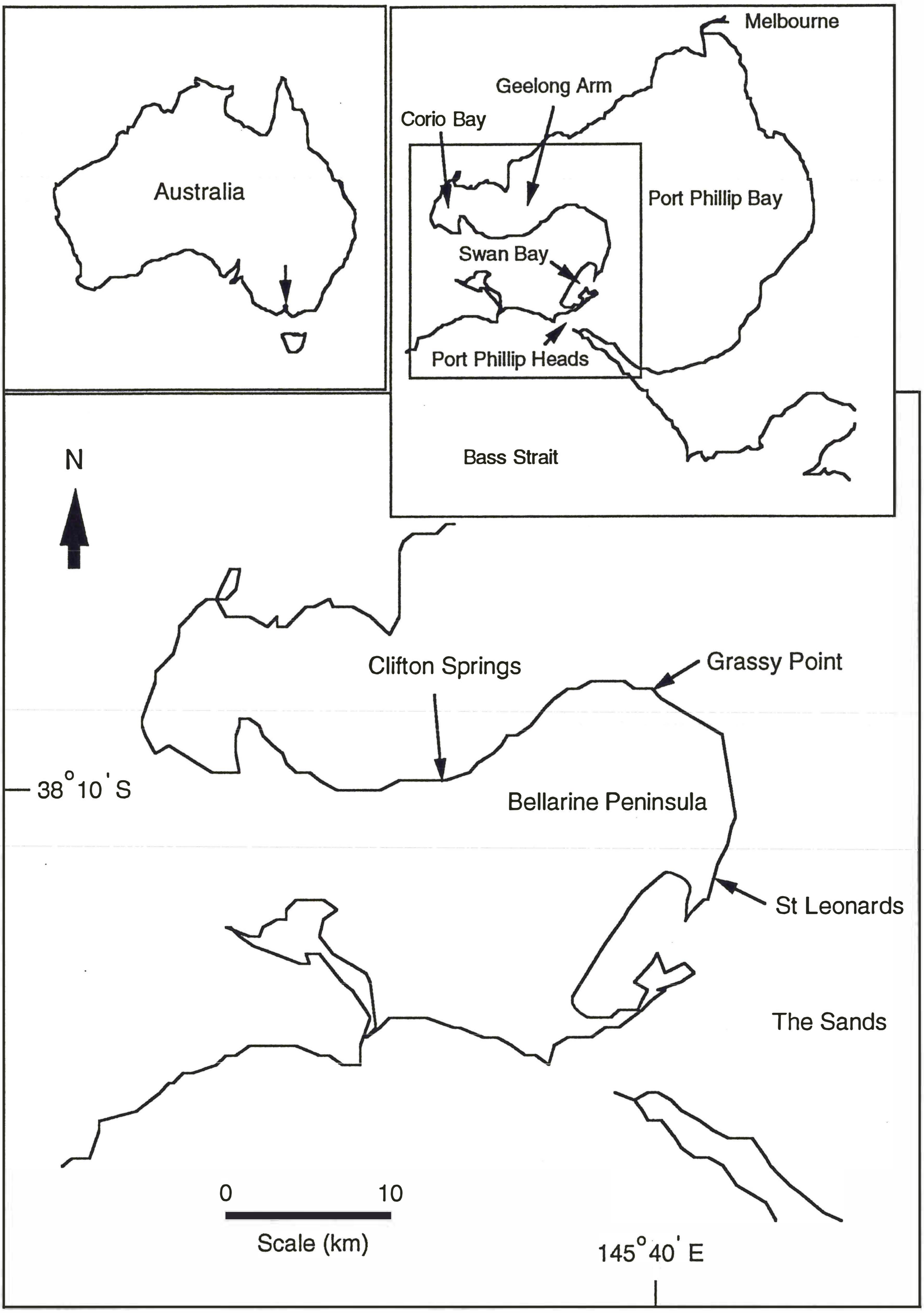

Fig. 2.1 Sampling locations around the Bellarine Peninsula region of Port Phillip Bay, Victoria, from which juvenile fishes were collected. Insets: Location of the Bellarine Peninsula in Port Phillip Bay and location of Port Phillip Bay on the Australian coast.

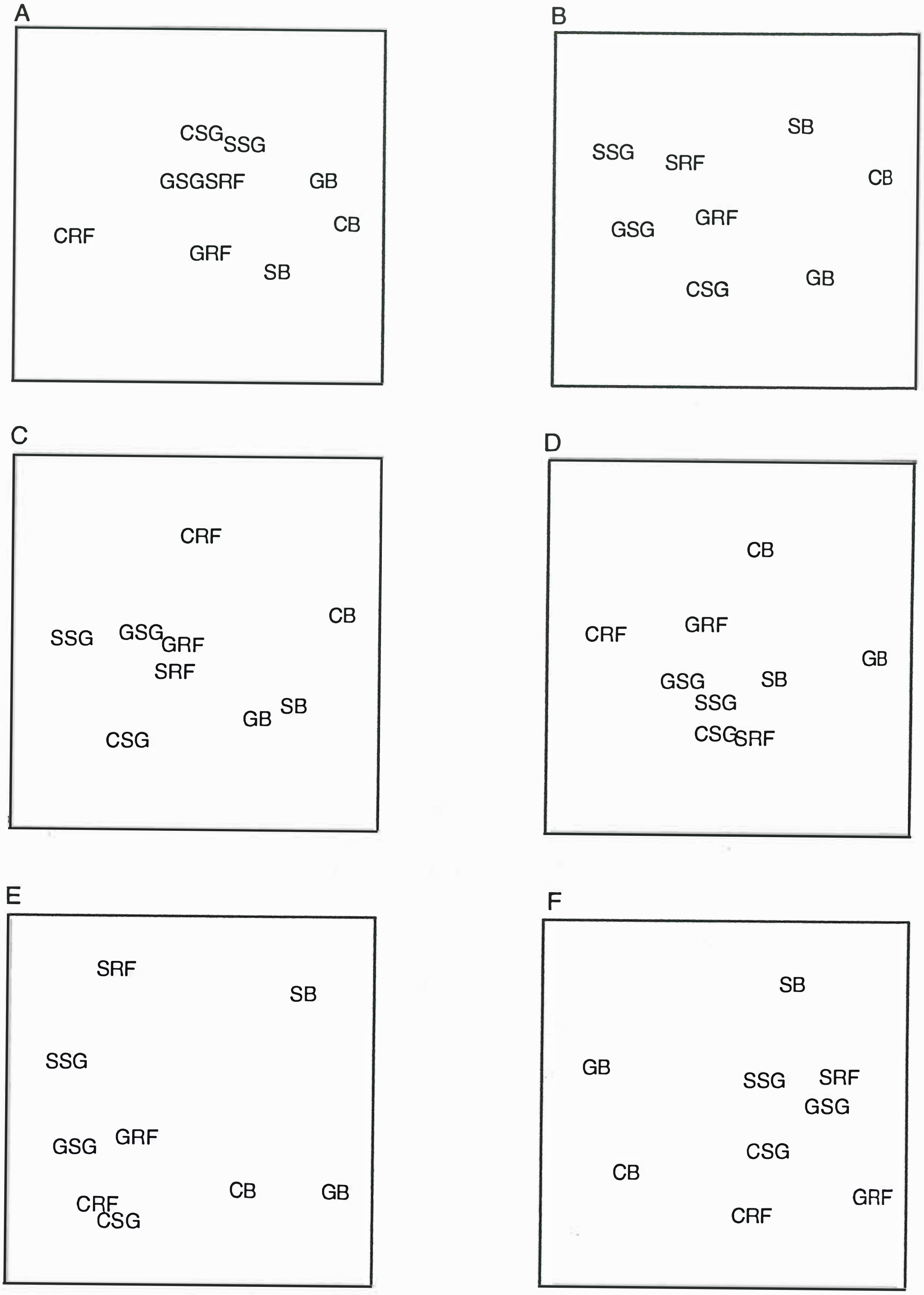

Fig. 2.2 Multidimensional scaling plots of relationships amongst fish assemblages associated with sites and habitats for each month of sampling. A. October (stress=0.10), B. November (stress=0.08), C. December (stress=0.09), D. January (stress=0.10), E. February (stress=0.11), F. March (stress=0.12). Symbol legend: "S" St Leonards, "G" Grassy Point, "C" Clifton Springs, "SG" seagrass, "RF" reef-algae, "B" unvegetated.

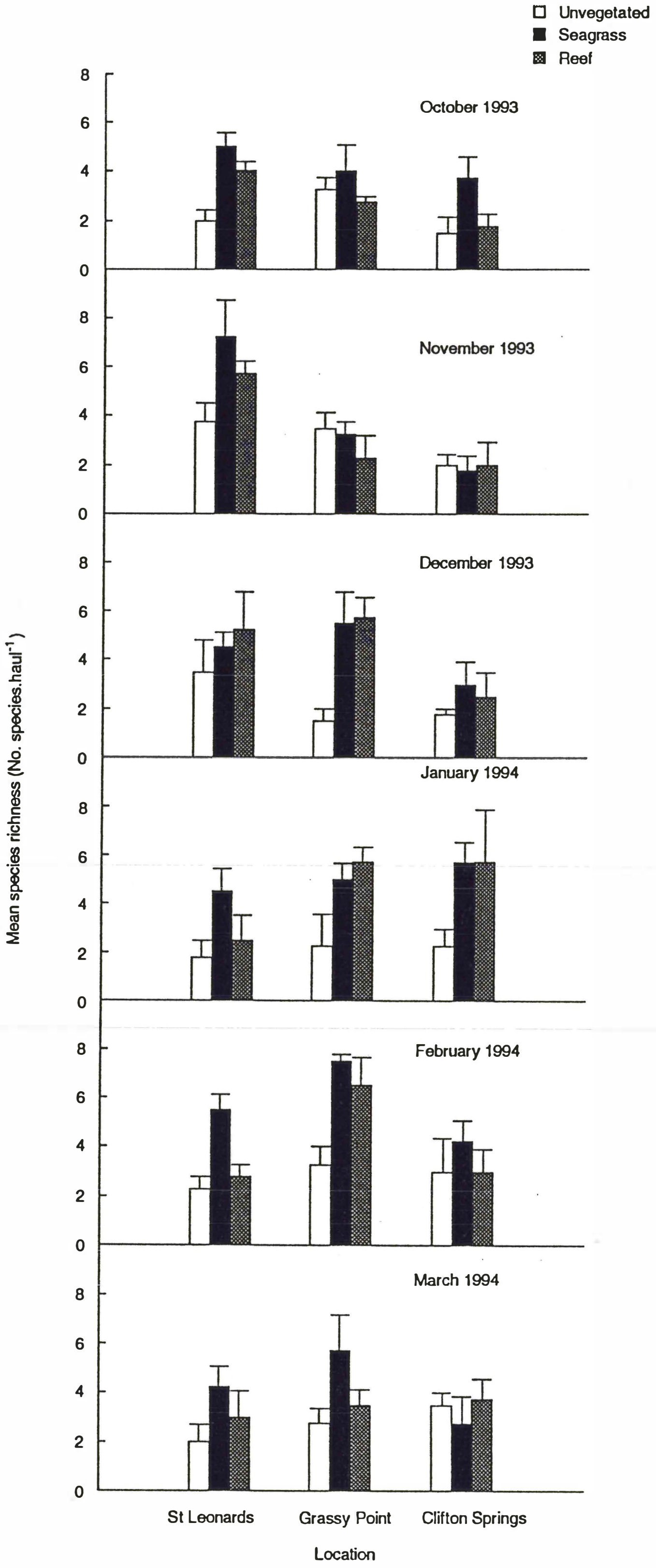

Fig. 2.3 Mean number of species of fishes collected at three locations around the Bellarine Peninsula over six sampling dates. Error bars are standard error.

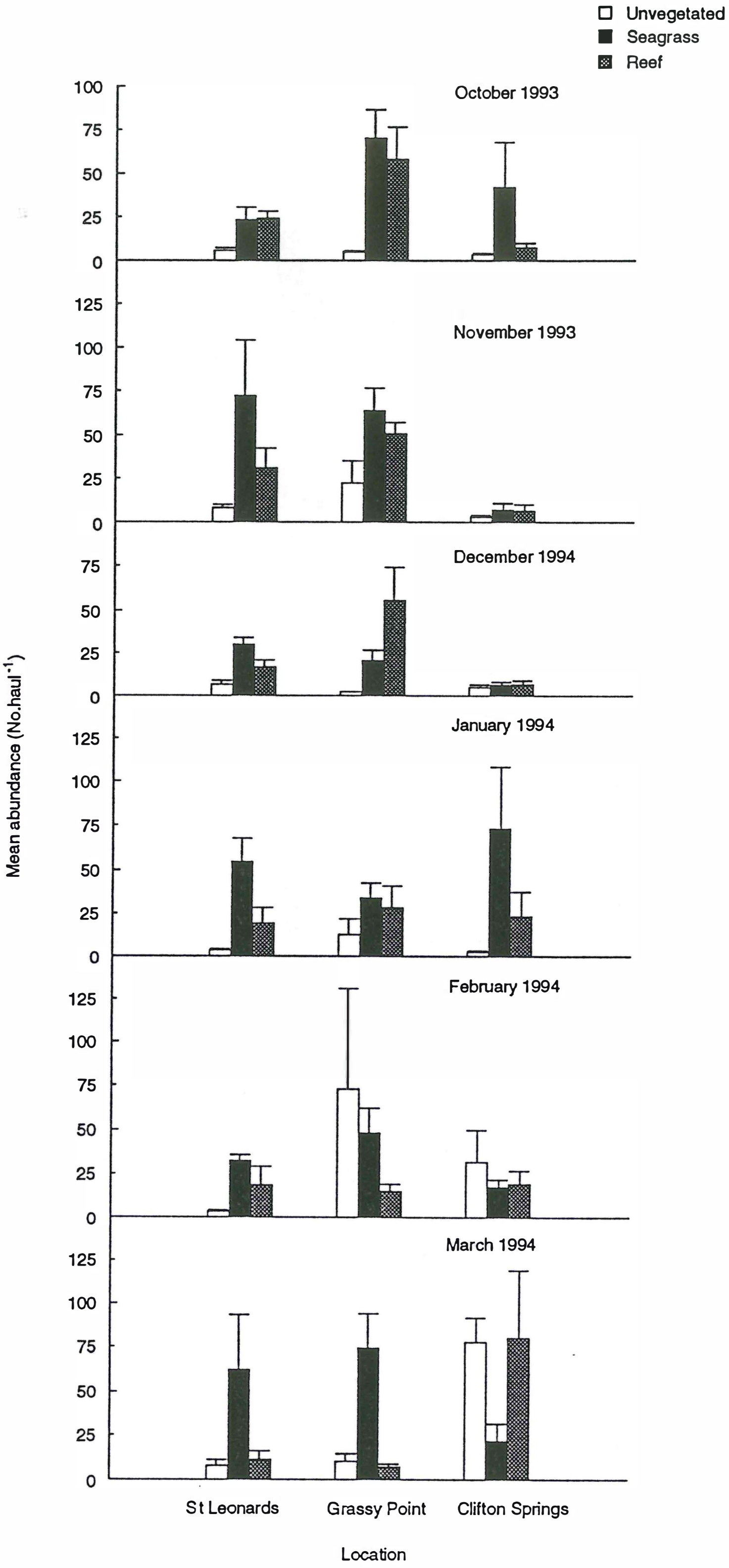

Fig. 2.4 Mean abundance of fishes collected at three locations around the Bellarine Peninsula over six sampling dates. Error bars are standard error.

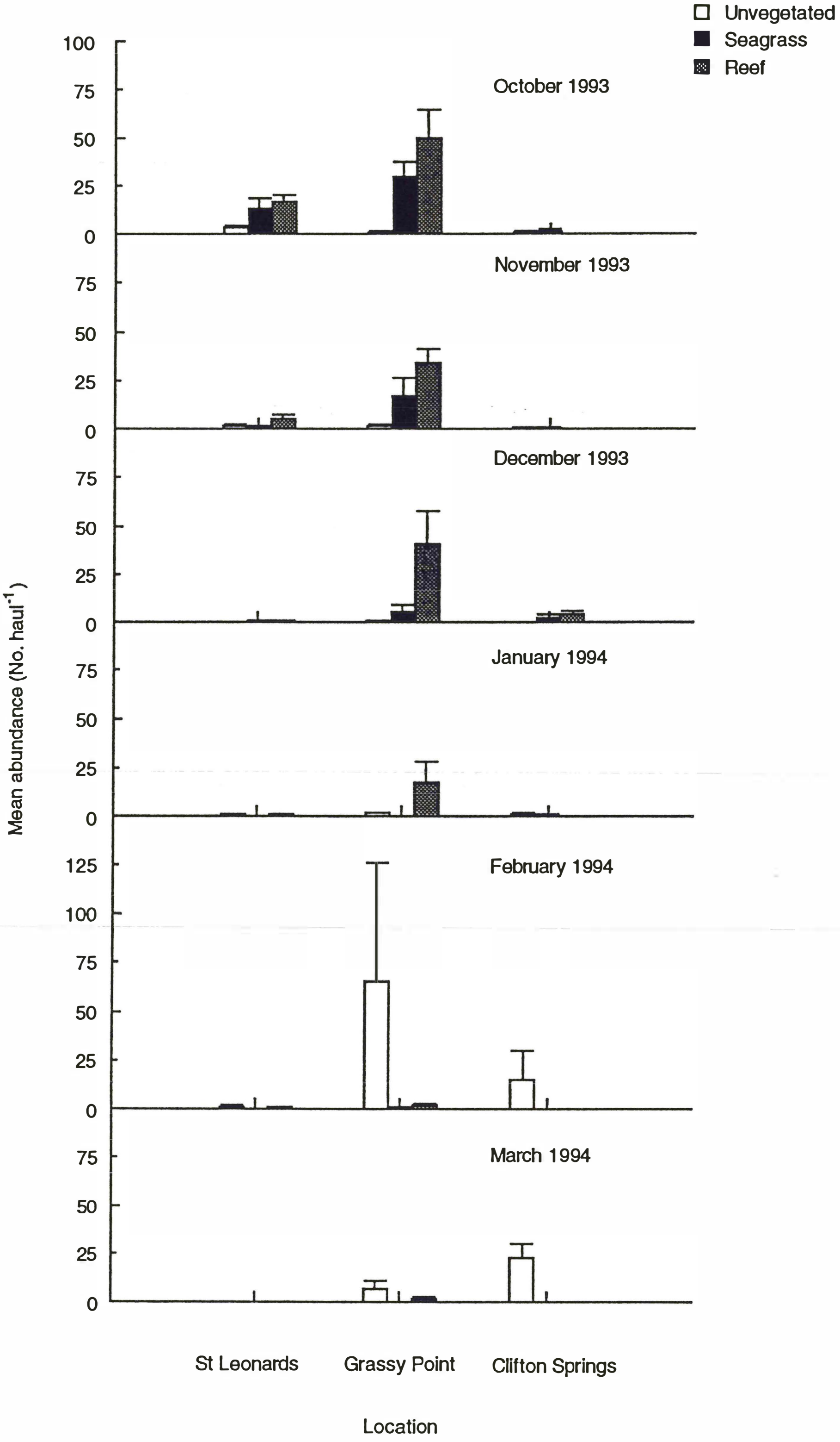

Fig. 2.5 Mean abundance of juvenile King George whiting, *Sillaginodes punctata*, at three locations around the Bellarine Peninsula over six sampling dates. Error bars are standard error.

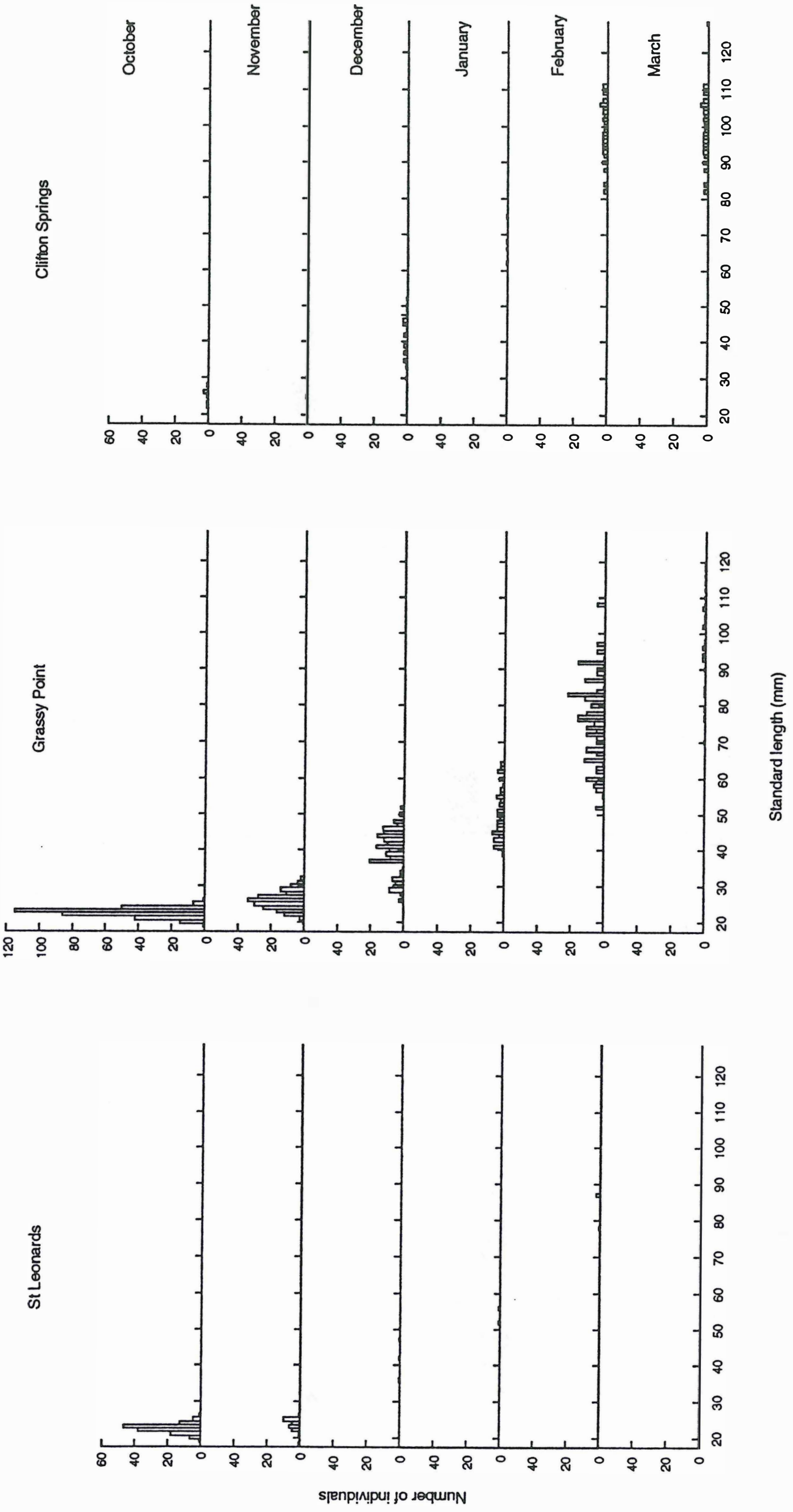

Fig. 2.6 Length frequency distributions of juvenile King George whiting, *Sillaginodes punctata*, at three locations around the Bellarine Peninsula over six sampling dates.

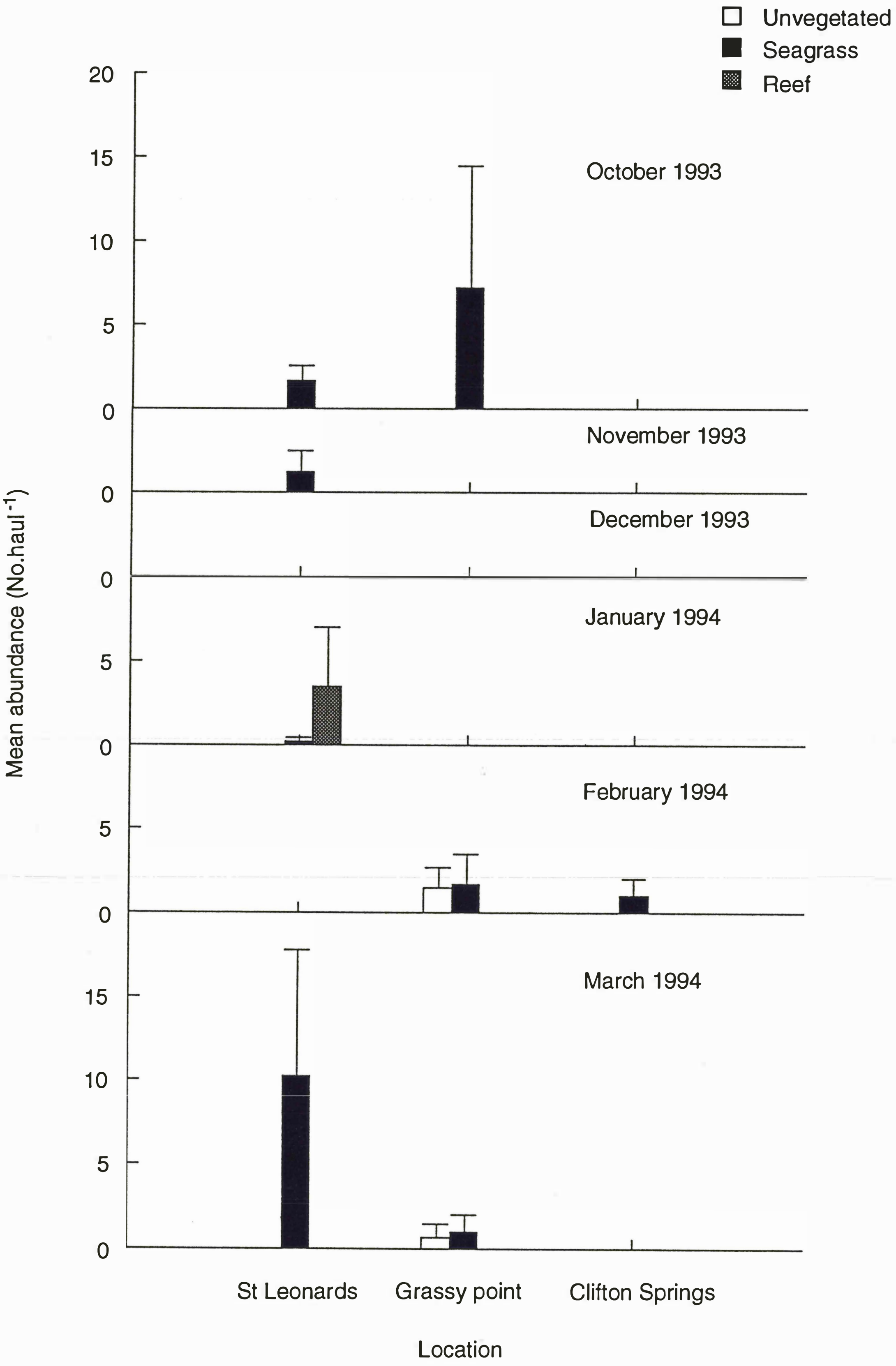

Fig. 2.7 Mean abundance of juvenile yellow-eye mullet, *Aldrichetta forsteri*, at three locations around the Bellarine Peninsula over six sampling dates. Error bars are standard error.

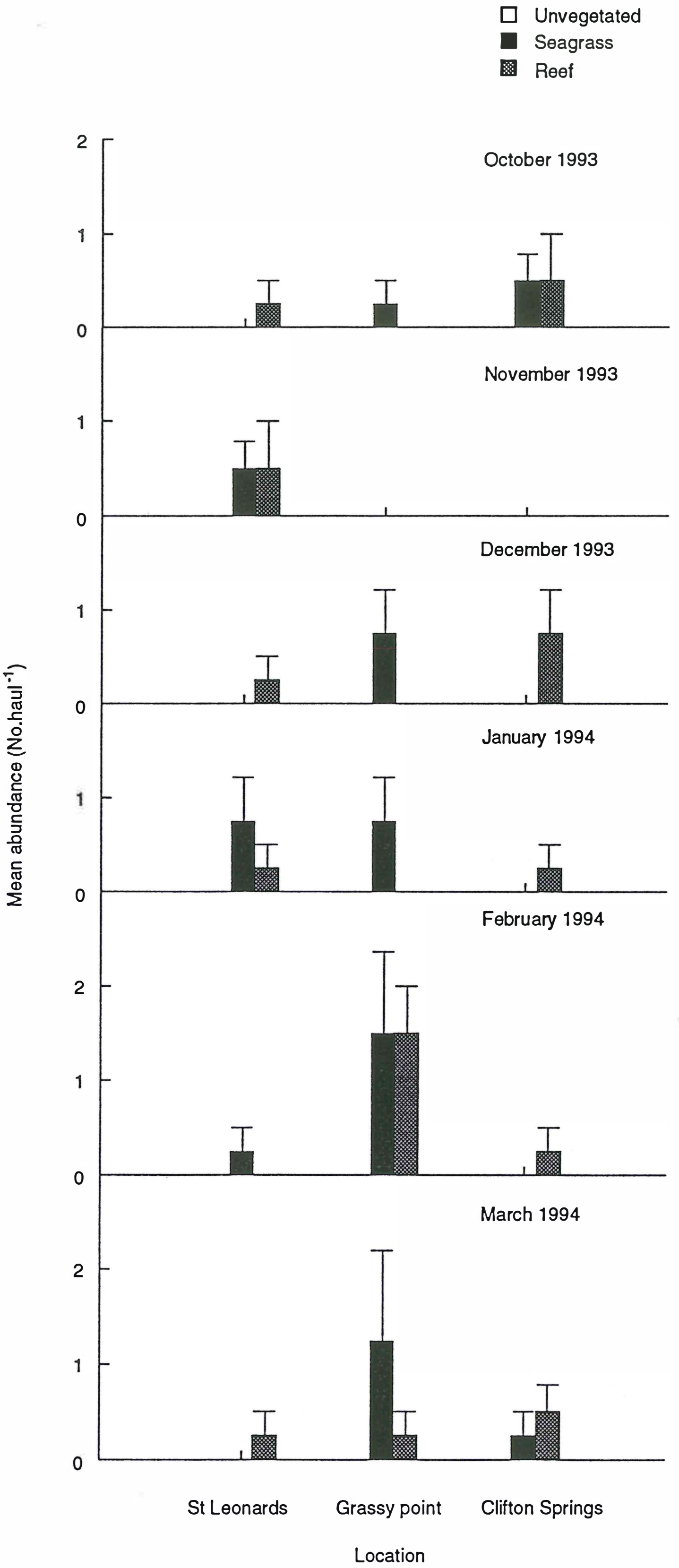

Fig. 2.8 Mean abundance of juvenile six-spine leatherjacket, *Meuschenia freycineti*, at three locations around the Bellarine Peninsula over six sampling dates. Error bars are standard error.

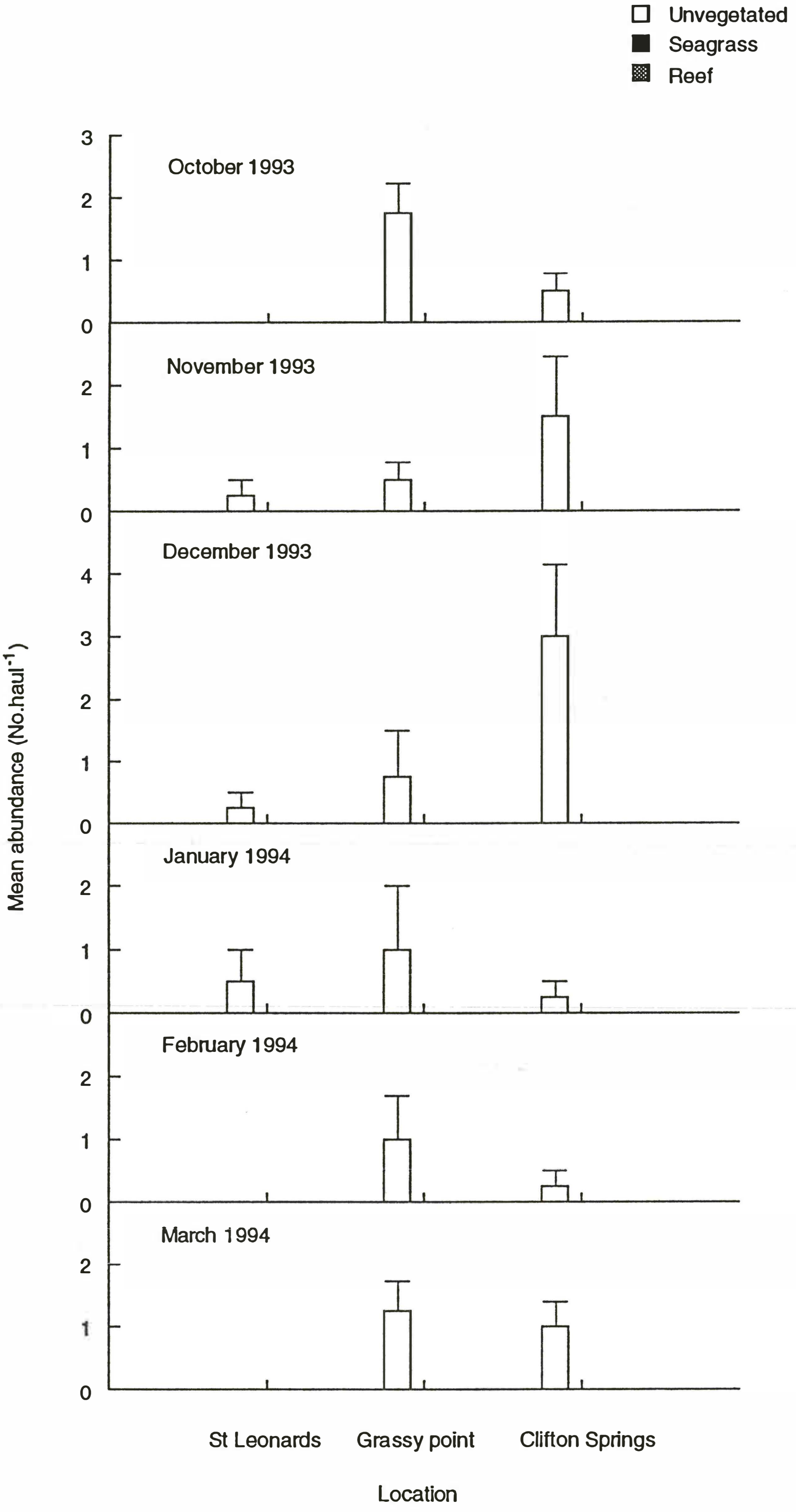

Fig. 2.9 Mean abundance of juvenile greenback flounder, *Rhombosolea tapirina*, at three locations around the Bellarine Peninsula over six sampling dates. Error bars are standard error.

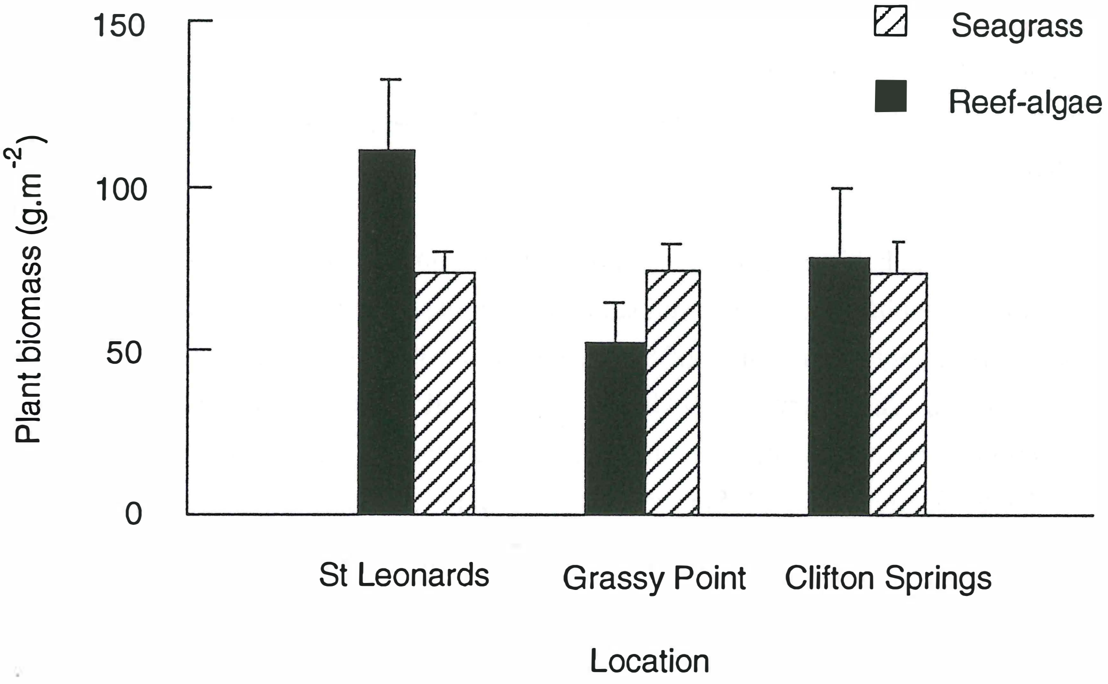

Fig. 2.10 Mean biomass of plant material from seagrass and reef-algal habitats at three locations around the Bellarine Peninsula in March 1994. Error bars are standard error.

CHAPTER 3

IMPORTANCE OF SHALLOW REEF-ALGAL HABITATS TO JUVENILE FISH OF COMMERCIAL IMPORTANCE ON THE YORKE PENINSULA, SOUTH AUSTRALIA, AND JERVIS BAY, NEW SOUTH WALES

3.1 INTRODUCTION

To extend the generality of results obtained from Port Phillip Bay we sampled two other locations in southeastern Australia. Locations chosen for this sampling were Gulf St Vincent in South Australia, and Jervis Bay in New South Wales. These sites were chosen because they share a number of characteristics with Port Phillip Bay. Both represent embayed areas of coastline that are relatively protected compared to the open coast, and are characteristically marine. Like Port Phillip Bay, both sites have well developed reef-algal and seagrass systems.

Shallow reef-algal habitats have received little study from researchers in these areas, although other habitats have been well studied. Seagrass, *Zostera* and *Heterozostera*, has been intensively sampled in Gulf St Vincent, primarily in the Barker Inlet area near Adelaide (Jones 1985; Connolly 1994a). The Barker Inlet system has proven to be an important nursery area for commercial species, particularly King George whiting (Jones 1985; Connolly 1994a). Seagrasses, *Zostera* and *Posidonia*, and unvegetated sand have been intensively studied in Jervis Bay in recent years (Ferrell and Bell 1991; Ferrell *et al.* 1993). Recruits of a number of commercial species were found on unvegetated sand adjacent to seagrass (Ferrell and Bell 1991).

Our aim was to sample shallow reef-algal and other habitats in Gulf St Vincent and Jervis Bay using the same methods employed in Port Phillip Bay to improve the generality of conclusions drawn about the importance of shallow reef-algal habitats to juvenile commercial fish in southeastern Australia. Lincoln Smith *et al.* (1991) surveyed reefs (<12 m depth) in central New South Wales including Jervis Bay and did not record significant recruitment of commercial species.

3.2 METHODS

3.2.1 Gulf St Vincent

3.2.1.1 Study area and sites

The western coast of Gulf St Vincent, like the western coast of Port Phillip Bay, is relatively protected from the predominant southwesterly winds in these latitudes. Further protection from southerly to southeasterly winds is afforded by a number of extensive sand spits along the coast, which can extend up to 5 km offshore in a northeasterly direction. Much of the coastline has intertidal low relief reef covered by a monospecific stand of the alga *Hormosira banksii.* The subtidal zone consists of unvegetated sand and seagrass *Posidonia*, while there is often substantial areas of eelgrass, *Heterozostera* / *Zostera*, in the shallow subtidal. In some areas, the intertidal has patches of *Zostera* interspersed with *Hormosira.* Seven sites were sampled along approximately 60 km of coastline (Fig. 3.1). With the exception of Port Julia, four main habitats were sampled: *Posidonia*, subtidal unvegetated, eelgrass (*Heterozostera* / *Zostera*) and *Hormosira.* At Edithburgh, Port Julia and Pine Point we sampled subtidal reef with a variety of algae, and subtidal *Posidonia* of equivalent depth. At She Oak Flat we sampled intertidal as well as subtidal unvegetated habitat.

3.2.1.2 Sampling methods

Sampling was conducted from December 7 to 16, 1994. Three or four haphazardly placed replicate samples were taken with a 20 m seine net in each habitat. The equipment, field methodology and laboratory analysis are identical to that described for Port Phillip Bay in chapter two.

