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Spawning and larval recruitment processes of commercially important species in coastal waters off Victoria 1997 - 1998

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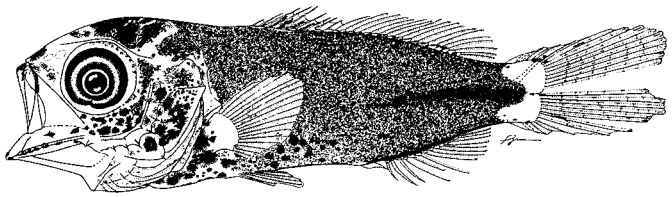

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OBJECTIVES

1. To describe the composition, abundance and spatial distribution of fish eggs and larvae, with particular reference to the early stages of commercially important inshore fish species and those of the southeast trawl fishery.
2. To determine the areas and season of the spawning of King George whiting (*Sillaginodes punctata*) off the Victorian coast.
3. To determine the abundance of the different developmental stages of King George whiting at different locations and identify the pathway(s) of larval transport by back-calculating from the age of larvae.
4. To determine the areas and season of spawning of pilchards (*Sardinops sagax*) off the Victorian coast, and to describe the horizontal and vertical distribution of eggs and larvae.
5. To identify regions of changing nutrient and chlorophyll *a* concentration, and their relationship to physical properties and ichthyoplankton abundance.
6. To collect physical oceanographic data and satellite images to extend the 3-D Bass Strait hydrodynamic model of coastal currents.
7. To describe the spatial and seasonal distribution of rock lobster phyllosomes and giant crab megalopa.

NON TECHNICAL SUMMARY

Information on spawning and larval recruitment processes of commercially important species in coastal waters in south-eastern Australian waters is provided based on four daytime surveys carried out on board the RV *Franklin* during the summer of 1997 (January-February and December) and the winter of 1998 (May-June and July). The principal objective of the project was to locate main spawning areas of commercial fish species, and to combine fish eggs and larval concentrations with hydrographic (currents, density) and hydrochemical (inorganic nutrients, fluorescence, chlorophyll *a*) data in an attempt to identify possible retention areas and advection pathways of larvae. All specific objectives of the project were accomplished to varying degrees of success, except those stated above in 7 since no specimens were obtained.

The survey area extended between Gabo Island (Vic) and Port MacDonnell (SA) and was divided into eight parallel transects placed 65 nautical miles (nm) apart. Surface (neuston) and discrete vertical plankton samples (25-0, 50-25, 75-50 and 100-75 m depth strata) were obtained at five fixed stations located 2, 4, 8, 16 and 32 nm offshore along each transect. Plankton samples (total = 576) were taken using both an opening-closing electronic zooplankton net and a bongo sampler fitted with 500 µm mesh nets.

Surface and vertical plankton samples taken at fixed stations yielded a total of 19,143 and 5,762 larval fishes in the summer and winter surveys, respectively (total = 24,905). Fish eggs were collected in very low numbers therefore no attempt was made to provide data on these. Larval fishes belonging to 96 teleost fish families were caught throughout the study, of which 85 occurred in summer and 56 in winter. Of these, 45 families occurred in both seasons, 40 were found solely in summer and 11 only in winter. Taxa found as larvae during the summer and winter surveys totalled 146 and 95, respectively. Larvae of clupeids (mostly pilchard), monacanthids (leatherjackets) and carangids (mostly jack mackerel) were the dominant groups during summer, whereas scorpaenid (scorpionfishes), morid (morid cods) and myctophid (lanternfishes) larvae dominated the winter samples.

The greatest concentrations of larvae (numbers per 100 m^3) were recorded off Port Campbell (Vic), Portland (Vic) and Port MacDonnell (SA) during summer cruise 1, and off Seaspray (east of Wilsons Promontory) during summer cruise 2. The high larval concentrations during cruise 1 were largely due to pilchard (*Sardinops sagax*) and, to a lesser extent, jack mackerel (*Trachurus declivis*). Dominant larvae off Seaspray during cruise 2 included those of pilchard, barracouta (*Thyrsites atun*) and sand flathead (*Platycephalus bassensis*). Overall larval concentrations during the winter cruises were markedly lower compared to those in summer, and were lowest during winter cruise 3.

Hydrodynamic modelling showed that average currents over the summer cruises were from east to west, reflecting the greater incidence of easterly winds during this period, whereas currents during winter were predominantly west to east. Data on sea surface temperatures and density vertical profiles indicated the presence of a wind-driven upwelling along western Victoria-eastern South Australia during summer cruise 1, which was accompanied by a subsurface enrichment of inorganic nutrients in the area. It is possible that the elevated larval concentrations found in this area at that time could have been related to the high primary productivity associated with this upwelling event. Although enrichment of inorganic nutrients was also observed in this area during summer cruise 2, no upwelling was detected and the overall larval concentrations were much lower than in cruise 1.

The elevated larval concentrations and high diversity of taxa found off Seaspray during summer cruise 2 (n = 32) are likely to reflect the abundance of inshore rocky reef habitats around Wilsons Promontory and its neighbouring islands, as well as the presence of the nearby Corner Inlet. Shipboard current data in this area at that time revealed the presence of an inshore anticyclonic eddy that would have lasted for at least two days. The presence of this eddy, combined with both the prevailing eastward current at that time and the southward protruding topography of Wilsons Promontory, is likely to favour the retention of ichthyoplankton in this area during summer.

The markedly low incidence of fish eggs during this study prevented us from locating spawning areas of important commercial species. However, given the typically low productivity of Bass Strait, the high larval concentrations in coastal waters of western Victoria-eastern South Australia and to the east of Wilsons Promontory indicate that both areas are of considerable importance to larval fishes and consequently possibly also for spawning. The high concentrations of pilchard and jack mackerel larvae in the former region during summer suggests that they may belong to the spawning stock found off central South Australia. Larval spotted warehou (*Seriollela punctata*) were restricted to the eastern corner of Victoria during the winter, implying that they spawn nearby. By contrast, the distribution of larvae of barracouta and blue warehou (*Seriollela brama*) suggests that they spawn across a much larger area. In the case of King George whiting, the very few larvae that were caught within Portland Bay during winter cruise 4 turned out to be the smallest (9.1-11.1 mm SL) and youngest (52-63 d) ever collected in Victorian waters. In addition, since the average current in this area during winter is predominantly westwards, these larvae were likely to have been transported from the west, which in turn implies that the main spawning grounds are to the west of the collection area. This finding is consistent with simulations to predict spawning areas of King George whiting, based on reverse modelling and larval durations of recruits caught in bays and inlets further to the east.

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m^3) corresponds to the highest concentration recorded; this value is followed by the transect (T), the station (in brackets) and the depth stratum where this concentration was recorded. Transects: T1, Gabo Island; T2, Cape Conran; T3, Seaspray; T4, Cape Liptrap; T5, Barwon Heads; T6, Port Campbell; T7, Portland; T8, Port MacDonnell.

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Figure 18D. Vertical fluorescence profiles in transects 1 (Gabo Island) to 6 (Port Campbell) in southeastern Australia during cruise 4 (Jul 1998). Transect 3 (Seaspray) was not sampled; data from transects 7 (Portland) and 8 (Port MacDonnell) are incomplete.

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Appendix

Appendix 1. Personnel from the Marine and Freshwater Resources Institute (MAFRI) who participated during the *RV Franklin* cruises 1 to 4 in 1997/98. Abbreviations: PI = Principal Investigator; MS = Marine Scientist; TO = Technical Officer; TA = Technical Assistant.

Appendix 2. Summary of transects (east to west) and stations sampled, and number of plankton samples taken with different sampling gear during summer cruise 1 (January/ February 1997). * indicates EZ not employed due to bad weather.

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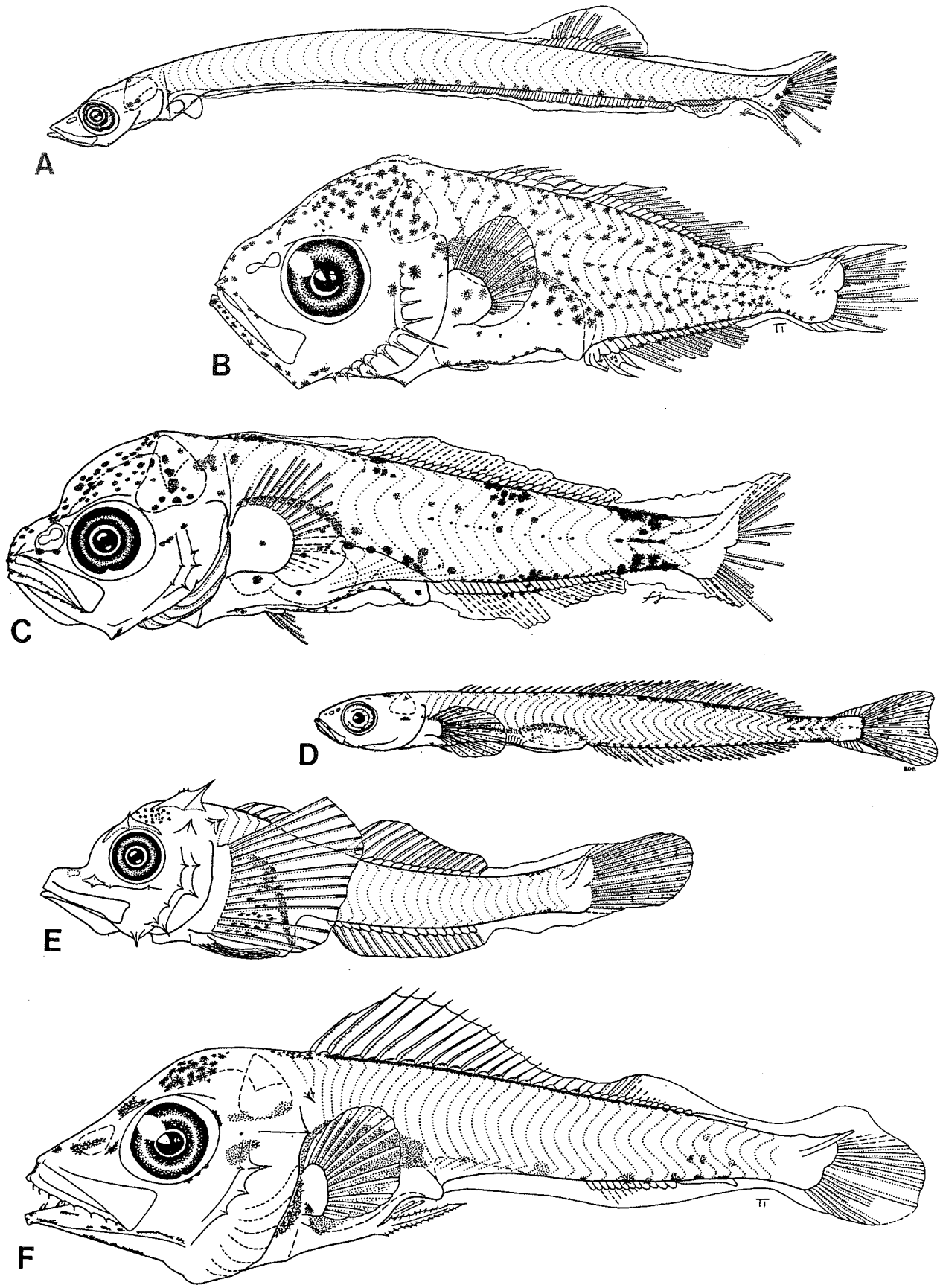
Front cover. 8.3 mm BL transforming stage of eastern Australian salmon, *Arripis trutta* (Arripidae) caught in offshore waters off eastern Tasmania. Illustrated by F.J. Neira (adapted from Neira *et al.*, 1998).

Last page (150). The RV *Franklin*, the research vessel utilised during all four surveys carried out during this study.



Some of the larval fishes refereed to in this report. **A**. 13.6 mm BL flexion larva of pilchard, *Sardinops sagax* (Clupeidae). **B**. 7.8 mm BL postflexion larva of jack mackerel, *Trachurus declivis* (Carangidae). **C**. 8.3 mm BL late flexion larva of blue warehou, *Seriolella brama* (Centrolophidae). **D**. 18.7 mm settlement stage of King George whiting, *Sillaginodes punctata* (Sillaginidae). **E**. 10.0 mm BL postflexion larva of gurnard, *Lepidotrigla modesta* (Triglidae). **F**. 8.2 mm BL late flexion larva of barracouta, *Thyrsites atun* (Gempylidae). Illustrated by F. J. Neira (A, C, E), T. Trnski (B,F) and B.D. Bruce (D) (adapted from Neira *et al.*, 1998).

1. BACKGROUND

There is very limited information on the spawning areas and/or the spatial and seasonal distribution of the early life history stages of many of the commercial species of finfish and also crustaceans in southern Australia, particularly in southeastern waters. This is the case with many species that support the South East trawl fishery, including eastern school whiting, western gemfish, jack mackerel, blue and spotted warehous, as well as inshore commercial species such as southern rock lobster, snapper, yellow-eye mullet, King George whiting and pilchard. In the case of pilchard for example, little is known on the spawning area(s) and season in Victorian waters despite its growing commercial importance in the State. Pilchard eggs have been collected in the area around Cape Schanck and nearby the entrance to Westernport Bay between November and January, while pilchard larvae have been caught in inshore waters off Cape Schanck from December to February (Hoedt & Dimmlich, 1995; Hoedt *et al.*, 1995). Although low concentrations of pilchard eggs have also been found within Port Phillip Bay (Jenkins, 1986), neither pilchard eggs nor larvae were caught during an extensive 12-month survey within this bay in 1996-97 (Neira *et al.*, 1999).

As with pilchard, little is known about the location of the spawning area of King George whiting in south-eastern Australia, despite constituting one of the most important commercial and recreational species in the area. However, evidence suggests that they spawn along the exposed coast off Victoria and that larvae are subsequently transported to bays and inlets up to four months after hatching (Jenkins & May, 1994). At this stage, spawning is estimated to occur mainly between May and July. Using both known age of postlarvae caught in bays and inlets (estimated from daily increments on otoliths), and reverse modelling with the Bass Strait hydrodynamic current model developed by VIMS (Victorian Institute of Marine Sciences), major spawning of this species has been predicted to occur between Cape Otway (Vic) and Cape Jaffa (SA) (Jenkins *et al.*, *in press*).

In order to obtain information on the early life history stages of all commercially important fish species and also crustaceans, a group of scientists from MAFRI (Marine and Freshwater Resources Institute) and VIMS successfully applied for ship time on board the Research Vessel (RV) *Franklin* in order to undertake a systematic survey of the ichthyoplankton assemblage of Bass Strait in 1997-98. Although the project was initially funded for one summer and one winter cruise, the funds obtained were used to carry out four cruises on two consecutive years (1997/98) with the aim of obtaining replicate summer and winter ichthyoplankton samples along the Victorian and eastern South Australian coasts. Consequently, cruises were carried out in January-February and December 1997 (summer cruises), and in May-June and July 1998 (winter cruises).

The granting of ship time on board the RV *Franklin* provided a unique opportunity to obtain data on abundance and distribution of eggs and larvae of commercially important species, and to correlate the information obtained with environmental (salinity, temperature, currents) and chemical variables (inorganic nutrients, chlorophyll *a*). The combined approach of this study attempts to provide a clearer account of the interaction between hydrodynamic/hydrochemical processes and the distribution and abundance of ichthyoplankton, and thus provide a better understanding of recruitment processes which are essential in fisheries assessment. In south-eastern Australia, the importance of nearshore hydrodynamic processes and the effect these have on the distribution and abundance of larval fishes has been demonstrated in a series of recent studies carried out on the Sydney shelf, which show that larval fishes can be considered as biological tracers of hydrographic variability (Dempster *et al.*, 1997; Smith *et al.*, 1999; Smith & Suthers, 1999),

Research on the early life history of fishes in Australia has become a major component of fisheries biology, fish biology and systematics, and aquaculture research during the last 30 years or so. Larval fish studies are essential to determine area(s) and season(s) of spawning, to assess the effect(s) that larval dispersal has on recruitment variability, and to elucidate systematic relationships among fish groups. Moreover, data on spawning dates and early growth rates can now be obtained from daily increments in otoliths taken from larvae, both of which are crucial parameters in stock assessment of important finfish species. The fundamental prerequisite for utilising larval fishes in any study is, without a doubt, their accurate identification to species level, although this can prove to be quite difficult as larvae are often morphologically different to their adult counterparts. For this study, however, the accurate identification of larvae of finfish species collected was greatly facilitated by the recent publication of the book *Larvae of Temperate Australian Fishes*, to date the only descriptive and illustrated text on larval fishes commonly found across temperate Australia (Neira *et al.*, 1998; FRDC partly funded Project 94/129).

The CSIRO has carried out occasional measurement of nutrient concentrations in Bass Strait over the past 40 years (Newell, 1961; Rochford, 1980; Smith & Longmore, 1980; Gibbs *et al.*, 1986, 1991). Most of the nutrient information available for Bass Strait includes inorganic nutrients such as phosphate, nitrate and silicate, with fewer studies carried out on ammonium concentration. Spatial and seasonal variations in nutrient concentration are probably greater than variation due to changes in sampling or analysis. Median concentrations within three nautical miles of the coast are 0.6 µM for ammonium, 0.7 µM for oxidised N, 0.4 µM for phosphate, 1.1 µM for silicate and 0.6µgL^{-1}chlorophyll *a*. These relative concentrations indicate a probable limitation of phytoplankton growth by nitrogen or possibly silicate (for diatoms). The coastal zone is

slightly enriched in ammonium, phosphate, silicate and chlorophyll *a* compared to the rest of Bass Strait. By contrast, the waters of central Bass Strait have low nutrient concentrations (Gibbs *et al.*, 1986). Given the shallow depth in this area, there is no opportunity for nutrient concentrations to be enhanced by upwelling. Thus, we could expect little change in vertical or horizontal nutrient distributions except off known coastal inputs. However, introduction of new nutrients is possible on the eastern and western margins. Transport of nutrient–rich water toward the surface on the western and eastern shelfs greatly affects nutrient distributions and primary production in summer, with enrichment also being observed in northeastern Victoria in the winter-spring period (Rochford, 1977, 1980; Gibbs *et al.*, 1991).

Major technological advances have been made in Australia during the last 10 years on the study of nutrients which, in combination with simultaneous biological sampling (eg. ichthyoplankton), provides a powerful research tool for understanding the early life history and recruitment process of fishes and invertebrates. The surveys conducted during this study employed a sophisticated on-board mobile laboratory designed by MAFRI scientists to measure real-time environmental parameters (eg. inorganic nitrogen) while underway. This development in technology, which originated as part of a $12 million Port Phillip Bay Environmental study funded by Melbourne Water, won a prestigious Commonwealth Government Technology Productivity Award in 1993/94. The method has been used extensively in Port Phillip Bay, off Victorian ocean outfall, and between Melbourne and Sydney. Downloading the data into a GIS database, the high-resolution data obtained with this on-board laboratory provides accurate maps of all the major physical and chemical parameters.

Hydrodynamic models of coastal waters around Australia have been developed by the Victorian Institute of Marine Sciences (VIMS) since 1985. Technically advanced and comprehensive three-dimensional models have been developed to simulate circulation patterns and other environmental processes such as tidal and wind-driven currents, and coastal trapped waves (Black *et al.*, 1991, 1993; Middleton & Black 1994, Jenkins *et al.*, *in press*). These developments have been funded from a variety of sources, including the Australian Research Council, oil companies, the Victoria Environment Protection Authority and the Fisheries Research & Development Corporation (eg. of scallop recruitment, 1988-89). These models have been applied oil spill trajectories, larval fish drift and transport for fisheries management, and pollutant and sediment transport. The application of these models to simulate circulation over the cruise period will allow ichthyoplankton distributions, larval dispersal from spawning areas and possible larval retention areas, to be interpreted in light of physical oceanographic characteristics.

2. NEED

There is only very limited information on the spawning areas and/or the early life stages of many of the commercial important species of finfish and also crustaceans in southeastern Australia. Undoubtedly, the lack of this information limits both the effectiveness of assessment and subsequent management of these resources, and also prevents the determination of the factors that govern recruitment patterns and variability. An good example are pilchard, which in Victoria are commercially targeted almost exclusively around the Lakes Entrance area and within Port Phillip Bay (Neira *et al.*, 1997a,b). For this species, the location of the main spawning area(s) is important given that there is no evidence on whether the fish caught in these areas are spawned in Victoria or elsewhere in south-eastern Australia. Given the existence of a large pilchard spawning area in coastal waters off South Australia (Ward *et al.*, 1998), it is possible that the 0+ - 1+ juvenile fish found at least in Port Phillip Bay may originate from the South Australia-western Victoria area, as it is believed to be the case with King George whiting. In addition, the need to locate the spawning area(s) of pilchard, if any, constitutes a necessary step prior to the application of the daily egg production method to estimate spawning biomass, as has been conducted in South Australia in the last four years (Ward *et al.*, 1998).

For species such as King George whiting, for which the fishery is based mainly on subadults in bays and inlets, it is extremely difficult to gain information on both the size and dynamics of the adult population, and the impact of different management strategies on mature fish without knowing the location and extent of their spawning areas. In addition, locating the extent of the spawning areas of this and other species would provide the basis for determining the relative importance of specific bays and inlets, and also coastal areas in Bass Strait, to population size. Thus, the data obtained during this study will provide valuable information on the distribution and abundance of eggs and larvae of commercial species of finfish and crustaceans in Bass Strait, and on how these variables relate to environmental conditions. This information will in turn help to locate potential zones of larval retention and contribute to the better understanding of processes such as larval dispersal and transport. In this regard, there is accumulating evidence that observed fluctuations in recruitment and abundance of some major species of the south-east fishery may be connected with an extensive larval advection phase and the oceanographic conditions prevailing at that time.

With the data obtained during this study we will attempt to provide for the first time a complete picture on the composition and abundance of eggs and larvae of commercially important finfish and crustaceans in Victorian waters, that is crucial for the management of inshore fisheries. For example, questions such as which species spawn in Bass Strait

and use bays and inlets as early (= larval) nursery area and which spawn within these systems and subsequently migrate to coastal waters, are likely to be determined during this project. Overall, the results of this proposed research will be important for fisheries management plans, ESD objectives, the prediction of recruitment, and to maximise harvest of important commercial fisheries.

3. OBJECTIVES

The main objective of this project was to collect ichthyoplankton and physical, chemical and oceanographic data along Victorian waters and eastern South Australia during the summer of 1997 and the winter of 1998. Data obtained on the composition, abundance and spatial distribution of fish eggs and larvae in the two seasons was used to estimate spawning areas and season of commercially important fish species. Distribution and abundance of fish eggs and larvae were correlated with environmental variables in an attempt to identify possible retention areas and evidence of passive/active transport of these early stages. Samples collected during both periods will also be used to determine the spatial and seasonal distribution of rock lobster phyllosomes and giant crab megalopa. Specific objectives of this study included:

1. To describe the composition, abundance and spatial distribution of fish eggs and larvae, with particular reference to the early stages of commercially important inshore fish species and those of the South East trawl fishery.
2. To determine the areas and season of the spawning of King George whiting (*Sillaginodes punctata*) off the Victorian coast.
3. To determine the abundance of the different developmental stages of King George whiting at different locations and identify the pathway(s) of larval transport by back-calculating from the age of larvae.
4. To determine the areas and season of spawning of pilchards (*Sardinops sagax*) off the Victorian coast, and to describe the horizontal and vertical distribution of eggs and larvae.
5. To identify regions of changing nutrient and chlorophyll concentration, and their relationship to physical properties and ichthyoplankton abundance.
6. To collect physical oceanographic data and satellite images to extend the 3-D Bass Strait hydrodynamic model of coastal currents.
7. To describe the spatial and seasonal distribution of rock lobster phyllosomes and giant crab megalopa.

4. MATERIALS AND METHODS

4.1 Study area and sampling stations

The area sampled during this project comprised the coastal region between 2 and 32 nautical miles (nm) offshore from Gabo Island in eastern Victoria (149°55'E; 37°36'S) to Port MacDonnell in eastern South Australia (140°17'E; 37°49'S) (Fig. 1). Survey cruises were carried out on board the Research Vessel (RV) *Franklin* in January-February and December of 1997 (summer cruises), and in May-June and July of 1998 (winter cruises) (Table 1). The sampling area was divided into eight fixed parallel transects placed 65 nm apart, and perpendicular to the coastline between Gabo Island and Port MacDonnell. In a westward direction, these transects run off Gabo Island (T1), Cape Conran (T2), Seaspray (T3), Cape Liptrap (T4), Barwon Heads (T5), Port Campbell (T6), Portland (T7) and Port MacDonnell (T8). Each transect contained five fixed stations located at 2, 4, 8, 16 and 32 nm offshore (Fig. 1). The track followed by the survey vessel in each of the four cruises in 1997/98 is shown in Figure 2.

Table 1. Summary of dates, departures and arrival ports, and number of sampling days on board the RV *Franklin* during the summer (1997) and winter (1998) cruises.

Cruise	Date	Departure port	Arrival port	No. days
1	24 January - 1 February 1997	Sydney (NSW)	Portland (Vic)	9
2	10 - 18 December 1997	Bell Bay (Tas)	Portland (Vic)	9
3	30 May - 8 June 1998	Portland (Vic)	Melbourne (Vic)	10
4	21 - 29 July 1998	Williamstown (Vic)	Portland (Vic)	9

Bad weather conditions in Bass Strait prevented sampling of some of the stations during each cruise (Table 2). The reason for omitting these stations was that the main sampler used in this study (EZ net; see below) could only be safely operated in winds of up to 20 knots. All eight transects were visited during cruise 1 except that sampling was omitted in the 32 nm offshore stations of transects 1, 2, 5 and 6 due to bad weather. Likewise, no sampling was conducted in any of the five stations along the Port Campbell transect (T6) in cruises 2 and the Seaspray transect (T3) in cruise 4 due to poor weather.

Sampling along the Port MacDonnell transect (T8) was omitted from cruise 3 since it was carried out by personnel of the South Australian Research and Development Institute (SARDI) on board the *RV Ngerin*.

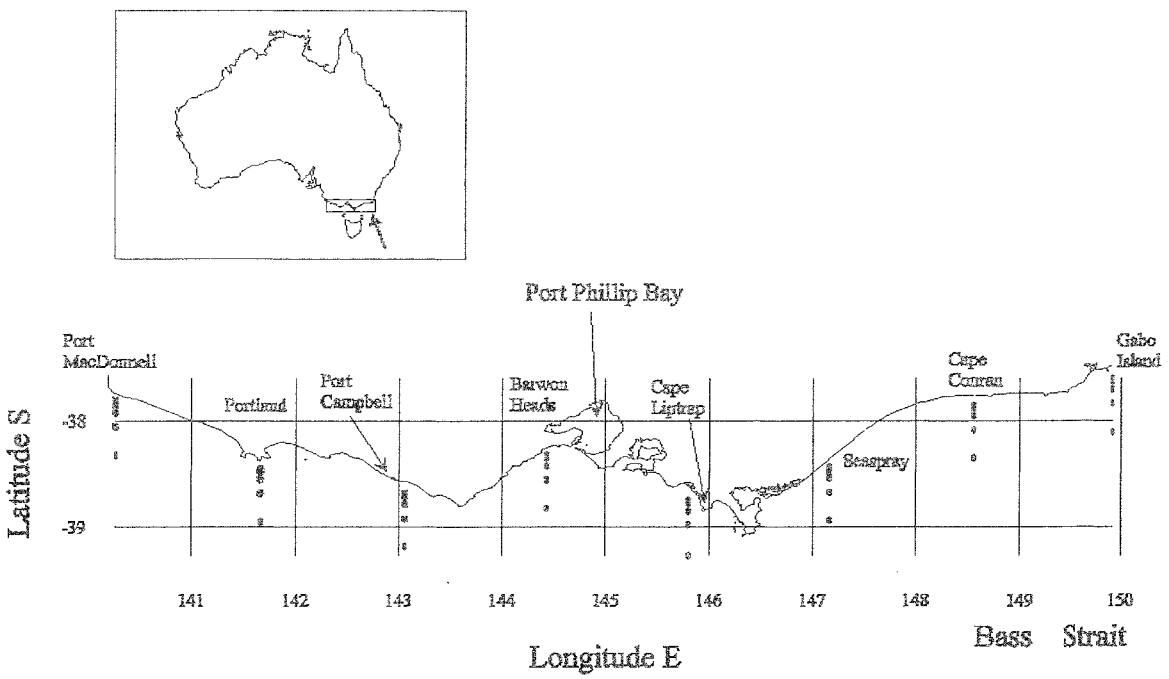


Figure 1. Transects and stations sampled along the South Australian/Victorian coast during the 1997/98 cruises.

Table 2. Summary of transects and stations sampled during the four cruises in 1997 and 1998. Station(s) that were not sampled in a transect due to bad weather are indicated (see text for transect abbreviations).

Cruise	No. transects completed	No. stations visited	Transect	Station (s) omitted
No. 1 Jan - Feb 97	8	40	T1	32
			T2	32
			T5	32
			T6	32
No. 2 Dec-97	7	34	T5	32
			T6	All
No. 3 May-June 98	7	35	T7	16, 32
			T8	All *
No. 4 Jul-98	7	31	T3	All
			T8	2, 4, 8, 16

* Sampling was carried out on-board the FV *Ngerin*

Sampling along each transect in each cruise was conducted mostly during daylight hours, commencing daily between 05:00 and 07:30 hrs, and finishing on the same day between 17:00 and 19:00 hrs, depending on season. Night plankton samples for comparison with day samples were obtained during cruise 3 (Appendix 4). Stations

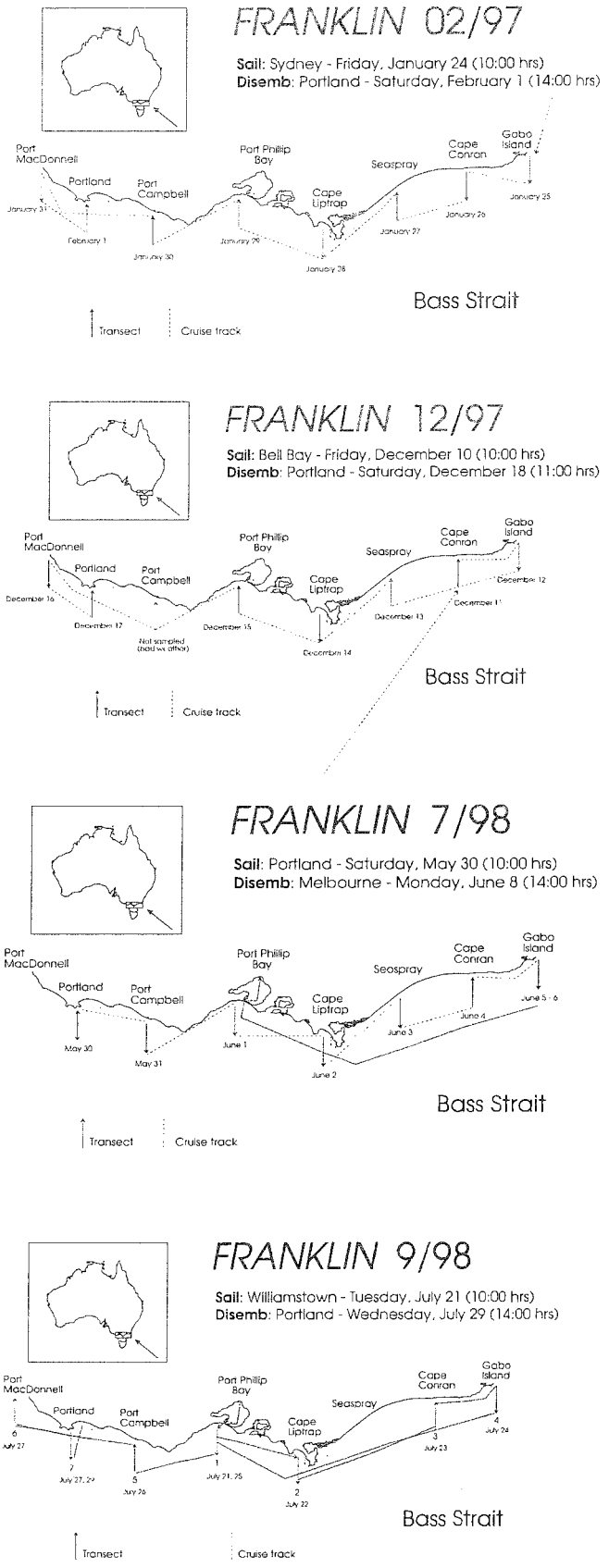


Figure 2. Map of the coast of southeastern South Australia and Victoria showing the cruise track followed by the RV *Franklin* during the four cruises in 1997 and 1998. The arrows in each transect indicate the direction in which the sampling was carried out.

along each transect were sampled starting either from the inshore-most (2 nm) southwards to the offshore-most station (32 nm), or from the offshore-most northwards to the inshore-most station, depending on sea conditions or the postion of the vessel at a particular time. Time spent on each station was about 2-3 hours.

4.2 Plankton sampling regime

4.2.1 Ichthyoplankton samples

A total of 345 vertically-stratified and 149 surface (neuston) ichthyoplankton samples were collected during the four cruises in 1997/98. An additional 73 random neuston samples were taken at night in all cruises (20:00 – 00:00 hrs). These additional samples consisted of three random samples taken after completing the last station of a transect and while underway to the next transect. Overall, a total of 567 samples were taken in all four cruises (Table 3).

Table 3. Total number of ichthyoplankton samples obtained during the four cruises on board the RV *Franklin* along the Victorian coast in 1997 and 1998.

	Cruise 1	Cruise 2	Cruise 3	Cruise 4	TOTAL
	Jan - Feb 97	Dec-97	May-June 98	Jul-98	
Vertically-stratified samples					
• **EZ net**	75	60	82	81	298
• **Bongo net (25-0 m)**	15	16	11	5	47
Neuston samples	40	32	38	39	149
Additional neuston samples	17	12	18	26	73
Total samples	**147**	**120**	**149**	**151**	**567**

4.2.1.1 *Vertically-stratified sampling*

Vertically-stratified ichthyoplankton samples were taken at each station with a $1m^2$ mouth opening-closing EZ (BIONESS) sampler fitted with four 500 µm mesh nets and removable soft codends (Fig. 3A,B). The EZ-net sampler was deployed from the stern of the *RV Franklin* and lowered to the maximum permissible depth (in waters <100 m deep) or to 100 m (in waters >100 m deep). Towing speed varied between 2 and 3 knots and all tows were carried out in an oblique fashion from the deepest stratum to the surface. Samples in waters ≥100 m deep were obtained in the strata 100-75, 75-50, 50-25 and 25-0 m using the four nets, each of which was opened and towed for 15 minutes per stratum. In shallow stations, ie. <30 m deep, a 15 minute oblique tow in the strata 25-0 m was carried out using the bongo sampler (see below) instead of the EZ-net. Each net was opened and closed at the desired depth employing an on-board control system

that linked a series of electronic sensors on the net frame and the vessel through a conducting tow wire. The on-board control system consisted of a PC fitted with CSIRO designed software capable of recording simultaneous data that included net depth (m), towing time (minutes), speed (m/s), distance covered (m), temperature (°C), salinity (practical salinity) and volume of water filtered (m^3). These data were transmitted to the vessel via the conducting tow wire and stored for analysis. Volume of water filtered by the EZ net ranged between 213 and 1370 m^3 (mean = 591 m^3).

4.2.1.2 *Surface (neuston) sampling*

Surface (neuston) ichthyoplankton samples were collected at each fixed station with a bongo sampler consisting of two 0.6 m diameter, 3 m long 500 μm mesh nets, and hard PCV codends (Fig. 3C). The bongo sampler was deployed from the starboard side of the vessel using the oceanographic winch associated with the A-frame, and towed twice along the surface for 15 minutes (two replicates) while the EZ-net was sampling the water column below. The total volume of water filtered by the bongo sampler during each tow was estimated after each sampling occasion from the data obtained from General Oceanics flowmeters mounted at the mouth of each net. The bongo sampler was also used for the additional surface night samples (three replicates per additional site), and to sample the 25-0 m stratum in stations with depths ≤30 m (one tow).

Upon completion of each tow, the nets of both the EZ and bongo samplers were washed down and the cod-end contents transferred to 1.0-2.5 litre capacity plastic containers and fixed with either 10% formaldehyde-seawater or 98% ethanol. All samples were labelled with data from cruise, transect, station and time of sampling.

4.3 Hydrochemical and physical data

4.3.1 Surface variables

A series of hydrochemical data were taken by continuous underway sampling of near-surface water both along transects between fixed stations, and between transects during the two summer and two winter cruises. Surface inorganic nutrients ammonium (NH_4), nitrite (NO_2), nitrate (NO_3), phosphate (PO_4) and silicate (SiO_4) were measured underway by segmented flow colorimetry on a stream of surface flitered (20 μm) pumped seawater. This continuous nutrient tracking system would typically run for about 15 hours each day. Ammonium (NH_4) was measured by the phenol-hypochlorite method of Solorzano (1969) as automated by Technicon (1973a). This method has been significantly modified by MAFRI to eliminate salinity-dependent sensitivity. Nitrite (NO_2) was measured employing the method of Bendschneider and Robinson (1952) as automated by Technicon (1972). Nitrate (NO_3) was measured as nitrite after reduction

with a cadmium coil (Morris & Riley, 1963) as automated by Technicon (1972). Phosphate (PO_4) was measured by the molybdenum blue method of Murphy and Riley (1962) as automated by Technicon (1973b). Monomeric reactive silicate (SiO_4) was measured by the method of Koroleff (1972) as automated by Technicon (1973c). System blanks and standards were analysed frequently to detect drift and changes in sensitivity. Nutrient concentrations measured in the field were digitised and recorded on computer, and are reported in micro-moles per litre (µM). Ammonium, nitrite and nitrate concentrations were added together to obtain dissolved inorganic nitrogen (DIN, µM).

By measuring the time a spiked sample took to travel through the system, and the degree to which the spike broadened, we were able to estimate that the system deployed from the RV *Franklin* was capable of resolving features no smaller than 60 seconds, or about 200-300 m horizontally, at a cruising speed of 8-10 knots. Therefore, data from surface underway analyses were averaged over one minute intervals.

Underway chlorophyll *a* fluorescence was measured with a Seatech submersible fluorometer. Data were digitised with a Data Electronics DT 500 data logger and stored on computer. Fluorescence was converted to chlorophyll *a* (µg/l) by least-squares linear regression against chlorophyll samples collected by gravity filtration through Whatman GF/F glass fibre filters. These were stored frozen, then extracted by ultrasonication in ice-cold 90% acetone, followed by polychromatic spectrophotometric determination (Strickland & Parsons, 1972) with the equations of Jeffrey and Humphrey (1975).

Precision for the various methods used during this study to measure hydrochemical variables is given in Table 4.

Table 4. Precision of underway methods employed to measure inorganic nutrient during the cruises carried out in southeastern Australia in 1997/98.

Variable	Precision
Ammonium	0.1 µM
Nitrite	0.05 µM
Nitrate	0.1 µM
Phosphate	0.05 µM
Silicate	0.1 µM
Chlorophyll *a*	~0.1 µg L^{-1}

Figure 3. Plankton samplers employed during this study. (A, B) the CSIRO EZ net used for sampling plankton at different strata through the water column; (C) the MAFRI bongo sampler used for surface (neuston) and some of the 25-0 m tows.

Surface temperature (°C) and salinity (practical units) were continuously recorded with a thermosalinograph. Data on current direction and speed (m/s) at different depths were obtained with an on-board Acoustic Droppler Current Profiler (ADCP). This instrument was only available during cruises 2 and 4.

4.3.2 Water column variables

Conductivity-temperature-depth (CTD) casts, and water samples for on-board inorganic nutrient analysis by depth, were obtained at each station from various depths prior to the plankton sampling using a CTD rosette fitted with up to eight Niskin bottles (Fig. 4). At each station, the CTD rosette was deployed from the A-frame on the starboard side of the *RV Franklin* and lowered down either to a 100 m deep (stations >100 m) or to the maximum permissible depth, before being slowly brought back to the vessel. Salinity, temperature (°C), fluorescence, depth (m) and density (sigma-T, σ_t) obtained with the CTD were recorded for each station in the on-board computer system. Water column stability was described from density (σ_t) values obtained from salinity and temperature.

Water samples obtained with the Niskin bottles at each fixed sampling station and at different depths were analysed for inorganic nutrients (ammonium, nitrite, nitrate, phosphate and silicate). Ammonium, nitrite and nitrate were summed to obtain dissolved inorganic nitrogen, and plotted by depth (m) and distance from shore (nm) for each sampling station in each cruise. Samples collected from specific depths were used for calibration of salinity and dissolved oxygen, both of which were analysed on-board with CSIRO standard methods.

Fluorescence in vertical profiles was measured by a Seatech model FL3000 submersible fluorometer connected to the CTD rosette. The response of this instrument was not converted to chlorophyll *a* concentrations and therefore this variable is reported here as uncalibrated fluorescence units. A summary of the physical and hydrochemical data obtained during the 1997/98 cruises is provided in Table 5.

4.4 Hydrodynamic current model of Bass Strait

4.4.1 Hydrography of study area

The region of interest was the coastal waters of Victoria and southeastern South Australia (Fig. 1). This area is dominated by Bass Strait, an approximately rectangular water body some 400 by 200 km in magnitude. The Strait consists of a shallow, mostly 70 m deep platform, flanked by 4-5 km deep ocean to the east and west, and by land to the north and south. Although tidal currents can be strong in certain areas, such as the eastern and western entrances to Bass Strait (Black, 1992), the net tidal circulation

Figure 4. The CSIRO CTD rosette used in this study showing five Niskin bottles.

Table 5. Summary of hydrological and inorganic nutrient data received, processed and plotted* for cruises 1-4 on board the *RV Franklin* in 1997/98. Water current data from the ADCP was only obtained in cruises 2 and 4. Dissolved inorganic nitrogen** = ammonium + nitrite + nitrate. Abbreviations: ID, Incomplete data; MD, Missing data; NA, Not available; NS, Not sampled. Transects: T1, Gabo Island; T2, Cape Conran; T3, Seaspray; T4, Cape Liptrap; T5, Barwon Heads; T6, Port Campbell; T7, Portland; T8, Port MacDonnell.

	CRUISE 1 JANUARY - FEBRUARY 1997								**CRUISE 2** DECEMBER 1997							
Transect/variable	T1	T2	T3	T4	T5	T6	T7	T8	T1	T2	T3	T4	T5	T6	T7	T8
Temperature	*	*	*	*	*	*	*	*	*	*	*	*	*	NS	*	*
Salinity	*	*	*	*	*	*	*	*	*	*	*	*	*	NS	*	*
Fluorescence	*	*	*	*	*	*	*	*	*	ID	*	*	*	NS	*	*
Sigma-T	*	*	*	*	*	*	*	*	*	*	*	*	*	NS	*	*
Phosphate	*	*	*	*	*	*	*	*	*	*	*	*	*	NS	*	*
Silicate	*	*	*	*	*	*	*	*	*	*	*	*	MD	NS	*	*
Dissolved inorganic nitrogen**	MD	*	*	*	*	*	*	*	*	MD	MD	*	MD	NS	*	*

	CRUISE 3 MAY-JUNE 1998								**CRUISE 4** JULY 1998							
Transect/variable	T1	T2	T3	T4	T5	T6	T7	T8	T1	T2	T3	T4	T5	T6	T7	T8
Temperature	*	*	*	*	*	*	*	NS	*	*	NS	*	*	*	ID	ID
Salinity	*	*	*	*	*	*	*	NS	*	*	NS	*	*	*	ID	ID
Fluorescence	*	*	*	*	*	*	*	NS	*	*	NS	*	*	*	ID	ID
Sigma-T	*	*	*	*	*	*	*	NS	*	*	NS	*	*	*	ID	ID
Phosphate	*	*	*	*	*	*	*	NS	*	*	NS	*	*	*	ID	ID
Silicate	*	*	*	*	*	*	*	NS	*	*	NS	*	*	*	ID	ID
Dissolved inorganic nitrogen**	*	*	*	*	*	*	ID	NS	*	*	NS	*	*	*	ID	ID

tends to be small and therefore tidal currents would have little influence on dispersal of larval fishes that go through long pelagic larval phases. The primary determinants of net water movement in the region are wind-driven currents and coastal trapped waves (Middleton & Black, 1994). The density structure of Bass Strait ranges from well mixed in winter to strongly stratified in central areas in summer (Baines & Fandry, 1983).

4.4.2 Numerical modelling

The western boundary of the model grid was placed near Ceduna, South Australia using the boundary condition techniques proved by Middleton and Black (1994). This involved adding coastal-trapped wave oscillations to the boundary sea levels using measured coastal water levels at Thevenard (Ceduna). Measured winds were taken from Ceduna, Cape Borda (Kangaroo Island), Cape Nelson (Portland), Cape Otway, Wilson's Promontory, Flinders Island, Low Head (Tasmania) and Gabo Island and interpolated using inverse distance weighting (Black, 1995) onto each model cell.

We used the three-dimensional hydrodynamic model 3DD (Black, 1995) and dispersal model POL3DD (Black, 1996). The three-dimensional hydrodynamic model had six depth strata, namely 0-5, 5-15, 15-35, 35-55, 55-75, and 75-6000 m. The model region was based on a grid of 10 x 10 km square cells, 178 cells east-west by 91 cells north-south. In the dispersal model the horizontal eddy diffusivity was set at 0.0015 m^2 s^{-1}. Calibration of the model is described in Jenkins *et al.* (in press). The periods simulated corresponded to the four sampling cruises: 24 January to 1 February 1997; 10 to 18 December 1997; 30 May to 8 June 1998 and 21 to 29 July 1998. The average current vectors over each cruise period were determined for each of the model depth layers.

Initial simulations did not include the significant water column stratification that was evident in CTD data from the two summer cruises. Simulations were repeated for the summer cruises incorporating water column stratification specified at the western boundary that was an approximate average stratification determined from the CTD data for each cruise. This inclusion had a minimal effect on the mean residual currents for the cruise periods, although finer-scale differences would be expected.

4.4.3 Shipboard ADCP

To investigate the possible existence of an anticyclonic gyre to the east of Wilsons Promontory in December 1997, ADCP underway current estimates were subjected to an approximate correction for tidal currents to determine the residual current flow. From a previous model simulation of tidal currents in Bass Strait we selected a fragment of tidal current data of the approximate period (days) and range that occurred near Wilsons Promontory on December 12/13, 1997. The approximate tidal current vector relevant to

the time and position of each ADCP measurement was subtracted from the ADCP estimate to obtain an approximate current residual.

4.5 Sea surface temperature imagery

Sea surface temperature (SST) images of the southeastern corner of Australia from a NOAA satellite were obtained from the CSIRO Division of Marine Research Remote Sensing Group on the days in 1997/98 when the sampling was carried out. Images were obtained four times a day over the period of each cruise and processed for cloud cover. Selected images presented in this report are used to illustrate important oceanographic processes.

4.6 Laboratory work

4.6.1 Sorting and identification of larval fishes

Ichthyoplankton samples were sorted under a dissection microscope. All larval fishes were removed and identified to the lowest possible taxonomic level and counted. Identifications of larvae to family, genus and/or species were carried out using the descriptions contained in the atlas of larval fishes of temperate Australia (Neira *et al.*, 1998) and references therein. Other references consulted included atlases describing larval fishes from Japan (Uchida *et al.*, 1958; Mito, 1966; Okiyama, 1988), the British Isles (Russell, 1976), southern Africa (Brownell, 1979), the Hawaiian Islands (Miller *et al.*, 1979), the Southern Ocean (Efremenko, 1983), northwest Atlantic (Fahay, 1983), the Indo-Pacific (Leis & Rennis, 1983; Leis & Trnski, 1989), south China Sea (Zhang *et al.*, 1985), western north Pacific (Ozawa, 1986), northeast Pacific (Matarese *et al.*, 1989), southeast Atlantic (Olivar & Fortuño, 1991), and the California Current region (Moser, 1996). Larval identifications were complemented with the use of guides for adult fishes of temperate Australia, particularly those of Last *et al.* (1983), Gomon *et al.* (1994) and Kuiter (1993).

Larval fishes that were identified only to family level belonged mostly to multispecies groups in which further work is required to provide species identification (eg. morids, monacanthids), and to groups in which the taxonomy is not yet well understood (eg. gobiids). Larvae that could not be identified to any taxonomic level, ie. mostly larvae that were either at the yolk-sac stage or that were extensively damaged, were placed in the unidentified category.

4.6.2 Treatment of data

4.6.2.1 *Larval fish abundances and mapping*

The numbers of larvae of all taxa combined and of each of the individual taxa caught by each net of the EZ sampler in each tow were transformed to concentration and expressed as numbers per 100 m^3 employing the total volume of water filtered. In the case of the bongo sampler, the number of larvae of all taxa combined and of each of the individual taxa caught were added for both nets and tranformed to concentrations (nos per 100 m^3) by totalling the volumes filtered by both nets. Larvae caught in the additional surface samples randomly taken with the bongo sampler in all four cruises across the survey area were treated in the same manner as above. Of the taxa caught, however, only larvae of pilchard (*Sardinops sagax*) were indiviadually counted and the data plotted together with the data obtained for each depth stratum sampled with the EZ sampler. For mapping and statistical analyses (see below), larval fish data were entered into an Microsoft ACCESS database with fields such as cruise, transect, station, depth, family, taxa, number of larvae and volume of water filtered.

Horizontal plots showing data on concentration of larvae of selected fish taxa per station and depth stratum (nos per 100 m^3) were constructed using the Classed Post Maps option of SURFER® software package. Concentrations of all larvae combined and those of selected fish species (nos per 100 m^3) by depth (m) against distance offshore (nm) were constructed using the Classed Post Maps option of SURFER® and overlayed to contour temperature profiles. Total number of taxa identified as larvae per transect and cruise were plotted by depth (m) against distance offshore (nm) in the same manner as above.

4.6.2.2 *Vertical and surface maps of physical and hydrochemical variables*

Depth profiles of temperature, salinity, density (Sigma-T), fluorescence and inorganic nutrients (dissolved inorganic nitrogen, phosphate and silicate) were produced for each transect and each cruise using the Kriging procedure (linear variogram model) of the SURFER® software package. Kriging is a geostatistical gridding method that interpolates irregularly spaced data to produce contour and surface plots, ie. it uses the spatial covariance between samples to estimate densities at points on a fine mapping grid. Each transect profile consists of a contour map of the specific variable plotted by depth (m) against distance offshore (nm).

Horizontal maps of surface temperature and chlorophyll *a* for the area surveyed during each of the four cruises were constructed by spatial interpolation using the Kriging procedure of the SURFER® software package (see above for details).

4.6.2.3 *Replication and statistical analyses*

Replicates samples were obtained in several occasions during the study. These included day day-night replicate samples at the same stations for comparison. One and two-way analysis of variance (ANOVA) was employed on data on concentration of larval fishes (nos per 100 m^3) to test for differences at the 5% level. ANOVA was also employed on various occasions to compare concentrations of larvae of selected species by station and depth stratum.

4.6.3 Ageing of King George whiting larvae

4.6.3.1 *Collection of larvae*

A total of 11 surface day samples were randomly taken within Portland Bay (Vic) on 28 July 1998, at the completion of cruise 4. These samples were obtained using the MAFRI bongo sampler and were aimed at collecting early life history stages of King George whiting, *Sillaginodes punctata*. After the routine washing down of the nets, the plankton samples were immediately fixed in ethanol 98% to preserve otoliths for later analysis.

4.6.3.2 *Otolith analysis*

The standard length (SL; tip of snout to caudal peduncle) of larval King George whiting collected in Portland Bay (Vic) was measured under a dissecting microscope fitted with an ocular micrometer. Methods for preparation and analysis of otolith microincrements are given in Jenkins & May (1994). Daily periodicity of increment formation in otoliths of *S. punctata* has been previously verified (Jenkins & May, 1994). Image analysis equipment was used to count otolith increments on otoliths, providing an estimate of the duration of the larval stage up to the point of sampling. The average of the readings from the two sagittae was used (Jenkins & May, 1994).

4.6.3.3 *Reverse modelling*

King George whiting larvae were represented in the Bass Strait numerical model to simulate the actual larval advection based on measured larval durations (Jenkins *et al.*, in press). To improve statistical reliability, each larva was represented by 10 neutrally buoyant particles that were seeded in Portland Bay (Vic) on the day of collection (28th July, 1998). Particles were then tracked for their estimated larval duration in a "reverse" simulation to the point of hatching. The final (hatching) position was plotted in space for all particles.

5. RESULTS

5.1 Hydrographic conditions

5.1.1 Currents

Hydrodynamic three-dimensional model simulations were undertaken for the period (days) during each of the summer and winter cruises (Figs 5-9). For summer cruise 1, the mean residual current over the cruise period was predominantly east to west (Fig 5A-E). Surface (0-5 m) currents were strongest along the east Gippsland coast and through Bass Strait, and also from western Victoria to Kangaroo Island in South Australia (Fig 1A). However, a weak counter-current was evident offshore from the main current in western Victoria and southeastern South Australia (Fig. 5A). Currents were conducive to upwelling along the coast west of Portland (Fig. 5A). Current velocity decreased significantly with depth (Fig. 5B-E).

For summer cruise 2, the mean residual current over the cruise period diverged in direction at about the western edge of Bass Strait, with currents to the east of this point being predominantly directed to the northeast and currents to the west being predominantly westward at all depth strata (Fig. 6A-E). The average circulation was influenced by a major change in current pattern on approximately 13 December 1997, when slow to moderate currents to the west were replaced by strong currents to the east. The strongest mean residual currents were observed in north-eastern Bass Strait and along the east Gippsland coast.

Winter cruise 3 was characterised by eastbound currents that were strongest in northern Bass Strait and along the east Gippsland coast (Fig. 7A-E). A similar pattern was evident in winter cruise 4, although in this case currents were relatively stronger from western Victoria across to Kangaroo Island (Fig. 8A-E) compared to those observed during winter cruise 3 (May-June 1998).

Mean residual currents patterns modelled for the entire cruise period masked shorter term variability in current patterns. For example, although the mean residual current off Gippsland in cruise 2 was directed to the north-east (Fig. 6A-E), currents to the immediate east of Wilsons Promontory changed in the period from 12:00 h on 12 December to 18:00 on 13 December 1997 from strong, southeastward directed currents to the formation of an anticyclonic eddy (Fig. 9A-F). This eddy was also evident when shipboard ADCP current measurements were subjected to an approximate correction for tidal current velocities (Fig. 10).

5.1.2 Sea surface temperatures

Satellite images of sea surface temperatures (SST) showed distinctive features over the summer cruise periods (Fig. 11A-B). A strong upwelling of cold water (10-12°C) was evident along the western Victorian coast between Port Campbell and Portland in both February and December 1997, which coincided with a period of strong along-shore westward currents that are common over summer (Fig. 11A,B). In addition, several small eddies, some of which may be associated with the East Australian Current (EAC), were present predominantly in the image from December 1997 (Fig. 11B). No distinctive features were identified in the image from May 1998 other than the presence of cold water of about 10°C over the whole of Bass Strait (Fig. 11C).

5.1.3 Vertical temperature and salinity profiles

Though vertical and horizontal variations were observed in both temperature (Fig. 12A-D) and salinity (Fig. 13A-D), the mixing of water bodies and impact of water bodies on neutral or positively buoyant particles such as fish eggs and larvae is much more easily understood by examining density (σ_t). While density is a complex function of both temperature and salinity, the major density features described during this study for Bass Strait were influenced much more by temperature than salinity variations.

5.1.4 Water column stability (Density, σ_t)

The major changes in density (σ_t) during cruise 1 (Jan-Feb 1997) were with depth (Fig. 14A). Density (σ_t) varied from 25.7 to 26.5 on the Gabo Island transect, with strong vertical gradients. Similar ranges and degree of vertical stratification were observed off Cape Conran, Barwon Heads, Portland and Port MacDonnell. The water column off Cape Liptrap and Port Campbell was well-mixed dowm to about 30 m and stratified below that depth, while the whole water column off Seaspray was well-mixed vertically, but became increasingly dense offshore. Off Portland, the $\sigma_t = 26.6$ line rose from 200 to 125 m within 10 nm of the coast, indicating the possibility of sub-surface nutrient enrichment by upwelling (Fig. 14A).

Differences in density with longitude were evident during cruise 2 (Dec 1997) (Fig. 14B). Density varied between 25.4 and 26.5 east of Seaspray, and between 25.9 and 26.6 west of Seaspray. This was due to the influence of surface waters east of Seaspray which were of a lower salinity than in the rest of Bass Strait (possibly from the East Australian Current). Off Gabo Island, Cape Conran and Port MacDonnell, the water

column was vertically stratified, with the isolines shallowing nearshore. For example, the σ_t = 26.3 line rose from 100 m 32 nm off Cape Conran to 20 m depth 2 nm from shore, indicating the possibility of upwelling on each of these transects. Off Port Campbell, the surface 30 m was well-mixed, but upwelling to within 50 m of the surface was evident offshore from about 8 nm. Density increased offshore of both Seaspray and Cape Liptrap, with vertically well-mixed water columns. The water column off Barwon Heads was vertically stratified below a well-mixed 30 m surface layer (Fig. 14B).

The major differences in density during cruise 3 (May-Jun 1998) were with distance from shore (Fig. 14C). There was no significant difference in density with longitude, and the range of density was smaller along most transects than on the two summer cruises (eg. 26.2-26.5 off Cape Conran). The densest water occurred close to shore for all transects except Cape Conran and Portland, where density increased offshore. At all sites, the water column was well-mixed vertically to at least 50 m from the surface. There was no evidence in the density structure to indicate upwelling (Fig. 14C).

Bad weather prevented any measurements off Portland and Port MacDonnell during cruise 4 (Jul 1998) (Fig. 14D). The density range declined further on each transect between June and July 1998, with σ_t for all samples in July ranging between 26.4 and 26.8. The water column was well-mixed vertically off Cape Liptrap, Barwon Heads and Port Campbell, with the highest density at the shore-ward end of the Cape Conran, Barwon Heads and Port Campbell transects. Lenses of high density water were observed at 100 depth 16 nm off Gabo Island, and at 50 m depth 4-8 nm off Cape Conran (Fig. 14D).