3.2.1.3 Data analyses

Univariate analyses of variance were conducted with combinations of habitat and site treatments. Habitat was considered to be a fixed factor and site a random factor. A two-way crossed ANOSIM was used to compare assemblages across habitats and sites, and assemblages associated with habitats were plotted separately for each site using multidimensional scaling (MDS). In some cases, outlying replicates in MDS plots were removed to aid the interpretation of overall relationships. Other details of data analyses are as described in chapters 1 and 2.

3.2.2 Jervis Bay

3.2.2.1 Study area and sites

Jervis Bay is a marine dominated embayment that is relatively more exposed to oceanic influences, such as swell waves, when compared with Port Phillip Bay or Gulf St Vincent. Reef occurs adjacent to rocky coastline. Areas of seagrass, *Posidonia*, occur subtidally, particularly in the northern segment of the bay. Seagrass, *Zostera capricorni*, occurs on the shallow fringe of the subtidal mainly near freshwater inputs. Seven sites were sampled in this study (Fig. 3.2) with both SCUBA transects of subtidal reefs (2 - 7 m) and seining on shallow (< 1 m) subtidal reef, *Posidonia* beds, and unvegetated sand. Subtidal reefs were visually transected at all sites. Most subtidal reefs sampled by visual transect consisted mainly of kelp, *Ecklonia*, forest habitat (Underwood *et al.* 1991). Seining was conducted at all sites with additional sampling in *Posidonia* habitat at Bindijine Beach, Scottish Rocks and Callala Point.

3.2.2.2 Sampling methods

Sampling was conducted from February 16 to 25, 1995. Visual transecting methods were the same as described for Port Phillip Bay in Chapter 1. Four replicates each of fast and slow transects were conducted. Seining was conducted using the same equipment and protocol as was used in Port Phillip Bay in Chapter 2. Four haphazardly placed replicates were conducted in each habitat using this procedure.

3.2.2.3 Data analysis

Univariate analyses of variance were conducted with combinations of habitat and site treatments. Habitat was considered to be a fixed factor and site a random factor. For SCUBA transecting data a two-way crossed ANOSIM was used to compare assemblages across habitats and sites, and assemblages associated with habitats and sites were plotted with the replicates pooled using multidimensional scaling (MDS). Other details of data analyses are as described in chapters 1 and 2.

3.3 RESULTS

3.3.1 Gulf St Vincent

3.3.1.1 Fish assemblages

Fish species varied in their use of habitat (Table 3.1). King George whiting, *Sillaginodes punctata*, were the dominant species in unvegetated and *Hormosira* habitats, and were also common in the eelgrass habitat. Blue rock whiting, *Haletta semifasciata*, were common in the subtidal vegetated habitats, particularly eelgrass. Striped perch, *Pelates octolineatus*, were moderately abundant in all habitats except subtidal reef. Spotted pipefish were common in the deeper vegetated habitats, *Posidonia* and subtidal reef, whilst gobies, *Favonigobius lateralis*, were common in the unvegetated and *Hormosira* habitats. Species that were common in only one habitat included soldierfish, *Gymnapistes marmoratus*, and spinytail leatherjacket, *Acanthaluteres brownii*, in *Posidonia*; yellow-eye mullet, *Aldrichetta forsteri*, in unvegetated, the pipefishes, *Kaupus costatus* and *Vanacampus phillipi*, in eelgrass; and toothbrush leatherjacket, *Acanthaluteres vittiger*, in subtidal reef.

ANOSIM of four habitats, *Posidonia*, unvegetated, eelgrass and *Hormosira*, across all sites except Port Julia, showed highly significant differences amongst sites (P=0.0) and habitats (P=0.0). Paired comparisons amongst habitats adjusted for multiple comparisons indicated assemblages associated with habitats were significantly different with the exception of unvegetated and *Hormosira*. Multidimensional scaling clearly showed separation of habitats with the exception of unvegetated and *Hormosira* (Fig. 3.3). Intertidal unvegetated habitat was also sampled at She Oak Flat and overlapped with shallow subtidal unvegetated and *Hormosira* (Fig. 3.3B). Subtidal reef at Edithburgh and Pine Point was clearly separated from other habitats (Fig. 3.3A,F).

3.3.1.2 Species richness and abundance

Analysis of variance of species number for four habitats over six sites showed a significant effect of habitat with post-hoc tests indicating that number of species was significantly higher ($P<0.05$) in *Posidonia* compared with unvegetated and *Hormosira* (Table 3.2, Fig.3.4). Comparison of species number between subtidal reef and seagrass, however, showed no significant difference (Table 3.2, Fig. 3.5).

Table 3.1 The mean number of individuals and percentage of the total individuals (in parentheses) for fish taxa collected from habitats along the western coast of Gulf St Vincent.

Species			Habitat		
	Posidonia mean haul^{-1}	Unvegetated mean haul^{-1}	*Zostera* mean haul^{-1}	*Hormosira* mean haul^{-1}	Subtidal Reef mean haul^{-1}
Rhinobatidae					
Trygonorrhina guanerius	0.04 (0.19)	0	0	0	0
Ophichthidae					
Muraenichthys australis	0.04 (0.19)	0	0	0	0
Gobiesocidae					
Parvicrepis sp.1	0.08 (0.39)	0	0	0	0
Syngnathidae					
Stigmatopora argus	1.62 (8.16)	0	0	0	3.07 (17.34)
Vanacampus phillipi	1.04 (5.24)	0	0.95 (7.87)	0.03 (0.22)	0.36 (2.02)
Vanacampus poecilolaemus	0.08 (0.39)	0.04 (0.14)	0	0	0.07 (0.4)
Kaupus costatus	0.04 (0.19)	0.12 (0.41)	1.43 (11.81)	0.24 (1.75)	0
Leptoichthys fistularius	0.88 (4.47)	0	0	0	0
Hypselognathus rostratus	0.12 (0.58)	0	0	0	0
Pugnaso curtirostris	0	0	0	0.03 (0.22)	0
Lissocampus runa	0	0	0	0	0.07 (0.4)
Unidentified Syngnathidae recruits	0.08 (0.39)	0	0.33 (2.76)	0.09 (0.66)	2.93 (16.53)
Hippocampus breviceps	0	0	0	0	1.14 (6.45)
Scorpaenidae					
Gymnapistes marmoratus	1.88 (9.51)	0	0.14 (1.18)	0.21 (1.53)	0
Platycephalidae					
Platycephalus laevigatus	0.08 (0.39)	0	0	0	0
Platycephalus bassensis	0	0.04 (0.14)	0	0	0
Terapontidae					
Pelates octolineatus	1.12 (5.63)	2.8 (9.46)	0.67 (5.51)	2.94 (21.23)	0
Apogonidae					
Siphaemia cephalotes	0.04 (0.19)	0	0	0	0
Sillaginidae					
Sillaginodes punctata	0.23 (1.16)	18.44 (62.3)	1.48 (12.2)	7.15 (51.64)	0
Sillago bassensis	0	0.04 (0.14)	0	0	0
Arripidae					
Arripis truttacea	0	0.12 (0.41)	0.05 (0.39)	0	0
Kyphosidae					
Kyphosus sydneyanus	0	0	0	0	0.57 (3.23)
Enoplosidae					
Enoplosus armatus	0	0	0.05 (0.39)	0	0
Cheilodactylidae					
Dactylophora nigricans	0	0	0	0	0.07 (0.4)
Mugilidae					
Aldrichetta forsteri	0	4.12 (14.00)	0.33 (2.76)	0.36 (2.63)	0
Odacidae					
Haletta semifasciata	2.38 (12.04)	0	5.62 (46.46)	0.03 (0.22)	2.22 (12.5)
Neoodax balteatus	0.5 (2.52)	0	0	0	0.14 (0.81)

Table 3.1 (Cont.) The mean number of individuals and percentage of the total individuals (in parentheses) for fish taxa collected from habitats along the western coast of Gulf St Vincent.

Species			Habitat		
	Posidonia mean haul^{-1}	Unvegetated mean haul^{-1}	*Zostera* mean haul^{-1}	*Hormorisa* mean haul^{-1}	Subtidal Reef mean haul^{-1}
Clinidae					
Heteroclinus perspicillatus	0.08 (0.39)	0.08 (0.27)	0.48 (3.94)	0.03 (0.22)	0
Cristiceps australis	0	0	0	0	0.43 (2.42)
Heteroclinus heptaeolus	0	0	0	0	0.14 (0.81)
Heteroclinus sp. 5	0	0	0	0	0.07(0.4)
Gobiidae					
Favonigobius lateralis	0	2.96 (10.00)	0.05 (0.39)	1.94 (14.00)	0
Nesogobius sp.1	0.04 (0.19)	0.36 (1.22)	0.14 (1.18)	0.33 (2.41)	0
Pseudogobius olorum	0	0	0.29 (2.36)	0	0
Pleuronectidae					
Rhombosolea tapirina	0	0.2 (0.68)	0	0	0
Ammotretis elongatus	0	0.08 (0.27)	0	0	0
Monacanthidae					
Acanthaluteres brownii	7.77 (39.22)	0	0.05 (0.39)	0	0.36 (2.02)
Acanthaluteres vittiger	0.12 (0.58)	0	0	0	4.86 (27.42)
Acanthaluteres spilomelanurus	0.38 (1.94)	0	0	0	0
Meuschenia freycineti	0.81 (4.08)	0.04 (0.14)	0	0	0.29 (1.61)
Unidentified Monocanthidae recruits	0	0	0	0.03 (0.22)	0.86 (4.84)
Tetraodontidae					
Contusus richei	0.04 (0.19)	0.08 (0.27)	0.05 (0.39)	0.15 (1.09)	0.07 (0.4)
Contusus brevicaudus	0.27 (1.36)	0.08 (0.27)	0	0.27 (1.97)	0
Torquigener pleurogramma	0.08 (0.39)	0	0	0	0
Mean number per haul	19.81	29.6	12.1	13.85	17.71
Total number of species	26	16	16	15	18

Table 3.2 Analysis of variance of species number for unvegetated, *Hormosira*, eelgrass and *Posidonia* habitats over six sites and subtidal reef and *Posidonia* over three sites. ** P<0.001, *P<0.05, ns = not significant.

	Overall			Subtidal reef / *Posidonia*		
Source	DF	MS	F	DF	MS	F
Site	5	1.569	0.580 ns	2	6.849	1.870 ns
Habitat	3	22.156	7.987 **	1	0.045	0.008 ns
Site*Habitat	15	2.774	1.026 ns	2	5.354	1.462 ns
Error	61	2.704		20	3.663	

Analysis of variance of total abundance in four habitats across six sites showed a significant interaction between habitat and site (Table 3.3, Fig. 3.6). When habitats were compared for individual sites, post-hoc tests showed that significant (P<0.05) differences between habitats only occurred at Stansbury, where unvegetated was higher than eelgrass, and Coobowie, where *Posidonia* was higher than unvegetated and *Hormosira*. Analysis of variance comparing subtidal reef and *Posidonia* across three sites showed no significant differences (Table 3.3, Fig. 3.7).

Table 3.3. Analysis of variance of log(x+1) abundance for unvegetated, *Hormosira*, eelgrass and *Posidonia* habitats over six sites and subtidal reef and *Posidonia* over three sites. ** P<0.001, *P<0.05, ns = not significant.

	Overall			Subtidal reef / *Posidonia*		
Source	DF	MS	F	DF	MS	F
Site	5	0.728	1.185 ns	2	1.403	2.948 ns
Habitat	3	1.380	1.100 ns	1	0.061	0.102 ns
Habitat*site	15	1.254	2.042 *	2	0.594	1.247 ns
Error	61	0.614		20	0.476	

The most important commercial species collected in this study was the King George whiting, *Sillaginodes punctata*. Catches were dominated by 0+ and 1+ individuals (Fig. 3.8). Analysis of variance of *S. punctata* abundance showed a highly significant effect of habitat (Table 3.4). Post-hoc tests showed that abundances in unvegetated and

Hormosira habitats were significantly higher ($P<0.05$) than eelgrass or *Posidonia*. Young of the year (0+) individuals were consistently collected in *Hormosira* whilst high abundances in unvegetated habitat mainly occurred at Stansbury and Pine Point (Fig. 3.9). Older (1+) individuals were collected in high abundances on unvegetated habitat at Port Vincent (Fig. 3.9). Size-frequency plots suggest that there was a trend for increasing average size of 0+ *S. punctata* from south to north, particularly if the Coobowie and Port Vincent data are not considered because of low sample size of 0+ individuals (Fig. 3.8). The modes of size frequency increased from approximately 40-45 mm at Edithburgh to 50-55 mm at Pine Point.

Table 3.4 Analysis of variance of log(x+1) transformed abundance of King George whiting, *Sillaginodes punctata*, for unvegetated, *Hormosira*, eelgrass and *Posidonia* habitats over six sites. ** $P<0.001$, *$P<0.05$, ns = not significant.

Source	DF	MS	F
Site	5	0.645	1.016 ns
Habitat	3	16.563	27.651**
Site*Habitat	15	0.599	0.943 ns
Error	61	0.635	

The blue rock whiting, *Haletta semifasciata*, occurred in subtidal structured habitats (Table 3.1). Young of the year (0+) individuals were collected primarily from eelgrass at Edithburgh and Coobowie (Fig. 3.10). Older juveniles and adults were collected from both *Posidonia* and eelgrass, again mainly from Edithburgh and Coobowie (Fig. 3.10). Juvenile (0+) yellow-eye mullet were mainly collected in unvegetated habitat, though some individuals were also collected in eelgrass and *Hormosira* habitats (Fig. 3.11). Juveniles of six-spine leatherjackets, *Meuschenia freycineti*, were primarily collected in *Posidonia* and to a lesser extent sub-tidal reef (Table 3.1). Low numbers of juvenile greenback flounder, *Rhombosolea tapirina*, and Western Australian salmon, *Arripis truttacea*, were collected in unvegetated habitat (Table 3.1).

3.3.2 Jervis Bay

3.3.2.1. Fish assemblages

3.3.2.1.1 Seine netting

Atherinids were a dominant group in seine nettings with the silverfish, *Leptatherina presbyteroides*, dominant in all three habitats and deep-water hardyhead, *Atherinason hepsetoides*, also very abundant in unvegetated habitat (Table 3.5). Blue sprat, *Spratelloides robustus*, was abundant in reef and *Posidonia* habitat (Table 3.5). Species which dominated in one habitat only included mado, *Atypichthys strigatus*, in reef habitat; flat-tail mullet, *Liza argentea*, in unvegetated habitat; and pipefishes of the genus *Stigmatopora* in *Posidonia* habitat (Table 3.5).

Two-way crossed ANOSIM analysis showed significant differences amongst sites (P=0.0) and habitats (P=0.0) for the three sites where reef, unvegetated and *Posidonia* were sampled. A multidimensional scaling plot for all sites and habitats with replicates pooled showed no clear pattern although there was a strong grouping of unvegetated habitats from four sites (Fig. 3.12).

3.3.2.1.2 SCUBA transecting

The dominant species encountered on SCUBA transects was juvenile Australian mado, *Atypichthys strigatus* (Appendix 1). Juveniles of the closely related silver sweep, *Scorpis lineolata*, were also very common at a number of sites (Appendix 1). Large numbers of schooling yellowtail, *Trachurus novaezelandiae*, eastern hulafish, *Trachinops taeniatus*, and small-scale bullseye, *Pempheris compressa*, were present at some sites (Appendix 1). Also very common at most sites were a number of wrasse species, particularly blue groper, *Achoerodus viridis*, crimson banded wrasse, *Notalabrus gymnogenis*, Maori wrasse, *Ophthalmolepis lineolata*, and senator wrasse, *Pictilabrus laticlavius* (Appendix 1).

Table 3.5 Mean abundance and percentage of total number (in parentheses) of fishes collected by seine net in three habitats (< 1 m depth) in Jervis Bay.

Species		Habitat	
	Reef	Bare	*Posidonia*
	No. haul^{-1}	No. haul^{-1}	No. haul^{-1}
Clupeidae			
Spratelloides robustus	2.50 (16.06)	0.39 (1.31)	18.17 (68.13)
Plotosidae			
Cnidoglanus macrocephala	0.04 (0.23)	0.07 (0.24)	0
Atherinidae			
Atherinason hepsetoides	0	16.89 (56.51)	0
Leptatherina presbyteroides	4.71 (30.28)	9.96 (33.33)	2.00 (7.50)
Atherinosoma microstoma	0.46 (2.98)	0.43 (1.43)	0
Syngnathidae			
Stigmatopora argus	0.04 (0.23)	0	2.25 (8.44)
Stigmatopora nigra	0.32 (2.06)	0.11 (0.36)	0.33 (1.25)
Histiogamphelus briggsii	0.07 (0.46)	0	0
Vanacampus margaritifer	0.04 (0.23)	0	0.08 (0.31)
Stigmatopora spp.	0.39 (2.52)	0	0.58 (2.19)
Platycephalidae			
Platycephalus caeruleopunctatus	0	0.04 (0.12)	0
Scorpaenidae			
Centropogon australis	0	0	0.17 (0.01)
Apogonidae			
Siphaemia cephalotes	0.11 (0.69)	0	0
Sillaginidae			
Sillago flindersi	0	0.14 (0.48)	0
Sillago ciliata	0	0.25 (0.84)	0
Carangidae			
Trachurus novaezelandiae	0	0	0.17 (0.63)
Pseudocaranx dentex	0	0.07 (0.24)	0
Arripidae			
Arripis trutta	0.04 (0.23)	0	0
Mullidae			
Parupeneus signatus	0.04 (0.23)	0	0
Monodactylidae			
Schuettea scalaripinnis	0.07 (0.46)	0	0
Scorpididae			
Scorpis lineolata	0.14 (0.92)	0	0.08 (0.31)
Microcanthidae			
Atypichthys strigatus	5.18 (33.26)	0	0.33 (1.25)
Enoplosidae			
Enoplosus armatus	0.25 (1.61)	0	0.50 (1.88)
Chironemidae			
Chironemus marmoratus	0	0	0.08 (0.31)
Aplodactylidae			
Crinodus lophodon	0	0	0.08 (0.31)
Cheilodactylidae			
Cheilodactylus fuscus	0.04 (0.23)	0	0
Mugilidae			
Liza argentea	0	1.11 (3.70)	0.33 (1.25)

Table 3.5 (Cont.) Mean abundance and percentage of total number (in parentheses) of fishes collected by seine net in three habitats (< 1 m depth) in Jervis Bay.

Species	Habitat Reef No. haul^{-1}	 Bare No. haul^{-1}	 *Posidonia* No. haul^{-1}
Sphyraenidae			
Sphyraena novaehollandiae	0	0	0.08 (0.31)
Labridae			
Ophthalmolepis lineolata	0.04 (0.23)	0	0
Achoerodus viridis	0.04 (0.23)	0	0
Odacidae			
Odax cyanomelas	0.04 (0.23)	0	0
Clinidae			
Cristiceps australis	0	0	0.08 (0.31)
Unidentified Clinidae	0.04 (0.23)	0	0
Pleuronectidae			
Ammotretis rostratus	0	0.04 (0.12)	0
Monacanthidae			
Brachaluteres jacksonianus	0.21 (1.38)	0	0.08 (0.31)
Scobinichthys granulatus	0.14 (0.92)	0	0.42 (1.56)
Meuschenia freycineti	0.04 (0.23)	0	0.08 (0.31)
Tetraodontidae			
Tetractenos glaber	0.07 (0.46)	0.21 (0.72)	0.92 (3.44)
Torquigener pleurogramma	0.54 (3.44)	0.18 (0.60)	0
Number of fish per haul	15.57	29.89	26.67
Total number of species	26.00	14.00	19.00

One-way ANOSIM showed that fish assemblages associated with sites were significantly different for both fast (P=0.0) and slow (P=0.0) transects. The MDS plot of fish assemblages at sites encountered on fast transects showed that while Bindijine Beach, Montagu Point and Callala Bay had distinct assemblages, assemblages at other sites tended to overlap (Fig. 3.13A). Patterns were less clear for slow transects with some overlap amongst all sites (Fig. 3.13B).

3.3.2.2 Species richness and abundance

3.3.2.2.1 Seine netting

Analyses of variance of species richness and abundance were undertaken for three habitats at the sites at which all habitats were sampled, and for two habitats (reef-algae and unvegetated) at all sites. For the comparison of species richness amongst three habitats there was a significant difference amongst habitats and sites (Table 3.6, Fig. 3.14), with the post-hoc test showing that number of species was significantly higher on *Posidonia* compared with reef-algae and unvegetated habitat (P<0.05) and significantly higher at Bindijine Beach compared with Scottish Rocks (P<0.05). For the comparison of reef-algae and unvegetated habitat at all sites, there was a significant interaction between site and habitat (Table 3.6, Fig. 3.14). Post-hoc testing showed that species number was significantly higher (P<0.05) in reef-algae relative to unvegetated sand at Hole in the Wall, Vincentia, and Bindijine Beach; no significant difference occurred at other sites.

For the comparison of abundance amongst three habitats there was a significant interaction between habitats and sites (Table 3.7, Fig. 3.15). Post-hoc testing showed that at both Scottish Rocks and Bindijine Beach, abundance in unvegetated was significantly higher than reef-algae (P<0.05) whilst at Callala Point, reef-algae and *Posidonia* were significantly higher than unvegetated habitat (P<0.05).

Table 3.6 Analysis of variance comparing species richness in habitats and across sites. A. Comparison of reef-algae, *Posidonia*, and unvegetated habitat across three sites, B. Comparison of reef-algae and unvegetated habitat across all sites. ** P<0.001, *P<0.05, ns = not significant.

	A.			B.		
Source	DF	MS	F	DF	MS	F
Site	2	7.53	5.31*	6	3.33	3.21*
Habitat	2	19.44	14.29*	1	14.00	5.69 ns
Site*Habitat	4	1.36	0.96 ns	6	2.46	2.37 *
Error	27	1.42		42	1.04	

For the comparison of abundance in reef-algae and unvegetated habitat at all sites, there was a significant interaction between site and habitat (Table 3.7, Fig. 3.15). Post-hoc testing showed that abundance was significantly higher (P<0.05) in reef relative to unvegetated sand at Vincentia and Callala Point, significantly higher (P<0.05) in unvegetated sand relative to reef at Scottish Rocks, Callala Bay, Montagu Point and Bindijine Beach, and not significantly different (P>0.05) between habitats at Hole in the Wall.

Table 3.7. Analysis of variance comparing fish abundance in habitats and across sites. A. Comparison of reef-algae, *Posidonia*, and unvegetated habitat across three sites, B. Comparison of reef-algae and unvegetated habitat across all sites. ** P<0.001, *P<0.05, ns = not significant.

	A.			B.		
Source	DF	MS	F	DF	MS	F
Site	2	0.84	4.12*	6	2.36	12.03**
Habitat	2	0.72	0.42 ns	1	1.16	0.86 ns
Site*Habitat	4	1.70	8.40 **	6	1.34	6.84 **
Error	27	0.20		42	0.20	

3.3.2.2.2 SCUBA transecting

Data on species richness were pooled for fast and slow transects (Fig. 3.16). One-way analysis of variance indicated that sites were significantly different (DF=6/21, F=6.24, P<0.001). Post-hoc testing indicated that Bindijine Beach had higher species richness than all sites except Montagu Point, and that these two sites were significantly higher than Callala Point and Callala Bay (P<0.05).

One-way analysis of variance indicated that abundances were not significantly different between sites for fast transects (DF=6/21, F=1.581, P>0.2) but were significant for slow transects (DF=6/21, F=3.64, P<0.05) (Fig. 3.17). Post-hoc testing showed that for slow transects, abundances were significantly higher at Bindijine Beach and Montagu Point compared with Callala Bay (P<0.05).

3.3.2.3 Commercial species

A variety of species of commercial value were collected in low numbers with the seine net from unvegetated habitat, including school whiting, *Sillago flindersi*, blue-nose whiting, *Sillago ciliata*, east Australian salmon, *Arripis trutta*, flat-tail mullet, *Liza argentea*, and silver trevally, *Pseudocaranx dentex* (Table 3.5). In the other two habitats sampled with the seine only the rough leatherjacket, *Scobinichthys granulatus*, was of minor commercial significance (Table 3.5).

A number of commercially important species were encountered on SCUBA transects, including, bream, *Acanthopagrus australis*, luderick, *Girella tricuspidata*, red mullet, *Upeneichthys vlamingii*, and leatherjackets, *Meuschenia freycineti* and *Scobinichthys* *granulatus*. Individuals of these species, however, were mainly sub-adult to adults rather than young-of-the-year recruits (Appendix 1). Bream and luderick were mainly encountered at the Hole in the Wall and Scottish Rocks sites at the southern end of Jervis Bay (Appendix 1, Fig. 3.2).

3.4 DISCUSSION

3.4.1 Gulf St Vincent

The fish assemblage sampled in the Gulf St Vincent was very similar to that sampled in Port Phillip Bay with a few notable exceptions, such as significant numbers of striped perch, *Pelates octolineatus*, and the spinytail leatherjacket, *Acanthaluteres brownii*, which were not sampled in Port Phillip Bay. Like Port Phillip Bay, the most important species found to utilise shallow habitats in Gulf St Vincent was King George whiting, *Sillaginodes punctata*. Fish assemblages in unvegetated and *Hormosira* were similar, and *S. punctata* was a dominant in both. Similarity between these two habitats is not surprising considering that the *Hormosira* habitat consisted of a very flat substrate of rock covered with a thin layer of sediment, and varying cover of *Hormosira*. Because there is a large area of *Hormosira* along the coast we studied, this alga must be considered an important habitat for juvenile *S. punctata*.

The finding that young-of-the year *S. punctata* of approximately 50 mm in length were more common on unvegetated and reef-algal habitat compared with seagrass habitats is consistent with the ontogenetic change in habitat preference previously found in Westernport (Robertson 1977) and Port Phillip Bay (Chapter 2). This result contrasts with the pattern found in Barker Inlet, Gulf St Vincent, where *S. punctata* were consistently more abundant over eelgrass compared with unvegetated habitat though the first year of life. A possible factor that might contribute to this difference is that Connolly(1994) sampled mainly *Zostera muelleri* which tends to be intertidal whilst Robertson (1977) and the present study (Chapter 2) sampled mainly *Heterozostera tasmanica* which occurs subtidally up to the intertidal fringe. Thus, the ontogenetic shift may be partially related to a shift from subtidal to intertidal habitat as much as the type of habitat. Our results (Chapter 2), however, show a shift from eelgrass to unvegetated sand at equivalent depth in the subtidal, indicating that depth cannot fully explain the differences.

The finding that there is a general increase in size of juvenile *Sillaginodes punctata* with distance into the gulf is consistent with results in Port Phillip Bay (Jenkins *et al.* 1996). The situation may be similar to Port Phillip Bay where larvae are transported from the open coast and recruit to habitats inside the entrance in relation to current patterns (Jenkins *et al.* 1996). A month or two after settlement individuals tend to migrate further into the bay, leading to an increasing size distribution with distance into the bay (Jenkins *et al.* 1996). The finding that *S. punctata* larvae tend to be found mainly near the entrance of gulfs in South Australia (Bruce 1989) tends to support such a mechanism.

Amongst other commercial species, distribution patterns of juveniles were consistent with Port Phillip Bay. The blue rock whiting, *Haletta semifasciata*, and six-spine leatherjacket, *Meuschenia freycineti*, were also mainly found in subtidal structured habitat in Port Phillip Bay (Jenkins *et al.* 1993, chapter 2). Juvenile yellow-eye mullet, *Aldrichetta forsteri*, seem to have variable habitat utilisation, with distribution probably more related to movement over the intertidal habitat with the tidal cycle rather than with specific habitats (Jenkins *et al.* 1993, chapter 4). The finding that juvenile greenback flounder, *Rhombosolea tapirina*, and Western Australian salmon, *Arripus truttacea*, were mainly associated with unvegetated sand is consistent with Port Phillip Bay (Jenkins *et al.* 1993, chapter 2). Lack of obvious habitat preference in *A. forsteri*, and preference for unvegetated sand in *R. tapirina*, is consistent with results for Barker Inlet (Connolly 1994a).

3.4.2 Jervis Bay

Juveniles of commercial species encountered in Jervis Bay were primarily collected in shallow (< 1 m) unvegetated habitat. A number of commercial species were observed on deeper reef using SCUBA; however, these were mainly older juveniles and adults. These results are consistent with previous studies from central New South Wales. Recruits of commercial species tend to mainly occur in estuarine *Zostera* beds or on unvegetated sand adjacent to *Zostera* beds (Middleton *et al.* 1984; Ferrell and Bell 1991; McNeill *et al.* 1992). With growth, some juveniles tend to migrate to other habitats, including subtidal reefs (Middleton *et al.* 1984; Bell and Worthington 1992; Gillanders and Kingsford 1992). Bream, *Acanthapagrus australis*, and luderick, *Girella tricuspidata*, are examples of species that are abundant in estuaries as juveniles, but also occur on offshore reefs in older stages (Bell and Worthington 1992).

The primary commercial species utilising shallow reef-algal habitat in Port Phillip Bay and Gulf St Vincent, the King George whiting, *Sillaginodes punctata*, probably does not occur in Jervis Bay in the young juvenile stage. Juveniles of other whiting species (genus *Sillago*) are typically found over seagrass and/or unvegetated sand in estuaries (Burchmore *et al.* 1988), which is consistent with their collection over shallow unvegetated sand in the present study.

3.5 CONCLUSIONS

Conclusions regarding recruitment to habitat for interstate sampling must be tempered by the fact that sampling was once off and young recruits of some species may have been missed. Sampling in both areas, however, was in the summer period when the highest abundances of juvenile fishes tends to occur (Middleton *et al.* 1984; Connolly 1994a).

Interstate sampling has a number of consistencies with our results from Port Phillip Bay. Like Port Phillip Bay, King George whiting, *Sillaginodes punctata*, from Gulf St Vincent utilised shallow (< 1m depth) reef-algal habitat. Ontogenetic shift in habitat preference of *S. punctata* observed in Victoria is probably also occurring on the western side of the Gulf St Vincent. As in previous studies, older juveniles and adults of commercial species in Jervis Bay were observed on reefs (2 - 7 m depth); previous studies would suggest that these species would initially recruit to estuarine *Zostera* / unvegetated areas.

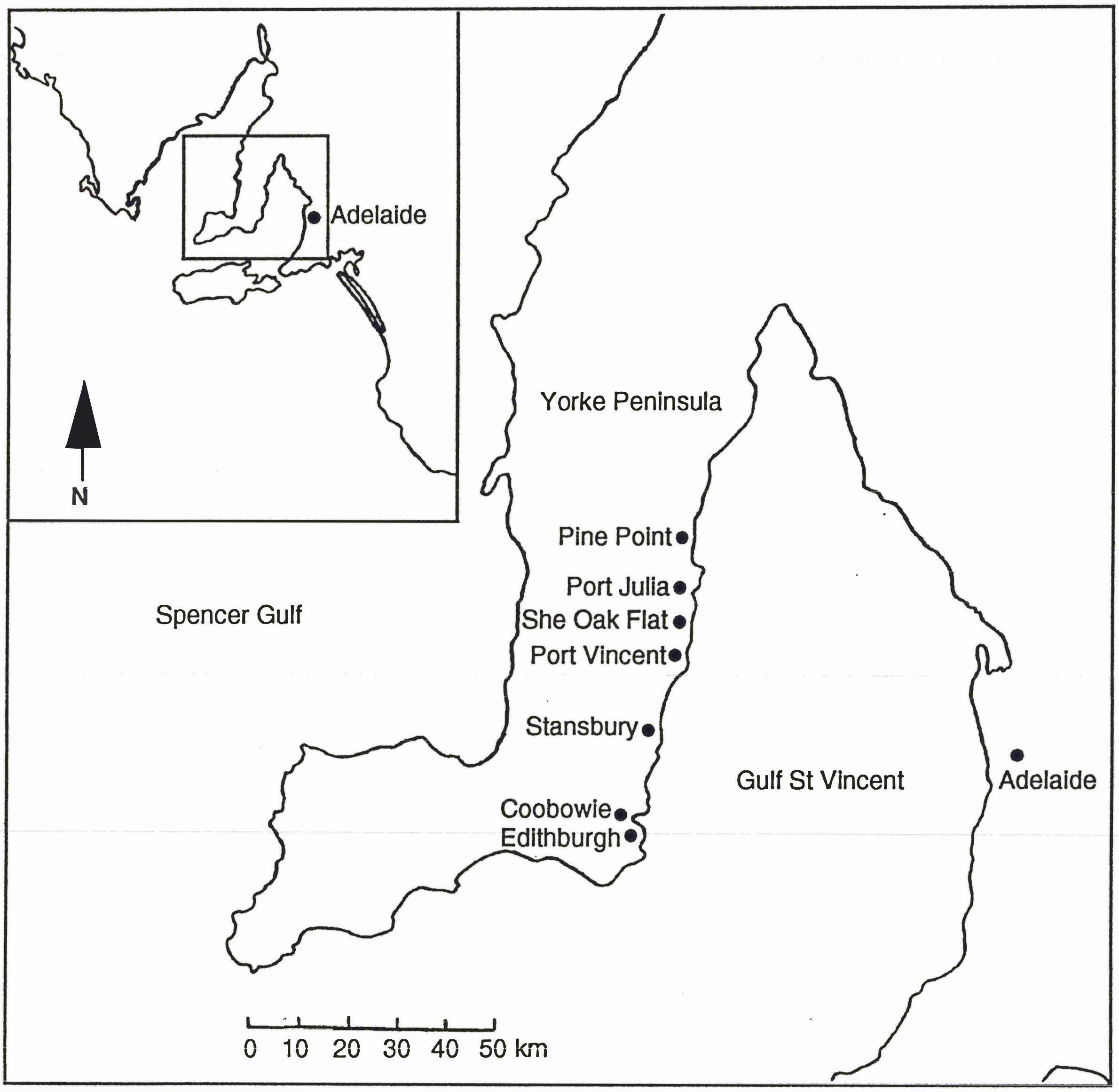

Fig. 3.1 Sampling locations on the Yorke Peninsula coast of the Gulf St Vincent, South Australia. Inset: Location of Gulf St Vincent on the South Australian coast.

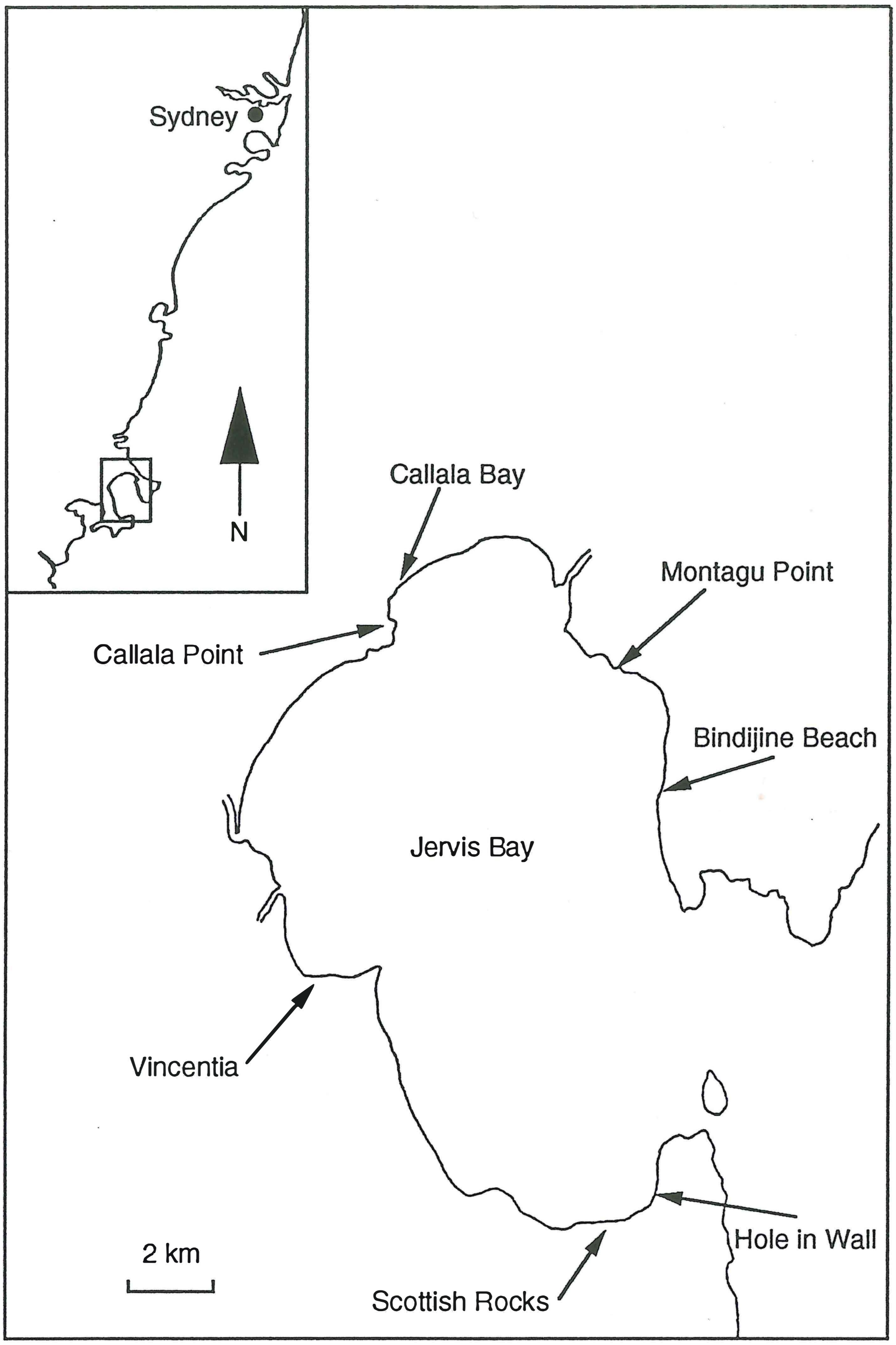

Fig. 3.2 Sampling locations in Jervis Bay, New South Wales. Inset: Location of Jervis Bay on the New South Wales coast.

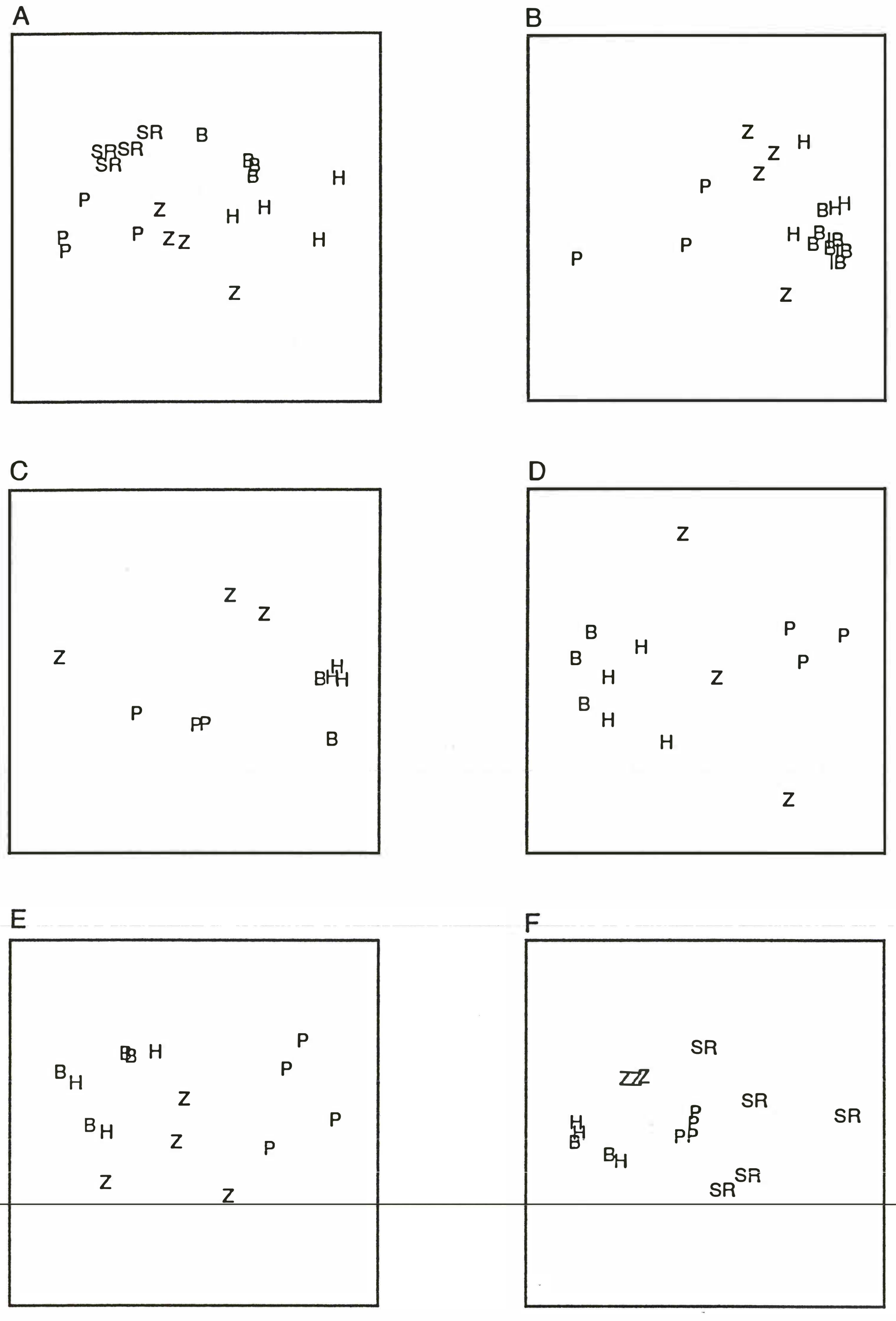

Fig. 3.3 Multidimensional scaling plots of relationships amongst fish assemblages associated with habitats at six sites. A. Pine Point (stress=0.12), B. She Oak Flat (stress=0.09), C. Port Vincent (stress=0.03), D. Stansbury (stress=0.02), E. Coobowie (stress=0.01), F. Edithburgh (stress=0.07). "P"=*Posidonia*, "SR"=subtidal reef, "Z"=eelgrass, "B"=unvegetated, "IB"=intertidal bare, "H"=*Hormosira*.