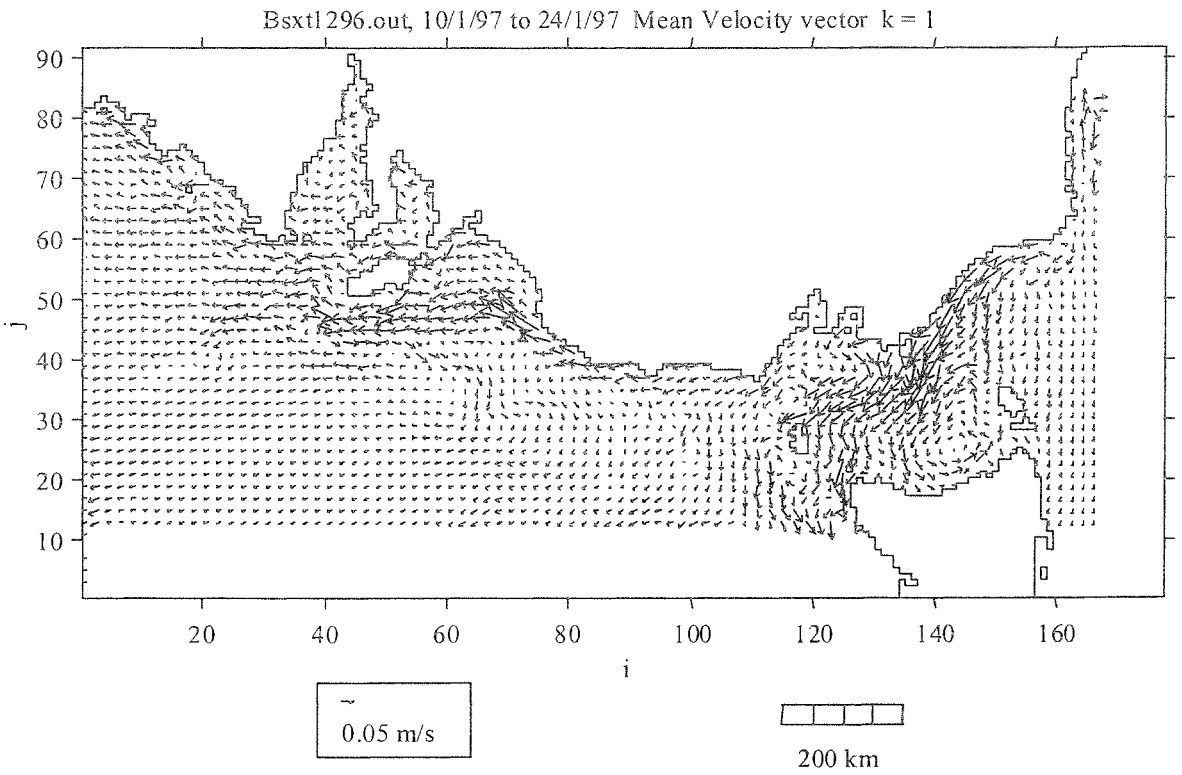


Figure 5A. Simulated hydrodynamic current model of southeastern Australia at a depth of 0-5 m obtained for the period 10-24 January 1997 (Cruise 1). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

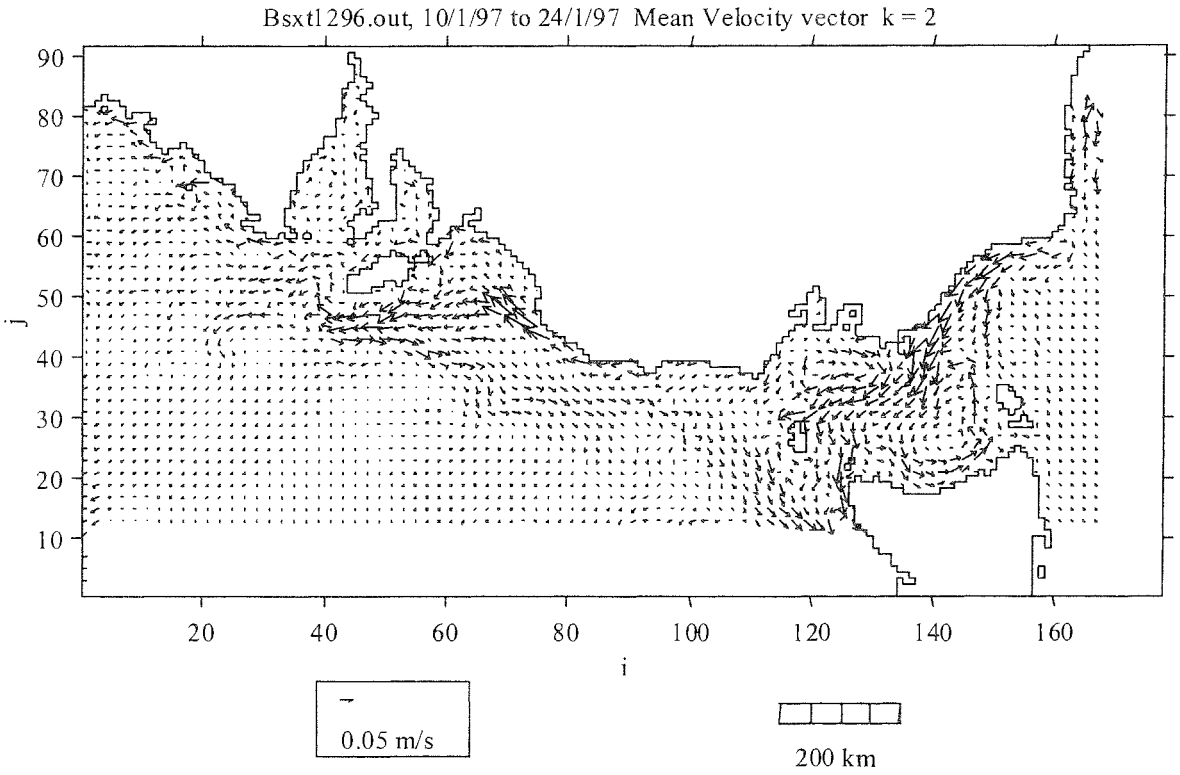


Figure 5B. Simulated hydrodynamic current model of southeastern Australia at a depth of 5-15 m obtained for the period 10-24 January 1997 (Cruise 1). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

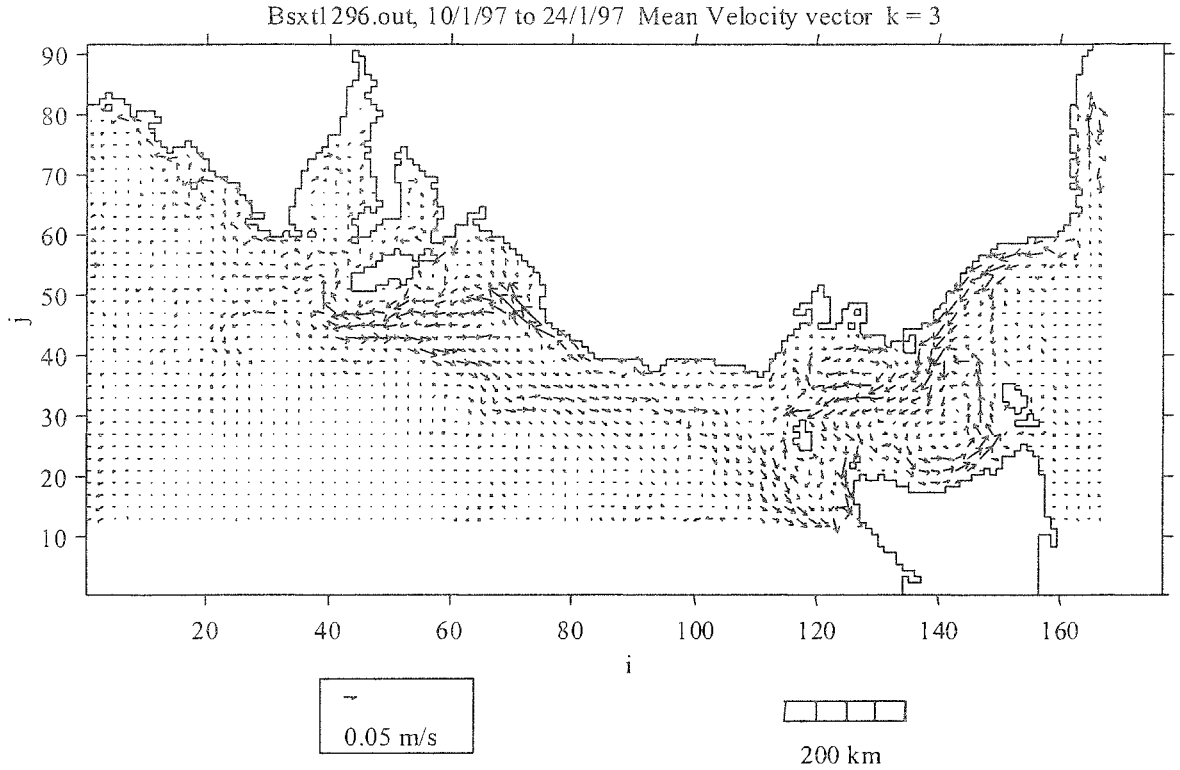


Figure 5C. Simulated hydrodynamic current model of southeastern Australia at a depth of 15-35 m obtained for the period 10-24 January 1997 (Cruise 1). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

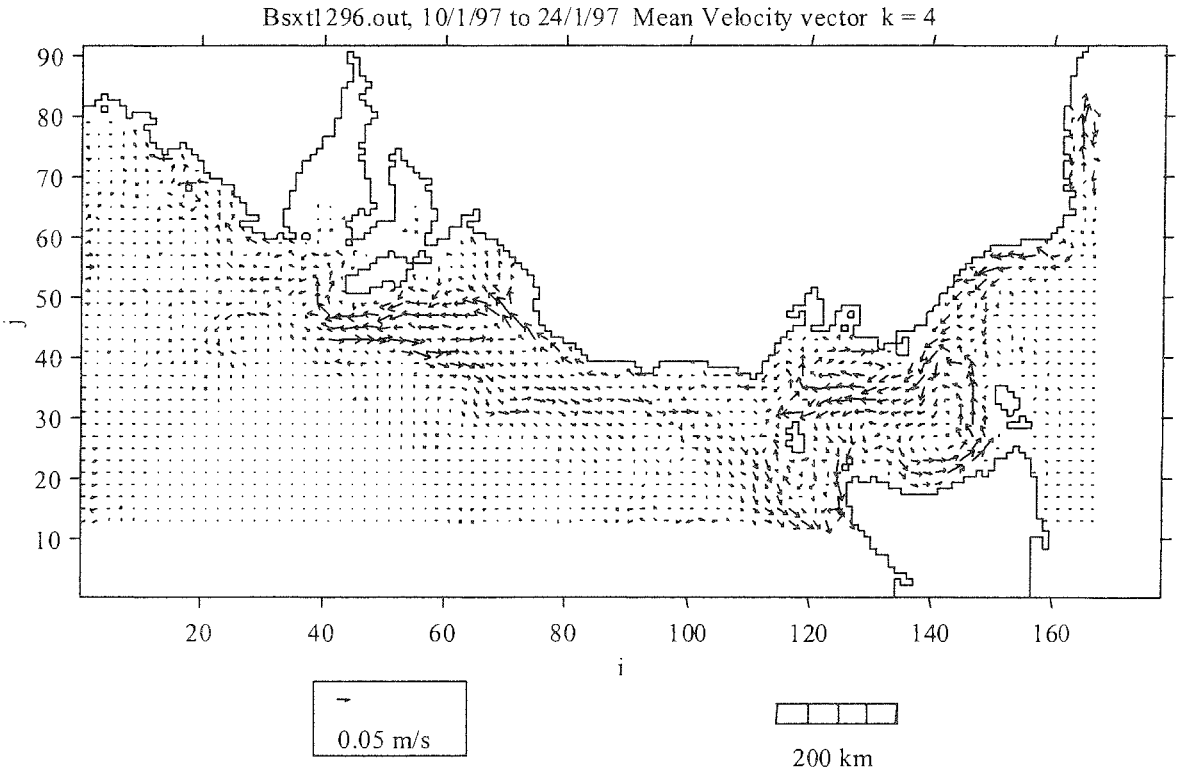


Figure 5D. Simulated hydrodynamic current model of southeastern Australia at a depth of 35-55 m obtained for the period 10-24 January 1997 (Cruise 1). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

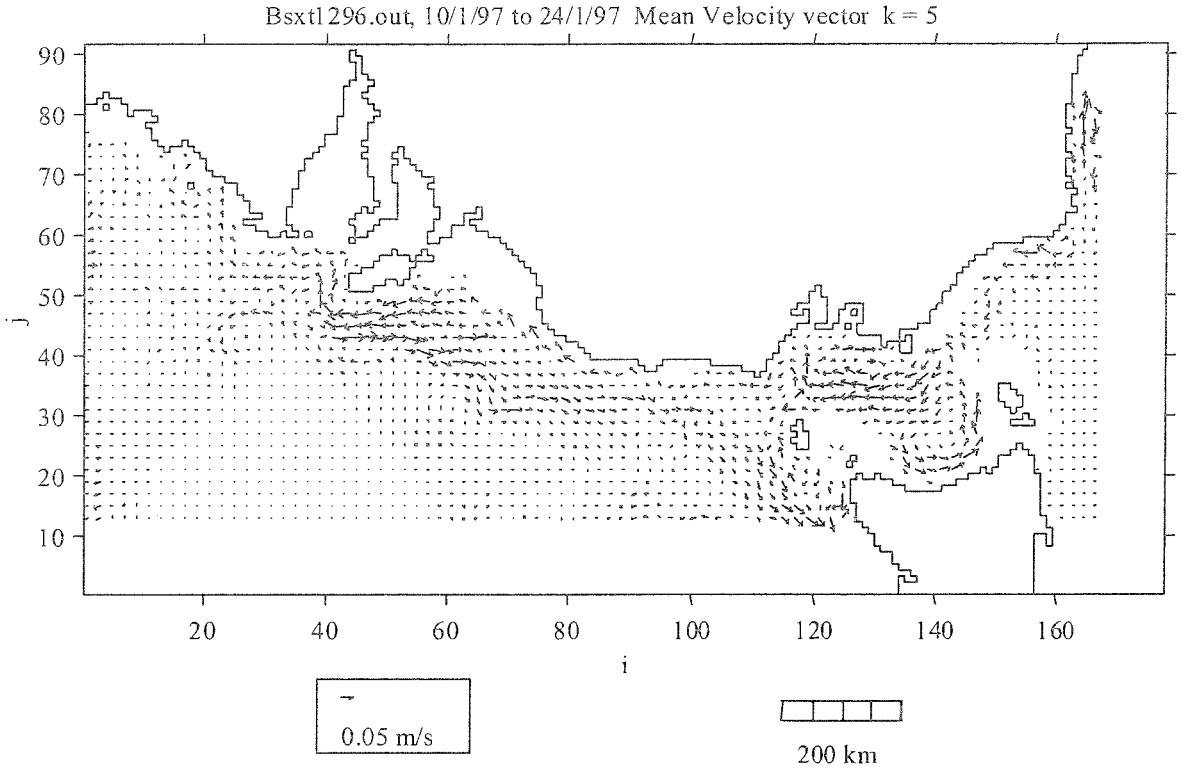


Figure 5E. Simulated hydrodynamic current model of southeastern Australia at a depth of 55-75 m obtained for the period 10-24 January 1997 (Cruise 1). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

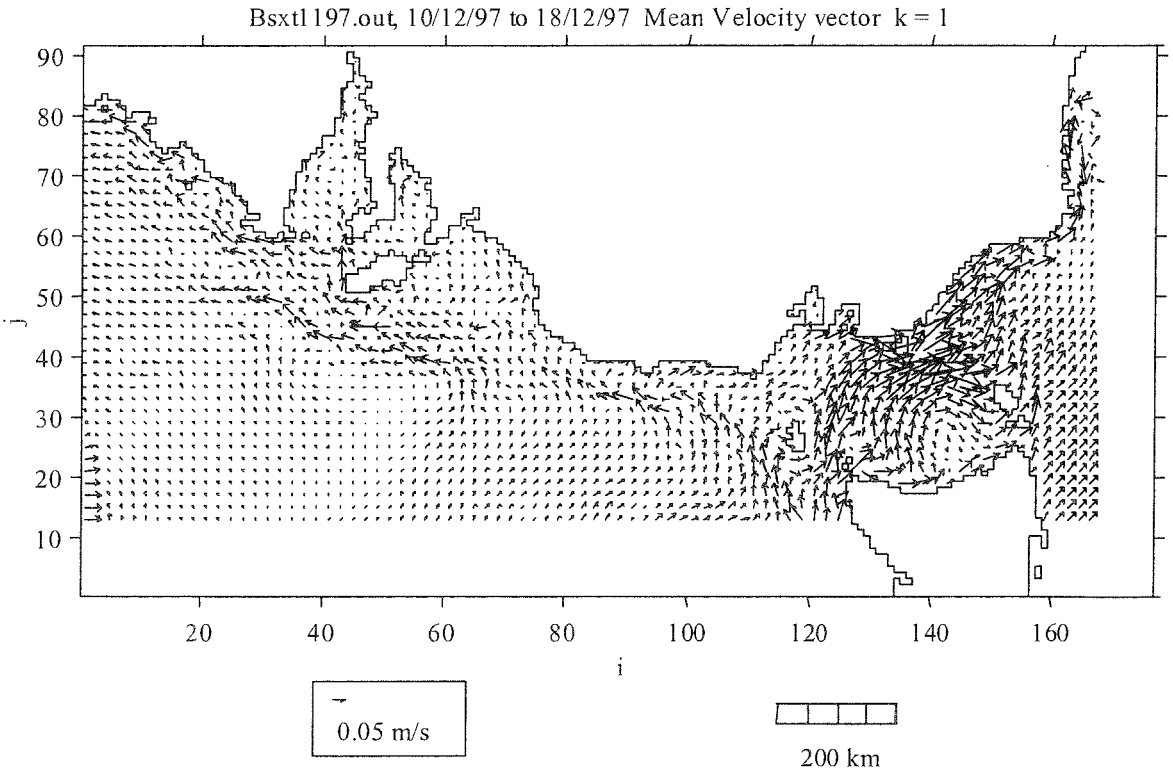


Figure 6A. Simulated hydrodynamic current model of southeastern Australia at a depth of 0-5 m obtained for the period 10-18 December 1997 (Cruise 2). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

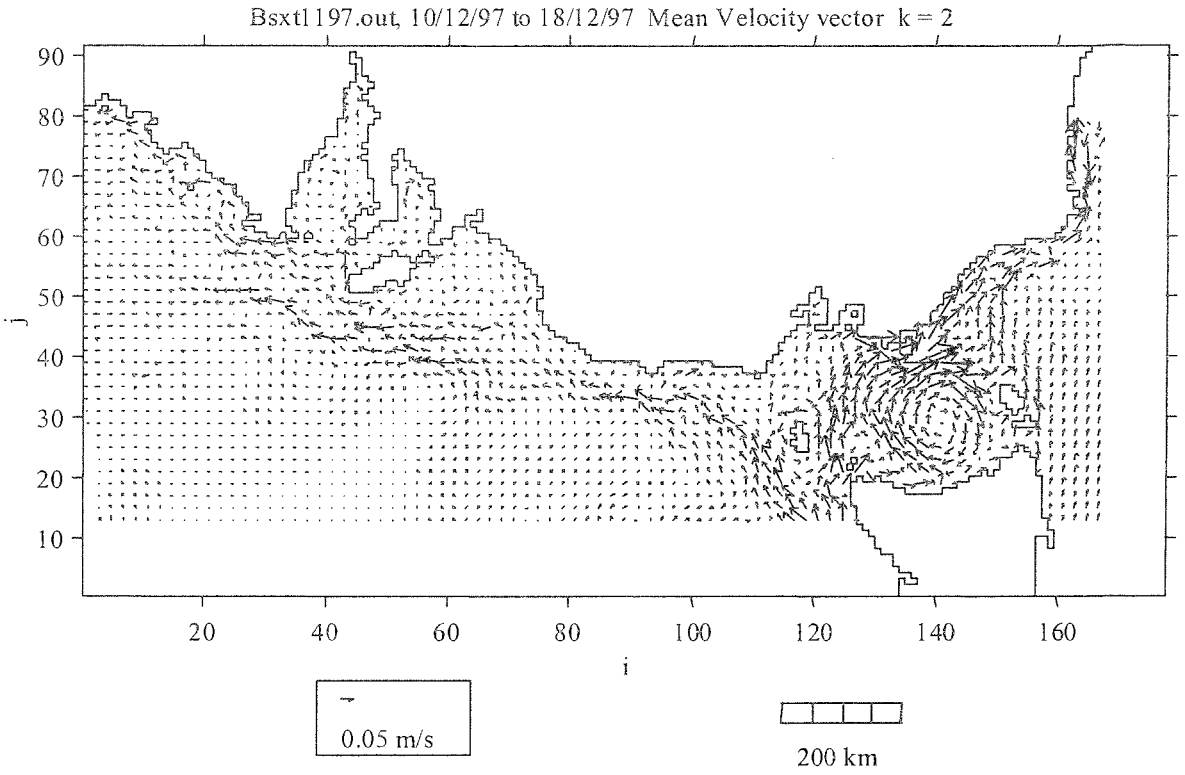


Figure 6B. Simulated hydrodynamic current model of southeastern Australia at a depth of 5-15 m obtained for the period 10-18 December 1997 (Cruise 2). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

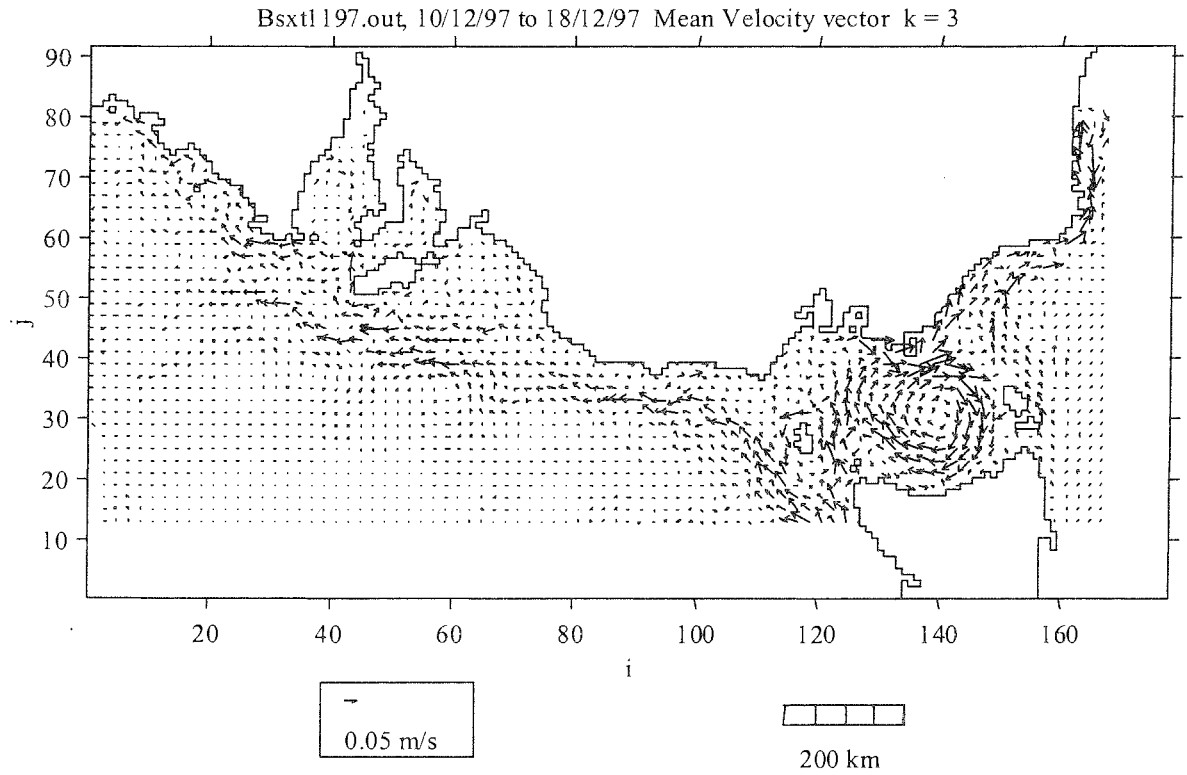


Figure 6C. Simulated hydrodynamic current model of southeastern Australia at a depth of 15-35 m obtained for the period 10-18 December 1997 (Cruise 2). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

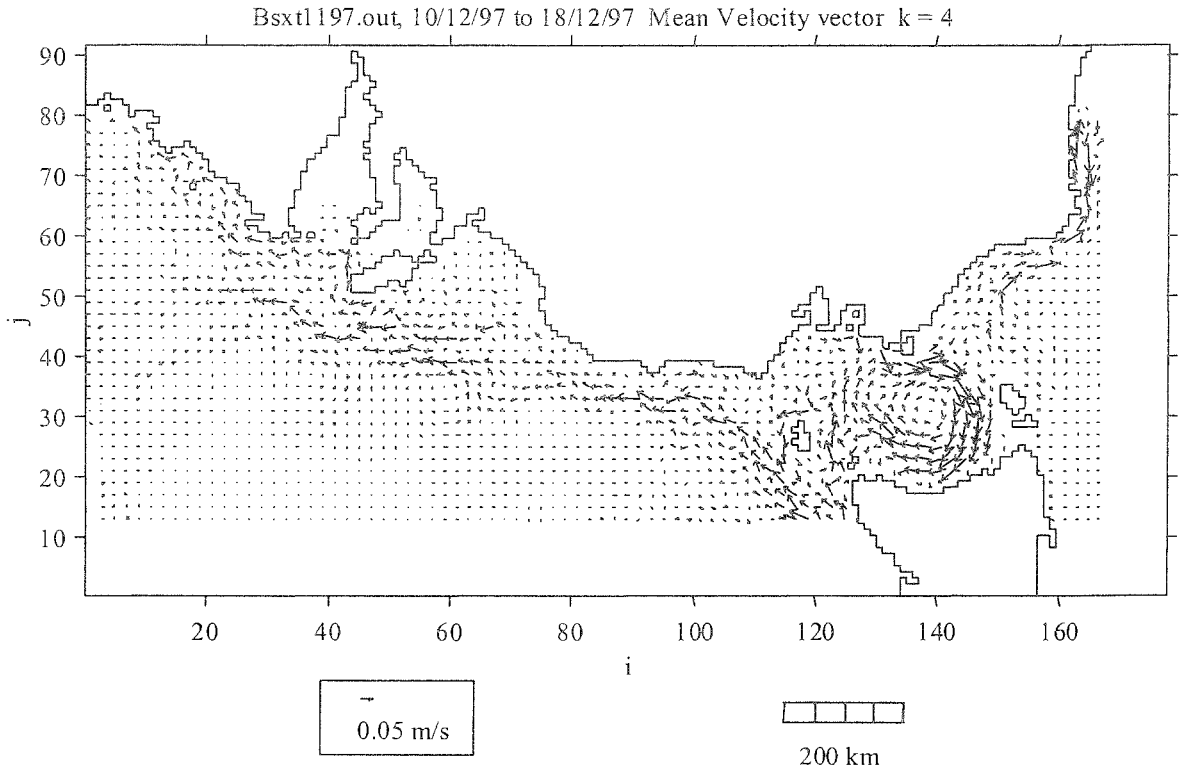


Figure 6D. Simulated hydrodynamic current model of southeastern Australia at a depth of 35-55 m obtained for the period 10-18 December 1997 (Cruise 2). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

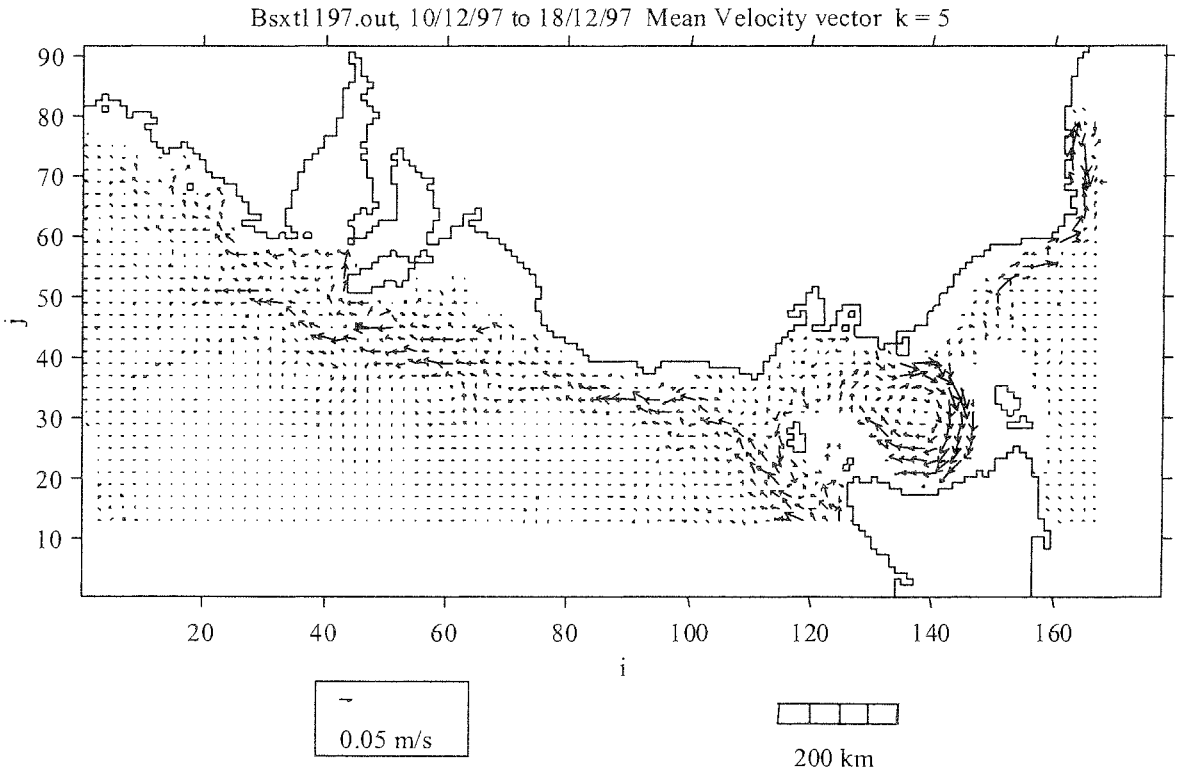


Figure 6E. Simulated hydrodynamic current model of southeastern Australia at a depth of 55-75 m obtained for the period 10-18 December 1997 (Cruise 2). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

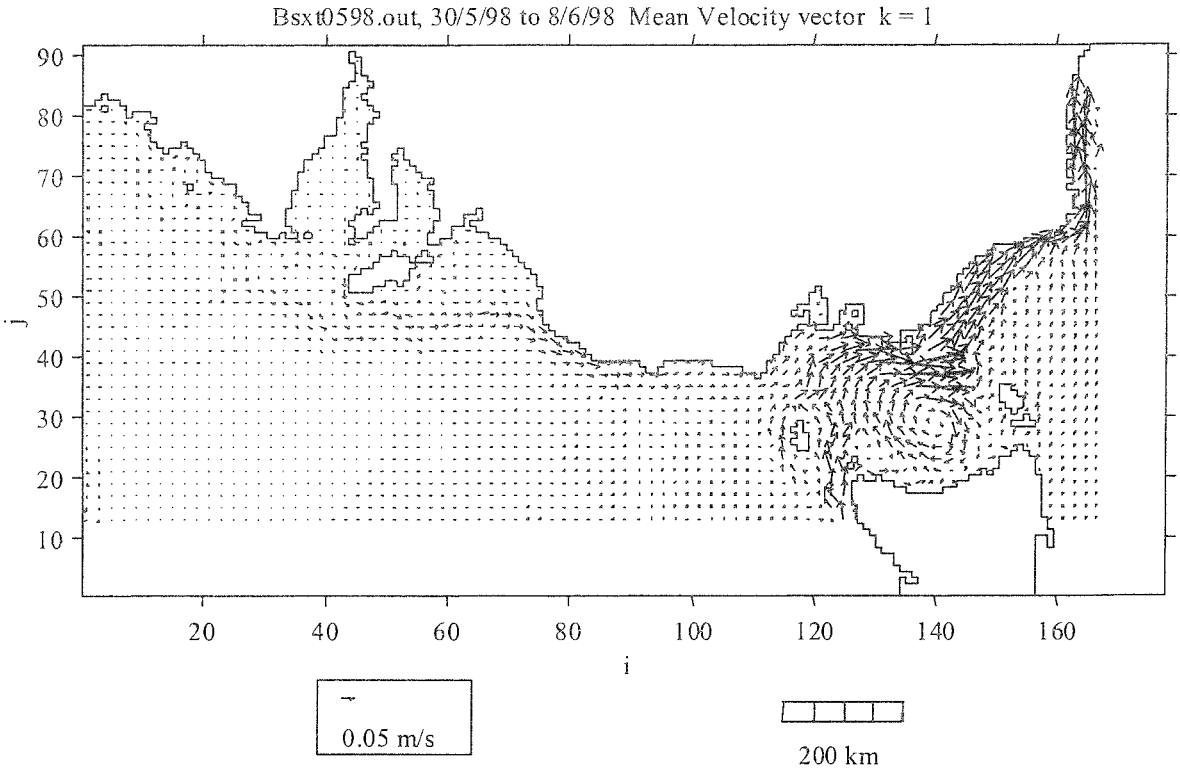


Figure 7A. Simulated hydrodynamic current model of southeastern Australia at a depth of 0-5 m obtained for the period 30 May to 8 June 1998 (Cruise 3). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

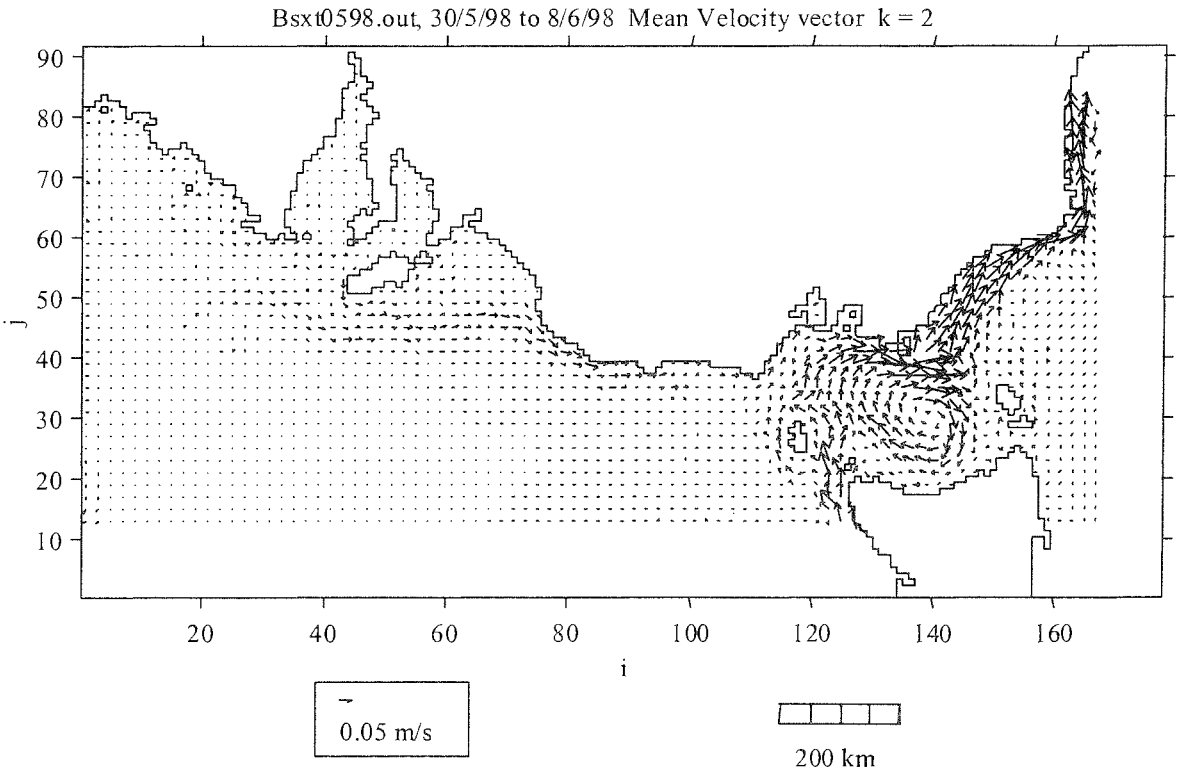


Figure 7B. Simulated hydrodynamic current model of southeastern Australia at a depth of 5-15 m obtained for the period 30 May to 8 June 1998 (Cruise 3). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

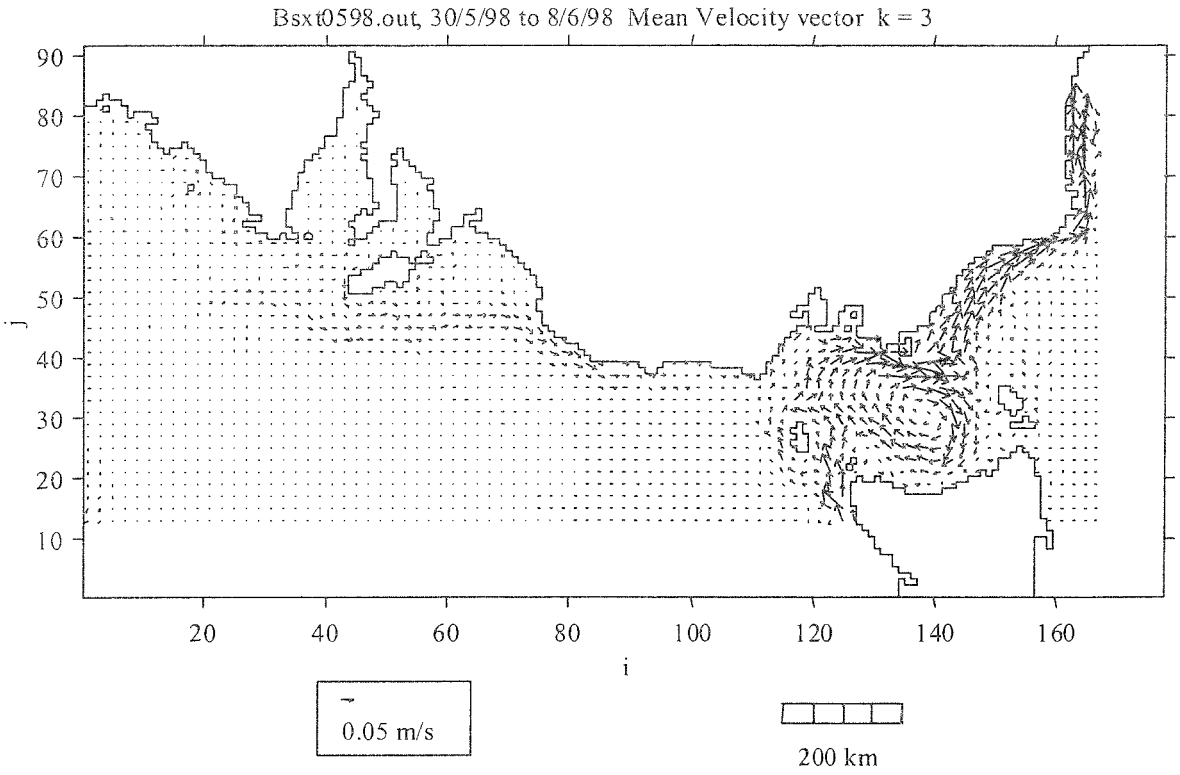


Figure 7C. Simulated hydrodynamic current model of southeastern Australia at a depth of 15-35 m obtained for the period 30 May to 8 June 1998 (Cruise 3). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

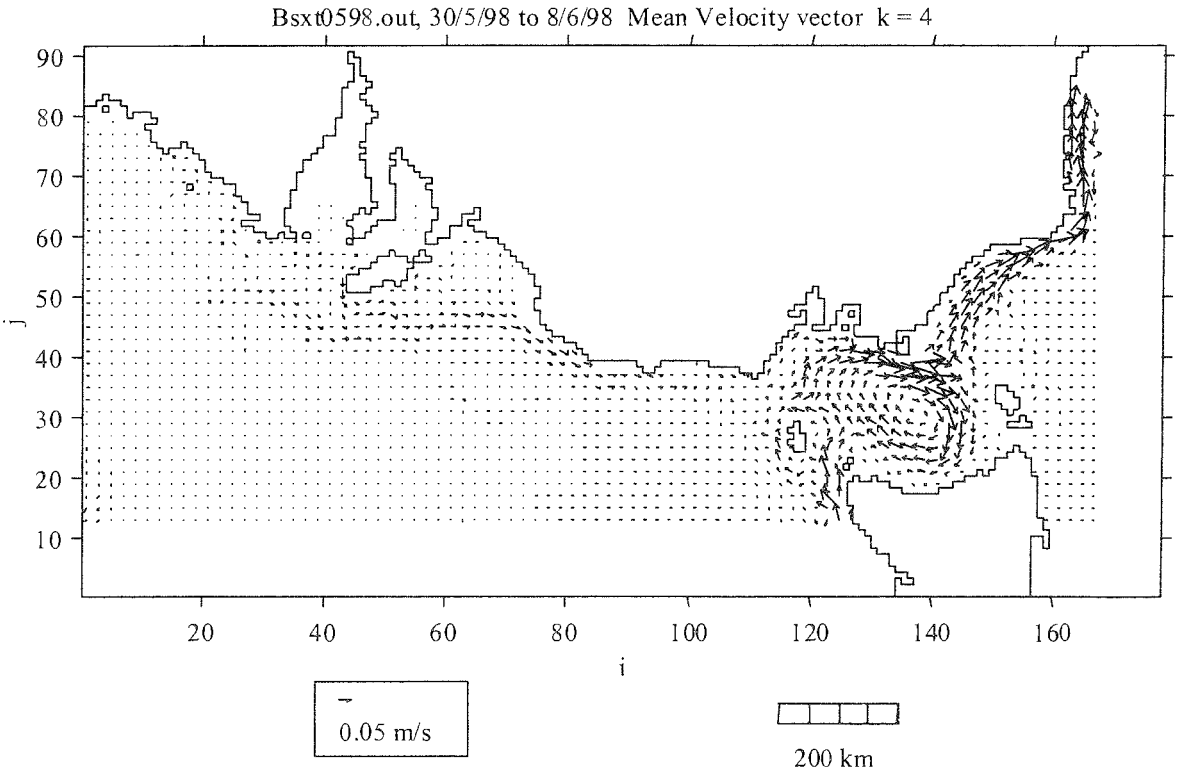


Figure 7D. Simulated hydrodynamic current model of southeastern Australia at a depth of 35-55 m obtained for the period 30 May to 8 June 1998 (Cruise 3). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

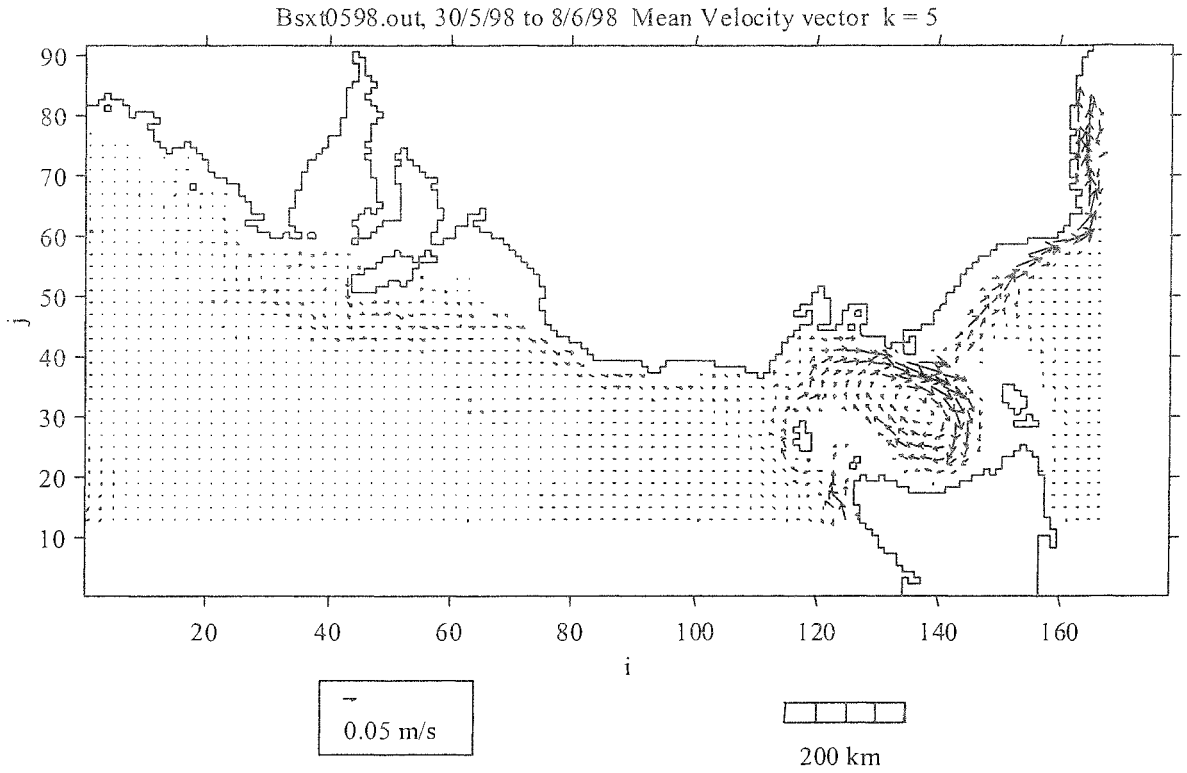


Figure 7E. Simulated hydrodynamic current model of southeastern Australia at a depth of 55-75 m obtained for the period 30 May to 8 June 1998 (Cruise 3). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

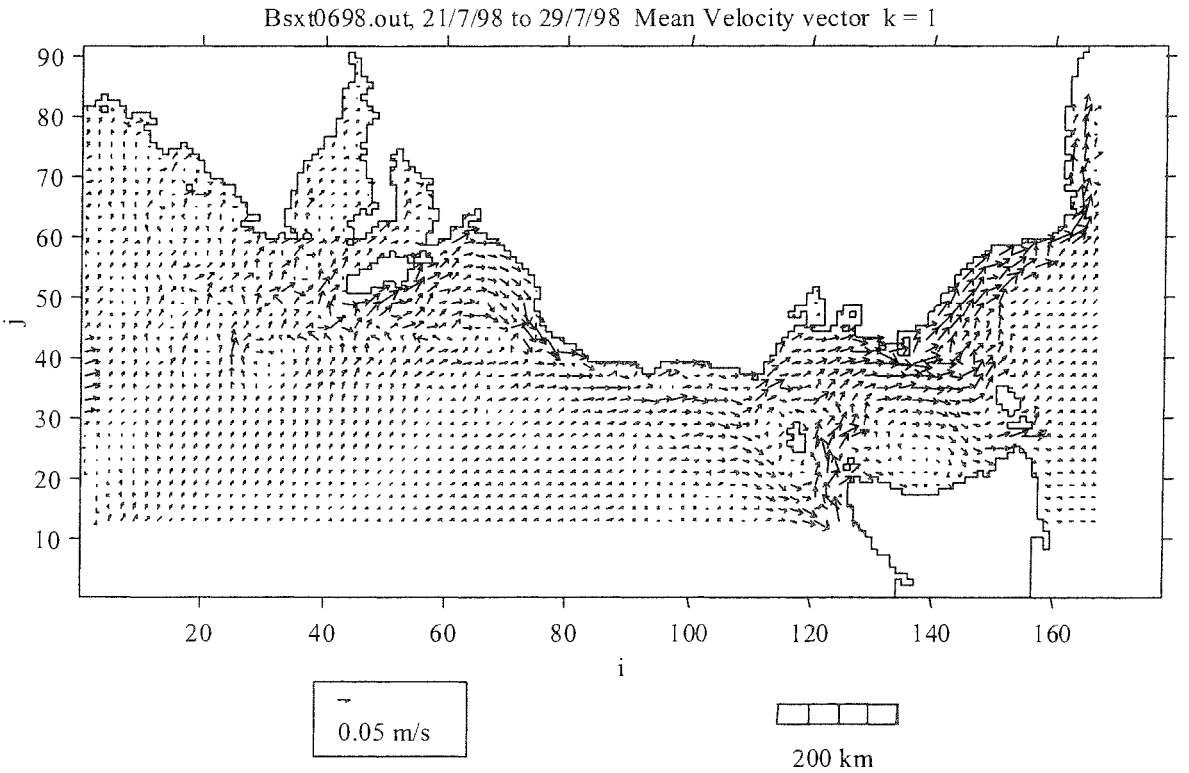


Figure 8A. Simulated hydrodynamic current model of southeastern Australia at a depth of 0-5 m obtained for the period 21-29 July 1998 (Cruise 4). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

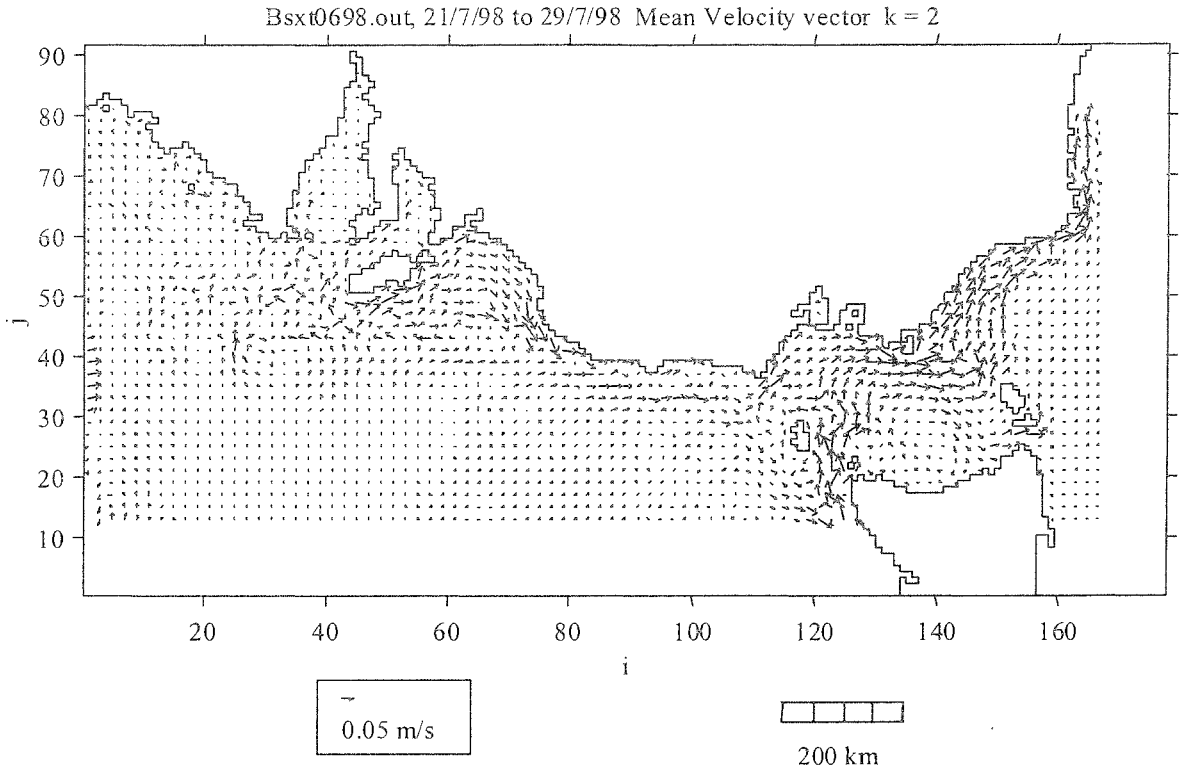


Figure 8B. Simulated hydrodynamic current model of southeastern Australia at a depth of 5-15 m obtained for the period 21-29 July 1998 (Cruise 4). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

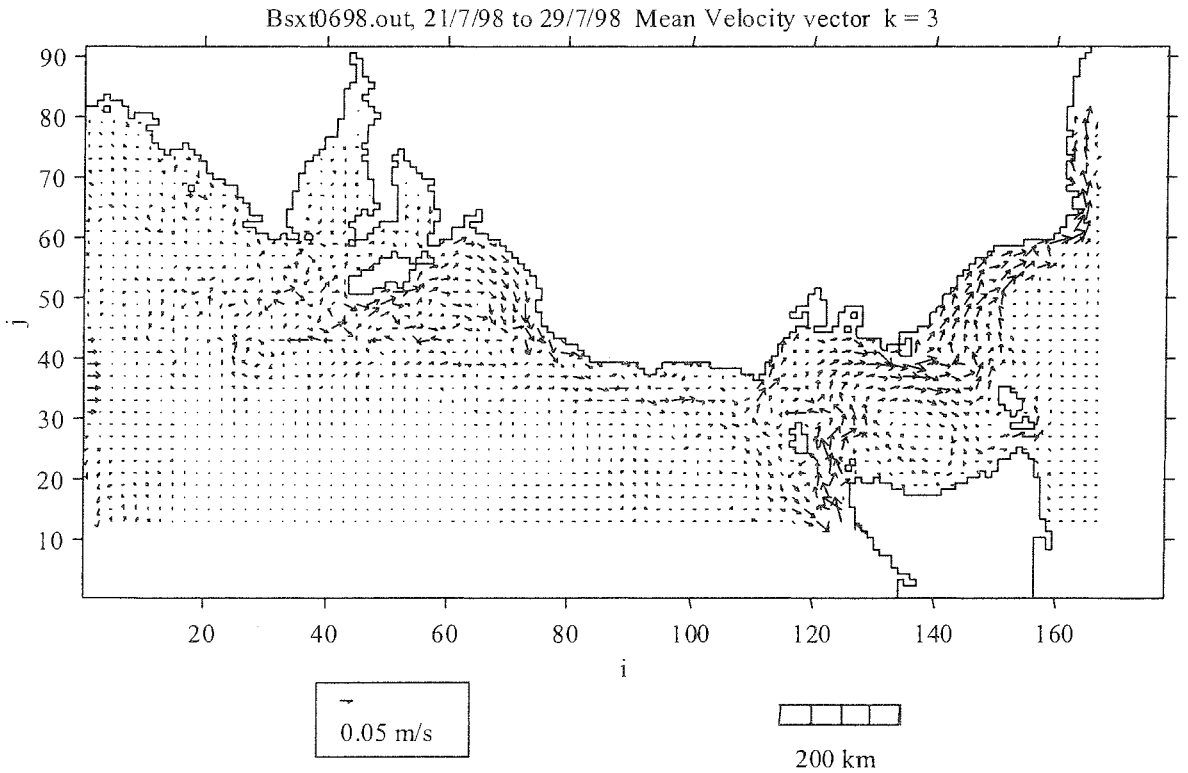


Figure 8C. Simulated hydrodynamic current model of southeastern Australia at a depth of 15-35 m obtained for the period 21-29 July 1998 (Cruise 4). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

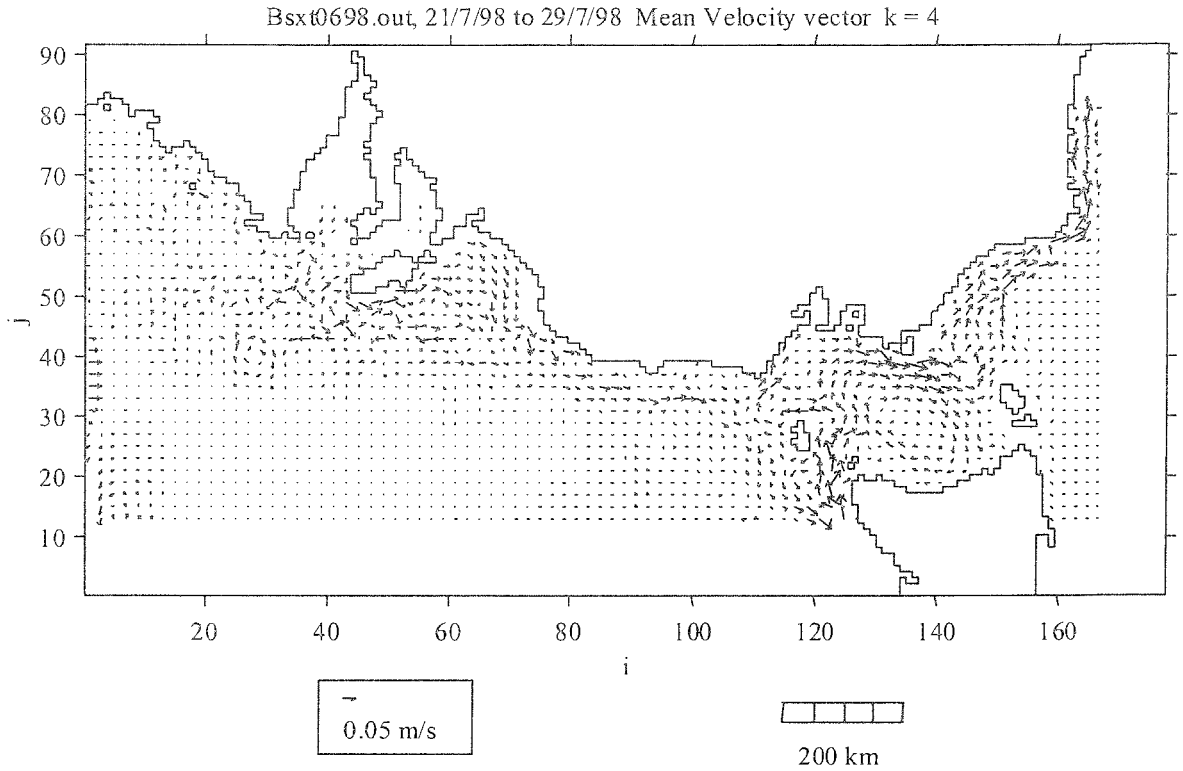


Figure 8D. Simulated hydrodynamic current model of southeastern Australia at a depth of 35-55 m obtained for the period 21-29 July 1998 (Cruise 4). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

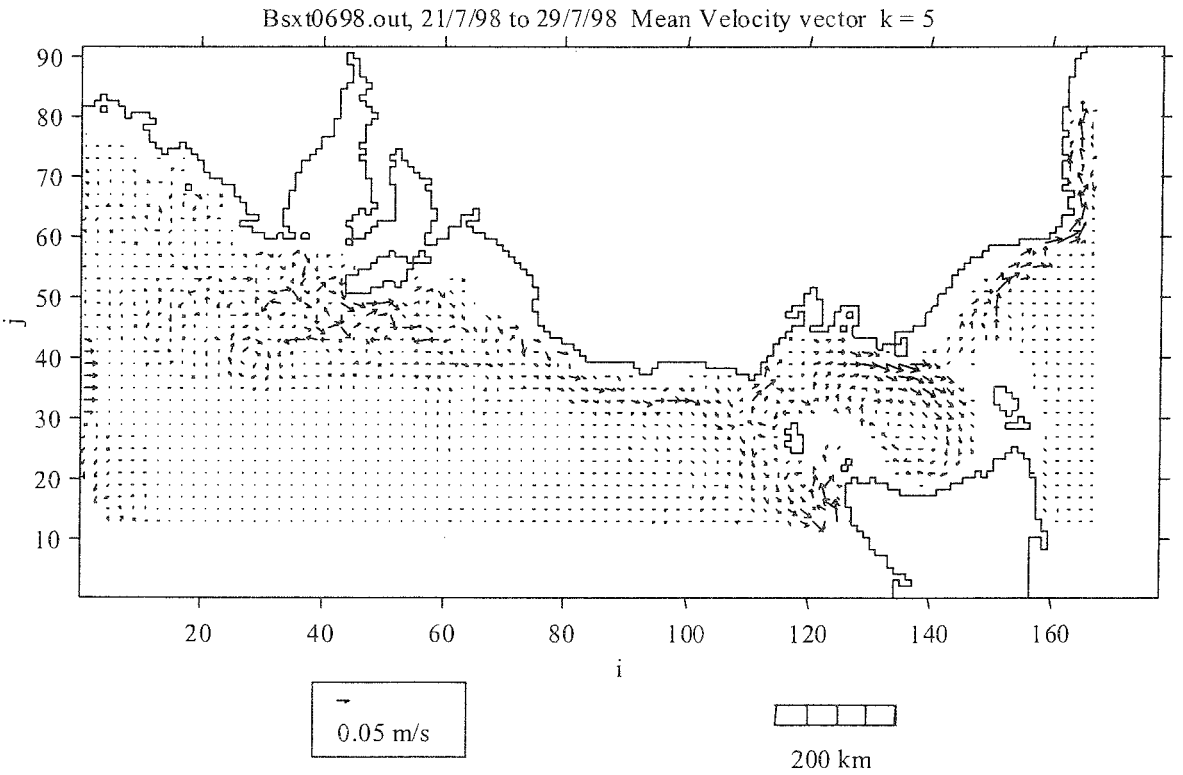


Figure 8E. Simulated hydrodynamic current model of southeastern Australia at a depth of 55-75 m obtained for the period 21-29 July 1998 (Cruise 4). Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

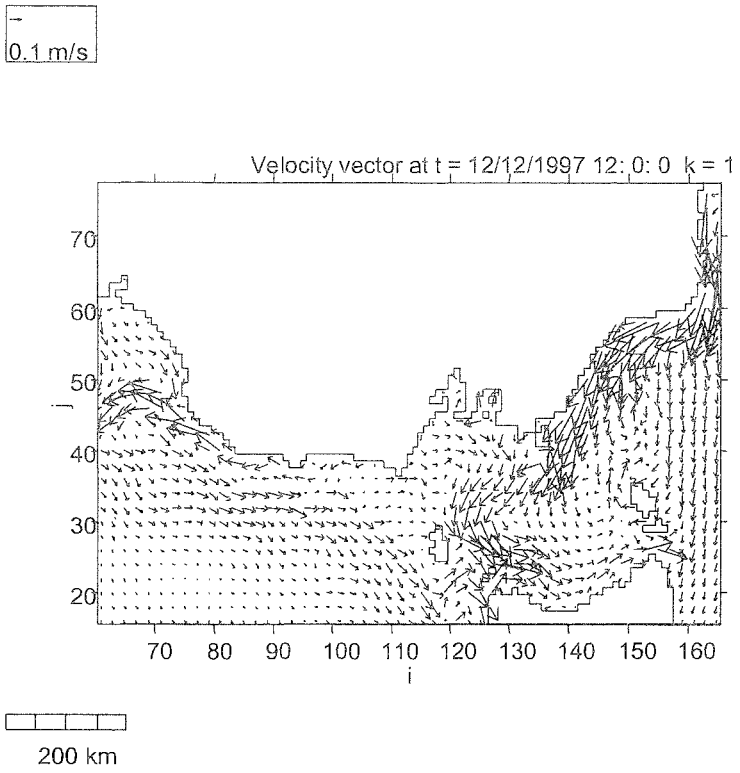


Figure 9A. Surface (0-5 m) current vectors predicted by hydrodynamic modelling for southeastern Australia during Cruise 2 at 12:00 h on December 12, 1997. Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

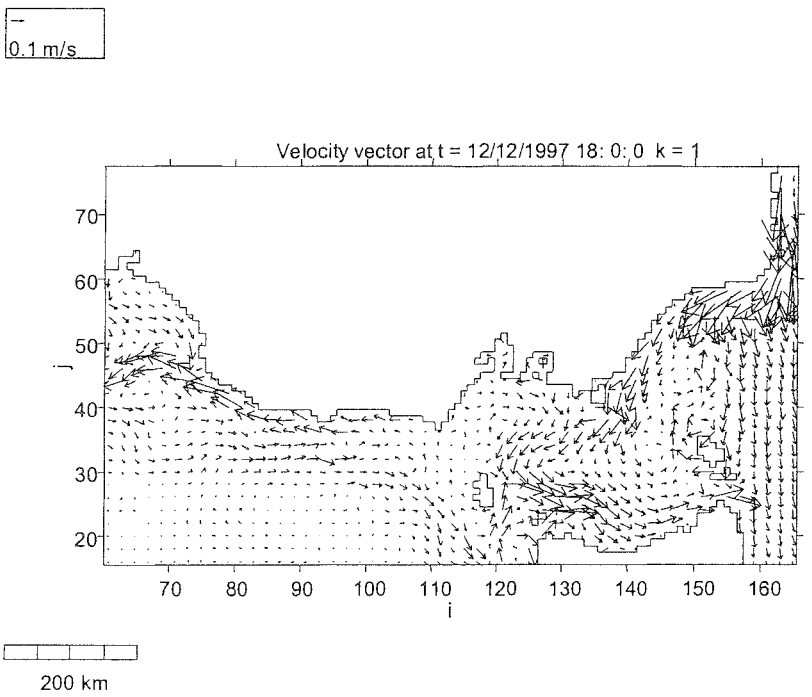


Figure 9B. Surface (0-5 m) current vectors predicted by hydrodynamic modelling for southeastern Australia during Cruise 2 at 18:00 h on December 12, 1997. Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

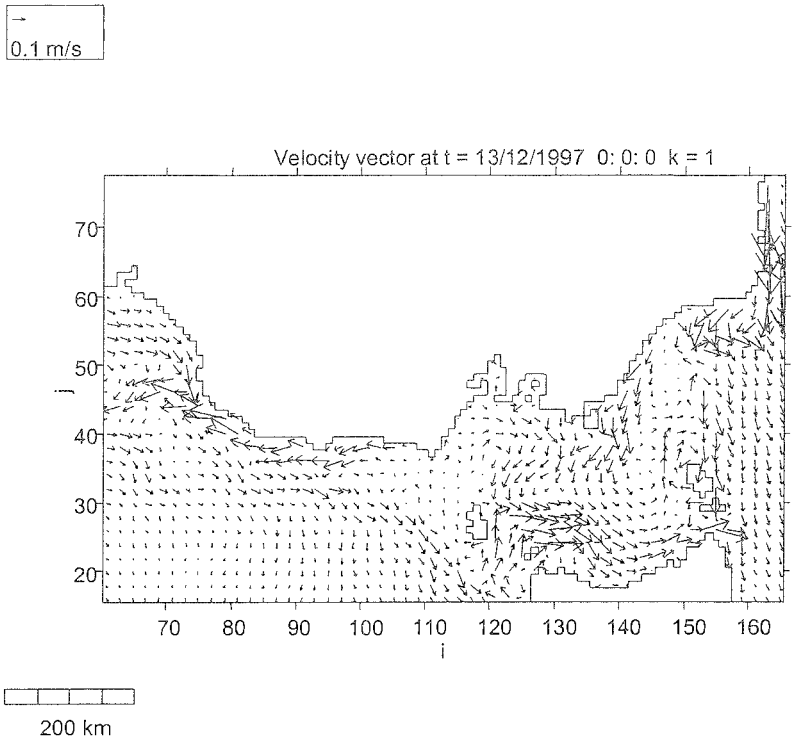


Figure 9C. Surface (0-5 m) current vectors predicted by hydrodynamic modelling for southeastern Australia during Cruise 2 at 00:00 h on December 13, 1997. Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

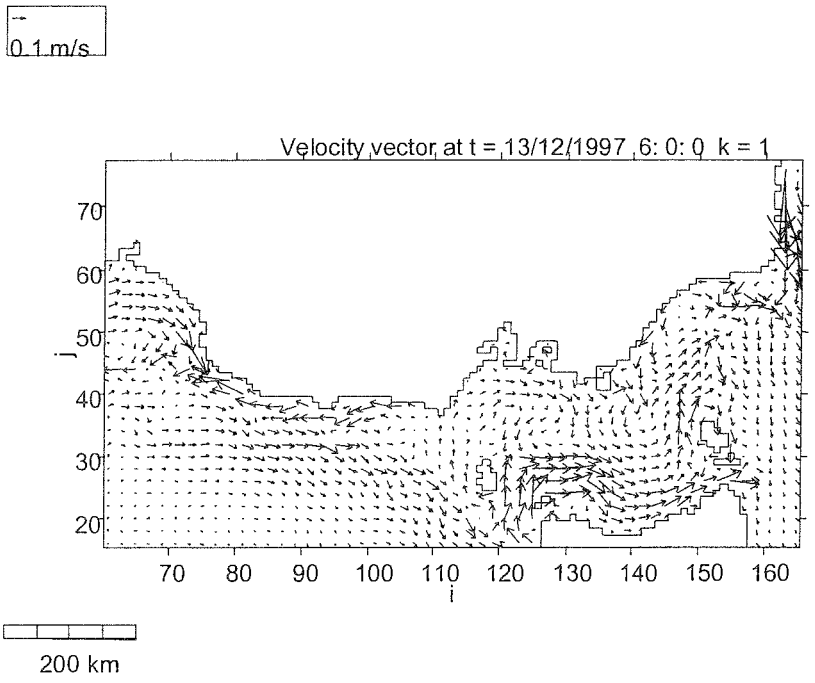


Figure 9D. Surface (0-5 m) current vectors predicted by hydrodynamic modelling for southeastern Australia during Cruise 2 at 06:00 h on December 13, 1997. Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

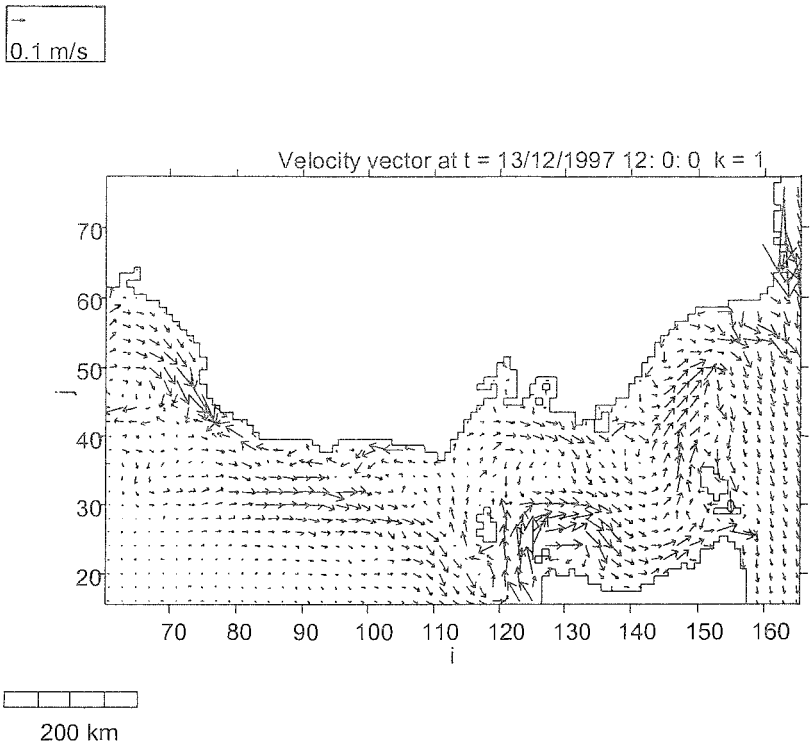


Figure 9E. Surface (0-5 m) current vectors predicted by hydrodynamic modelling for southeastern Australia during cruise 2 at 12:00 h on December 13, 1997. Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

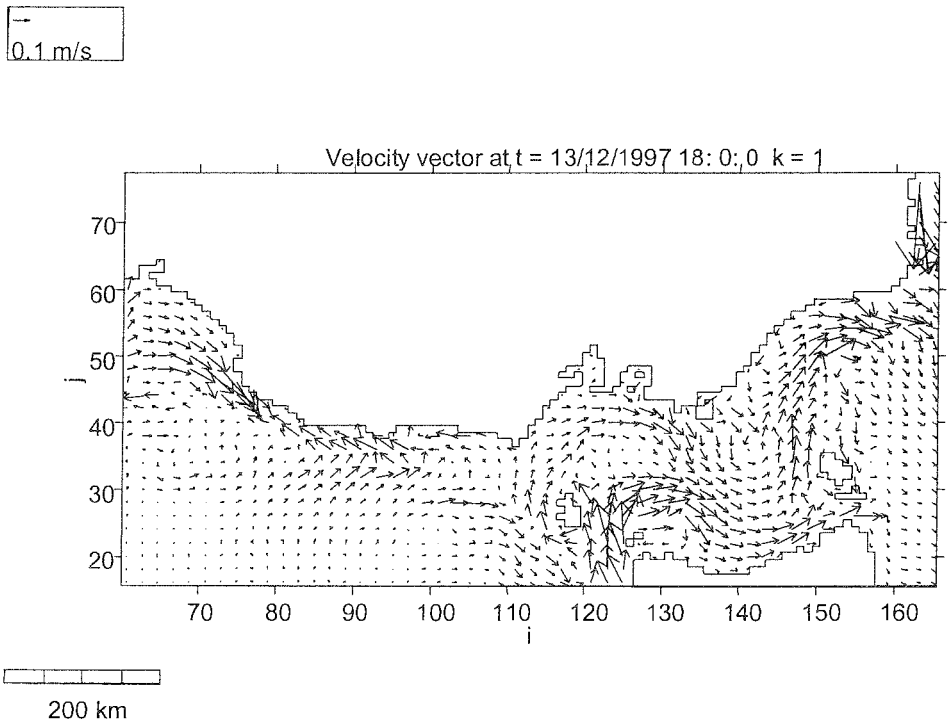


Figure 9F. Surface (0-5 m) current vectors predicted by hydrodynamic modelling for southeastern Australia during cruise 2 at 18:00 h on December 13, 1997. Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

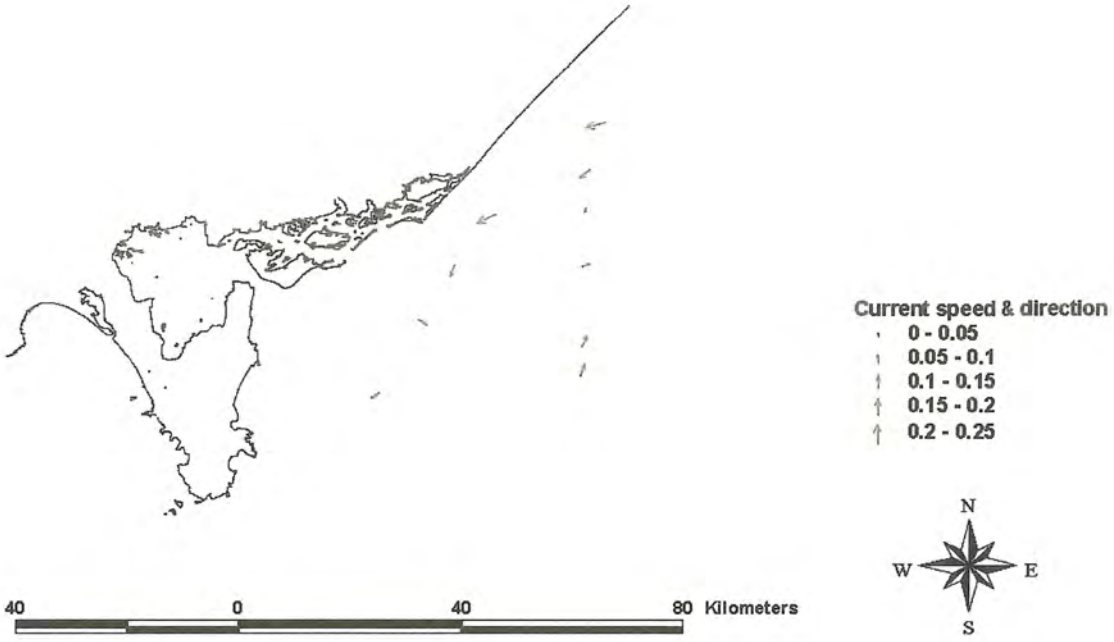


Figure 10. Tidally corrected shipboard ADCP current measurements for the area just east of Wilsons Promontory during cruise 2 on the 12/13 of December, 1997. Arrows indicate current direction; length of lines are proportional to current velocity (m/s).

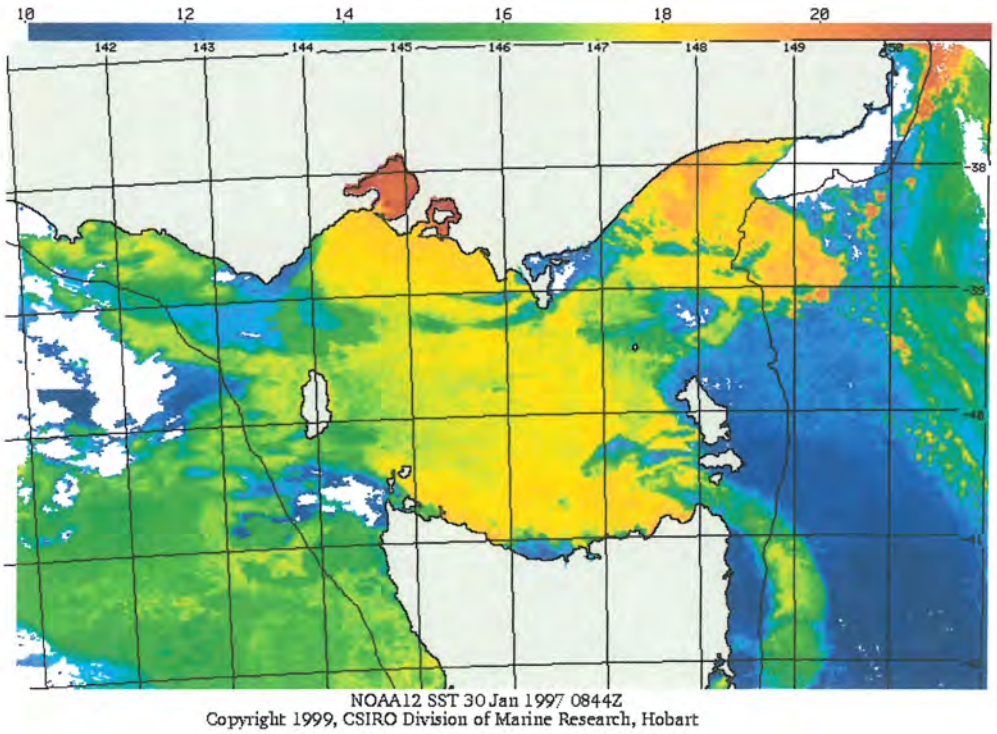


Figure 11A. Sea surface temperatures in southeastern Australia on January 30, 1997 (NOAA satellite image obtained from CSIRO).

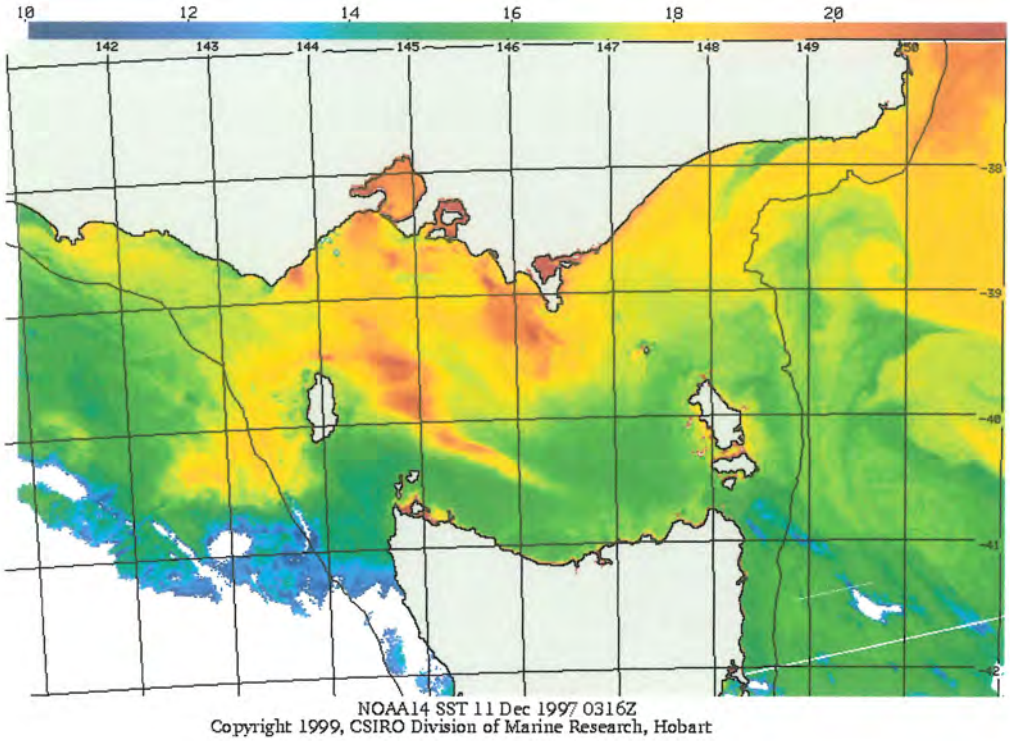


Figure 11B. Sea surface temperatures in southeastern Australia on December 11, 1997 (NOAA satellite image obtained from CSIRO).

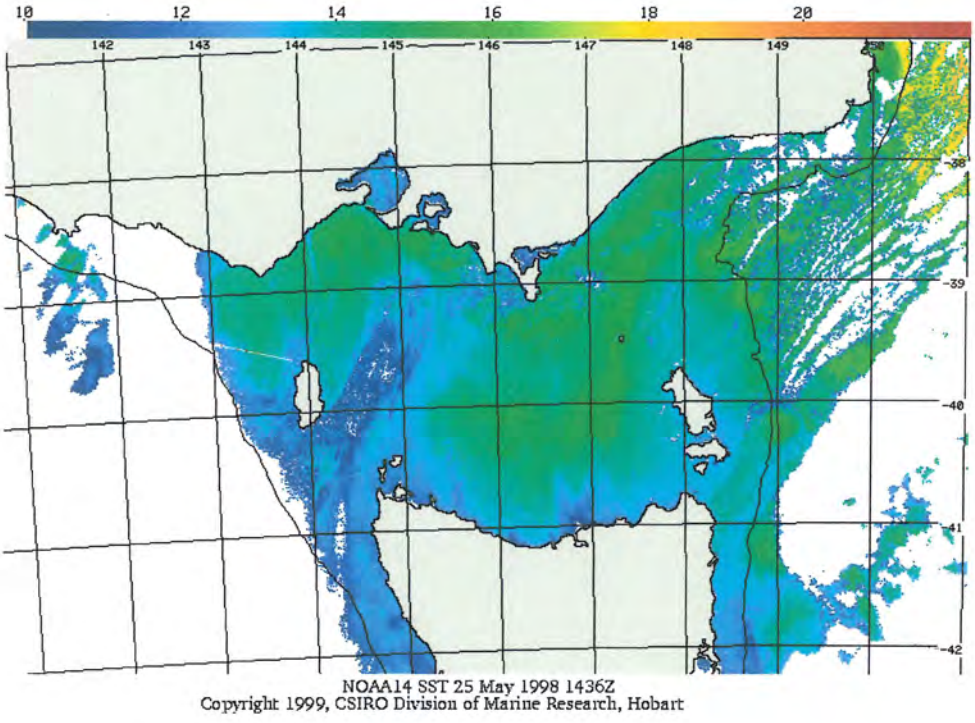


Figure 11C. Sea surface temperatures in southeastern Australia on May 25, 1998 (NOAA satellite image obtained from CSIRO).

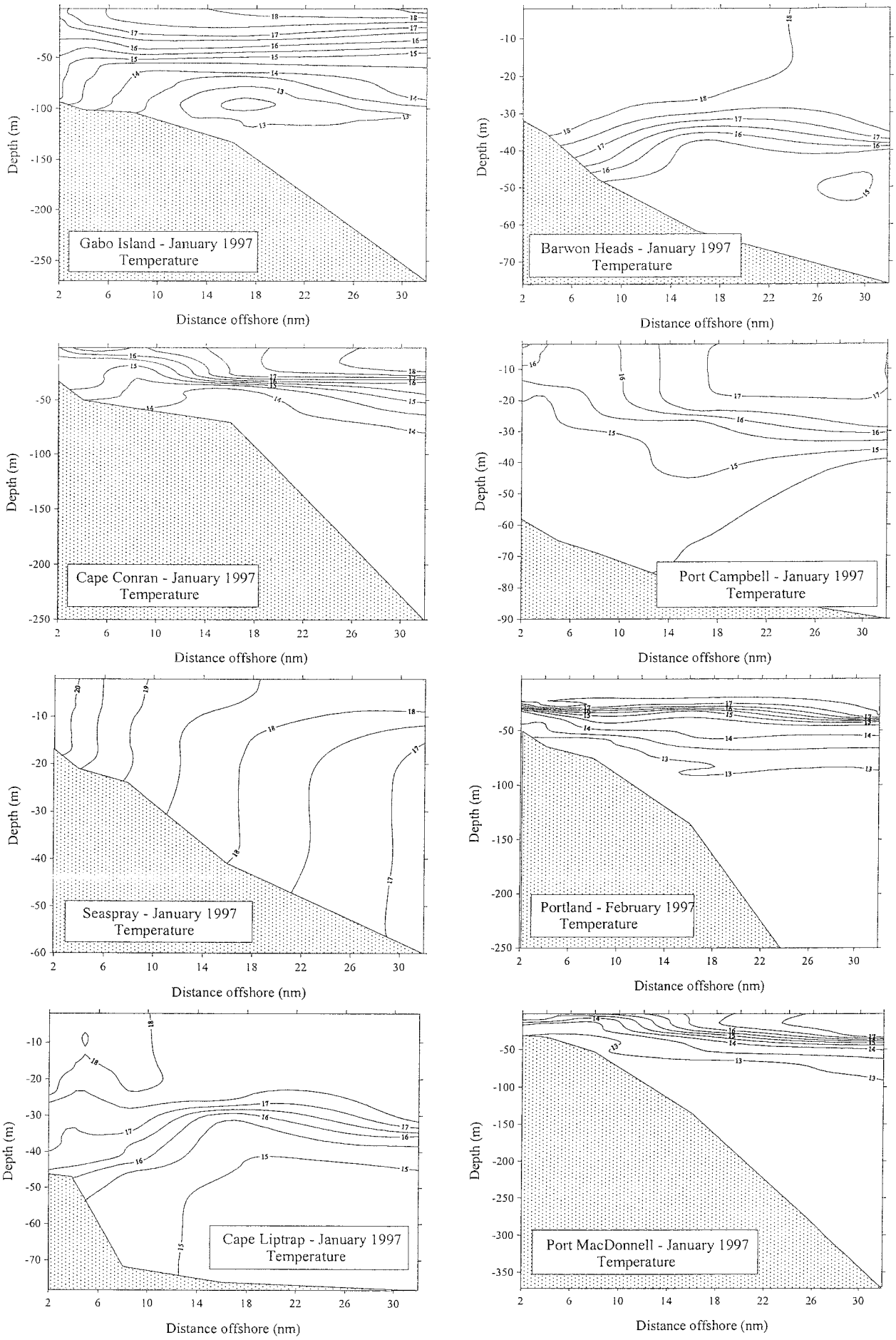


Figure 12A. Vertical temperature profiles in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 1 (Jan-Feb 1997).

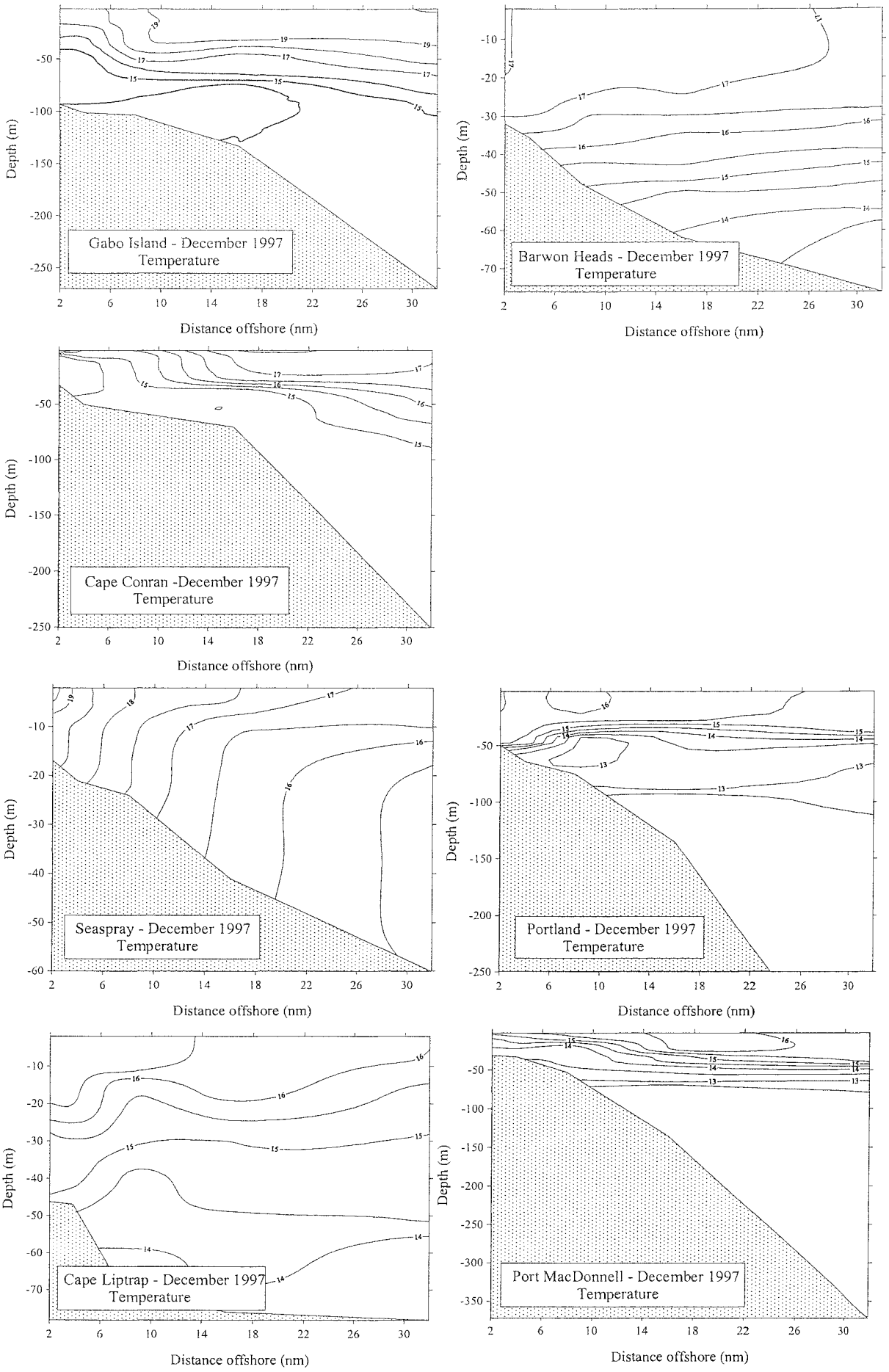


Figure 12B. Vertical temperature profiles in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 2 (Dec 1997). Transect 6 (Port Campbell) was not sampled.

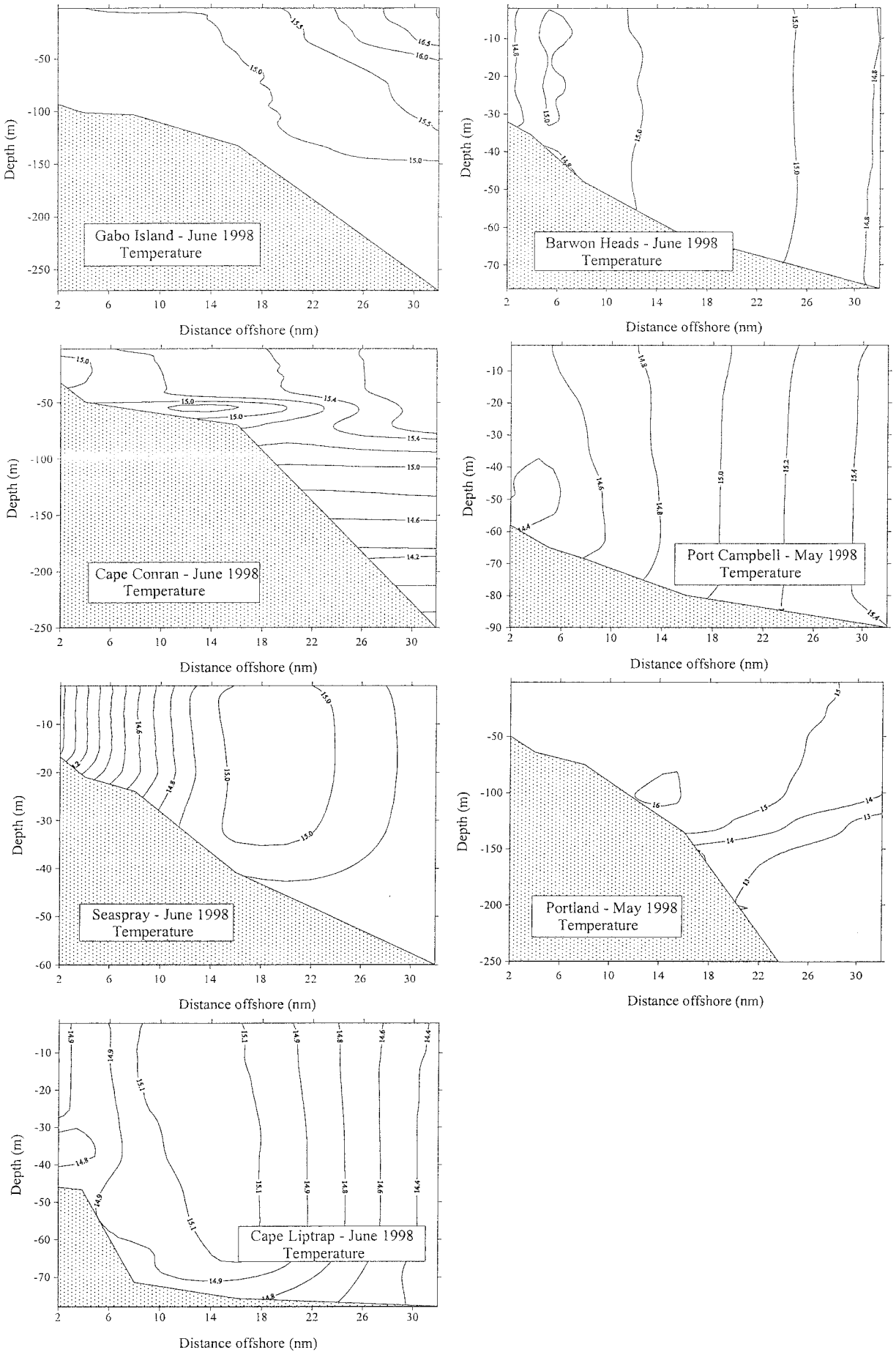


Figure 12C. Vertical temperature profiles in transects 1 (Gabo Island) to 7 (Portland) in southeastern Australia during cruise 3 (May-Jun 1998). Transect 8 (Port MacDonnell) was not sampled.

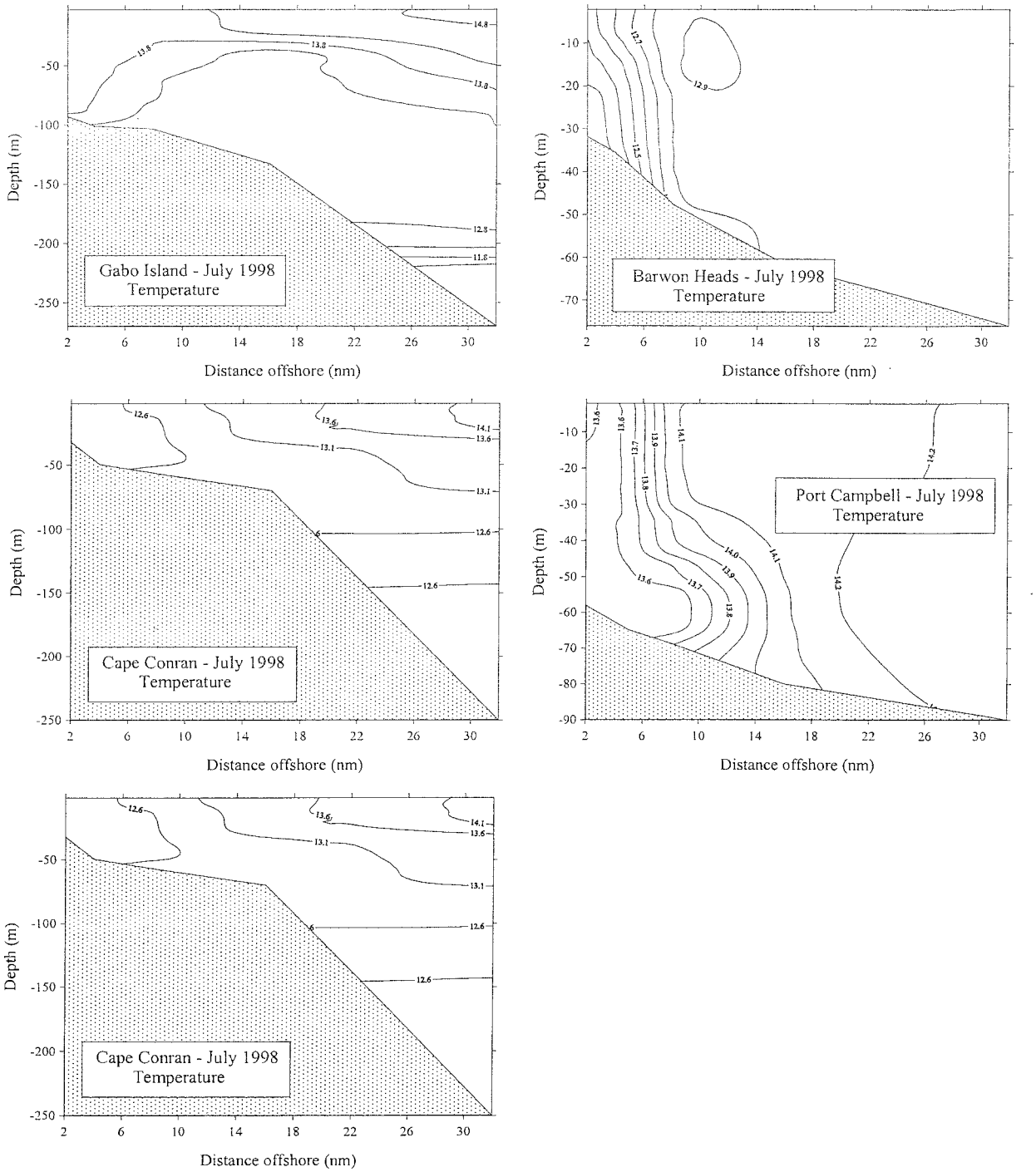


Figure 12D. Vertical temperature profiles in transects 1 (Gabo Island) to 6 (Port Campbell) in southeastern Australia during cruise 4 (Jul 1998). Transect 3 (Seaspray) was not sampled; data for transects 7 (Portland) and 8 (Port MacDonnell) are incomplete.

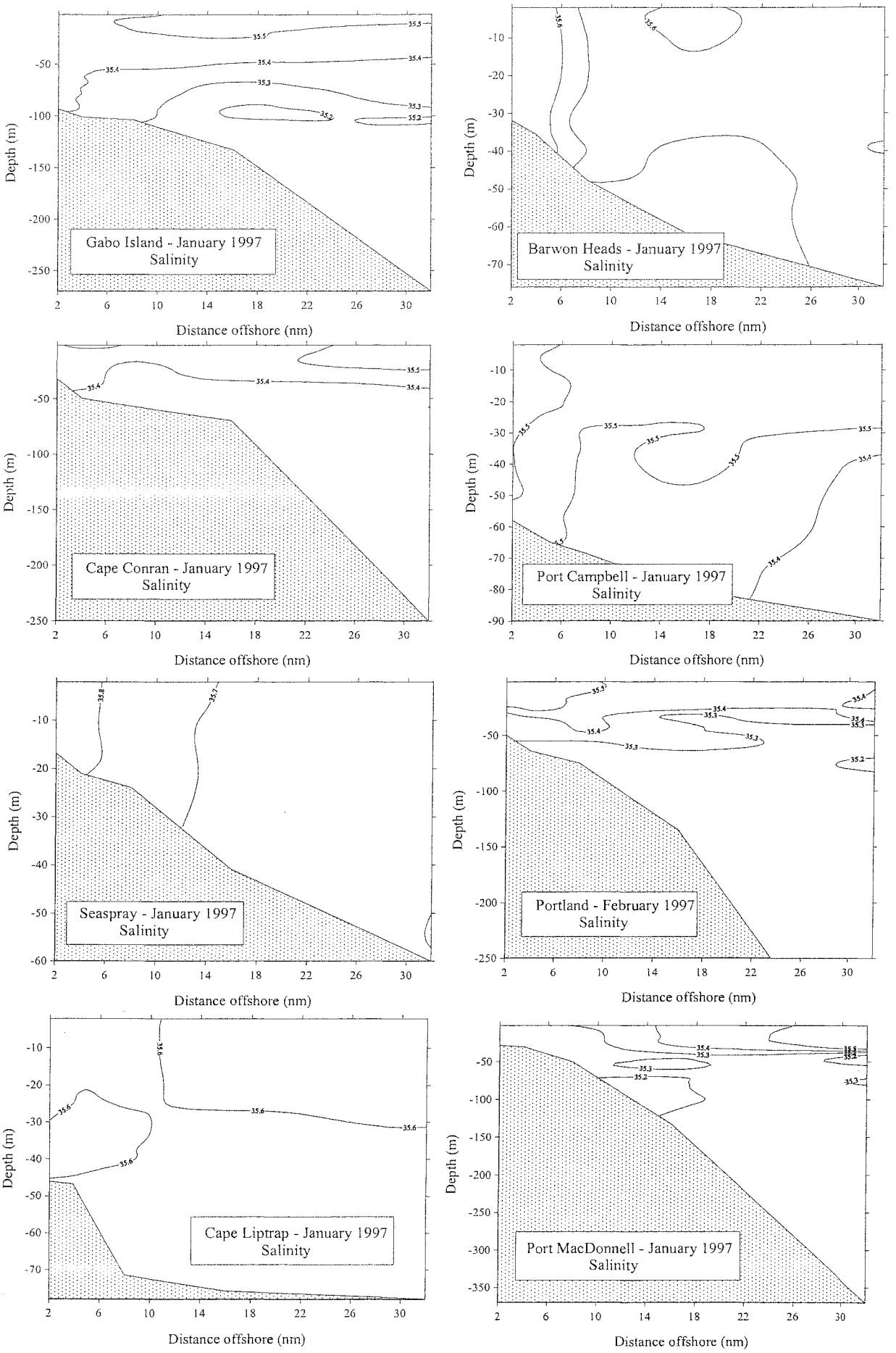


Figure 13A. Vertical salinity profiles in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 1 (Jan-Feb 1997).

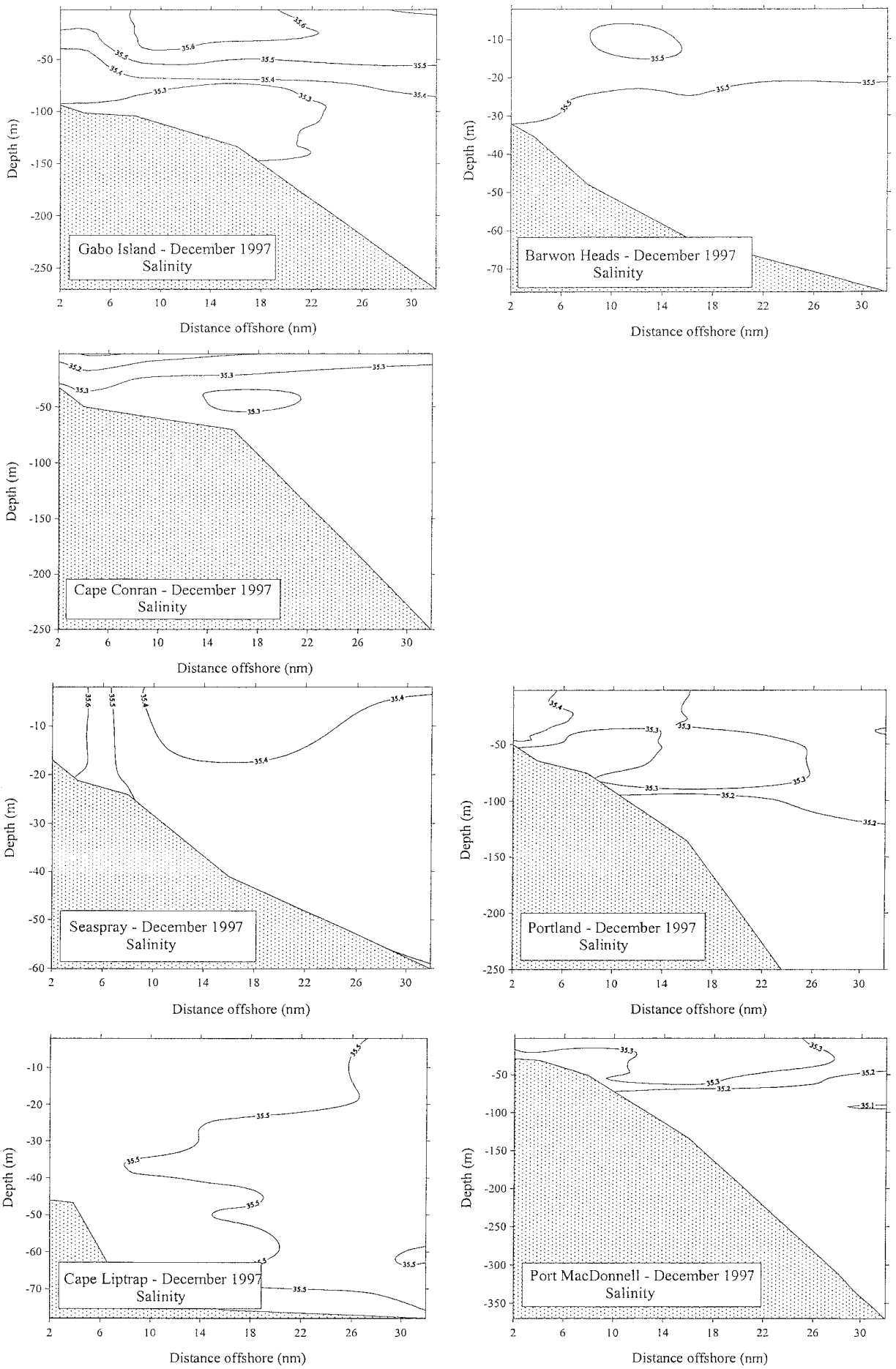


Figure 13B. Vertical salinity profiles in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 2 (Dec 1997). Transect 6 (Port Campbell) was not sampled.

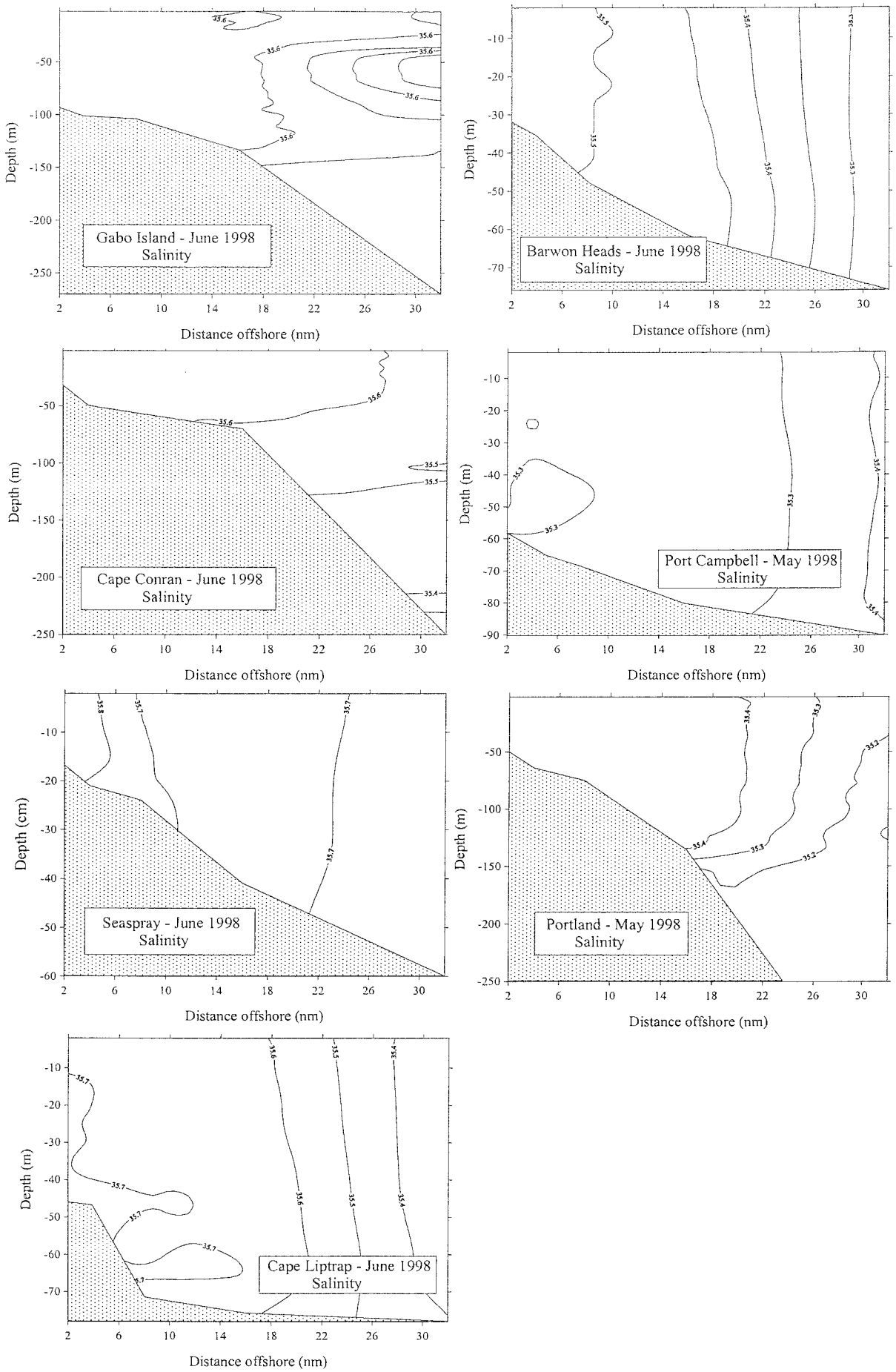


Figure 13C. Vertical salinity profiles in transects 1 (Gabo Island) to 7 (Portland) in southeastern Australia during cruise 3 (May-Jun 1998). Transect 8 (Port MacDonnell) was not sampled.

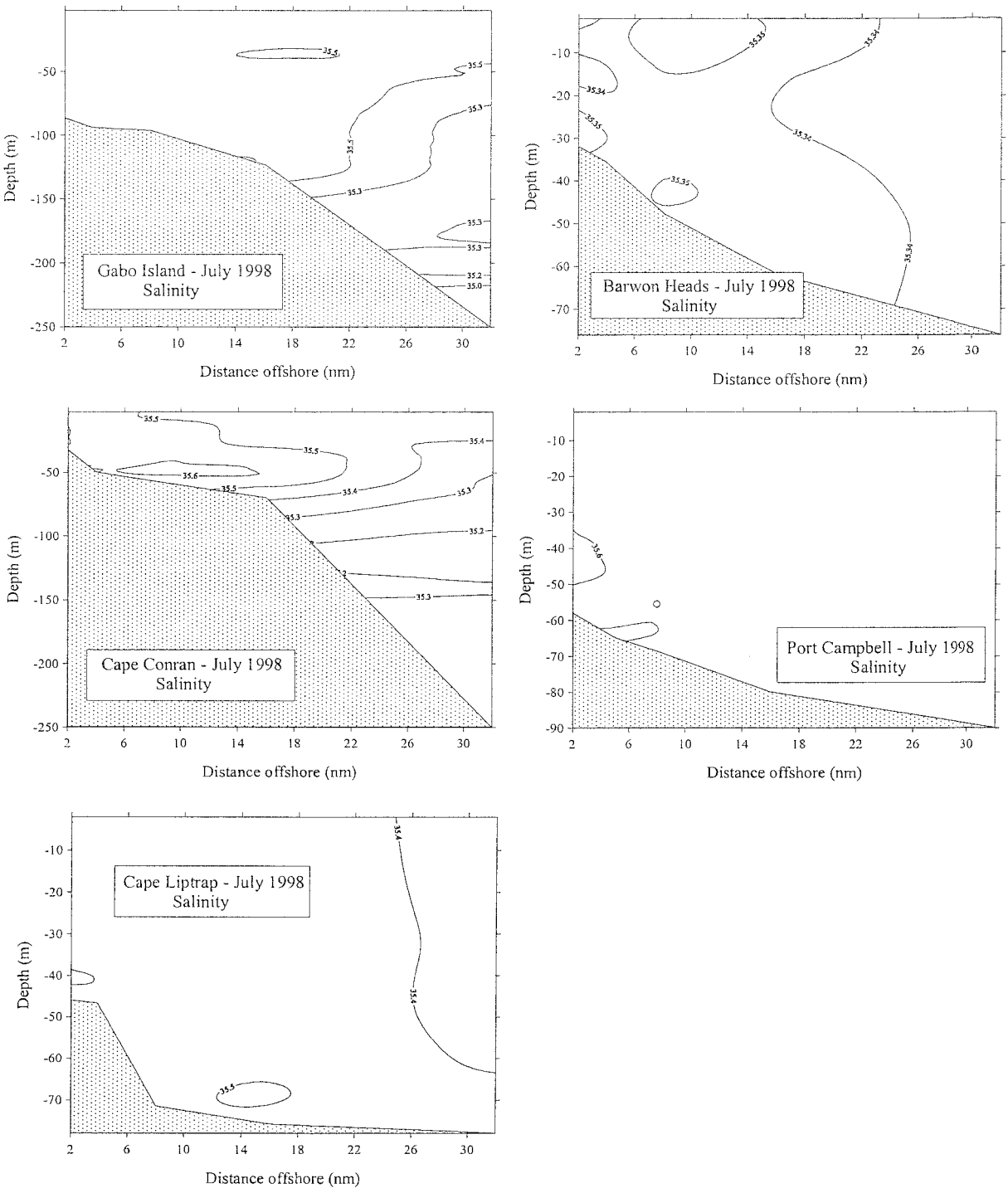


Figure 13D. Vertical salinity profiles in transects 1 (Gabo Island) to 6 (Port Campbell) in southeastern Australia during cruise 4 (Jul 1998). Transect 3 (Seaspray) was not sampled; data for transects 7 (Portland) and 8 (Port MacDonnell) are incomplete.

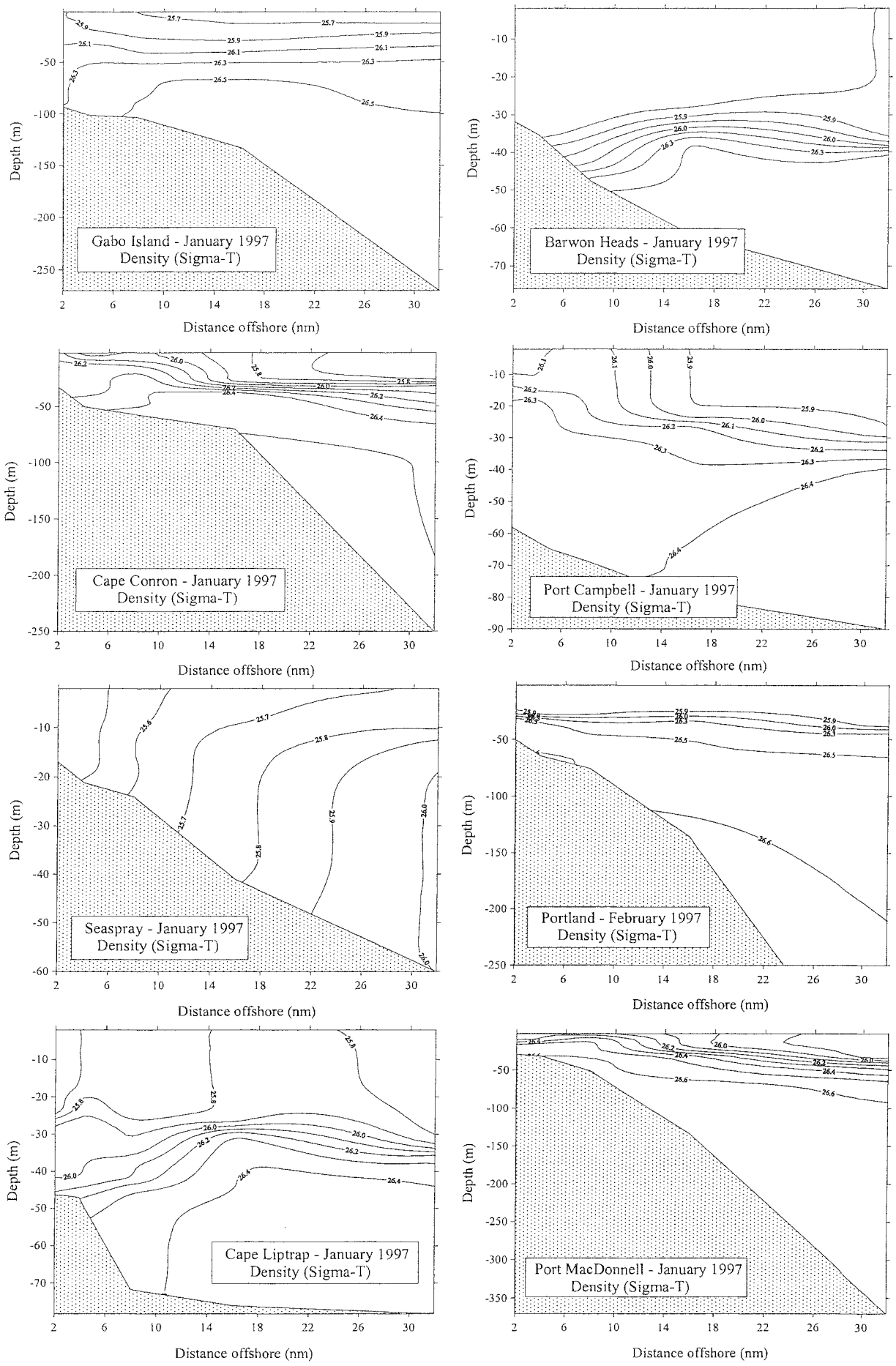


Figure 14A. Vertical density profiles (Sigma-T) in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 1 (Jan-Feb 1997).

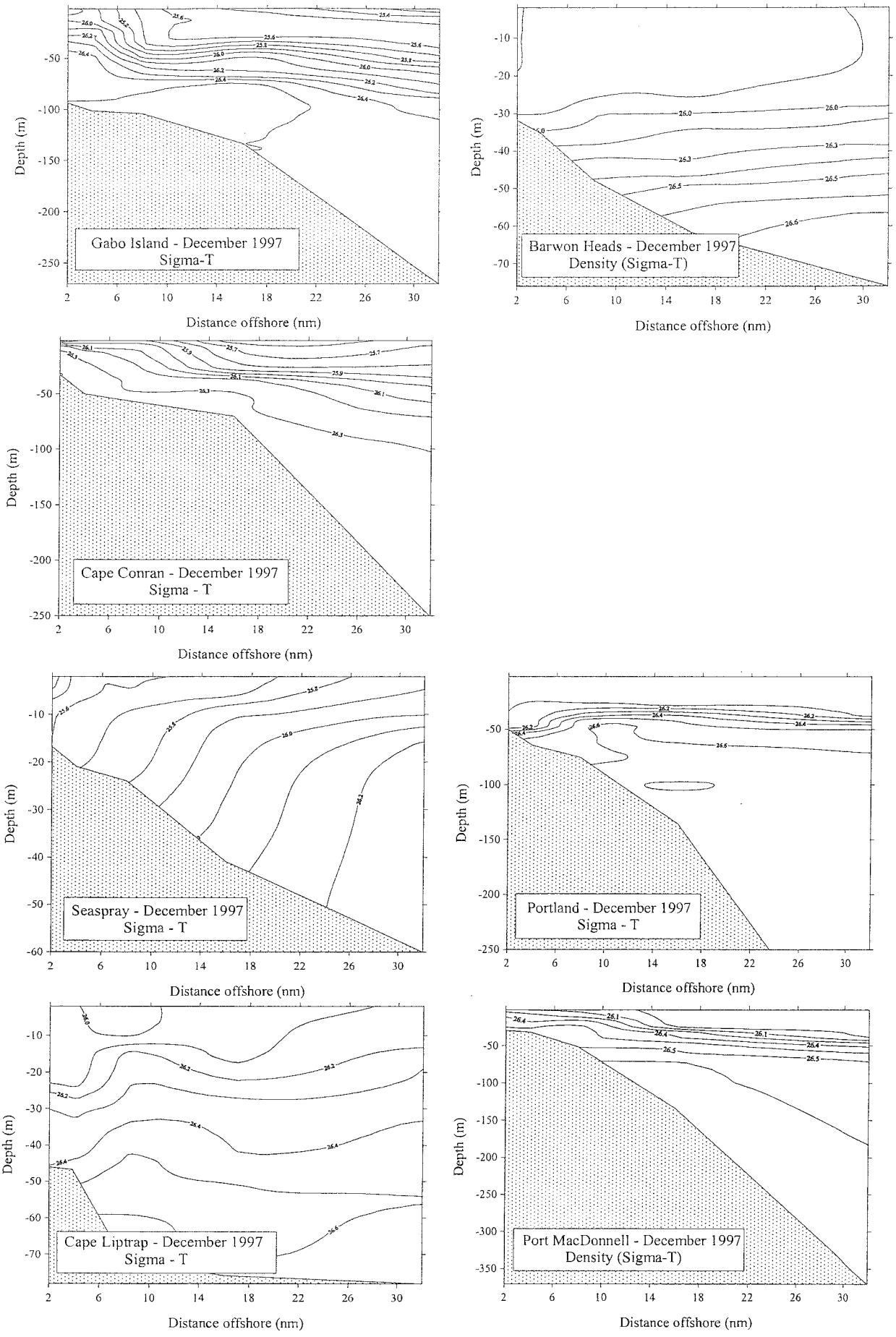


Figure 14B. Vertical density profiles (Sigma-T) in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 2 (Dec 1997). Transect 6 (Port Campbell) was not sampled.

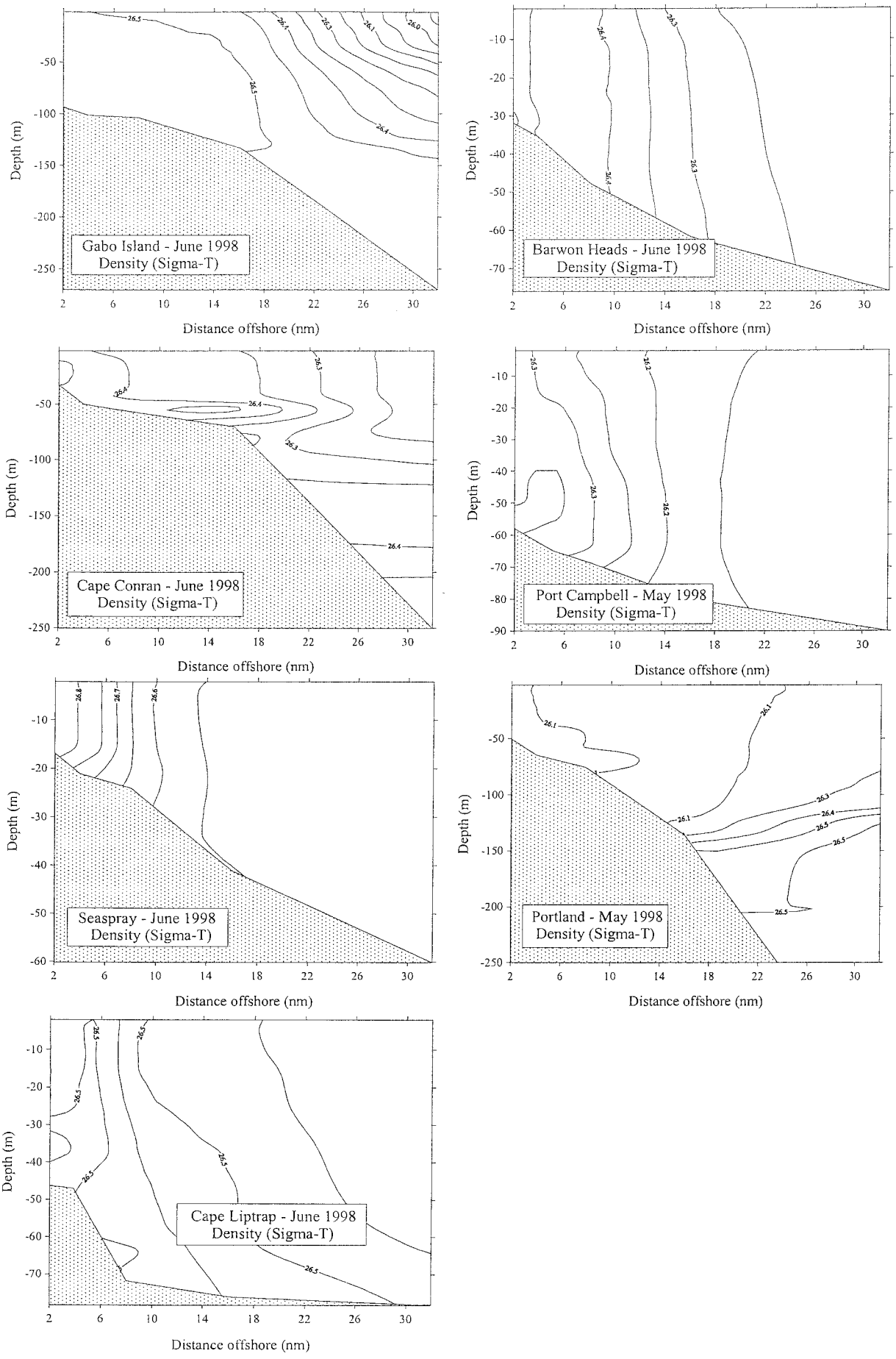


Figure 14C. Vertical density profiles (Sigma-T) in transects 1 (Gabo Island) to 7 (Portland) in southeastern Australia during cruise 3 (May-Jun 1997). Transect 8 (Port MacDonnell) was not sampled.