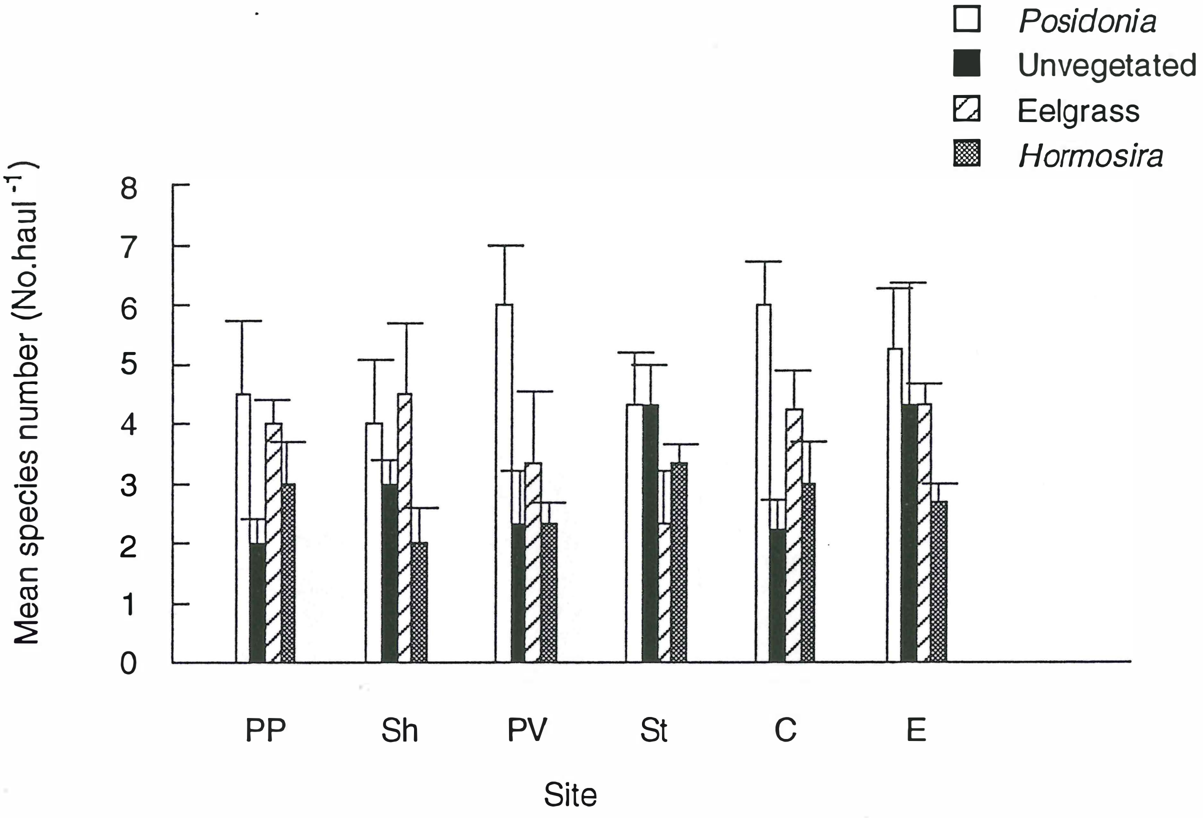

Fig. 3.4 Mean number of species collected in four habitats at six sites along the Yorke Peninsula coast of the Gulf St Vincent. "PP"= Pine Point, "Sh"= She Oak Flat, "PV"= Port Vincent, "St"= Stansbury, "C"= Coobowie, "E"= Edithburgh. Error bars are standard error.

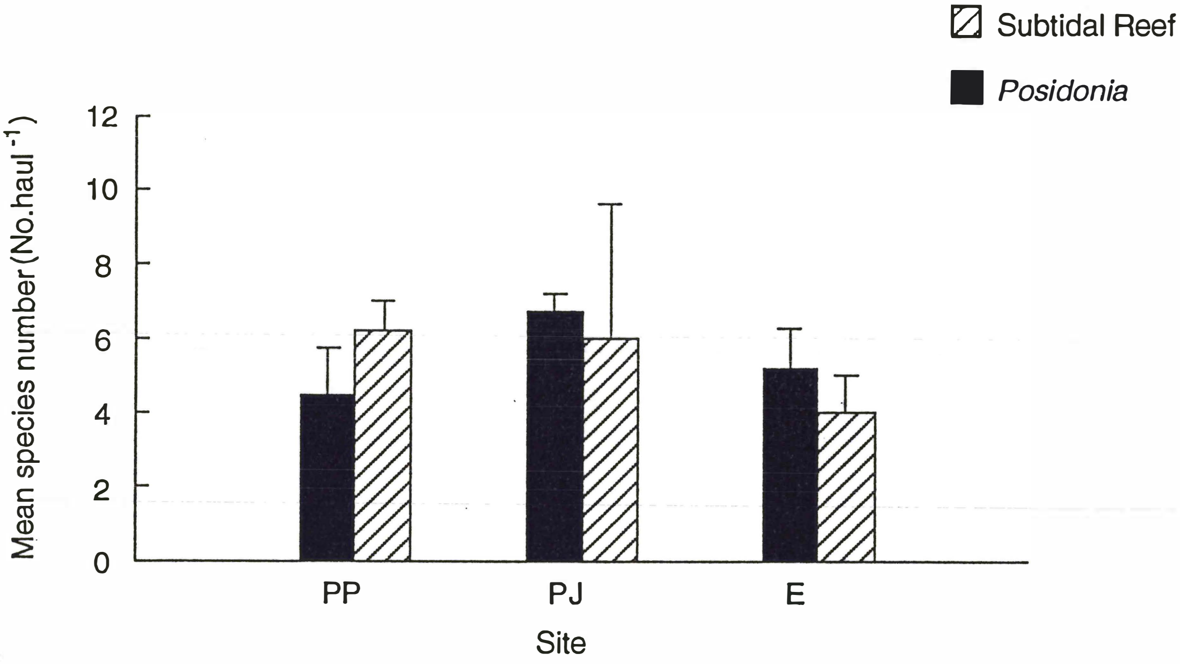

Fig. 3.5 Mean number of species collected in two habitats at three sites along the Yorke Peninsula coast of the Gulf St Vincent. "PP"=Pine Point, "PJ"=Port Julia", "E"=Edithburgh. Error bars are standard error.

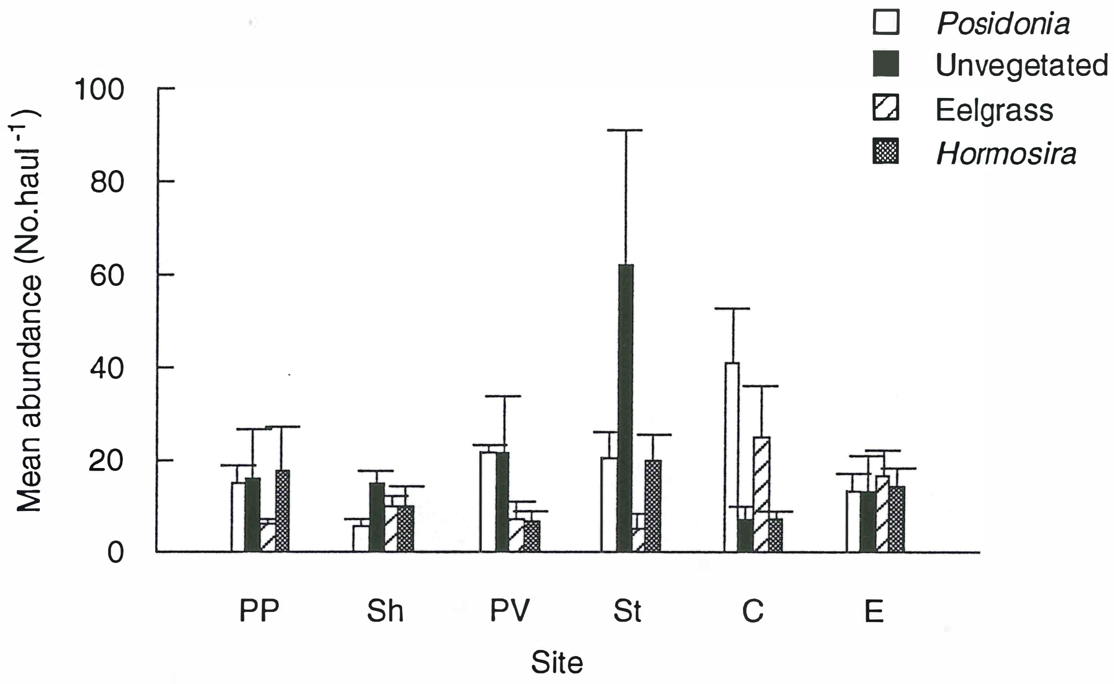

Fig. 3.6 Mean abundance of fishes collected in four habitats at six sites along the Yorke Peninsula coast of the Gulf St Vincent. Site legend as for Figure 3.4. Error bars are standard error.

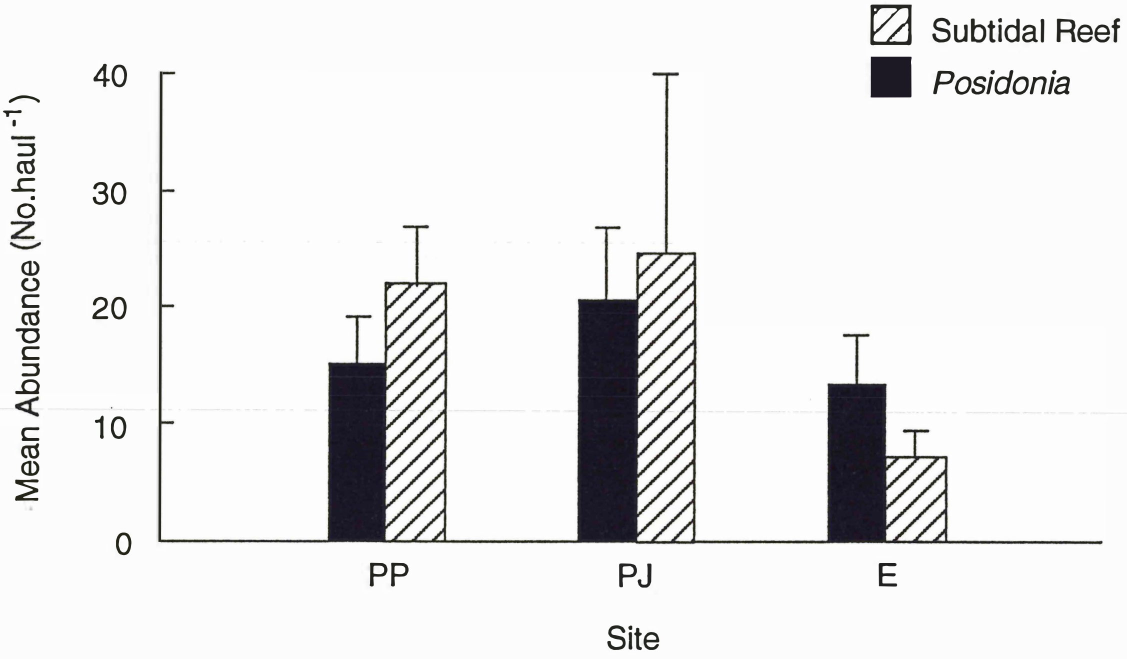

Fig. 3.7 Mean abundance of fishes collected in two habitats at three sites along the Yorke Peninsula coast of the Gulf St Vincent. Site legend as for Figure 3.5. Error bars are standard error.

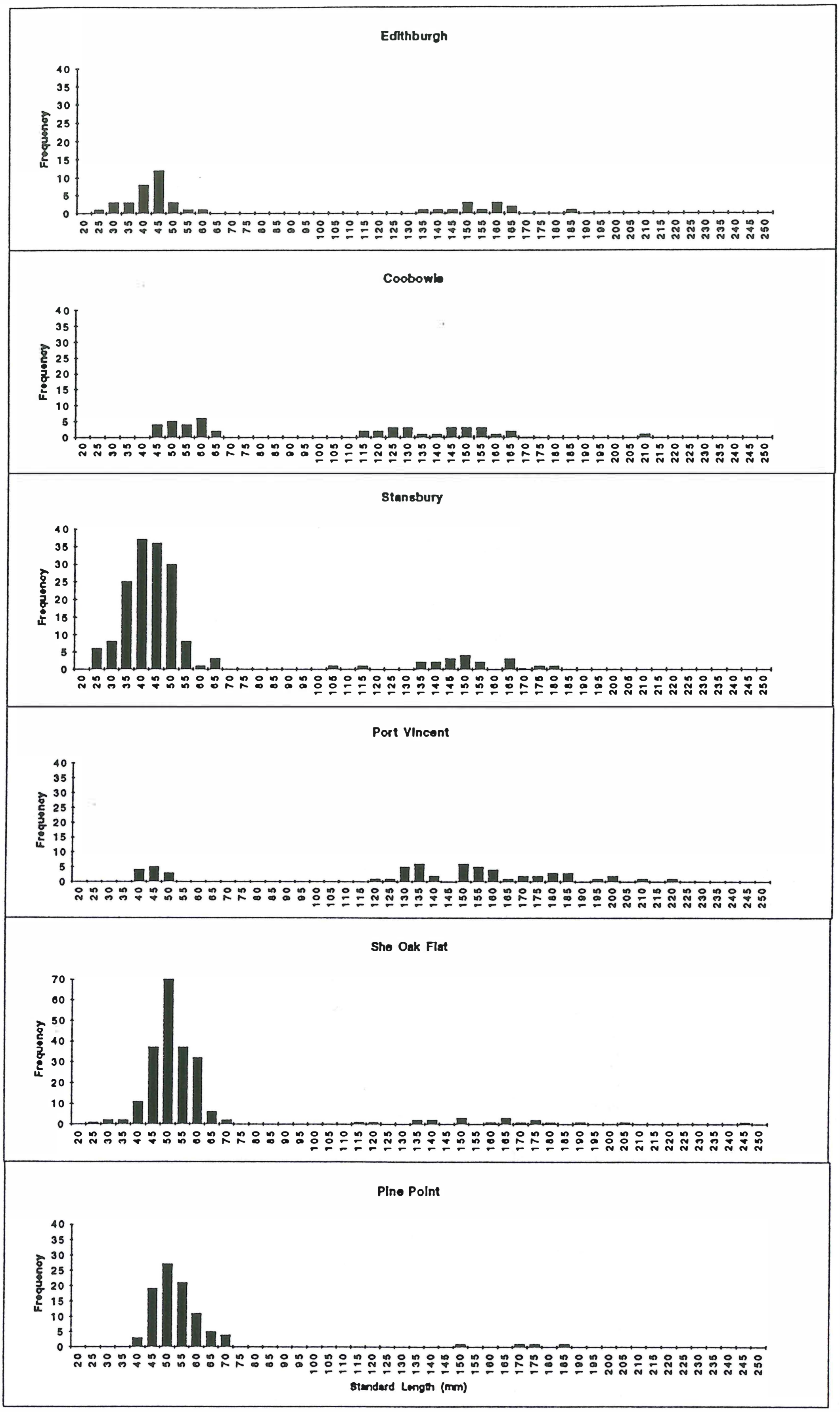

Fig. 3.8 Size-frequency distributions of King George whiting, *Sillaginodes punctata*, from six sites along the Yorke Peninsula coast of the Gulf St Vincent.

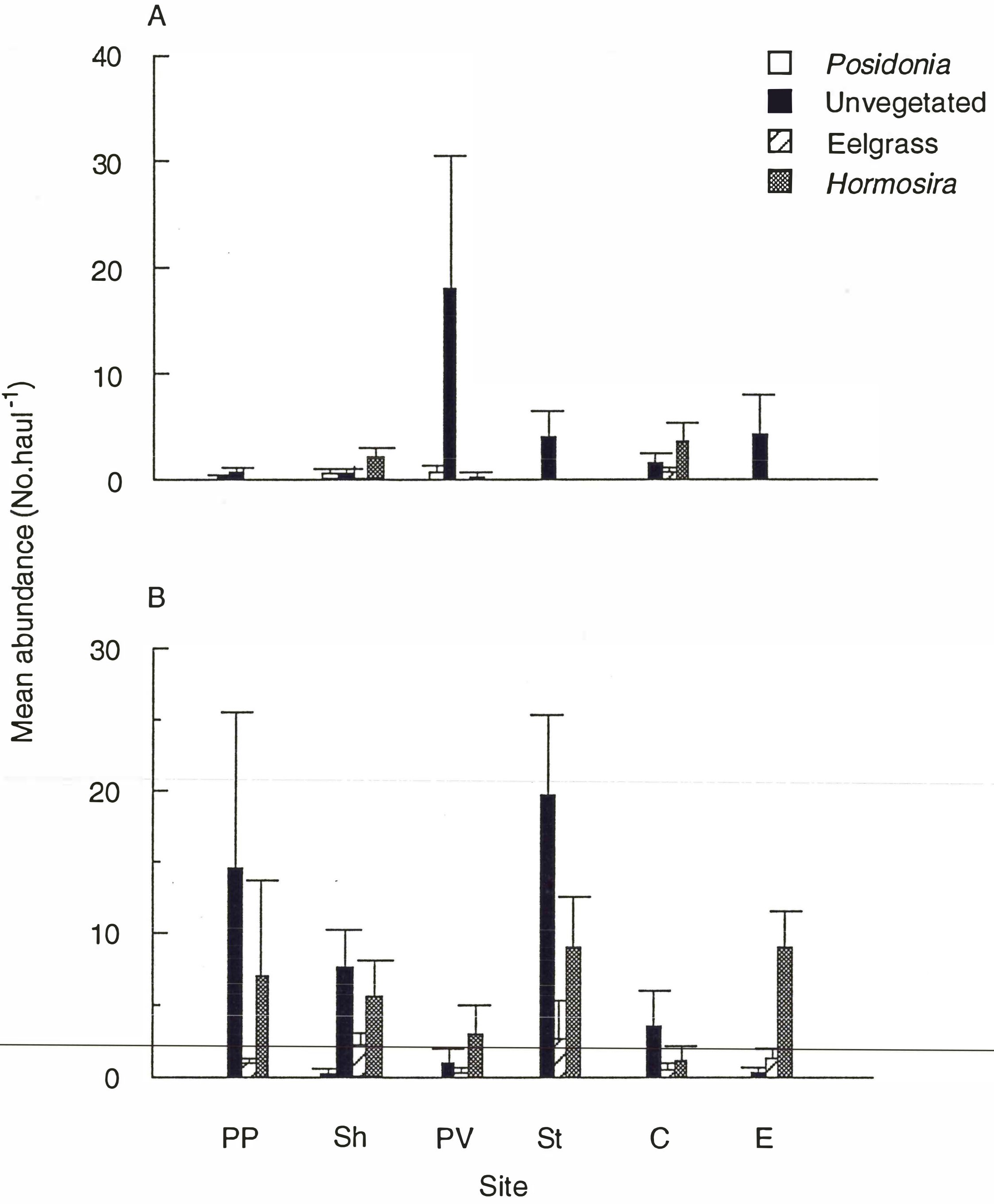

Fig. 3.9 Mean abundance of King George whiting, *Sillaginodes punctata*, collected in four habitats at six sites along the Yorke Peninsula coast of the Gulf St Vincent. A. 1+ age group, B. 0+ age group. Site legend as for Figure 3.4. Error bars are standard error.

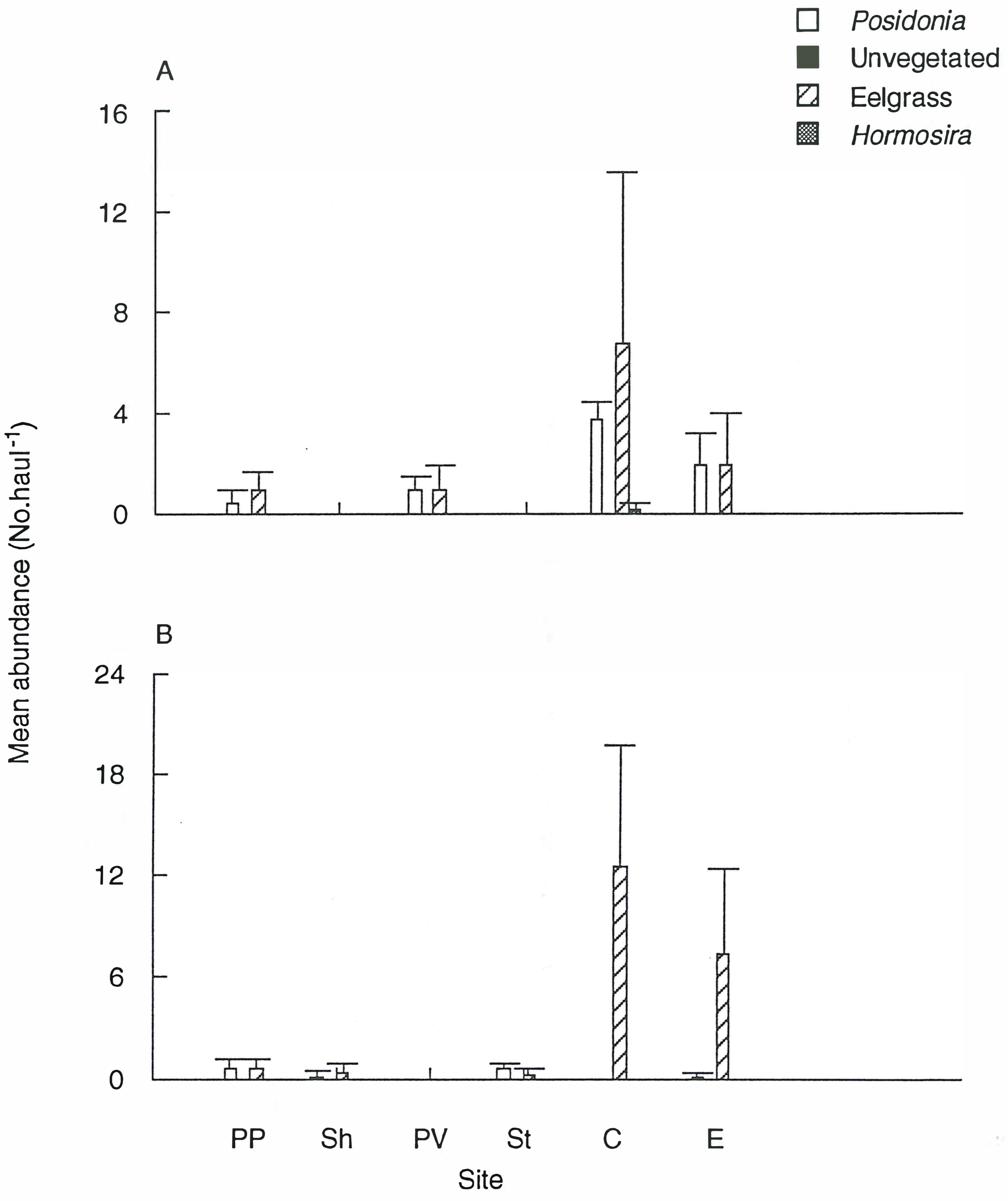

Fig. 3.10 Mean abundance of blue rock whiting, *Haletta semifasciata*, collected in four habitats at six sites along the Yorke Peninsula coast of the Gulf St Vincent. Site legend as for Figure 3.4. Error bars are standard error.

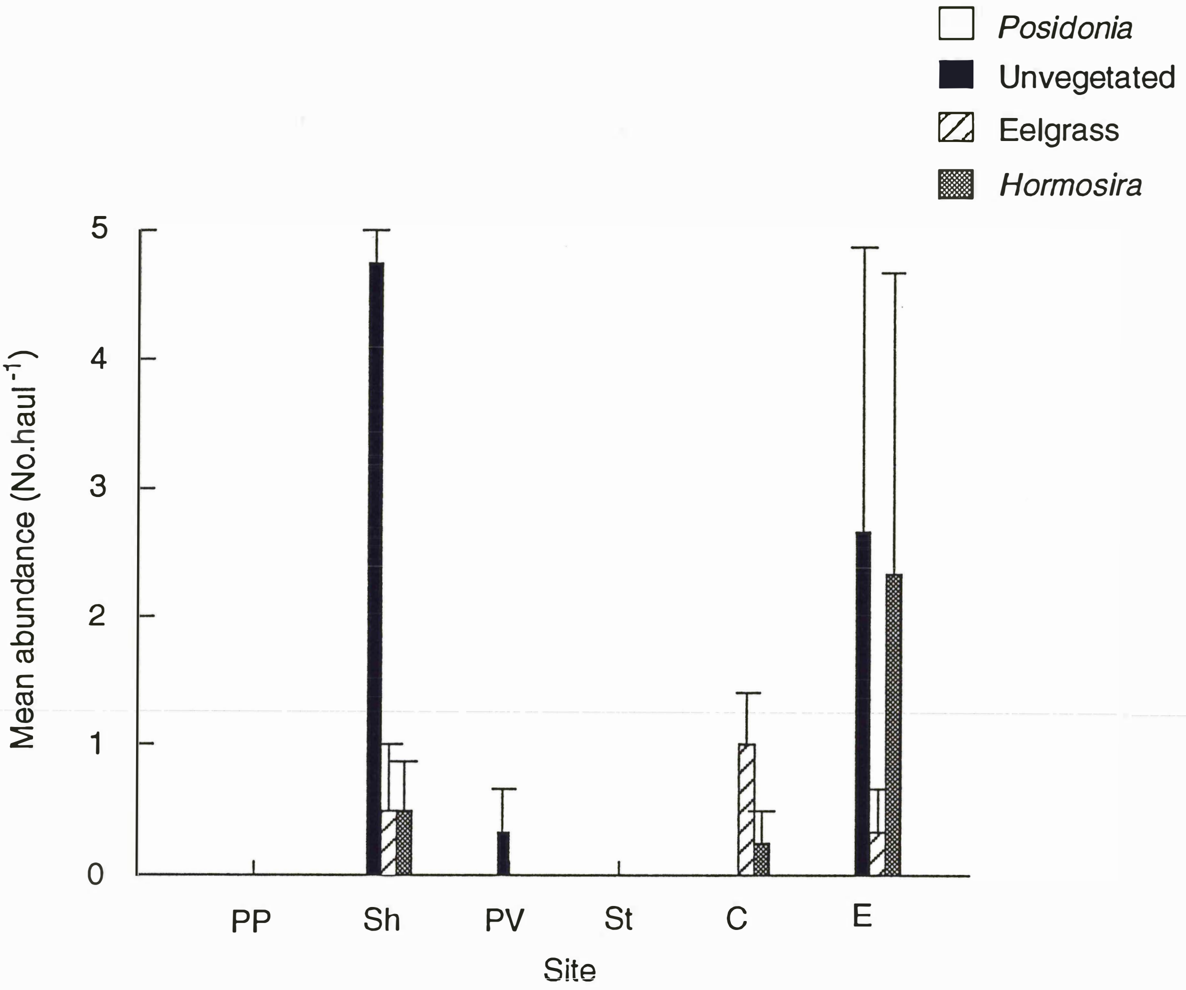

Fig. 3.11 Mean abundance of yellow-eye mullet, *Aldrichetta forsteri*, collected in four habitats at six sites along the Yorke Peninsula coast of the Gulf St Vincent. Site legend as for Figure 3.4. Error bars are standard error.

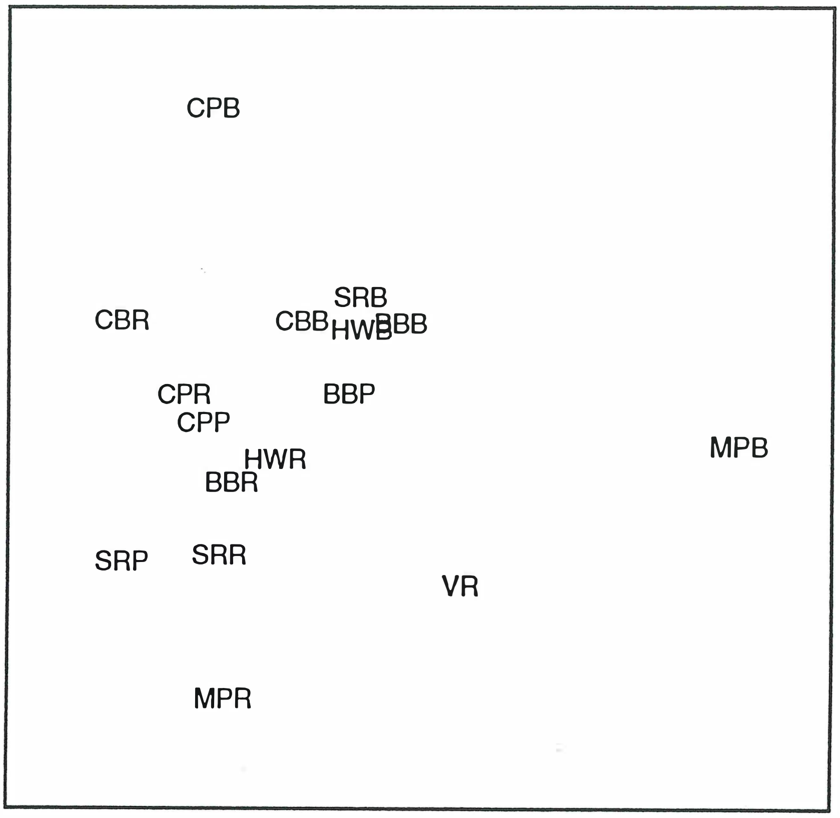

Fig. 3.12 Multidimensional scaling plot of relationships amongst fish assemblages associated with habitats at seven sites, sampled by seine net. Stress = 0.11. "SR"= Scottish Rocks, "HW" = Hole in the Wall, "V" = Vincentia, "CP" = Callala Point, "CB" = Callala Bay, "MP" = Montagu Point, "BB" = Bindijine Beach. "R" = reef, "P" = *Posidonia*, "B" = unvegetated.

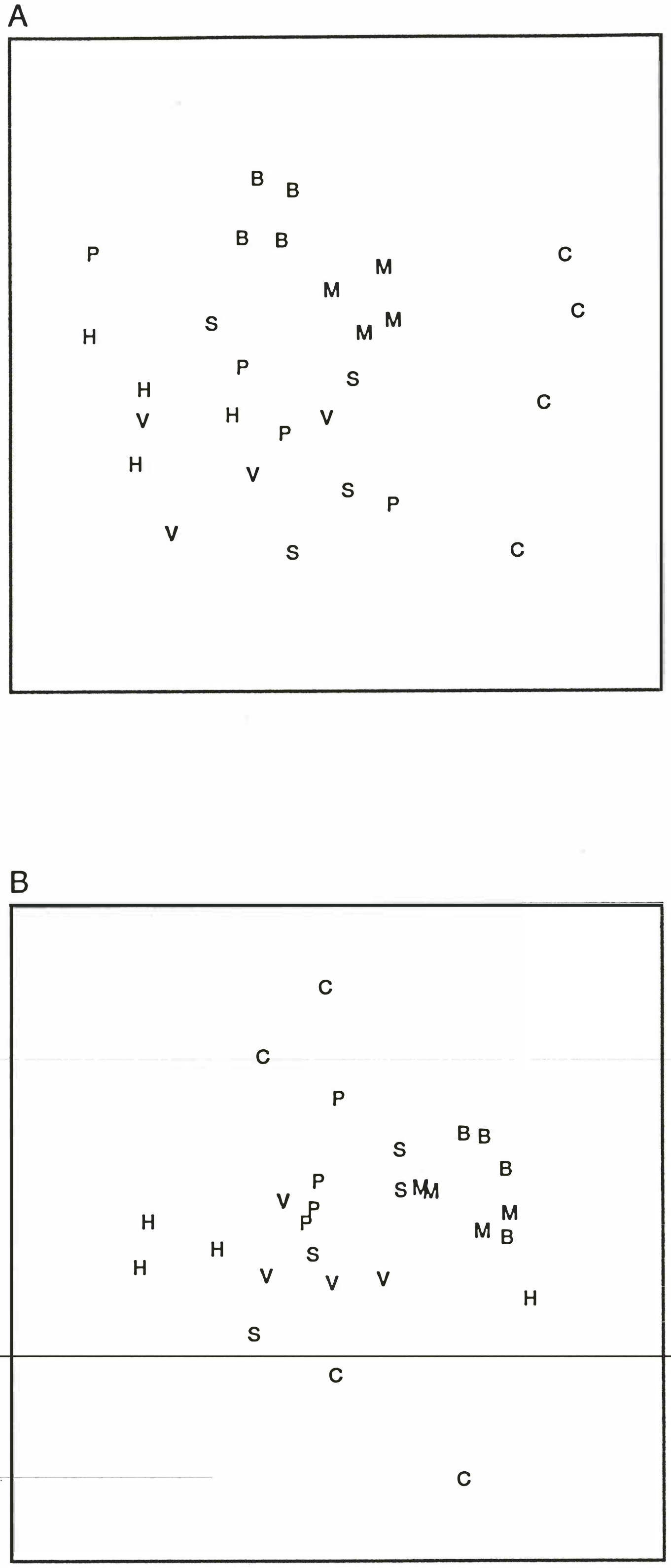

Fig. 3.13 Multidimensional scaling plot of relationships amongst fish assemblages associated with reefs at seven sites, sampled by SCUBA transects. A. "Fast" transects, Stress = 0.21. B. "Slow" transects, Stress = 0.20. "S"= Scottish Rocks, "H" = Hole in Wall, "V" = Vincentia, "P" = Callala Point, "C" = Callala Bay, "M" = Montague Point, "B" = Bindijine Beach.

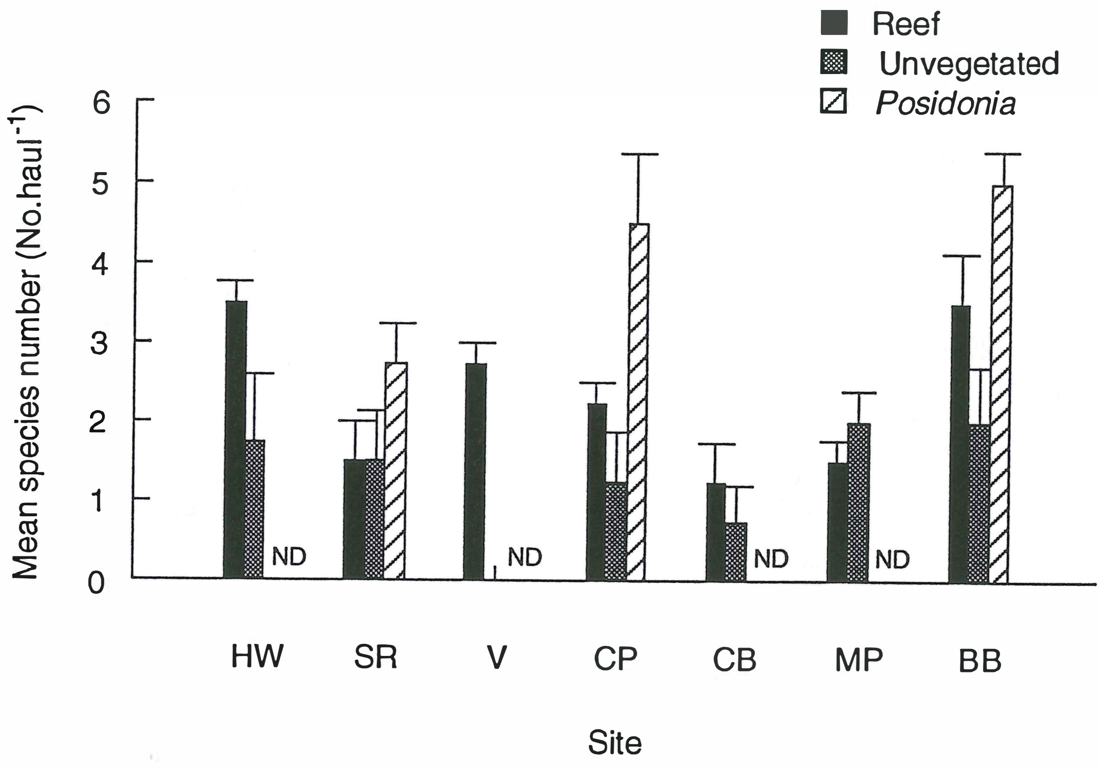

Fig. 3.14 Mean number of species in habitats at seven sites in Jervis Bay sampled by seine net. Error bars are standard error. "SR"= Scottish Rocks, "HW" = Hole in the Wall, "V" = Vincentia, "CP" = Callala Point, "CB" = Callala Bay, "MP" = Montague Point, "BB" = Bindijine Beach. "ND" = no data.