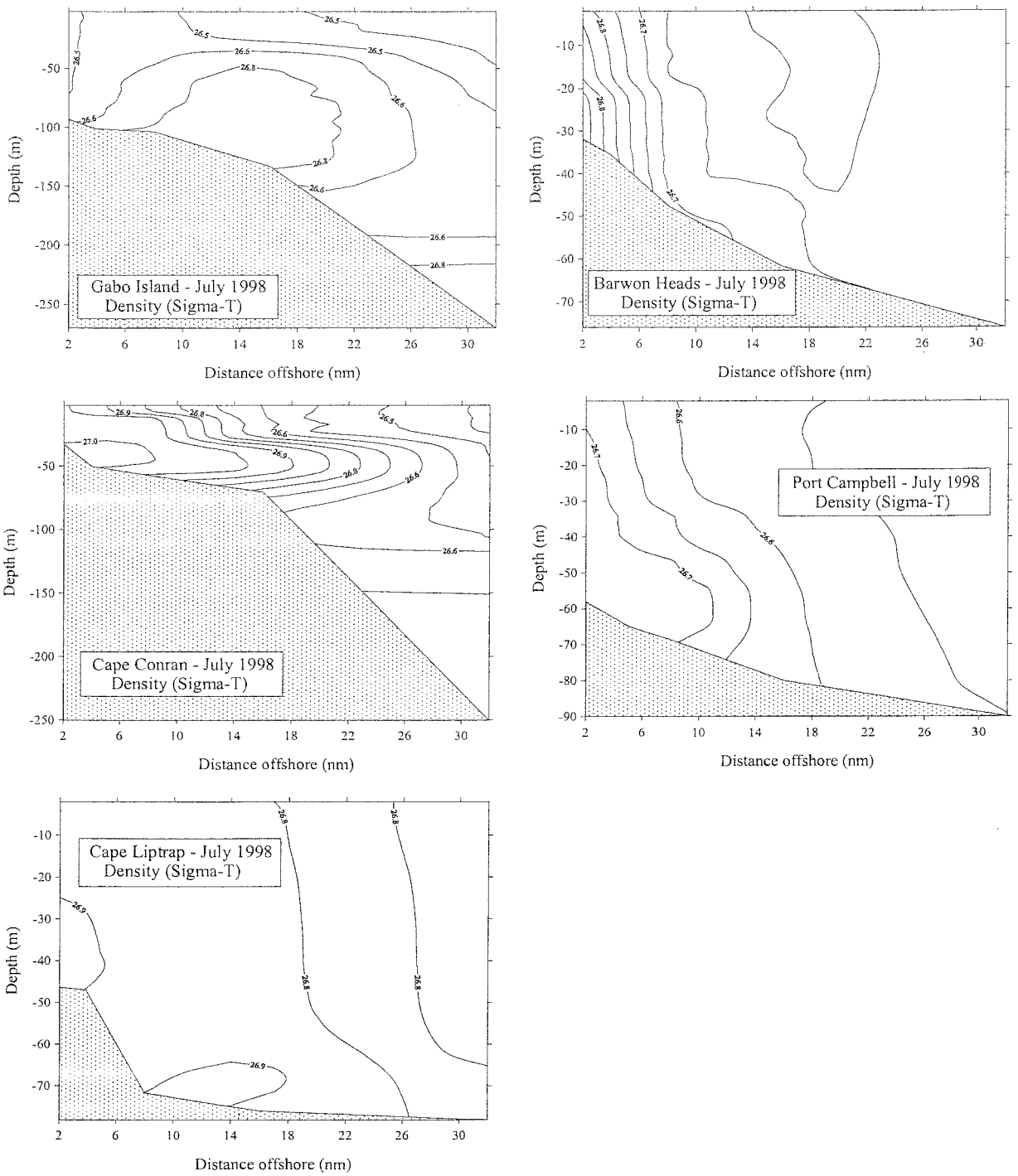


Figure 14D. Vertical density profiles (Sigma-T) in transects 1 (Gabo Island) to 6 (Port Campbell) in southeastern Australia during cruise 4 (Jul 1998). Transect 3 (Seaspray) was not sampled; data for transects 7 (Portland) and 8 (Port MacDonnell) are incomplete.

5.2 Hydrochemistry

5.2.1 Inorganic nutrients

5.2.1.1 *Dissolved inorganic nitrogen*

No dissolved inorganic nitrogen (DIN) data was available for the Gabo Island transect during the summer cruise 1 (Jan-Feb 1997) (Fig. 15A). Surface DIN concentrations were <1 µM on all other transects, and there was strong vertical stratification in DIN concentration for each transect except Seaspray. Highest DIN concentrations (>8 µM) occurred below 100 m off Cape Conran. Dissolved inorganic nitrogen concentrations were lowest (<1 µM) at all depths off Seaspray, and increased for each transect west to 5-8 µM at depth off Portland and Port MacDonnell. The variation with depth was more significant than variation with distance from shore. The slope on lines of equal concentration on the Port MacDonnell transect indicated the possibility of near-shore upwelling (Fig. 15A).

During summer cruise 2 (Dec 1997), DIN varied from <0.4 to >12 µM (Fig. 15B). There was strong vertical stratification along most transects, with little change in concentration with distance from shore. The highest concentrations occurred below 100 m off Port MacDonnell, while surface concentrations were all below 2 µM. There was evidence of a possible sub-surface intrusion to 35 m depth about 8 nm off Portland. Along the Gabo Island transect, concentrations were quite variable with depth and distance from shore, although highest concentrations (~5 µM) were observed at a depth of about 50 m.

Dissolved inorganic nitrogen concentrations of 0.6-7.5 µM were observed during the winter cruise 4 (Jul 1998) (Fig. 15D). Highest concentrations were observed in the east, on the Gabo Island and Cape Conran transects, where high concentrations were observed both in the near-shore sub-surface and at depth beyond 16 nm offshore. Moderate DIN concentrations (<4 µM) were observed 32 nm offshore on the Port MacDonnell transect, with much lower concentrations (<2 µM) along the shallower transects.

5.2.1.2 *Phosphate*

Surface phosphate concentrations were <0.3 µM on all transects during the summer cruise 1 (Jan-Feb 1997) (Fig. 16A). Although there were variations in concentration with depth, they were neither as large nor as consistent as with DIN. A cell of high

concentration (~0.8 µM) was observed at 80 m depth between 4 and 8 nm off Gabo Island. Phosphate concentrations decreased with distance from shore on the Seaspray transect, indicating the possibility of a near-shore discharge. Phosphate concentrations increased with depth on all other transects to ~0.5-0.6 µM below 100 m (Fig. 16A).

Phosphate concentrations during the summer cruise 2 (Dec 1997) were <0.2 µM in surface waters on all transects, and at all depths on the Seaspray and Portland transects (Fig. 16B). The water column was vertically stratified on the Gabo Island and Port MacDonnell transects, with phosphate concentration below 80 m depth exceeding 0.7 and 0.5 µM, respectively. The water column was horizontally rather than vertically stratified on the Cape Conran transect, with phosphate concentration increasing from <0.2 µM at 32 nm to ~0.8 µM within 2 nm of the coast. The opposite was observed along the Seaspray transect, where phosphate concentrations increased from 0.09 to 0.19 µM with distance from shore.

During the winter cruise 3 (May-Jun 1998), phosphate concentrations varied between 0.2 and 1.5 µM, but on most transects the variation was much smaller and showed no spatial pattern (Fig. 16C). Concentrations increased from 0.3 to 1.0 µM with distance offshore on the Cape Liptrap transect. Off Port Campbell, concentrations varied from 0.5 µM at the surface to 0.9 µM at 25 m depth, while the maximum concentration of 1.5 µM recorded at 130 m depth 16 nm from shore may have been the remnant of an upwelling event.

Phosphate concentrations during the winter cruise 4 (Jul 1998) varied over a narrow range (0.2-0.4 µM) on all transects except off Gabo Island, where concentrations varied from 0.6 µM at the surface to >1.0 µM below the shelf break (>16 nm offshore) (Fig. 16D).

5.2.1.3 *Silicate*

Silicate concentrations varied significantly between transects during the summer cruise 1 (Jan-Feb 1997) (Fig. 17A-D). Concentrations increased with depth on most transects, from <1 µM at the surface to 2-3 µM at depth. However, the water column along the Seaspray transect was vertically well-mixed, and silicate concentration increased with distance offshore from <0.2 at 2 nm to >1.8 µM at 32 nm (Fig. 17A). The highest silicate concentration on the Portland transect occurred as a cell at 100 m depth 8 nm from shore. The slope on lines of equal concentration on the Port MacDonnell transect indicated the possibility of near-shore (2-8 nm) upwelling.

Silicate concentrations during the summer cruise 2 (Dec 1997) varied between <0.1 and 3 µM (Fig. 17B). All sites were vertically stratified except for Seaspray, where silicate concentration increased with distance from shore from <0.1 to >0.8 µM. A lens of high concentration occurred at 75 m depth at the near-shore Gabo Island site. A similar lens to 3 µM occurred at a depth of 25-50 m at the near-shore Cape Conran site. There was evidence of a sub-surface intrusion 8 nm from Portland, but no evidence of upwelling at Port MacDonnell.

During the winter cruise 3 (May-Jun 1998), silicate concentrations varied within a narrow range (0.5-1.6 µM), and generally increased offshore and with depth (Fig. 17C). However, concentrations decreased offshore on the Port Campbell transect.

During the winter cruise 4 (Jul 1998), silicate concentrations between the Cape Liptrap and Port Campbell transects varied between 0.1-0.4 µM, with the highest concentrations being recorded onshore (Fig. 17D). Further east and west, concentrations were higher at the surface (0.9-1.5 µM), increasing to 1.5-5 µM at depths > 100 m.

5.2.1.4 *Fluorescence*

The pattern in fluorescence during the summer cruise 1 (Jan-Feb 1997) was similar along all except the Seaspray transect, and was characterised by a near-shore sub-surface maximum (20-50 m) that was accompanied by another maximum at 40-50 m depth 32 nm from shore (Fig. 18A). Fluorescent response was lowest (10-40 units) on the Cape Conran, Seaspray and Port MacDonnell transects, and highest (10-75 units) on the Gabo Island, Port Campbell and Portland transects. The nutrient upwelling inferred at Port MacDonnell did not lead to an increase in fluorescence in the vertical profiles, either near-shore or elsewhere. The maximum fluorescence on the Seaspray transect occurred at >10 m depth near-shore, and is consistent with enhanced productivity from a nearshore nutrient discharge (Fig. 18A).

Fluorescence during the summer cruise 2 (Dec 1997) varied from 2 to 44 units, with all surface waters less than 6 units. Maximum fluorescence occurred at 25-80 m (Fig. 18B). The distance from shore of the zone of peak fluorescence varied from 32 nm off Barwon Heads (32 units), to 4-8 nm from Portland, Port MacDonnell and Gabo Island (40, 31 and 22 units, respectively), and to 2 nm from Cape Liptrap (44 units). The zone of highest fluorescence off Portland coincided with a sub-surface intrusion of cold water, identified by peaks in DIN, phosphate and silicate concentrations.

During the winter cruise 3 (May-Jun 1998), fluorescence varied over the range 2-22 units, with maxima at depths of 20-50 m (Fig. 18C). Higher fluorescence occurred close to shore at Cape Liptrap and Barwon Heads, but further offshore on all other transects. Highest fluorescence during this cruise was recorded between Barwon Heads and Port Campbell. During the winter cruise 4 (Jul 1998), fluorescence varied over the range of 4-20 units, with a maximum at 10-30 m depth at all sites (Fig. 18D).

5.2.2 Surface chlorophyll *a* concentrations

Surface chlorophyll *a* concentrations ranged between 0.2 and 1.5 μgL^{-1}, with substantial differences between cruises and transects (Figs 19, 20). Surface chlorophyll *a* concentrations during the summer cruise 1 (Jan-Feb 1997) varied between 0.2 and 1.5 μgL^{-1}; with relatively high concentrations (>0.6 μgL^{-1}) observed 16 nm off Port MacDonnell, and midway between Cape Conran and Gabo Island (Fig. 19A). These were both areas of high DIN concentration (Fig.15A). The observation that increased fluorescence was not observed in vertical profiles in these areas during this cruise (section 5.2.1.4 above) suggests that there is a lag between upwelling and subsequent phytoplankton growth.

Surface chlorophyll *a* concentrations during the summer cruise 2 (Dec 1997) covered a similar range as that during cruise 1, except that the maximum (0.6-1.5 μgL^{-1}) occurred offshore between Portland and Barwon Heads, off Western Port and inshore at Cape Conran (Fig. 19B). On this occasion, however, an increase in fluorescence in the vertical profiles was also observed off Portland, and was accompanied by a sub-surface increase in DIN concentration (Fig. 15B).

The range in surface chlorophyll *a* concentrations during the winter cruise 3 (May-Jun 1998) was small (0.2-0.6 μgL^{-1}), with onshore maxima at Port Campbell and Barwon Heads (Fig. 20A). The increase in concentrations near Port Campbell accompanied high silicate concentrations near-shore, and some evidence in phosphate concentrations of a recent upwelling further offshore (Figs 16,17).

The range in chlorophyll *a* concentrations increased (0.2-1.5 μgL^{-1}) from June to July 1998, with maxima near Port Campbell, off Barwon Heads and onshore at Cape Conran (Fig. 20B). Only at Cape Conran did high surface chlorophyll *a* concentrations coincide with high nutrient concentrations.

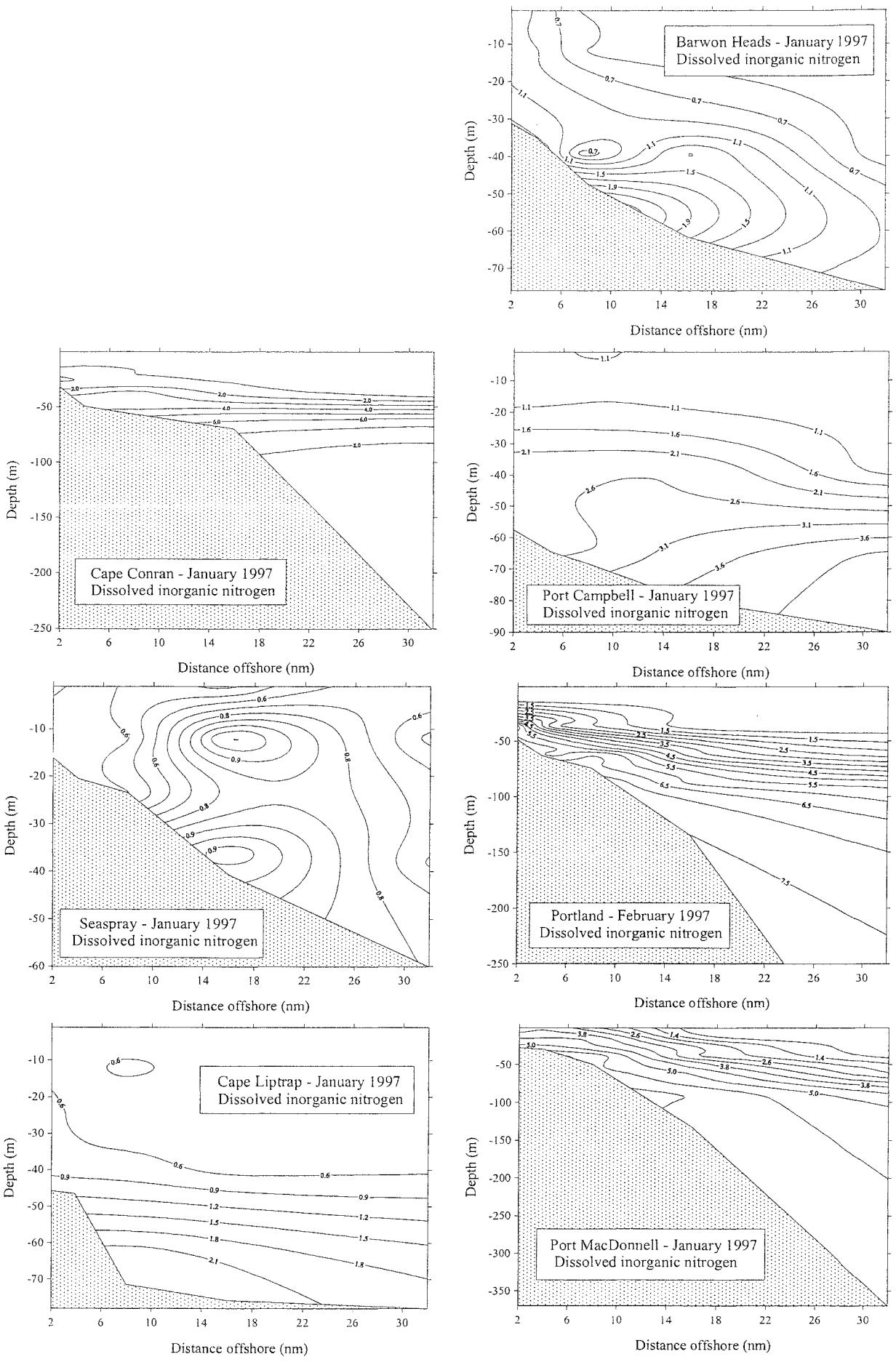


Figure 15A. Vertical dissolved inorganic nitrogen profiles in transects 2 (Cape Conran) to 8 (Port MacDonnell) in southeastern Australia during cruise 1 (Jan-Feb 1997). Data for transect 1 (Gabo Island) are incomplete.

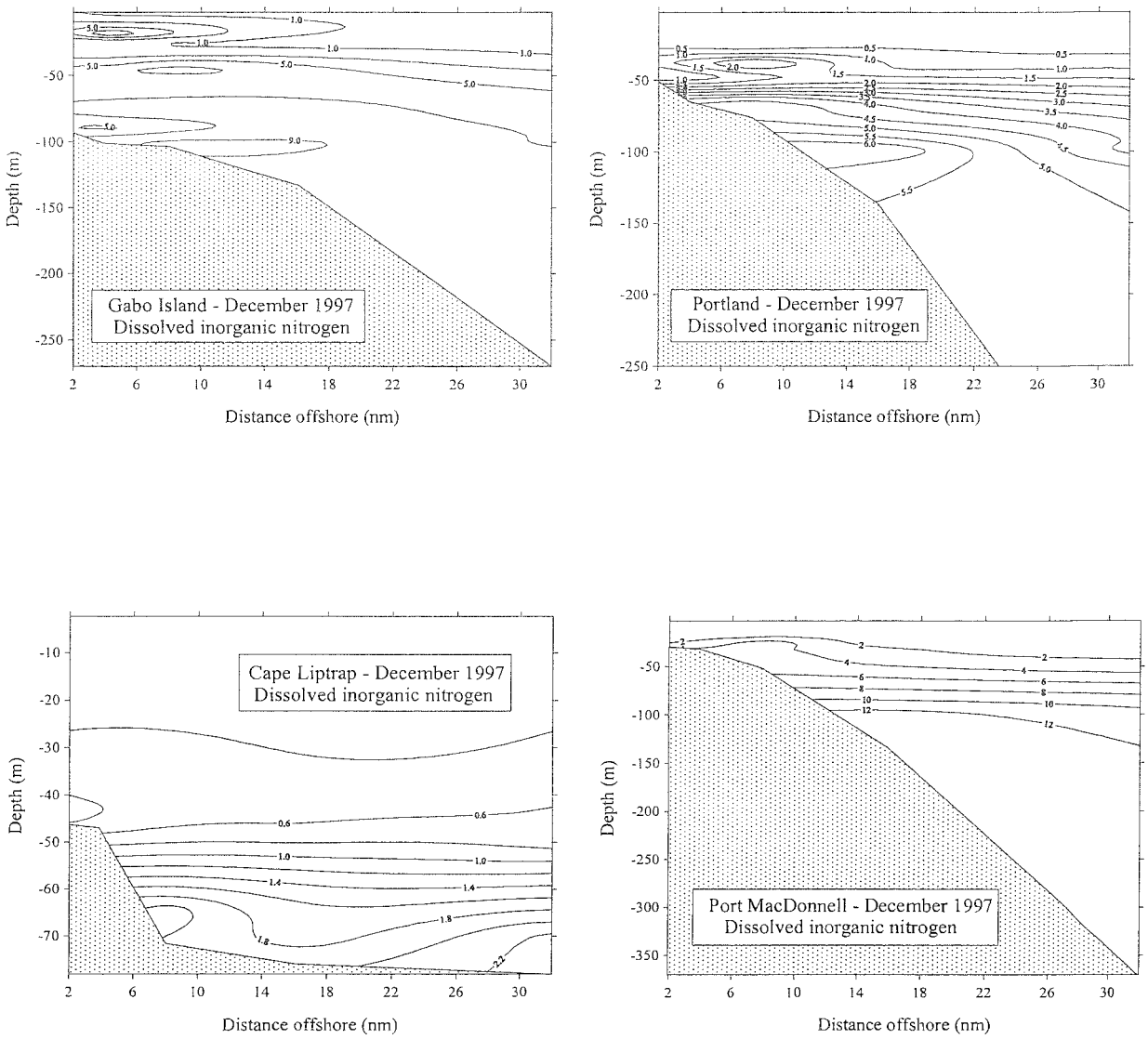


Figure 15B. Vertical dissolved inorganic nitrogen profiles in transects 1(Gabo Island), 4 (Cape Liptrap), 7 (Portland) and 8 (Port MacDonnell) in southeastern Australia during cruise 2 (Dec 1997). Data for transects 2 (Cape Conran), 3 (Seaspray) and 5 (Barwon Heads) are incomplete; transect 6 (Port Campbell) was not sampled.

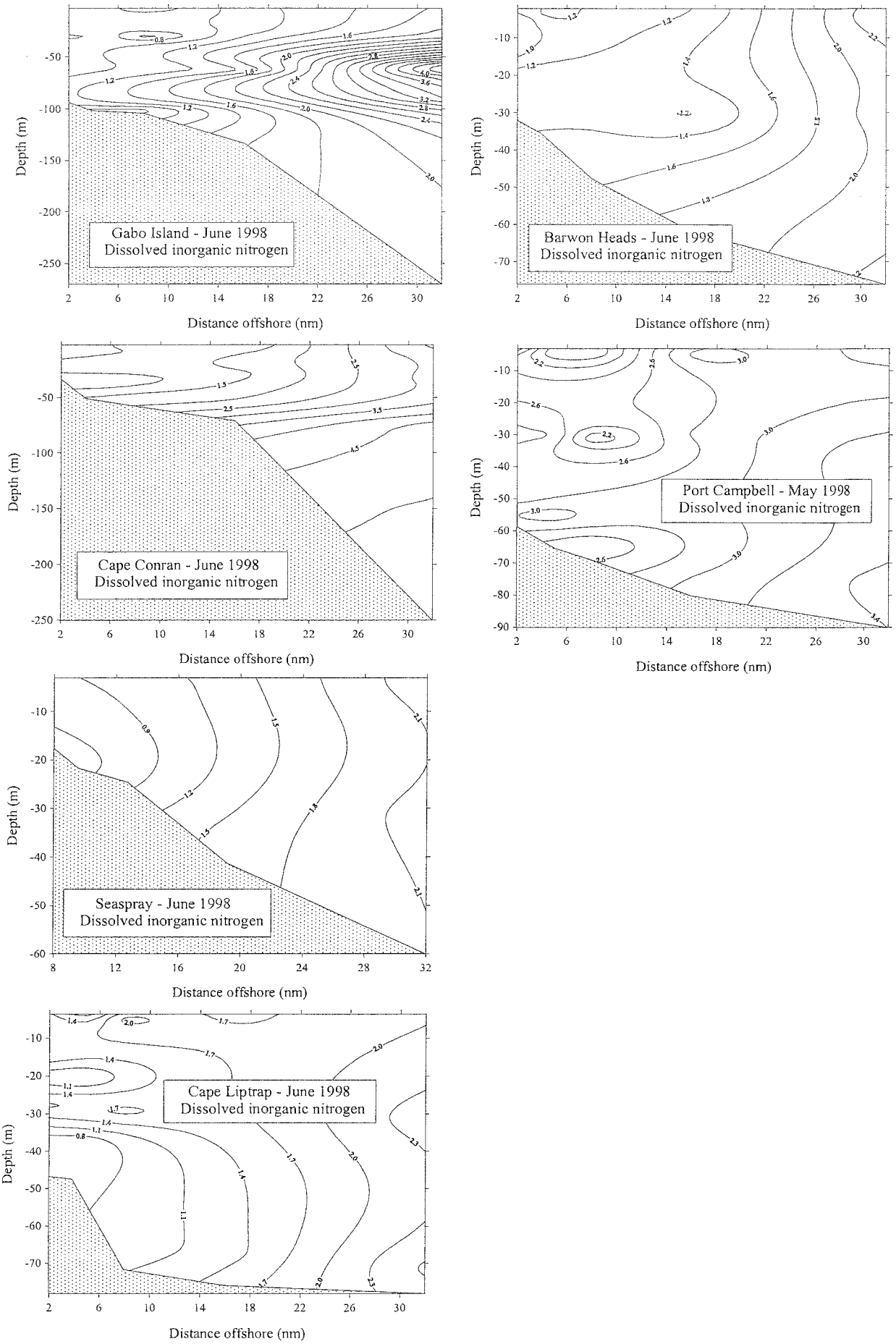


Figure 15C. Vertical dissolved inorganic nitrogen profiles in transects 1 (Gabo Island) to 6 (Port Campbell) in southeastern Australia during cruise 3 (May-Jun 1998). Data for transect 7 (Portland) are incomplete; transect 8 (Port MacDonnell) was not sampled.

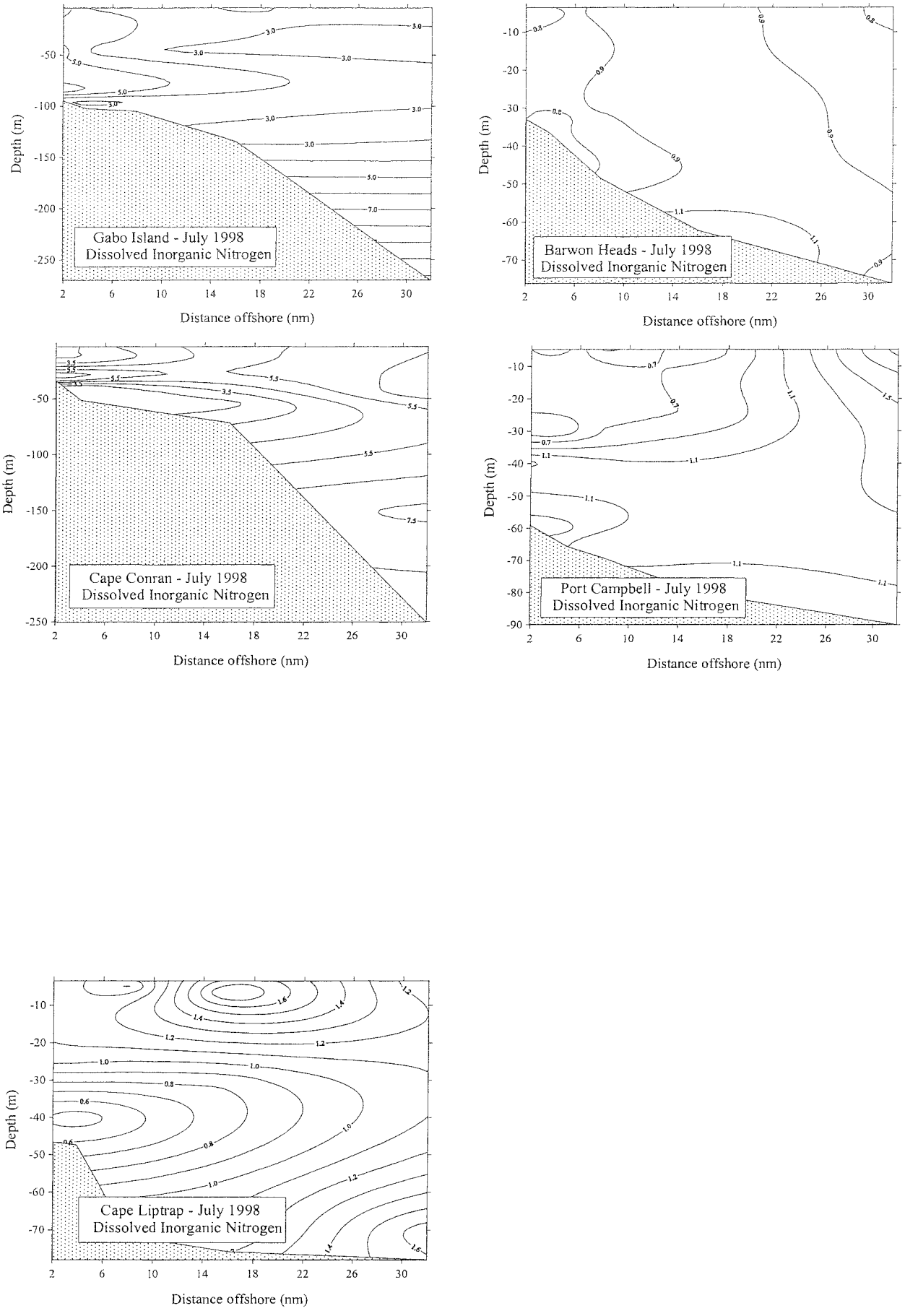


Figure 15D. Vertical dissolved inorganic nitrogen profiles in transects 1 (Gabo Island) to 6 (Port Campbell) in southeastern Australia during cruise 4 (Jul 1998). Transect 3 (Seaspray) was not sampled; data for transects 7 (Portland) and 8 (Port MacDonnell) are incomplete.

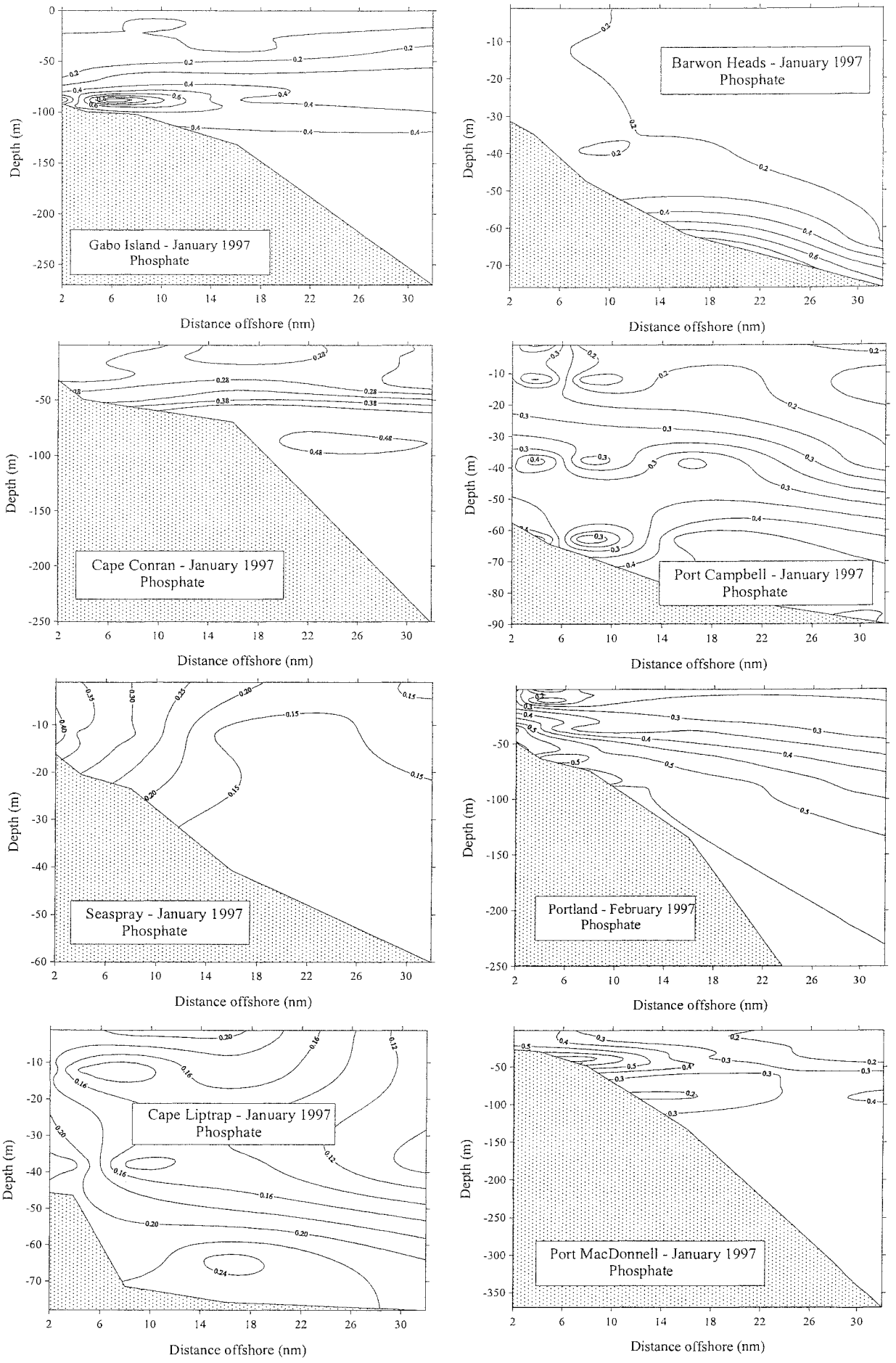


Figure 16A. Vertical phosphate profiles in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 1 (Jan-Feb 1997).

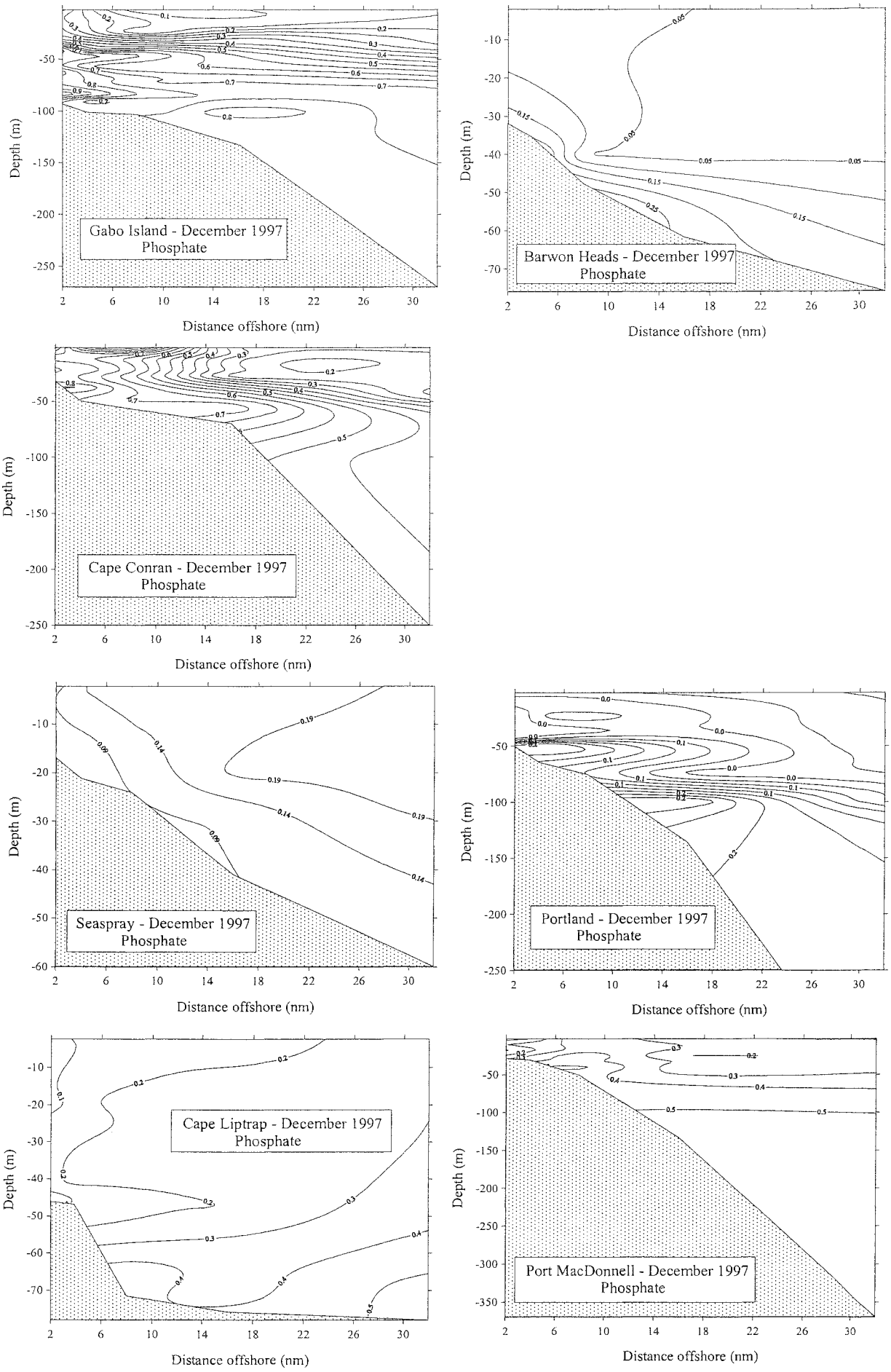


Figure 16B. Vertical phosphate profiles in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 2 (Dec 1997). Transect 6 (Port Campbell) was not sampled.

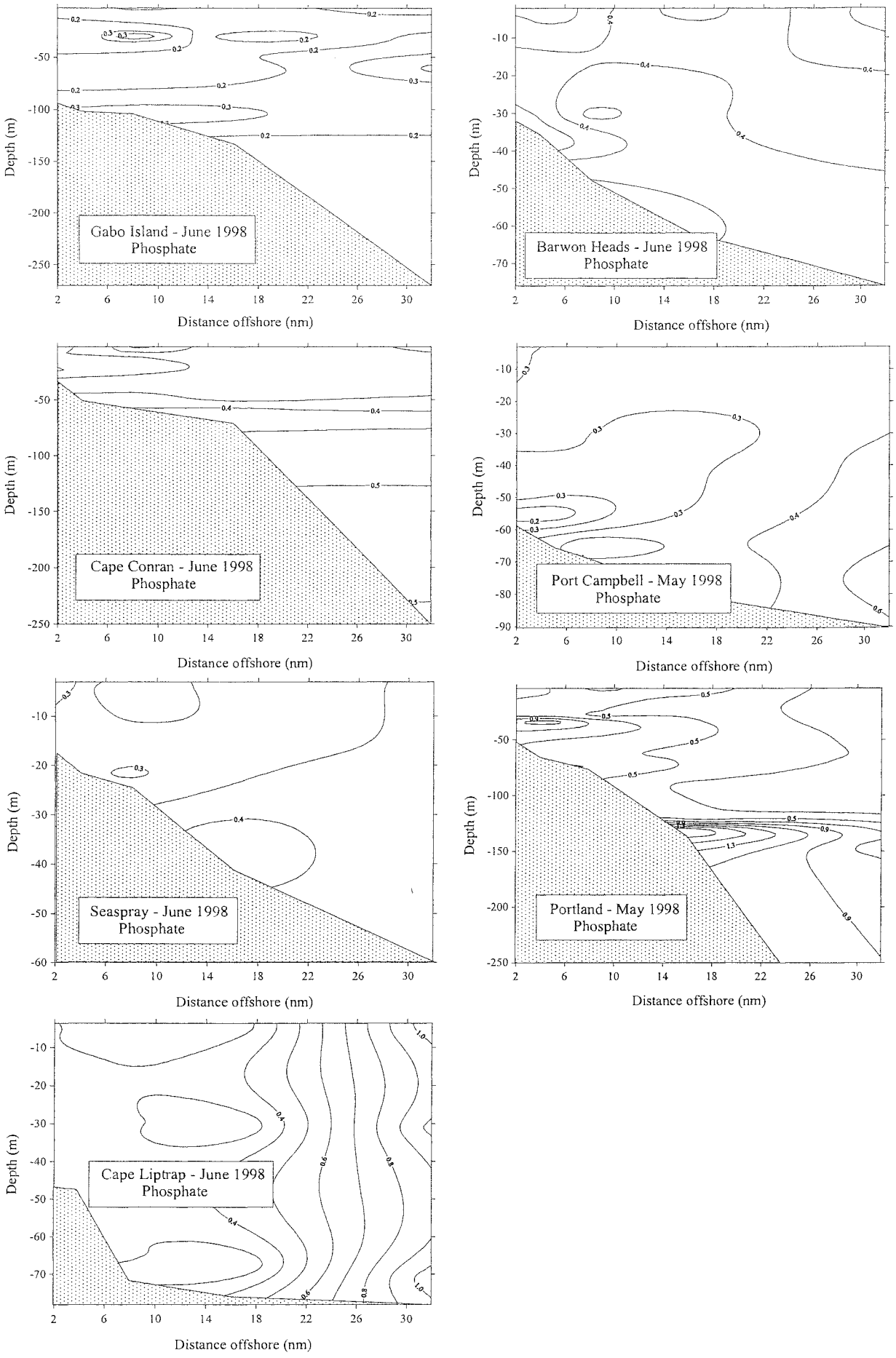


Figure 16C. Vertical phosphate profiles in transects 1 (Gabo Island) to 7 (Portland) in souteastern Australia during cruise 3 (May-Jun 1998). Transect 8 (Port MacDonnell) was not sampled.

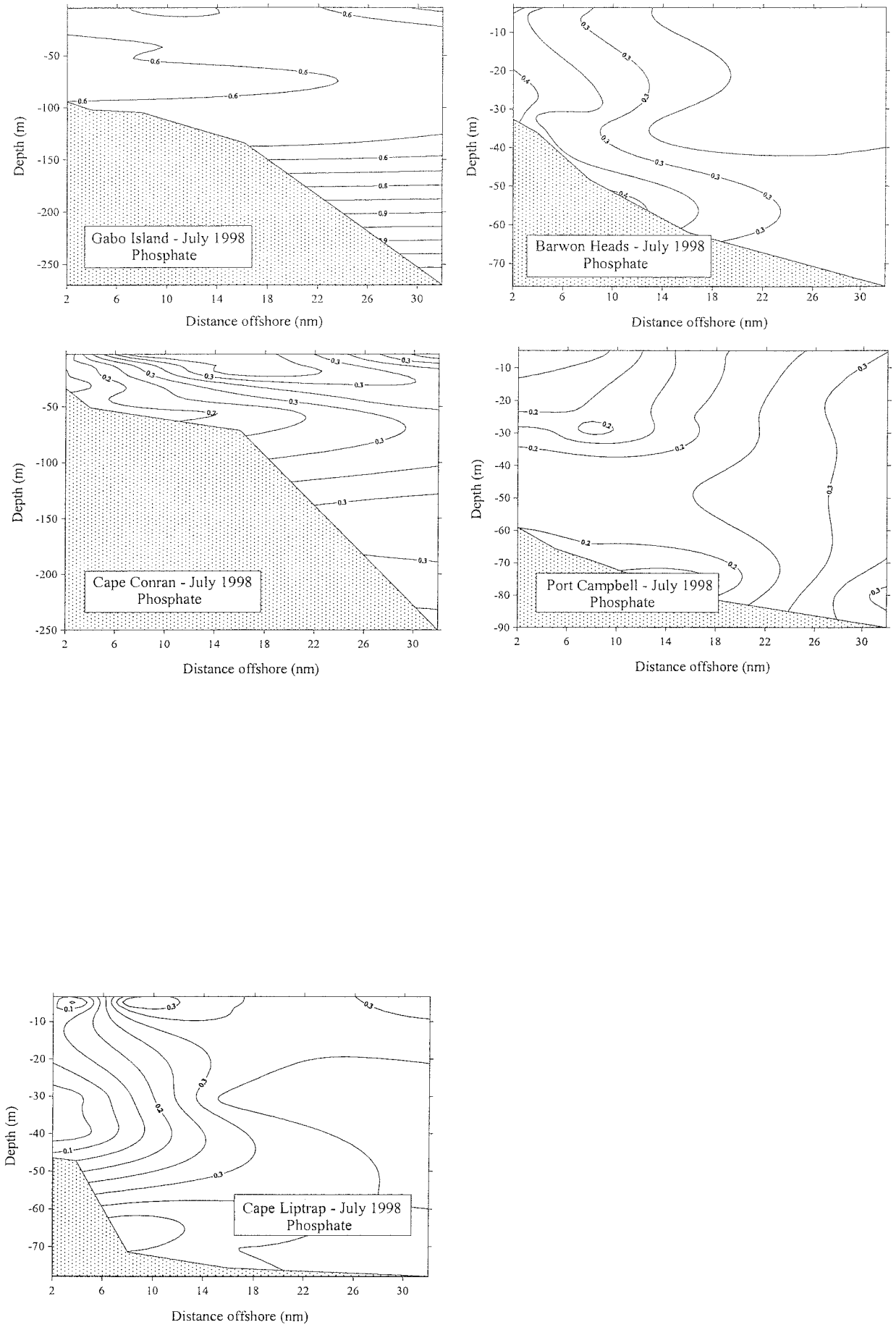


Figure 16D. Vertical phosphate profiles in transects 1 (Gabo Island) to 6 (Port Campbell) in southeastern Australia during cruise 4 (Jul 1998). Transect 3 (Seaspray) was not sampled; data for transects 7 (Portland) and 8 (Port MacDonnell) are incomplete.

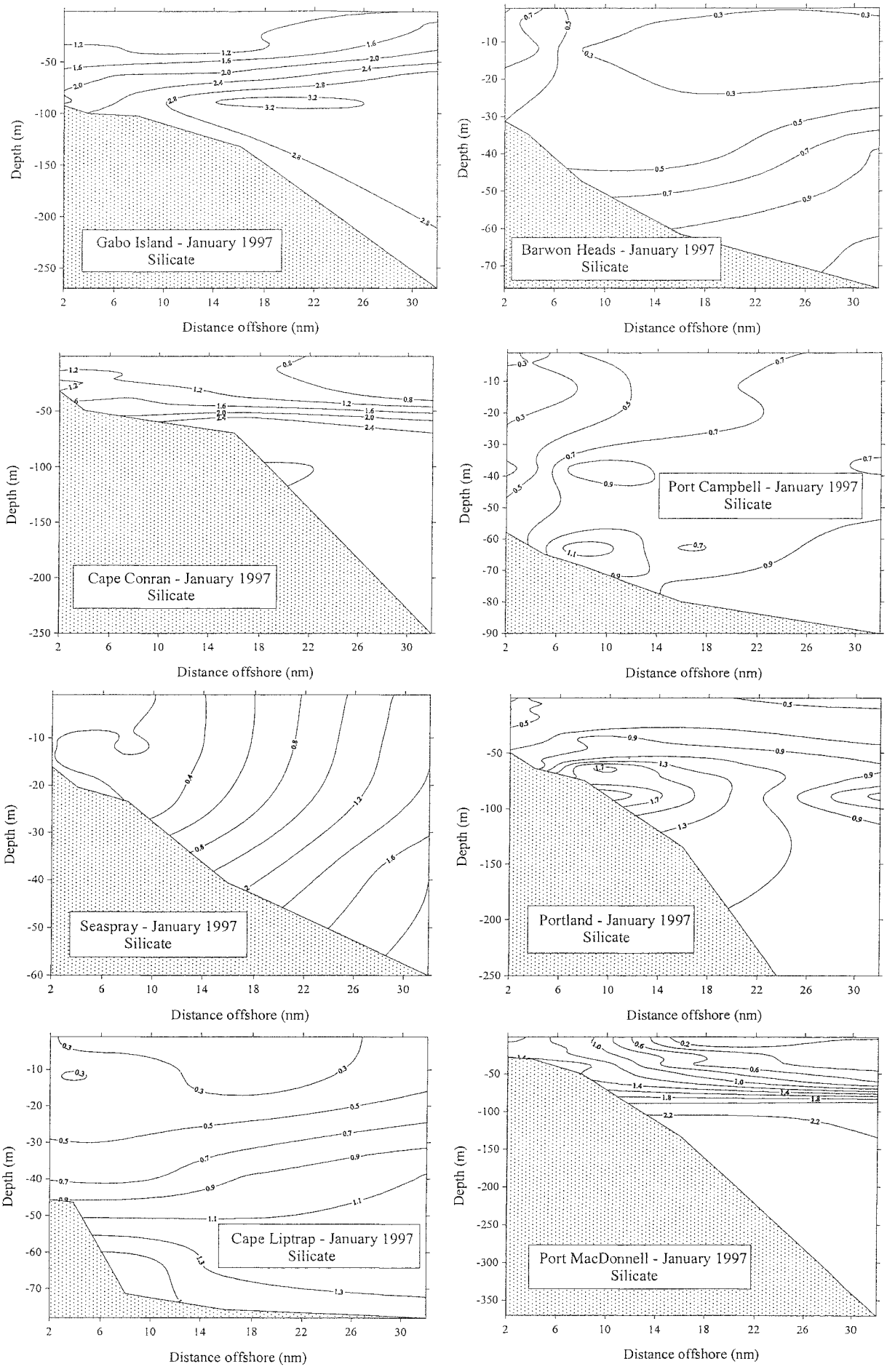


Figure 17A. Vertical silicate profiles in transects 1 (Gabo Island) and 8 (Port MacDonnell) in southeastern Australia during cruise 1 (Jan - Feb 1997).

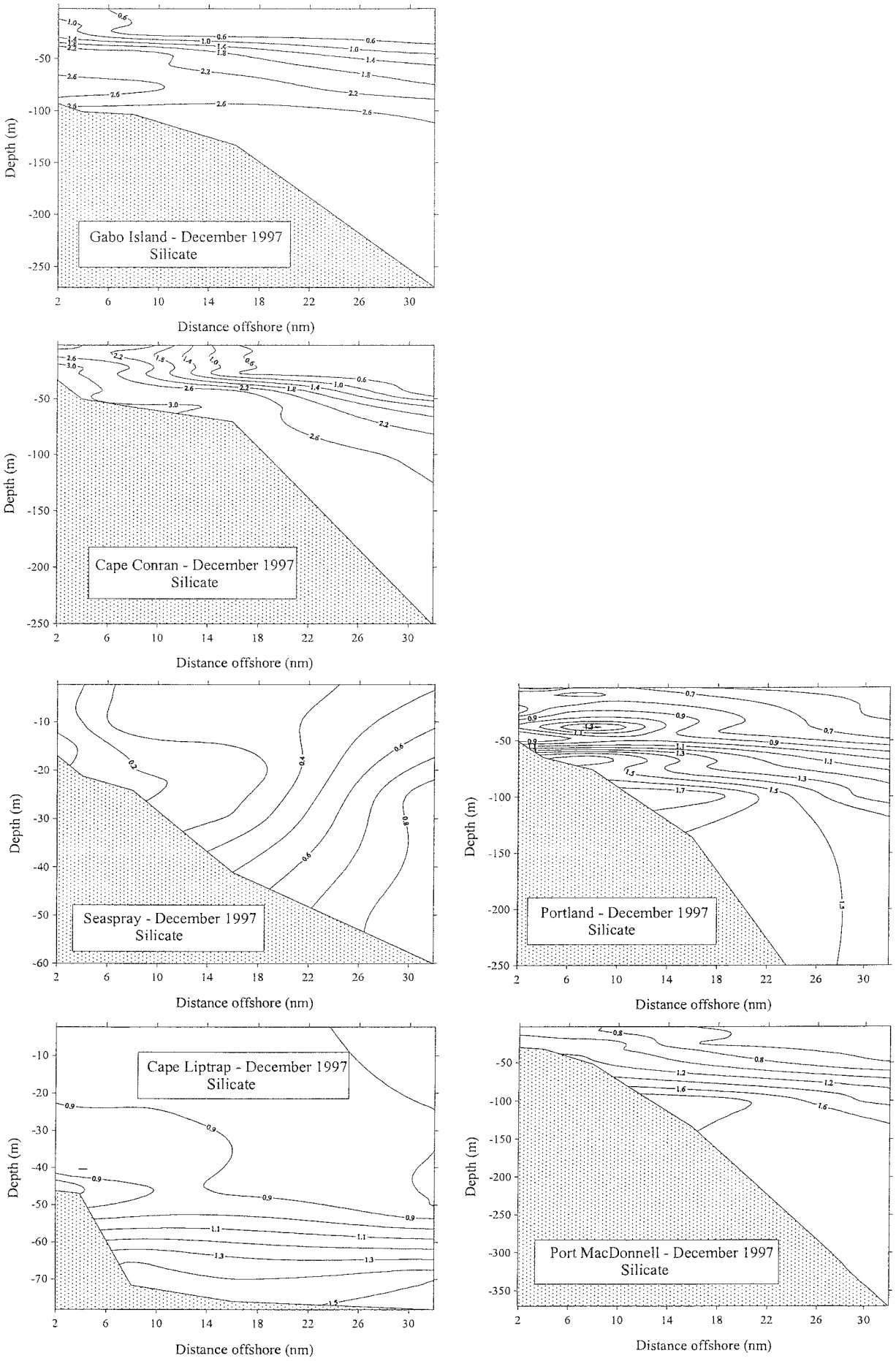


Figure 17B. Vertical silicate profiles in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 2 (Dec 1997). Data from transect 5 (Barwon Heads) were incomplete; transect 6 (Port Campbell) was not sampled.

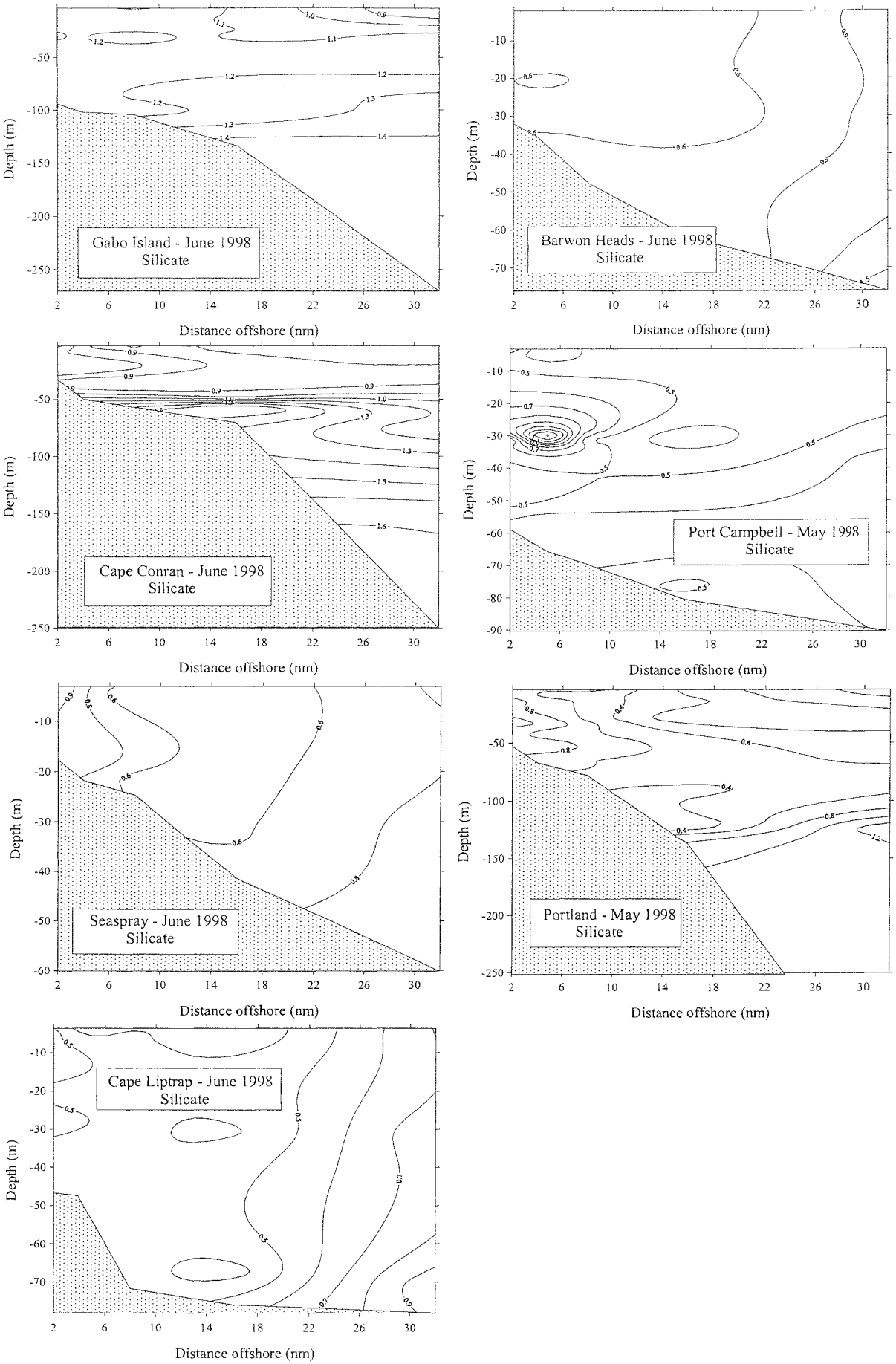


Figure 17C. Vertical silicate profiles in transects 1 (Gabo Island) to 7 (Portland) in southeastern Australia during cruise 3 (May-Jun 1998). Transect 8 (Port MacDonnell) was not sampled.

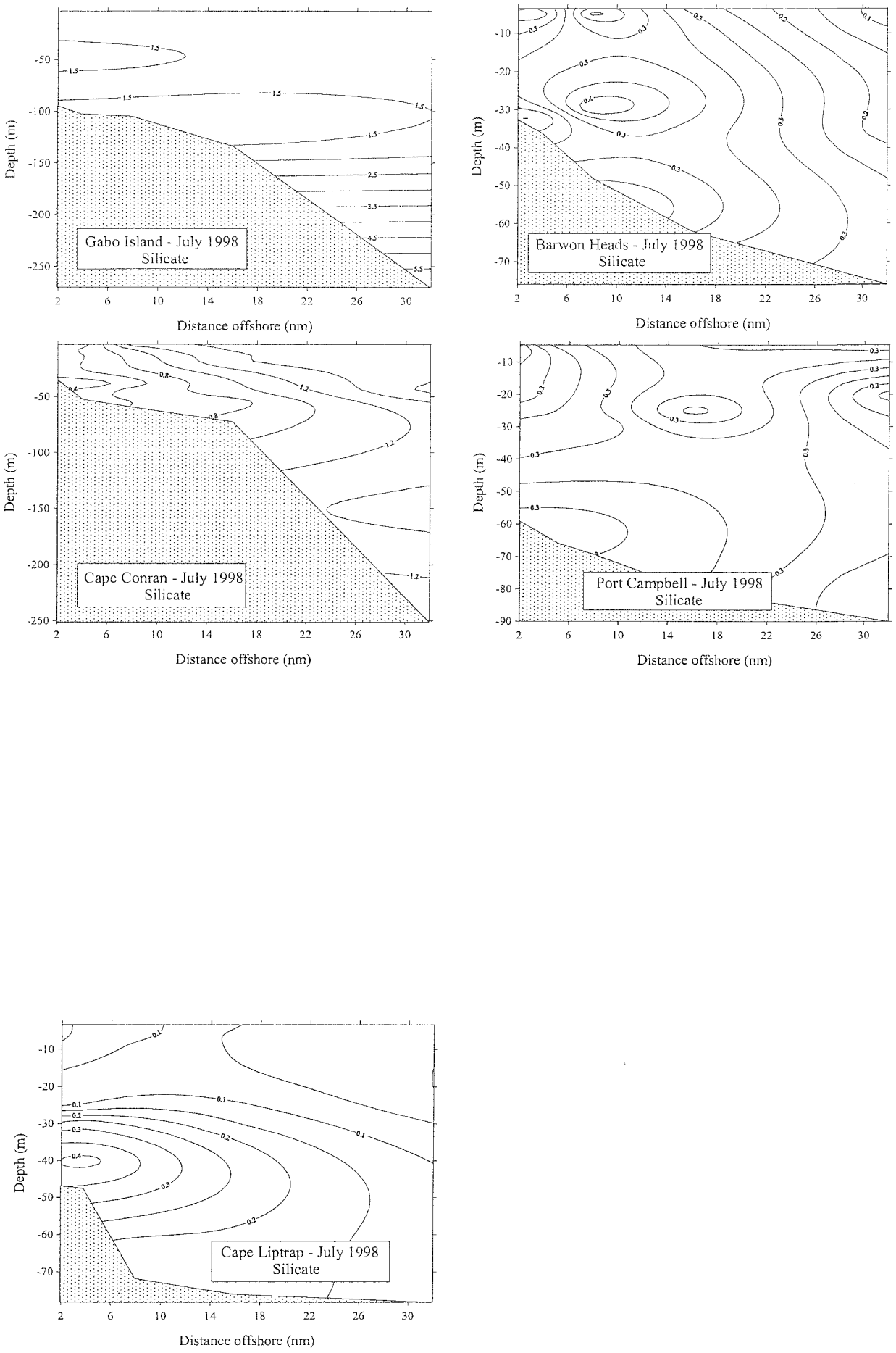


Figure 17D. Vertical silicate profiles in transects 1 (Gabo Island) to 6 (Port Campbell) in southeastern Australia during cruise 4 (Jul 1998). Transect 3 (Seaspray) was not sampled; data for transects 7 (Portland) and 8 (Port MacDonnell) are incomplete.