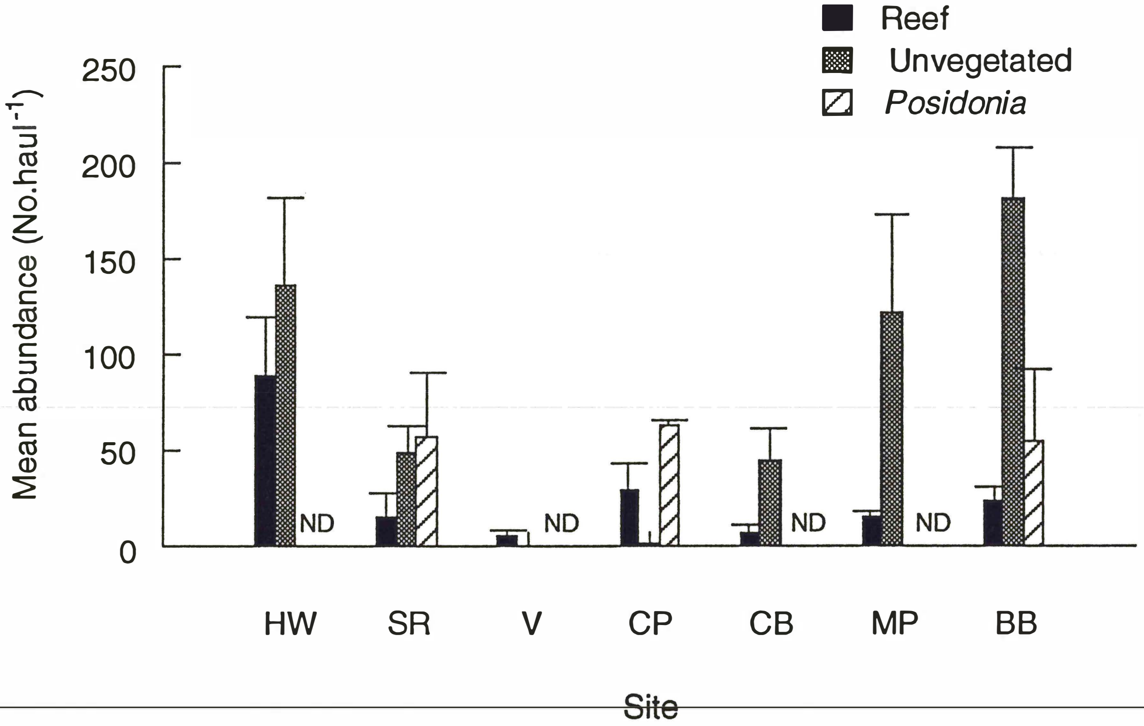

Fig. 3.15 Mean abundance of fishes in habitats at seven sites in Jervis Bay sampled by seine net. Error bars are standard error. Legend as for fig. 3.14

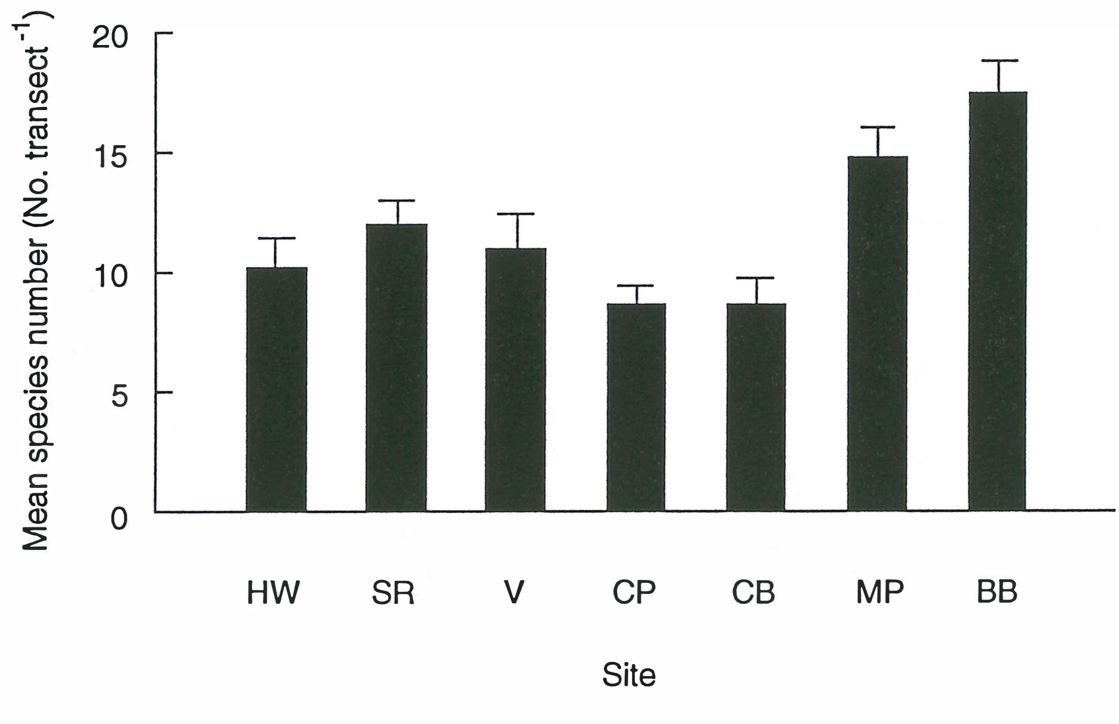

Fig. 3.16 Mean number of species on reefs at seven sites in Jervis Bay sampled by SCUBA transect. Error bars are standard error. Legend as for fig. 3.14

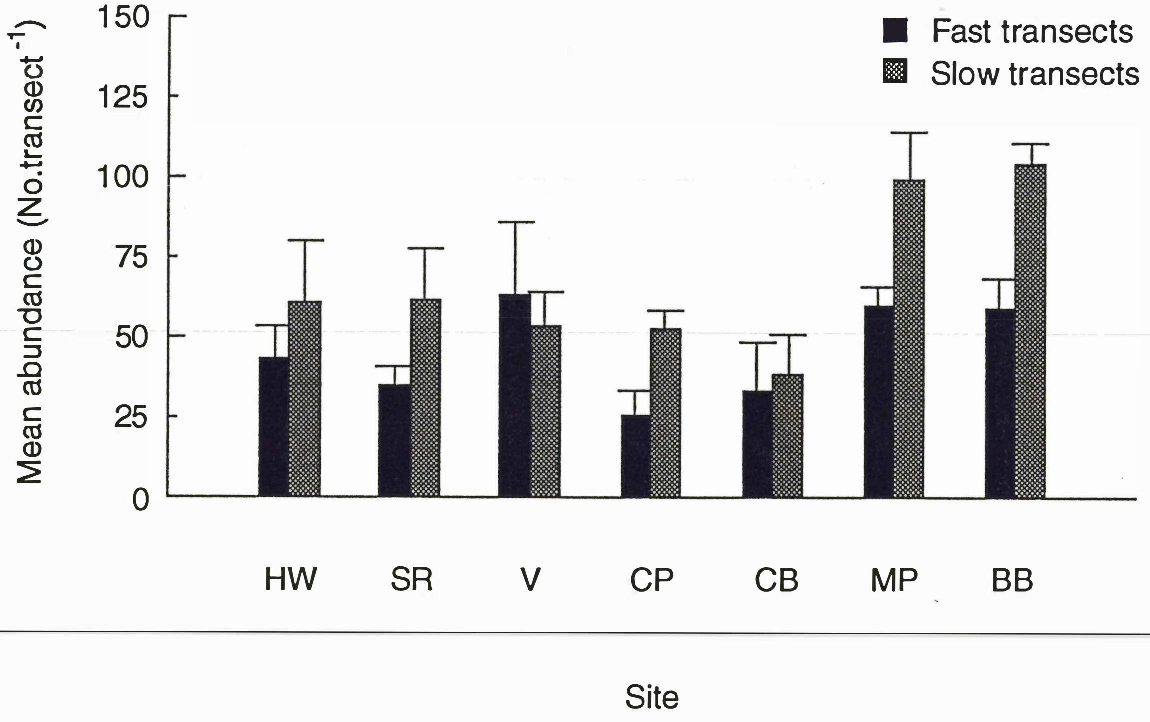

Fig. 3.17 Mean abundance of fishes on reefs at seven sites in Jervis Bay sampled by SCUBA transect. Error bars are standard error. Legend as for fig. 3.14

CHAPTER 4

THE DISTRIBUTION, ABUNDANCE, RECRUITMENT AND GROWTH OF JUVENILE FISHES ASSOCIATED WITH SANDY BEACHES IN PORT PHILLIP BAY

4.1 INTRODUCTION

Structured habitats from shallow waters, particularly seagrasses and mangroves, are generally considered to be nursery areas for juvenile fishes. Unvegetated sandy habitats are often found to have a lower diversity and abundance of fishes than structured habitats (Bell and Pollard 1989), and therefore maybe considered of lower importance by coastal managers. A number of studies, however, have shown that unvegetated habitats can be important nursery areas for juvenile commercial fish. For example, the surf zones of coastal beaches have been found to be nursery habitats for juvenile fishes in South Africa (Lasiak 1986; Bennett 1989), United States of America (Saloman and Naughton 1979; Modde and Ross 1981; Peters and Nelson 1987) and Australia (Lenanton 1982; Robertson and Lenanton 1984). Also, the protected sandy beaches of the south-western Australian coast have been found to be nursery habitats (Lenanton 1982; Ayvazian and Hyndes 1995). Our previous results from Port Phillip Bay show that whilst seagrasses and reefs may support a higher abundance and diversity of fishes, unvegetated habitat can be important for some commercial species (Jenkins *et al.* 1993).

Sandy beaches of marine embayments share characteristics with both estuaries and surf beaches, habitats that are increasingly regarded as nursery areas for juvenile fishes (Blaber and Blaber 1980; Modde and Ross 1981; Bennett 1989; Loneragan *et al.* 1989). Like estuaries, sandy beaches of marine embayments are protected from strong wave action by a limited fetch, however, a surf zone is still present, though greatly reduced when compared with surf beaches.

Port Phillip Bay (Fig. 4.1) is a semi-enclosed marine embayment of south-eastern Australia that has many of the habitats regarded as nursery areas, e.g., mangroves, rocky reefs, seagrass meadows and estuarine areas. Sandy beaches form a substantial percentage (>50%) of the coastline and characteristically receive low to moderate wave action (<0.5 - 1.5 m). The prominence of near-shore habitats being utilised as nursery areas by juvenile fishes suggests that the very location of these habitats, i.e., shallow water, furnishes these habitats with some inherent advantage. For instance, Ruiz (1993) found small species of fishes were most abundant in water depths less than 70 cm due to depth-dependant mortality. The aim of the present study was to determine if the sandy beaches of Port Phillip Bay are utilised as nursery habitats for juvenile fishes and also to determine whether shallow depth 'per se' provides a nursery habitat.

4.2 METHODS

4.2.1 Sites and zones

Sites sampled in this study are shown in Fig. 4.1. At each site, two zones were sampled. The inshore zone was defined as seaward from the waterline to a distance of 10 metres. This zone characteristically included a shallow (depth < 1 metre) channel running parallel with the beach. A sandbar defining this channel was commonly present seaward of this zone. The distance of 10 m was chosen as this was the length of the seine net used for sampling.

The offshore zone was defined as approximately 50 m seaward of the waterline. Characteristically, this zone was located on the seaward edge of a longshore sandbar. This sandbar was usually the same sandbar delineating the inshore channel as described above. However, the Portarlington and Mt Martha sites had different profiles from the Port Melbourne, Mentone and Frankston sites. The Portarlington site had no discernible longshore sandbar, while the sandbar at the Mt Martha site was approximately 100 m offshore.

4.2.2 Site characteristics

Portarlington (Lat. S 38^{O} 06.825'; Long. E 144^{O} 38.696'):- On the western shore of Port Phillip Bay, this site received the greatest wave-action with northerly winds. The maximum water depths of the inshore zone range from 0.8 m to 1.2 m, while the water depths of the offshore zone ranged from 1.5 m to 1.8 m.

Port Melbourne (Lat. S 37^{O} 50.897'; Long. E 144^{O} 56.586'):- This site is an inner-suburban beach located on the northern shore of Port Phillip Bay. The greatest wave-action is generated by southerly to southwesterly winds. From January, 1994, the shallow longshore channel was interrupted by headlands created by storm events in late December, 1993. Maximum water depths of the inshore zone ranged from 0.2 m to 0.8 m. The water depths of the offshore zone ranged from a minimum of 0.5 m to a maximum of 1.6 m.

Mentone (Lat. S 37^{O} 59.678'; Long. E 145^{O} 03.856'):- This site is located on the eastern shore of Port Phillip Bay. Wave-action was greatest when southwesterly to westerly winds prevailed. The maximum water depths of the inshore zone ranged from 0.2 m to 1.0 m, while water depths of the offshore zone ranged from 0.5 m to 1.5 m.

Frankston (Lat. S 38^{o} 07.994'; Long. E 145^{o} 07.255'):- Also located on the eastern shore of Port Phillip Bay, this site received the greatest wave-action when south-westerly to north-westerly winds prevailed. The maximum water depth of the inshore zone was 1.0 m. The water depths of the offshore zone ranged between 1.0 m and 1.6 m.

Mount Martha (Lat. S 38^{o} 16.150'; Long. E 145^{o} 00.557'):- Located on the southern shore of Port Phillip Bay, this site is susceptible to northerly through to south-westerly winds. Resulting from the increased wave-action at this site, the beach has a reflecting profile. Consequently, the maximum water depths of the inshore zone ranged from 1.0 m to 1.5 m. The water depths of the offshore zone ranged from 1.5 m to 1.8 m.

4.2.3 Field methods

Three sites, Port Melbourne, Mentone and Frankston, were sampled monthly from June, 1993 until May, 1994 inclusive. Mt. Martha and Portarlington were sampled every three months, commencing in July, 1993. However, Mt Martha was not sampled in April, 1994 due to inclement weather.

Juvenile fish were captured using a fine-mesh seine net (10 x 3 m with 1 x 2 mm mesh) with a 2.5 m bunt. The seine net was hauled parallel with the shoreline to a stationary point 10 m from the net, sampling an area of 50 m^2. In the inshore zone hauls were made so that 10 m of the shoreline was sampled. The offshore zone was sampled with the aid of a tractor tyre inner-tube, with a base attached, to facilitate setting and retrieving the net.

Five hauls of the seine net were made in each of the two zones per site per sampling date. Sampling was conducted on the flood tide, commencing one hour after low water. One site was sampled per day.

For each haul, all fish were extracted, and the volume of drift weed was measured using a graduated 10 litre bucket. The collected fish were placed in a plastic bag, anaesthetised, labelled, and stored in ice to slow food digestion and for transport to the laboratory. In the laboratory, samples of fish from each day were frozen for later processing.

4.2.4 Laboratory methods

In the laboratory, the collected fish from each haul were identified and enumerated. Subsequently, fish from the five seines in the same zone were pooled according to species. These fish were then measured (standard length and fork/total length where appropriate) to the nearest millimetre and weighed. Where there were more than ten individuals of a species, ten fish were chosen over the size range available to be weighed and measured. The remaining fish were only measured for standard length.

4.2.5 Data analysis

Univariate analyses of variance (ANOVA) was used to estimate the significance of differences in the number of species collected and abundance amongst sites, times and zones. Site was considered a 'random' variable, while month and zone were 'fixed' variables. Box plots were used to examine data for departures from the assumptions of ANOVA. To stabilise variances, abundance data were transformed to the fourth root, i.e. (number caught per haul)$^{0.25}$. Seasonal sampling data were analysed using all five sites for three seasons (Winter, Spring and Summer) as no sampling was conducted at Mount Martha in Autumn. ANOVA was performed on the number of species collected and total abundances in seasonal and monthly samples, and the abundance data for *Aldrichetta forsteri* from monthly samples. Variance component analysis was conducted following ANOVA to estimate the contribution of each source in the analysis to the overall variation (Sokal and Rohlf 1981).

Cluster analysis was used to compare the fish communities amongst sites and zones. Abundances of species were pooled across replicates. Dissimilarities were estimated using the Bray-Curtis coefficient on the (number caught)$^{0.25}$ transformed data. Amalgamation was achieved using the average linkage method (Wilkinson *et al.* 1992).

4.3 RESULTS

A total of 430 seine hauls captured 28,108 fish of 33 species, 30 genera and 20 families. Of these fish, 18,547 (65.98%) were taken from the inshore zone. The majority of the fishes collected were late-larvae and juveniles. The catch statistics for all fish captured are summarised in Table 4.1. Fish of the family Atherinidae and the genera *Arripis* and *Platycephalus* were combined for analyses as individuals of the different species within these groups were not distinguished.

Table 4.1 The total number, percentage of catch and biomass of fishes collected in seine net samples from the sandy beaches of Port Phillip Bay.

Taxon	Total number	Percentage of catch	Biomass (g)
Urolophidae			
Urolophus cruciatus	2	0.007	241.60
Clupeidae			
Hyperlophus vittatus	22523	80.139	4,616.60
Sardinops neopilchardus	1	0.004	3.44
Spratelloides robustus	16	0.057	42.09
Engraulididae			
Engraulis australis	102	0.363	125.70
Atherinidae	2066	7.351	922.13
Atherinosoma microstoma			
Leptatherina presbyteroides			
Hemiramphidae			
Hyporhamphus melanochir	30	0.107	297.50
Syngnathidae			
Stigmatopora nigra	28	0.100	2.90
Pegasidae			
Pegasus lancifer	1	0.004	0.80
Scorpaenidae			
Gymnapistes marmoratus	4	0.014	2.10
Platycephalidae	185	0.658	615.46
Platycephalus bassensis			
P. laevigatus			
P. speculator			
Sillaginidae			
Sillaginodes punctata	27	0.096	203.90
Arripidae	11	0.039	47.22
Arripis trutta			
A. truttacea			
Mugilidae			
Aldrichetta forsteri	2355	8.379	8,714.90
Odacidae			
Neoodax balteatus	6	0.021	0.03
Leptoscopidae			
Crapatalus munroi	10	0.036	47.20
Clinidae			
Cristeceps australis	1	0.004	2.30
Heteroclinus perspicillatus	7	0.025	21.00
Gobiidae	33	0.117	3.50
Pleuronectidae			
Ammotretis rostratus	50	0.178	568.00
Rhombosolea tapirina	458	1.630	2,161.40

Table 4.1 (Cont.). The total number, percentage of catch and biomass of fishes collected in seine net samples from the sandy beaches of Port Phillip Bay.

Taxon	Total number	Percentage of catch	Biomass (g)
Monocanthidae			
Acanthaluteres spilomelanurus	1	0.004	0.10
Brachaluteres jacksonianus	1	0.004	0.40
Meuschenia freycineti	1	0.004	0.20
Tetraodontidae			
Contusus brevicaudus	125	0.445	187.00
Tetractenos glaber	60	0.213	1,585.10
Diodontidae			
Diodon nichthemerus	1	0.004	24.40
Total	28105		20,436.97

The five most numerically important taxa captured were *Hyperlophus vittatus*, *Aldrichetta forsteri*, Atherinidae, *Rhombosolea tapirina* and *Platycephalus* spp. respectively. *Hyperlophus vittatus* contributed 80.13% (22,523) to the total catch (Table 4.1). The majority (19,424) of *H. vittatus* were captured on two dates, 26 June, 1993 at Port Melbourne and 14 April, 1994 at Mentone. As these catches greatly influence all analyses, and the percentage occurrence of this species was quite low, *H. vittatus* was omitted from further statistical analyses.

When the frequency of occurrence in samples is considered, the ranking of groups changes to *Aldrichetta forsteri*, *Rhombosolea tapirina*, *Platycephalus* spp., *Hyperlophus vittatus* and Atherinidae. *Aldrichetta forsteri*, the second most numerous species collected (2,355 individuals), was the most commonly occurring species, captured in 66.05% and 11.16% of inshore and offshore seines, respectively.

The biomass of individual species are shown in Table 4.1. *Aldrichetta forsteri*, *Hyperlophus vittatus*, *Rhombosolea tapirina*, *Tetractenos glaber,* Atherinidae and *Platycephalus* spp. contributed 18615.59 g , or 91.9% to the total biomass.

4.3.1 Seasonal samples

A total of 190 seine hauls were made in seasonal sampling, resulting in the collection of 17,858 fish of 28 species, 24 genera and 18 families (Appendix 2). The majority (16,532 or 92.57%) of these fish were captured in the inshore zone.

The mean number of species captured per haul were lowest in winter, increasing through spring to peak in summer and autumn in most cases (Fig. 4.2). More species were also captured in the inshore zone than the offshore zone on most occasions. The mean number of species per haul from winter to summer showed significant differences for all main effects, and for the site by month and month by zone interactions (Table 4.2). The highest contribution to the overall variation was from the zone main effect (45%), while the interaction between month and zone was also relatively important (27%) (Table 4.2).

Peaks in abundances generally occurred in winter or autumn for different sites, and the inshore abundances were higher than offshore in the majority of cases (Fig. 4.3). The transformed catch data from the seasonal samples from five sites were compared by ANOVA (Table 4.2). The site and zone main effects were significant, as was the site by month interaction and the third order interaction amongst all factors (Table 4.2). A variance component analysis reveals that zone is responsible for the greatest proportion (45%) of the overall variance (Table 4.2).

Table 4.2 Analysis of variance of the number of fish species, and $x^{0.25}$ transformed total abundances of fishes, collected in zones at the five sites sampled seasonally, and the variance (V-C) each source contributes to the overall variation. * <0.05, **<0.001, ns=non significant.

		Species number			Abundance		
Source	DF	MS	F	V-C (%)	MS	F	V-C
Site (S)	4	3.08	3.46 *	3	3.10	6.76**	10
Season (M)	2	22.93	9.48 *	18	2.30	1.48ns	2
Zone (Z)	1	76.33	78.12**	45	30.47	64.27 *	45
S x M	8	2.42	2.72 *	6	1.55	3.39 *	12
S x Z	4	0.98	1.10ns	0	0.47	1.03ns	0
M x Z	2	16.33	17.15 *	27	3.18	2.10ns	7
S x M x Z	8	0.95	1.07ns	1	1.51	3.30 *	24
Residual	120	0.89			0.458		

A cluster analysis of seasonal catches was conducted on the 24 species groups captured. Sites and zones were separated into two groups with one outlier (Fig. 4.4). Both zones of Portarlington, and the inshore zones of Frankston, Mentone and Mt. Martha clustered together, while the offshore zones of Frankston, Mentone and both zones of Port Melbourne clustered together. The offshore zone of Mt. Martha was separated from other sites. In general, clustering occurred primarily as a function of zone and secondarily as a function of site.

4.3.2 Monthly samples

During the twelve months of sampling (June, 1993 to May, 1994 inclusive) 25,869 individuals were collected, representing 19 families, 25 genera and 28 species (Appendix 2). Of these, 16,368 (63.27%) and 9,501 (36.73%) individuals were collected from seines made in the inshore and offshore zones respectively.

The mean number of species captured in seine hauls are compared in Figure 4.5 and Table 4.3. Significant differences were found for all main effects and the month by zone interaction (Table 4.3). On the majority of occasions species number inshore was higher than offshore, reflected in the variance contribution of 38% (Table 4.3). The magnitude of the difference, however, varied greatly from month to month, hence the significant variance contribution of the month by zone interaction (Table 4.3).

The transformed abundance data from the three monthly sampled sites of Frankston, Mentone and Port Melbourne are compared in Fig. 4.6. Significant differences were found for the Month and Zone main effects and the site by month and month by zone interactions (Table 4.3). Variance component analysis revealed that zone was responsible for 46% of the overall variation in the catches (Table 4.3). Numbers inshore were generally higher than offshore with the exception of June, 1993, when large numbers of *H. vittatus* were collected from Mentone and Port Melbourne (not included in statistical analysis) (Fig. 4.6).

A cluster analysis of the sites and zones resulted in both Frankston zones being clustered together, the offshore zones of Mentone and Port Melbourne were closely associated together with the inshore zone of Port Melbourne, whilst the inshore zone of Mentone was shown to be remote from the other areas (Fig. 4.7). No strong grouping was evident relating to either site or zone (Fig. 4.7).

Table 4.3 Analysis of variance of the number of fish species, and $x^{0.25}$ transformed total abundances of fishes, collected in zones at the three sites sampled monthly, and the variance (V-C) each source contributes to the overall variation. * <0.05, **<0.001, ns=non significant.

		Species number			Abundance		
Source	DF	MS	F	V-C (%)	MS	F	V-C (%)
Site (S)	2	3.34	3.11 *	1	0.37	1.00ns	0
Month (M)	11	10.02	6.42**	18	3.63	2.63 *	13
Zone (Z)	1	105.63	102.25 *	38	49.67	249.61 *	46
S x M	22	1.56	1.45ns	3	1.38	3.71**	17
S x Z	2	1.03	0.96ns	0	0.20	0.53ns	0
M x Z	11	9.66	13.86**	39	2.44	5.87**	23
S x M x Z	22	0.70	0.65ns	1	0.42	1.11ns	1
Residual	288	1.07			0.373		

4.3.3 *Hyperlophus vittatus*

This species was the most abundant collected (21,582 individuals), contributing 83.43% to the total catch. The majority (19,424) of these fish were caught on two dates, 26 June, 1993 at Port Melbourne and 14 April, 1994 at Mentone. This species was patchily distributed with 11.11% and 17.78% of hauls capturing them in the inshore and offshore zones respectively (Appendix 2). The size of fish collected ranged from 10 to 60 mm SL. Size-frequency distributions (Fig. 4.8) of *H. vittatus* show that this species recruited to the beaches during December 1993 and January 1994. Due to the patchy distribution and the very large numbers of this species caught on only two occasions, this species will not be dealt with further.

4.3.4 *Aldrichetta forsteri*

This species was concentrated in the inshore zone with 2,119 (92.61%) of the total 2,288 individuals collected in this zone. Further, 71.11% of hauls made in the inshore zone captured *A. forsteri*, compared with 12.78% of hauls made in the offshore zone (Appendix 2). Analysis of variance of *A. forsteri* abundances showed significant effects of site and zone, significant interactions between site and month and site and zone, and a significant third order interaction (Table 4.4) Abundances of *A. forsteri* were much higher in the inshore zone, and although there were minor differences in timing of peaks in abundances between sites, the abundances of *A. forsteri* peaked during autumn and winter (Fig. 4.9).

The size of fish caught ranged from 22 mm to 148 mm SL. The size-frequency distributions of *A. forsteri* for each month and zone are shown in Fig. 4.10. These graphs show a bi modal size-frequency distribution of juvenile *A. forsteri* for many of the months sampled. These distributions also show that recruitment of small (21 - 30 mm) juveniles occurs over an extended period from January until August. Few large juveniles (> 100 mm SL) were collected.

Table 4.4 Analysis of variance of the $x^{0.25}$ transformed abundance of yellow-eye mullet, *Aldrichetta forsteri*, collected in zones at the three sites sampled monthly, and the variance (V-C) each source contributes to the overall variation.* <0.05, **<0.001, ns=non significant.

Source	DF	MS	F	V-C (%)
Site (S)	2	1.74	4.36 *	1
Month (M)	11	1.52	1.31ns	2
Zone (Z)	1	98.43	64.08 *	69
S x M	22	1.16	2.89**	10
S x Z	2	1.54	3.85 *	2
M x Z	11	1.54	1.94ns	6
S x M x Z	22	0.79	1.99 *	10
Residual	288	0.40		

4.3.5 *Rhombosolea tapirina*

Greenback flounder were the second most commonly occurring species with 36.67% of all hauls capturing individuals of this species. The occurrence of this species varied from 46.67% to 26.67%, in the inshore and offshore zones respectively (Appendix 2). Numerically, *R. tapirina* was ranked fourth (414 individuals; 280 inshore; 134 offshore) and contributed 1.6% to the total catch (Appendix 2).

The mean abundances of *R. tapirina* caught at each site per month are shown in Fig. 4.11. Seine hauls at Port Melbourne captured the greatest number of this species while hauls at Frankston caught the least. The peak in mean abundances at each site varied from August (Mentone) to November (Port Melbourne). In most cases, highest abundances occurred inshore (Fig. 4.11).

The size of animals captured ranged from 7 - 185 mm SL. The recruitment of juvenile flounder to these beaches commenced between July and August, 1993 and continued until October (Fig. 4.12). The growth of this 0^+year group can be followed through until January 1994. Few animals were caught after February 1994 (Fig. 4.11).

4.3.6 Atherinidae

This family was the third most numerous group captured, contributing 3.7% to the total catch (960 individuals; 610 inshore; 350 offshore: Appendix 2). This group consisted of *Atherinosoma microstoma* and *Leptatherina presbyteroides.* The majority (>99%) of these were *L. presbyteroides* and any conclusions about this group only relate to this species. The catches were variable as indicated by the percentage occurrence of 19.44% inshore and 8.33% offshore (Appendix 2). Fig. 4.13 shows the mean number of fish caught per seine at each of the three sites for each month from June, 1993 to May, 1994. Collections of this species from Port Melbourne were infrequent and few in number, while those from Mentone were more numerous and variable. However, collections from Frankston show a pattern of increasing catches beginning in February, 1994, peaking in March before declining through until May.

The size-frequency distributions for each month are shown in Fig. 4.14. Collections made in December, 1994 were dominated by small (<5 - 25 mm SL) juvenile *L.* presbyteroides indicating a recruitment period for this species. From June to November 1993 and February to May 1994, collections were dominated by larger individuals of 26 - 55 mm SL.

4.3.7 *Platycephalus* spp.

This genus was the third most commonly occurring group captured with the percentage occurrence in hauls varying from 22.78% inshore to 22.22% offshore (Appendix 2). Numerically, this group contributed 0.63% to the total catch (164 individuals; 73 inshore; 91 offshore: Appendix 2). This group consisted of *P. bassensis*, *P. speculator* and *P. laevigata.* Flathead were present throughout the year with peaks in abundances occurring in March 1994 at all three sites (Fig. 4.15). Catches were dominated by juveniles, ranging in size from 15 mm to 190 mm SL (Fig. 4.16). Size-frequency distributions of *Platycephalus* spp. show that larger juveniles (61 - 100 mm SL) were present from June 1993 until April 1994 (Fig. 4.16). Small juvenile flathead recruited to these beaches from February to April 1994 (4.16).

4.4 DISCUSSION

The sandy beaches of Port Phillip Bay are an important habitat for juvenile fishes. The ichthyofauna of these beaches was dominated by juveniles and sub-adults. A second, larger (50 x 1.5 m with 10 mm mesh) net was temporarily used in July and November, 1993. The use of this net was discontinued as the sizes of fishes captured were no larger than those captured in the small net used. Therefore, the fishes collected in this study are considered to be a good representation of the fish community present at these beaches.

These assemblages are dominated by a small number of species either occurring frequently, for example *Aldrichetta forsteri*, or in high densities but captured infrequently, for example, *Hyperlophus vittatus*. The numerical dominance of a few species is also common off surf beaches (McFarland 1963; Lenanton 1982; Robertson and Lenanton 1984; Bennett 1989; Ayvazian and Hyndes 1995), and the unvegetated habitats of estuaries (Livingston *et al.* 1976; Loneragan *et al.* 1989; Loneragan and Potter 1990; Humphries *et al.* 1992; Potter *et al.* 1993).

Jenkins *et al.* (1993) describe a similar community of juvenile fishes at their unvegetated sand habitat at St Leonards, Port Phillip Bay. This habitat was located inshore of seagrass beds in shallow water (water depth < 1m) and extended to the shoreline. This community was dominated by *Aldrichetta forsteri* and the two common flounder species, *Rhombosolea tapirina* and *Ammotretis rostratus*. *Hyperlophus vittatus* were not captured in Port Phillip Bay during their study. In the study of habitats on the western coast of Port Phillip Bay (chapter 2), *Rhombosolea tapirina* was on unvegetated habitat as in the present study, however, unlike the present study, *Aldrichetta forsteri* was mainly collected on seagrass habitat.

The community of juvenile fishes collected in this study from the sandy beaches of Port Phillip Bay is similar in structure to that found off surf beaches and from bare sand habitats of estuaries in Western Australia. These habitats are generally dominated by Clupeidae or Atherinidae with Mugilidae also contributing substantial numbers to the community (Lenanton 1982; Bennett 1989; Potter *et al.* 1990; Potter and Hyndes 1994; Ayvazian and Hyndes 1995).

The dominance of sandy beach habitats of Port Phillip Bay by 0^+year fish, and the recruitment of several of the dominant species at quite small sizes, indicates that these habitats play an important nursery role for several species of fishes. The recruitment of species from late winter until summer was largely responsible for the observed increase in the number of species collected over this period. This increase from winter to summer has also been observed for surf beaches (Saloman and Naughton 1979; Bennett 1989) and estuaries (Dahlberg and Odum 1970; Humphries *et al.* 1992).

The recruitment of the four most common taxa to shallow water habitats has been previously noted. The recruitment of *Aldrichetta forsteri* to the sandy beaches of Port Phillip Bay from January in this study is similar to that found by Robertson (1978), Jessop (1988) and Jenkins *et al.* (1993) where recruitment was found to commence in February. *Rhombosolea tapirina* have previously been found to recruit to Port Phillip Bay and Swan Bay from July until August (Jessop 1988; Jenkins *et al.* 1993). The present study, however, recorded the recruitment over a more extended period commencing in July and continuing through until October. This extended recruitment period agrees well with May and Jenkins (1992) and is further supported by the extended spawning period reported by Crawford (1984). The recruitment of Atherinidae was reported by Jessop (1988) to occur from November until February in Swan Bay. The collection of quite small individuals in December during the present study indicates that Port Phillip Bay shows a similar pattern of recruitment. Species of Platycephalidae were reported to recruit to Corner Inlet over Summer (Jenkins *et al.* 1993). The recruitment of this genus from February to April in the present study extends this period into autumn. The nursery role of the sandy beaches of Port Phillip Bay is further supported by the persistence of species in these habitats for a number of months and the growth of cohorts seen in consecutive monthly collections of species such as *A. forsteri* and *R. tapirina.*

The inshore zone, or near-shore margin, was distinct from the offshore zone. These zonal differences persisted over a wide geographic area and through time. In all analyses of catch data the major contributing factor to the total variation was the effect of zone. More species, higher numbers, and greater biomasses of fish were collected from the inshore zone than the offshore zone. Zones also generally clustered together across sites with some sites clustering together, e.g. Port Melbourne (seasonal samples) and Frankston (monthly samples). The persistence of the difference between zones across several variables identifies the inshore zone as a distinct habitat type.

Shallow water has been suggested to be a refuge habitat for fish, offering protection from predators (Ruiz *et al.* 1993) and surf beaches have recently been recognised as nursery habitats, offering adequate food resources and protection from predation (Modde and Ross 1981; Bennett 1989). The sandy beaches of Port Phillip Bay share several physical characteristics with these habitats and it is likely that food and protection are important features for juvenile fishes and determine the differences observed between inshore and offshore zones.

4.5 CONCLUSIONS

This study has shown the sandy beaches of Port Phillip Bay to be nursery habitats for juveniles of a number of commercial fish species. The inshore zone, or near-shore margin, was found to support significantly more fish of a greater number of species than the offshore zone and is identified as being a distinct habitat type. Protection from predators and the availability of food are likely to be distinguishing factors between these two zones for juvenile fishes . Further research is required to distinguish the relative importance of these two factors in the habitat choices of juvenile fishes.

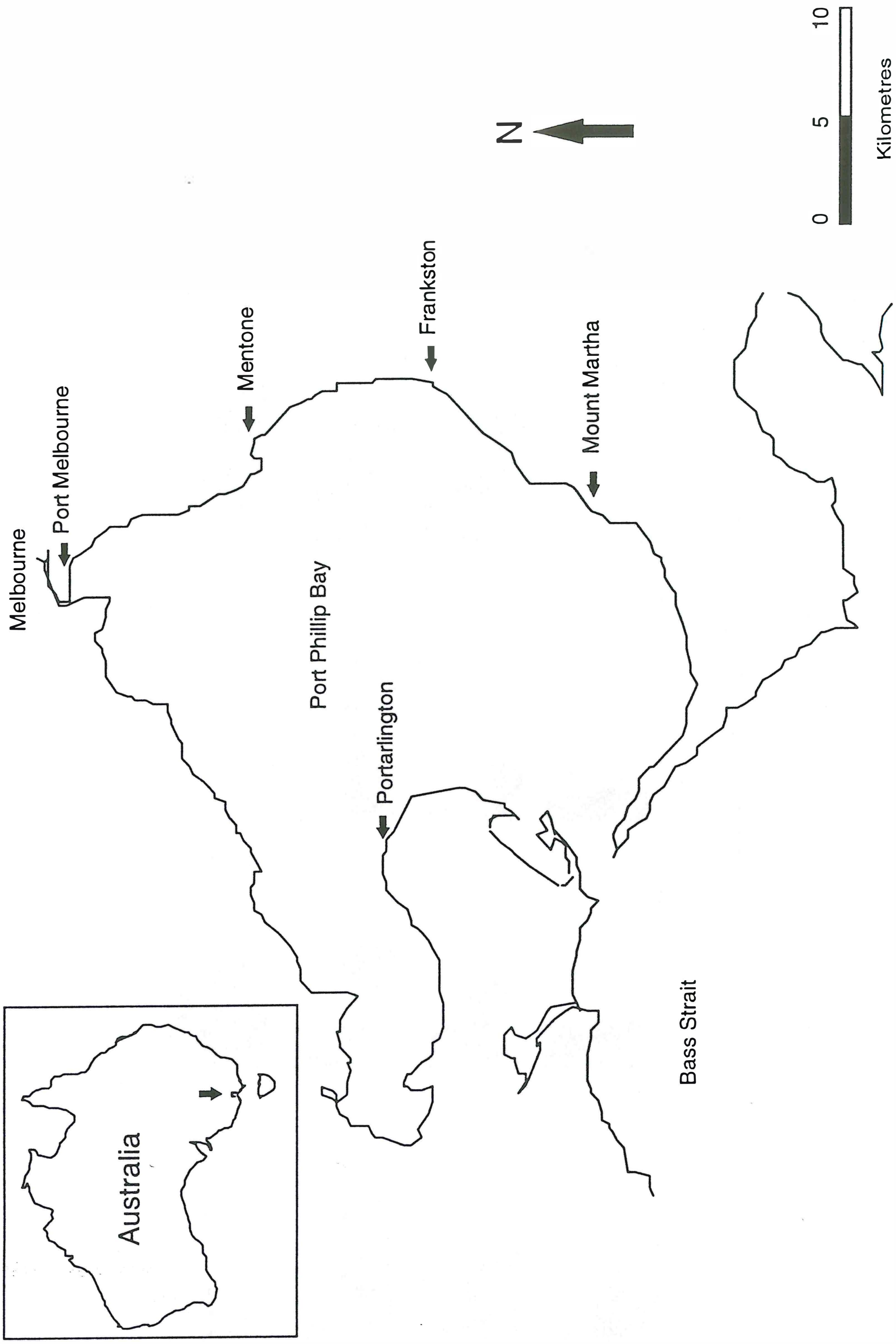

Fig. 4.1 Location of the study sites within Port Phillip Bay. Inset: Location of Port Phillip Bay on the Australian coast.

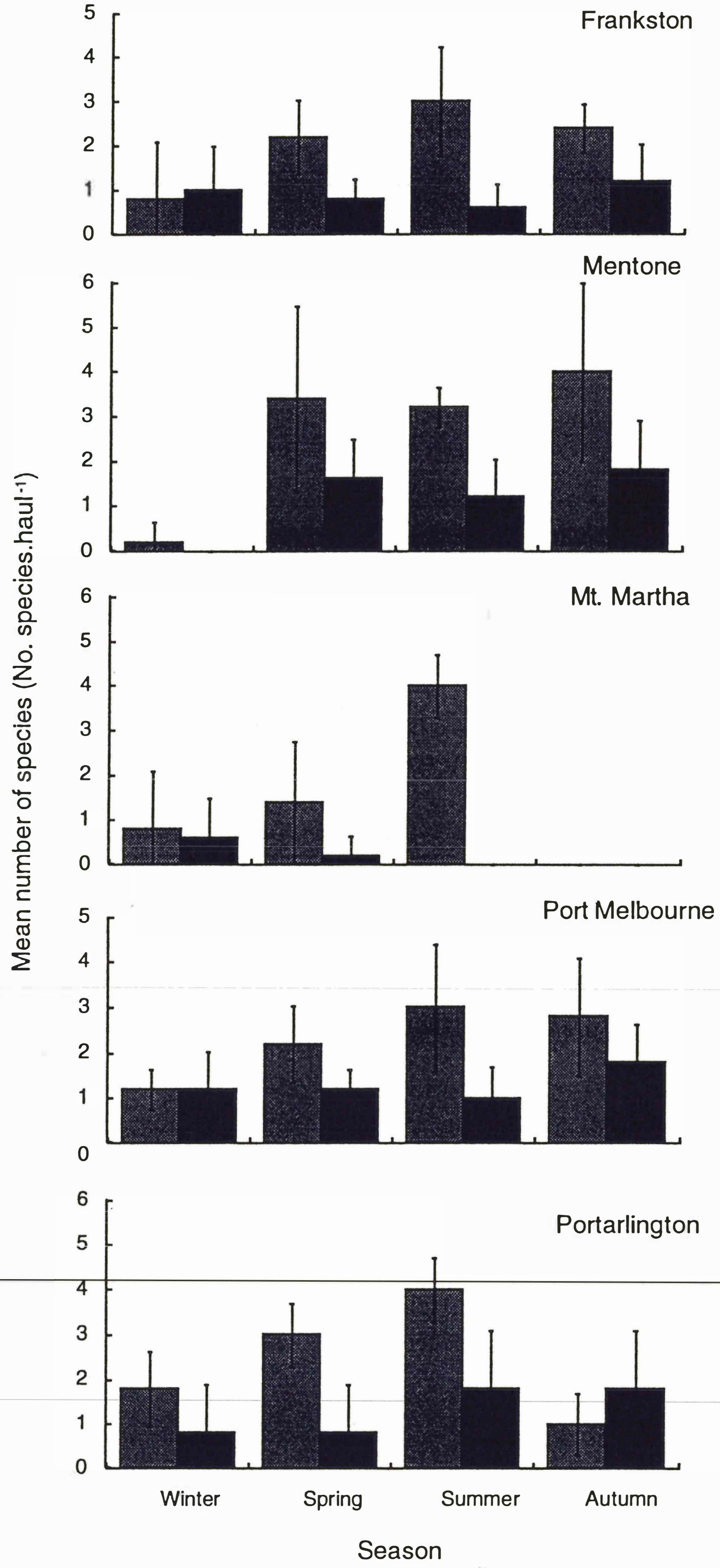

Fig. 4.2 Mean number of fish species collected per seine haul from inshore and offshore zones in each season at each site in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore. Error bars are standard error.