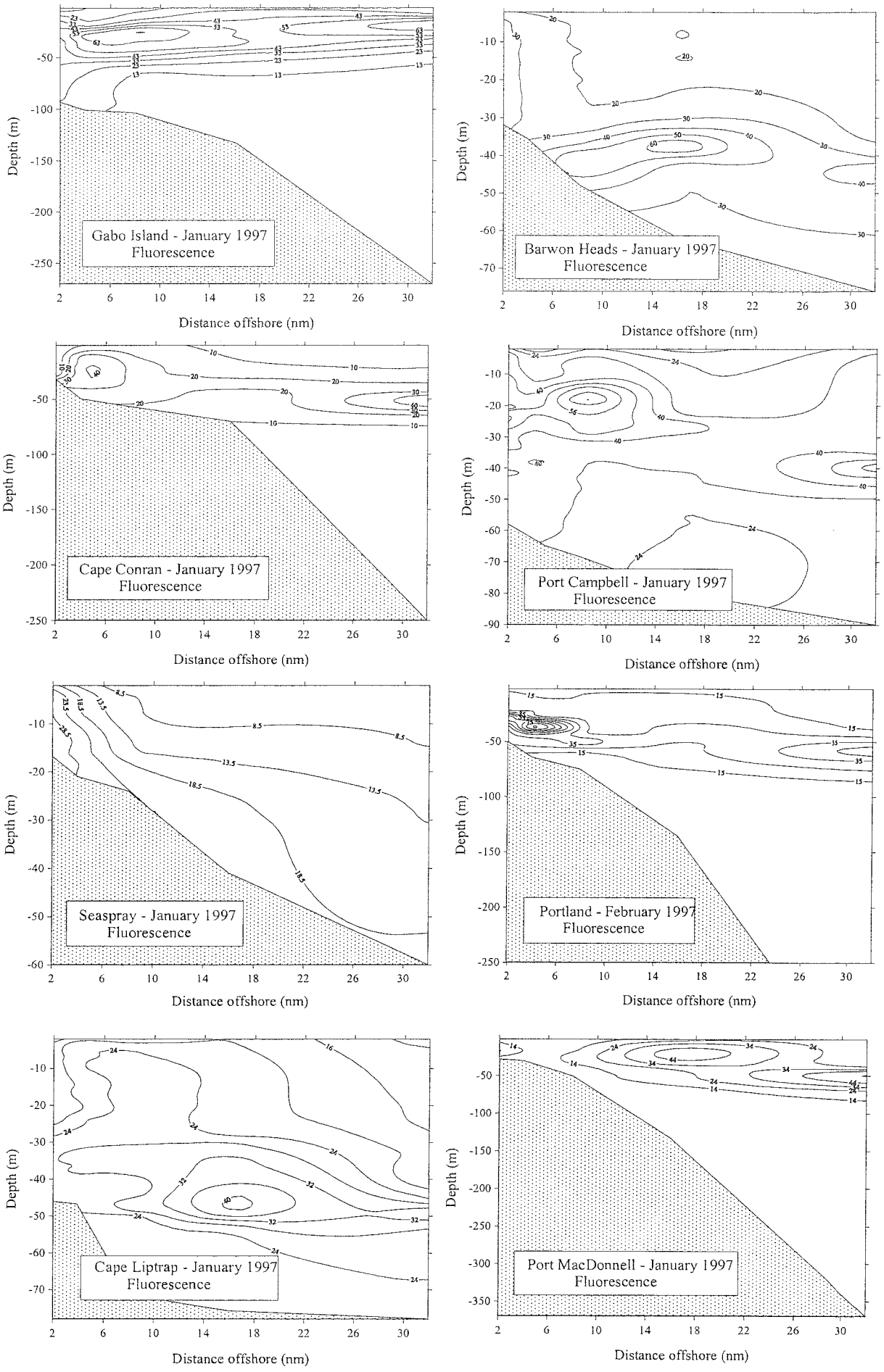


Figure 18A. Vertical fluorescence profiles in transects 1 (Gabo Island) to 8 (Port MacDonnell) in southeastern Australia in cruise 1 (Jan-Feb 1997).

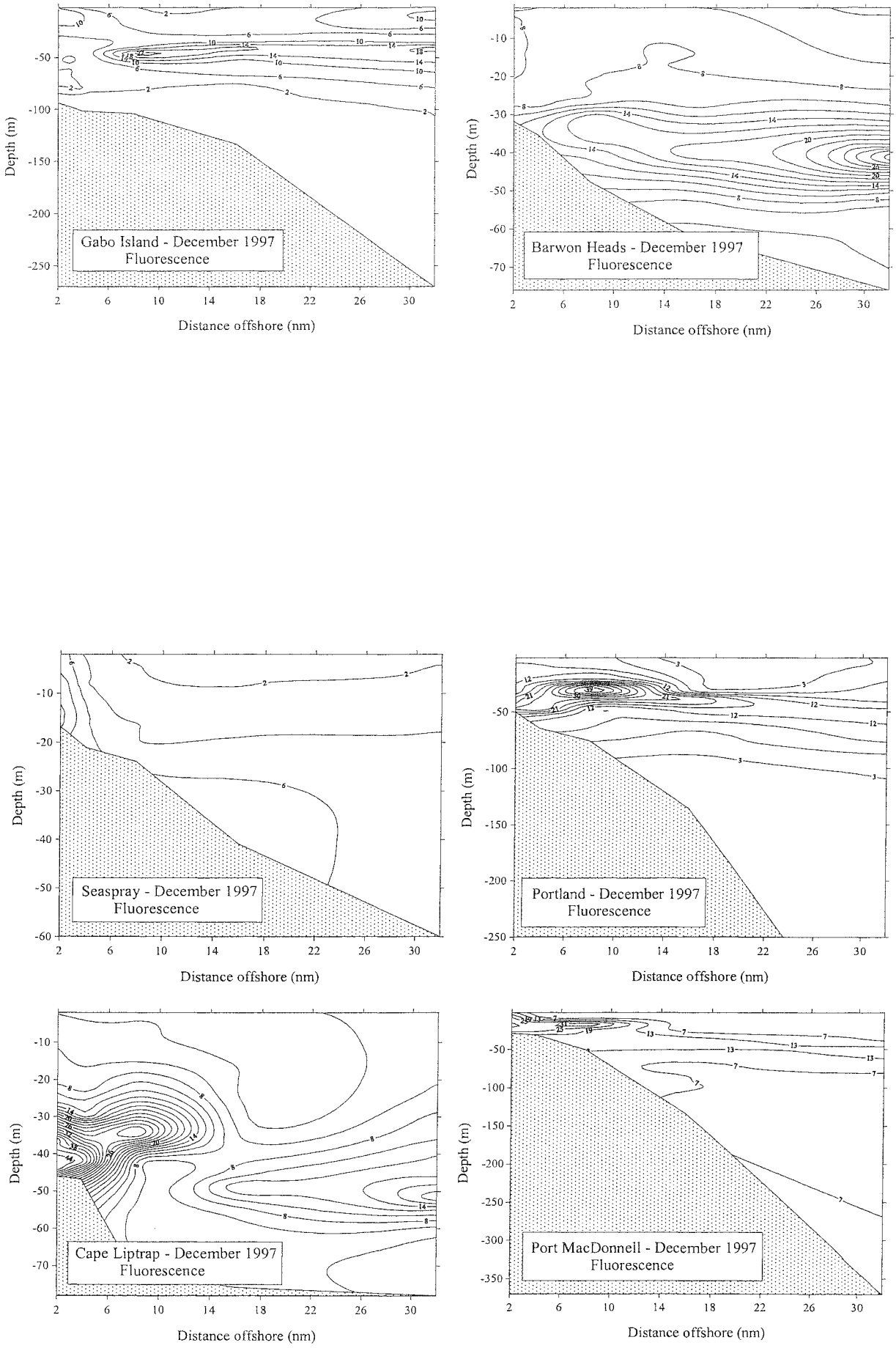


Figure 18B. Vertical fluorescence profiles in transects 1 (Gabol Island) to 8 (Port MacDonnell) in southeastern Australia during cruise 2 (Dec 1997). Data from transect 2 (Cape Conran) are incomplete; transect 6 (Port Campbell) was not sampled.

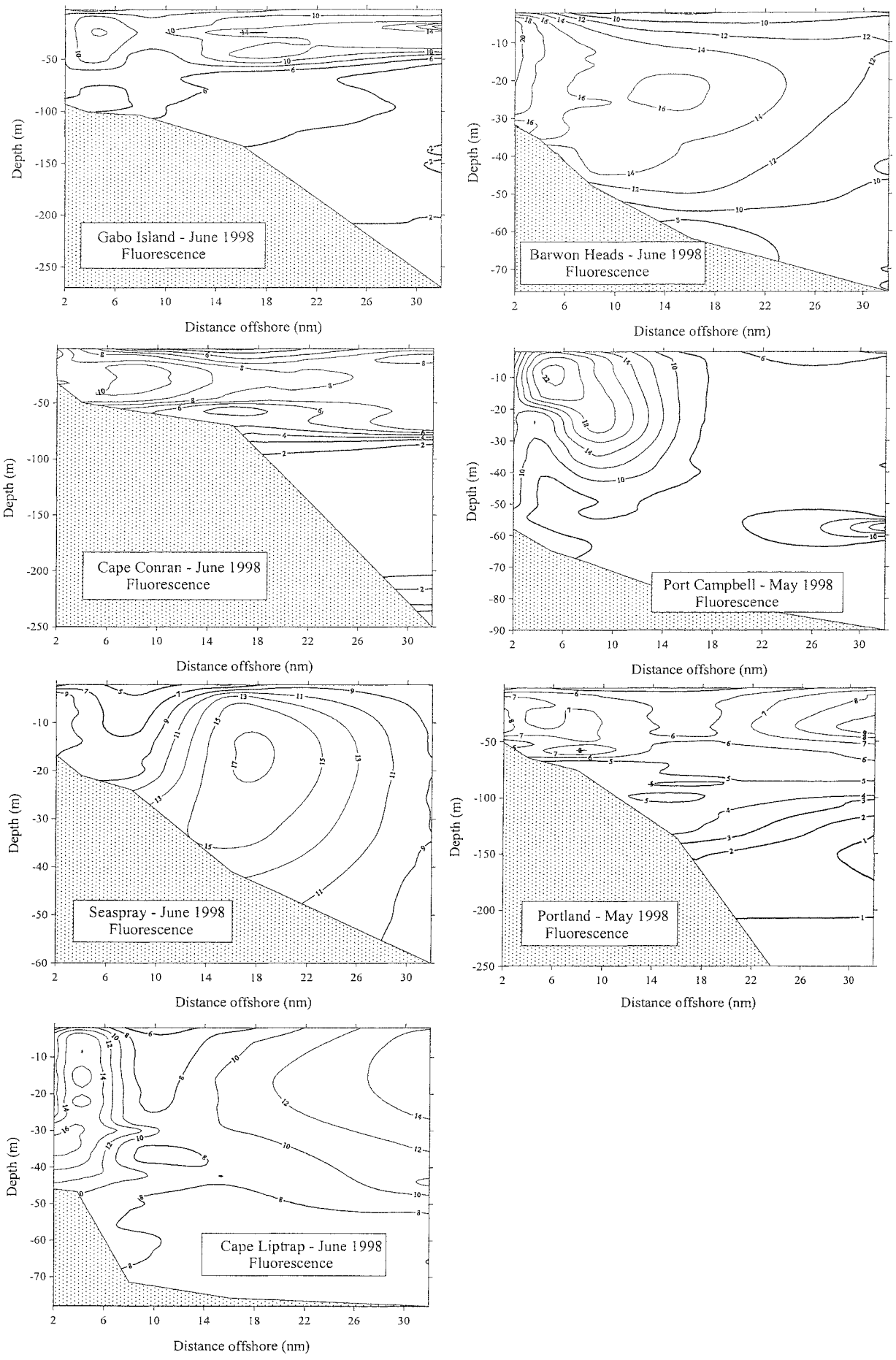
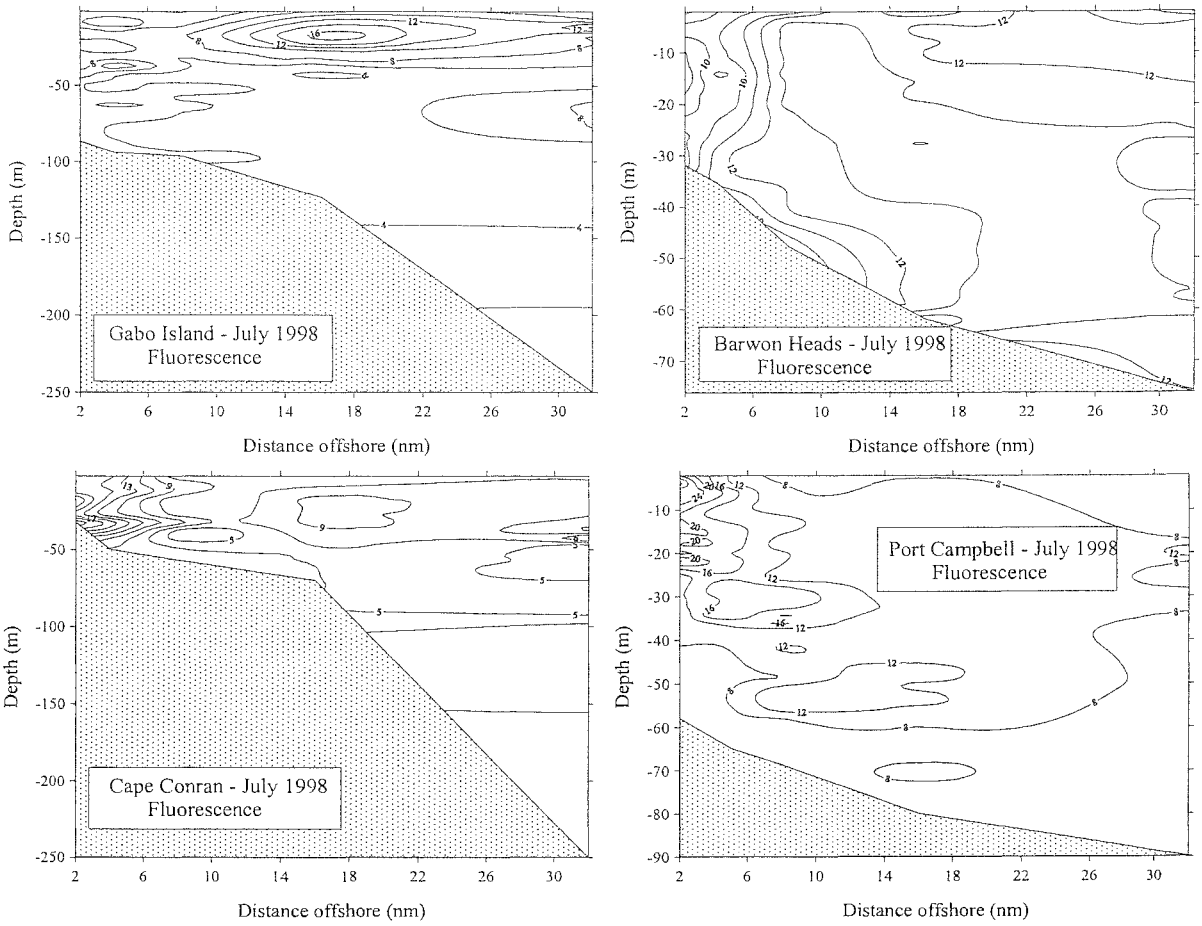


Figure 18C. Vertical fluorescence profiles in transects 1 (Gabo Island) to 7 (Portland) in southeastern Australia during cruise 3 (May-Jun 1998). Transect 8 (Port MacDonnell) was not sampled.



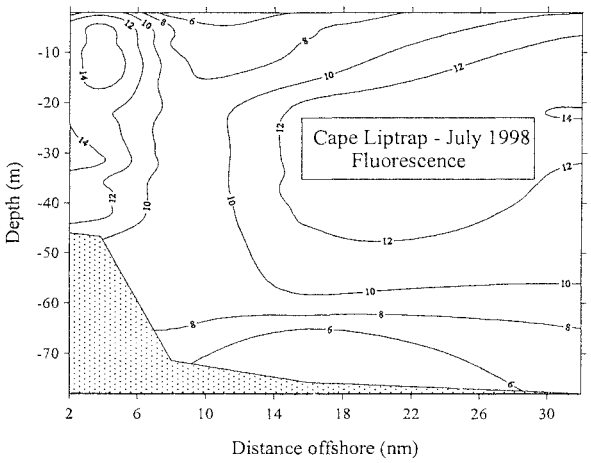


Figure 18D. Vertical fluorescence profiles in transects 1 (Gabo Island) to 6 (Port Campbell) in southeastern Australia during cruise 4 (Jul 1998). Transect 3 (Seaspray) was not sampled; data from transects 7 (Portland) and 8 (Port MacDonnell) are incomplete.

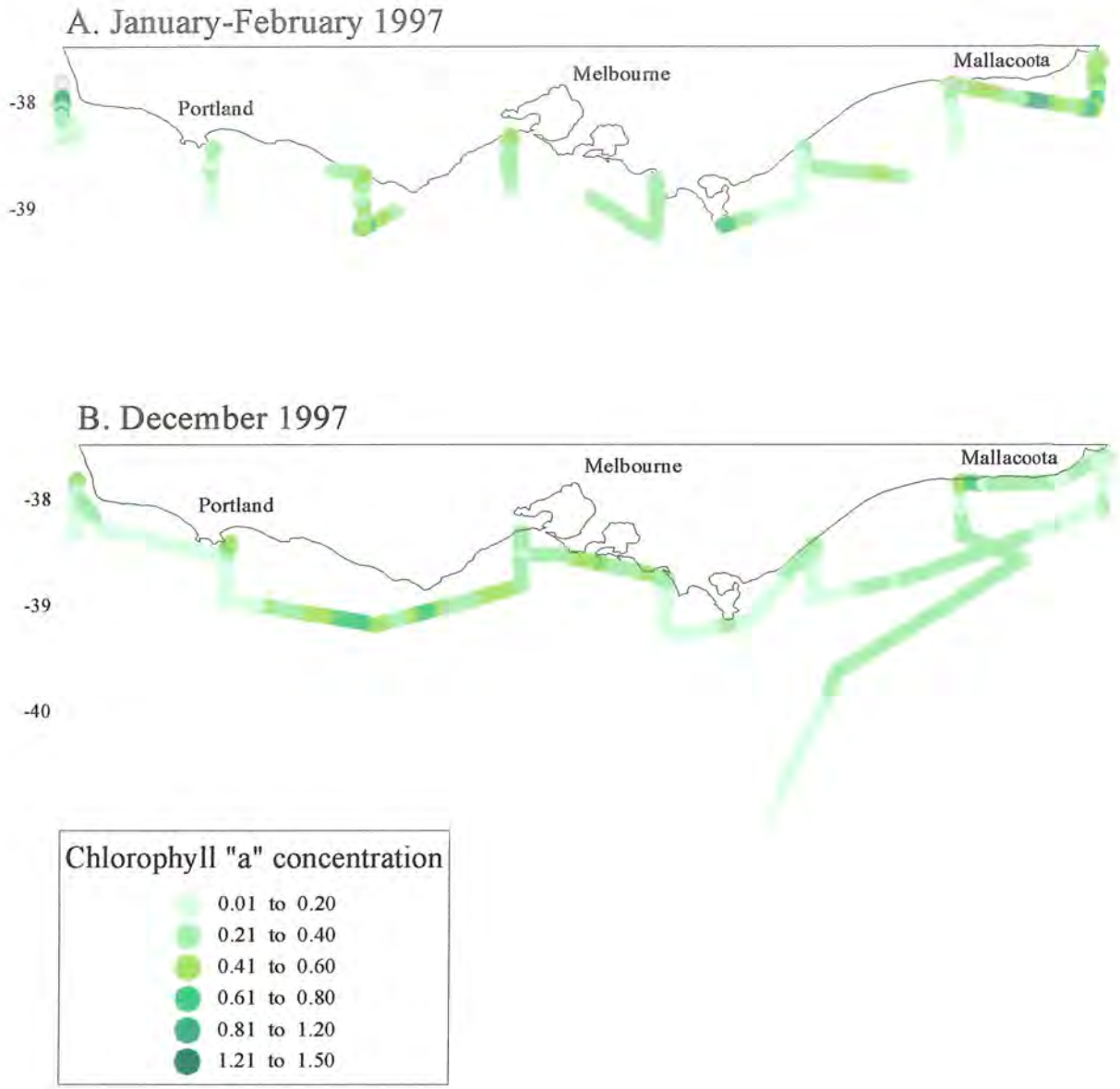


Figure 19. Surface chlorophyll "a" concentrations during cruise 1 (Jan-Feb 1997; A) and cruise 2 (Dec 1997; B). Chlorophyll values were recorded while underway using the on-board continuous nutrient tracking system (see Materials and Methods).

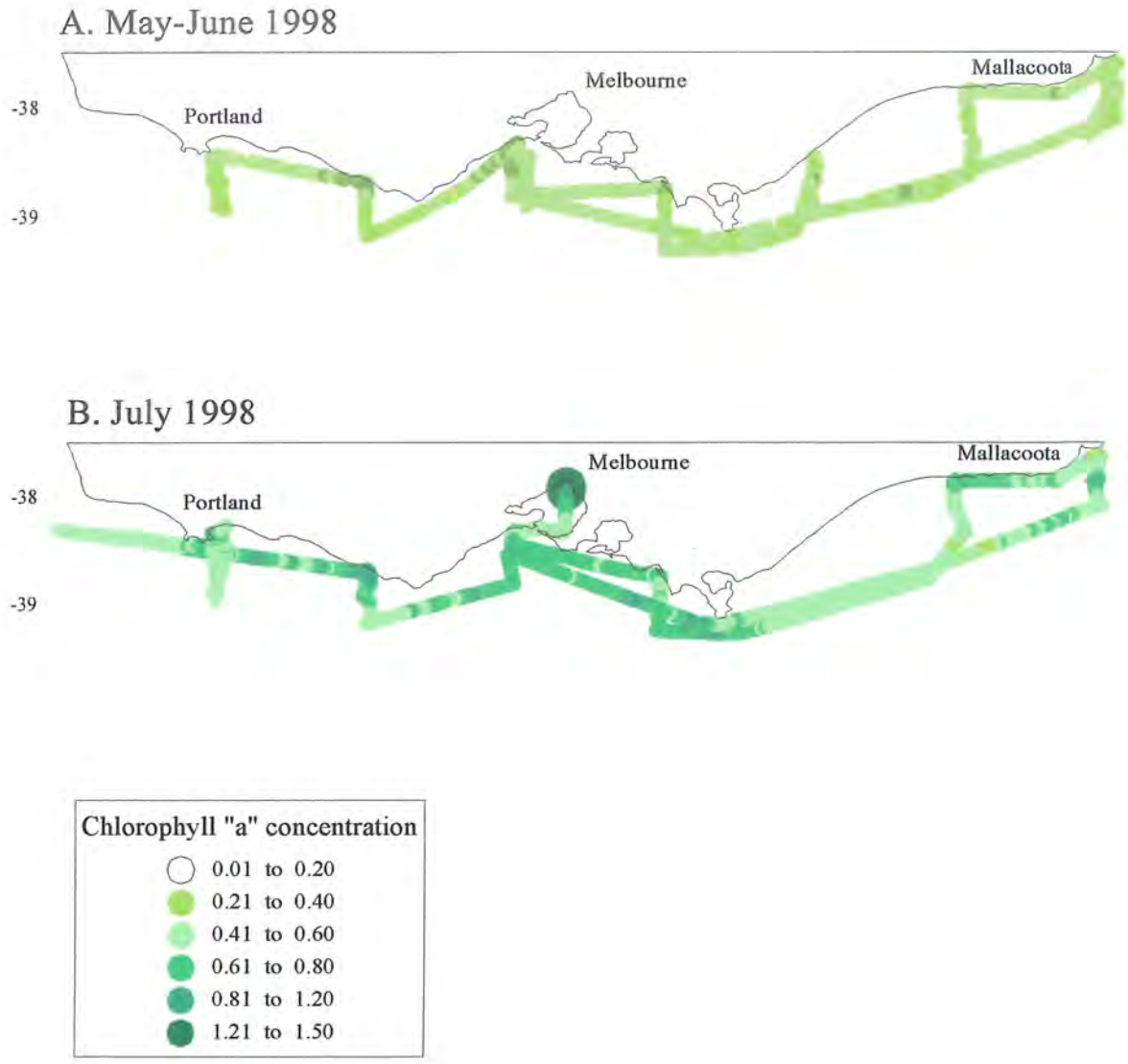


Figure 20. Surface chlorophyll "a" concentrations during cruise 3 (May-Jun 1998; A) and cruise 4 (Jul 1998; B). Chlorophyll values were recorded while underway using the on-board continuous nutrient tracking system (see Materials and Methods).

5.3 Family and species composition

5.3.1 Summer surveys

A total of 12,550 and 6,593 larval fishes were caught at fixed stations both with the bongo (surface) and EZ (25-0, 50-25, 75-50,100-75 m depth strata) nets during cruise 1 (Jan-Feb 1997) and cruise 2 (Dec 1997), respectively. The overall total in both cruises comprised larval fishes belonging to 85 teleost fish families, of which 71 were present in cruise 1 and 77 in cruise 2 (Table 6). Fish families that were common to both cruises totalled 63. In terms of total numbers, the most abundant larval fishes caught during cruise 1 belonged to the Clupeidae (63.3%), followed by those of the Carangidae (7.8%), Monacanthidae (4.3%) and Serranidae (2.5%). In contrast, the most abundant larval fishes caught during cruise 2 belonged to the Monacanthidae (21.0%) followed by those of the Clupeidae (11.5%), Platycephalidae (6.0%), Gempylidae and Serranidae (5.3% each), Pinguipedidae (3.9%), Gobiidae (3.3%) and Engraulidae (3.0%). Larval fishes belonging to the remaining fish families in cruises 1 (n = 67) and 2 (n = 69) accounted for <2 and <3% to the total caught in these cruises, respectively, and included those of families such as the Triglidae, Moridae and Sillaginidae (Table 6).

Nearly 72% of the fish families in cruise 1 (n = 51) and 68% in cruise 2 (n = 52) were represented by <50 larvae, each accounting for <0.8% of the total numbers caught in each cruise. In addition, nine fish families in cruise 1 and 14 in cruise 2 were represented by only one larva. Unidentified larvae in cruises 1 and 2 totalled 93 (0.7%) and 147 (2.3%), respectively (Table 6).

Fish taxa within the 85 identified families totalled 146 for both summer cruises combined (Table 6). Of these, the most abundant larvae that could be identified to species were those of pilchard (*Sardinops sagax*, Clupeidae), jack mackerel (*Trachurus declivis*, Carangidae), sand flathead (*Platycephalus bassensis*, Platycephalidae), barracouta (*Thyrsites atun*, Gempylidae), anchovy (*Engraulis australis*, Engraulidae), red mullet (*Upeneichthys vlamingii*, Mullidae) and barred grubfish (*Parapercis allporti*, Pinguipedidae). Larvae of the Serranidae contained a mixture of mostly seaperch (*Hypoplectrodes* spp.) and perch (*Caesioperca* spp.), whereas larvae of the Gobiidae and Monacanthidae could not be identified to species except for those of pigmy leatherjacket (*Brachaluteres jacksoniensis*) in the latter (Table 7). Larvae of other fish species which were fairly well represented during both summer cruises included those of deepwater gurnard (*Lepidotrigla mulhalli*, Triglidae), cod (*Pseudophycis* spp., Moridae) and eastern school whiting (*Sillago flindersi*, Sillaginidae) (Table 7).

Table 6. Summary of teleost fish families identified during summer cruises 1 (January-February 1997) and 2 (December 1997) in coastal waters of southeastern Australia, the total number of larvae caught in each (non-standardised), and their respective contributions to the total caught during each cruise. Families have been arranged in alphabetical order.

		Cruise 1 – Jan/Feb 97		Cruise 2 – Dec 97	
No.	Family	Total No. larvae	Percentage (%) of total	Total No. larvae	Percentage (%) of total
1	Anatopteridae			1	0.02
2	Anguillidae	1	0.01		
3	Aploactinidae	12	0.10	5	0.08
4	Apogonidae	25	0.20	42	0.65
5	Argentinidae	30	0.24	89	1.38
6	Arripidae	4	0.03	1	0.02
7	Atherinidae	1	0.01	11	0.17
8	Aulopidae	14	0.11	6	0.09
9	Berycidae	1	0.01		
10	Blenniidae	45	0.36	39	0.61
11	Bothidae	46	0.37	39	0.61
12	Bythitidae			1	0.02
13	Callionymidae	79	0.63	65	1.01
14	Carangidae	982	7.88	120	1.86
15	Carapidae	8	0.06	9	0.14
16	Centrolophidae	24	0.19	1	0.02
17	Cepolidae	12	0.10	5	0.08
18	Chandidae			1	0.02
19	Cheilodactylidae	2	0.02		
20	Chlorophthalmidae	4	0.03	18	0.28
21	Clinidae	177	1.42	140	2.17
22	Clupeidae	7946	63.79	759	11.77
23	Creediidae	156	1.25	25	0.39
24	Cynoglossidae			5	0.08
25	Dinolestidae	10	0.08	5	0.08
26	Diodontidae	12	0.10	5	0.08
27	Emmelichthyidae	2	0.02	3	0.05
28	Engraulidae	130	1.04	198	3.07
29	Enoplosidae	3	0.02	8	0.12
30	Exocoetidae	1	0.01	10	0.16
31	Gempylidae	105	0.84	350	5.43
32	Girellidae	29	0.23	1	0.02
33	Gnathanacanthidae	1	0.01		
34	Gobiesocidae	98	0.79	183	2.84
35	Gobiidae	63	0.51	221	3.43
36	Gonostomatidae	1	0.01	1	0.02
37	Hemiramphidae	3	0.02	1	0.02
38	Hoplichthyidae			1	0.02
39	Labridae	161	1.29	150	2.33
40	Leptoscopidae	5	0.04	2	0.03
41	Macroramphosidae	1	0.01	1	0.02
42	Macrouridae	2	0.02		
43	Melamphaidae			3	0.05

Table 6. Summary of teleost fish families ..... cont.

		Cruise 1 – Jan/Feb 97		Cruise 2 – Dec 97	
No.	Family	Total No. larvae	Percentage (%) of total	Total No. larvae	Percentage (%) of total
44	Microcanthidae	2	0.02	13	0.20
45	Monacanthidae	542	4.34	1387	21.52
46	Moridae	172	1.38	68	1.05
47	Mugilidae	35	0.28	13	0.20
48	Mullidae	233	1.87	71	1.10
49	Myctophidae	51	0.41	126	1.95
50	Notosudidae			2	0.03
51	Odacidae	9	0.07	15	0.23
52	Ophichthidae	9	0.07	2	0.03
53	Ophidiidae	1	0.01	2	0.03
54	Paralepididae			2	0.03
55	Pataeciadae	2	0.02	1	0.02
56	Pegasidae	24	0.19	114	1.77
57	Pempheridae	23	0.18	49	0.76
58	Percichthyidae			2	0.03
59	Percophidae	18	0.14	11	0.17
60	Photichthyidae	12	0.10	195	3.03
61	Pinguipedidae	37	0.30	258	4.00
62	Platycephalidae	178	1.43	395	6.13
63	Plesiopidae	3	0.02	9	0.14
64	Pleuronectidae	2	0.02	3	0.05
65	Pomacentridae	49	0.39	125	1.94
66	Regalecidae	1	0.01		
67	Scomberesocidae	2	0.02		
68	Scombridae	9	0.07	16	0.25
89	Scopelarchidae			1	0.02
70	Scorpaenidae	73	0.59	162	2.51
71	Serranidae	318	2.55	350	5.43
72	Serrivomeridae			1	0.02
73	Sillaginidae	82	0.66	127	1.97
74	Soleidae	15	0.12	28	0.43
75	Sparidae	13	0.10	63	0.98
76	Syngnathidae	30	0.24	31	0.48
77	Synodontidae			1	0.02
78	Terapontidae			6	0.09
79	Tetraodontidae	3	0.02	6	0.09
80	Trachichthyidae	8	0.06	7	0.11
81	Trachipteridae			4	0.06
82	Triglidae	237	1.90	172	2.67
83	Tripterygiidae	55	0.44	79	1.23
84	Uranoscopidae	2	0.02	4	0.06
85	Zeidae	11	0.09		
	Unidentified	93	0.75	147	2.28

Table 7. Total number of larvae (non-standardised) caught per fish family and per taxa within family along southeastern Australia during summer cruises 1 (January-February 1997) and 2 (December 1997) combined. Families and taxa within families have been arranged in decreasing order of abundance according to the total numbers caught.

Family	Total family	Taxa	Total taxa
Clupeidae	8705	*Sardinops sagax*	8697
		Hyperlophus vittatus	8
Monacanthidae	1929	Monacanthid	1926
		Brachaluteres jacksoniensis	3
Carangidae	1102	*Trachurus declivis*	1066
		Pseudocaranx dentex	35
		Seriola sp.	1
Serranidae	668	*Hypoplectrodes* spp.	372
		Caesioperca spp.	277
		Acanthistius spp.	16
		Serranid	3
Platycephalidae	573	*Platycephalus bassensis*	356
		Platycephalus spp.	110
		Platycephalus fuscus	77
		Platycephalus speculator	18
		Neoplatycephalus spp.	8
Gempylidae	455	*Thyrsites atun*	455
Triglidae	409	*Lepidotrigla mulhalli*	194
		Lepidotrigla modesta	93
		Lepidotrigla papilio	59
		Lepidotrigla vanessa	54
		Lepidotrigla spp.	9
Engraulidae	328	*Engraulis australis*	328
Clinidae	317	Clinid	317
Labridae	311	Labrid	311
Mullidae	304	*Upeneichthys vlamingii*	304
Pinguipedidae	295	*Parapercis allporti*	295
Gobiidae	284	Gobiid	284
Gobiesocidae	281	Gobiesocid	222
		Alabes spp.	59
Moridae	240	*Pseudophycis* spp.	232
		Morid	6
		Pseudophycis bachus	1
		Pseudophycis breviscula	1
Scorpaenidae	235	*Neosebastes* spp.	133
		Helicolenus percoides	78
		Scorpaena papillosa	13
		Gliptauchen panduratus	7
		Centropogon australis	2
		Scorpaenodes spp.	2

Table 7. Total number of larvae per fish family ..... cont.

Family	Total family	Taxa	Total taxa
Sillaginidae	209	*Sillago flindersi*	209
Photichthyidae	207	*Vinciguerria attenuata*	207
Creediidae	181	*Creedia haswelli*	181
Myctophidae	177	Myctophid	54
		Lampanyctus spp.	29
		Diaphus spp.	27
		Lampadena spp.	26
		Symbolophorus spp.	19
		Hygophum spp.	18
		Myctophum spp.	4
Pomacentridae	174	*Chromis* spp.	96
		Parma spp.	47
		Pomacentrid	27
		Pomacentrus spp.	3
		Abudefduf spp.	1
Callionymidae	144	Callionymid	144
Pegasidae	138	*Pegasus lancifer*	138
Tripterygiidae	134	Tripterygiid	133
		Norfolkia spp.	1
Argentinidae	119	*Argentina australiae*	119
Bothidae	85	*Arnoglossus muelleri*	68
		Bothid	9
		Arnoglossus spp.	8
Blenniidae	84	*Parablennius tasmanianus*	88
Sparidae	76	*Pagrus auratus*	73
		Sparid	3
Pempheridae	72	*Parapriacanthus elongatus ?*	46
		Pempherid	23
		Pempheris multiradiata	3
Apogonidae	67	Apogonid	67
Syngnathidae	61	*Maroubra preserrata*	27
		Stigmatopora nigra	17
		Syngnathid	9
		Lissocampus spp.	7
		Vanacampus spp.	1
Mugilidae	48	*Aldrichetta forsteri*	39
		Liza argentea	9
Soleidae	43	Soleid	43
Girellidae	30	*Girella tricuspidata*	27
		Girella zebra	3
Percophidae	29	*Enigmapercis reducta*	29
Centrolophidae	25	*Seriollela brama*	25
Scombridae	25	*Scomber australasicus*	25

Table 7. Total number of larvae per fish family ..... cont.

Family	Total family	Taxa	Total taxa
Odacidae	24	Odacid	16
		Siphonognathus spp.	5
		Neoodax balteatus	1
		Odax acroptilus	1
		Odax cyanomelas	1
Chlorophthalmidae	22	*Chlorophthalmus nigripinnis*	22
Aulopidae	20	*Aulopus purpurissatus*	20
Carapidae	17	*Echiodon rendahli*	17
Cepolidae	17	*Cepola australis*	17
Diodontidae	17	Diodontid	17
Aploactinidae	17	*Aploactisoma milesii*	16
		Aploactinid	1
Dinolestidae	15	*Dinolestes lewini*	15
Microcanthidae	15	*Atypichthys strigatus*	15
Trachichthyidae	15	*Optivus* spp.	7
		Aulotrachichthys spp.	4
		Trachichthyid	4
Atherinidae	12	*Atherinosoma* spp.	12
Plesiopidae	12	*Trachinops caudimaculatus*	9
		Paraplesiops spp.	3
Enoplosidae	11	*Enoplosus armatus*	11
Ophichthidae	11	Ophicthid	11
Exocoetidae	11	*Exocoetus volitans*	9
		Cheilopogon sp.	1
		Exocoetid	1
Zeidae	11	*Cyttus australis*	7
		Zeus faber	4
Tetraodontidae	9	Tetraodontid	9
Leptoscopidae	7	*Leuseurina platycephala*	7
Terapontidae	6	Terapontid	6
Uranoscopidae	6	Uranoscopid	6
Arripidae	5	*Arripis trutta*	5
Cynoglossidae	5	*Cynoglossus* sp.	5
Emmelichthyidae	5	*Emmelichthys nitidus*	5
Pleuronectidae	5	*Ammotretis* spp.	3
		Pleuronectid	2
Hemiramphidae	4	*Hyporhamphus melanochir*	4
Trachipteridae	4	*Trachipterus arawatae*	4
Melamphaidae	3	Melamphaid	3
Ophidiidae	3	Ophidiid	2
		Genypterus blacodes	1
Pataecidae	3	*Neopataecus waterhousii*	2
		Aetapcus maculatus	1
Cheilodactylidae	2	*Nemadactylus macropterus*	2
Macroramphosidae	2	*Macroramphosus scolopax*	2

Table 7. Total number of larvae per fish family ..... cont.

Family	Total family	Taxa	Total taxa
Macrouridae	2	Macrourid	2
Notosudidae	2	*Scopelosaurus meadi*	2
Paralepididae	2	*Lestidiops pacifica*	2
Percichthyidae	2	*Howella brodiei*	2
Scomberesocidae	2	*Scomberesox saurus*	2
Gonostomatidae	2	*Cyclothone*	1
		Gonostomatid	1
Anatopteridae	1	*Anatopterus pharao*	1
Anguillidae	1	Leptocephalus	1
Berycidae	1	*Centroberyx berradi*	1
Bythitidae	1	*Ogilbia* sp.	1
Chandidae	1	*Ambassis* sp.	1
Gnathanacanthidae	1	*Gnathanacanthus goetzeei*	1
Hoplichthyidae	1	*Hoplichthys haswelli*	1
Regalecidae	1	*Regalecus glesne*	1
Scopelarchidae	1	*Scopelarchus analis*	1
Serrivomeridae	1	*Serrivomer* sp.	1
Synodontidae	1	*Synodus*	1
		Unidentified	240

Larvae of several commercial important fish species to southeastern Australia were caught during the summer cruises. These included those of pilchard, anchovy, sand flathead, eastern school whiting and jack mackerel, southern flathead (*Platycephalus speculator*, Platycephalidae), ocean perch (*Helicolenus percoides*, Scorpaenidae), silver trevally (*Pseudocaranx dentex*, Carangidae), Australian salmon (*Arripis trutta*, Arripidae), snapper (*Pagrus auratus*, Sparidae), blue warehou (*Seriolella brama*, Centrolophidae) and blue mackerel (*Scomber australasicus*, Scombridae) (Table 7).

5.3.2 Winter surveys

A total of 1,387 and 4,375 larval fishes were caught at fixed stations both with the bongo (surface) and EZ (25-0, 50-25, 75-50,100-75 m depth strata) nets during cruise 3 (May-Jun 1998) and cruise 2 (Jul 1998), respectively. The overall total in both cruises comprised larval fishes belonging to 56 teleost fish families, of which 46 were present in both cruises (Table 8). Fish families that were common to both cruises totalled 36. In terms of total numbers, the most abundant larval fishes caught during cruise 3 belonged to the Moridae (18.6%), followed by those of the Myctophidae (14.8%), Engraulidae (12.9%), Gobiidae (8.7%) and Cheilodactylidae (8.2%). In contrast, the most abundant larval fishes caught during cruise 4 belonged to the Scorpaenidae (37.4%) followed by those of the Moridae (16.2%), Myctophidae (10.2%), Gempylidae (6.2%) and

Table 8. Summary of teleost fish families identified during winter cruises 3 (May-June 1998) and 4 (July 1998) in coastal waters of southeastern Australia, the total number of larvae caught in each (non-standardised), and their respective contributions to the total caught during each cruise. Families have been arranged in alphabetical order.

		Cruise 3 – May/Jun 98		Cruise 4 – Jul 98	
No.	Family	Total No. larvae	Percentage (%) of total	Total No. larvae	Percentage (%) of total
1	Anguillidae			1	0.02
2	Aplodactylidae			14	0.32
3	Argentinidae	1	0.07	7	0.16
4	Aulopidae	1	0.07		
5	Berycidae	1	0.07		
6	Bothidae	28	2.03	4	0.09
7	Bovichtidae			130	2.97
8	Callanthiidae	1	0.07	1	0.02
9	Callionymidae	46	3.33	28	0.64
10	Carangidae			36	0.82
11	Carapidae	4	0.29	5	0.11
12	Centrolophidae	18	1.30	250	5.71
13	Cepolidae	1	0.07	13	0.30
14	Cheilodactylidae	113	8.18	13	0.30
15	Chiasmodontidae	1	0.07		
16	Chironemidae	2	0.14	2	0.05
17	Clinidae			65	1.49
18	Clupeidae	109	7.89	1	0.02
19	Creediidae	6	0.43	2	0.05
20	Cynoglossidae	22	1.59	2	0.05
21	Dinolestidae	9	0.65	10	0.23
22	Diodontidae	7	0.51	1	0.02
23	Engraulidae	178	12.89	1	0.02
24	Galaxiidae	2	0.14	11	0.25
25	Gempylidae	21	1.52	270	6.17
26	Gobiidae	120	8.69	148	3.38
27	Gonostomatidae			2	0.04
28	Idiacanthidae	5	0.36	4	0.09
29	Latridae			92	2.10
30	Leptoscopidae	3	0.22	2	0.05
31	Lophiidae			1	0.02
32	Macroramphosidae	4	0.29	7	0.16
33	Monacanthidae	12	0.87	9	0.21
34	Moridae	257	18.61	709	16.21
35	Mugilidae	58	4.20		
36	Myctophidae	205	14.84	446	10.19
37	Odacidae	3	0.22		
38	Ophidiidae	1	0.07	14	0.32
39	Paralepididae	4	0.29	3	0.07
40	Percichthyidae	1	0.07		
41	Photichthyidae	4	0.29	5	0.11
42	Pinguipedidae	1	0.07	1	0.02
43	Platycephalidae	1	0.07		
44	Pleuronectidae	16	1.16	173	3.95

Table 8. Summary of teleost fish families .....cont.

		Cruise 3 – May/Jun 98		Cruise 4 – Jul 98	
No.	Family	Total No. larvae	Percentage (%) of total	Total No. larvae	Percentage (%) of total
45	Scaridae	1	0.07		
46	Scomberesocidae	11	0.80	1	0.02
47	Scorpaenidae	3	0.22	1637	37.42
48	Scorpididae	7	0.51	22	0.50
49	Serranidae	1	0.07	20	0.46
50	Soleidae	4	0.29		
51	Syngnathidae	38	2.75	4	0.09
52	Trachichthyidae	4	0.29		
53	Triglidae	4	0.29	53	1.21
54	Tripterygiidae			2	0.05
55	Uranoscopidae			15	0.34
56	Zeidae	3	0.22	6	0.14
	Unidentified	39	2.82	132	3.02

Centrolophidae (5.7%). Larval fishes belonging to the remaining fish families in cruises 3 and 4 (n = 41) accounted for <8 and <5% to the total caught in these cruises, respectively, and included those of families such as the Clupeidae, Pleuronectidae and Bovichtidae (Table 8).

Nearly 85% of the fish families in cruise 3 (n = 39) and 78% in cruise 4 (n = 36) were represented by <50 larvae, each accounting for <4% of the total numbers caught in each cruise. In addition, 12 fish families in cruise 3 and eight in cruise 4 were represented by only one larva. Unidentified larvae in cruises 3 and 4 totalled 39 (2.8%) and 132 (3.0%), respectively (Table 8).

Fish taxa within the 56 identified families totalled 95 for both winter cruises combined (Table 9). Of these, the most abundant larvae were those of an unidentified scorpaenid (possibly *Neosebastes* sp.), and those of the Moridae and Myctophidae, both of which contained a mixture of species. Of those larvae that could be identified to species, the most abundant included those of barracouta (*T.atun*, Gempylidae), anchovy (*E.australis*, Engraulidae), cobbler (*Gymnapistes marmoratus*, Scorpaenidae), spotted and blue warehous (*S.punctata* and *S.brama*, Centrolophidae) and thornfish (*Bovichtus angustifrons*, Bovichtidae). Larvae of the Triglidae contained a mixture of mostly *Lepidoperca* spp., whereas larvae of the Gobiidae could not be identified to species. Larvae of other fish species which were fairly well represented during one or both winter cruises were those of flounder (*Ammotretis* spp., Pleuronectidae), pilchard (*S.sagax*, Clupeidae), magpie perch (*Cheilodactylus nigripes*, Cheilodactylidae) and trumpeter (*Latris* sp. ?, Latridae) (Table 9).

Larvae of several commercial important fish species to southeastern Australia were caught during the winter cruises. These included those of anchovy, spotted and blue warehous, pilchard, jackass morwong (*Nemadactylus macropterus*, Cheilodactylidae), yellow-eye mullet (*Aldrichetta forsteri*, Mugilidae), silver trevally (*P.dentex*, Carangidae), ocean perch (*H.percoides*, Scorpaenidae) and rock ling (*Genypterus tigerinus*, Ophidiidae) (Table 9).

Larvae of King George whiting (*Sillaginodes punctata*, Sillaginidae) were not caught during the two winter cruises along any of the western transects routinely sampled (Port Campbell, Portland and Port MacDonnell), or along the transect off Barwon Heads. However, additional surface sampling carried out during daily hours within Portland Bay on 28 July 1998 (cruise 4) produced five larvae of this species (see Section 5.7).

5.4 Spatial distribution of larval fish assemblage

5.4.1 Summer surveys

Concentrations of all larval fishes combined in cruise 1 (Jan-Feb 1997) were markedly greater across all depth strata over the three western-most transects (Port Campbell, Portland and Port MacDonnell) than along transects eastwards of Barwon Heads (T5), and were particularly high at the surface and in the 25-0 and 50-25 m depth strata at the 2-8 nm offshore stations (Fig. 21). By contrast, concentrations of larval fishes during summer cruise 2 (Dec 1997) were usually greater along the five eastern-most transects, particularly off Seaspray to the east of Wilsons Promontory in the 25-0 and 50-25 m depth strata (Fig. 22).

Most positive stations across the surveyed area during the summer 1997 cruises produced concentrations of larval fishes ranging between 0.1 and 50 larvae per 100 m^3, with only a few stations yielding >50 larvae per 100 m^3 (Figs 21, 22). Maximum larval fish concentrations in these cruises were 361.1 larvae per 100 m^3 at the station 2 nm off Port Campbell (25-0 m) in cruise 1, and 247.3 larvae per 100 m^3 at the station 16 nm off Seaspray (50-25 m) in cruise 2 (Figs 21, 22; Table 10). No significant differences were found in the overall concentrations of larval fishes at the 2-8 nm offshore stations between Port Campbell (T6) and Portland (T7) in the 25-0 and 50-25 m depth strata (P >0.05). In stations ≥100 m deep, larval fish concentrations >50 m (ie. 75-50 and 100-75 m) were generally low (<25 larvae per 100 m^3) across the sampling area in both summer cruises (Figs 21, 22).

Diversity of taxa found as larvae during the summer 1997 cruises was generally higher over inshore shelf areas between 2 and 16 nm offshore, particularly in the three western-

Table 9. Total number of larvae (non-standardised) caught per fish family and per taxa within family along southeastern Australia in winter cruises 3 (May-June 1998) and 4 (July 1998) combined. Families and taxa within families have been arranged in decreasing order of abundance according to the total numbers caught.

Family	Total family	Taxa	Total taxa
Scorpaenidae	1640	Scorpaenid	1336
		Gymnapistes marmoratus	142
		Scorpaenodes spp.	132
		Helicolenus percoides	12
		Neosebastes spp.	14
		Scorpaena spp.	4
Moridae	966	Morid	696
		Pseudophycis spp.	260
		Pseudophycis breviscula	10
Myctophidae	651	Myctophid	354
		Diaphus spp.	112
		Lampadena spp.	107
		Symbolophorus spp.	34
		Hygophum spp.	22
		Lampanyctus spp.	13
		Myctophum spp.	9
Gempylidae	291	*Thyrsites atun*	291
Centrolophidae	268	*Seriollela punctata*	137
		Seriollela brama	131
Gobiidae	268	Gobiid	268
Pleuronectidae	189	*Ammotretis* spp.	121
		Rhombosolea	39
		Pleuronectid	29
Engraulidae	179	*Engraulis australis*	179
Bovichtidae	130	*Bovichtus angustifrons*	130
Cheilodactylidae	126	*Cheilodactylus nigripes*	98
		Nemadactylus macropterus	15
		Cheilodactylus	11
		Cheilodactylid	2
Clupeidae	110	*Sardinops sagax*	107
		Hyperlophus vittatus	3
Latridae	92	*Latris* sp.	92
Callionymidae	74	Callionymid	74
Clinidae	65	Clinid	65
Mugilidae	58	*Aldrichetta forsteri*	57
		Liza argentea	1
Triglidae	57	*Lepidotrigla modesta*	31
		Lepidotrigla vanessa	12
		Lepidotrigla mulhalli	6
		Lepidotrigla spp.	4
		Chelidonichthys kumu	2
		Lepidotrigla papilio	2
Syngnathidae	42	*Stigmatopora nigra*	41
		Maroubra preserrata	1
Carangidae	36	*Pseudocaranx dentex*	35
		Trachurus declivis	1

Table 9. Total number of larvae per fish family ..... cont.

Family	Total family	Taxa	Total taxa
Bothidae	32	*Arnoglossus* spp.	11
		Pseudorhombus spp.	9
		Bothid	8
		Arnoglossus muelleri	4
Scorpididae	29	*Scorpis lineolata*	29
Cynoglossidae	24	*Cynoglossus* sp.	24
Monacanthidae	21	Monacanthid	21
Serranidae	21	Serranid	20
		Lepidoperca ?	1
Dinolestidae	19	*Dinolestes lewini*	19
Ophidiidae	15	*Genypterus tigerinus*	15
Uranoscopidae	15	Uranoscopid	15
Aplodactylidae	14	*Crinodus lophodon*	14
Cepolidae	14	*Cepola australis*	14
Galaxiidae	13	*Galaxias* sp.	13
Scomberesocidae	12	*Scomberesox saurus*	12
Macroramphosidae	11	*Macroramphosus scolopax*	11
Carapidae	9	*Echiodon rendahli*	9
Idiacanthidae	9	*Idiacanthus atlanticus*	9
Photichthyidae	9	*Vinciguerria attenuata*	9
Zeidae	9	*Zeus faber*	5
		Cyttus australis	3
		Cyttus sp.	1
Argentinidae	8	*Argentina australiae*	8
Creediidae	8	*Creedia haswelli*	8
Diodontidae	8	Diodontid	8
Paralepididae	7	*Lestidiops pacifica*	5
		Paralepidid	2
Leptoscopidae	5	*Crapatalus* sp. ?	3
		Leuseurina platycephala	2
Chironemidae	4	*Chironemus marmoratus*	4
Soleidae	4	Soleid	4
Trachichthyidae	4	Trachichthyid	2
		Paratrachichthys	2
Odacidae	3	Odacid	3
Callanthiidae	2	*Callanthias australis*	1
		Callanthias sp.	1
Pinguipedidae	2	*Parapercis allporti*	1
		Parapercis sp.	1
Tripterygiidae	2	Tripterygiid	2
Gonostomatidae	2	*Cyclothone*	2
Anguillidae	1	*Anguilla australis*	1
Aulopidae	1	*Aulopus purpurissatus*	1
Berycidae	1	*Centroberyx australis*	1
Chiasmodontidae	1	*Chiasmodon*	1
Lophiidae	1	*Lophiodes*	1
Percichthyidae	1	*Howella brodiei*	1
Platycephalidae	1	*Platycephalus* sp.	1
Scaridae	1	Scarid	1
		Unidentified	171

most transects in cruise 1 (Port Campbell, Portland and Port MacDonnell), and along the Seaspray transect in cruise 2 (Figs 23-26). Generally, low numbers of taxa (1-10) were found in positive stations off Gabo Island (T1), Cape Conran (T2), Cape Liptrap (T4) and Barwon Heads (T5) during cruise 1 (Jan-Feb 1997) (Table 10). The number of taxa found as larvae in positive stations during cruise 1 ranged from 9 at the 8 nm stations off Cape Conran (25-0 m) and Barwon Heads (50-25 m), to 27 at the 16 nm station off Port MacDonnell (25-0 m) (Figs 23, 24); number of taxa found during cruise 2 ranged from 4 at the 32 nm station off Portland (25-0 m) to 32 at the 8 nm station off Seaspray (25-0 m) (Figs 25,26;Table 10). As with the greatest larval fish concentrations, the highest diversity of taxa during the summer 1997 cruises was recorded in the 25-0 m and 50-25 depth strata (Figs 23-26; Table 10).

5.4.2 Winter surveys

Concentrations of all larval fishes combined in cruise 3 (May-Jun 1998) and cruise 4 (Jul 1998) were generally low across all depth strata (<50 larvae per 100 m^3), although they were slightly greater during cruise 4, particularly along transects off Gabo Island (T1) and Cape Conran (T2) in eastern Victoria (Figs 27, 28).

Most positive stations across the sampling area during the winter 1998 cruises produced concentrations of larval fishes ranging between 0.1 and 10 larvae per 100 m^3 (Figs 27, 28). Maximum larval fish concentrations recorded in these cruises were 14.6 larvae per 100 m^3 at the 2 nm station off Portland (surface) in cruise 3 (Fig. 27), and 76.2 larvae per 100 m^3 at the 2 nm station off Port Campbell (25-0 m) in cruise 4 (Fig. 28; Table 10). In stations ≥100 m deep, larval fish concentrations below 50 m (ie. 75-50 and 100-75 m) across the sampling area were generally low (<16 larvae per 100 m^3) in both winter cruises (Figs 27, 28).

Diversity of taxa found as larvae during the winter 1998 cruises was fairly similar along all transects, with all except some stations along the Gabo Island, Cape Conran and Port Campbell in cruise 4 producing larvae belonging to <10 taxa (Figs 29-32). The greatest diversity of taxa during the winter cruises was recorded at the 8 and 16 nm stations (50-25 and 25-0 m) along the Gabo Island transect during cruise 4 (Fig. 31).

Overall, the range in maximum number of taxa found as larvae in positive stations during cruise 3 (4-9) was markedly lower than that obtained during cruise 4 (5-22) (Table 10). The number of taxa found as larvae in positive stations during cruise 3 ranged from 4 at the 8 nm stations off Cape Conran (25-0 m) and Portland (50-25 m) to 9 at the 32 and 16 nm stations off Gabo Island (surface) and Seaspray (surface) (Figs 29, 30); number of taxa found in positive stations during cruise 4 ranged from 5 at the

Table 10. Summary of maximum larval fish concentrations (nos per 100 m^3) and maximum number of taxa identified as larvae by transect, station (nm offshore) and depth strata (m) during this study.

		Larval concentration			Number of taxa		
Cruise	Transect	Station	Depth strata	Larvae	Station	Depth strata	Taxa
Cruise 1 Jan-Feb 1997	Gabo Island	32	Surface	66.9	32	Surface	14
	Cape Conran	8	25-0 m	2.9	8	25-0 m	9
	Seaspray	16	25-0 m	25.9	16	25-0 m	22
	Cape Liptrap	2	25-0 m	11.1	2	25-0 m	12
	Barwon Heads	2	Surface	23.7	8	50-25 m	9
	Port Campbell	2	25-0 m	361.1	4	50-25 m	26
	Portland	2	25-0 m	104.1	4	50-25 m	19
	Port MacDonnell	16	25-0 m	196.4	16	25-0 m	27
Cruise 2 Dec 1997	Gabo Island	16	25-0 m	27.8	16	25-0 m	21
	Cape Conran	8	50-25 m	18.1	16	50-25 m	18
	Seaspray	16	50-25 m	247.3	8	25-0 m	32
	Cape Liptrap	4	25-0 m	37.6	4	25-0 m	27
	Barwon Heads	2	Surface	28.4	2	25-0 m	10
	Port Campbell	Not sampled					
	Portland	32	25-0 m	1.1	32	25-0 m	4
	Port MacDonnell	2	25-0 m	73.3	2,4	25-0 m	10
Cruise 3 May-Jun 1998	Gabo Island	2	50-25 m	4.5	32	Surface	9
	Cape Conran	4	50-25 m	2.3	8	25-0 m	4
	Seaspray	16	50-25 m	5.6	16	Surface	9
	Cape Liptrap	4	25-0 m	11.9	4	25-0 m	8
	Barwon Heads	32	50-25 m	2.9	32	50-25	7
	Port Campbell	4	50-25 m	5.2	32	75-50	7
	Portland	8	Surface	1.8	8	50-25	4
	Pt MacDonnell	No sampled					
Cruise 4 Jul 1998	Gabo Island	8	50-25 m	29.0	8	50-25	22
	Cape Conran	4	25-0 m	31.9	32	50-25	11
	Seaspray	No sampled					
	Cape Liptrap	16	Surface	1.8	32	50-25 75-50	5
	Barwon Heads	32	50-25 m	8.2	32	Surface	10
	Port Campbell	2	25-0 m	76.2	8	50-25	14
	Portland	8	Surface	5.5	2	25-0	8
	Port MacDonnell	Incomplete sampling					

32 nm station off Cape Liptrap (25-0 and 75-50 m) to 22 at the 8 nm station off Gabo Island (50-25-0) (Figs 31, 32; Table 10). As with the greatest larval fish concentrations, the highest diversity of taxa during the winter 1998 cruises was recorded in the 25-0 m and 50-25 depth strata (Figs 29-32; Table 10).

5.5 Overview of summer and winter larval fish assemblages

The summer (1997) and winter (1998) cruises carried out in southeastern Australia during this study yielded larval fishes belonging to a total of 96 teleost fish families. Of these, 45 families were represented in both seasons, and included families such as the Scorpaenidae, Triglidae and Moridae. Larvae from 40 families were only found during the summer cruises, whereas larvae of 11 families were found exclusively during the winter cruises (Tables 6, 8). Fish families found only in the summer surveys included the Arripidae, Atherinidae, Blenniidae, Girellidae and Scombridae; families recorded only in the winter surveys included the Bovichtidae, Chironemidae, Idiacanthidae, Scorpididae and Latridae.

The number of fish families recorded during the summer surveys (n = 85) was higher than that found during the winter surveys (n = 56). Similarly, the overall number of taxa found as larvae during the summer surveys (n = 146) was higher than that found during the winter surveys (n = 95). For all surveys, the most speciose families for which larvae could be identified to genus/species level were the Myctophidae, Platycephalidae, Scorpaenidae and Triglidae (Tables 7, 9).

In terms of number of taxa and larval concentrations (nos per 100 m^3) per cruise, both the highest larval concentrations and greatest number of taxa during during the summer cruise 1 (Jan-Feb 1997) were recorded in the three western-most transects, namely Port Campbell, Portland and Port MacDonnell (Table 10). A high number of taxa was also recorded along the Seaspray transect to the east of Wilsons Promontory during cruise 1 (n = 22), although the larval concentrations along this transect were markedly lower. In contrast, the highest larval concentrations and greatest number of taxa during the summer cruise 2 were recorded along the Seaspray transect (n = 32 taxa) to the east of Wilsons Promontory, with the Cape Liptrap transect producing a comparably high number of taxa (n = 27) but much lower larval fish concentrations (Table 10). During the winter cruises, the greatest number of taxa was recorded along the Gabo Island transect in eastern Victoria during the winter cruise 4 (n = 22), while the highest larval concentrations during the same cruise were obtained along the Port Campbell transect. Overall, the lowest number of taxa and larval fish concentrations throughout the study were found during the winter cruise 3 (Table 10).

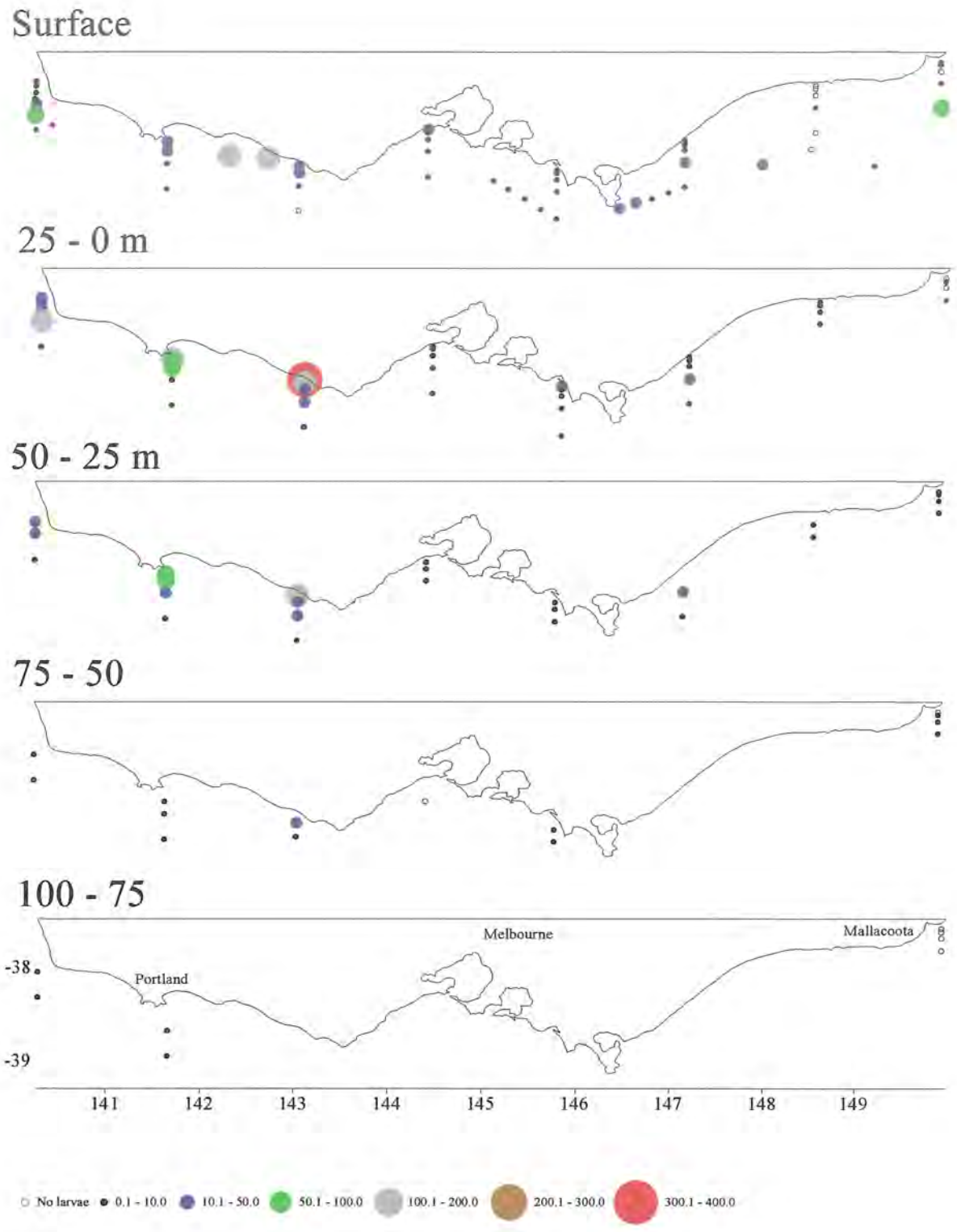


Figure 21. Spatial distribution of all larval fishes combined (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 1 (Jan-Feb 1997). Surface distribution plot (top) includes randomly collected additional surface samples.

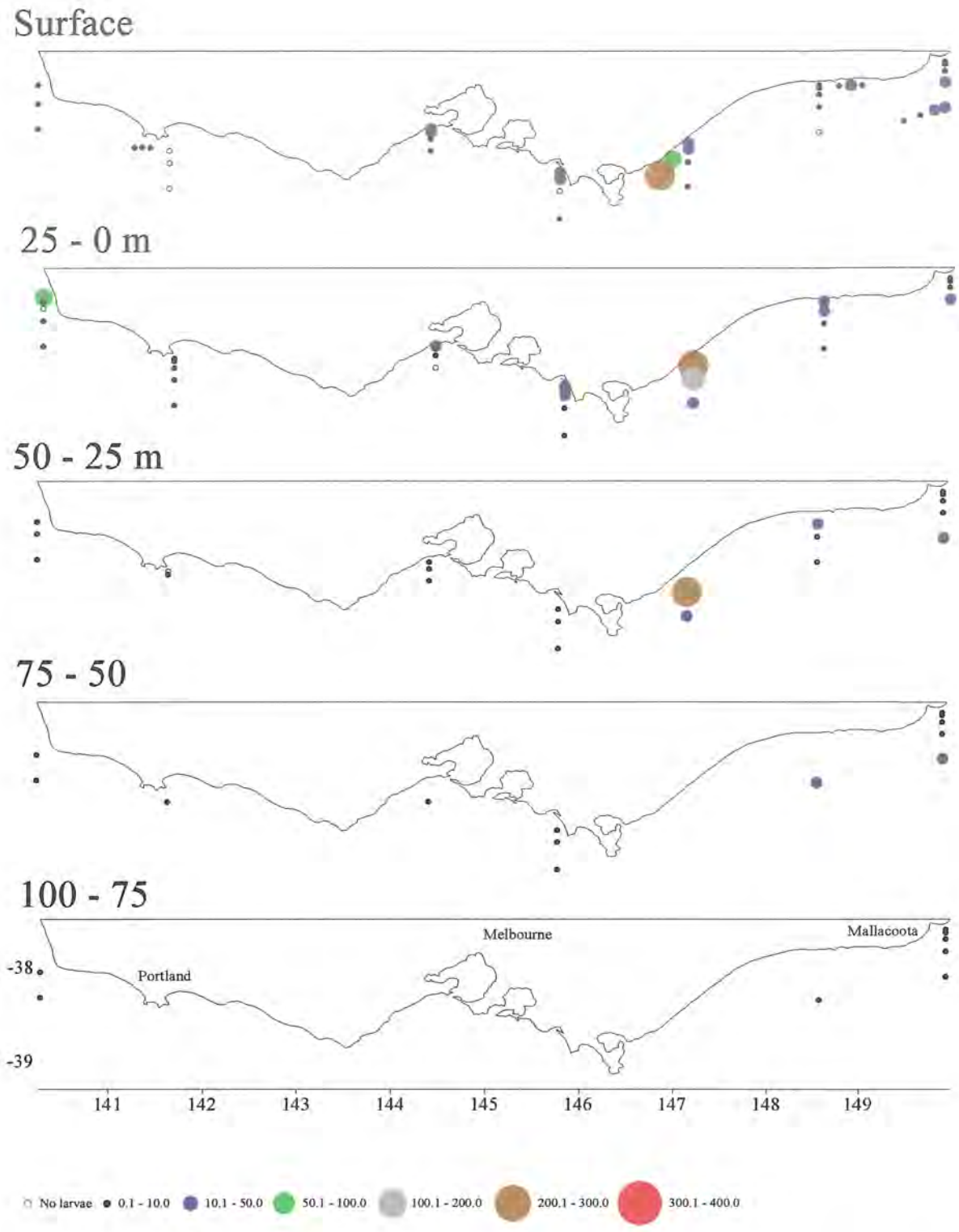


Figure 22. Spatial distribution of all larval fishes combined (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 2 (Dec 1997). Surface distribution plot (top) includes randomly collected additional surface samples.

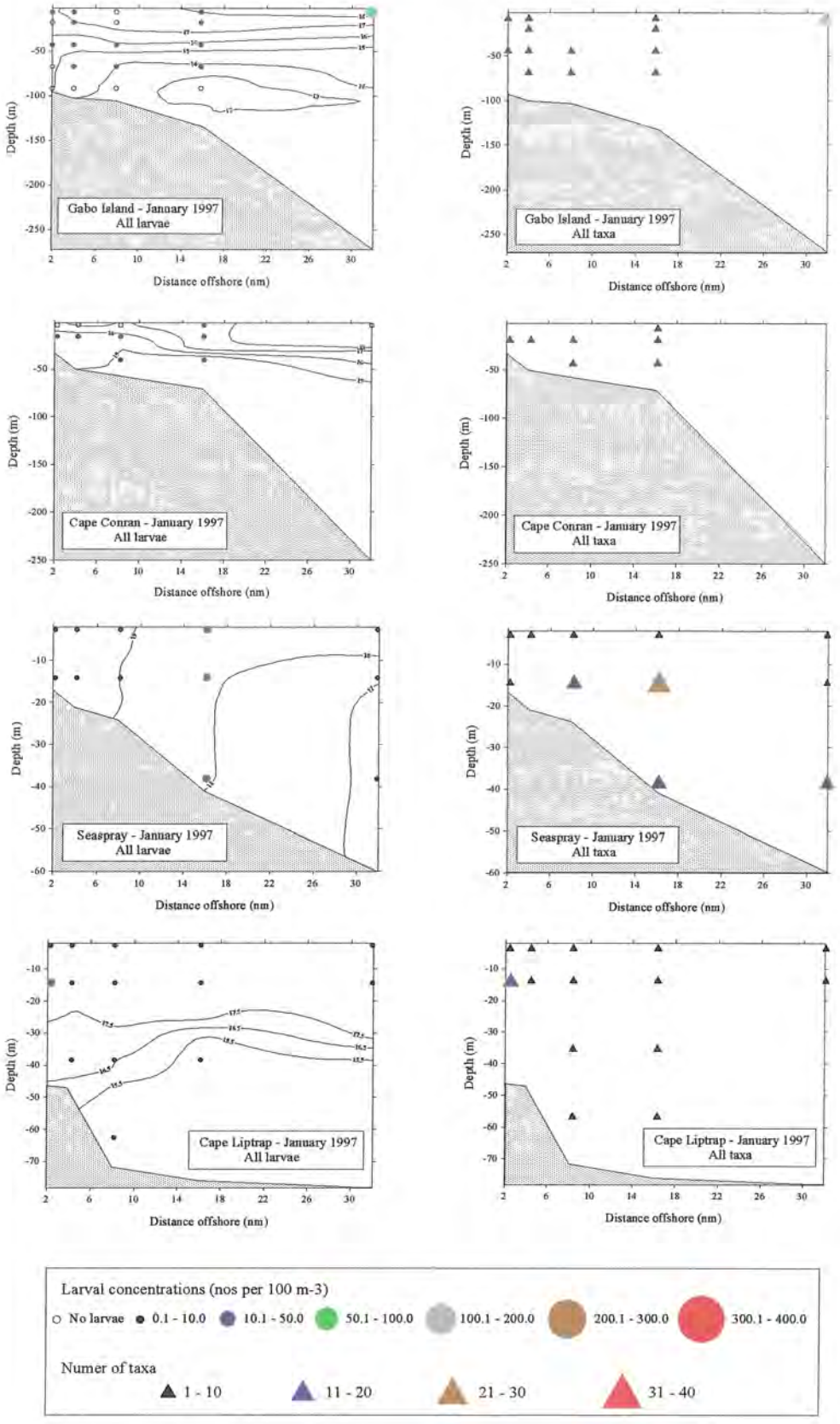


Figure 23. Concentrations of all larval fishes combined (nos per 100 m-3) along transects on the eastern Victorian coast (T1-T4; left plots), and the respective number of taxa found as larvae (right plots) during cruise 1 (Jan-Feb 1997). Larval fish concentrations have been plotted over vertical temperature profiles obtained during sampling period. Shaded area in each plot corresponds to the shelf profile.

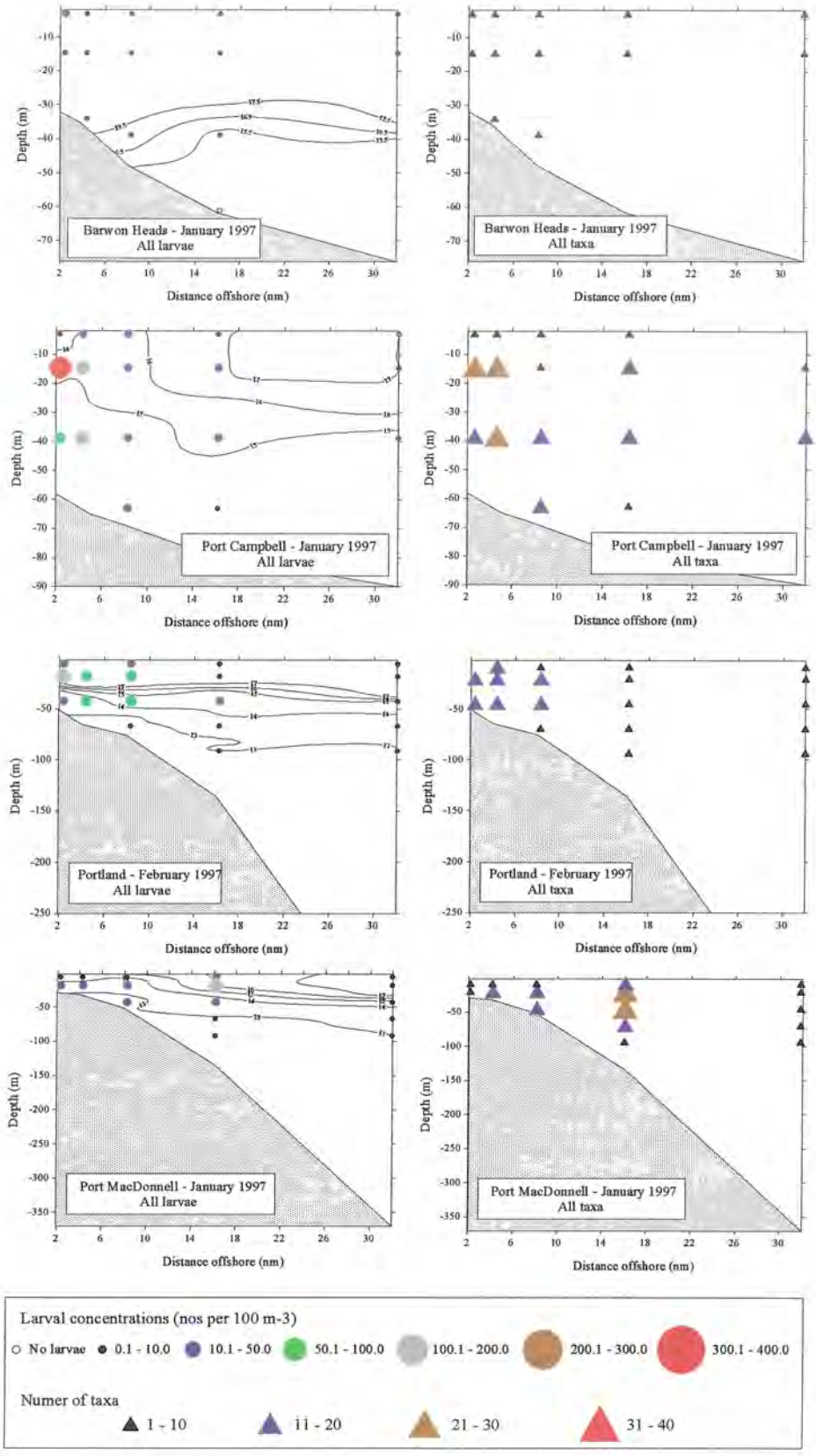


Figure 24. Concentrations of all larval fishes combined (nos per 100 m-3) along transects on the western Victoria and eastern South Australian coasts (T5-T8; left plots), and the respective number of taxa found as larvae (right plots) during cruise 1 (Jan-Feb 1997). Larval fish concentrations have been plotted over vertical temperature profiles obtained during sampling period. Shaded area in each plot corresponds to the shelf profile.

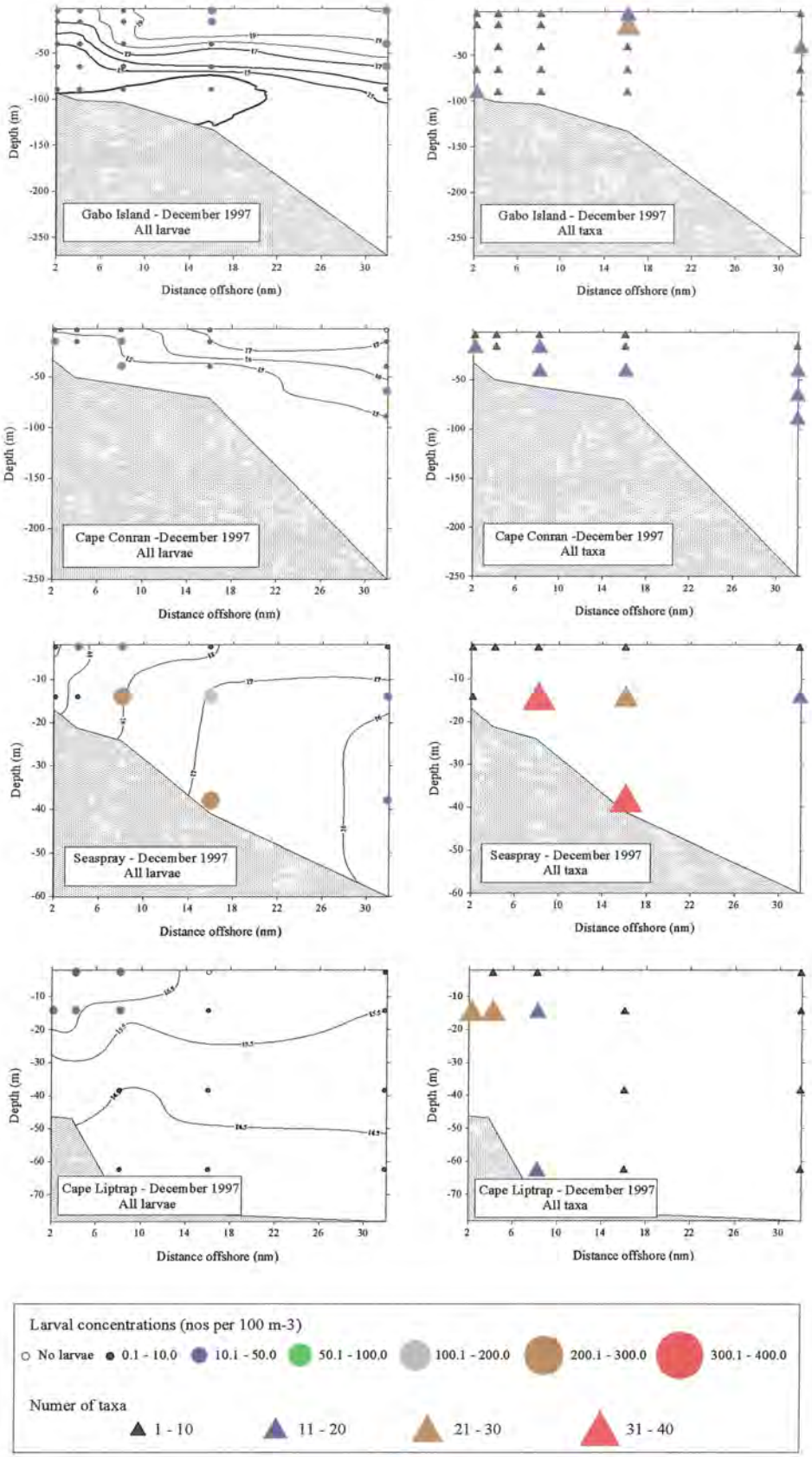


Figure 25. Concentrations of all larval fishes combined (nos per 100 m-3) along transects on the eastern Victorian coast (T1-T4; left plots), and the respective number of taxa found as larvae (right plots) during cruise 2 (Dec 1997). Larval fish concentrations have been plotted over vertical temperature profiles obtained during the sampling period. Shaded area in each plot corresponds to the shelf profile.

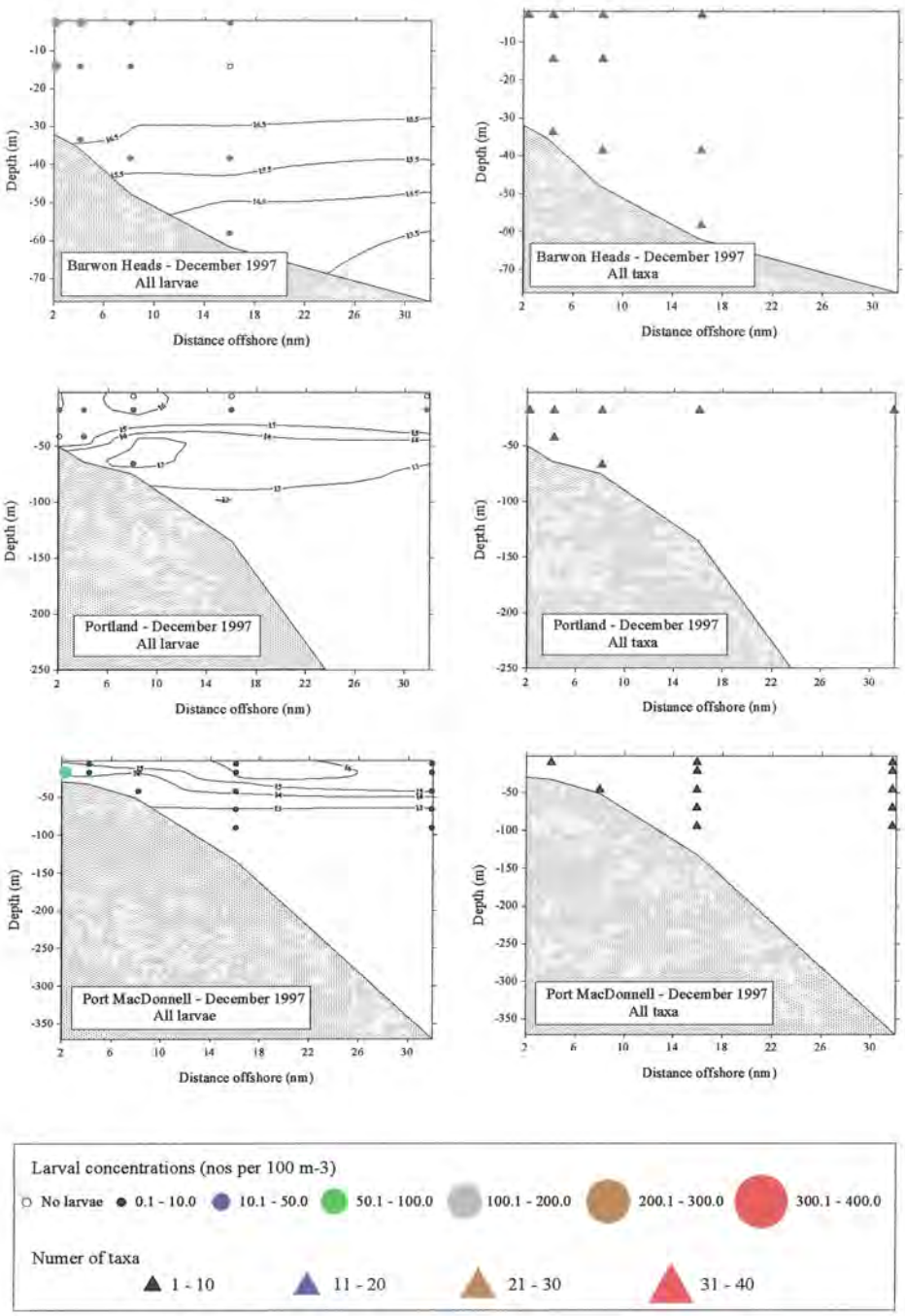


Figure 26. Concentrations of all larval fishes combined (nos per 100 m-3) along transects on the western Victorian and eastern South Australian coasts (T5-T8; left plots), and the respective number of taxa found as larvae (right plots) during cruise 2 (Dec 1997). Transect 6 (Port Campbell) was not sampled. Larval fish concentrations have been plotted over vertical temperature profiles obtained during the sampling period. Shaded area in each plot corresponds to the shelf profile.

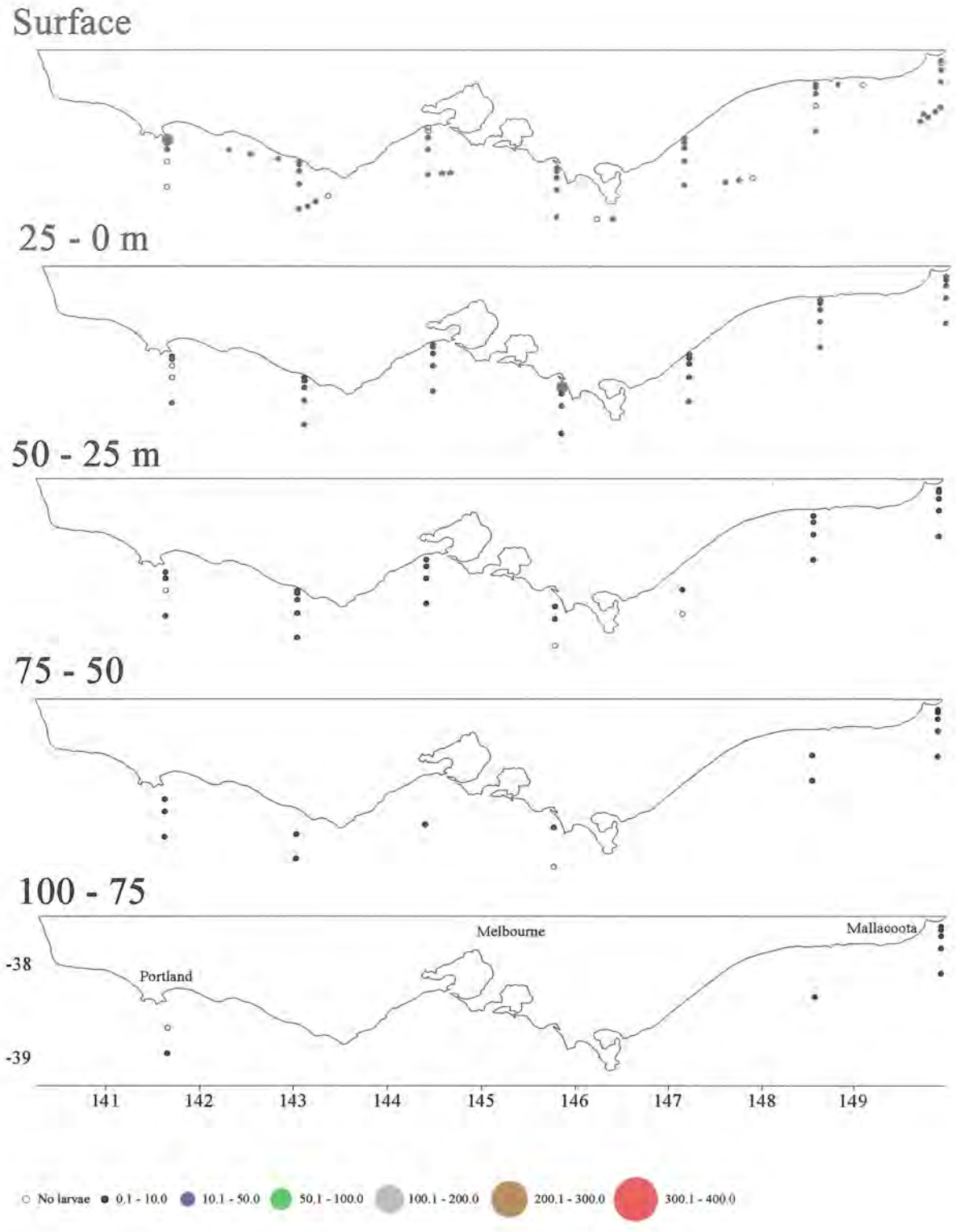


Figure 27. Spatial distribution of all larval fishes combined (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 3 (May-Jun 1998). Transect 3 (Seaspray) was not sampled. Surface distribution plot (top) includes randomly collected additional surface samples.

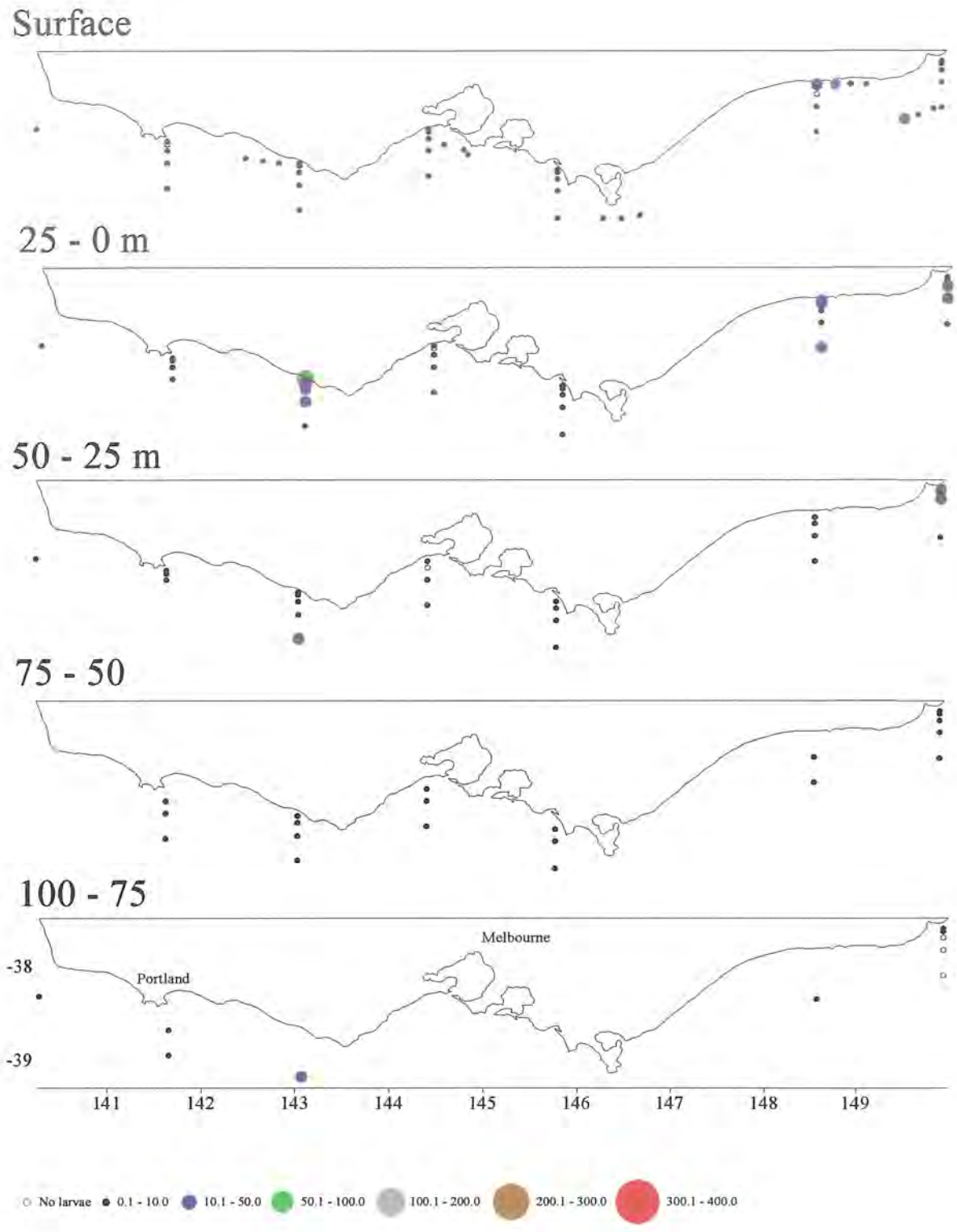


Figure 28. Spatial distribution of all larval fishes combined (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 4 (Jul 1998). Transects 3 (Seaspray) and 8 (Port MacDonnell) were not sampled. Surface distribution plot (top) includes randomly collected additional surface samples.

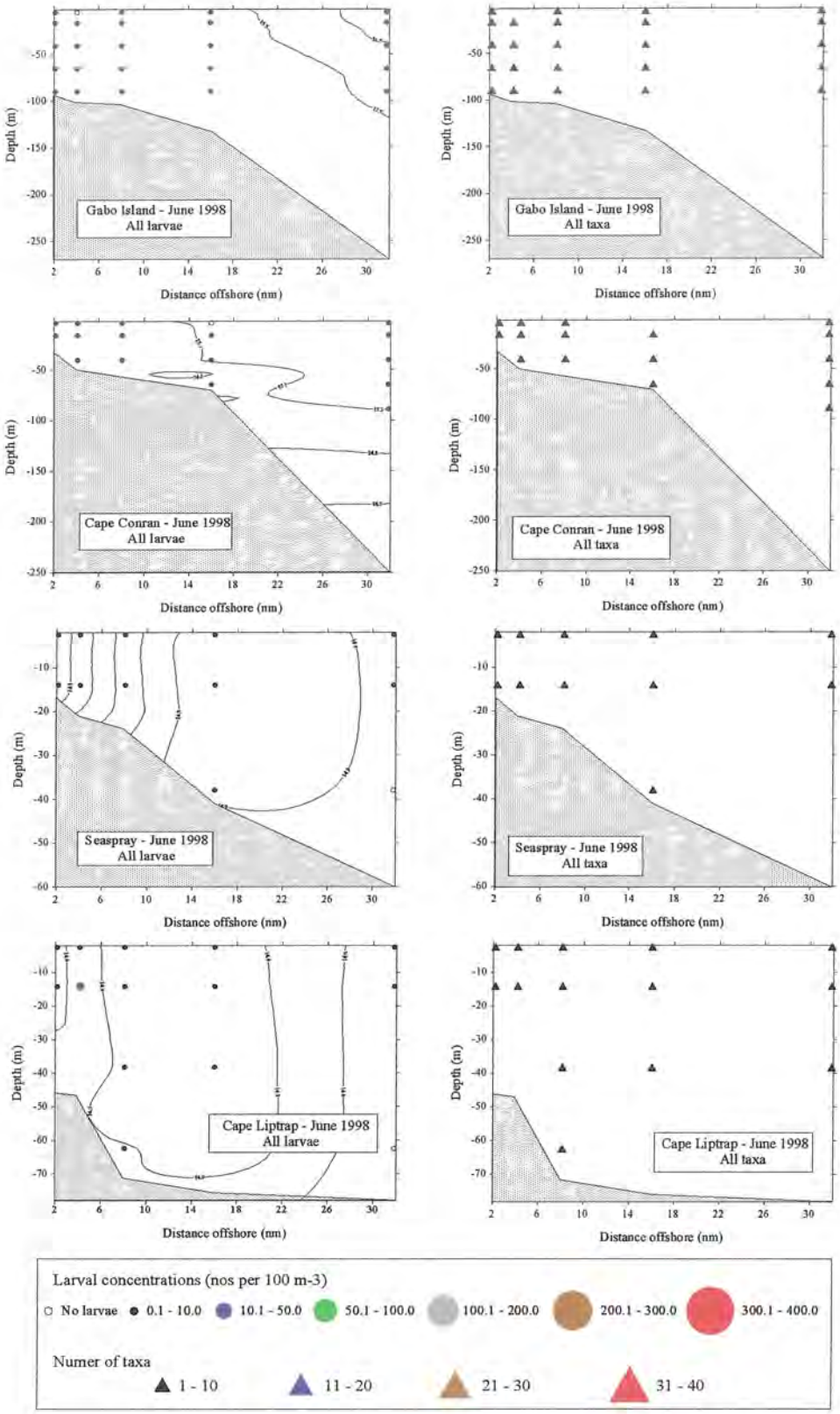


Figure 29. Concentrations of all larval fishes combined (nos per 100 m-3) along transects on the eastern Victorian coast (T1 - T4; left plots), and the respective number of taxa found as larvae (right plots) during cruise 3 (May-Jun 1998). Larval fish concentrations have been plotted over vertical temperature profiles obtained during the sampling period. Shaded area in each plot corresponds to the shelf profile.

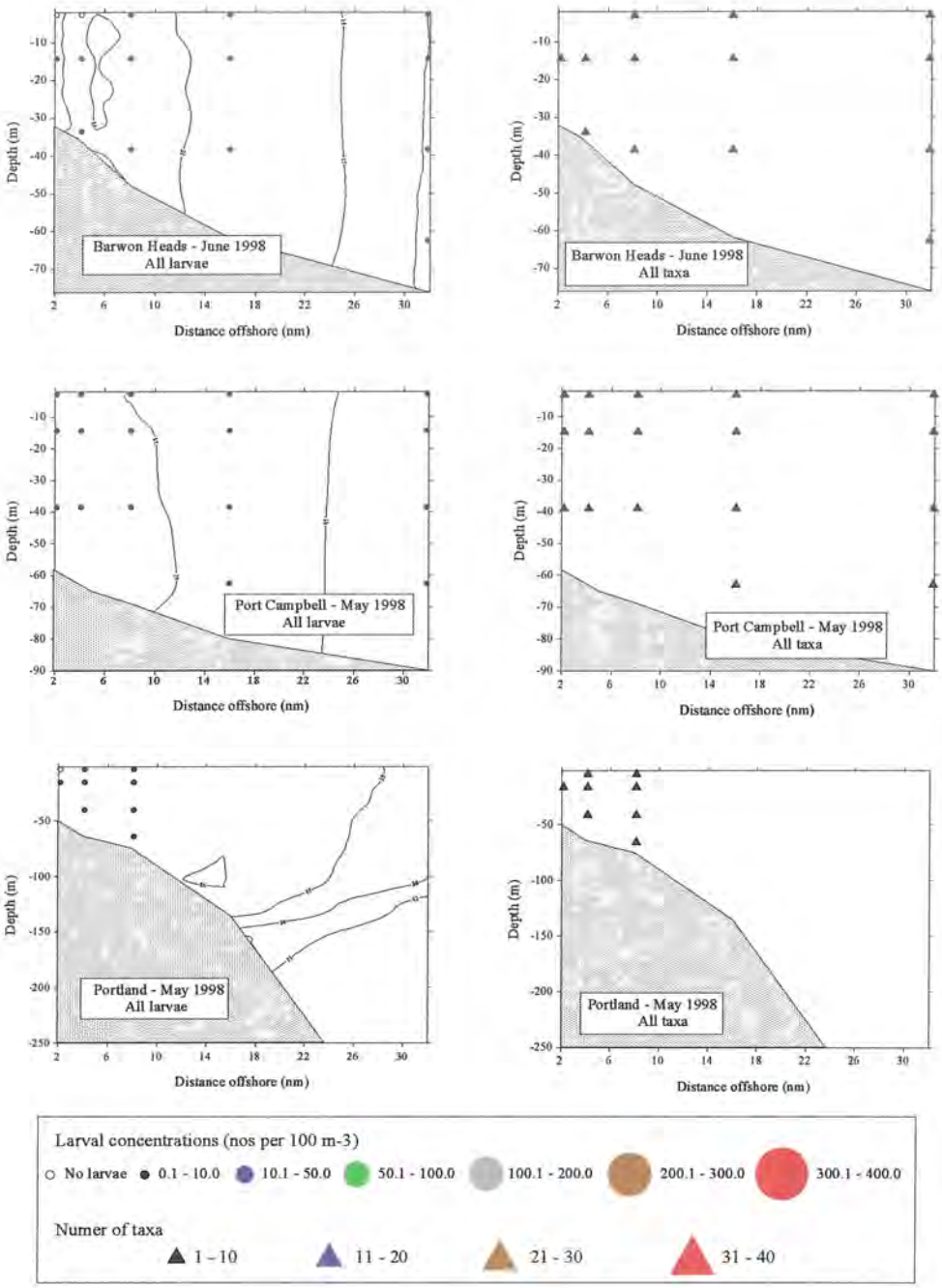


Figure 30. Concentrations of all larval fishes combined (nos per 100 m-3) along transects on the western Victorian coast (T5 - T7; left plots), and the respective number of taxa found as larvae (right plots) during cruise 3 (May-Jun 1998). Sampling along transect 8 (Port McDonnell) was omitted. Larval fish concentrations have been plotted over vertical temperature profiles obtained during the sampling period. Shaded area in each plot corresponds to the shelf profile.

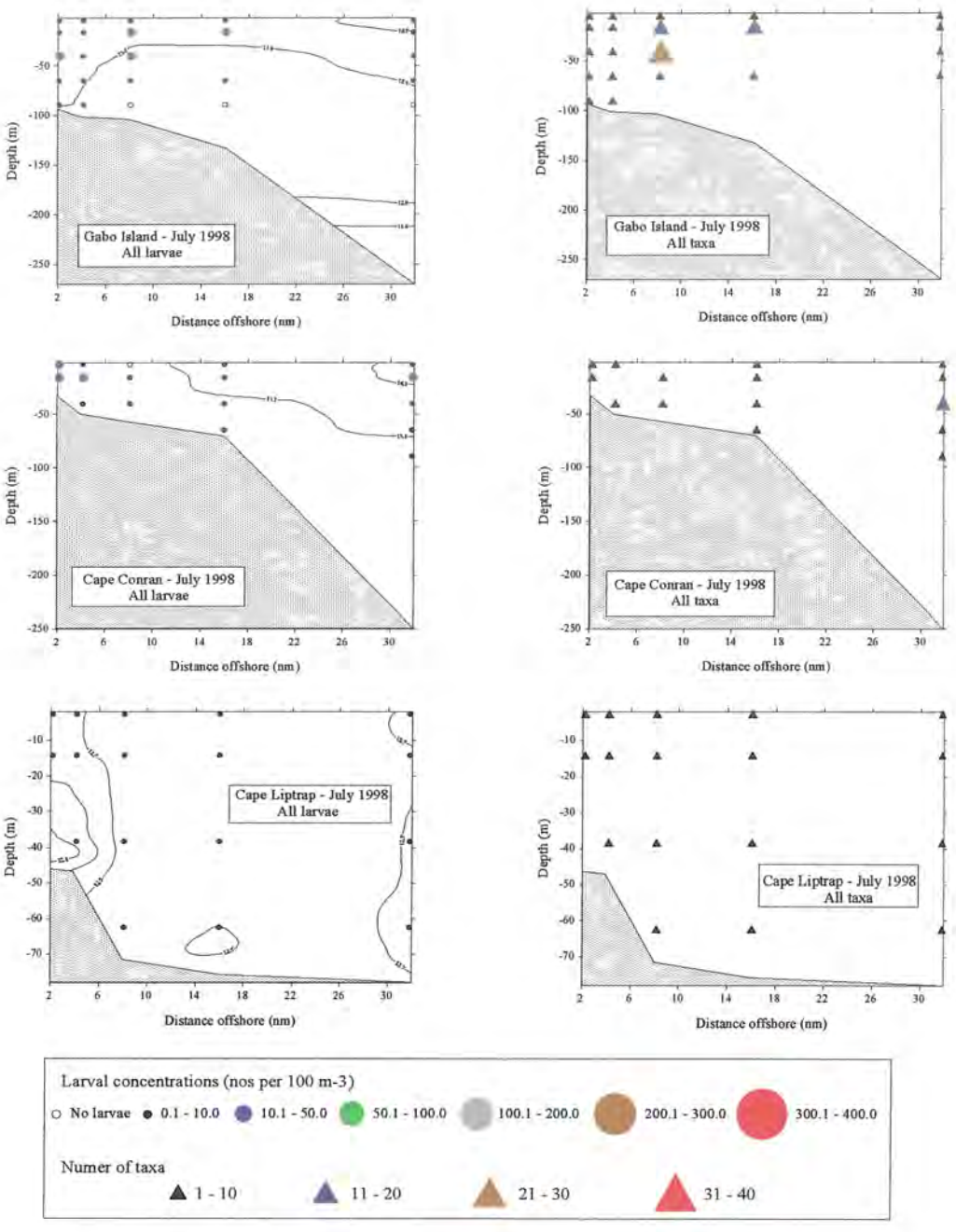


Figure 31. C oncentrations of all larval fishes combined (nos per 100 m-3) along transects on the eastern Victorian coast (T1, T2, T4; left plots), and the respective number of taxa found as larvae (right plots) during cruise 4 (Jul 1998). Transect 3 (Seaspray) was not sampled. Larval fish concentrations have been plotted over vertical temperature profiles obtained during the sampling period. Shaded area in each plot corresponds to the shelf profile.

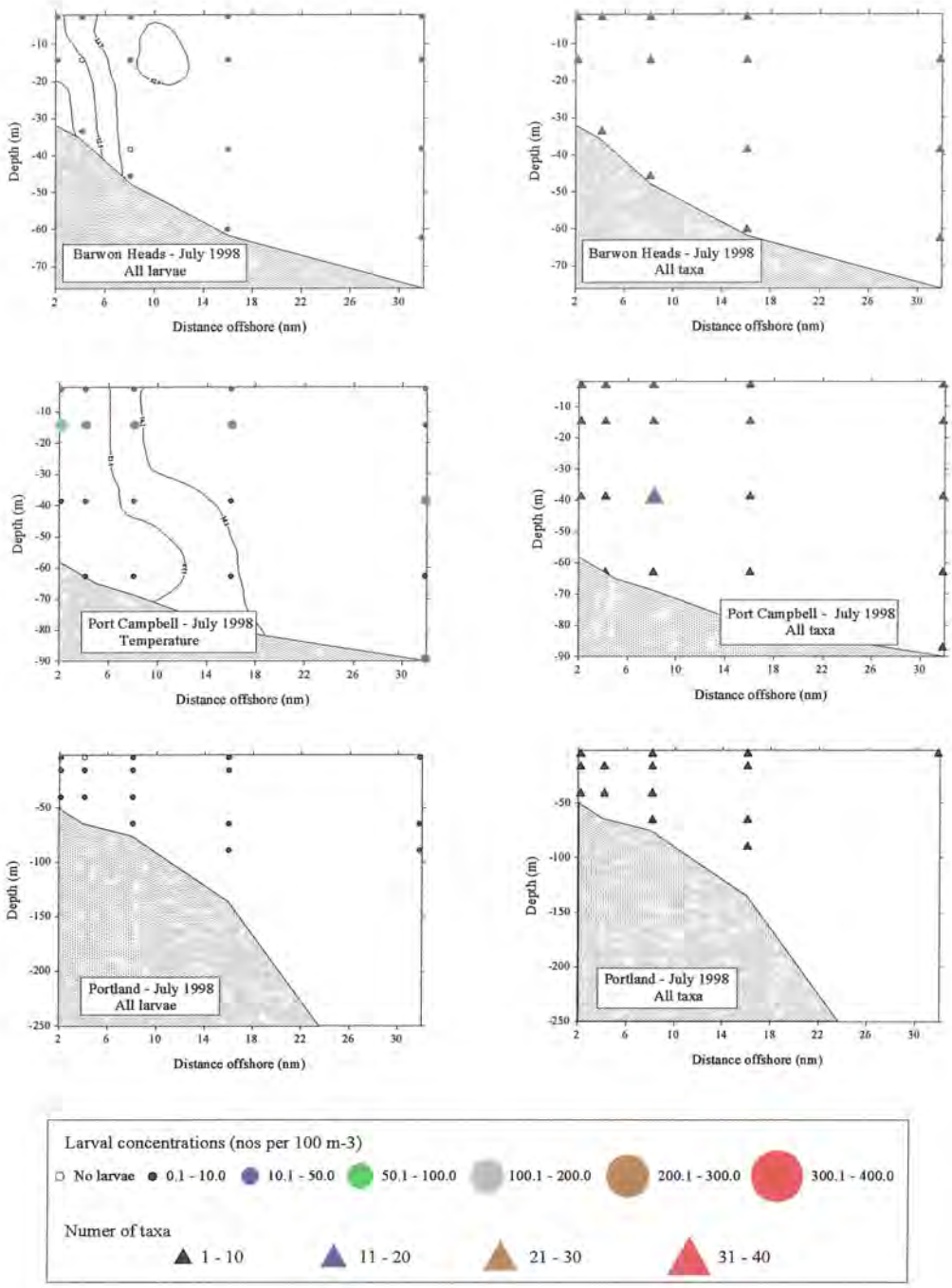


Figure 32. Concentrations of all larval fish combined (nos per 100 m-3) along transects on the western Victorian coast (T5 - T7; left plots), and the respective number of taxa found as larvae (right plots) during cruise 4 (Jul 1998). Transect 8 (Port MacDonnell) was not sampled. Larval fish concentrations have been plotted over vertical temperature profiles obtained during the sampling period except for transect 7 (Portland). Shaded area in each plot corresponds to the shelf profile.

5.6 Distribution and abundance of larvae of dominant species

5.6.1 Pilchard (*Sardinops sagax*)

Pilchard larvae occurred almost exclusively during the summer cruises (Jan-Feb and Dec 1997), whereas comparatively very few larvae were found during the winter cruises (May-Jun and Jul 1998) (Figs 33, 35-37). In terms of totals caught by cruise (excluding additional surface samples), pilchard larvae were most abundant during cruise 1 (n = 7,946), accounting for 63.8% of the total number of larvae caught during that cruise. By contrast, considerably lower numbers of larvae were caught during cruise 2 (n = 759), representing 11.7% of the total caught during that cruise (Table 6). Very few pilchard larvae were caught during winter cruise 3 (n = 114), while only one pilchard larva was caught during winter cruise 4 (Table 8).

Pilchard larvae during cruise 1 were predominantly found along the Port MacDonnell, Portland and Port Campbell transects in western Bass Strait (Fig. 33). By contrast, fewer larvae (<10 larvae per 100 m^3) were present along eastern Victoria except for a relatively dense patch (45 larvae per 100 m^3) caught in surface waters at the 32 nm station off Gabo Island. Additional surface (neuston) samples taken during cruise 1 resulted only in a few larvae being caught just east of Wilsons Promontory (Fig. 33).

Pilchard larvae in western Bass Strait were caught both at surface and throughout the water column to a depth of 75 m, and were particularly abundant between 0 and 50 m (Fig. 33). No larvae were found below 75 m and only one larva was caught 32 nm offshore (Port Campbell, 50-25 m). In terms of distance from the coast, most pilchard larvae along the Portland and Port Campbell transects were caught over the shelf, ie. between 2 and 8 nm from the coast, although they were also found near the shelf brake 16 nm off Port MacDonnell (Fig. 34). Most pilchard larvae found during cruise 1 in western Bass Strait were caught in water temperatures of 14.5-18.0°C (Fig. 34).

The greatest concentration of pilchard larvae during cruise 1 (333 larvae per 100 m^3) was recorded at the 2 nm station off Port Campbell, in the 25-0 m depth stratum. Concentrations of 100-200 pilchard larvae per 100 m^3 were also found at the surface between Portland and Port Campbell, in the 25-0 m depth stratum at the 16 nm station off Port MacDonnell and the 4 nm off Port Campbell, and in the 50-25 m depth stratum at the 2 nm station off Port Campbell (Fig. 33). Most other positive stations during cruise 1 yielded <100 pilchard larvae per 100 m^3. Two-way ANOVA (depth × distance) showed that the mean concentrations of pilchard larvae combined for the three western-most transects were significantly greater in the 25-0 m depth stratum than at the

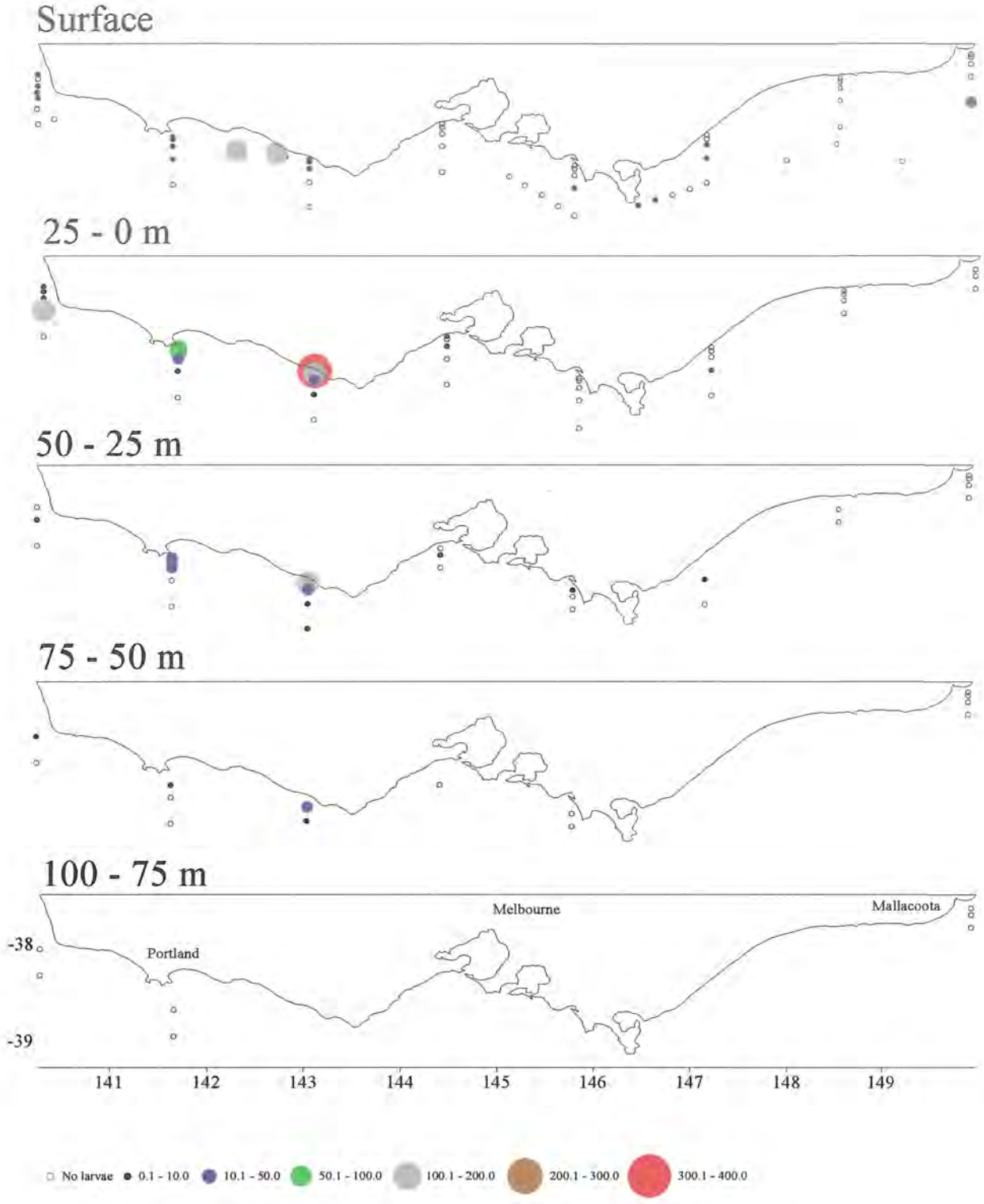


Figure 33. Spatial distribution of pilchard larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 1 (Jan-Feb 1997). Surface distribution plot (top) includes randomly collected additional surface samples.

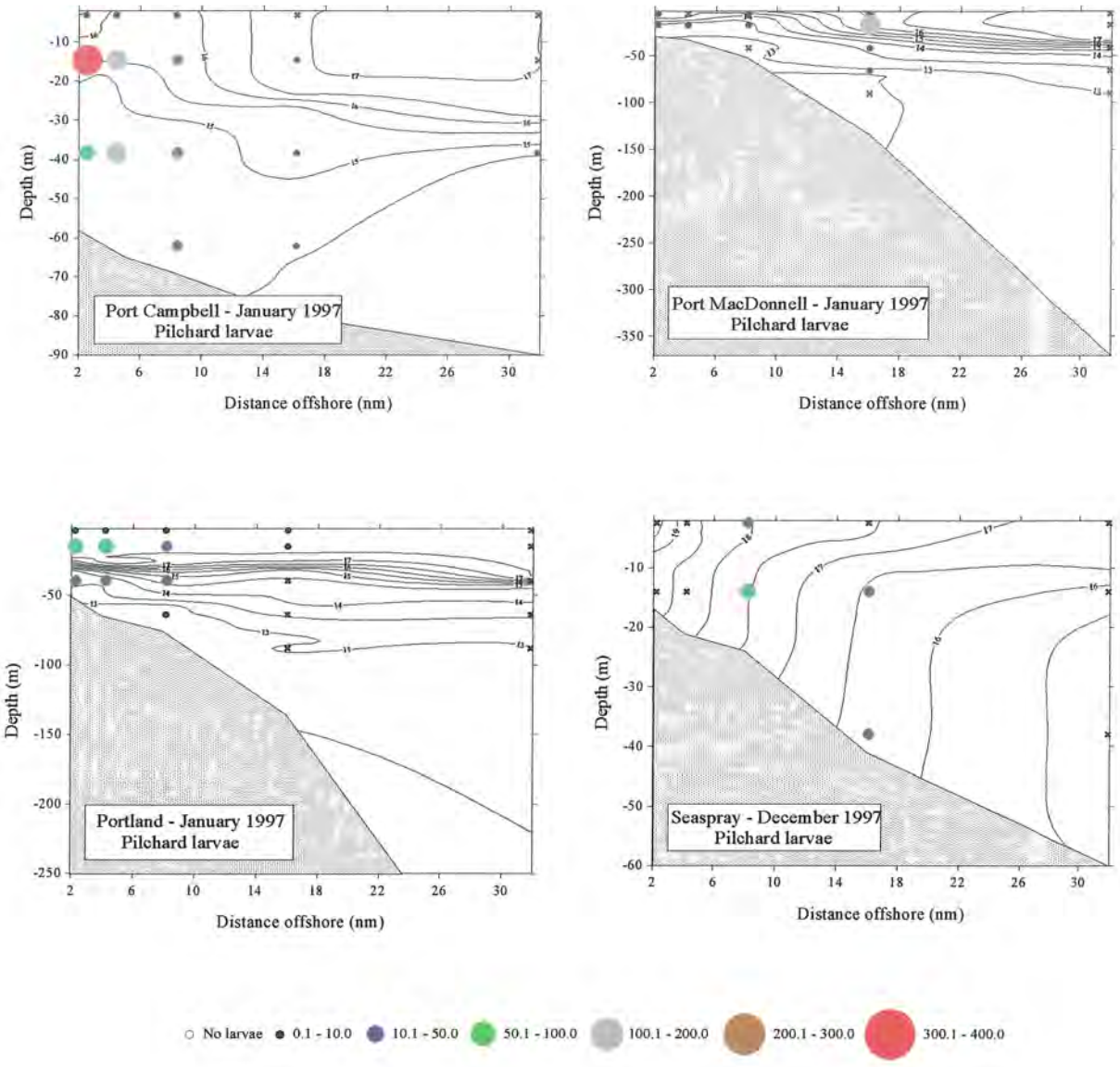


Figure 34. Vertical distribution of pilchard larvae (nos per 100 m-3) along Port Campbell (T6), Portland (T7) and Port MacDonnell (T8) during cruise 1 (Jan-Feb 1997), and along Seaspray (T3) during cruise 2 (Dec 1997). Pilchard larval concentrations have been plotted over vertical temperature profiles obtained during sampling period. Shaded area in each plot corresponds to the shelf profile.

surface ($P<0.05$), while no significant differences were found with distance from shore (2-16 nm) (Fig. 35).