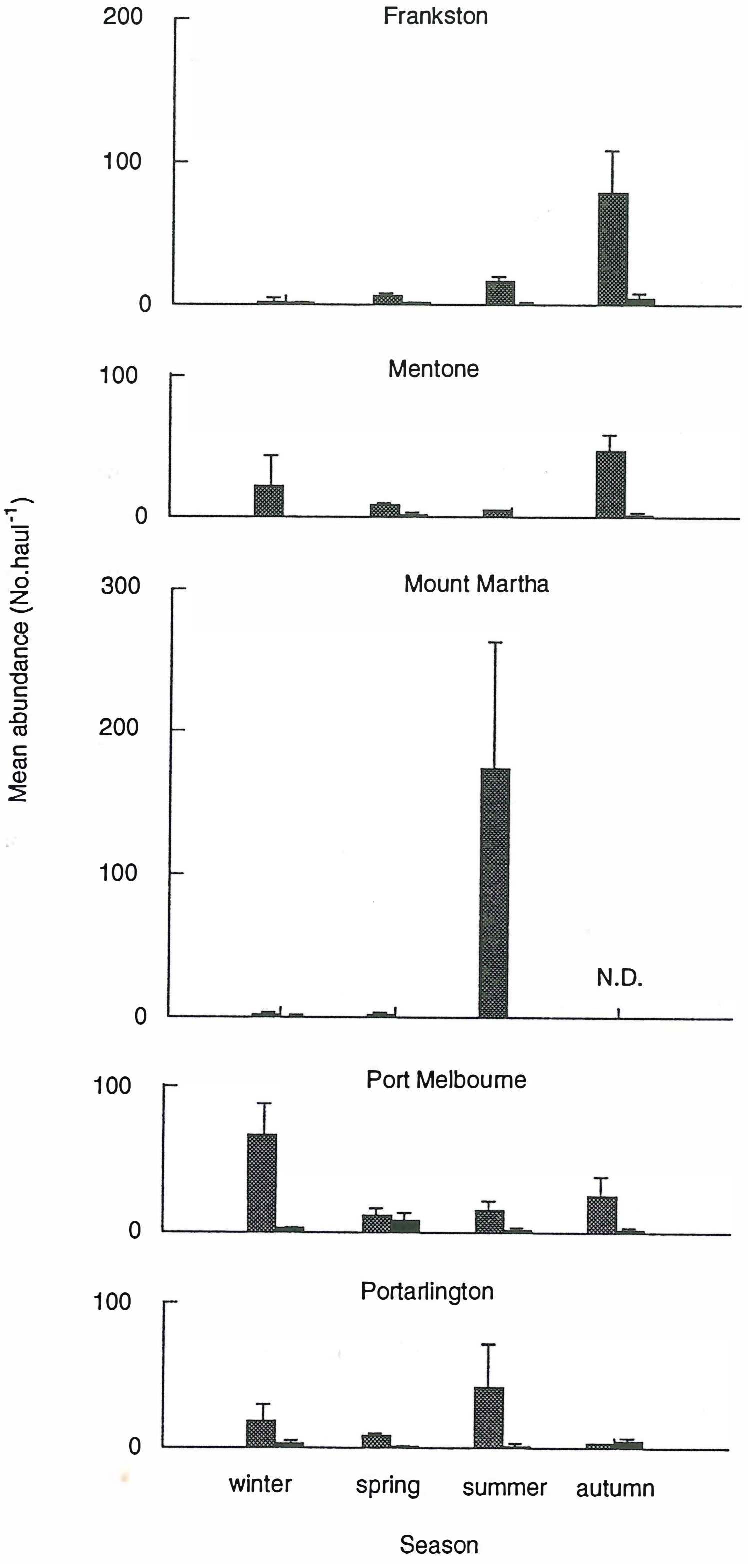

Fig. 4.3 Mean abundance of fishes collected per seine haul from inshore and offshore zones in each season at each site in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore. Error bars are standard error.

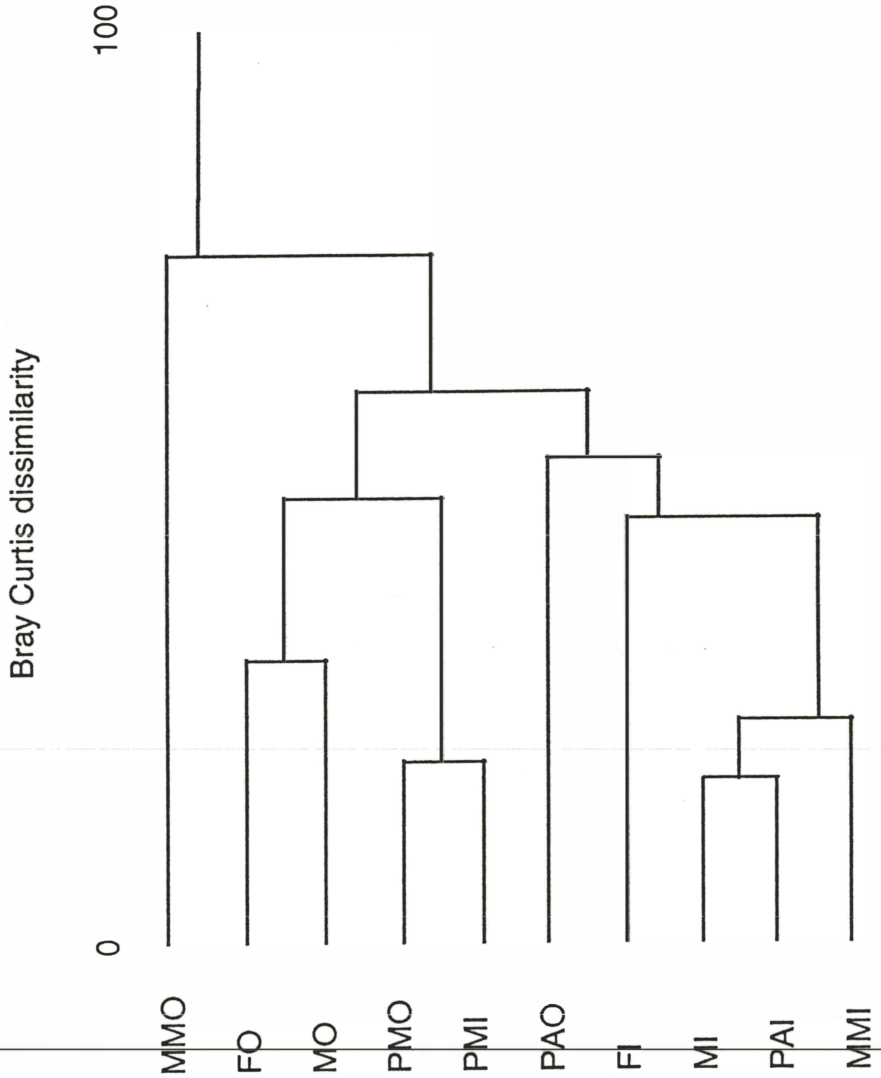

Fig. 4.4 Cluster diagram showing dissimilarities in the community composition of fishes at five sites over four seasons in Port Phillip Bay. MM - Mount Martha; PM - Port Melbourne; PA - Portarlington; F - Frankston; M - Mentone. I - inshore; O - offshore.

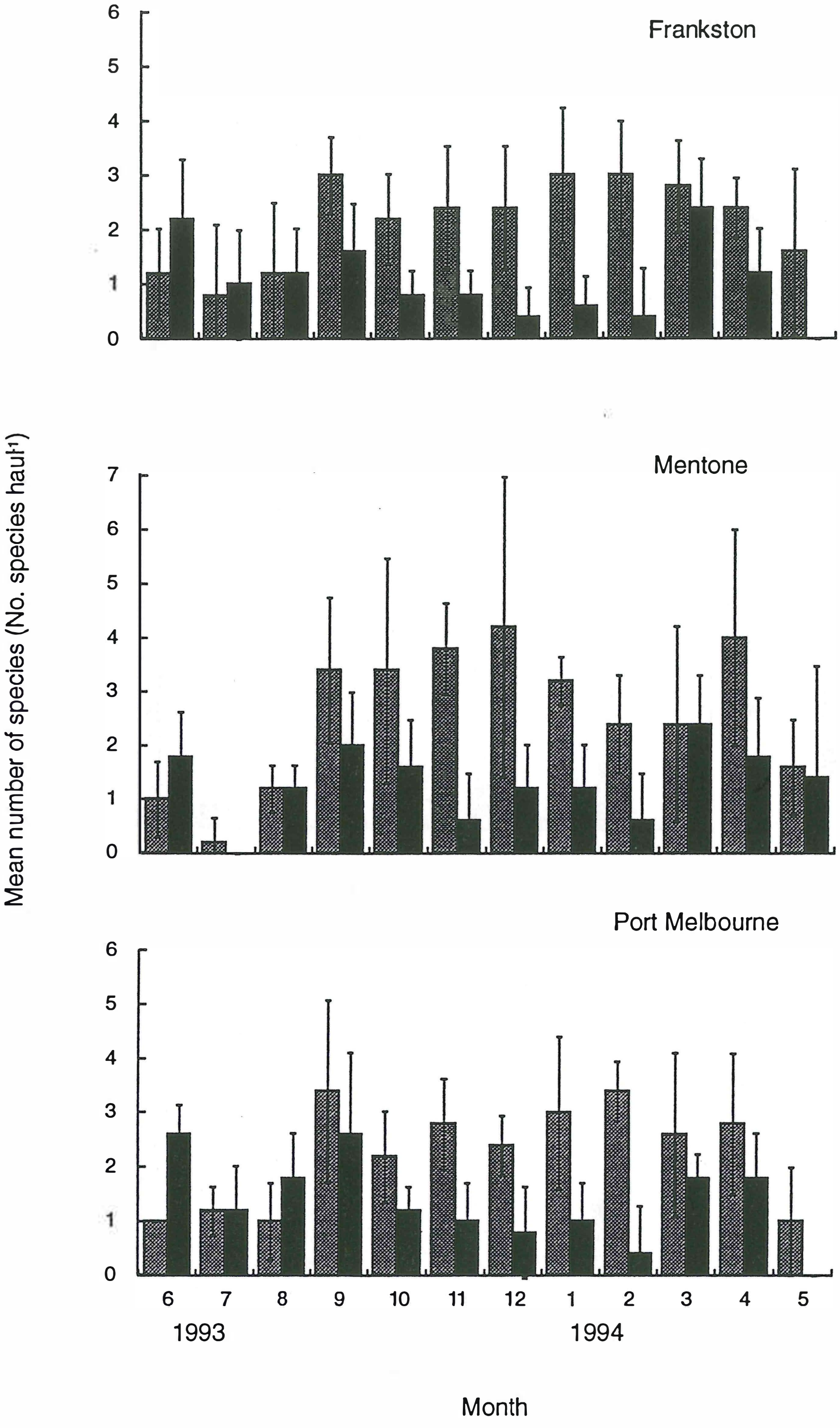

Fig. 4.5 Mean number of fish species collected per seine haul from inshore and offshore zones at sites sampled monthly in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore. Error bars are standard error.

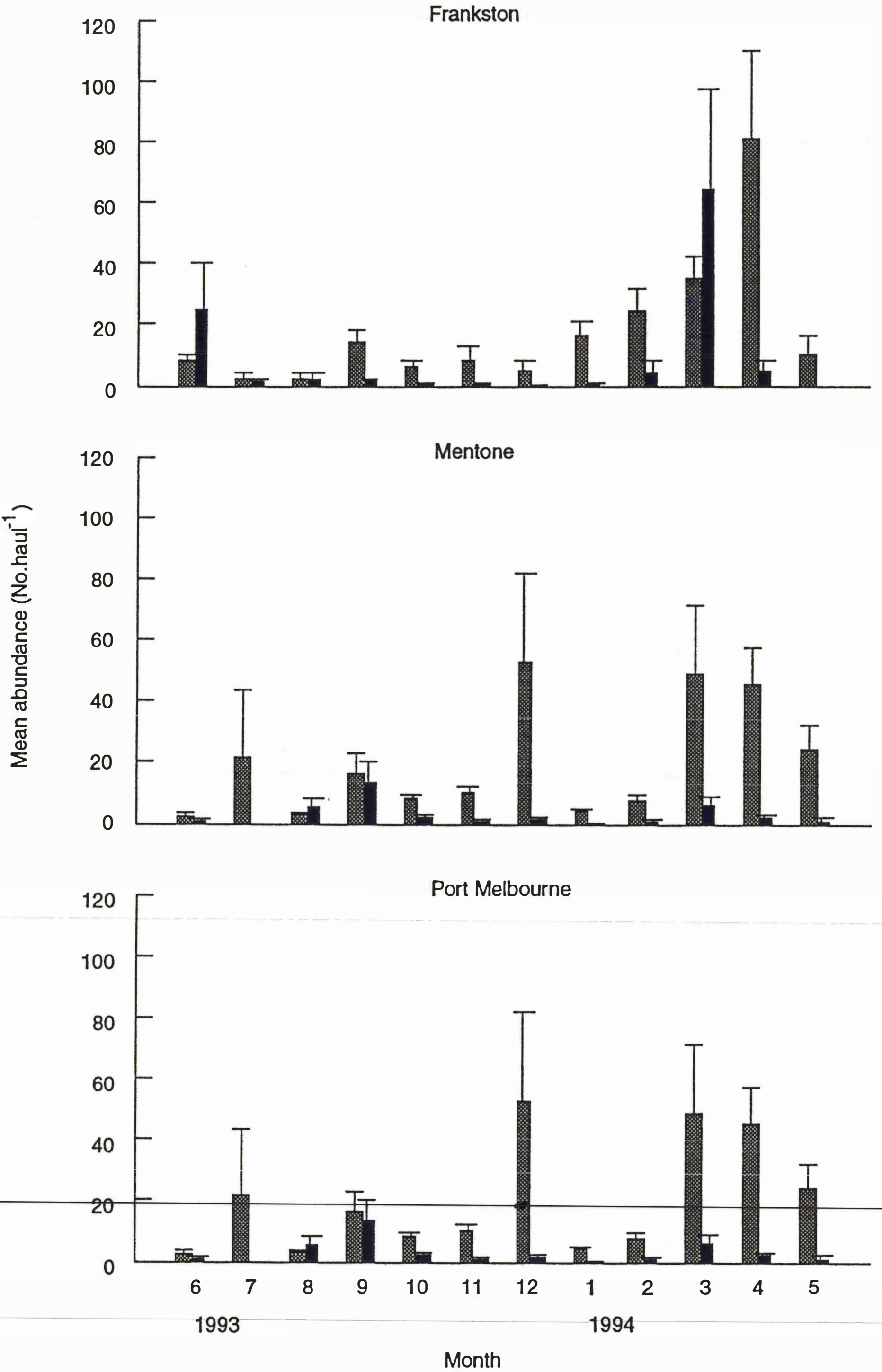

Fig. 4.6 Mean abundance of fishes collected per seine haul from inshore and offshore zones at sites sampled monthly in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore. Error bars are standard error.

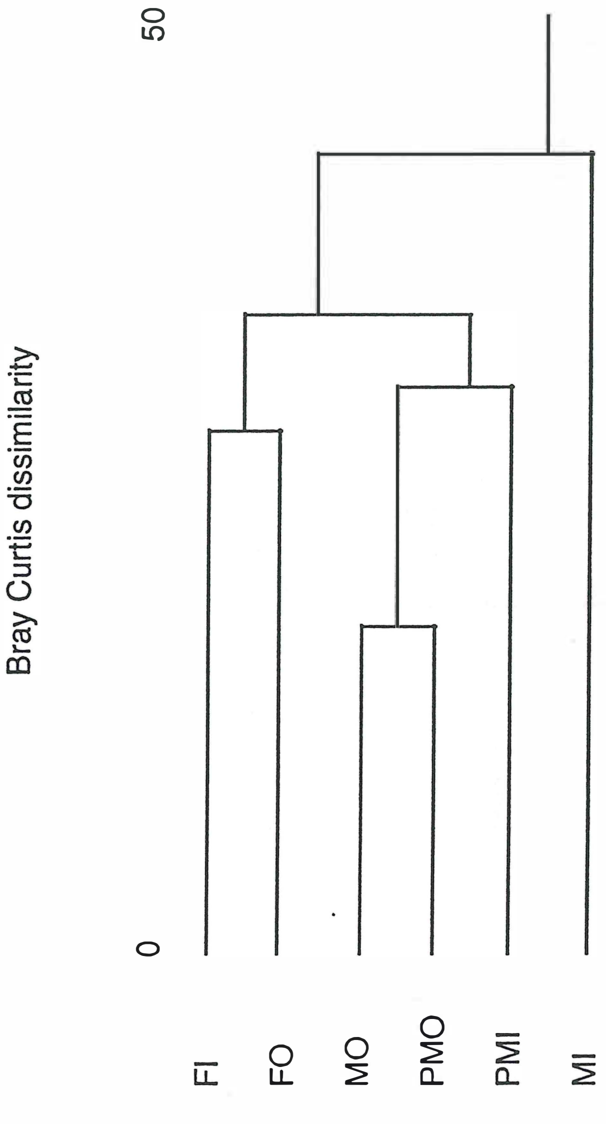

Fig. 4.7 Cluster diagram showing dissimilarities in the community composition of fishes at three sites sampled monthly in Port Phillip Bay. Legend as for Fig. 4.4.

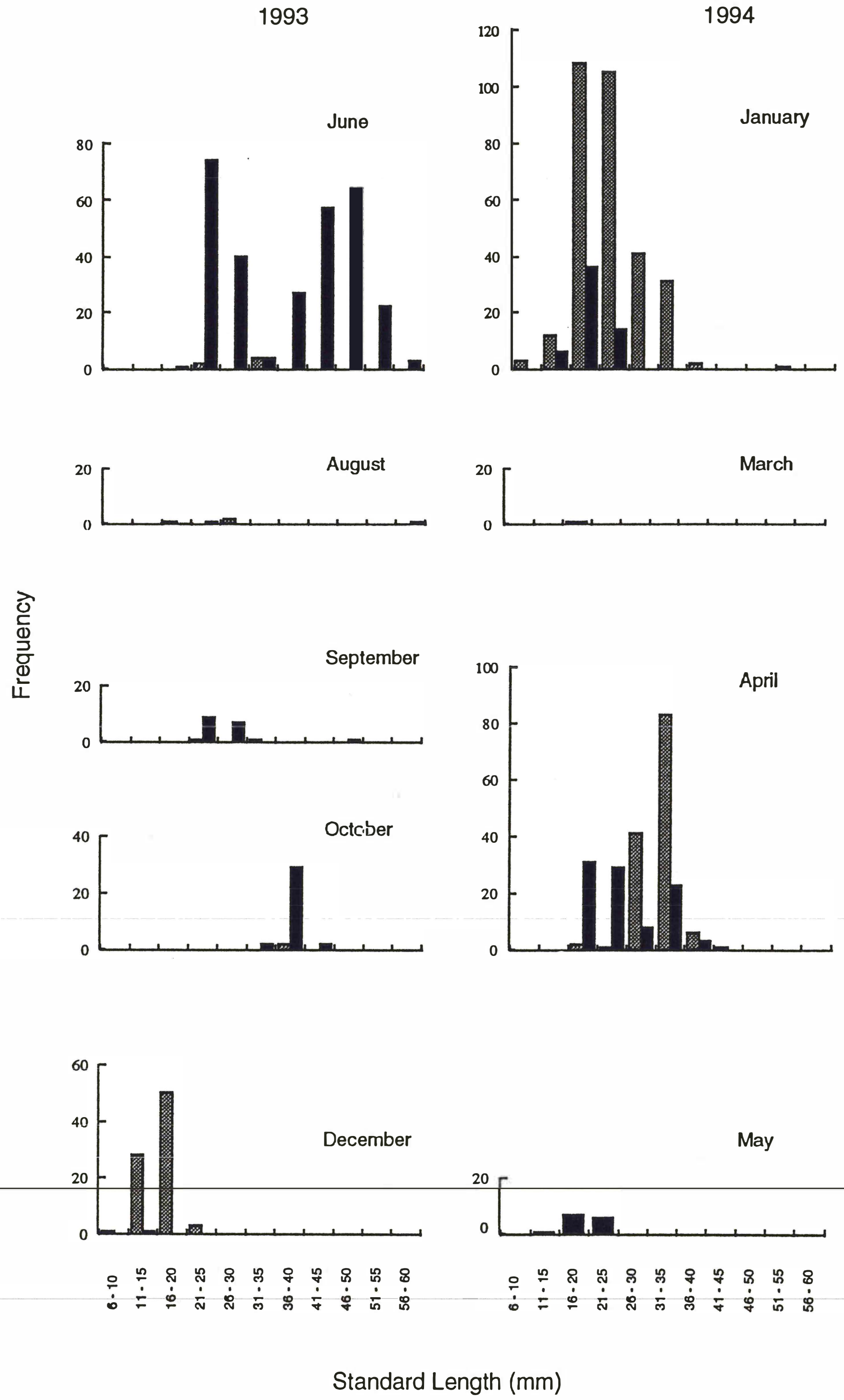

Fig. 4.8 Size - frequency histograms for *Hyperlophus vittatus* in seine net samples from inshore and offshore zones in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore.

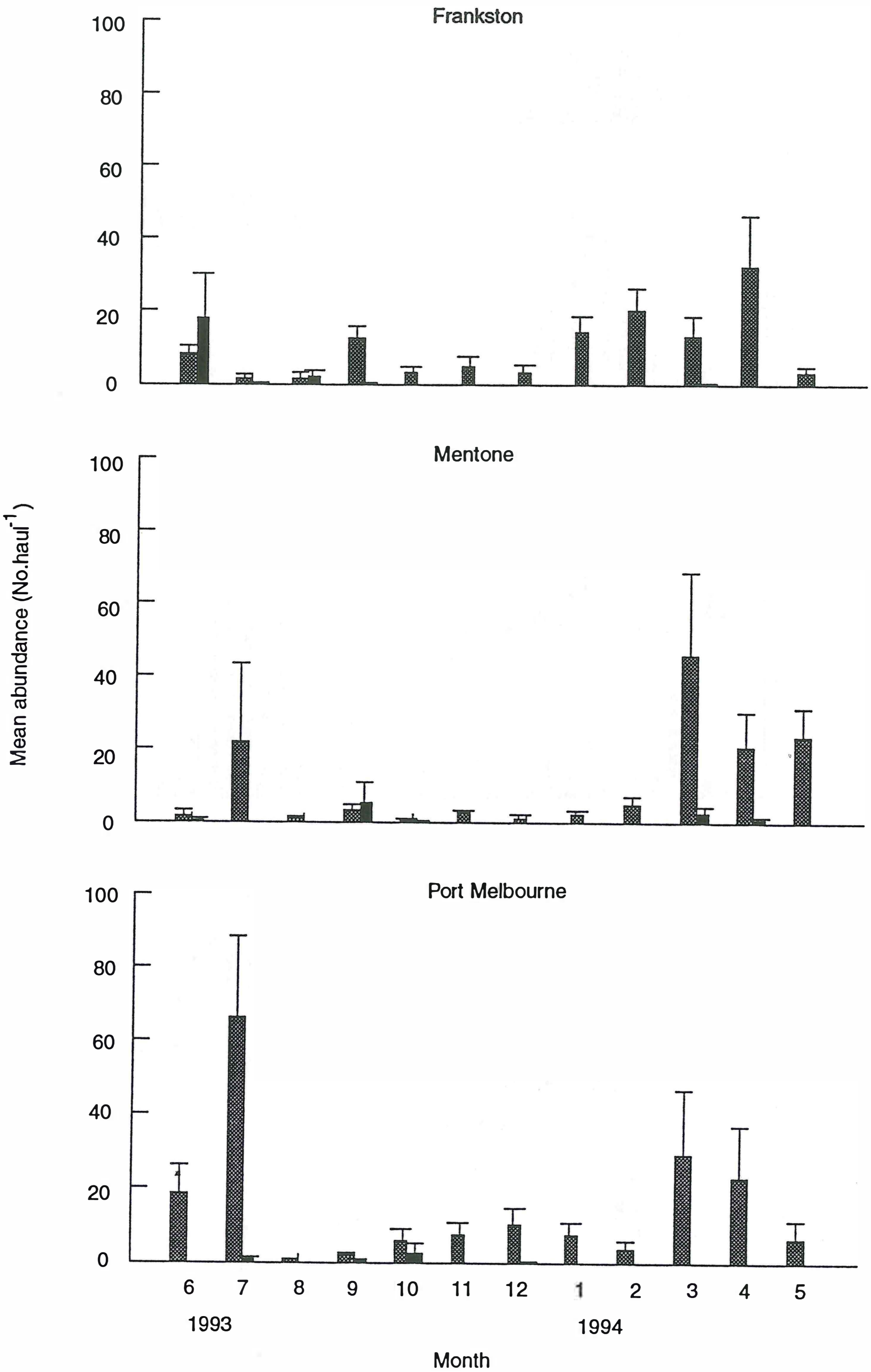

Fig. 4.9 Mean abundance of *Aldrichetta forsteri* collected per seine haul from inshore and offshore zones at sites sampled monthly in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore. Error bars are standard error.

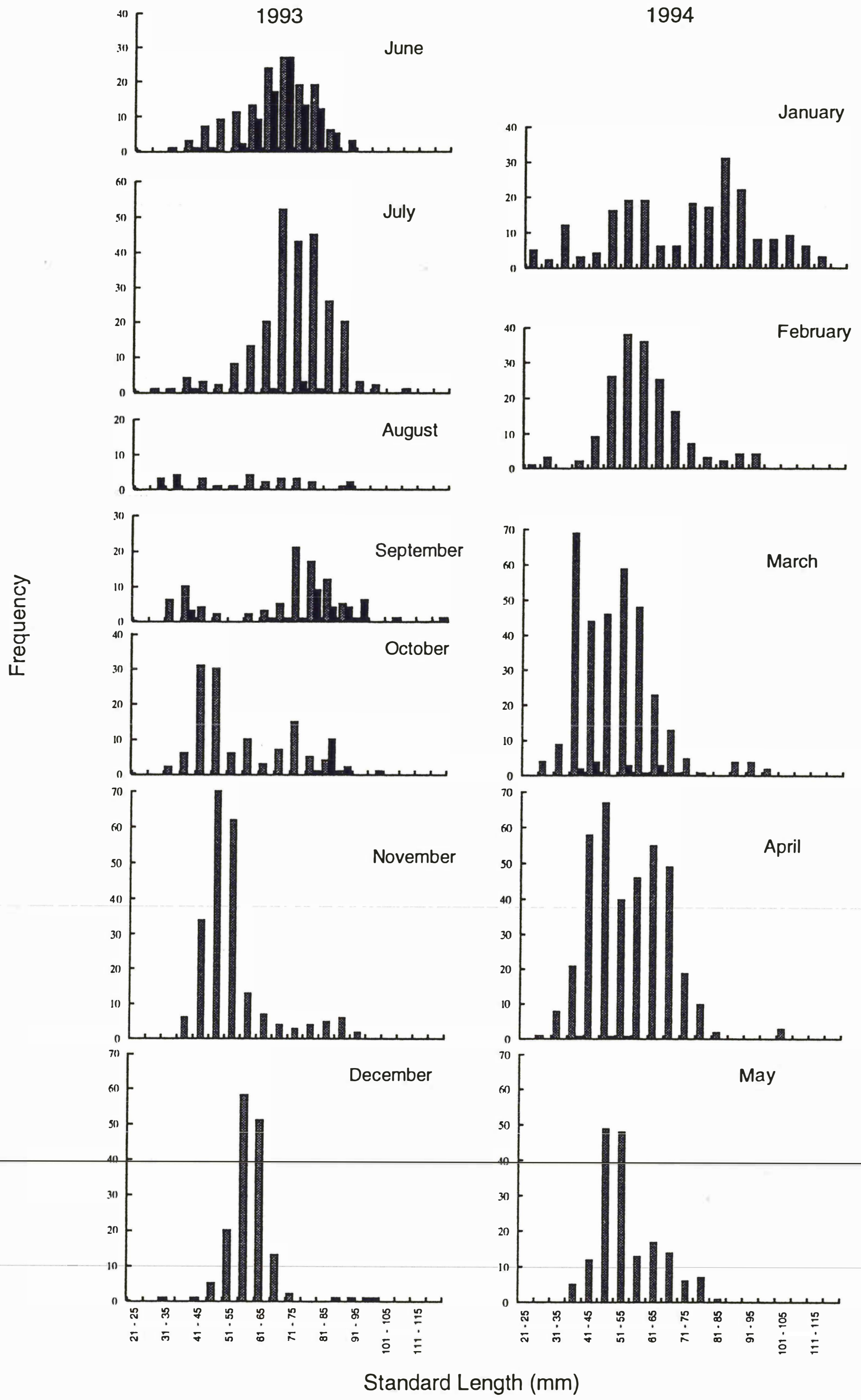

Fig. 4.10 Size - frequency histograms for *Aldrichetta forsteri* in seine net samples from inshore and offshore zones in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore.

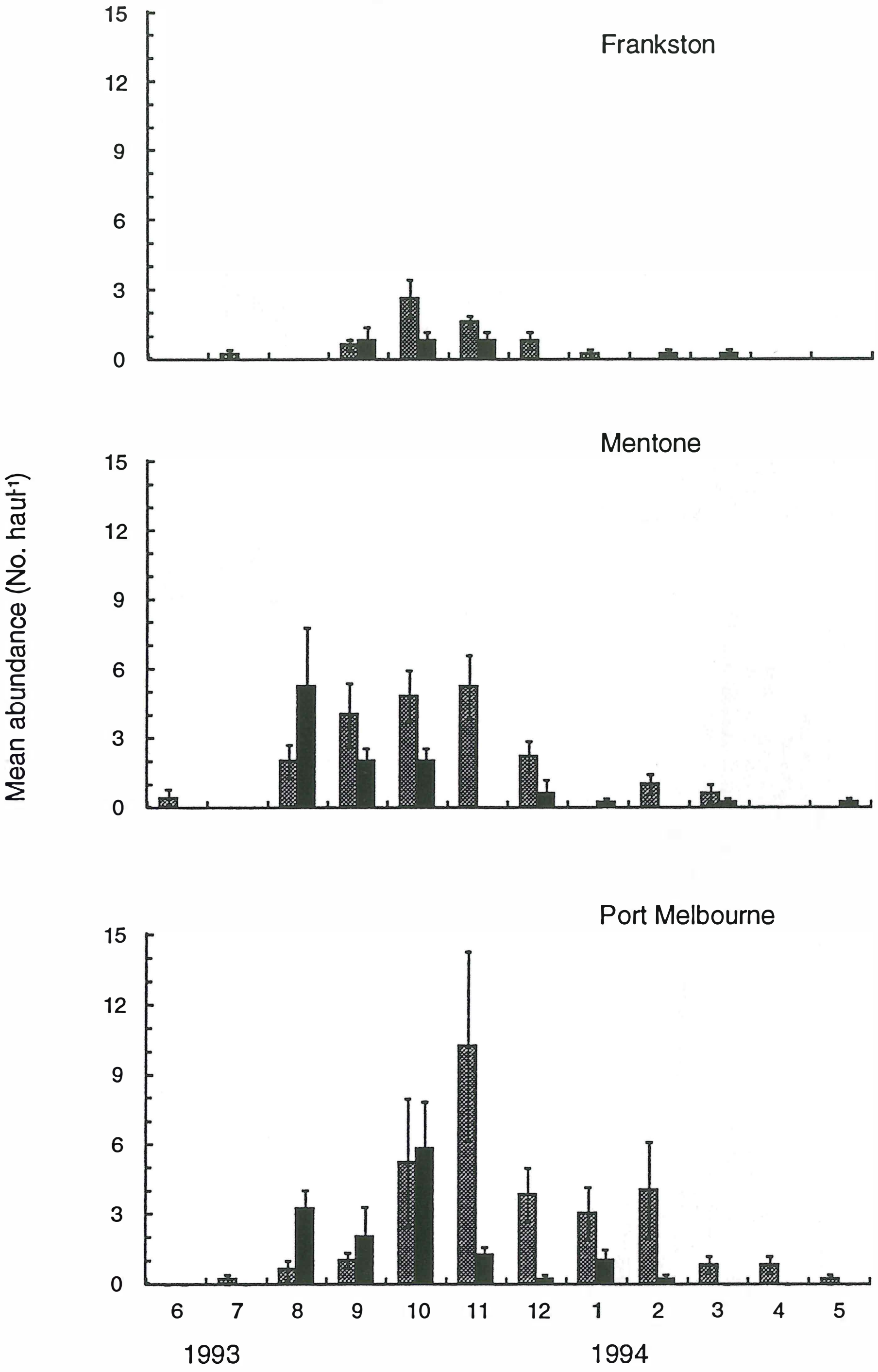

Fig. 4.11 Mean abundance of *Rhombosolea tapirina* collected per seine haul from inshore and offshore zones at sites sampled monthly in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore. Error bars are standard error.

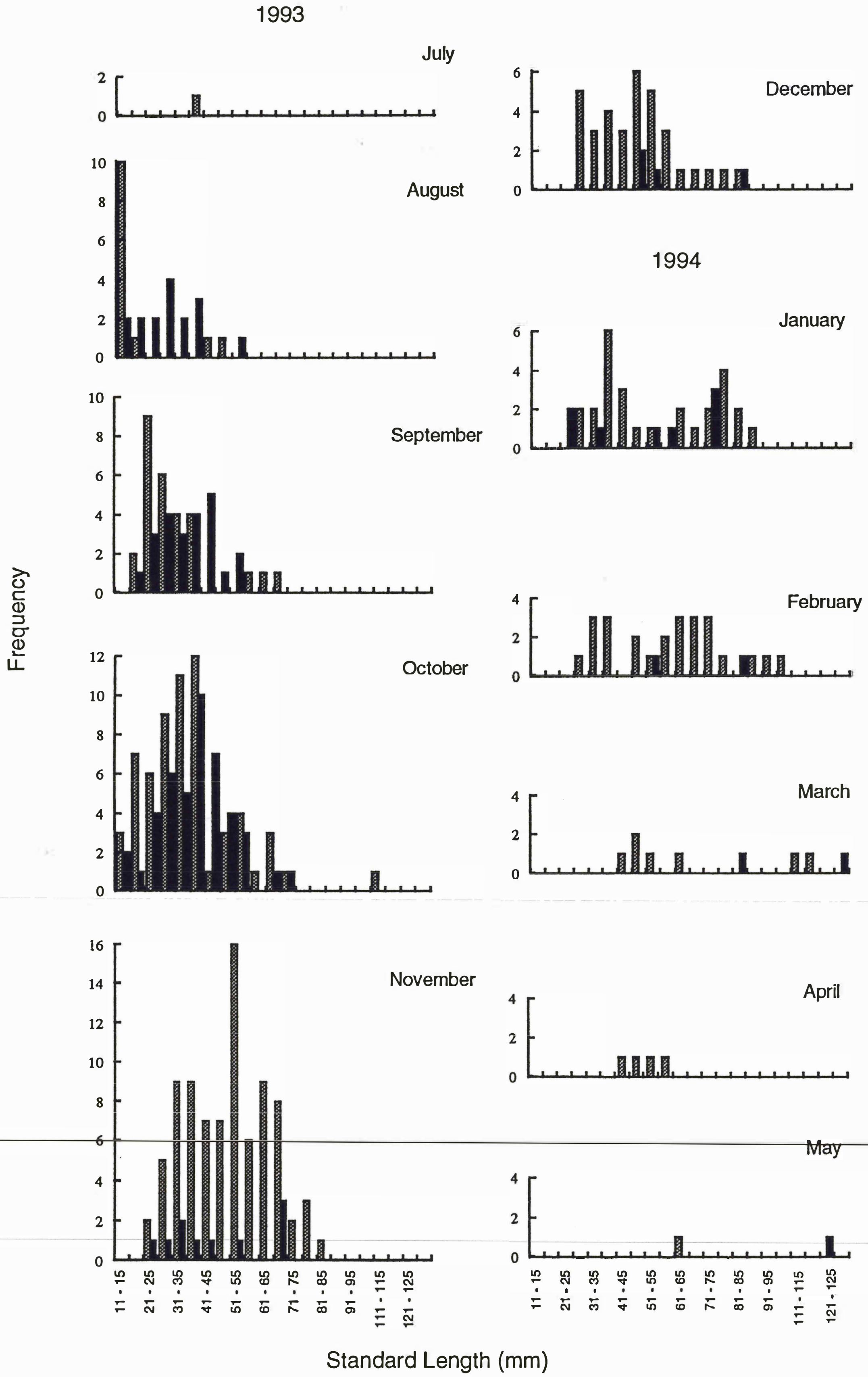

Fig. 4.12 Size - frequency histograms for *Rhombosolea tapirina* in seine net samples from inshore and offshore zones in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore.

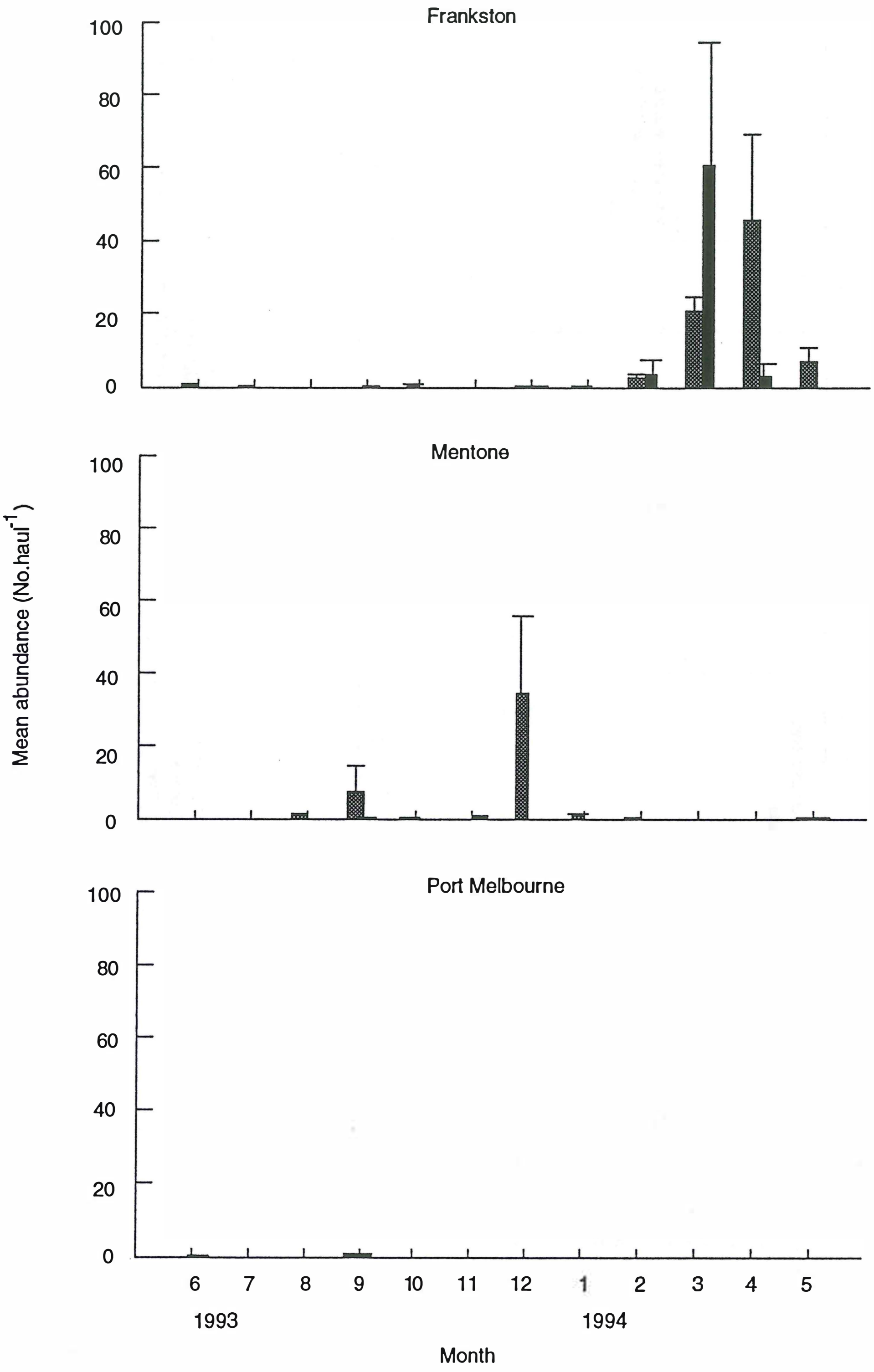

Fig. 4.13 Mean abundance of Atherinidae collected per seine haul from inshore and offshore zones at sites sampled monthly in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore. Error bars are standard error.