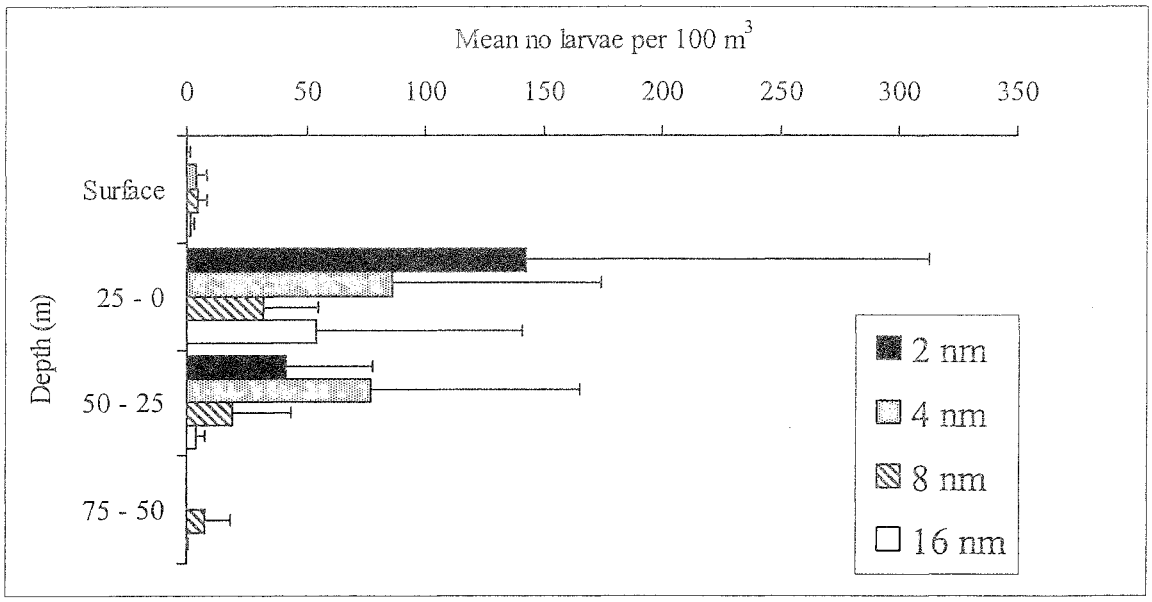


Figure 35. Mean concentration (+ 1SD) of pilchard larvae (nos per 100 m^3) by depth stratum and distance from shore for the Port MacDonnell, Portland and Port Campbell transects combined (western Bass Strait) during cruise 1 (Jan-Feb 1997). No pilchard larvae were caught in the 100-75 m depth stratum; only one pilchard larva was caught at a 32 nm offshore station in the area surveyed (Por Campbell, 50-25 m).

Pilchard larvae during cruise 2 were mostly caught in eastern Bass Strait, mostly off Seaspray to the east of Wilson's Promontory, and in the area between Gabo Island and Cape Conran (Fig. 36). Larvae also occurred at the inshore-most stations off Port MacDonnell (25-0 m) in eastern South Australia. As with cruise 1, pilchard larvae during cruise 2 were caught mostly at the surface and in 50-0 m depth interval, the majority within 16 nm off the coast. The greatest concentration of pilchard larvae during cruise 2 (53 larvae per 100 m^3) was recorded at the 8 nm station off Seaspray, in the 25-0 m depth stratum, and in water temperatures of 17.5-18.0°C (Fig. 34). Larval pilchard concentrations at the remaining positive stations were <50 larvae per 100 m^3 (Fig. 36).

Pilchard larvae during winter cruise 3 were patchily distributed across Bass Strait in concentrations of <10 larvae per 100 m^3 (Fig. 37). Larvae were caught on all transects except Barwon Heads and Cape Conran (Port McDonnell transect was not sampled during this cruise). As with the summer cruises, pilchard larvae during cruise 3 were caught at the surface and in the 50-0 m depth interval, mostly within 16 nm off the coast (Fig. 37).

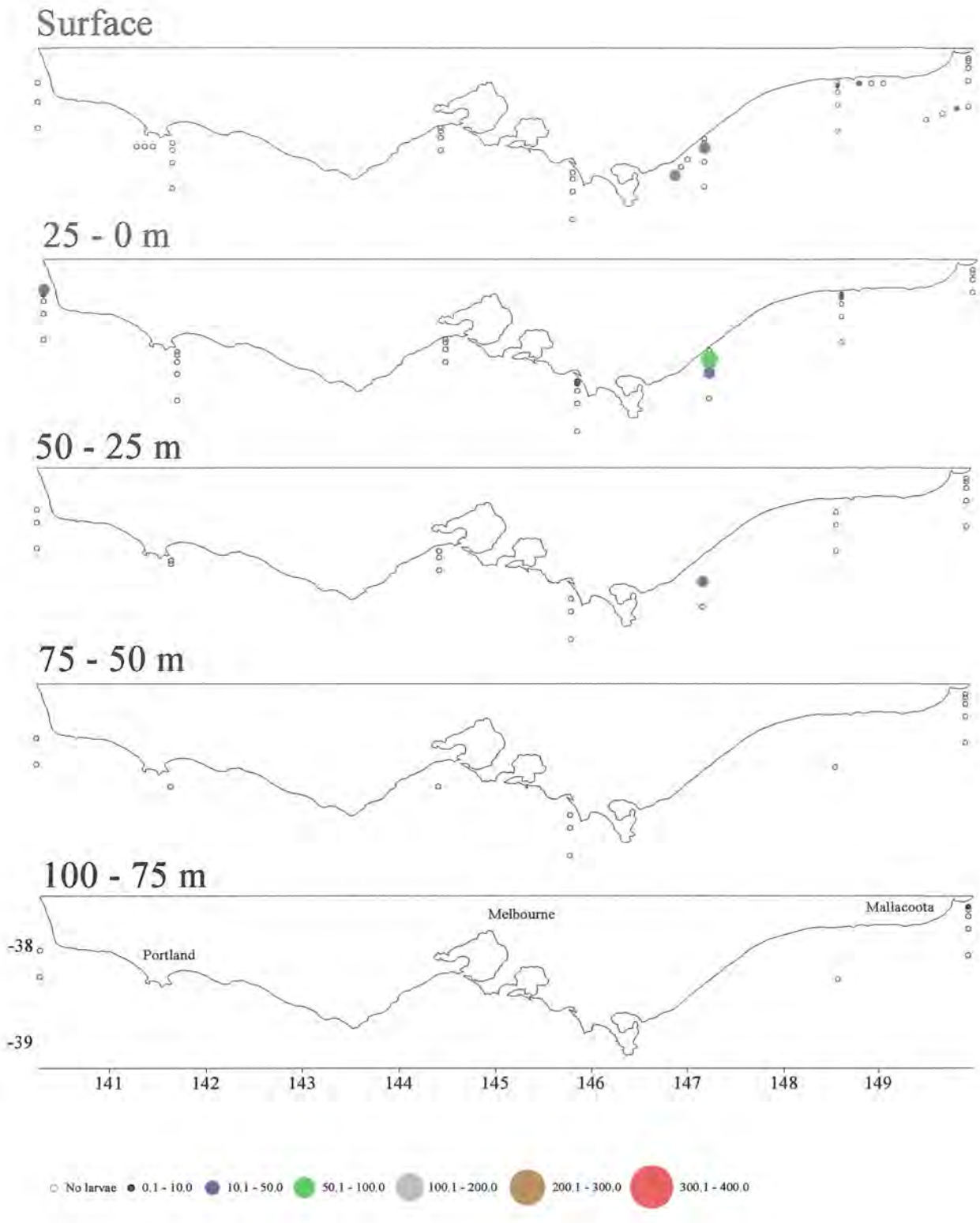


Figure 36. Spatial distribution of pilchard larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 2 (Dec 1997). Transect 6 (Port Campbell) was not sampled. Surface distribution plot (top) includes randomly collected additional surface samples.

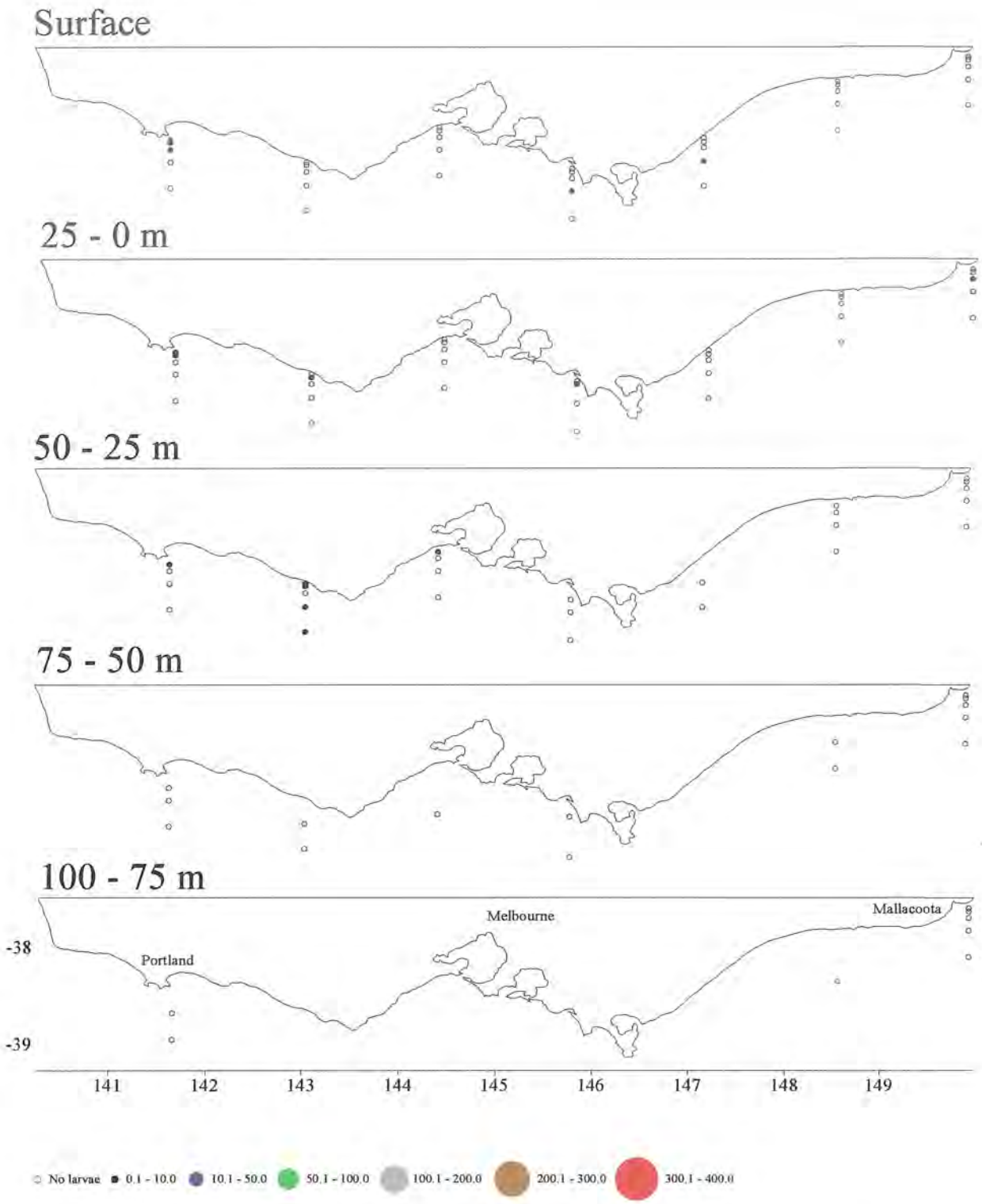


Figure 37. Spatial distribution of pilchard larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 3 (May-Jun 1998). Transect 8 (Port MacDonnell) was not sampled. Surface distribution plot (top) includes randomly collected additional surface samples.

5.6.2 Barracouta (*Thyrsites atun*)

Barracouta larvae were present across the area surveyed during all cruises, and were generally more common during the summer than the winter cruises (Figs 38-40). During cruise 1 (Jan-Feb 1997), larvae were caught mostly off Portland, Port Campbell and Barwon Heads, and were patchily distributed along the transects east of Port Phillip Bay (Fig. 38). By contrast, larvae during cruise 2 (Dec 1997) were caught only eastwards of Port Phillip Bay, mainly off Cape Liptrap and Seaspray, with no larvae occurring in any of the stations west of Cape Liptrap (Fig. 39).

Barracouta larvae were caught in very low numbers (<0.5 larvae per 100 m^3) during winter cruise 3 (May-Jun 1998), and were mostly found in the area between the Port Campbell and Cape Conran transects (Fig. 40). By contrast, larvae were more abundant during the winter cruise 4 than cruise 3, and were found mostly along the Port Campbell and Portland transects in western Victoria (Fig. 41).

Overall, barracouta larvae were caught at the surface and throughout the water column to the maximum stratum sampled (75-100 m), and were found at each of the sampled stations from 2 to 32 nm from the coast (Figs 42, 43). Two-way ANOVA showed no significant differences in the mean concentrations of barracouta larvae by depth and distance in the Portland and Port Campbell transects combined for cruise 1 (P>0.05). During cruise 2, however, larvae in eastern Bass Strait were more abundant in the 25-0 and 50-25 m depth strata than at the surface or the 75-50 m depth stratum. In addition, barracouta larvae were caught in the 75-100 m depth stratum during the summer cruise 1 and winter cruise 4, whereas no larvae were found below 75 m in the summer cruise 2 or winter cruise 3 (Figs 38-41).

The greatest concentration of barracouta larvae during the entire survey (21.3 larvae per 100 m^3) was recorded at the 2 nm station off Port Campbell during cruise 4, at the 25-0 m depth strata (Fig. 41). Other high larval concentrations (12-17 larvae per 100 m^3) were recorded at the 16 and 32 nm stations off Seaspray during cruise 2, in the 25-0 and 50-25 m depth strata. All other positive stations during the survey yielded concentrations of <10 larvae per 100 m^3 (Figs 38-41).

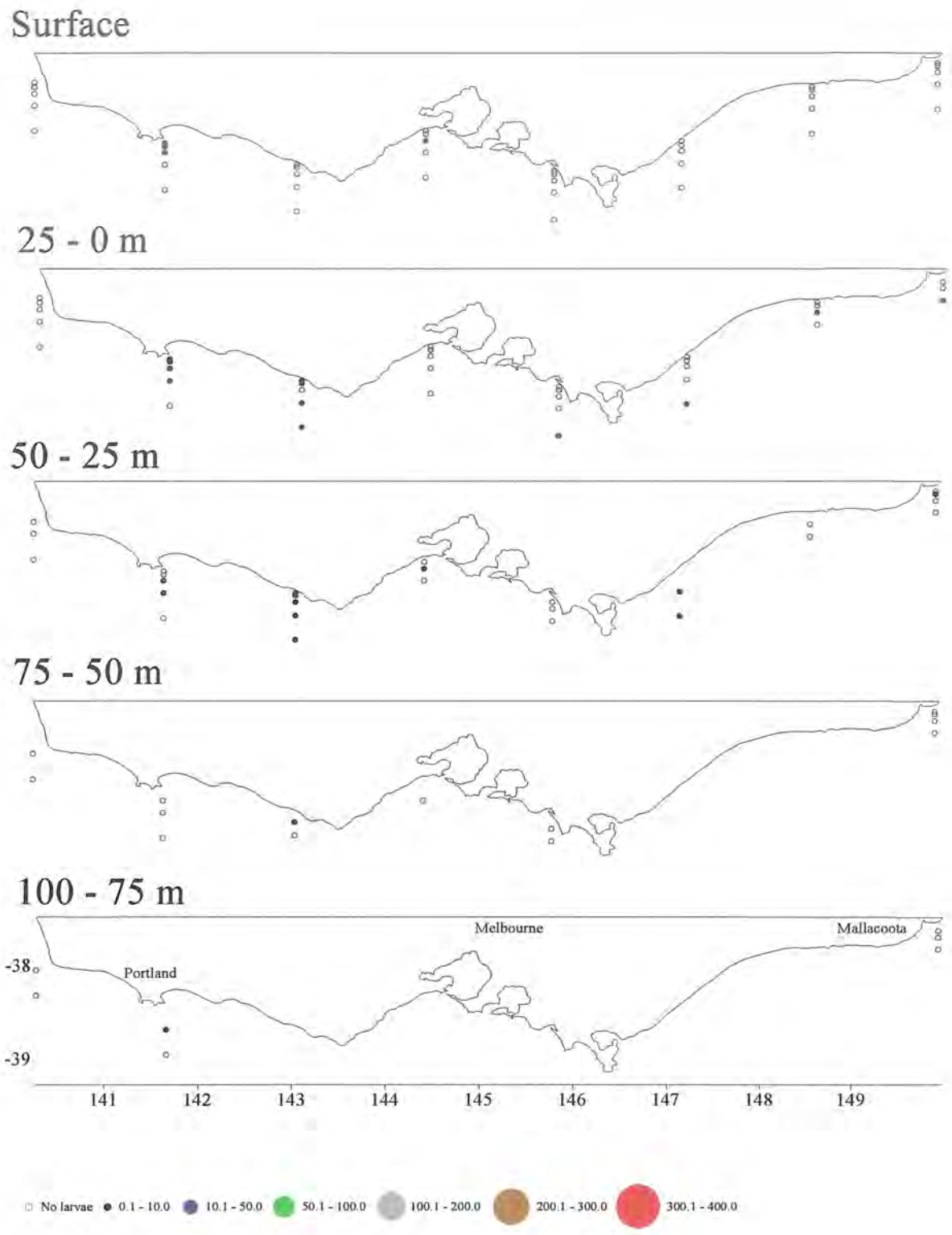


Figure 38. Spatial distribution of barracouta larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 1 (Jan-Feb 1997).

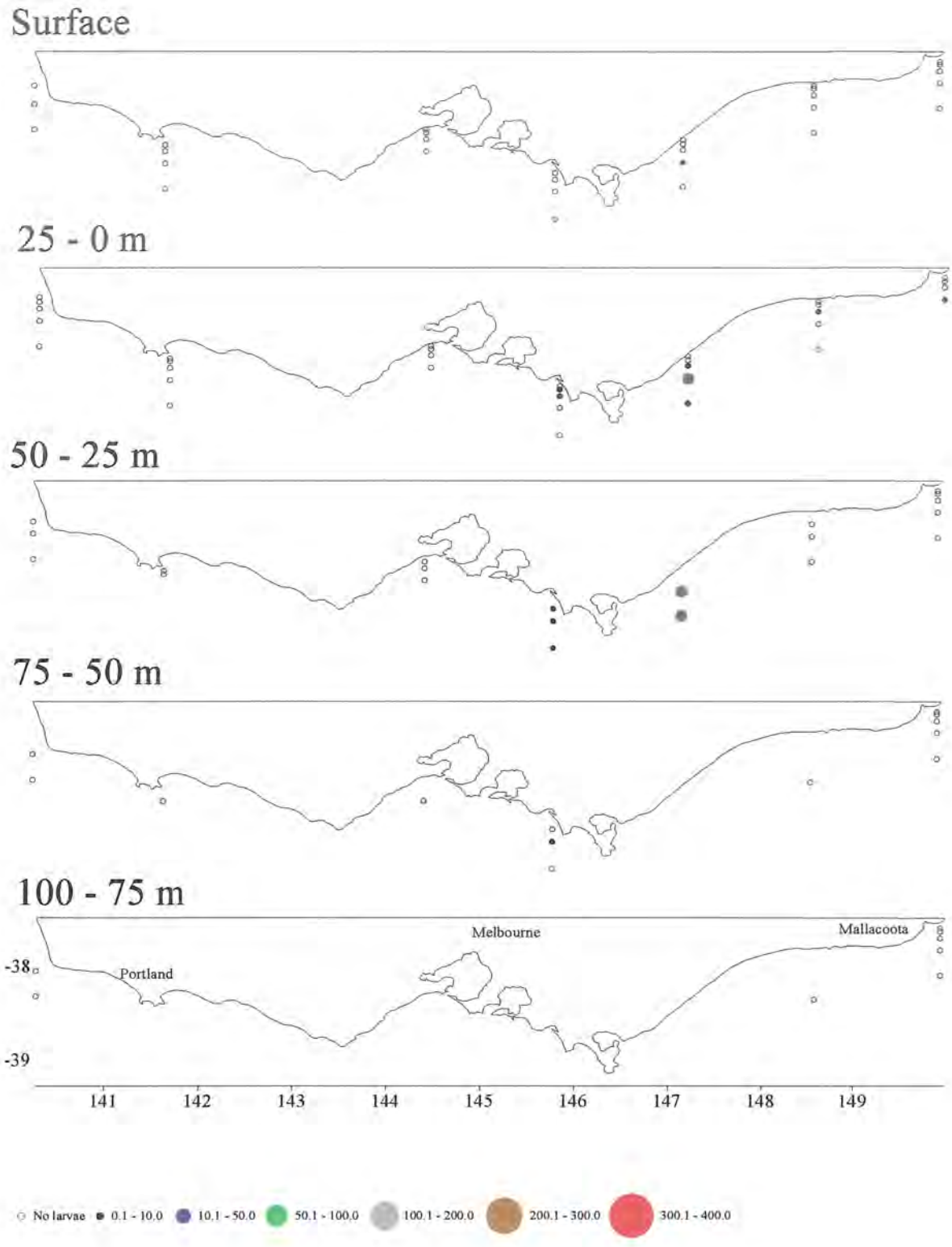


Figure 39. Spatial distribution of barracouta larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 2 (Dec 1997). Transect 6 (Port Campbell) was not sampled.

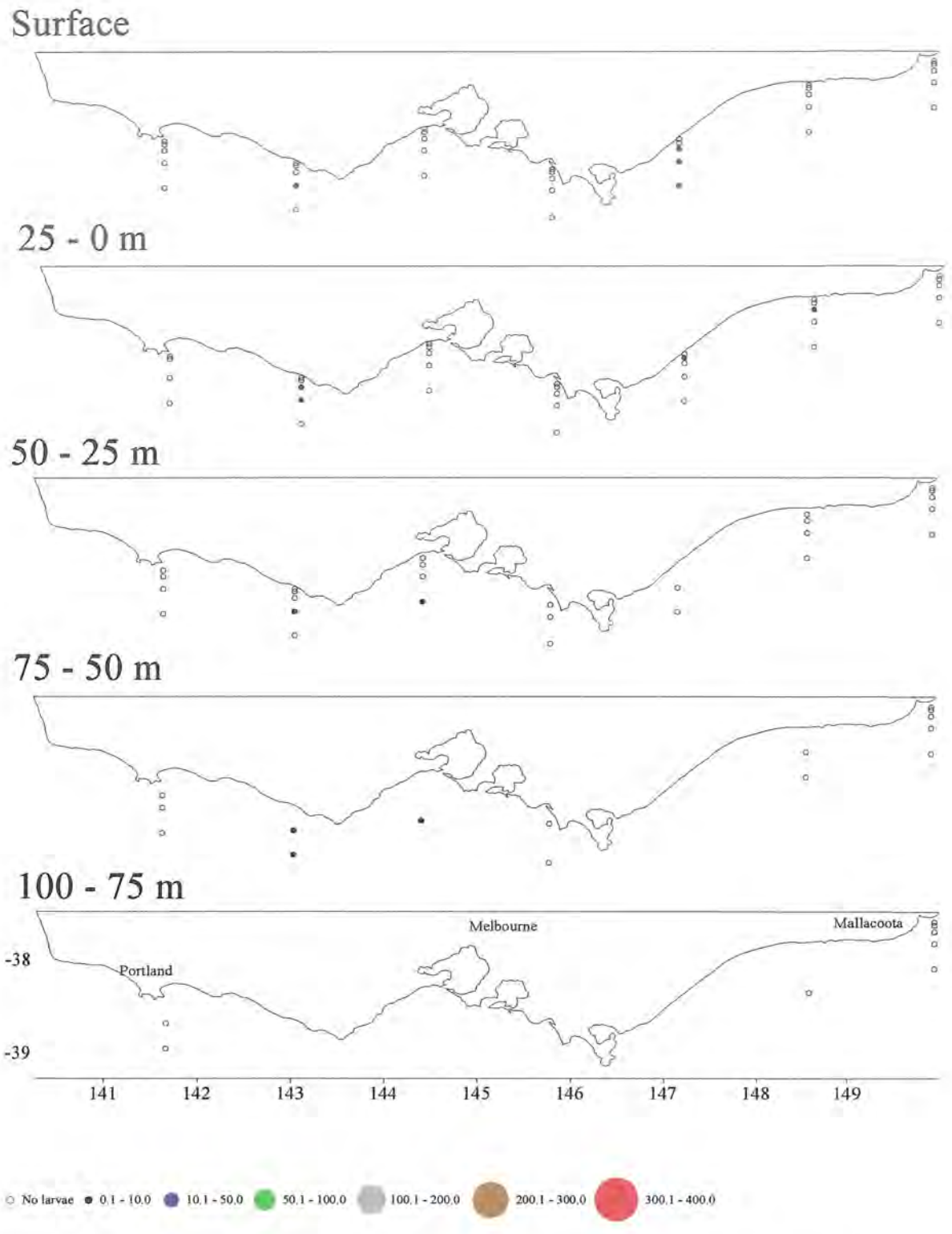


Figure 40. Spatial distribution of barracouta larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 3 (May-Jun 1998). Transect 8 (Port MacDonnell) was not sampled.

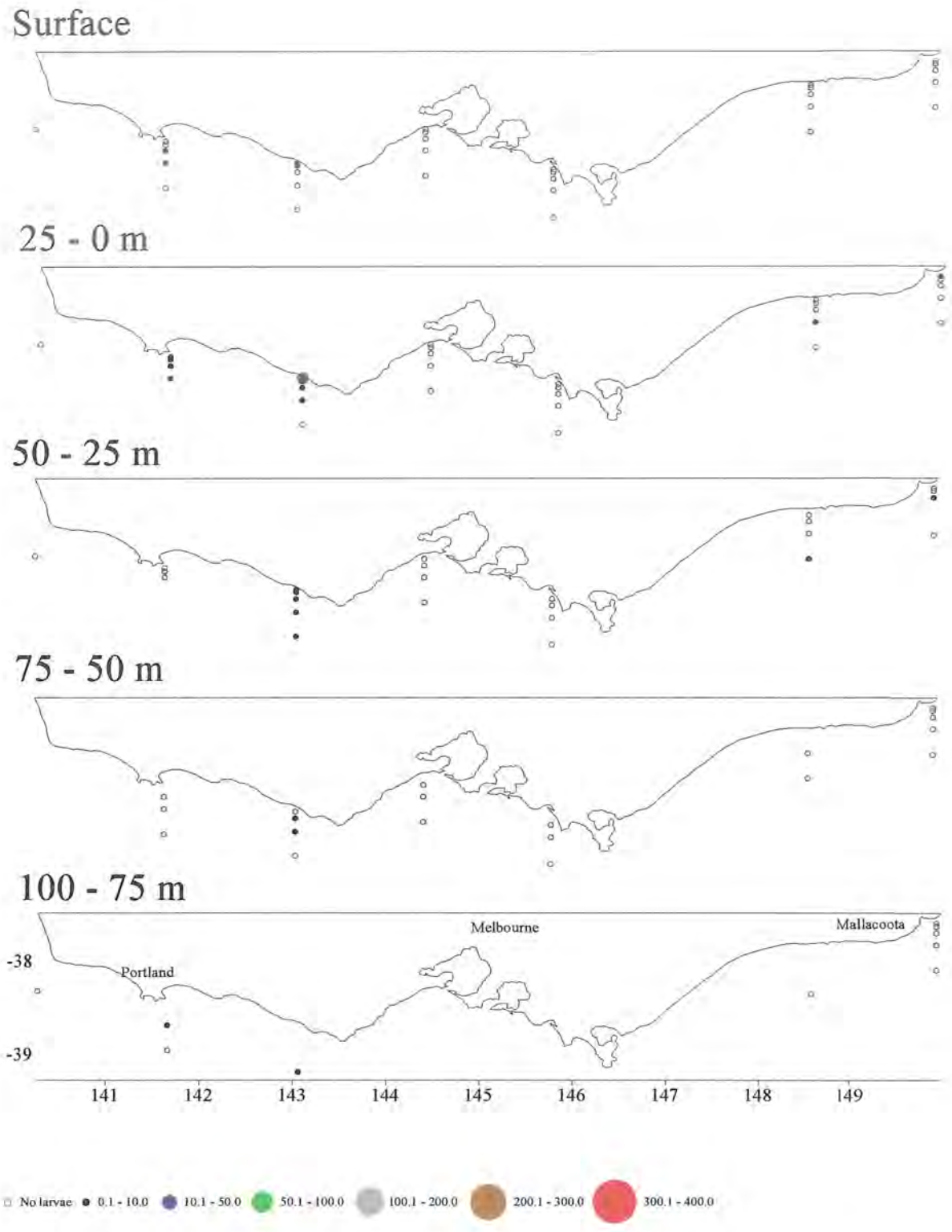


Figure 41. Spatial distribution of barracouta larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 4 (Jul 1998). Transects 3 (Seaspray) and 8 (Port MacDonnell) were not sampled.

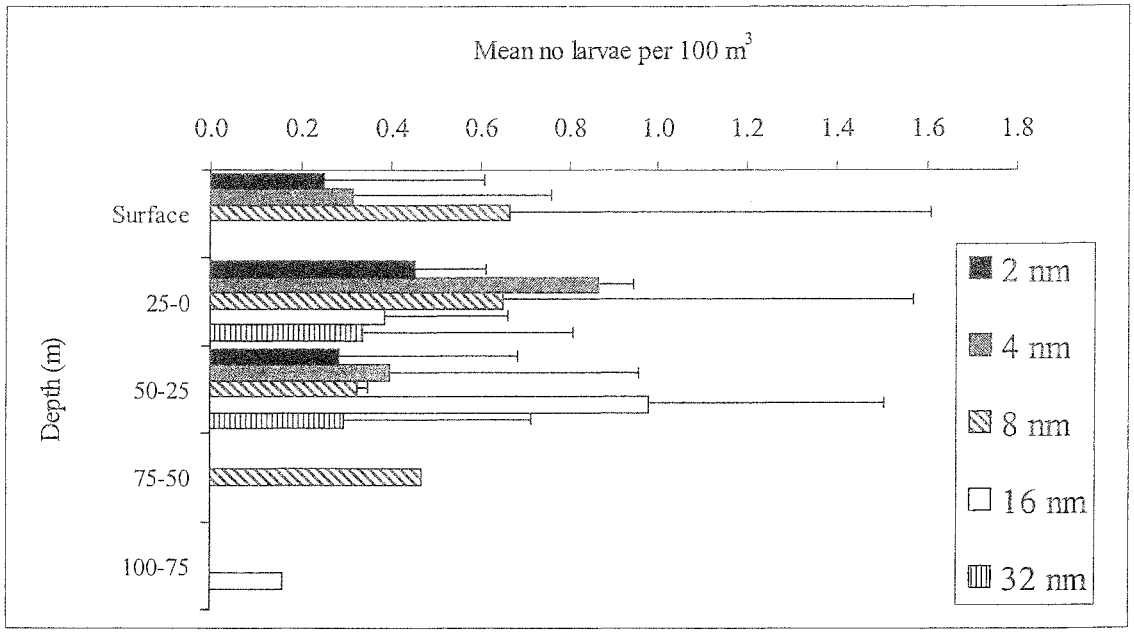


Figure 42. Mean concentration (+ 1SD) of barracouta larvae (nos per 100 m^3) by depth stratum and distance from shore for the Portland and Port Campbell transects combined (western Bass Strait) during cruise 1 (Jan-Feb 1997).

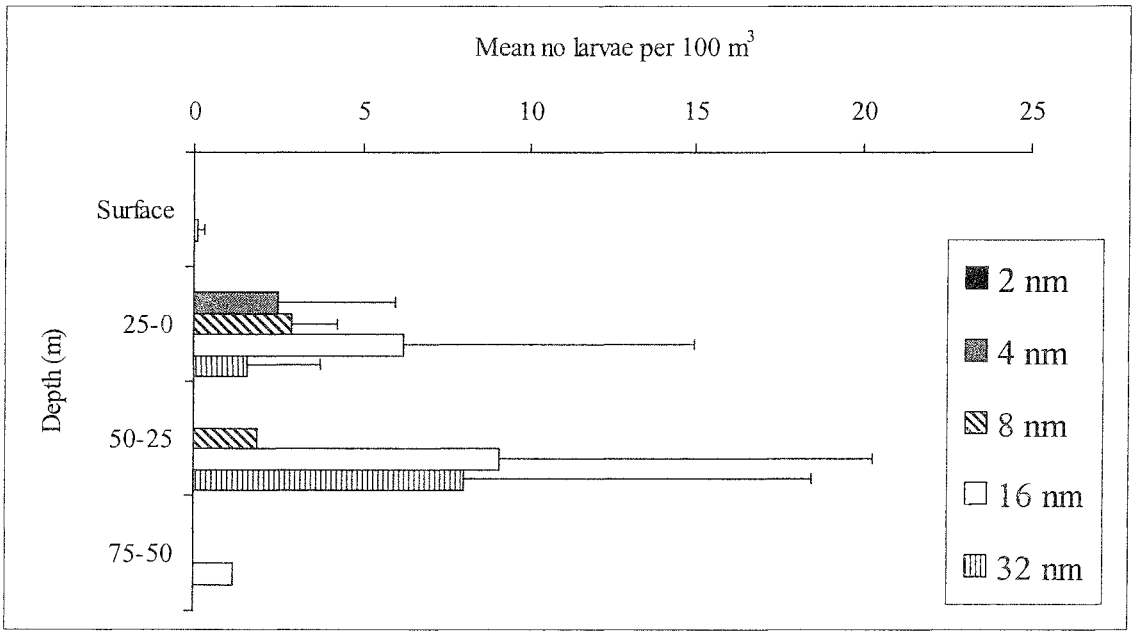


Figure 43. Mean concentration (+ 1SD) of barracouta larvae (nos per 100 m^3) by depth stratum and distance from shore for the Cape Liptrap and Seaspray transects combined (eastern Bass Strait) during cruise 2 (Dec 1997). No larvae were caught in the 100-75 m depth strata.

5.6.3 Jack mackerel (*Trachurus declivis*)

Larval jack mackerel (*Trachurus declivis*, Carangidae) were caught almost exclusively during the summer cruises, and were more abundant during cruise 1 (Jan-Feb 1997) (Figs 44, 45). Larvae during cruise 1 were caught mostly in western Victoria and eastern South Australia, along the Port Campbell, Portland and Port MacDonnell transects (Fig. 44). Larvae during this cruise were also present along all remaining transects except Cape Liptrap. Most jack mackerel larvae found during cruise 1 in western Bass Strait were caught in water temperatures of 14.5-17.5°C (Fig. 46).

Larvae during cruise 2 were only found along the four eastern-most transects, and were relatively more common at the stations 8, 16 and 32 nm off Seaspray, in the 25-0 and 50-25 m depth strata (Fig. 45). No jack mackerel larvae were found during the winter cruises 3 and only one larva was caught during winter cruise 4 (Table 9).

The greatest concentrations of jack mackerel larvae during the summer cruise 1 were obtained over the shelf at the stations 4, 8 and 16 nm off Portland, in the 25-0 and 50-25 m depth strata (Figs 44, 46). The maximum concentration off Portland (45.7 larvae per 100 m^3) was obtained at the 4 nm station in the 50-25 m depth stratum. Fewer larvae (<10 larvae per 100 m^3) were collected either at the surface or at depths >50 m in this and the Port Campbell and Port MacDonnell transects (Fig. 47). Two-way ANOVA (depth × distance) showed that the mean concentrations of jack mackerel larvae combined for the Port Campbell and Portland transects (log_{10} transformed) were significantly greater in either the 25-0 or the 50-25 m depth strata than at the surface ($P<0.05$), while no significant differences were found in the concentrations of larvae between the 25-0 and 50-25 m depth strata with distance from shore ($P>0.05$) (Fig. 47).

Concentrations of jack mackerel larvae along the remaining positive stations during cruise 1, as well as all positive stations during cruise 2, were <10 larvae per 100 m^3 (Figs 44, 45).

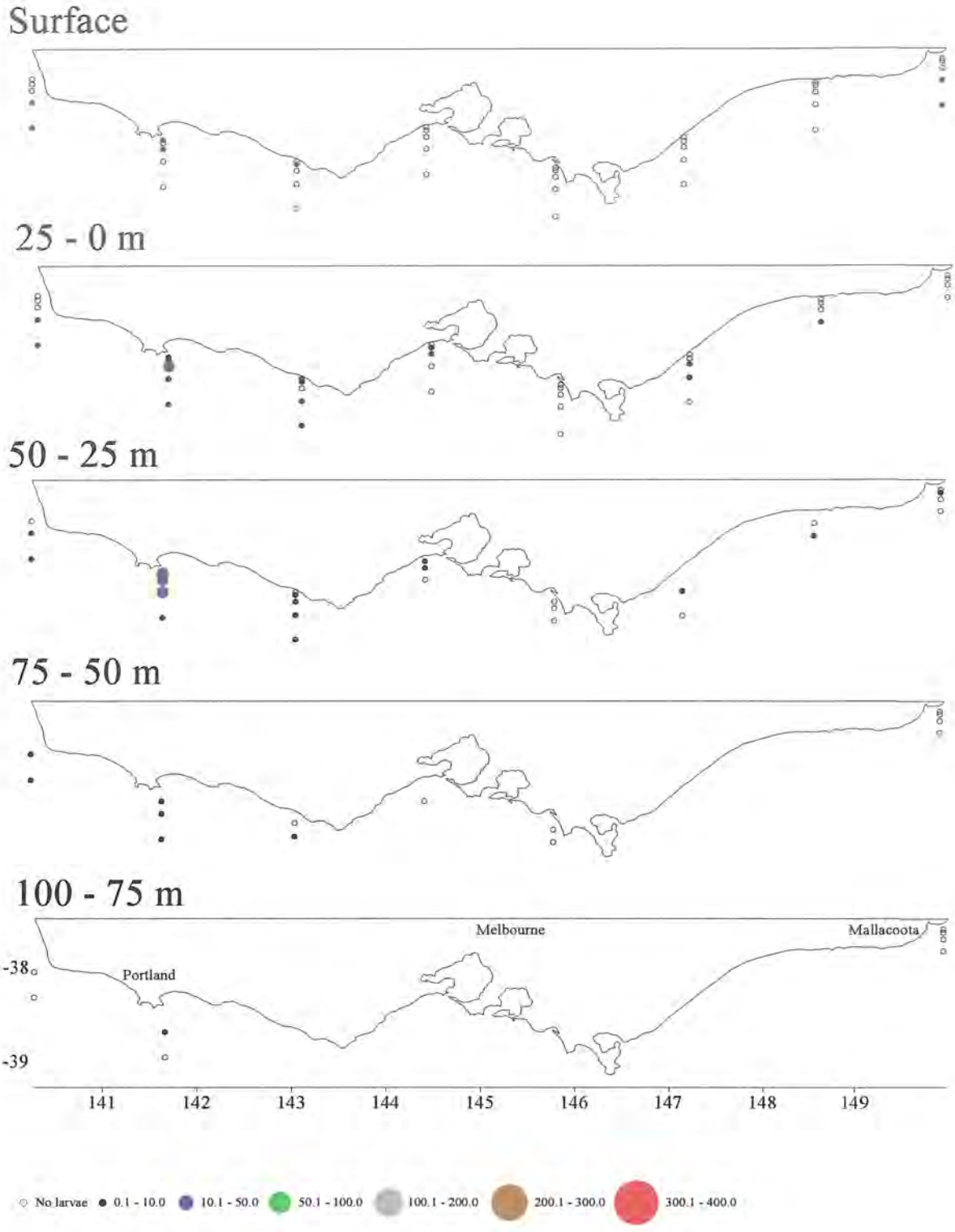


Figure 44. Spatial distribution of jack mackerel larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 1 (Jan-Feb 1997).

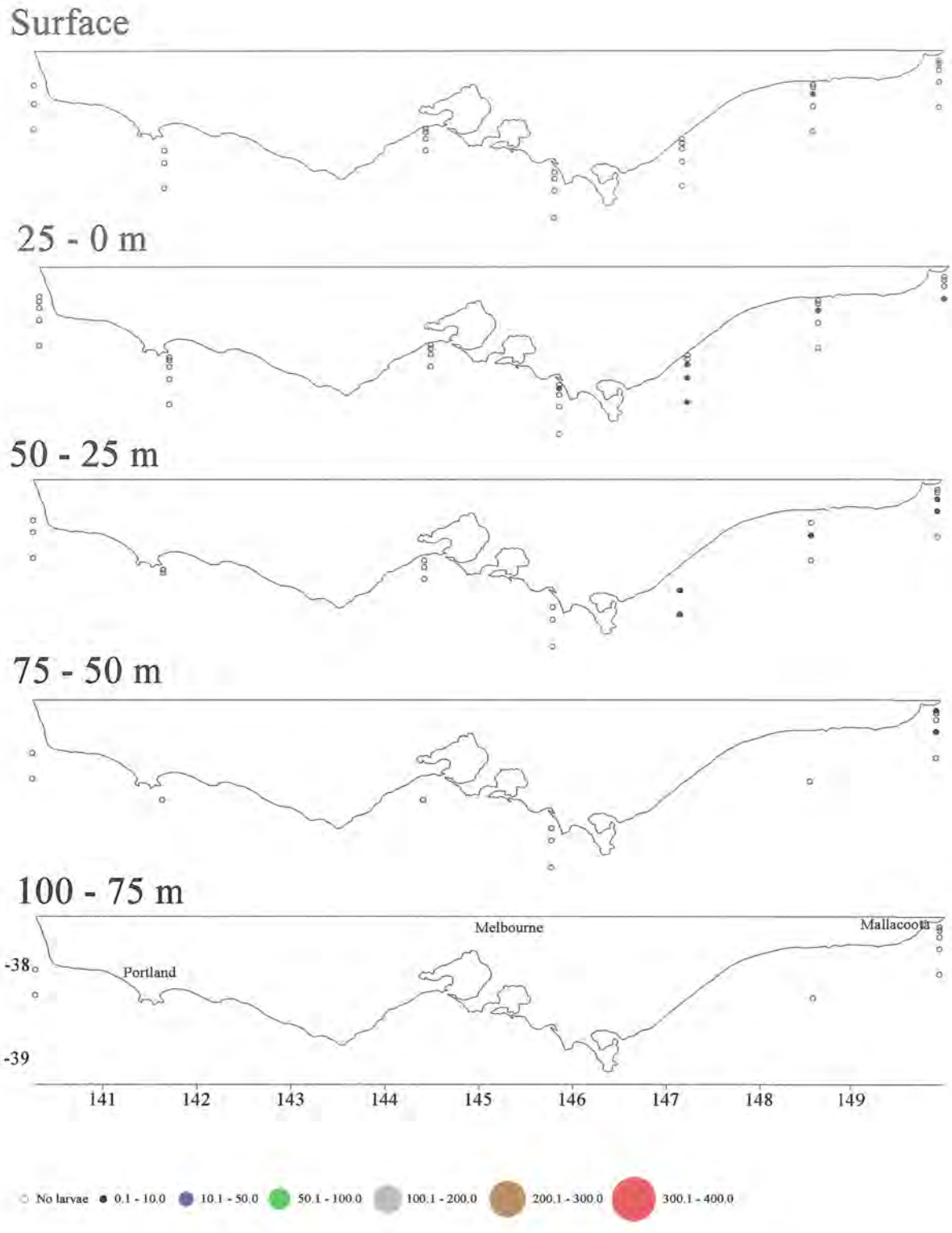


Figure 45. Spatial distribution of jack mackerel larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 2 (Dec 1997). Transect 6 (Port Campbell) was not sampled.

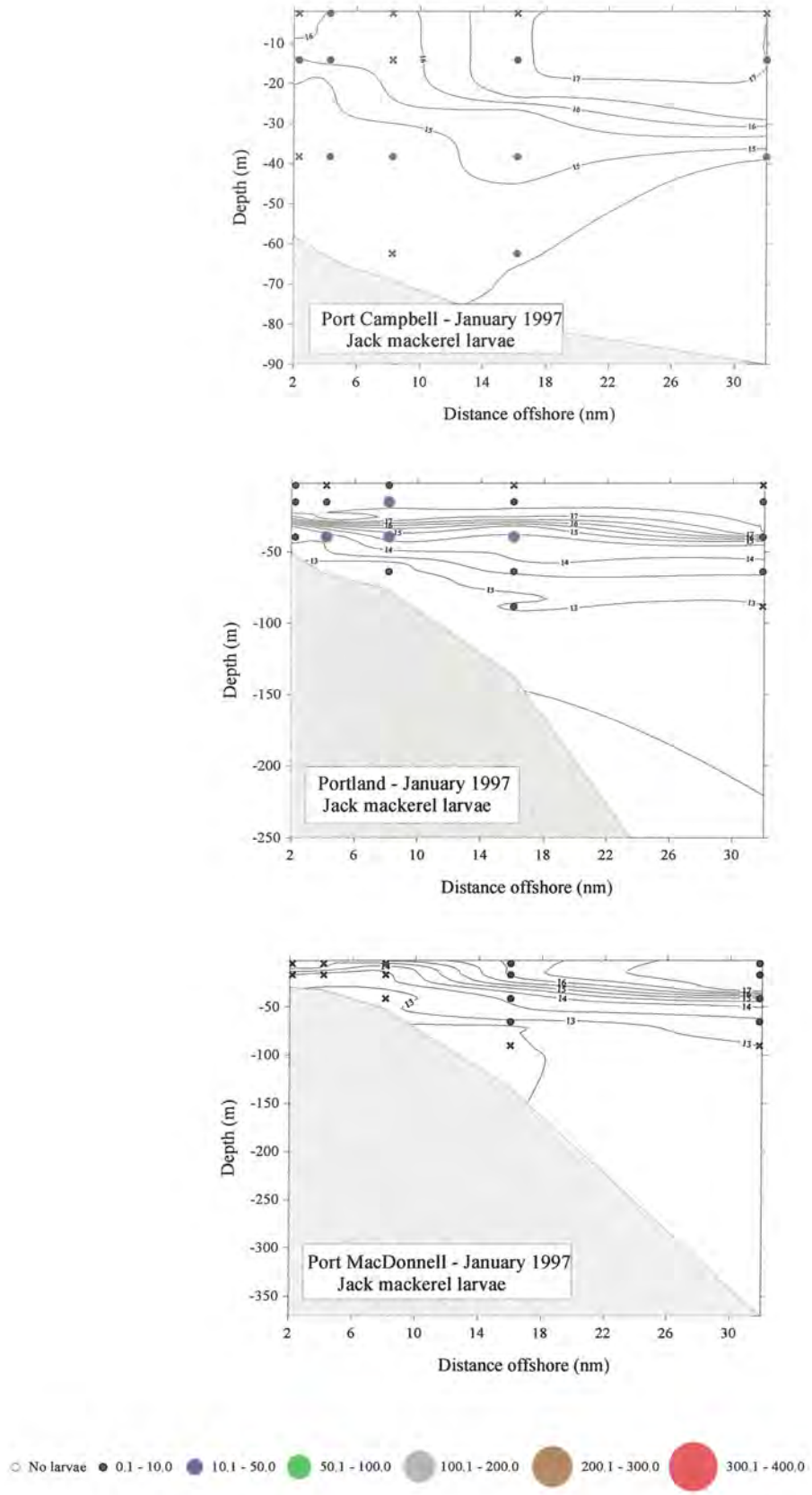


Figure 46. Vertical distribution of jack mackerel larvae (nos per 100 m-3) along Port Campbel (T6), Portland (T7) and Port MacDonnell (T8) during cruise 1 (Jan-Feb 1997). Larval concentrations have been plotted over vertical temperature profiles obtained during sampling period. Shaded area in each plot corresponds to the shelf profile.

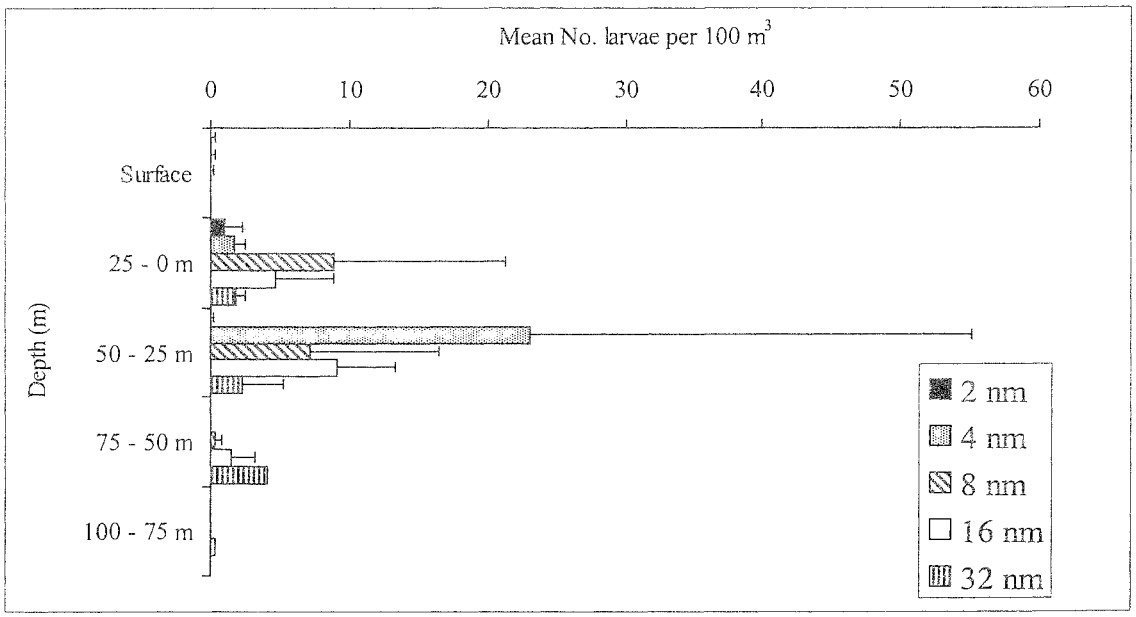


Figure 47. Mean concentration (+ 1SD) of jack mackerel larvae (nos per 100 m^3) by depth stratum and distance from shore for the Portland and Port Campbell transects combined (western Bass Strait) during cruise 1 (Jan-Feb 1997).

5.6.4 Sand flathead (*Platycephalus bassensis*)

Larvae of sand flathead (*Platycephalus bassensis*) were caught only during the summer cruises, and were more abundant during cruise 2 (Dec 1997). During summer cruise 1 (Jan-Feb 1997), larvae of this species were caught in concentrations of <10 larvae per 100 m^3 mainly along the transects off Portland, Port Campbell, Barwon Heads and Cape Liptrap (Fig.48). Most larvae in these transects were caught from the surface to the 75-50 m depth stratum as far as the station 8 nm off the coast.

Larvae during summer cruise 2 were caught almost exclusively along the Cape Liptrap and Seaspray transects, at either side of the Wilsons Promontory, and were present as far as the station 32 nm off the coast (Fig. 49). The greatest concentration of sand flathead larvae during cruise 2 (31 larvae per 100 m^3) was obtained at the station 16 nm off the Seaspray transect, in the 50-25 m depth stratum. Concentrations between 11 and 13 larvae per 100 m^3 were also recorded at the stations 8 and 16 nm off Seaspray in the 25-0 m depth stratum, while no larvae were caught in surface samples along this transect. Larvae along the Cape Liptrap transect were caught from the surface to the 75-50 m depth strata, although in lower concentrations (<1 larvae per 100 m^3) than those obtained along the Seaspray transect. Few sand flat head larvae were also caught along the Gabo Island and Barwon Heads transect during cruise 2 (Fig. 49).

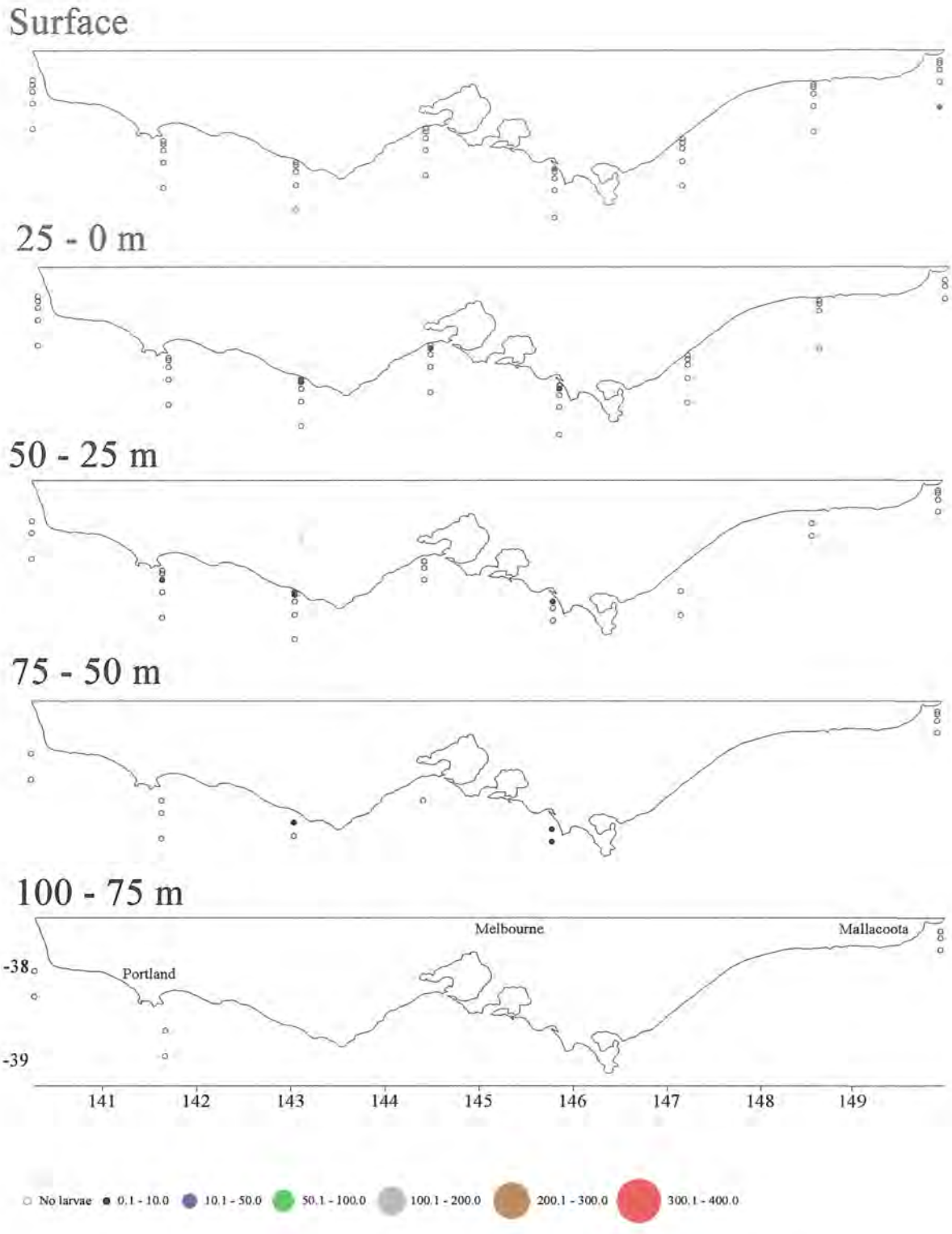


Figure 48. Spatial distribution of sand flathead larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 1 (Jan-Feb 1997).

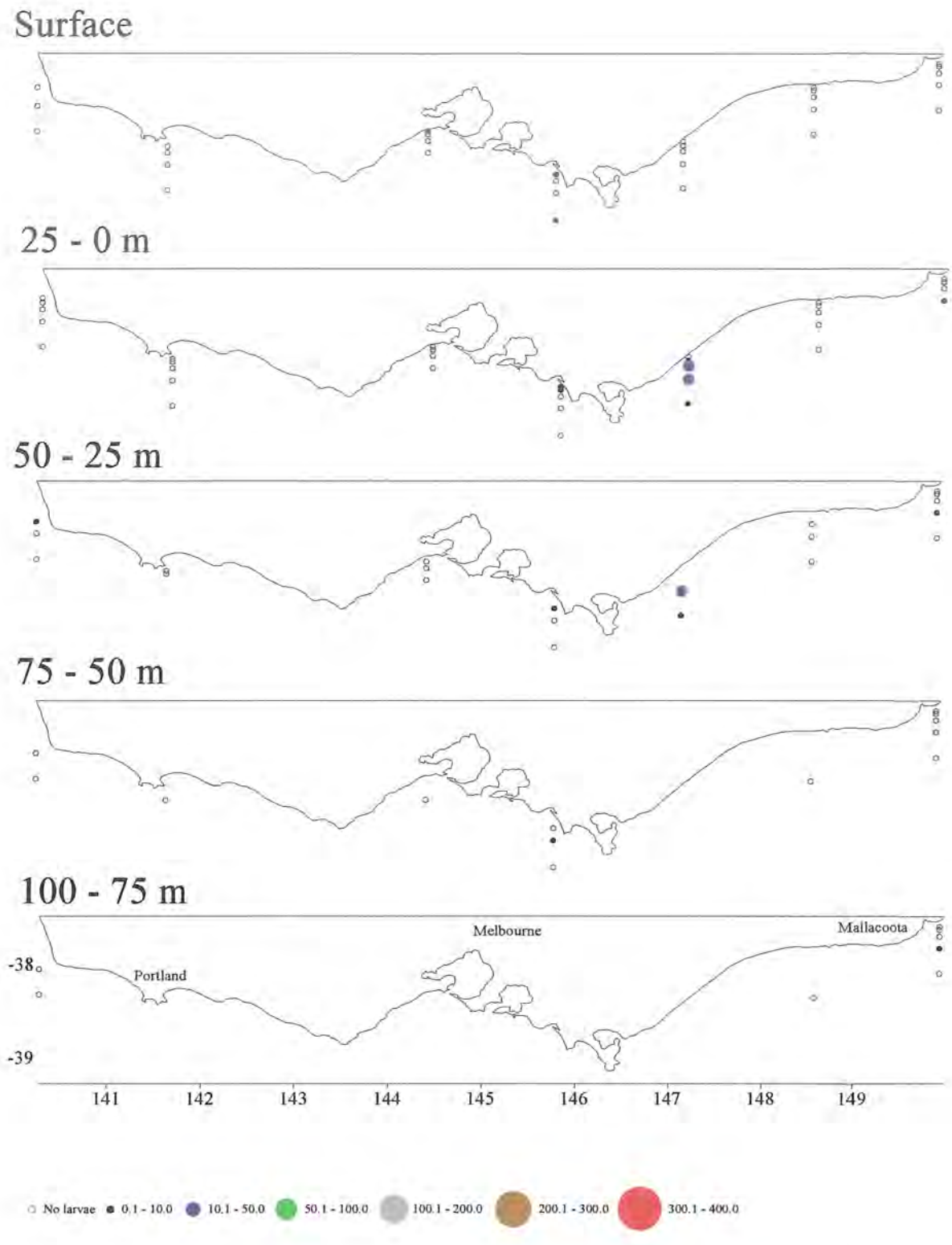


Figure 49. Spatial distribution of sand flathead larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 2 (Dec 1997). Transect 6 (Port Campbell) was not sampled.

5.6.5 Eastern school whiting (*Sillago flindersi*)

Larvae of eastern school whiting (*Sillago flindersi*) were caught only during the summer cruises in concentrations of <10 larvae per 100 m^3 (Fig. 50). During summer cruise 1 (Jan-Feb 1997), larvae of this species were caught mainly off Seaspray, Cape Liptrap, Port Campbell and Portland, and were mostly found in the 25-0 and 50-25 m depth strata as far as the station 8 nm off the coast. Only three larvae were caught in surface samples (Gabo Island) and none were found below 50 m during this cruise.

Larvae during the summer cruise 2 were caught mostly along the Seaspray and Cape Liptrap transects, in the 25-0 m depth stratum, and as far as the station 16 nm off the coast (Fig. 50). The greatest concentration of eastern school whiting larvae during cruise 2 (10 larvae per 100 m^3) was obtained at the station 8 nm off Seaspray, in the 25-0 m depth stratum. No larvae were caught either in surface samples or below 50 m along any of the transects during this cruise. No larvae occurred at the station 32 nm off the coast in either this or cruise 1 (Fig. 50).

5.6.6 Blue warehou (*Seriollela brama*)

Larvae of blue warehou (*Seriollela brama*) were caught throughout the survey area in all cruises, and were more generally more abundant during the winter than the summer cruises. Larvae during summer cruise 1 (Jan 1997) were found predominantly towards western Victoria, mostly along the Port Campbell and Portland transects (Fig. 51). The majority of larvae in these transects were obtained in the 25-0 and 50-25 m depth strata, with very few larvae occurring either at the surface or at the 75-50 m depth stratum. No larvae was caught in depths >75 m in this or any of the remaining three cruises (Figs 51-53). Larvae during winter cruise 3 (May-Jun 1998) were found in the area between Gabo Island (T1) and Barwon Heads (T5), none occurring west of the latter transect (Fig. 52). By contrast, larvae during winter cruise 4 (Jul 1998) were found in the area between Cape Liptrap (T4) and Port Campbell (T6), and were most common along the latter transect (Fig. 53). As with summer cruise 1, most larvae during cruises 3 and 4 were caught in the 25-0 and 50-25 m depth strata, although some were found in surface samples off Port Campbell during cruise 4 (Figs 53, 54). Larval blue warehou were found as far as the 32 nm station during the four cruises.