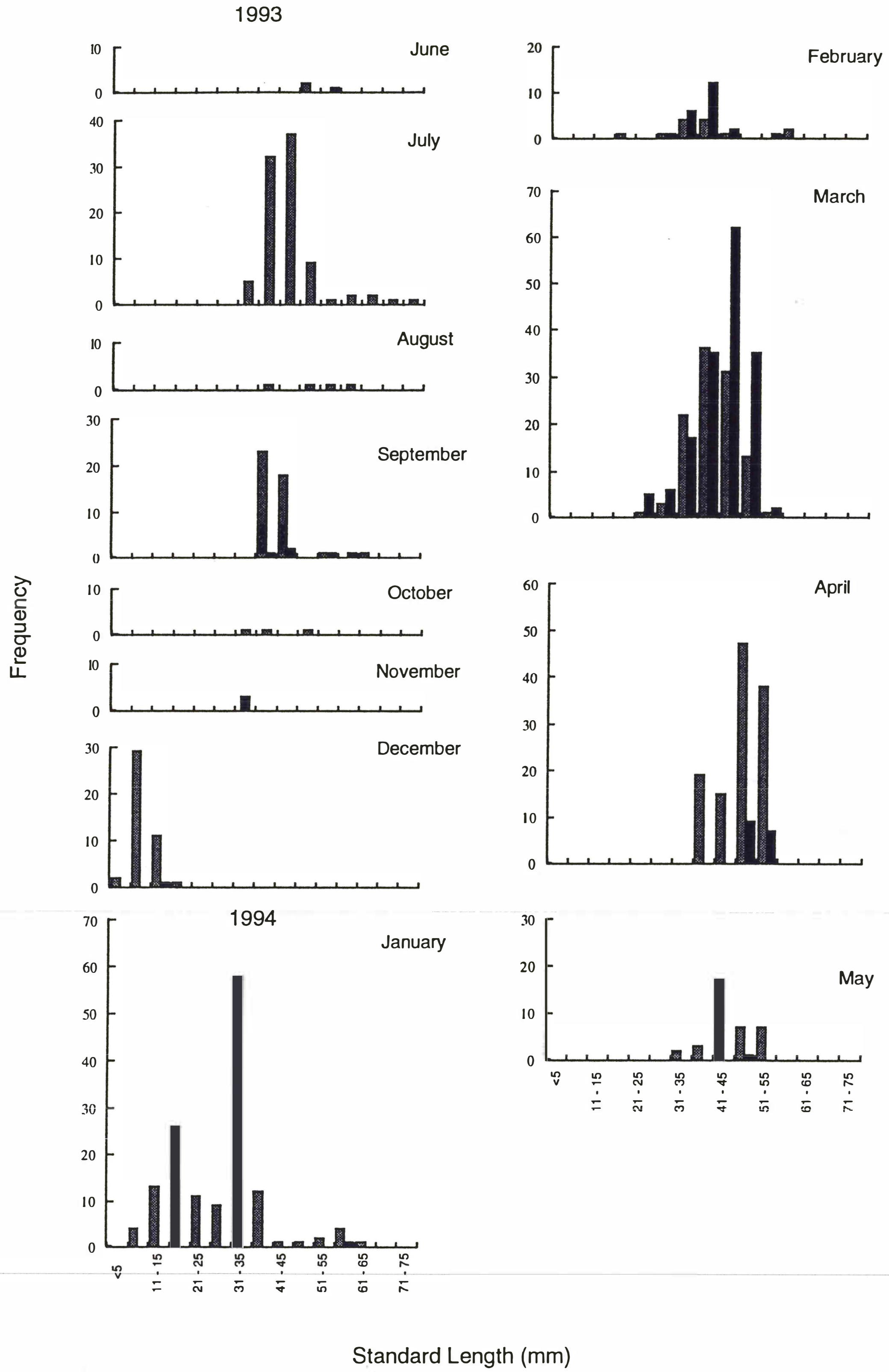

Fig. 4.14 Size - frequency histograms for Atherinidae in seine net samples from inshore and offshore zones in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore.

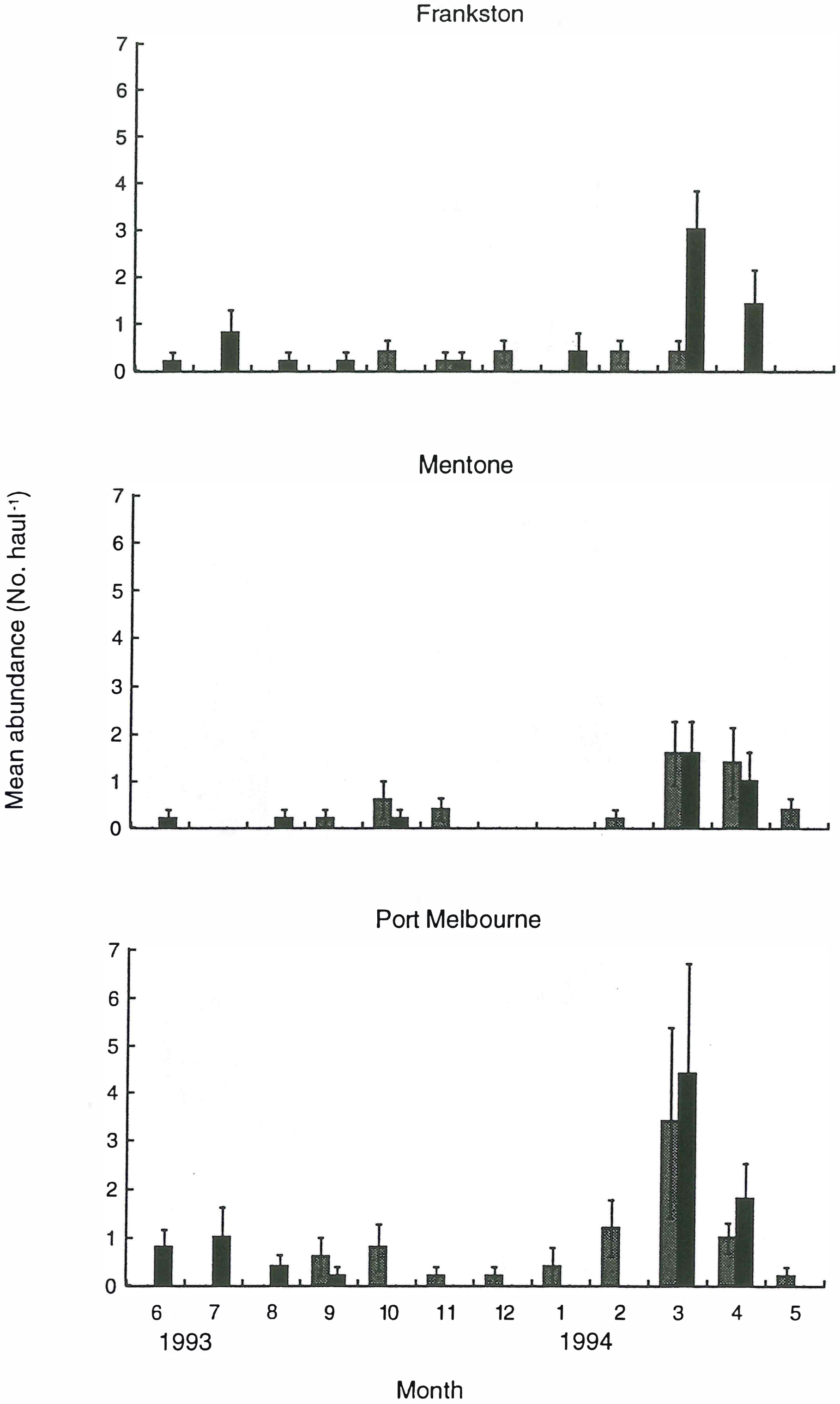

Fig. 4.15 Mean abundance of *Platycephalus* spp. collected per seine haul from inshore and offshore zones at sites sampled monthly in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore. Error bars are standard error.

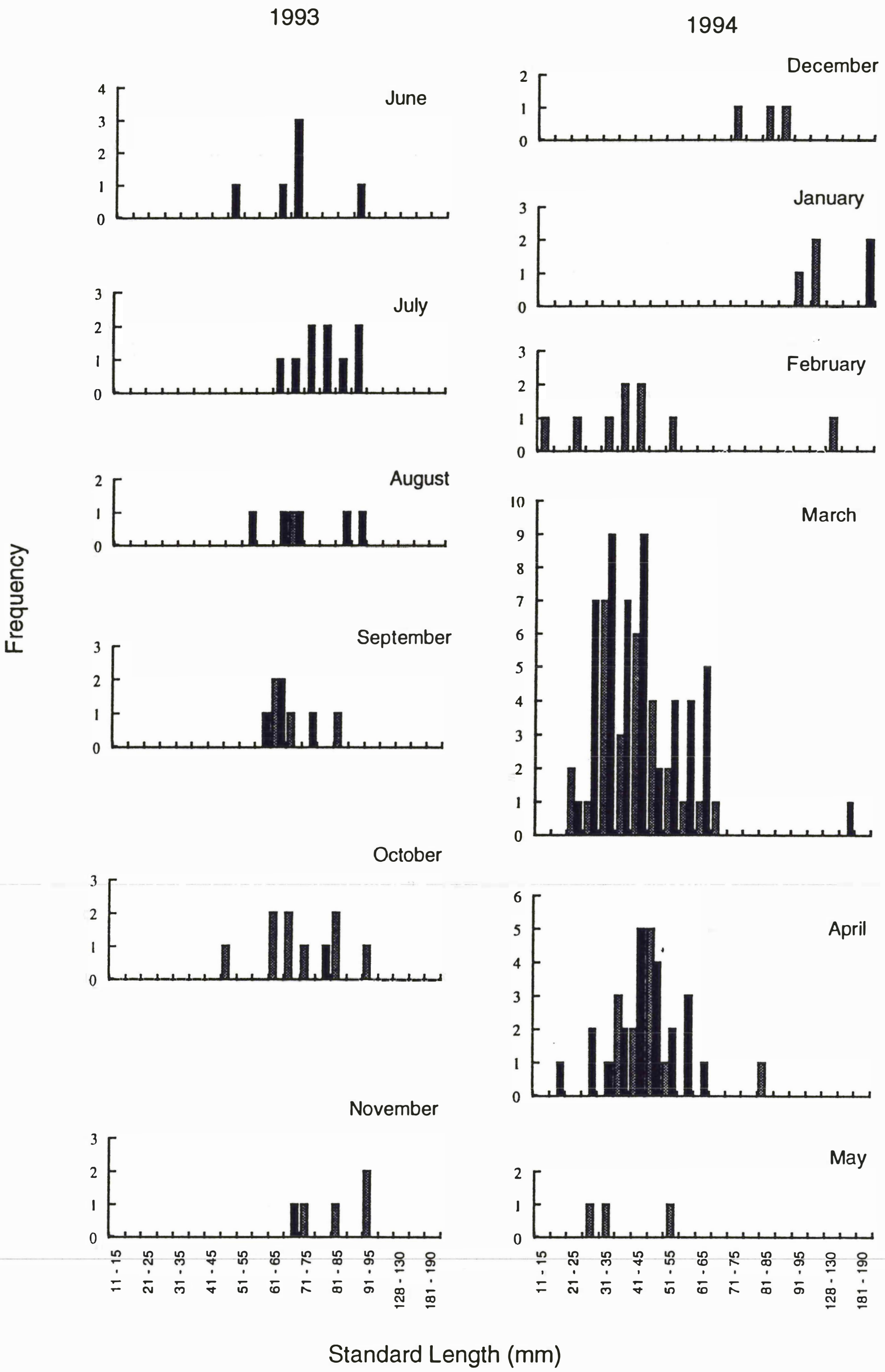

Fig. 4.16 Size - frequency histograms for *Platycephalus* spp. in seine net samples from inshore and offshore zones in Port Phillip Bay. Stippled histogram, inshore; closed histogram, offshore.

CHAPTER 5

CLIMATIC AND OCEANOGRAPHIC FACTORS INFLUENCING THE RECRUITMENT OF PRE-SETTLEMENT KING GEORGE WHITING, *SILLAGINODES PUNCTATA*, TO PORT PHILLIP BAY

5.1 INTRODUCTION

Most sedentary or demersal marine animals have a dispersive larval phase. Recruitment of young can be highly variable, and this variability may have a long-term influence on the demography of a population (Hughes 1990; Raimondi 1990; Doherty and Fowler 1994). One potential source of recruitment variability is variation in larval supply, and links between larval supply and recruitment have been demonstrated for some species (Gaines *et al.* 1985; Hurlbut 1992; Milicich *et al.* 1992). It is likely that a major influence on larval supply will be the coastal oceanography responsible for transport of larvae (Underwood and Fairweather 1989).

A strong influence of coastal oceanography on larval supply has been demonstrated for some invertebrate species (Goodrich *et al.* 1989; Farrell *et al.* 1991; Little and Epifanio 1991). However, the linkage between coastal oceanography and larval supply of demersal fishes is less clear. Large-scale recruitment of a temperate reef fish estimated from visual transects and population age structure was found to be strongly influenced by large-scale oceanography (Cowen 1985). The linkage between oceanographic processes and larval supply of tropical reef fishes measured by light-traps (Milicich 1994) and channel nets (Thorrold *et al.* 1994) was variable between taxa, years, habitats and other factors. Thorrold *et al.* (1994) suggested that fishes are less likely to be influenced primarily by physical transport processes because they have relatively well-developed swimming abilities and complex behaviours.

King George whiting, *Sillaginodes punctata*, is an important commercial fish species in southern Australia. Post-larvae, defined as newly settled specimens prior to scale formation (Bruce 1995), and juveniles up to approximately 3 years of age, are generally associated with seagrass habitats in sheltered gulfs, bays and inlets (Jones 1980; Hutchins and Swainston 1986). In central Victoria, settlement occurs from August through to November, the southern spring (Robertson 1977; Jessop 1988; Jenkins and May 1994). The larval duration is long (100 to 170 d), with spawning estimated to occur from approximately April to July, and although spawning areas have not been identified, they are thought to be offshore from the coastal nursery habitat (Jenkins and May 1994). Newly settled fish entering coastal habitats tend to be 15 to 20 mm in length (Jenkins and May 1994; Bruce 1995).

Jenkins and Black (1994) showed a strong correlation between temporal patterns of settlement of *Sillaginodes punctata*, estimated from otolith microstructure, and the predictions of a numerical hydrodynamic model that simulated transport of neutrally buoyant particles to the coastal habitats. A complex interaction of oceanographic and climatic factors appeared to lead to a net transport of larvae into the bay on a 10 to 14 d cycle (Jenkins and Black 1994). These results considered temporal variability only and were related to a relatively small area of juvenile habitat. The aim of the present study is to examine the influence of coastal hydrodynamics on settlement on a short-term temporal scale and also on a relatively broad spatial scale within Port Phillip Bay. Recruitment is estimated both from high frequency sampling and otolith microstructure. For the first time we identify individual climatic and hydrodynamic factors influencing temporal variability in recruitment of this species.

5.2 METHODS

5.2.1 Study area

Port Phillip Bay is a large, semi-enclosed, predominantly tidal embayment linked to the ocean of Bass Strait by a narrow entrance (Fig. 5.1). The hydrodynamics are characterised by an entrance region where fast (3 $m.sec^{-1}$) ebb and flood jets dominate the circulation, a large flood-tidal delta, known as the Sands region, where strong currents occur in the major channels, and an "inner" zone where tidal currents are weak (Black *et al.* 1993). On the western side of Port Phillip Bay, tidal currents drop to below 10 $cm.sec^{-1}$ at about the entrance to the Geelong arm. Tidal range inside the bay is less than one metre.

Seagrass around the Bellarine Peninsula region of Port Phillip Bay consists generally of narrow (20 m wide) bands of the subtidal seagrass *Heterozostera tasmanica* running parallel to the shoreline. Towards Corio Bay within the Geelong Arm, however, seagrass beds become more widespread. This pattern reflects the distribution of sediment grain size, which becomes progressively finer from the sands region around the Bellarine Peninsula and into the Geelong Arm (Anon. 1973).

5.2.2 Field sampling

Sampling was conducted at three locations on the Bellarine Peninsula (Fig. 5.1). At each location *Heterozostera*, averaging approximately 0.5 m below MLWS, was sampled. Samples were collected 2 hr each side of low tide and the order of sampling sites was varied. Sampling was conducted at approximate 3 to 4 day intervals from September 2 to October 29, 1993.

Post-settlement *Sillaginodes punctata* were sampled with a seine net of 10 metres in length, a 3 metre drop, and a mesh of approximately 1 mm^2. Two 10 m ropes were attached to each end of the seine. Four replicate hauls, haphazardly placed and non-overlapping, were made at each site. Hauls were made by two people walking out to the appropriate depth, one person walking 10 m further, setting the net parallel to shore and returning to the position of the second person where the net was then hauled into a bucket. The net was then carried back to shore where post-larvae and juveniles were sorted, anaesthetised in benzocaine, and preserved in 95% ethanol. A beach seine net has been shown to be an efficient sampler of post-settlement *S. punctata* in seagrass habitat (Connolly 1994c).

5.2.3 Modelling

The circulation was depicted using a Eulerian, numerical, hydrodynamic model of Port Phillip Bay and the adjacent ocean of Bass Strait (Black *et al.* 1993). Both 2 and 3 dimensional models were available (Black *et al.* 1993 and references therein). The model incorporated the important processes identified by analysis of current and sea level measurements. A high level of calibration against three years of field data has been achieved (Black *et al.* 1993). The open boundary was placed 20 km south of the entrance in Bass Strait (Fig. 5.1). Tidal oscillations were obtained from records based on previous measurements at the model boundary in Bass Strait (Black *et al.* 1993). Low frequency (non-tidal) oscillations due to factors such as wind, barometric pressure and coastal-trapped waves were represented by using actual sea levels recorded at Point Lonsdale (Fig. 5.1) during the settlement period. Tidal analyses (Foreman 1977) were applied to remove the tidal component of sea level oscillations at Point Lonsdale. Actual wind measurements over the settlement period were incorporated.

Dispersal of passive "larvae" was simulated in a Lagrangian particle model (Black *et al.* 1990). The hydrodynamic model solved the fluid flow equations to produce a 1.5 km-square grid of currents for calculation of the advection in the dispersal model, while diffusion was modelled as a Monte Carlo random walk (Black *et al.* 1990). The horizontal diffusion coefficient was taken such that the random step was 40% of the advection distance along the flow direction and 10% laterally. The larger value attempts to represent the shear in the boundary layers (Black *et al.* 1990). Sensitivity testing of the eddy diffusivity showed that the general conclusions were not strongly affected by the choice of the eddy diffusivity coefficient. The advection of particles moving with the currents was more important.

Two release points were used in dispersal simulations. One release point was immediately outside Port Phillip Heads whilst the second was at Breamlea, approximately 20 km west of Port Phillip Heads, along a line extending 10 km from the coast (Fig. 5.1). In both cases, 16 particles were released every two h from the start of the model run. Simulations began at 0000 h on 15 August, 1993. Results were recorded spatially as numbers of particles in 1.5 km^2 cells over the model grid (scaled as a percentage of the largest number of particles recorded in any cell on the grid), and temporally was recorded in a 'box' superimposed on the model grid in the St Leonards region (Fig. 5.1).

5.2.4 Data analysis

Time series of post-larval abundance, model outputs, and physical variables were compared using correlation. Before correlations were performed we had to address the problem of autocorrelation within individual series. Traditional methods of time series analysis (Box and Jenkins 1986) remove autocorrelation from time series and therefore may result in the loss of important information relating to low frequency variation. We have therefore retained the original time series but have adjusted the 'effective' sample size to account for autocorrelation using the method outlined by Bayley and Hammersley (1946) and applied to physical oceanographic problems by Garrett and Petrie (1981) and Garrett and Toulany (1981). Where model time series showed an upward trend and increasing variance due to accumulation of particles, data were log and trend transformed to stabilise the time series (Wilkinson *et al.* 1992). This procedure was justified because, unlike particles which accumulated over time, larvae would leave the planktonic system with the onset of juvenile life. Correlations were examined for lags of up to 3 d.

5.3 RESULTS

The pattern of abundance over the sampling period varied widely amongst sites (Fig. 5.2). At the St Leonards site, occurrence of post-larvae occurred in pulses, centred around 23 September, 14 and 22 October, each of which declined rapidly a few days after they appeared (Fig. 5.2). Abundances at the Grassy Point site showed a similar pattern to St Leonards except that there was an accumulation of post-larvae over time, particularly in October (Fig. 5.2). There was a significant correlation between abundances at St Leonards and the differenced data from Grassy Point (n=15, r=0.769, P<0.001). The pattern of abundance was quite different at the Grand Scenic site (Fig. 5.2); abundances were generally low, gradually increasing from 20 September to 7 October, and then remained low and variable thereafter. There was no significant correlation between the Grand Scenic site and the other two sites.

The abundance data recorded from frequent sampling at St Leonards were compared with physical data pooled for the equivalent time periods. No significant autocorrelation was found in the data sets. A significant positive correlation was found between barometric pressure and abundance, whilst a significant negative correlation was found between wind velocity and abundance (Table 5.1). Highest abundances were related to the passage high pressure and associated calm conditions (Fig. 5.3).

Table 5.1 Correlations between climatic data and abundance of *S. punctata* at St Leonards. Climatic data were averaged over the equivalent period to recruit sampling (n=15).

Physical variable	r	Probability
East-west wind vector	0.390	ns
North-south wind vector	0.248	ns
Wind velocity	- 0.610	P<0.05
Residual sea-level	0.035	ns
Actual sea-level	0.169	ns
Barometric pressure	0.554	P<0.05
Tidal range	0.442	ns

Daily increment data showed that otolith transitions for individuals collected from St Leonards occurred predominantly in three groups; approximately 19 to 24 September, 9 to 14 October and 17 to 22 October (Fig. 5.4). Individuals with otolith transitions formed between 17 and 26 September were well represented at Grassy Point whilst a smaller peak occurred between 12 and 16 October (Fig. 5.4). Individuals from Grand Scenic had otolith transitions formed almost entirely between 17 and 28 September (Fig. 5.4).

Otolith transitions for individuals collected at St Leonards were primarily formed within the four days previous to sampling on 23 September, 14 October and 22 October (Fig. 5.5). Some individuals from Grassy Point and Grand Scenic also had otolith transitions formed a few days before collection, particularly in the period from 16 September to 27 September, although the majority were formed a significant period before collection (Fig. 5.5).

The pattern of otolith transitions at St Leonards also showed significant correlation with some physical variables; positive correlation with the west-east wind vector, actual sea-level and residual sea-level, and negative correlation with barometric pressure (Table

5.2). Major peaks in west-wind velocity, sea level, and residual sea level, together with troughs in barometric pressure, corresponded to major peaks in settlement (Fig. 5.6).

The time series of particles in the St Leonards region showed a similar pattern amongst all four simulations, with peaks in particle numbers occurring around 15 to 25 September, 8 to 13 October and 18 to 23 October (Fig. 5.7 A - D). Releases from outside Port Phillip Heads showed a relatively broad peak in mid to late September and had an additional minor peak around 3 - 6 October; these time series were relatively stable across time (Fig. 5.7 A - B). The 2D run released from Breamlea had more sharply defined peaks (Fig. 5.7 C), whilst the 3D run showed an upward trend with increasing variance (Fig. 5.7 D), and was therefore transformed for statistical analyses. All time series were significantly correlated with the otolith transition time series from St Leonards, with otolith data lagging model data by a greater margin for releases from outside Port Phillip Heads (Table 5.3).

Table 5.2 Correlations between mean daily values of physical variables and the time series of settlement estimated from otoliths of *S. punctata* at St Leonards. The unadjusted n for each time series is 45 at zero lag. The maximum value of Pearson's correlation coefficient is given for lags between zero and 3 d.

Physical variable	Effective n	Max r	Lag	Probability
East-west wind vector	26	0.546	1	P<0.005
North-south wind vector	27	- 0.337	3	ns
Wind velocity	19	- 0.241	0	ns
Residual sea-level	17	0.596	1	P<0.01
Actual sea-level	17	0.505	1	P<0.05
Barometric pressure	17	- 0.593	2	P<0.01
Tidal range	15	0.434	1	ns

Instantaneous spatial plots from the first major influx of particles (20 September) showed that particles from both releases penetrated further into the bay in the 3D simulation (Fig. 5.8). Particles tended to penetrate further on the western side of the bay, and in the Breamlea releases most particles were on the western side of the Sands region (Fig. 5.8). Particles that had recently entered the bay extended to about Grassy Point, whilst in the 3D plots a group of particles that had previously entered the bay was concentrated at about the entrance to the Geelong Arm (Fig. 5.8).

Spatial plots of particle concentration integrated over the entire model run show that particles in the 2D runs were concentrated in the lower half of the bay, although, in the

Breamlea release a single particle entered the Geelong Arm. In the 3D runs, particularly in the Breamlea release, particles occurred most often on the western side of the bay from Port Phillip Heads to the entrance of the Geelong Arm (Fig. 5.9). A few particles in the 3D runs extended almost to the Grand Scenic site.

Table 5.3 Correlations between the temporal series of otolith transitions at St Leonards with the time series of particles in the St Leonards model grid 'box'.

Variables correlated	Effective n	r	Lag	Probability
Model seeded from Port Phillip Heads				
2 - Dimensional	15	0.559	3	<0.025
3 - Dimensional	18	0.557	2	<0.01
"	17	0.569	3	<0.01
Model seeded from Breamlea				
2 - Dimensional	29	0.512	1	<0.0025
"	27	0.493	2	<0.005
3 - Dimensional	18	0.452	1	<0.05
"	21	0.481	2	<0.025

5.4 DISCUSSION

Our current knowledge suggests that otolith transitions are related to the arrival of larvae in Port Phillip Bay, rather than arrival at particular sites (Jenkins and May 1994; Jenkins *et al.* 1996). Previous studies have shown that smallest recruits typically have only a few post-transition increments (Jenkins and May 1994). Furthermore, particle entry to Port Phillip Bay predicted by 2D simulation and otolith transition data were significantly correlated at zero lag (Jenkins and Black 1994). Finally, some pre-settlement larvae within the bay have post-transition increments (Jenkins *et al.* 1996). We have hypothesised that the otolith transition may be related to changed conditions of temperature and food supply upon entry to the bay, rather than the conditions at a particular site (Jenkins and Black 1994; Jenkins and May 1994). High frequency sampling in the present study shows that at the St Leonards site, otolith transitions were generally formed within a few days prior to sampling, indicating that the transition is closely related to arrival of larvae to this site, whereas otolith transitions and abundance were decoupled further into the bay, particularly at Grand Scenic. These results support the contention that the otolith transition is formed near the entrance. One caveat is that in the present study, otolith transition data for St Leonards lagged model predictions by one to three days. However, it is not surprising that a time lag occurs before changed conditions in the bay, compared with Bass Strait, becomes visible as changed otolith microstructure.

For the first time we have been able to identify specific climatic and hydrodynamic factors influencing the temporal pattern of ingress of *Sillaginodes punctata* to Port Phillip Bay. As previously postulated (Jenkins and Black 1994), the proximate cause of larval pulsing appears to be fluctuating sea levels in Port Phillip, with the temporal pattern of recruitment positively correlated with residual sea level, that is, increases in sea level within Port Phillip, independent of the tidal cycle, lead to influxes of larvae. Correlation analysis revealed that recruitment was positively related to westerly wind stress and negatively related to barometric pressure. These variables are known to be amongst the most important factors influencing sea level along the Victorian coast. The combined effect of strong westerly winds across Bass Strait and Coriolos forces cause the sea level to increase along the Victorian coast (Black *et al.* 1993). In addition, barometric pressure changes associated with the passage weather systems induce fluctuations in sea level of approximately 1cm per hPa (Black *et al.* 1993). In 1989, ingress of pre-settlement *S. punctata* showed a cycle of approximately 7 -14 d associated with the periodic passage of weather systems (Jenkins and Black 1994). The passage of weather systems often shows deviation from a regular cycle, as was the case in the present study. Thus, apparent periodicity in recruitment data will only occur over periods of a 'stable' weather cycle. A corollary of this is that interannual variation in weather patterns, such as those induced by the el nino southern oscillation, will lead to parallel interannual variation in the number of recruitment events (and also their magnitude and timing).

Causes of temporal variation in recruitment of *S. punctata* to Port Phillip are very similar to those influencing ingress of brachyuran megalopae to the east coast of the United States (Goodrich *et al.* 1989; Little and Epifanio 1991). Periodic peaks in megalopae abundance were related to coastal set-up induced by wind events (Goodrich *et al.* 1989; Little and Epifanio 1991). Little and Epifanio (1991) found that longshore wind events influencing recruitment occurred on an approximate 10 d cycle, similar to that which can occur in the Bass Strait region (Jenkins and Black 1994). Inshore recruitment of fish larvae associated with onshore currents produced by phenomena such as Eckman transport has been widely reported (Parrish *et al.* 1981; Norcross and Shaw 1984; Boehlert and Mundy 1987; Shenker *et al.* 1993; Milicich 1994)
Jenkins and Black (1994) postulated that cyclic changes in sea level in Port Phillip associated with the passage of pressure systems and associated rotating winds was

responsible for the pulsing of particle (and larval) entry to the bay. The lack of influence of larval behaviour on temporal recruitment patterns near Port Phillip Heads should not be surprising considering the strong tidal currents in the area (Black *et al.* 1993).

Climate also appears to strongly influence the pattern of abundance of recruits at sites. The passage of rotating weather systems means that strong westerly winds and low pressure are usually followed by a calm period of high pressure before winds increase from the north and barometric pressure begins to fall. The St Leonards site is exposed to the greatest wave fetch of the sites examined, a relatively sharp drop-off to deep water so that waves break over seagrass beds, and strong tidal currents just offshore. We hypothesise that recruits can only persist at this site during calm conditions; rough conditions would lead to a re-suspension of larvae and further transport by currents. The correlation between the differenced abundance data at Grassy Point and abundance at St Leonards suggests that abundance at this site was also influenced by rough weather. Otolith transitions and the pattern of abundance from high frequency sampling became decoupled further into the bay. Major factors influencing this relationship were the persistence of recruits at sites, and the apparent lag between transition formation (presumably upon entry to the bay) and arrival at the site, particularly at Grand Scenic, where all recruits were derived from the first cohort identified by otolith transitions. The process of re-suspension and transport hypothesised earlier could explain the apparent delay between arrival in the bay and recruitment to more distant sites.

The relative influence of weather conditions and larval supply on the pattern of abundance of recruits at a particular site will probably relate to the degree of exposure of the site. In Swan Bay, which is relatively protected from wave fetch and tidal current, there was a significant correlation between the temporal supply of larvae and the temporal pattern of abundance of small, recently arrived recruits (Hamer and Jenkins, unpublished manuscript). However, the longer term pattern of abundance of recruits was strongly influenced by strong wind events (Hamer and Jenkins, unpublished manuscript).

Although results for 2D and 3D simulations were broadly similar, particles in the 3D simulations showed greater penetration into the bay. Three-dimensional simulations would be expected to be more realistic because they allow for variation on the vertical profile of current strength. The lower recruitment in the Geelong Arm, which has also been recorded in previous sampling (Jenkins *et al.* 1996; chapter 2), is consistent with the model results that show low penetration of particles into the Geelong Arm. The models, however, also predicted that similar numbers of larvae would be present in the

St Leonards and the Grassy Point area, while the abundance data showed much greater recruitment at Grassy Point, also consistent with previous sampling (Jenkins *et al.* 1996, chapter 2). The otolith data show that at the St Leonards site, recruits do not persist beyond a few days, suggesting a high rate of post-settlement mortality or movement. As we have explained above, it seems likely that the high exposure of the St Leonards site means that recruitment in the area will only be possible in calm weather conditions, and accumulation of recruits is unlikely to occur. The successful modelling of recruitment will probably need to incorporate a simulation of mixing at sites due to wave action and currents, as well as a simulation of larval input.

5.5 CONCLUSIONS

This study provides a mechanism for the strong temporal variability in larval ingress of *Sillaginodes punctata* to Port Phillip Bay, and also variability in recruitment to specific sites. Strong westerly winds and low barometric pressure associated with the passage of weather systems produces coastal set-up and a net shoreward transport of larvae. Interannual variation in weather patterns, due to factors such as the el nino southern oscillation, would be expected to produce interannual variation in recruitment of *S. punctata* to Port Phillip. While the general pattern of declining recruitment with distance into Port Phillip Bay is probably related to larval supply, low recruitment at some sites near the entrance to the bay is probably related to the high wave energy and strong tidal currents in the area.

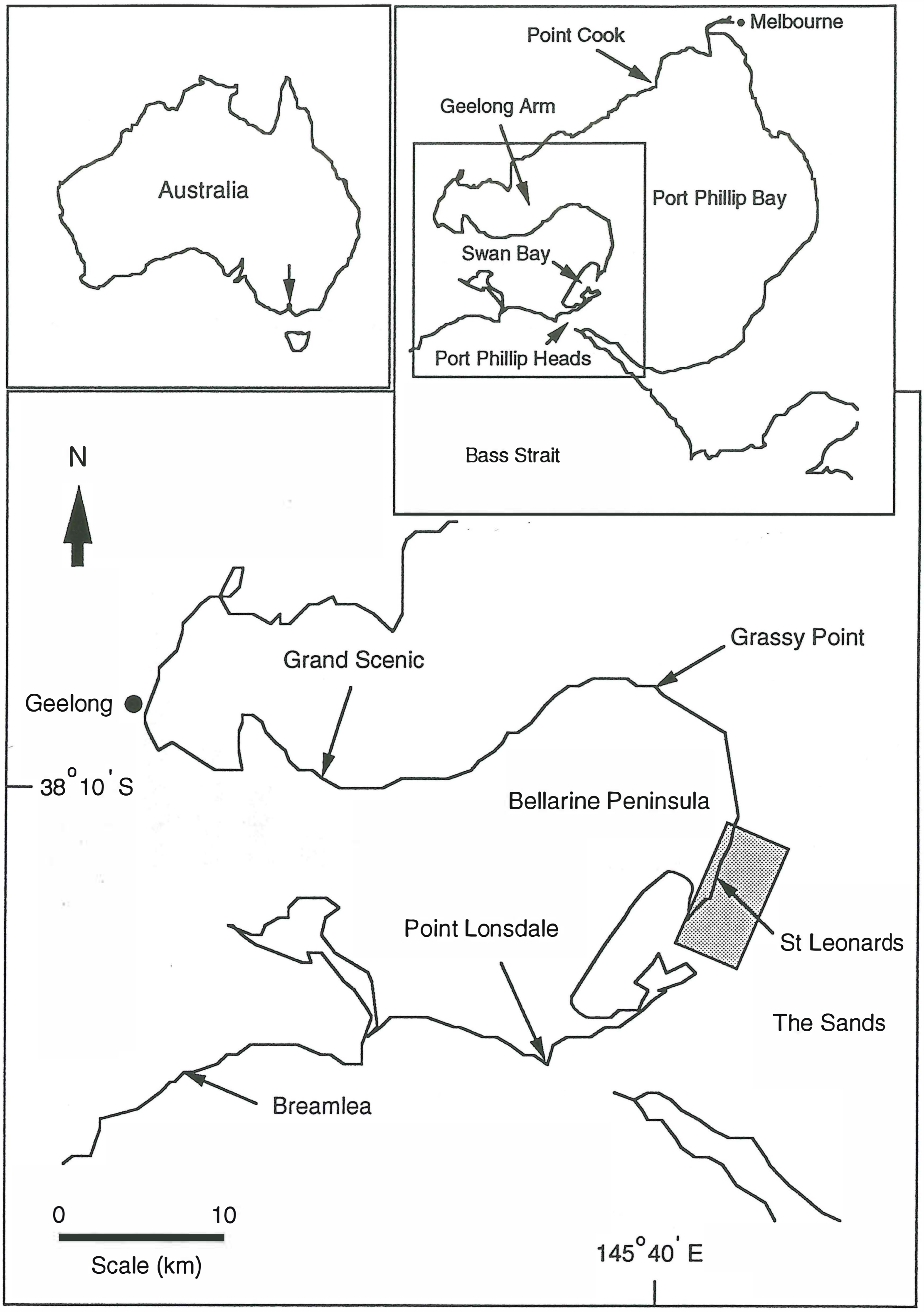

Fig. 5.1 Location of sampling sites around the Bellarine Peninsula region of Port Phillip Bay, Victoria, from which post-larval *Sillaginodes punctata* were collected. Stippled area represents model 'box' where particle numbers were recorded during simulations. Insets: Location of the Bellarine Peninsula in Port Phillip Bay and location of Port Phillip Bay on the Australian coast.

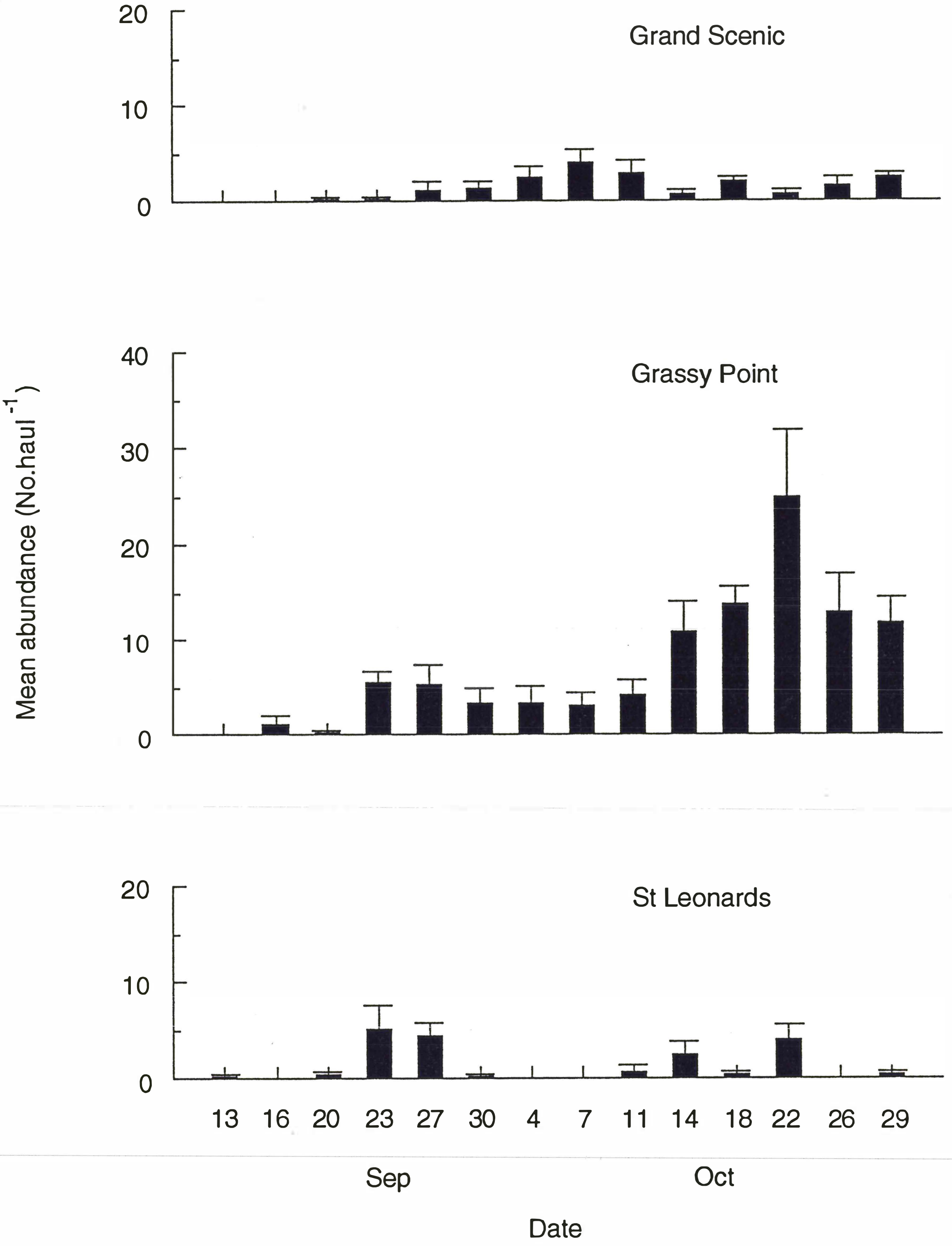

Fig. 5.2 Mean abundance of post-larval *Sillaginodes punctata* collected every 3-4 d at sites around the Bellarine Peninsula. Error Bars are Standard Error.