Concentrations of larval blue warehou in all four cruises were <10 larvae per 100 m^3 (Figs 51-53). The highest concentration (9.8 larvae per 100 m3) was recorded during the winter cruise 4 (Jul 1998) at the 2 nm station off Port Campbell, in the 25-0 m depth strata. Larvae in this depth strata were caught at all five station sampled along this transect (Fig. 53).

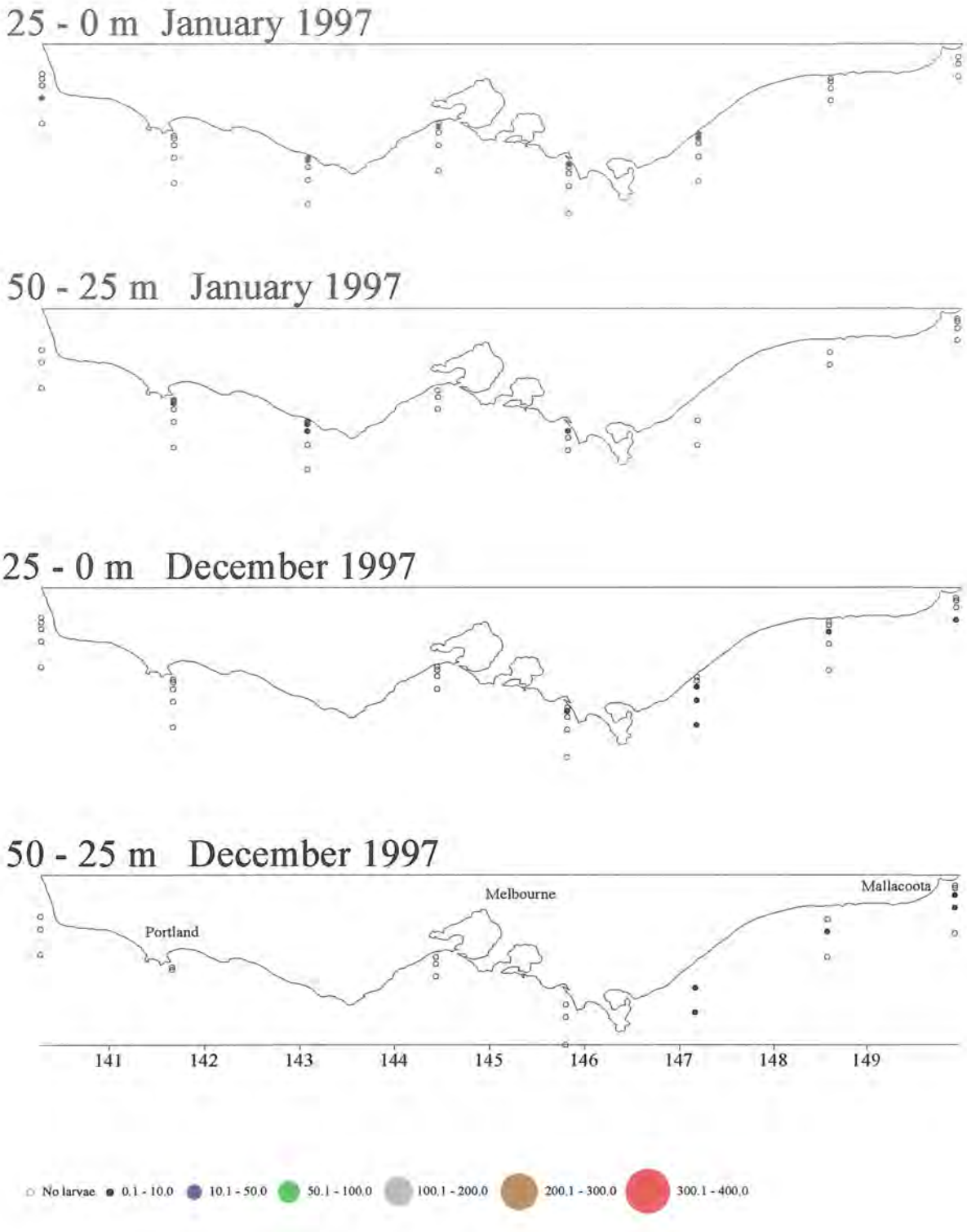


Figure 50. Spatial distribution of eastern school whiting larvae (nos per 100 m-3) at the 25-0 and 50-25 m depth strata along southeastern Australia during cruises 1 (Jan-Feb 1997) and 2 (Dec 1997).

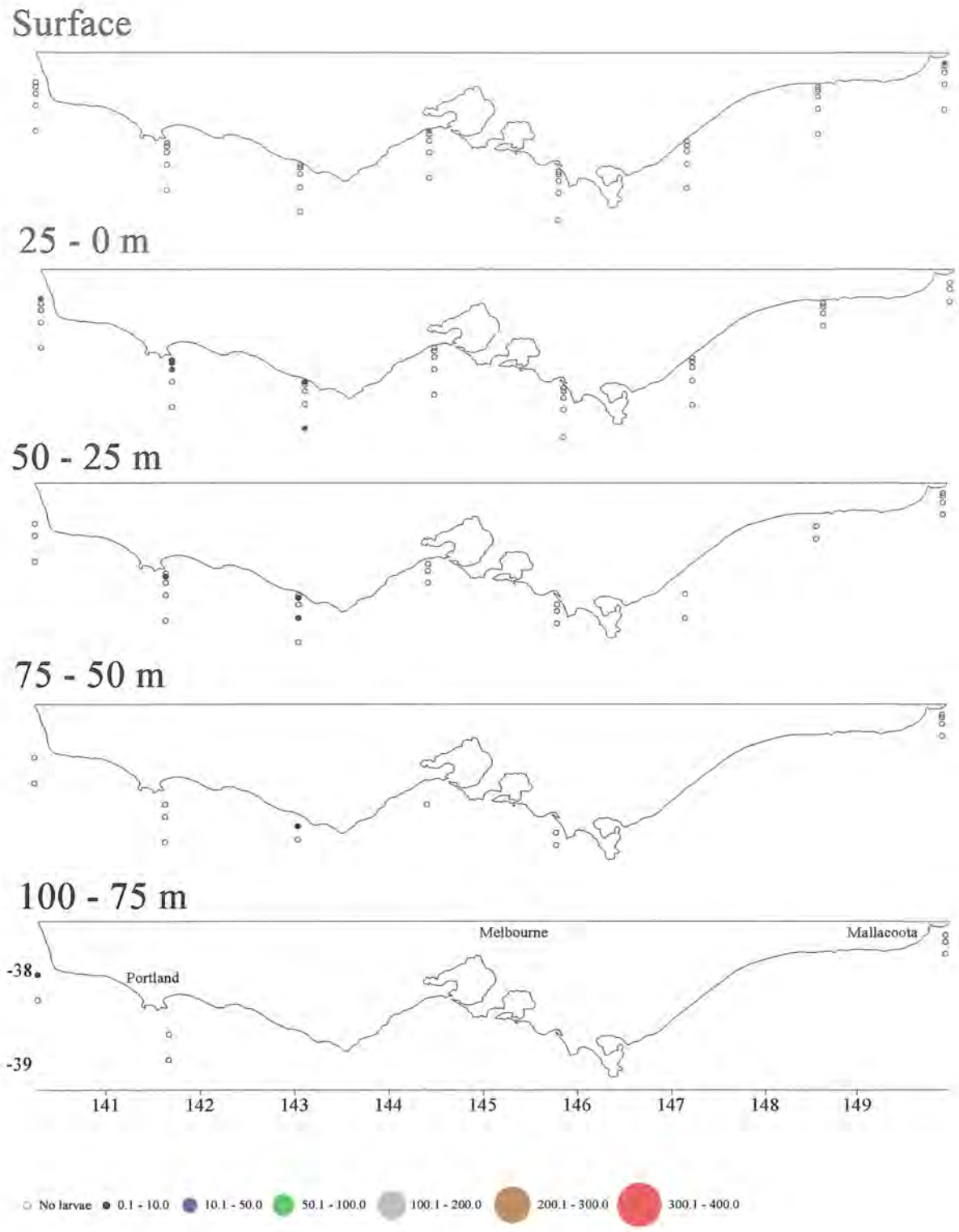


Figure 51. Spatial distribution of blue warehou larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 1 (Jan-Feb 1997).

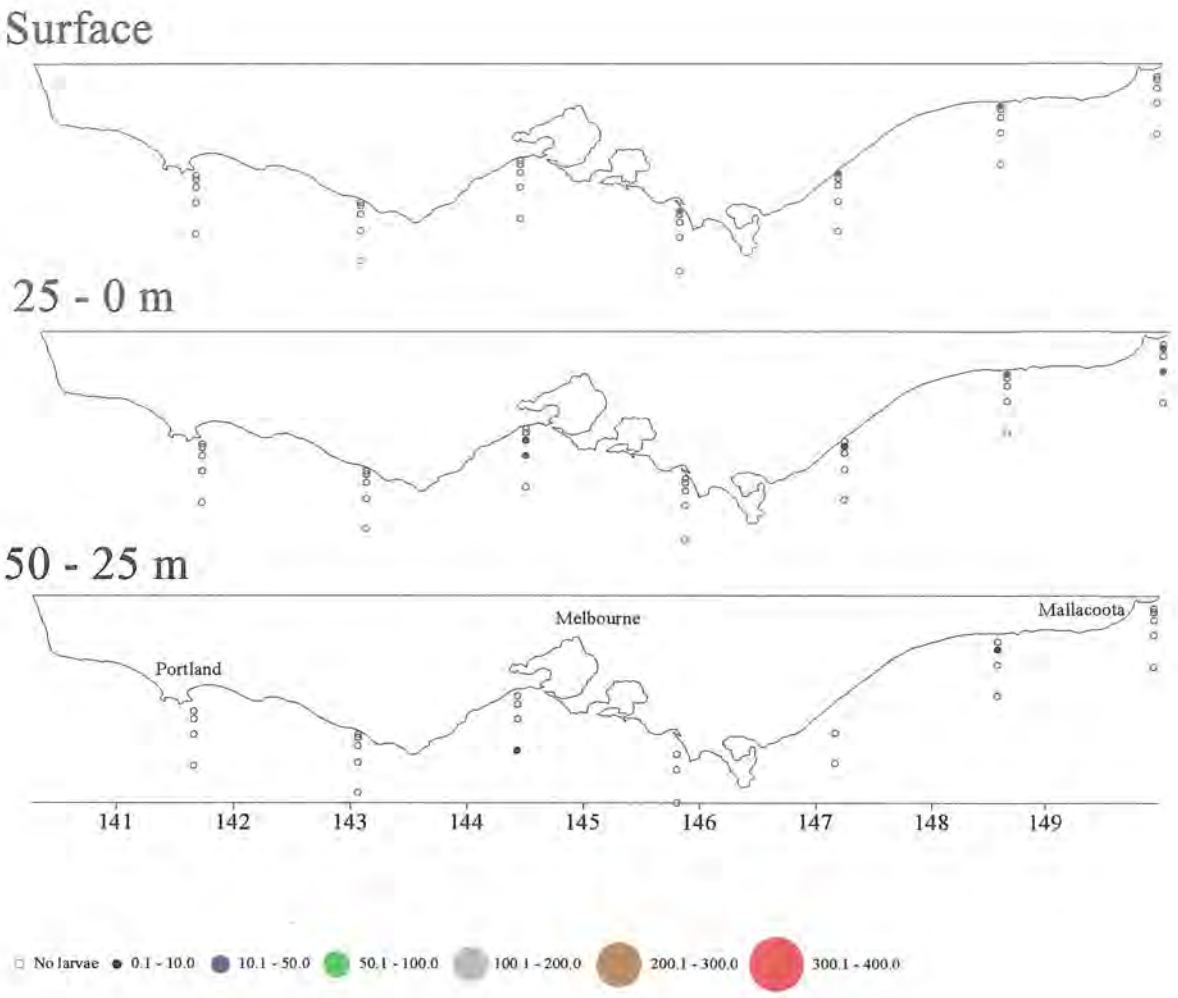


Figure 52. Spatial distribution of blue warehou larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 3 (May-Jun 1998). Transect 8 (Port MacDonnell) was not sampled. No larvae were caught in the 75-50 or the 100-75 m depth strata.

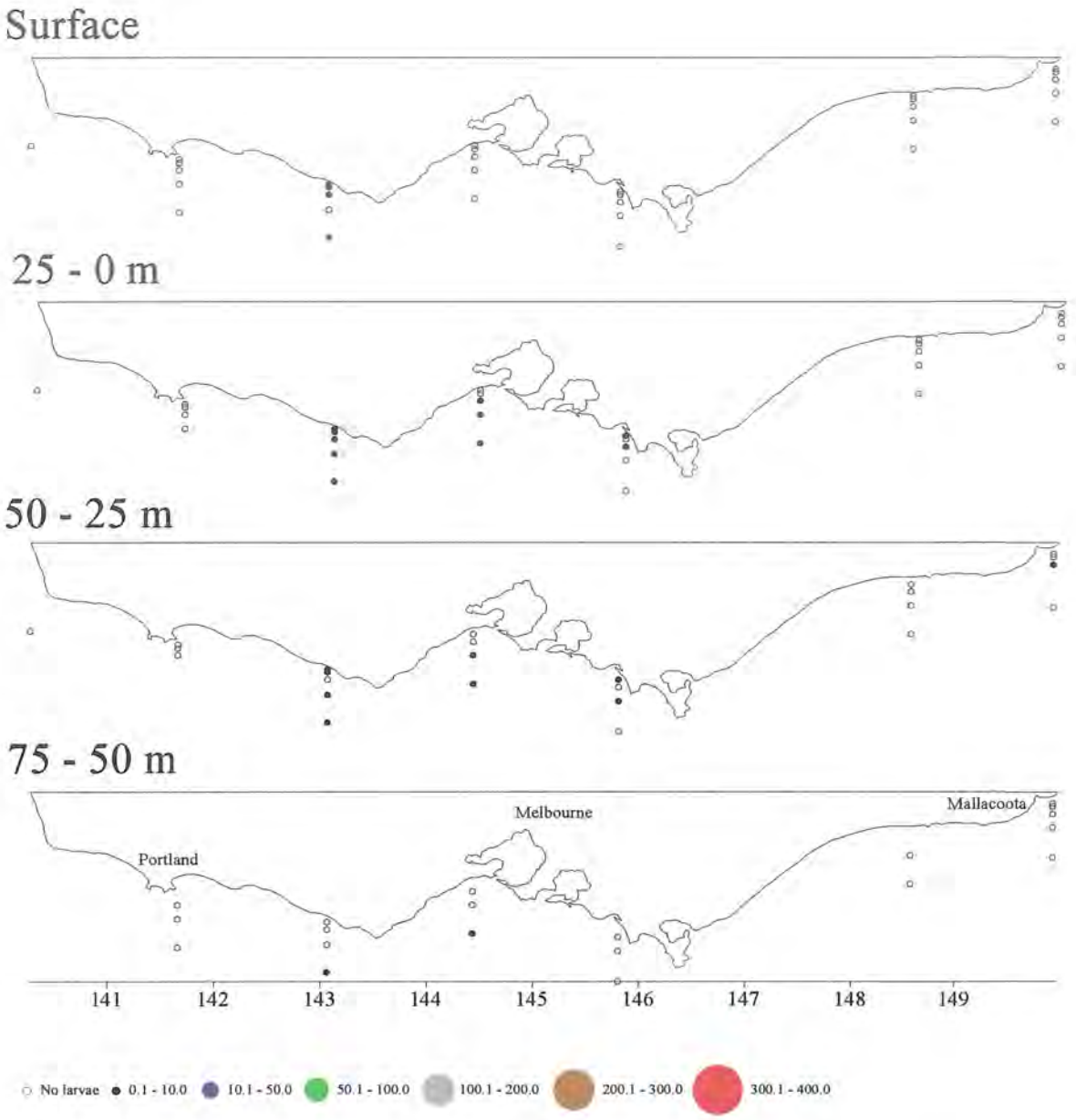


Figure 53. Spatial distribution of blue warehou larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 4 (Jul 1998). Transects 3 (Seaspray) and 8 (Port MacDonnell) were not sampled. No larvae were caught in the 100-75 m depth stratum.

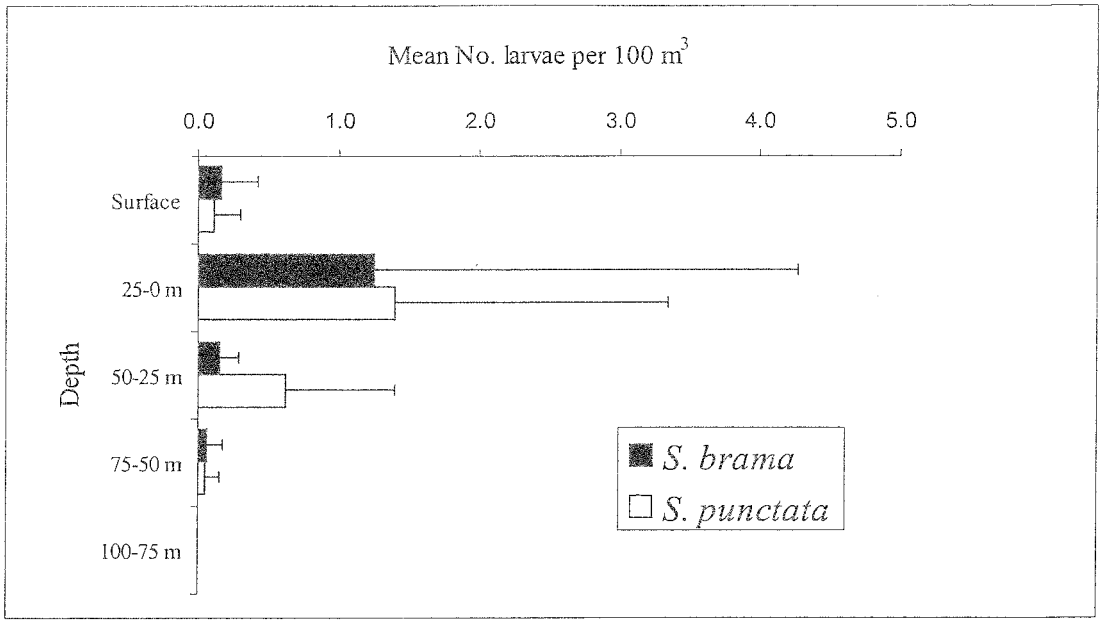


Figure 54. Mean concentration (+1SD) of blue (*Seriollela brama*) and spotted warehou (*Seriollela punctata*) larvae (nos per 100 m^3) combined for the Barwon Heads-Port Campbell and the Gabo Island-Cape Conran transects, respectively, during winter cruise 4 (Jul 1998). Concentration data were pooled for all stations sampled in those transects.

5.6.7 Spotted warehou (*Seriollela punctata*)

Larvae of spotted warehou (*Seriollela punctata*) were present only during the winter cruises, and almost all were caught during winter cruise 4 (Jul 1998). Larvae during cruise 4 were recorded only off Gabo Island and Cape Conran in eastern Victoria, and occurred as far as the 32 nm station along both transects (Fig. 55). Larval concentrations during this cruise were <10 larvae per 100 m^3, with the highest (5.1 larvae per 100 m^3) recorded at the station 32 nm off Cape Conran, in the 25-0 m depth strata. Larval spotted warehou were found in surface samples as well as in the 25-0, 50-25 and 75-50 depth strata, whereas none were found below 75 m (Figs 54, 55). The few larvae that were recorded during the winter cruise 3 (May-Jun 1998) were caught at the stations 2, 4 and 8 off Gabo Island, in the 25-0 and 50-25 m depth strata (data not plotted).

5.6.8 Other taxa

Larval fishes belonging to the Monacanthidae, Serranidae, Scorpaenidae and Moridae were very abundant through survey, and were caught in all four cruises. Monacanthid and serranid larvae were abundant during the summer cruises (Table 7), whereas scorpaenid and morid larvae were abundant during the winter cruises (Table 9). All these families are represented across temperate Australia by several species whose larval taxonomy is not yet well known. Monacanthid larvae were particularly abundant

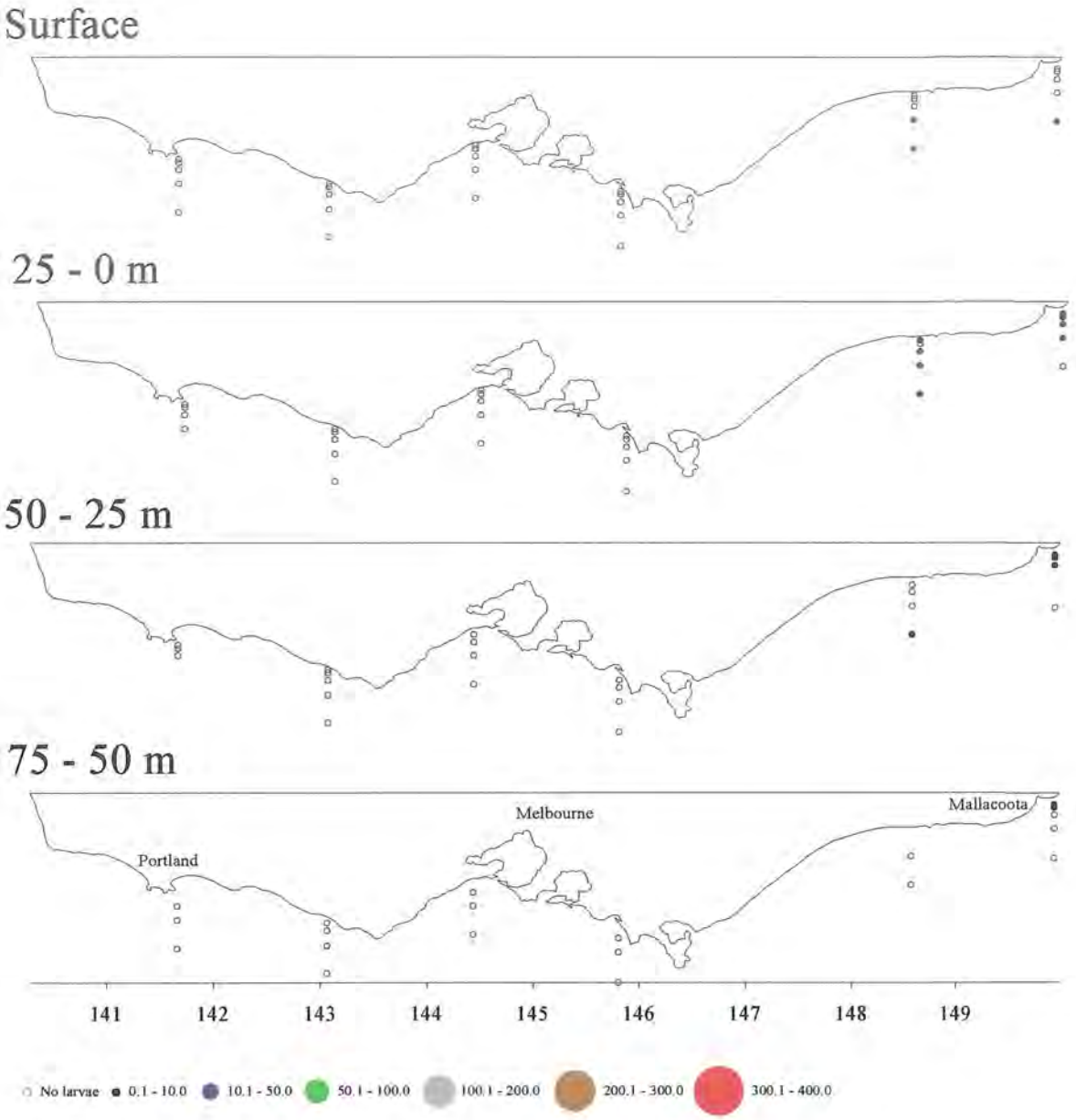


Figure 55. Spatial distribution of spotted warehou larvae (nos per 100 m-3) by depth stratum along southeastern Australia during cruise 4 (Jul 1998). Transects 3 (Seaspray) and 8 (Port MacDonnell) were not sampled. No larvae were caught in the 100-75 m depth stratum.

during summer cruise 2 (Dec 1997; Table 6), while morid and scorpaenid larvae were markedly abundant during winter cruise 4 (Jul 1998; Table 8). Scorpaenid larvae during cruise 4 were mostly represented by the preflexion stage of an unidentified species, which were present in high concentrations is western Victoria, particularly off Port Campbell and Portland. The highest concentrations of this taxa (21.0-46.2 larvae per 100 m^3) were recorded at the 2 and 4 nm stations off Port Campbell, in the 25-0 m depth stratum.

Temporal occurrence of larvae of other fish species varied throughout cruises. For example, larvae of yellow-eye mullet (*Aldrichetta forsteri*) were found in all except cruise 4, while larvae of snapper (*Pagrus auratus*) and red mullet (*Upeneichthys vlamingii*) were caught only during the summer cruises (Table 11). Larvae of anchovy (*Engraulis australis*) were found in all four cruises, whereas those of ocean perch (*Helicolenus percoides*) and magpie perch (*Cheilodactylus nigripes*) were recorded only in cruises 2-4 and 3, respectively (Table 11).

In terms of abundance, the highest concentration of yellow-eye mullet larvae (6 larvae per 100 m^3) was recorded in the surface sample taken at the 2 nm station of Portland during winter cruise 3; most larvae of this species were caught in surface waters, with a few also being recorded in the 25-0 m depth stratum. Similarly, most larval red mullet were found in surface waters, the highest concentrations (7.3-21.1 larvae per 100 m^3) being recorded in surface samples obtained at the 16 nm station off Port MacDonnell (cruise 1) and the 8 nm station off Seaspray (cruise 2). Magpie perch larvae, which occurred only during winter cruise 3, were found widespread throughout the survey area and were also caught mostly in surface samples (Table 11).

Anchovy larvae were found throughout the survey area, and were more widespread during summer cruise 1 (Table 11). The highest concentrations (7.7-11.0 larvae per 100 m^3) were obtained at the 8 and 16 nm stations off Seaspray during summer cruises 1 and 2, respectively, in the 25-0 and 50-25 depth strata, and at the 4 nm station of Cape Liptrap during winter cruise 3, in the 25-0 m depth stratum.

Snapper larvae were found only off Gabo Island and Seaspray in both summer cruises, and were more abundant during summer cruise 2. The highest concentration (8.4 larvae per 100 m^3) was recorded at the 8 nm station off Seaspray, in the 25-0 m depth stratum. Ocean perch larvae occurred throughout most of the survey area during summer cruise 2, and were more abundant in this than during winter cruise 4.

Table 11. Occurrence of larvae of selected fish species during this study. The transects (T) where larvae were caught are given for each of the four cruises. The concentration value provided for each of the species under each of the positive cruises (nos per 100 m^3) corresponds to the highest concentration recorded; this value is followed by the transect (T), the station (in brackets) and the depth stratum where this concentration was recorded. Transects: T1, Gabo Island; T2, Cape Conran; T3, Seaspray; T4, Cape Liptrap; T5, Barwon Heads; T6, Port Campbell; T7, Portland; T8, Port MacDonnell.

	CRUISE			
SPECIES (Family)	1 (Jan-Feb 1997)	2 (Dec 1997)	3 (May-Jun 1998)	4 (Jul 1998)
Aldrichetta forsteri (Mugilidae)	T3, T5, T6	T1, T2, T3, T4	T3, T4, T5, T6, T7	
	2.7 per 100 m^3 T5(2), surface	1.3 per 100 m^3 T3(8), surface	6.2 per 100 m^3 T7(2), surface	
Cheilodactylus nigripes (Cheilodactylidae)			T1, T2, T3, T4, T5, T6, T7	
			1.8 per 100 m^3 T2(32), surface	
Engraulis australis (Engraulidae)	T1, T3, T4, T5, T6, T7, T8	T2, T3, T8	T3, T4, T5, T6, T7	
	8.8 per 100 m^3 T3(16), 50-25 m	11.0 per 100 m^3 T3(8), 25-0 m	7.6 per 100 m^3 T4(4), 25-0 m	<0.1 per 100 m^3
Helicolenus percoides (Scorpaenidae)		T1, T2, T4, T5, T8		T2, T4, T5
		3.9 per 100 m^3 T4(32), 50-25 m		<1 per 100 m^3
Pagrus auratus (Sparidae)	T1, T3	T1, T3		
	<1 per 100 m^3	8.4 per 100 m^3 T3(8), 25-0 m		
Upeneichthys vlamingii (Mullidae)	T3, T4, T6, T7, T8	T1, T2, T3, T4		
	21.1 per 100 m^3 T8(16), surface	7.3 per 100 m^3 T3(8), surface		

5.7 Ageing of King George whiting larvae

The five King George whiting larvae (*Sillaginodes punctata*, Sillaginidae) collected within Portland Bay during cruise 4 on 28 July 1998 ranged from 9.4 to 11.1 mm SL in length, and were 52 to 64 days old post-hatching (Table 12). All specimens were at the early postflexion stage. The prediction from the reverse model simulation indicated that these larvae may have been born in coastal waters between Cape Jaffa in southeastern South Australia and just west of Portland (Fig. 1)

Table 12. Size (SL, mm) and age (days old post-hatching) of the five larval King George whiting (*Sillaginodes punctata*) collected within Portland Bay (Vic) on 28 July 1998 during the winter cruise 4.

Specimen No.	Standard Length (SL) (mm)	Age (days old post-hatching)
1	9.4	53
2	10.1	52
3	10.2	64
4	10.4	61
5	11.1	63

5.8 Fish eggs

Very few fish eggs were collected during the four cruises carried out in this study. Due to their low numbers, no attempt was made at identifying these eggs except for those few of pilchard that were collected in samples taken along the Port Campbell transect (T6) in western Victoria during summer cruise 1 (Jan-Feb 1997).

5.9 Rock lobster phyllosomas and giant crab megalopa

No phyllosoma larvae of rock lobster or giant crab megalopa were ever found in the area surveyed during this study. However, a total of 110 phyllosoma larvae were collected during the summer cruise 1 (Jan-Feb 1997), of which 104 and 6 were identified by CSIRO as those of *Ibacus peronii* and *Scyllarus* sp. (Family Palemonidae), respectively. All the specimens were deposited with the CSIRO (Hobart) collection.

6. GENERAL DISCUSSION

6.1 Hydrodynamics

The hydrodynamic modelling showed a markedly different average current pattern for the summer and winter cruises. During winter, the currents throughout the study area were predominantly west to east, which reflect the dominance of westerly winds that occur over the winter period. By contrast, average currents over the summer cruises were from east to west, reflecting the much greater incidence of easterly winds during this period. The most conspicuous oceanographic feature associated with these easterly winds was the offshore currents along coastal waters off western Victoria-eastern South Australia, which were responsible for the upwelling event that was apparent in both satellite SST images, and the vertical profiles of density and inorganic nutrients (see section 6.2). Wind-driven summer upwelling events in this area have previously been described in detail (Lewis, 1981).

In the summer, periods of easterly winds are regularly interrupted by south-westerly frontal systems that results in a rapid wind reversal that may last for several days. Although masked by longer-term averaging, this phenomenon was probably responsible for the anticyclonic eddy observed immediately to the east of Wilsons Promontory during summer cruise 2 (Dec 1997) that, according to the simulation, would have lasted for a period of at least two days. This anticyclonic eddy, which has not been previously described for this area, was discovered after analysing current data (corrected for tides) obtained with the on-board Acoustic Droppler Current Profiler (ADCP). Given the prevailing eastward current at the time, and the southward protruding topography of Wilsons Promontory, this eddy could well be responsible for the retention of high concentrations of ichthyoplankton in the area (see section 6.3). An anticyclonic summer eddy near the coast has previously been reported for this area, although its location was further east, ie. Lakes Entrance to Gabo Island (Rochford, 1977). This eddy is believed to be involved as a possible factor in the summer upwelling event detected along the Gippsland coast in western Victoria (Rochford, 1977).

Hydrodynamic current patterns, particularly at local scales, would have been more complex in summer than in winter due to the presence of stratification. We ran simulations with a simple specification for stratification based on an average density profile. This specification had little effect on average predicted currents over each cruise period. In reality, small-scale temporal and spatial variability in currents would be affected significantly by stratification. However, detailed specification of stratification in the modelling was beyond the scope of this study.

6.2 Inorganic nutrients, fluorescence and upwelling

Unlike the technique utilised during this study to measure inorganic nutrients, most previous studies of Bass Strait waters have been carried out on surface waters at fixed sites, followed by analyses in land-based laboratories. This traditional approach has several shortcomings, including: (a) high staff and boat costs per unit sample; (b) no knowledge of vertical structure; (c) imperfect preservation of samples; (d) large sample storage volume needed; (e) limited number of samples from which to draw conclusions about spatial patterns; and (f) delays of days to months between sampling and analysis.

By coupling a fluorometric sensor with continuous-flow nutrient analytical systems, it is possible to obtain far greater sample density than is practical with discrete samples. This approach has been used for many years to sample vertical profiles (Armstrong *et al.*, 1967; Strickland, 1968; Anderson & Okubo, 1982; Moll *et al.*, 1984; Jones *et al.*, 1991; Yin *et al.*, 1995), but has seldom been used for sampling horizontal transects (Morris *et al.*, 1981, 1995; Longmore *et al.*, 1990, 1996). The spatial resolution of such systems depends on several factors, including digitising interval, pump lowering speed (for vertical profiles) or boat speed (for horizontal transects), degree of peak spreading in the water transmission system and response time of sensors (Mackas & Owen, 1982; Anderson & Okubo, 1982).

During this study, seasonal variation was observed in the concentrations of dissolved inorganic nitrogen (DIN) and in chlorophyll fluorescence, but not in phosphate or silicate concentrations. The DIN concentrations in surface waters, which varied between 0.1 and 1 µM, were highest in winter, while fluorescence was greatest in summer. Off Portland during cruise 2 in December 1997, very low surface phosphate and oxidised N concentrations (~0.03 and 0.02 µM, respectively) occurred in an area of high fluorescence. It is thus possible that the low nutrient concentrations were due to plankton uptake. Most of the inorganic N at that time was ammonium, which is a by-product of phytoplankton grazing and decomposition through the water column. The decline in fluorescence in winter suggests that phytoplankton biomass may be limited by light or temperature. The relative concentrations of DIN, phosphate and silicate also suggest that phytoplankton growth may be silicate-limited at times, particularly in surface waters.

It is well known that waters of central Bass Strait contain low nutrient concentrations (Gibbs *et al.*, 1986). Given the generally shallow water depths in this area, there is no opportunity for nutrient concentrations to be enhanced by upwelling. We could therefore expect little change in vertical or horizontal nutrient distributions, except off known inputs. However, introduction of new nutrients is highly possible on the eastern and

western margins of Bass Strait. In winter, Gibbs *et al.* (1991) observed a peak in the concentration of chlorophyll *a* of 2 μgL^{-1} off Mallacoota, which they attributed to the northward winter movement of nutrient-rich Tasman and sub-Antarctic water along the edge of the continental shelf. The chlorophyll *a* concentration within Bass Strait was <0.5 μgL^{-1} at during the same period, and is likely to be controlled by zooplankton grazing. The increase in oxidised N and silicate concentrations in near-shore eastern Bass Strait reflects this enrichment, and our observations indicate the subsurface enrichment may occur off Gabo Island in summer as well as winter. Rochford (1984) also observed sporadic summer upwelling events off Eden, these nitrate-rich waters being a mixture of sub-Antarctic and Coral Sea waters.

Gibbs *et al.* (1986) observed an intrusion of low-salinity, nitrate-rich water at a depth of 40 m off Cape Otway in January. This intrusion, which was observed on only one out of 11 occasions, was regarded by Gibbs *et al.* (1986) to be of sub-Antarctic origin. Further west, it has been well documented that upwelling near Kangaroo Island (SA) in November-March is caused by wind-driven advection. Wind from the south-east forces surface water offshore, which is then replaced by upwelling of deeper, colder, nitrate-rich sub-Antarctic water (Lewis, 1981). During this study, an upwelling summer event in western Victoria was clearly evident from the subsurface enrichment of oxidised N and silicate observed off Portland during the summer cruises 1 (Jan-Feb 1997) and 2 (Dec 1997). In both cases, enrichment was greater at 2 than at 4 nm from the coast, which implies that local topographic and wind conditions are likely to be important in determining where upwelling events occur. Although density values during cruise 1 show the summer upwelling event taken place off Portland, high DIN values suggest that the event could have been located off Port MacDonnell (SA). This finding agrees with the fact that upwelling, at least off eastern South Australia, is not uniform and can occur in a number of localized centres (Lewis, 1981). In contrast to the summer cruises, no enrichment of oxidised N or silicate was detected in either of the two winter cruises (May-Jun and Jul 1998).

6.3 Diversity and abundance of larval fishes

Larval fishes belonging to 96 teleost fish families were caught during this study, 85 during the summer cruises (1997) and 56 during the winter cruises (1998). As there are no previous comparable studies of larval fishes in the area surveyed during this study, it is difficult to infer on the significance of this diversity. However, similar diversity of families have been found in larval fish surveys carried out in coastal and shelf regions elsewhere, including California (101 families; Moser *et al.*, 1993, 1994), the Gulf of Mexico (100 families; Richards *et al.*, 1993), north-western Australia (103 families; Young *et al.*, 1986), and Sydney (111 families; Smith & Suthers, 1999). In the latter

study, which was based on intensive sampling over 7 nights at five stations across the continental shelf of Sydney (NSW) in January and April, the high taxonomic diversity was attributed to the convergence of temperate and tropical waters in that region (Smith & Suthers, 1999).

The overall higher number of taxa found as larvae during the summer surveys (n = 146) compared to that recorded in the winter surveys (n = 95) suggests that a high percentage of the temperate species in south-eastern Australia spawn during this period. This is emphasised by the fact that taxa belonging to 40 families were found exclusively during summer, compared to 11 families that occurred solely during winter.

Comparatively high larval concentrations (nos per 100 m^3) were recorded off Port Campbell, Portland and Port MacDonnell during the summer cruise 1 (Jan-Feb 1997). The high larval abundances recorded off these areas could be attributed to the increased productivity associated with the upwelling event detected off Portland (Vic) and Port MacDonnell (SA) at that time, the effect of which could also have reached the area off Port Campbell (Vic). By contrast, the overall lower larval concentrations off Portland and Port MacDonnell during the summer cruise 2 (Dec 1997) possibly reflect the absence of upwelling in the area at the time of sampling. The higher larval abundances off Port Campbell, Portland and Port MacDonnell during cruise 1 were largely due to the presence of larval pilchard (*Sardinops sagax*) and, to a lesser extent, jack mackerel (*Trachurus declivis*). As with larval concentrations, comparatively high numbers of larval taxa were also found in these transects during cruise 1 (19-27).

In contrast to the situation during summer cruise 1, both the greatest larval fish concentrations and greatest number of taxa (n = 32 taxa) during the summer cruise 2 were recorded off Seaspray, to the east of Wilsons Promontory, with area off Cape Liptrap producing a comparably high number of taxa (n = 27) but an overall lower larval concentrations. A relatively high number of taxa was also recorded off Seaspray during the summer cruise 1 (n = 22). Larvae that were abundant in this area during the summer cruise 2 included those of pilchard, barracouta (*Thyrsites atun*) and sand flathead (*Platycephalus bassensis*), the latter species being quite abundant within Corner Inlet as well as throughout Bass Strait (Neira *et al.*, 1997a).

Both the high larval concentrations and high number of taxa off Seaspray and nearby areas during summer cruise 2 are likely to be related to the variety and abundance of inshore rocky reef areas around Wilsons Promontory and its neighbouring islands, as well as to the presence of nearby Corner Inlet. In addition, the presence of the inshore anticyclonic eddy detected from shipboard current data, combined with both the prevailing eastward current at that time and the southward protruding topography of

Wilsons Promontory, are likely to favour the retention of ichthyoplankton in this area during summer. The accumulation and subsequent retention of larvae in this area could also be augmented by the advection of larvae spawned to the east of Wilsons Promontory, as the current flow over the summer period is predominantly eastwards. In addition, spawning nearby the Gippsland Basin could be greatly enhanced by short-term upwelling events which have been reported to occur in this area during February-March (Rochford, 1977). Although the predominantly eastwards flowing current during summer suggests that most older larvae collected during this period would have been spawned further to the east of the sampling location, such 'average' transport would obviously be modified by smaller-scale current features and/or the influence of larval behaviour.

Larval concentrations during the winter cruises were markedly lower compared to those during the summer cruises, and were lowest during cruise 3 (May-Jun 1998). Despite the lower concentrations, a high number of taxa recorded at least off Gabo Island during cruise 4 (n = 22). This relatively high number of taxa in winter could well be the result of the eastwards advection of larvae from the nearby Gippsland Basin, mixed along the shelf brake at the eastern end of Bass Strait with larval fishes from more southern areas.

6.4 Spawning areas/seasons of selected species

Larvae of pilchard (*Sardinops sagax*) were caught mainly during summer cruises in eastern South Australia and western Victoria and, to a lesser extent, off Seaspray to the east of Wilsons Promontory. Pilchard eggs and larvae in Bass Strait have previously been reported in the area around Cape Schanck and nearby the entrance to Westernport Bay in Victoria between November and February (Hoedt & Dimmlich, 1995; Hoedt *et al.*, 1995). As pilchard are known to spawn across a large area off central and western South Australia (Ward *et al.*, 1998), it is possible that the larvae found to the west of the survey area late January-early February (cruise 1) belong to the same spawning stock. This view is supported by the fact that the timing of greatest concentrations of pilchard larvae found to the west during this study falls within the main spawning period reported for pilchard in South Australia, ie. January to April (Ward *et al.*, 1998).

It has been reported that Port Phillip Bay (Vic) supports a large pilchard fishery which is mostly based on juvenile 0+ and 1+ fish (Neira *et al.*, 1997b; 1999). Since results of this study showed the existence of a single significant pilchard spawning area towards western Victoria, it is possible that a high proportion of the juvenile pilchard that enter Port Phillip Bay during spring/summer (Neira *et al.*, 1999) could originate from this area. However, more detailed studies are required to verify this hypothesis.

Larvae of barracouta (*Thyrsites atun*) were caught in all cruises, but were more abundant during summer. Larvae were found west of Port Phillip Bay during cruise 1 (Jan-Feb 1997), east of this bay during cruise 2 (Dec 97), and scattered across the survey area during the winter cruises, although they were more common towards western Victoria during cruise 4. The distribution of larvae found during this study coincides with the reported commercial fishing areas of this species in southeastern Australia (Kailola *et al.*, 1983). There is little data on adult populations of this species except for the detailed study of Blackburn & Gartner (1954). According to these authors, barracouta show rather complex spawning patterns, with the existence of at least five populations that migrate to spawn in different areas and seasons. In the area of our study, the reported spawning migrations of populations include: one in winter and spring to southern New South Wales and eastern Victoria; one from spring to autumn to Bass Strait; and one in autumn and winter to South Australia and western Victoria (Blackburn & Gartner, 1954). Following Blackburn & Gartner (1954), the summer larvae found in this study possibly belong to the Bass Strait population. This population appears in early spring at the eastern end of Bass Strait and spawns continuously as it moves westward towards eastern South Australia during spring and summer. The distribution of larvae caught during this study during the summer cruises seem to support this reported sequential spawning. Barracouta larvae caught in western Victoria during the winter cruise 4 could well be derived from the population that migrates eastwards from South Australia to spawn in western Victoria in autumn and winter (Blackburn & Gartner, 1954).

Larvae of jack mackerel (*Trachurus declivis*) were caught almost exclusively during the summer cruises, and were more abundant between Port Campbell and Portland in western Bass Strait during cruise 1 (Jan-Feb 1997). The distribution of larvae during cruise 1 suggests that they may belong to the South Australian-Great Australian Bight stock which is known to spawn in summer (Stevens *et al.*, 1984). Although the timing of larval occurrence in our study coincides with the main spawning time reported for eastern Tasmania, ie. mid December to mid February (Jordan, 1994), it would be highly unlikely these larvae would have been spawned along eastern Tasmania and then transported against the prevailing Eastern Australian Current towards western Victoria. The high concentration of larvae found off Portland during cruise 1 was obtained in highly stratified waters, with most larvae being caught below the thermocline in temperatures 14-16°C. Similarly, it has been reported that jack mackerel in eastern Tasmania spawns in waters of approximately 13-15°C (Jordan *et al.*, 1995). The data collected during cruise 1 also shows that concentrations of larval jack mackerel off Portland were higher towards the inshore stations (2-4 nm) than over the shelf brake. Given the upwelling event observed in this area during cruise 1, it is possible that these larvae could have been spawned over the shelf brake and then transported inshore with the influx of colder water. Spawning of jack mackerel on the bottom over the shelf

brake has previously been reported for the population of eastern Tasmania (Jordan *et al.*, 1995).

Larvae of sand flathead (*Platycephalus bassensis*) were caught only during the summer cruises, and were more abundant off Seaspray during cruise 2. This species is heavily fished within Corner Inlet, a permanently open system to the west of Seaspray in the area of Wilsons Promontory, as well as in other areas of Bass Strait (Neira *et al.*, 1997a). As there have been no larval fish studies within Corner Inlet, it could be assumed that larvae found in the area outside this inlet may originate from adults that spawn either outside or inside this system, or both. In this context, it is perhaps relevant that sand flathead in waters of eastern and southern Tasmania are known to spawn over an extended period (October-March) at several locations, including estuaries, coastal embayments and inshore shelf waters (Jordan, *in press*).

Larvae of blue warehou (*Seriollela brama*) were caught during all cruises, but were more abundant during winter cruise 4. The distribution of blue warehou larvae indicates that this species spawns throughout the survey area during winter, and that older larvae are found towards the western end of Bass Strait during late summer. By contrast, larvae of spotted warehou (*Seriollela punctata*), which were caught almost exclusively during the winter cruise 4, were restricted to the two eastern-most transects, ie. Gabo Island and Cape Conran. The larval distributions of both warehou species in southeastern Australia parallels those described by Bruce *et al.* (*in press*). However, whereas these authors stated that both species spawn predominantly during late July-August, larvae of both species were also caught during cruise 3, in the period May-June 1998. This implies that the spawning season of both species in the area starts earlier than previously thought.

6.5 Transport of larval King George whiting

King George whiting larvae caught in Portland Bay on 28 July 1998 were the smallest and youngest ever collected in Victorian waters. The smallest and youngest larval King George whiting previously recorded had been caught in Port Phillip Bay (Vic) and were approximately 15 mm SL in length and 80 days in age (Jenkins *et al.*, *in press*). Simulations to predict spawning areas of King George whiting, based on reverse modelling and larval durations of recruits collected from Port Phillip Bay, Western Port and Corner Inlet, suggested that the major spawning area was from approximately Cape Otway (Vic) to Cape Jaffa (SA) (Jenkins *et al.*, *in press*). Thus, the predicted spawning area for larvae collected in the present study was within the range predicted for larvae from central Victorian bays. The stage of development relative to the date of collection was also consistent with larvae collected in central Victoria. For example, larvae in Port Phillip Bay are generally collected from mid September to early November, and have a

mean age of approximately 120 days. Thus, larvae collected in the present study were collected approximately two months earlier and they were approximately 2 months younger. Overall, the results suggest that the larvae collected in Portland came from the same spawning area and time as fish that eventually recruit to central Victorian bays. These results provide further evidence that King George whiting recruiting to central Victorian bays originate from a single spawning area to the west, possibly as far as south-eastern South Australia (Jenkins *et al.*, *in press*).

The fact that the average current in the survey area during winter is predominantly westwards is consistent with hydrodynamic model simulations of transport of King George whiting larvae in Bass Strait (Jenkins *et al.*, *in press*). Results of this latter study suggested that for post-larvae entering bays and inlets of central Victoria, spawning was mostly concentrated from Cape Otway (Vic) to eastern South Australia, which in turn suggested strong transport from the west over the winter period (Jenkins *et al.*, *in press*). In this context, it could be assumed that larvae collected during the winter cruises, particularly those from winter cruise 4, could have been spawned to the west of the collection area, the distance depending on the age of the larvae.

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Many thanks to all.

9. INTELLECTUAL PROPERTY

No commercially valuable property has resulted from this research.

10. STAFF

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11. APPENDIX

Appendix 1. Personnel from the Marine and Freshwater Resources Institute (MAFRI) who participated during the *RV Franklin* cruises 1 to 4 in 1997/98. Abbreviations: PI = Principal Investigator; MS = Marine Scientist; TO = Technical Officer; TA = Technical Assistant.

Name (Position)	Cruise 1 Jan-Feb 1997	Cruise 2 December 1997	Cruise 3 May-June 1998	Cruise 4 July 1998
Dr F. J. Neira (PI)	*	*	*	*
Mr A. Longmore (MS)				*
Mr R. Cowdell (MS)	*	*		
Mr G. Nicholson (MS)	*		*	
Mr M. Lourey (MS)		*	*	*
Mr P. Hamer (MS)			*	*
Mr S. Conron (MS)			*	
Mr D. McKeown (TO)	*	*	*	
Mr D. Beyer (TO)				*
Ms P. Oliveiro (TO)		*		
Ms S. Tait (TA)	*			*

Appendix 2. Summary of transects (east to west) and stations sampled, and number of plankton samples taken with different sampling gear during summer cruise 1 (January/ February 1997). * indicates EZ not employed due to bad weather.

	Transect	1	2	3	4	5	6	7	8	
Distance offshore (nautical miles)	Location	Gabo Island	Cape Conran	Seaspray	Cape Liptrap	Barwon Heads	Port Campbell	Portland	Port MacDonnell	Total samples
	Longitude	149° 55'	148° 33'	147° 10'	145° 48'	144° 26'	143° 04'	141° 40'	140° 17'	
2	Latitude	37° 36.0'	37° 50.5'	38° 26.0'	38° 44.5'	38° 19.0'	38° 41.0'	38° 27.0'	37° 49.0'	
	Max depth (m)	100	29	20	16	30	50	52	22	
	Neuston samples	1	1	1	1	1	1	1	1	8
	Bongo 25-0 m			1		1			1	3
	EZ samples	4	1		1		2	2		10
	Subtotal samples	5	2	2	2	2	3	3	2	**21**
4	Latitude	37° 38.0'	37° 52.5'	38° 28.0'	38° 46.5'	38° 21.0'	38° 43.0'	38° 29.0'	37° 51.0'	
	Max depth (m)	120	40	20	42	48	64	57	26	
	Neuston samples	1	1	1	1	1	1	1	1	8
	Bongo 25-0 m			1					1	2
	EZ samples	4	1		2	2	2	2		13
	Subtotal samples	5	2	2	3	3	3	3	2	**23**
8	Latitude	37° 42.0'	37° 56.5.0'	38° 32.0'	38° 50.5'	38° 25.0'	38° 47.0'	38° 33.0'	37° 55.0'	
	Max depth (m)	120	54	30	67	63	67	75	50	
	Neuston samples	1	1	1	1	1	1	1	1	8
	Bongo 25-0 m			1			1		1	3
	EZ samples	4	2		3	2	2	3	2	18
	Subtotal samples	5	3	2	4	3	4	4	4	**29**
16	Latitude	37° 50.0'	38° 04.5'	38° 40.0'	38° 58.5'	38° 33.0'	38° 55.0'	38° 41.0'	38° 03.0'	
	Max depth (m)	100	60	40	76	75	76	135	120	
	Neuston samples	1	1	1	1	1	1	1	1	8
	Bongo 25-0 m							1	1	2
	EZ samples	4	2	2	3	3	3	3	3	23
	Subtotal samples	5	3	3	4	4	4	5	5	**33**
32	Latitude	38° 06.0'	38° 20.5'	38° 56.0'	39° 14.5'	38° 49.0'	39° 11.0'	38° 57.0'	38° 19.0'	
	Max depth (m)	150	361	60	80	80	84	1760	1470	
	Neuston samples	1	1	1	1	1	1	1	1	8
	Bongo 25-0 m					1	2	1	1	5
	EZ samples	*	*	2	3	*	*	3	3	11
	Subtotal samples	1	1	3	4	2	3	5	5	**24**
Total samples		21	11	12	17	14	17	20	18	**130**
							EXTRA SURFACE TOWS:			**17**

Appendix 3. Summary of transects (east to west) and stations sampled, and number of plankton samples taken with different sampling gear during cruise summer 2 (December 1997). * indicates EZ not employed due to bad weather.

	Transect	1	2	3	4	5	6	7	8	
Distance offshore	Location	Gabo Island	Cape Conran	Seaspray	Cape Liptrap	Barwon Heads	Port Campbell	Portland	Port MacDonnell	Total samples
(nautical miles)	Longitude	149° 55'	148° 33'	147° 10'	145° 48'	144° 26'	143° 04'	141° 40'	140° 17'	
	Latitude	37° 36.0'	37° 50.5'	38° 26.0'	38° 44.5'	38° 19.0'	38° 41.0'	38° 27.0'	37° 49.0'	
	Max depth (m)	95	29	20	16	30	50	52	22	
2	Neuston samples	1	1	1		1		1		5
	Bongo 25-0 m		1	1	1	1			1	5
	EZ samples	4					*	2		6
	Subtotal samples	5	2	2	1	2	0	3	1	**16**
	Latitude	37° 38.0'	37° 52.5'	38° 28.0'	38° 46.5'	38° 21.0'	38° 43.0'	38° 29.0'	37° 51.0'	
	Max depth (m)	101	50	20	40	49	64	60	28	
4	Neuston samples	1	1	1	1	1		1	1	7
	Bongo 25-0 m		1	1	1				1	4
	EZ samples	4				2	*	2		8
	Subtotal samples	5	2	2	2	3	0	3	2	**19**
	Latitude	37° 42.0'	37° 56.5.0'	38° 32.0'	38° 50.5'	38° 25.0'	38° 47.0'	38° 33.0'	37° 55.0'	
	Max depth (m)	101	54	30	72	63	67	78	47	
8	Neuston samples	1	1	1	1	1		1	1	7
	Bongo 25-0 m			1				1		2
	EZ samples	4	2		3	2	*	1	2	14
	Subtotal samples	5	3	2	4	3		3	3	**23**
	Latitude	37° 50.0'	38° 04.5'	38° 40.0'	38° 58.5'	38° 33.0'	38° 55.0'	38° 41.0'	38° 03.0'	
	Max depth (m)	139	63	41	77	77	76	140	122	
16	Neuston samples	1	1	1	1	1		1	1	7
	Bongo 25-0 m							1	1	2
	EZ samples	4	2	2	3	3	*	*	3	17
	Subtotal samples	5	3	3	4	4		2	5	**26**
	Latitude	38° 06.0'	38° 20.5'	38° 56.0'	39° 14.5'	38° 49.0'	39° 11.0'	38° 57.0'	38° 19.0'	
	Max depth (m)	272	361	60	70	80	84	1760	1550	
32	Neuston samples	1	1	1	1			1	1	6
	Bongo 25-0 m			1				1	1	3
	EZ samples	4	4	1	3	*	*	*	3	15
	Subtotal samples	5	5	3	4	0	0	2	5	**24**
Total samples		25	15	12	15	12	0	13	16	**108**
							EXTRA SURFACE TOWS:			**12**

Appendix 4. Summary of transects (east to west) and stations sampled, and number of plankton samples taken with different sampling gear during winter cruise 3 (May/June 1998). n indicates night sample; * indicates EZ not employed due to bad weather.

	Transect	1	2	3	4	5	6	7	
Distance offshore	Location	Gabo Island	Cape Conran	Seaspray	Cape Liptrap	Barwon Heads	Port Campbell	Portland	Total samples
(nautical miles)	Longitude	149° 55'	148° 33'	147° 10'	145° 48'	144° 26'	143° 04'	141° 40'	
2	Latitude	37° 36.0'	37° 50.5'	38° 26.0'	38° 44.5'	38° 19.0'	38° 41.0'	38° 27.0'	
	Max depth (m)	95	29	20	16	30	50	52	
	Neuston samples	1	1	1	1	1	1	2 (n=1)	8 (n=1)
	Bongo 25-0 m	1	1	1	1	1		2 (n=1)	7 (n=1)
	EZ samples	3					2		5
	Subtotal samples	5	2	2	2	2	3	4 (n=2)	**20 (n=2)**
4	Latitude	37° 38.0'	37° 52.5'	38° 28.0'	38° 46.5'	38° 21.0'	38° 43.0'	38° 29.0'	
	Max depth (m)	101	50	20	40	49	64	60	
	Neuston samples	1	1	1	1	1	1	2 (n=1)	8 (n=1)
	Bongo 25-0 m			1	1				2
	EZ samples	4	2			2	2	4 (n=2)	14 (n=2)
	Subtotal samples	5	3	2	2	3	3	6 (n=3)	**24 (n=3)**
8	Latitude	37° 42.0'	37° 56.5.0'	38° 32.0'	38° 50.5'	38° 25.0'	38° 47.0'	38° 33.0'	
	Max depth (m)	101	54	30	72	63	67	78	
	Neuston samples	1	1	1	1	1	1	2 (n=1)	8 (n=1)
	Bongo 25-0 m			1					1
	EZ samples	4	2		3	2	2	6 (n=3)	19 (n=3)
	Subtotal samples	5	3	2	4	3	3	8 (n=4)	**28 (n=4)**
16	Latitude	37° 50.0'	38° 04.5'	38° 40.0'	38° 58.5'	38° 33.0'	38° 55.0'	38° 41.0'	
	Max depth (m)	139	63	41	77	77	76	140	
	Neuston samples	1	1	1	1	1	1	n=1	7 (n=1)
	Bongo 25-0 m								
	EZ samples	4	3	2	3	3	3	n=4	22 (n=4)
	Subtotal samples	5	4	3	4	4	4	n=5	**29 (n=5)**
32	Latitude	38° 06.0'	38° 20.5'	38° 56.0'	39° 14.5'	38° 49.0'	39° 11.0'	38° 57.0'	
	Max depth (m)	272	361	60	70	80	84	1760	
	Neuston samples	1	1	1	1	1	1	n=1	7 (n=1)
	Bongo 25-0 m							n=1	1 (n=1)
	EZ samples	4	4	2	3	3	3	n=3	22 (n=3)
	Subtotal samples	5	5	3	4	4	4	n=5	**30 (n=5)**
Total samples		25	17	12	16	16	17	18 (n=19)	**131 (n=19)**
						EXTRA SURFACE TOWS:			**18**

Appendix 5. Summary of transects (east to west) and stations sampled, and number of plankton samples taken with different sampling gear during winter cruise 4 (July 1998). * indicates EZ not employed due to bad weather.

	Transect	1	2	4	5	6	7	8	
Distance offshore	Location	Gabo Island	Cape Conran	Cape Liptrap	Barwon Heads	Port Campbell	Portland	Port MacDonnell	Total samples
(nautical miles)	Longitude	149° 55'	148° 33'	145° 48'	144° 26'	143° 04'	141° 40'	140° 17'	
2	Latitude	37° 36.0'	37° 50.5'	38° 44.5'	38° 19.0'	38° 41.0'	38° 27.0'	37° 49.0'	
	Max depth (m)	100	29	16	30	50	52	22	
	Neuston samples	1	1	1	1	2	2		8
	Bongo 25-0 m		1	1	1				3
	EZ samples	4				2	2	*	8
	Subtotal samples	5	2	2	2	4	4	0	**19**
4	Latitude	37° 38.0'	37° 52.5'	38° 46.5'	38° 21.0'	38° 43.0'	38° 29.0'	37° 51.0'	
	Max depth (m)	120	40	42	48	64	57	26	
	Neuston samples	1	1	1	1	2	2		8
	Bongo 25-0 m	1							1
	EZ samples	3	2	2	2	3	2	*	14
	Subtotal samples	5	3	3	3	5	4	0	**23**
8	Latitude	37° 42.0'	37° 56.5.0'	38° 50.5'	38° 25.0'	38° 47.0'	38° 33.0'	37° 55.0'	
	Max depth (m)	120	54	67	63	67	75	50	
	Neuston samples	1	1	1	1	2	2		8
	Bongo 25-0 m								
	EZ samples	4	2	3	3	3	3	*	18
	Subtotal samples	5	3	4	4	5	5	0	**26**
16	Latitude	37° 50.0'	38° 04.5'	38° 58.5'	38° 33.0'	38° 55.0'	38° 41.0'	38° 03.0'	
	Max depth (m)	100	60	76	75	84	135	120	
	Neuston samples	1	1	1	2	1	1		7
	Bongo 25-0 m	1							1
	EZ samples	2	3	3	3	4	3	*	18
	Subtotal samples	4	4	4	5	5	4	0	**26**
32	Latitude	38° 06.0'	38° 20.5'	39° 14.5'	38° 49.0'	39° 11.0'	38° 57.0'	38° 19.0'	
	Max depth (m)	150	361	80	80	84	1760	1470	
	Neuston samples	1	1	1	2	1	1	1	8
	Bongo 25-0 m								
	EZ samples	4	4	3	3	4	2	3	23
	Subtotal samples	5	5	4	5	5	3	4	**31**
Total samples		24	17	17	19	24	20	4	**125**
						EXTRA SURFACE TOWS:			**26**

The RV *Franklin*, the research vessel utilised during all four surveys carried out during this study.