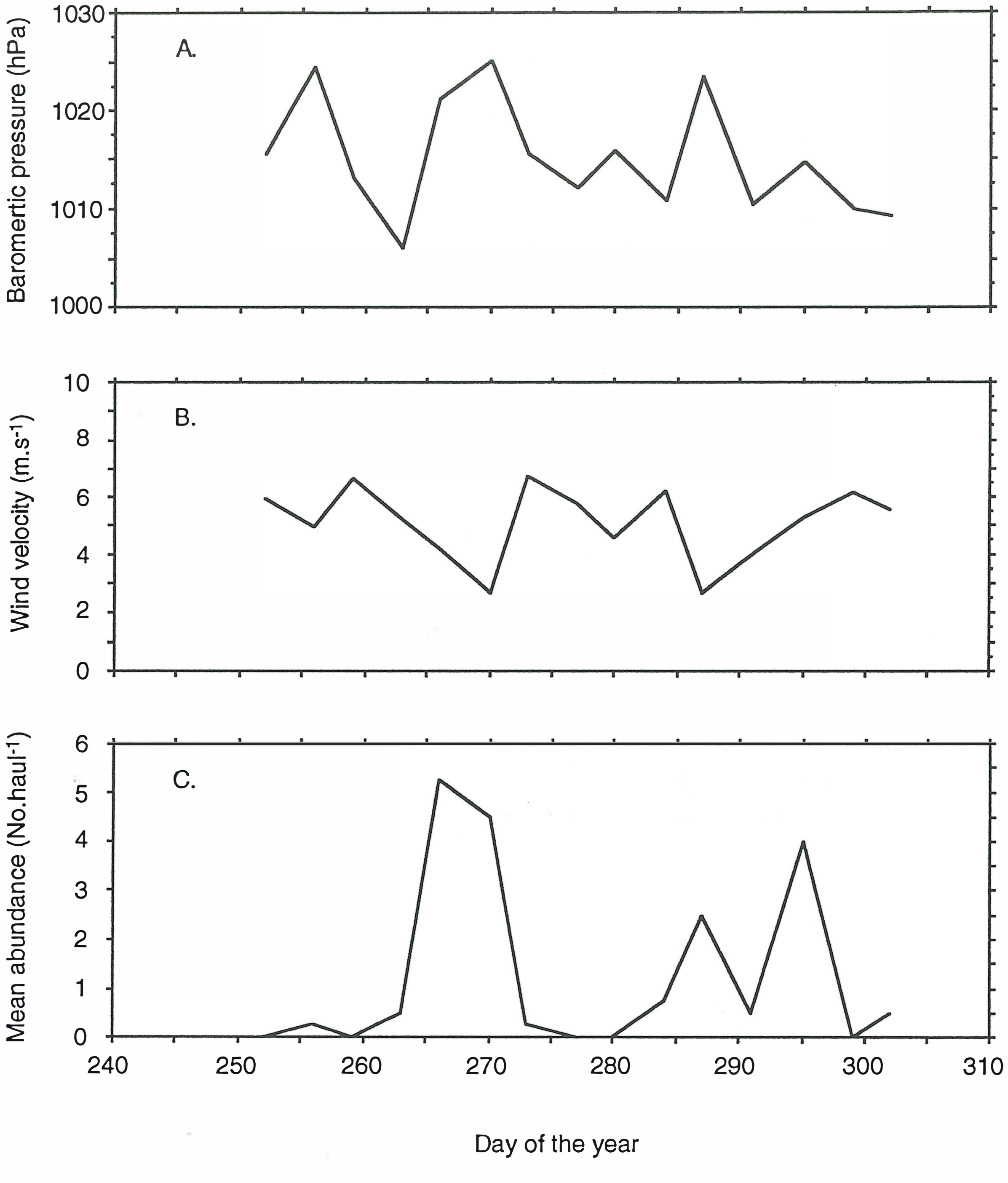

Fig. 5.3 Physical variables that were significantly correlated with abundance of post-larval *Sillaginodes punctata* at the St Leonards site over the settlement period. Values were averaged over the 3-4 d time period prior to each sampling event. A. Barometric pressure measured at 3 h intervals. B. Wind velocity measured at Point Cook at 1 h intervals. C. Mean abundance of post-larval *S. punctata* collected from St Leonards.

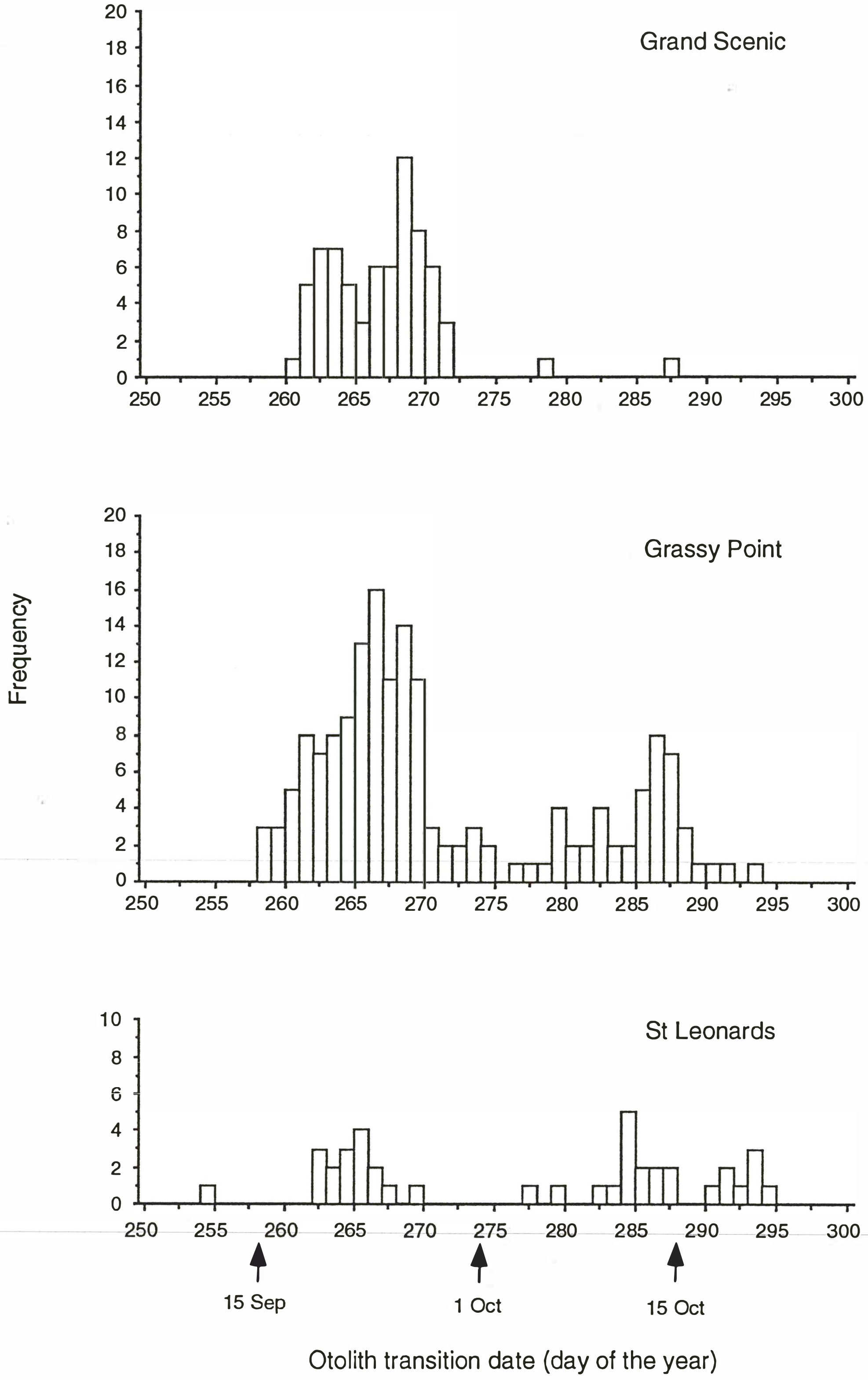

Fig. 5.4 Frequency distribution of otolith transition dates for post-larval *Sillaginodes punctata* collected from three sites around the Bellarine Peninsula pooled over sampling days.

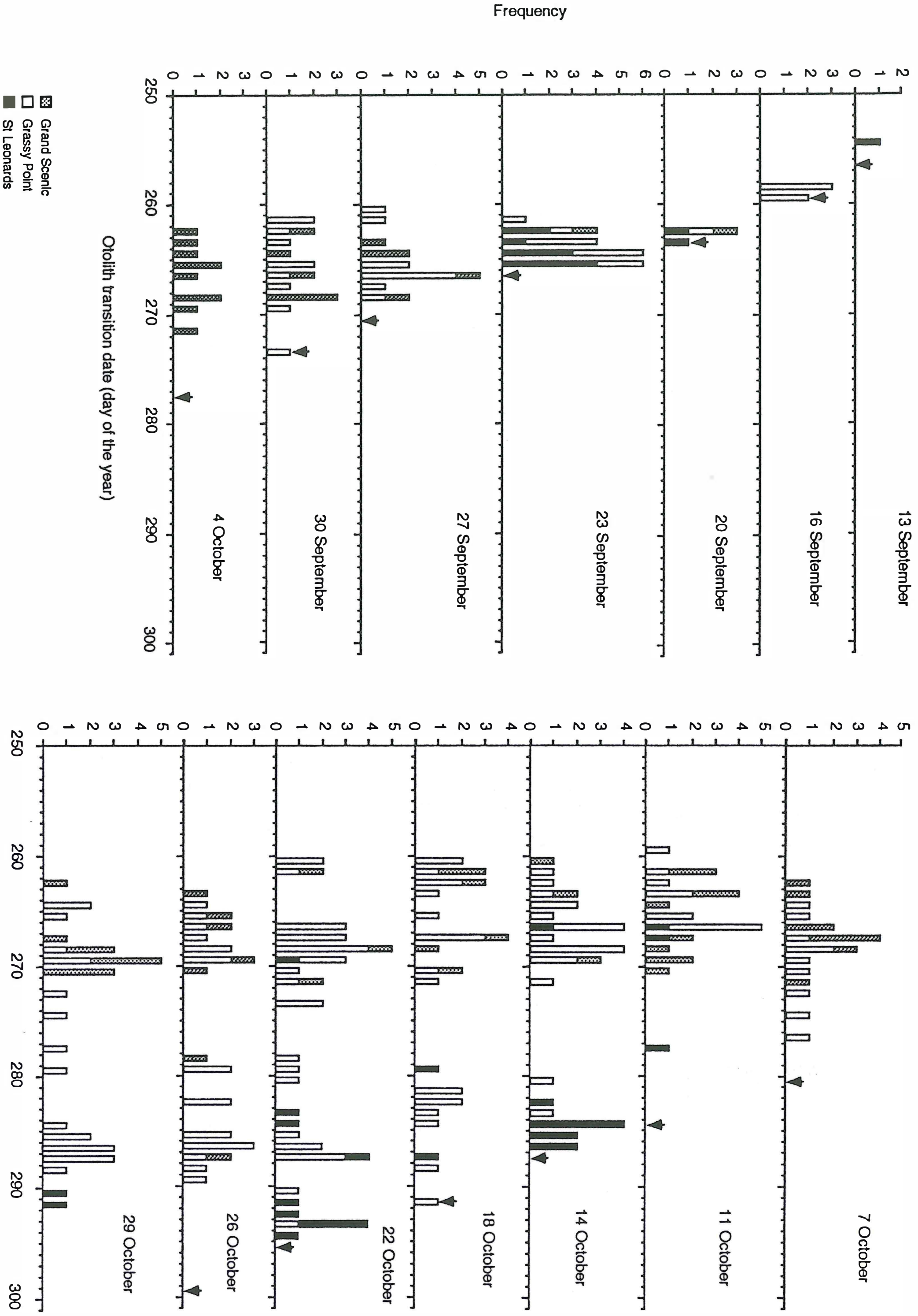

Fig. 5.5 Frequency distribution of otolith transition dates for post-larval *Sillaginodes punctata* collected from three sites around the Bellarine Peninsula on individual sampling days.

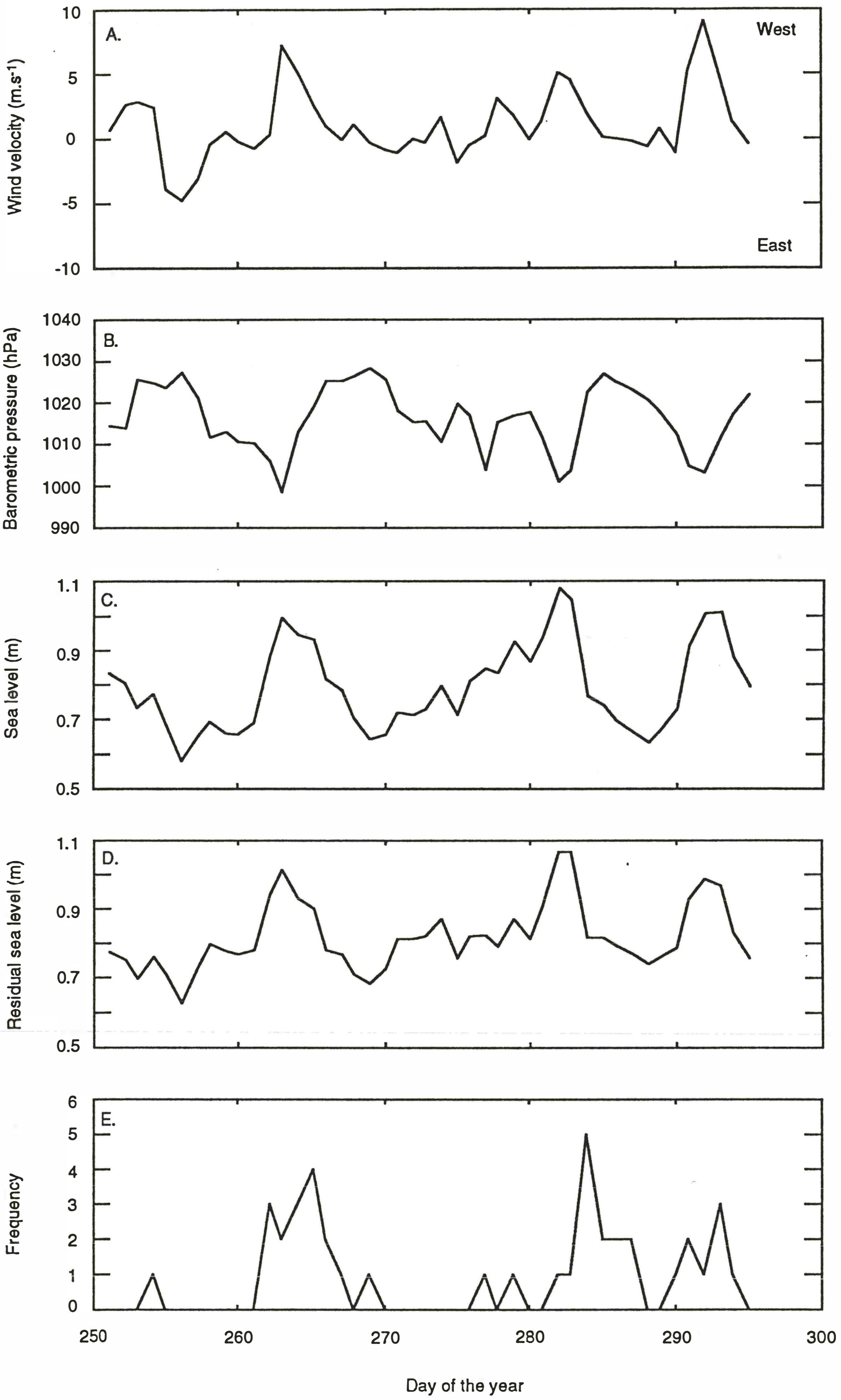

Fig. 5.6 Mean daily values of physical variables that were significantly correlated with abundance of post-larval *Sillaginodes punctata* at the St Leonards site over the settlement period. A. Magnitude of east-west wind vectors measured at Point Cook at 1 h intervals. B. Barometric pressure measured at 3 h intervals. C. Sea level at Point Lonsdale measured at 1 h intervals. D. Residual sea level (with tidal component extracted) at Point Lonsdale measured at 3 h intervals. E. Frequency distribution of otolith transition dates for post-larval *Sillaginodes punctata* collected from St Leonards.

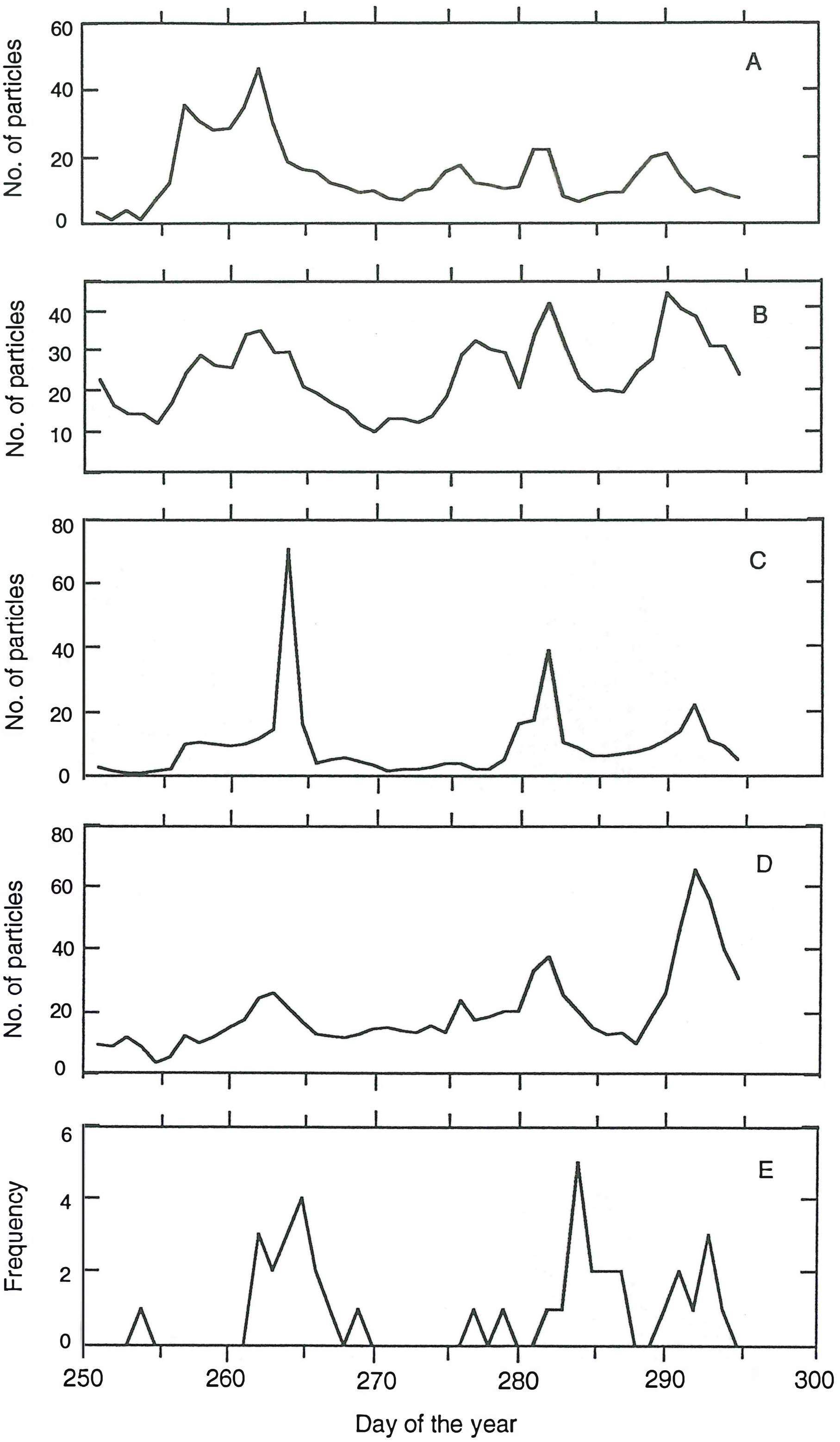

Fig. 5.7 Time series of abundance of particles in the St Leonards model grid 'box'. A. Release outside Port Phillip Heads - two dimensional simulation. B. Release outside Port Phillip Heads - three dimensional simulation. C. Release from Breamlea - two dimensional simulation. D. Release from Breamlea - three dimensional simulation. E. Frequency distribution of otolith transitions for *Sillaginodes punctata* recruits at St Leonards

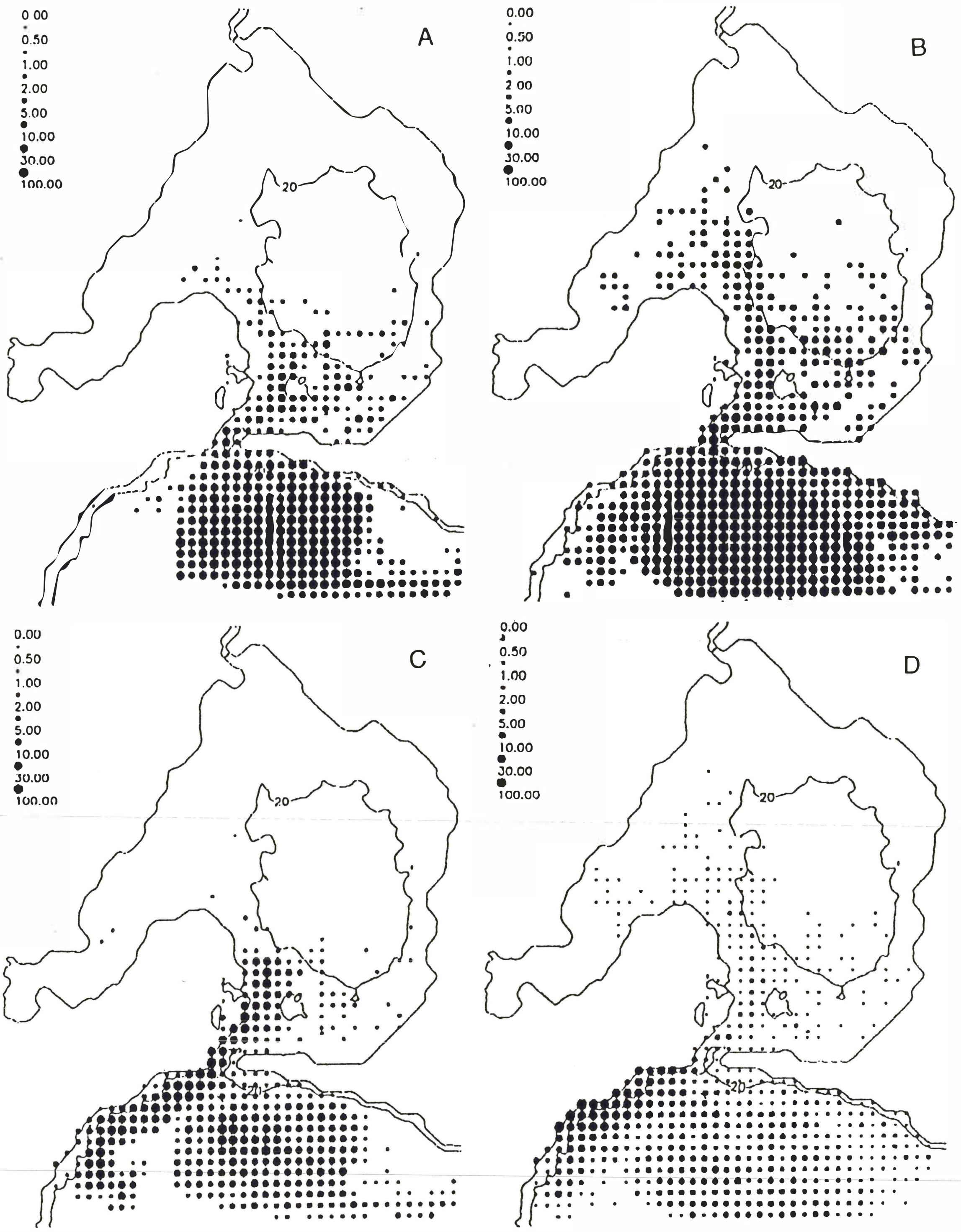

Fig. 5.8 The instantaneous distribution of particles in Port Phillip Bay at 0800 h on 22 September, 1993. A. Release outside Port Phillip Heads - two dimensional simulation. B. Release outside Port Phillip Heads - three dimensional simulation. C. Release from Breamlea - two dimensional simulation. D. Release from Breamlea - three dimensional simulation.

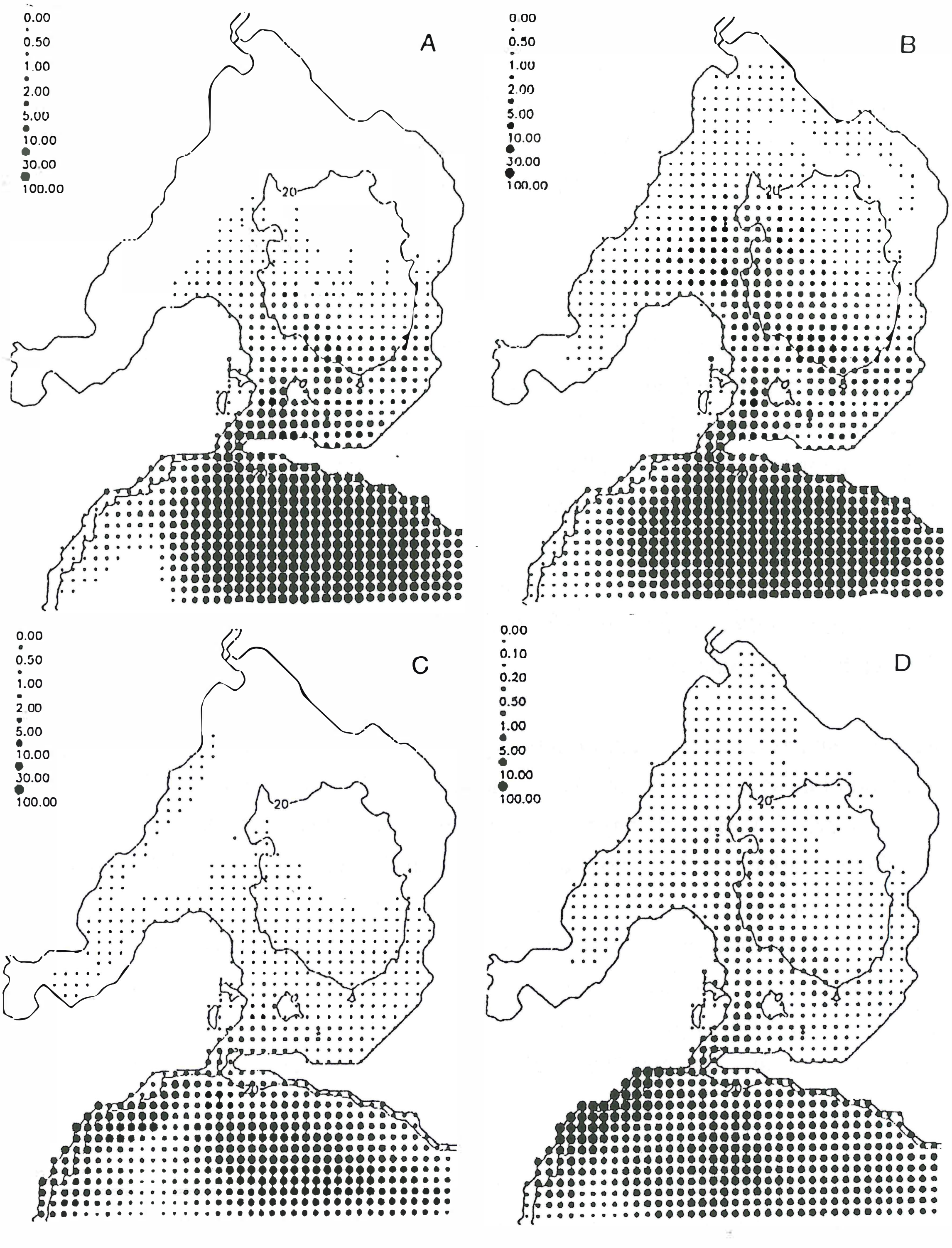

Fig. 5.9 The integrated distribution of particles in Port Phillip Bay over the entire model run recorded at 1200 h on 31 October, 1993. A. Release outside Port Phillip Heads - two dimensional simulation. B. Release outside Port Phillip Heads - three dimensional simulation. C. Release from Breamlea - two dimensional simulation. D. Release from Breamlea - three dimensional simulation.

CHAPTER 6

THE RELATIVE CONTRIBUTIONS OF LOCATION AND HABITAT STRUCTURE TO THE DISTRIBUTION OF POST-SETTLEMENT KING GEORGE WHITING, *SILLAGINODES PUNCTATA*, IN PORT PHILLIP BAY

6.1 INTRODUCTION

The relative importance of the various factors that may determine the distribution and abundance of benthic animals is a contentious issue. Earlier studies tended to assume that there was an excess of pre-settlement larvae and that populations were limited by a resource required by adults, usually food or space. However, recent research has increasingly demonstrated the importance of varying recruitment of young in determining abundance and composition in these communities (Doherty and Williams 1988; Roughgarden *et al.* 1988; Doherty and Fowler 1994). The importance of 'supply side ecology' is reflected in the proliferation of research in this area (Underwood and Fairweather 1989; Sale 1990).

Recruitment has five major components: input of propagules into a given water body; transport of those propagules; planktonic mortality; settlement; and post-settlement growth/survival. Variability in these components will eventually translate into recruitment variability. Some progress in understanding has been made in the areas of input of propagules and post-settlement growth and survival; settlement has been well studied for some invertebrate groups in the laboratory but field data are limited; and larval transport and mortality is probably the least understood phase in the recruitment process. Most of our knowledge has come from specific systems, such as coral reef fishes (Doherty and Williams 1988) and rocky reef invertebrates (Roughgarden *et al.* 1988).

Important factors influencing recruitment depend greatly on the system and scale examined. A case in point is the recruitment of demersal fishes. On coral reefs the influence of habitat selection appears relatively unimportant, except at a few restricted scales, compared to factors influencing the distribution of pre-settlement larvae (Doherty and Williams 1988; Sale 1991). Recruitment of fish to temperate seagrass can show strong responses to habitat structure at local scales such as individual beds (Orth *et al.* 1984; Bell and Westoby 1986b), but at larger scales, at least in one system studied, recruitment again appears to be more influenced by the availability of planktonic larvae (Bell and Westoby 1986c; Bell *et al.* 1988). Recruitment of temperate reef fish, however, shows correlations with habitat structure over larger scales, and a greater range of scales, than coral reef or temperate seagrass fishes, probably due to the dynamic and highly variable nature of temperate algal distributions at a variety of scales (Jones 1984c; Connell and Jones 1991; Levin 1993; Carr 1994). At the largest scales, however, recruitment variation in temperate reef fish is again dominated by factors influencing the distribution of larvae (Cowen 1985; Ebeling and Hixon 1991). Because habitat structure can influence recruitment at a variety of scales, variation in recruitment attributable to pre-settlement factors is best studied using artificial habitats where structure and complexity are controlled (Bell *et al.* 1988)

The role of variation in larval supply has been mostly inferred from the temporal and spatial distribution of recruits, few studies have directly related larval distributions to recruitment patterns in space or time. Spatial and temporal distribution of barnacle recruits has been shown to be related to the distribution of larvae (Grosberg 1982; Gaines *et al.* 1985; Minchinton and Scheibling 1991). A close temporal relationship between larval supply and recruit abundances has been found for a colonial ascidian with short-lived larvae (Hurlbut 1992). The development of light traps for sampling pre-settlement coral reef fishes (Doherty 1987) has led to studies linking temporal variability in larval supply with recruitment of reef fish (Milicich *et al.* 1992; Meekan *et al.* 1993; Doherty *et al.* 1994). Little information is available relating larval supply to recruitment of temperate demersal fishes. Breitberg (1991), however, showed that the aggregated distribution of pre-settlement larvae of a temperate goby was reflected in post-settlement distributions. Our own recent research has found a significant temporal link between larval supply and recruitment of a temperate demersal fish associated with macrophyte beds, the King George whiting, *Sillaginodes punctata* (Hamer & Jenkins, unpublished manuscript).

The King George whiting, *Sillaginodes punctata*, is an important commercial and recreational fish species in temperate Australia (Hutchins and Swainston 1986). Juveniles of this species are associated with shallow macrophyte habitats of sheltered bays and inlets (Jones 1980). Larvae of *S. punctata* enter Port Phillip Bay, Victoria (Fig. 6.1), at a size of approximately 15 to 20 mm, from August to November each year (Jenkins and May 1994). The larval life of *S. punctata* entering Port Phillip is long and variable, ranging from 100 to 170 days (Jenkins and May 1994; Jenkins *et al.* 1996). Entry of larvae to Port Phillip is largely governed by low frequency hydrodynamics (Jenkins and Black 1994).

Recruitment of *Sillaginodes punctata* to seagrass beds in Port Phillip over a spatial scale of 10's of kilometres has been found to be unrelated to seagrass biomass (Jenkins *et al.*

1996). However, a negative correlation between recruitment and distance from the bay entrance led to the suggestion that recruitment to the inner bay is limited by larval supply (Jenkins *et al.* 1996). This general pattern of decreasing recruitment with distance from the entrance was only disrupted by low recruitment at some sites close to the entrance (Jenkins *et al.* 1996). We hypothesised from these results that, at a scale of 10's of kilometres, larval supply, rather than habitat structure, is the overriding influence on recruitment. The present study aims to investigate this hypothesis by (1) the deployment of artificial seagrass beds to examine broad-scale variation in recruitment under conditions of constant habitat structure; and (2) examine the linkage between abundances of pre-settlement larvae and recruits to seagrass beds at a scale of 10's of kilometres.

6.2 METHODS

6.2.1 Study area

Port Phillip Bay is a large, semi-enclosed, predominantly tidal embayment linked to the ocean of Bass Strait by a narrow entrance (Fig. 6.1). The hydrodynamics are characterised by an entrance region, where fast (3 $m.s^{-1}$) ebb and flood jets dominate the circulation; a large flood-tidal delta, known as the Sands region, where strong currents occur in the major channels; and an "inner" zone, where tidal currents are weak (Black *et al.* 1993). On the western side of Port Phillip Bay, tidal currents drop to below 10 $cm.s^{-1}$ at about the entrance to the Geelong arm. Tides are semidiurnal and the range inside the bay is less than one metre.

Seagrass around the Bellarine Peninsula region of Port Phillip Bay consists generally of narrow (20 m wide) bands of the subtidal seagrass *Heterozostera tasmanica* running parallel to the shoreline. Towards Corio Bay within the Geelong arm, however, seagrass beds become more widespread due to protection from the predominant south-westerly wind experienced in the region. This pattern reflects the distribution of sediment grain-size, which becomes progressively finer from the sands region around the Bellarine Peninsula and into the Geelong arm (Anon. 1973). Salinity in the sampling area is essentially marine (Longmore *et al.* 1990).

6.2.2 Sampling sites

Sampling of seagrass beds and offshore plankton in 1994 was conducted at nine sites around a 50 km section of the Bellarine Peninsula (Fig. 6.1). *Heterozostera* beds averaging approximately 0.5 m below MLWS were sampled. At five of these sites, Edwards Point, Grassy Point, Spray Farm, Clifton Springs and Point Henry, we also deployed 5 replicate artificial seagrass units (ASUs). In 1991 at Edwards Point and

Grassy Point we conducted a pilot study comparing abundances of *Sillaginodes punctata* post-larvae on artificial seagrass attached to wire mesh, wire mesh only, and bare substrate.

6.2.3 Artificial seagrass

Artificial seagrass units (ASUs) were constructed from 2m x 1m galvanised steel mesh. Meshes were 0.1 m x 0.1 m, providing 200 cross-points for attachment of artificial seagrass. Green polypropylene ribbon of 0.5 cm width was used to simulate *Heterozostera*. Eight, 90 cm lengths of ribbon were tied to each cross point, forming individual bunches with 16 leaves of approximately 40 cm length. Thus the total density of leaves was 1600 m^{-2}. Meshes without leaves were used to control for possible habitat provided by the mesh.

6.2.4 Sampling methods

Post-settlement *Sillaginodes punctata* in seagrass beds were sampled with a seine net of 10 metres in length, a 3 metre drop, and a mesh of approximately 1 mm^2. Two 10 m ropes were attached to each end of the seine. Hauls were made by two people walking out to the appropriate depth, one person walking 10 m further, setting the net parallel to shore and returning to the position of the second person where the net was then hauled into a bucket. The net was then carried back to shore where post-larvae and juveniles were sorted, anaesthetised in benzocaine, and preserved in 95% ethanol. A beach seine net is an efficient sampler of post-settlement *S. punctata* in seagrass habitat (Connolly 1994a).

Sampling of ASUs was undertaken with a seine net made of the same material as the net described above, however in this case the net was 6 m in length, 2 m drop and a cod end of 0.5 m depth was sewn into the middle of the net. Sampling consisted of encirclement of the ASU (or equivalent area of mesh or bare sand) and retrieval to a bucket where fish were extracted from the net, anaesthetised in benzocaine, and preserved in 95% ethanol.

Pre-settlement larvae were sampled with a plankton net consisting of a 0.64 m^2 opening square frame with a 4 m long, 1 mm mesh net attached. The net was deployed at the surface in approximately 2 to 4 m of water several hundred metres offshore from the seagrass bed at each site. The net was towed for approximately 20 minutes at a speed of about 1 m s^{-1}. A calibrated General Oceanics flowmeter was used to determine the volume filtered. Samples were strained on a 1mm sieve, preserved in 95% ethanol, and sorted in the laboratory.

6.2.3 Sampling procedure

The pilot experiment using ASUs was conducted at two locations, Edwards Point and Grassy Point. ASUs and mesh controls were deployed on September 26, 1991. Five replicate ASUs, mesh controls and areas of bare substrate, providing three treatments for the habitat factor, were regularly interspersed in a line extending approximately 400 m along a sand-bank running parallel to shore. This sand bank was immediately offshore from the seagrass bed normally sampled at each site in the field program, in a depth of approximately 0.75 m below MLWS. Equivalent areas of habitat treatments were sampled on October 28, 1991.

On September 15, 1994, five replicate ASUs, the same as used in the pilot study, were deployed at each of the five sites on unvegetated sand patches, no less than three metres from the nearest seagrass. Sampling of ASUs was interspersed with the sampling of an equivalent area of natural seagrass. Sampling was conducted on 29 September, 12 and 27 October, and 10 November, over an approximate 5 h period encompassing low tide.

For the comparison of pre- and post-settlement abundances, two replicate hauls, haphazardly placed and non-overlapping, were taken at each of the nine sites while concurrently a plankton sample was collected offshore. Sampling was undertaken on 8 and 30 September, 13 and 22 October, and 4 and 11 November. Sampling was conducted over a 5 h period encompassing low tide.

6.2.4 Seagrass structure

Seagrass from the five ASU sampling sites was sampled on November 12, 1994. A 25 x 25 cm quadrat was used to take six, haphazardly placed, replicate samples at each site. Scissors were used to cut the stems at the sediment interface within the quadrat. Samples were placed on ice for transport to the laboratory and frozen for later analysis. Variables measured were number of stems per quadrat, average length of a randomly selected subsample of 10 plants per quadrat, and biomass determined after drying for 2 days at 60^{o}C.

6.2.5 Data analysis

Repeated measures analysis of variance with time as a random factor and habitat (ASU, mesh, bare) as a fixed factor was used to analyse the pilot experiment. In the main experiment, abundances in natural and artificial seagrass were compared using repeated measures analysis of variance with time as a random factor and habitat (natural or artificial) as a fixed factor. Correlation analysis was used to relate pre-settlement and post-settlement abundances, and post-settlement abundances with habitat structure.

6.3 RESULTS

The pilot study revealed a significant preference for artificial seagrass relative to bare mesh and sand habitats (Fig. 6.2). A low level of recruitment occurred at Edwards Point and recruits were only found on artificial seagrass (Fig. 6.2). Recruitment at Grassy Point was higher and although most recruits were on artificial seagrass, low numbers were recorded on the other habitat treatments. Repeated measures analysis of variance of the Grassy Point data showed that habitat differences were significant, as was the variation amongst dates (Table 6.1).

Table 6.1 Repeated measures analysis of variance comparing three habitat treatments over three dates at the Grassy Point site. *<0.05, **<0.001, ns=not significant.

Between subjects			
Source	DF	MS	F
Habitat	2	1.465	8.042*
Error	12	0.182	
Within subjects			
date	2	0.959	6.546*
date*habitat	4	0.121	0.823 ns
Error	24	0.146	

Abundances of *S. punctata* recruits showed a strong pattern related to site, particularly on the first three sampling dates, where highest numbers occurred at Grassy Point (Fig. 6.3). The relative abundances in artificial and natural seagrass showed no strong trend, although abundances were consistently higher in artificial relative to natural seagrass at Spray Farm and Point Henry (Fig. 6.3). The overall repeated measures analysis showed significant effects of site and habitat, and their interaction; and within subjects a significant effect of date and the interaction between date and site (Table 6.2). When variance components are calculated averaged across dates, the majority of the variance is attributable to the site main effect (Table 6.2).

Table 6.2 Repeated measures analysis of variance comparing two habitat treatments at five sites over four dates. *<0.05, **<0.001, ns=not significant.

Source	DF	MS	F	% Variance
Between subjects				
Site	4	13.812	34.470**	77.6
Habitat	1	3.026	7.551*	6.1
Site*habitat	4	1.228	3.064 *	9.5
Error	30	0.401		6.8
Within subjects				
Date	3	2.090	6.961**	
Date*site	12	0.596	1.986*	
Date*habitat	3	0.547	1.821 ns	
Date*site*habitat	12	0.189	0.628 ns	
Error	90	0.300		

The overall analysis was subdivided to investigate the basis of the site by habitat interaction. Both natural and artificial seagrass, when analysed individually, showed a highly significant effect of site, with site contributing 83% of the variance in natural seagrass and marginally lower at 80% for artificial seagrass (Table 6.3). When sites were analysed individually, significant differences between habitats were found at Spray Farm and Point Henry (Table 6.4). The influence of habitat structure was tested by hypothesising that the habitat by site interaction is a function of the characteristics of natural seagrass at each site. To test this hypothesis an unevenly spaced (dependent on natural seagrass characteristics) linear contrast was fitted to the interaction term. Intercorrelation was found amongst seagrass biomass, density and stem length, while total plant length was relatively independent (Fig. 6.4). We chose density and total plant length as our variables for analysis. Plant density did not have a significant effect (P=0.141) but total plant length did have a significant effect (P=0.001) on abundance.

Table 6.3 Repeated measures analysis of variance comparing abundances of *S. punctata* across five sites separately for artificial and natural seagrass habitats. *<0.05, **<0.001, ns=not significant.

Between subjects		Artificial		
Source	DF	MS	F	% variance
Site	4	6.270	16.696**	80
Error	15	0.376		20
Within subjects				
Date	3	1.718	5.701 *	
Date*site	12	0.485	1.608 ns	
Error	45	0.301		

Between subjects		Natural		
Source	DF	MS	F	% variance
Site	4	8.769	20.593**	83
Error	15	0.426		17
Within subjects				
Date	4	0.919	3.070*	
Date*site	15	0.300	1.004 ns	
Error	45	0.299		

The major variation in abundance in the experiment was related to site, independent of seagrass structure. A possible factor in site differences was larval supply. We correlated the abundance of recruits at nine sites around the Bellarine Peninsula with numbers of larvae collected offshore. The results showed some degree of consistency with the larval supply hypothesis with highest abundances at Grassy Point and Point Richards, declining into the Geelong Arm. A major exception, however, was the Edwards Point site, where larval abundances were relatively high but recruitment was low (Fig. 6.5). Larval abundances were not significantly correlated with recruit abundances (r=0.52, P=0.153) at the nine sites sampled in this study.

Table 6.4 Repeated measures analysis of variance comparing abundances of *S. punctata* in two habitat treatments for individual sampling sites. *<0.05, **<0.001, ns=not significant.

Between subjects		Edwards Point		Grassy point	
Source	DF	MS	F	MS	F
Habitat	1	0.010	0.028 ns	0.122	0.180 ns
Error	6	0.364		0.676	
Within subjects					
Date	3	0.628	2.854 ns	0.694	2.115 ns
Date*habitat	3	0.130	0.593 ns	0.262	0.799 ns
Error	18	0.220		0.328	

Between subjects		Spray Farm		Clifton	
Source	DF	MS	F	MS	F
Habitat	1	3.608	7.975*	0.193	0.517 ns
Error	6	0.452		0.373	
Within subjects					
Date	3	0.586	1.631 ns	0.672	2.451 ns
Date*habitat	3	0.036	0.101 ns	0.254	0.924 ns
Error	18	0.360		0.274	

Between subjects		Point Henry	
Source	DF	MS	F
Habitat	1	4.003	28.976*
Error	6	0.138	
Within subjects			
Date	3	1.894	5.936*
Date*habitat	3	0.618	1.936 ns
Error	18	0.319	

6.4 DISCUSSION

The results of this study suggest that most of the variation in recruitment to seagrass beds at a broad (10's of kilometres) scale is not attributable to characteristics of seagrass structure. The pattern of recruitment found shows interannual consistency, with low recruitment close to the entrance of Port Phillip, high recruitment near the entrance to the Geelong Arm, and declining recruitment within the Geelong Arm (Jenkins *et al.* 1996; chapter 2,5). This suggests that there is interannual consistency in the underlying mechanisms producing recruitment patterns. The major environmental gradients influencing the coastline under study are the strong tidal currents near Port Phillip Heads that gradually decline with distance into the bay, and greater exposure of seagrass beds to wave action and tidal currents near Port Phillip Heads (Black *et al.* 1993).

Larval supply is likely to have a significant influence on recruitment of King George whiting. Hamer and Jenkins (ms) have found a significant correlation between larval supply and recruitment in Swan Bay, a small bay adjacent to Port Phillip. Jenkins *et al.* (1996) found a significant negative correlation between recruitment and distance from the entrance to Port Phillip Bay which they suggested was likely to be related to larval supply. The results of the present study, however, suggest that larval supply is not driving recruitment levels at all sites. We have previously identified the Edwards Point area as a site with significant pulses of recruitment but with rapid post-settlement movement or mortality (Chapter 5). The mechanism for this movement or mortality is unknown, however, a correlation between abundance of recruits at this site and calm weather conditions suggests that physical disturbance due to wind and currents may be a major factor (Chapter 5). Movement of juveniles a month or two after settlement tends to be further into the bay, with no appearance of juveniles in the Edwards Point area, suggesting that conditions are also unfavourable for older juveniles (Jenkins *et al.* 1996).

Bell and co-workers, experimenting with ASUs on the east coast of Australia, also found broad-scale variation in juvenile fish numbers in seagrass beds not associated with habitat structure (Bell *et al.* 1988). Bell and Westoby (1986c) hypothesised that broad-scale variation would be mainly driven by patchy larval supply and that larvae would "settle and stay", seeking out areas of higher habitat complexity within the bed. This 'indiscriminate settlement' hypothesis was later modified when large-scale trends in abundance of some recruits were detected and were related to distance from the entrance; a trend that was particularly noticeable for species known to spawn at sea or near the mouth of the estuary (Bell *et al.* 1988). Thus, a limitation of supply of pelagic larvae to the upper estuary was implicated. A similar process may be occurring in the case of King George whiting recruitment. While larval supply is certainly "patchy' in a temporal sense (Hamer and Jenkins, ms), it may be quite predictable spatially, given that larvae are carried into the bay by tidal currents that are relatively stable over time.

Our results for King George whiting are not consistent with the hypotheses of Bell *et al.* (1988) in two areas. Firstly, whilst limited larval supply may be important in some areas, such as within the Geelong Arm, recruitment to Edwards Point area is apparently more influenced by post-settlement factors. Secondly, there is post-settlement migration of many recruits within a month or two after settlement (Jenkins *et al.* 1996), so that the 'stay' after settlement may be only short-term. The results of Sogard(1989) also suggest that juvenile fish associated with seagrass beds may be relatively mobile, migrating over expanses of unvegetated habitat between seagrass beds.

Some behavioural characteristics of King George whiting recruits may contribute to the patterns we have found. Post-settlement individuals tend to occur either above the seagrass, or within, but towards the tips, of the seagrass blades (Connolly 1994d), and often form small schools (personal observation). Although in the area we studied individuals preferred seagrass over unvegetated areas, our experiments suggest that the preference is for sparse rather than dense seagrass. This observation is at odds with the usual observation that post-settlement fishes in seagrass beds select more complex areas of the habitat (Bell and Westoby 1986a; Bell and Pollard 1989; Orth *et al.* 1994). The behavioural characteristics of King George whiting described here may reflect the fact that the primary attraction of seagrass for this species is probably food supply rather than protection from predators (Connolly 1994b; Connolly 1994d). The distribution of individuals relative to seagrass, and preference for sparser seagrass, would expose this species to the effects of physical disturbance from waves and currents to a greater degree than species that prefer denser seagrass and for which preferred habitat is on the sediment at the base of the seagrass shoots.

6.5 CONCLUSIONS

Broad-scale recruitment of *Sillaginodes punctata* was predominantly related to the location of the site, although a minor influence of habitat structure, whereby recruitment was negatively related to seagrass plant length, was also evident. Factors determining recruitment to a site appear to be variable, with both location of the bed relative to tidal currents carrying larvae, and disturbance of the seagrass bed by wave and current action, likely to be important.

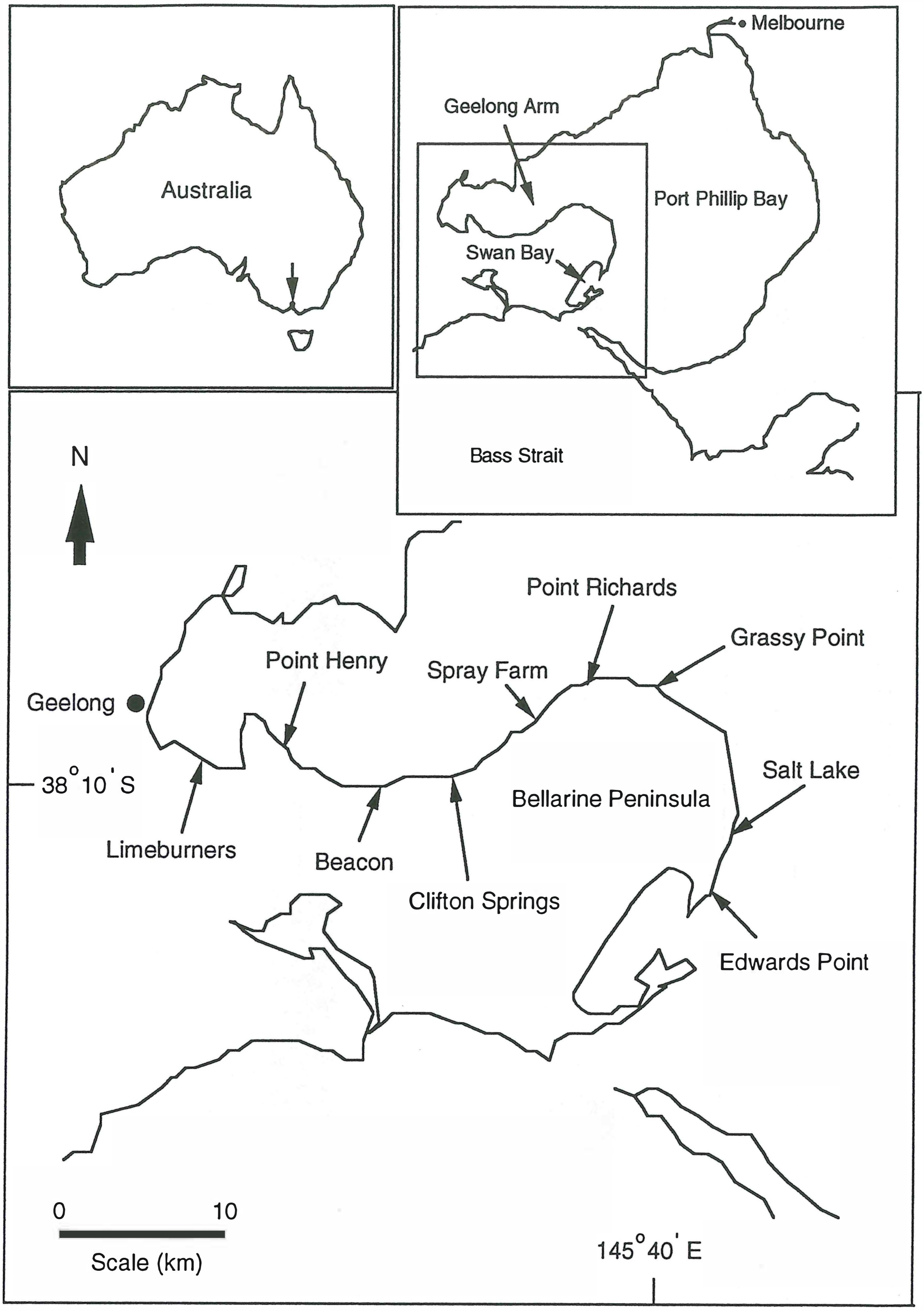

Fig. 6.1 Location of sampling sites around the Bellarine Peninsula region of Port Phillip Bay, Victoria. Insets: Location of the Bellarine Peninsula in Port Phillip Bay and location of Port Phillip Bay on the Australian coast.

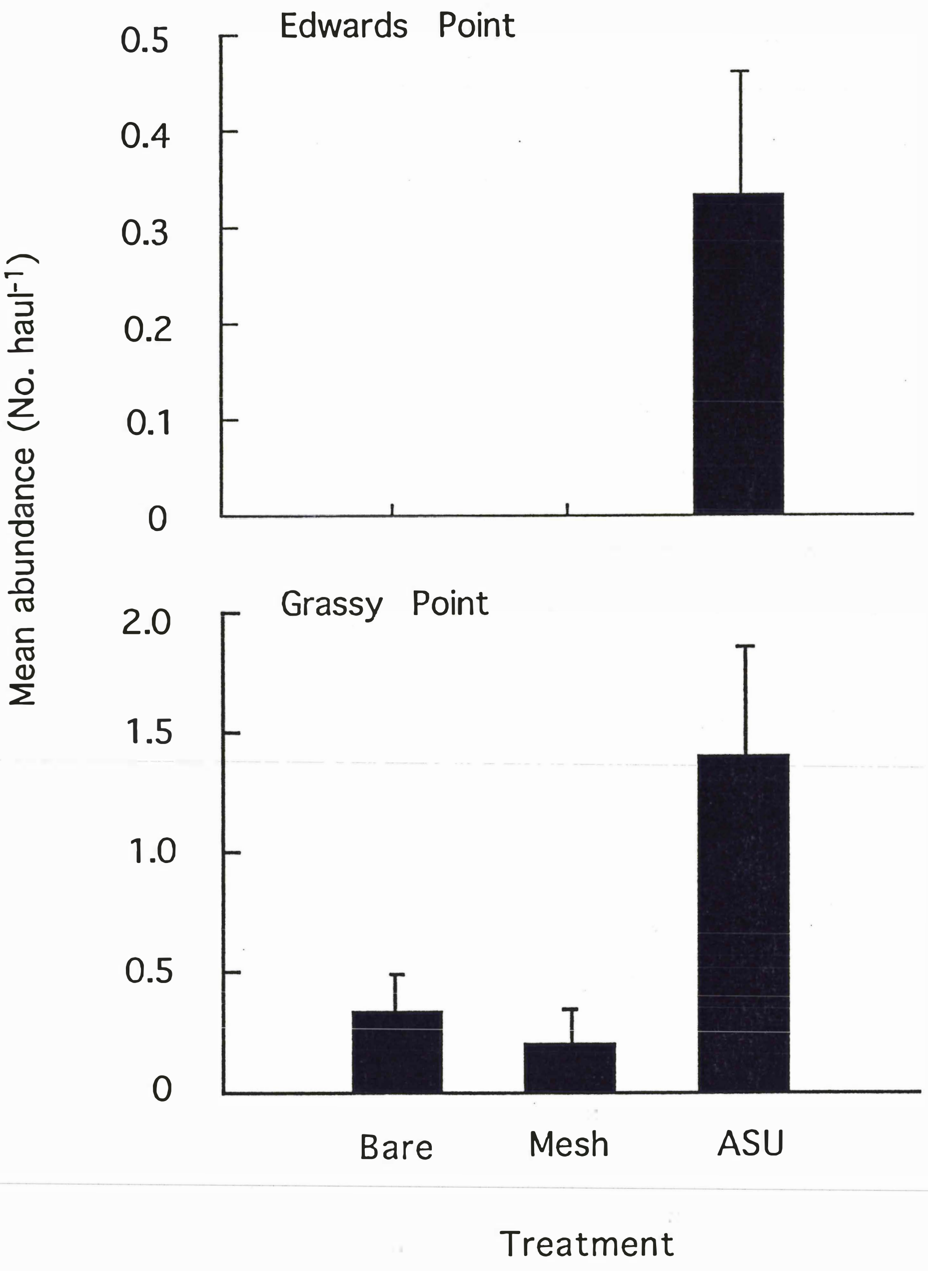

Fig. 6.2 Mean abundance of post-settlement *Sillaginodes punctata* in artificial seagrass, mesh and unvegetated sand habitats at Edwards Point and Grassy Point. Error bars are standard error.

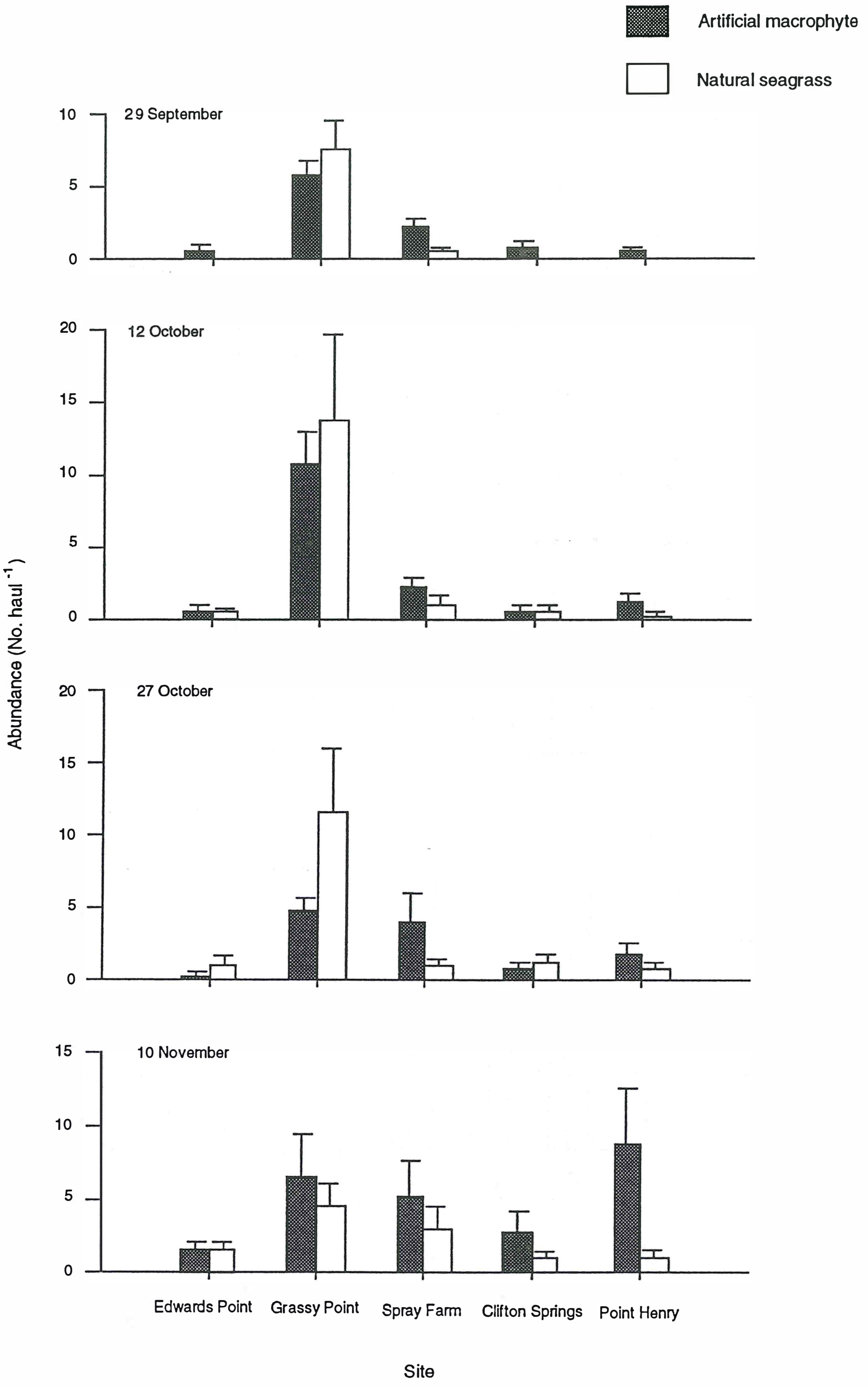

Fig. 6.3 Mean abundance of *Sillaginodes punctata* in artificial and natural seagrass at five sites around the Bellarine Peninsula. Error bars are standard error.

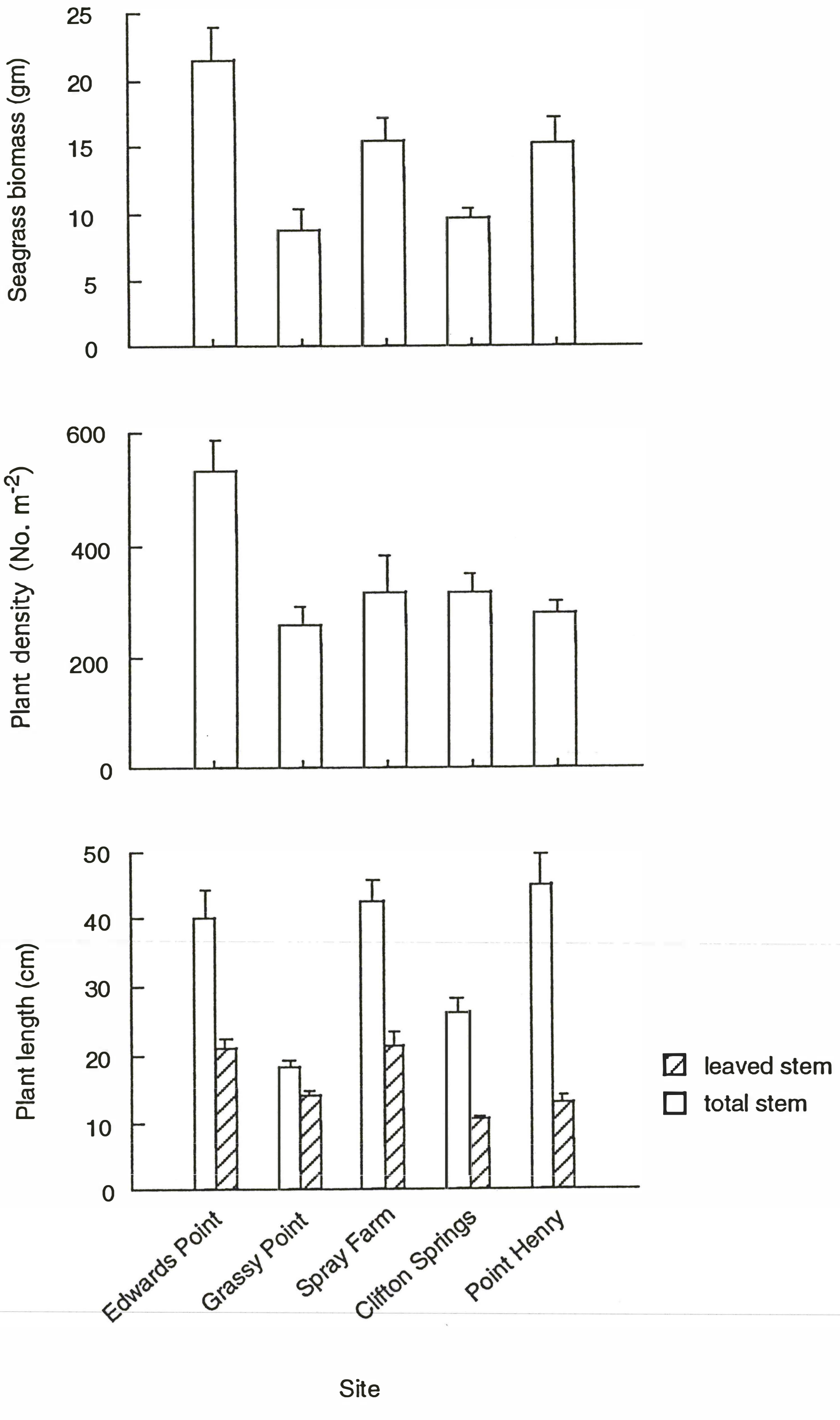

Fig. 6.4 Characteristics of natural seagrass at five sites around the Bellarine Peninsula. Error bars are standard error.

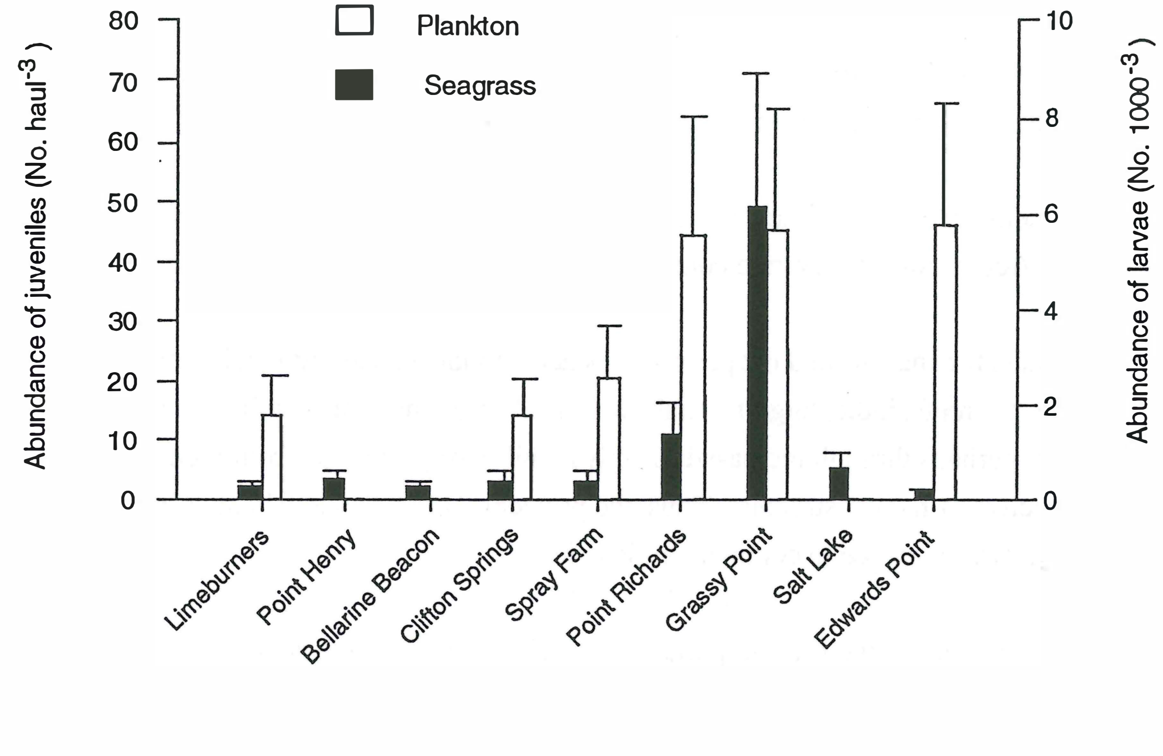

Fig. 6.5 Mean abundance of *Sillaginodes punctata* in the plankton, and post-larvae in seagrass, at nine sites around the Bellarine Peninsula. Error bars are standard error.

IMPLICATIONS AND RECOMMENDATIONS

Implications

1) Juvenile commercial fish previously found to utilise seagrass habitats were also found to be at least as common on shallow reef-algal habitats, indicating that reef-algal habitats are of at least of equal value to seagrass as nursery areas for juvenile fish. Thus, the emphasis placed on seagrass habitats in the past may have been misleading.

2) Deeper reefs appear not to be important habitats for the recruitment of juvenile commercial fish, however, these habitats are probably important for older, sub-adult stages.

3) Results for Port Phillip Bay were largely supported by interstate sampling, implying that the results have generality for southeastern Australia.

4) Moderately exposed beaches and other unvegetated areas formed an important habitat for a different suite of juvenile commercial fish to that found on seagrass or reef.

5) Results for shallow and deeper sandy beach habitats supported results for shallow and deeper reefs, indicating that shallow water 'per se' may form an important juvenile habitat, perhaps through increased food availability or protection from predators, irrespective of habitat structure. Thus, the protection of all shallow habitat in bays and inlets is of importance to commercial fisheries

6) For juveniles of the most important commercial fish utilising shallow habitats, King George whiting, as long as some structure is present, location of the habitat is much more important than the structural characteristics of the habitat. Important influences are likely to be currents delivering larvae and exposure to waves and currents detrimental to the survival of post-settlement individuals. These important habitat locations appear to be consistent from year to year. Information on important sites for King George whiting recruitment has already been taken into consideration in proposals for dredge spoil disposal from the Port of Geelong.

Recommendations

1) Shallow reef-algal habitats should be given equal importance to seagrass habitats when considering impact of pollution and the detrimental consequences of development, such as the dumping of dredge spoil, on juvenile commercial fish in southeastern Australia.

2) Unvegetated habitats should also be afforded protection because they are used by juveniles of a different suite of important commercial species.

3) In general, all shallow (< 1 m) habitats in bays and inlets are probably more important to juvenile fish than deeper habitats. Thus, the shallow margin of bays and inlets, which is often most vulnerable to degradation, should be given maximum protection. Further research is recommended to determine what factors make shallow water, irrespective of habitat, advantageous to juvenile commercial fish.

4) For some species, certain locations, irrespective of habitat structure, may be crucial nursery areas because of their position relative to hydrodynamic processes, and these locations must be identified and protected. The techniques of numerical hydrodynamic modelling, and sampling of artificial habitat, may be useful in identifying such areas.

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Appendix 1. Mean abundance and percentage of total number (in parentheses) of fishes counted on SCUBA transects at seven sites within Jervis Bay.

Species	Site						
	Hole in Wall	Scottish Rocks	Vincentia	Callala Point	Callala Bay	Bindijine Beach	Montagu Point
	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}
Scyliorhinidae	0	0	0	0	0.13 (0.4)	0	0
Plotosidae							
Cnidoglanis macrocephalus	0.13 (0.2)	0	0	0	0.13 (0.4)	0.13 (0.2)	0.13 (0.2)
Syngnathidae							
Stigmatopora argus	0	0.13 (0.3)	0	0	0	0	0
Stigmatopora nigra	0	0.13 (0.3)	0	0	0	0	0
Scorpaenidae							
Scorpaena papillosa	0	0	0	0.13 (0.3)	0.13 (0.4)	0	0
Serranidae							
Hypoplectrodes maccullochi	0	0	0	0	0	0.63 (0.8)	0
Plesiopidae							
Trachinops taeniatus	5.38 (10.3)	0.38 (0.8)	0.25 (0.4)	0.38 (1)	0	2.63 (3.2)	7 (8.8)
Apogonidae							
Siphaemia cephalotes	0	0	0	2.63 (6.7)	0.25 (0.7)	0	2.88 (3.6)
Dinolestidae							
Dinolestes lewini	0.13 (0.2)	0.25 (0.5)	0	0	0	0	0.13 (0.2)
Carangidae							
Trachurus novaezelandiae	0	0	14 (23.8)	0	19.13 (54.4)	0.13 (0.2)	8.13 (10.2)
Sparidae							
Acanthopagrus australis	0.63 (1.2)	0.25 (0.5)	0.25 (0.4)	0	0	0	0
Mullidae							
Parupeneus signatus	0	0.25 (0.5)	0.13 (0.2)	0	0	0	0
Upeneichthys vlamingii	0.25 (0.5)	1.5 (3.1)	1.25 (2.1)	1.5 (3.8)	0.38 (1.1)	0	0.13 (0.2)
Monodactylidae							
Schuettea scalaripinnis	0	0	0.38 (0.6)	0	0	2.5 (3.1)	0.13 (0.2)
Pempherididae							
Pempheris compressa	3 (5.7)	0	6.25 (10.6)	0	1.88 (5.3)	2.63 (3.2)	0
Pempheris multiradiata	0.13 (0.2)	0	0	0	0	7.88 (9.7)	0
Girellidae							
Girella elevata	4.75 (9.1)	0.25 (0.5)	0	0	0	0	0.25 (0.3)
Girella tricuspidata	3.75 (7.2)	0	0	0	0	0	0

Appendix 1 (cont.). Mean abundance and percentage of total number (in parentheses) of fishes counted on SCUBA transects at seven sites within Jervis Bay.

Species				Site			
	Hole in Wall	Scottish Rocks	Vincentia	Callala Point	Callala Bay	Bindijine Beach	Montagu Point
	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}
Scorpididae							
Atypichthys strigatus	20.88 (39.9)	24.88 (52)	20.25 (34.5)	17.5 (44.7)	6.13 (17.4)	27.75 (34.3)	25.75 (32.3)
Scorpis lineolata	6.88 (13.1)	3.38 (7)	8.25 (14)	5.38 (13.7)	0.25 (0.7)	3.25 (4)	2.63 (3.3)
Chaetodontidae							
Chelmonops truncatus	0.38 (0.7)	0.13 (0.3)	0	0	0	0.13 (0.2)	0.25 (0.3)
Enoplosidae							
Enoplosus armatus	0	0	0.38 (0.6)	0	0.38 (1.1)	0.63 (0.8)	0.25 (0.3)
Chironemidae							
Chironemus marmoratus	0	0.38 (0.8)	0.25 (0.4)	0	0	0.25 (0.3)	0.38 (0.5)
Threpterius maculosus	0	0	0	0	0	0.25 (0.3)	0.25 (0.3)
Cheilodactylidae							
Cheilodactylus fuscus	0.25 (0.5)	0.13 (0.3)	1 (1.7)	1 (2.6)	0.13 (0.4)	0.25 (0.3)	0
Pomacentridae							
Chromis hypsilepis	0	0	0	0	0	0.25 (0.3)	0
Parma microlepis	0.5 (1)	0.88 (1.8)	0	0.25 (0.6)	0	7.13 (8.8)	1.25 (1.6)
Parma unifasciata	0	0	0	0	0	0.75 (0.9)	0.13 (0.2)
Parma victoriae	0.38 (0.7)	0	0.13 (0.2)	0.13 (0.3)	0	0.5 (0.6)	0
Labridae	0.13 (0.2)	0.13 (0.3)	0.13 (0.2)	0.13 (0.3)	0.25 (0.7)	0.25 (0.3)	0
Achoerodus viridis	0.5 (1)	2.25 (4.7)	2.25 (3.8)	1.38 (3.5)	0.38 (1.1)	1.38 (1.7)	1.63 (2)
Eupetrichthys angustipes	0	0	0	0	0.13 (0.4)	0	0.25 (0.3)
Notolabrus gymnogenis	1.38 (2.6)	5 (10.4)	1.75 (3)	4.5 (11.5)	0.13 (0.4)	6.75 (8.3)	6 (7.5)
Ophthalmolepsis lineolata	0	1.75 (3.7)	0.13 (0.2)	0	1.13 (3.2)	7.88 (9.7)	11.25 (14.1)
Pictilabrus laticlavius	0.38 (0.7)	1.38 (2.9)	0.75 (1.3)	3.25 (8.3)	2.63 (7.5)	3.5 (4.3)	6.5 (8.2)
Odacidae							
Neoodax balteatus	0	3.13 (6.5)	0.38 (0.6)	0	1 (2.8)	0	3.13 (3.9)
Odax cyanomelas	0.25 (0.5)	0	0.13 (0.2)	0	0	2.88 (3.6)	0.88 (1.1)
Tripterygiidae	2 (3.9)	0	0	0	0	0	0
Clinidae	0	0.25 (0.5)	0	0.25 (0.6)	0.25 (0.7)	0.13 (0.2)	0
Callionymidae							
Eocallionymus papilio	0	0	0	0.13 (0.3)	0.25 (0.7)	0	0

Appendix 1 (cont.). Mean abundance and percentage of total number (in parentheses) of fishes counted on SCUBA transects at seven sites within Jervis Bay.

Species	Site						
	Hole in Wall	Scottish Rocks	Vincentia	Callala Point	Callala Bay	Bindijine Beach	Montagu Point
	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}	No. transect^{-1}
Gobiidae	0.13 (0.2)	0.75 (1.6)	0	0	0	0	0
Monacanthidae	0.13 (0.2)	0	0	0	0	0	0
Brachaluteres jacksonianus	0	0.13 (0.3)	0.38 (0.6)	0.38 (1)	0.13 (0.4)	0	0
Meuschenia freycineti	0	0	0	0	0	0	0.13 (0.2)
Meuschenia trachylepis	0	0.13 (0.3)	0	0	0	0	0
Scobinichthys granulatus	0.13 (0.2)	0	0.13 (0.2)	0.25 (0.6)	0	0.13 (0.2)	0.25 (0.3)
Tetraodontidae							
Torquigener pleurogramma	0	0	0	0	0	0.38 (0.5)	0
Diodontidae							
Diodon nichthemerus	0	0.13 (0.3)	0	0	0	0	0
No. fish trans.$^{-1}$	52.38	47.88	58.75	39.13	35.13	80.88	79.63
Total species number	24	24	22	17	21	27	25

Appendix 2. The total number, percentage of catch and percent occurrence of fishes collected in seine net samples from the inshore (I) and offshore (O) zones during seasonal and monthly sampling of sandy beaches of Port Phillip Bay.

			Seasonal						Monthly			
	Total		Percentage		Occurrence		Total		Percentage		Occurrence	
Taxon	I	O	I	O	I	O	I	O	I	O	I	O
Urolophidae												
Urolophus cruciatus	-	1	-	< 0.01	-	1.05	-	2	-	0.02	-	0.56
Clupeidae												
Hyperlophus vittatus	13784	1123	83.38	84.69	21.05	14.74	12942	8640	79.07	90.94	11.11	17.78
Sardinops neopilchardus	1	-	0.01	-	1.05	-	1	-	< 0.01	-	0.56	-
Spratelloides robustus	1	-	0.01	-	1.05	-	12	4	0.07	0.04	1.67	1.11
Engraulididae												
Engraulis australis	98	1	0.59	0.08	4.21	1.05	98	4	0.6	0.04	2.22	1.11
Atherinidae	1332	26	8.06	1.96	27.37	3.16	612	350	3.74	3.68	20.56	8.33
Atherinosoma microstoma												
Leptatherina presbyteroides												
Hemiramphidae												
Hyporhamphus melanochir	18	10	0.11	0.75	1.05	3.16	18	12	0.11	0.13	0.56	2.78
Syngnathidae												
Stigmatopora nigra	9	3	0.05	0.23	8.42	3.16	20	-	0.12	-	5.56	-
Pegasidae												
Pegasus lancifer	-	-	-	-	-	-	-	1	-	0.01	-	0.56
Scorpaenidae												
Gymnapistes marmoratus	-	4	-	0.3	-	1.05	-	-	-	-	-	-
Platycephalidae	37	40	0.22	3.02	24.21	22.11	73	91	0.45	0.96	22.78	22.22
Platycephalus bassensis												
P. laevigatus												
P. speculator												
Sillaginidae												
Sillaginodes punctata	3	13	0.02	0.98	2.11	2.11	14	1	0.09	0.01	3.89	0.56
Arripidae	4	-	0.02	-	2.11	-	11	-	0.07	-	5	-
Arripis trutta												
A. truttacea												

Appendix 2 (Cont.). The total number, percentage of catch and percent occurrence of fishes collected in seine net samples from the inshore (I) and offshore (O) zones during seasonal and monthly sampling of sandy beaches of Port Phillip Bay.

	Seasonal						Monthly					
	Total		Percentage		Occurrence		Total		Percentage		Occurrence	
Taxon	I	O	I	O	I	O	I	O	I	O	I	O
Mugilidae												
Aldrichetta forsteri	1056	24	6.39	1.81	58.95	8.42	2119	169	12.95	1.78	71.11	12.78
Odacidae												
Neoodax balteatus	-	-	-	-	-	-	6	-	0.04	-	1.11	-
Leptoscopidae												
Crapatalus munroi	3	3	0.02	0.23	3.16	3.16	7	-	0.04	-	3.89	-
Clinidae												
Cristeceps australis	1	-	0.01	-	1.05	-	1	-	< 0.01	-	0.56	-
Heteroclinus perspicillatus	9	1	0.05	0.08	7.37	1.05	2	-	0.01	-	1.11	-
Gobiidae	4	2	0.02	0.15	4.21	2.11	28	-	0.17	-	2.22	-
Pleuronectidae												
Ammotretis rostratus	6	8	0.04	0.6	5.26	7.37	20	28	0.12	0.29	8.33	14.44
Rhombosolea tapirina	124	54	0.75	4.07	37.89	21.05	280	134	1.71	1.41	46.67	26.67
Monocanthidae												
Acanthaluteres spilomelanurus	1	-	0.01	-	1.05	-	1	-	< 0.01	-	0.56	-
Brachaluteres jacksonianus	-	-	-	-	-	-	1	-	< 0.01	-	0.56	-
Meuschenia freycineti	1	-	0.01	-	1.05	-	-	-	-	-	-	-
Tetraodontidae												
Contusus brevicaudus	27	12	0.16	0.9	8.42	6.32	69	41	0.42	0.43	11.67	6.11
Tetractenos glaber	11	1	0.07	0.08	10.53	1.05	30	24	0.18	0.25	8.89	8.33
Diodontidae												
Diodon nichthemerus	1	-	0.01	-	1.05	-	1	-	< 0.01	-	0.56	-
TOTAL	16523	1326	92.57	7.43	86.32	63.16	16368	9501	63.27	36.73	90.56	72.22