CSIRO Publishing

# Marine & Freshwater Research

VOLUME 53, 2002


A journal for the publication of original contributions
in physical oceanography, marine chemistry,
marine and estuarine biology and limnology

**All enquiries and manuscripts should be directed to:**

*Marine and Freshwater Research*
CSIRO Publishing
PO Box 1139 (150 Oxford St)
Collingwood, Vic. 3066, Australia

Telephone: +61 3 9662 7618
Fax: +61 3 9662 7611
Email: publishing.mfr@csiro.au

CSIRO
PUBLISHING

Published by CSIRO Publishing
for CSIRO and the Australian Academy of Science

www.publish.csiro.au/journals/mfr

*Mar. Freshwater Res.*, 2002, **53**, 339–354

# Use of ichthyoplankton ecology to evaluate ecosystem changes: a case study in a large, semi-enclosed Australian bay

*Francisco J. Neira*[A] *and Miriana I. Sporcic*

Faculty of Fisheries and Marine Environment, Australian Maritime College, PO Box 21 Beaconsfield, Tas. 7270, Australia

[A]To whom correspondence should be addressed

*Abstract.* Intensive night sampling was conducted fortnightly in 1995/96 to investigate the ichthyoplankton assemblage of Port Phillip Bay. Results are compared with those from a similar survey in 1983/84, and are used to ascertain whether major changes have occurred in the composition and abundance of fish eggs and larvae, and whether these are related to ecosystem changes in the bay between 1969 and 1995. The 17 157 larvae caught during this study belonged to 60 taxa from 32 teleost fish families, with Gobiidae (54.2%), Engraulidae (16.7%), Clinidae (10.0%) and Odacidae (5.9%) dominating the catches. Larval concentrations peaked only in summer, in contrast to summer and winter in 1983/84. Larvae from 13 families recorded in 1995/96 did not occur in 1983/84, including Gobiesocidae (9 spp.) and Odacidae (3 spp.). Larvae absent in 1995/96 but present in 1983/84 included *Acanthopegasus lancifer* (Pegasidae) and taxa from another seven families. *Neoodax balteatus* larvae ranked fourth in 1995/96 but were absent in 1983/84, while *Engraulis australis* eggs and *Gymnapistes marmoratus* larvae were comparatively fewer in 1995/96. We suggest that some of the main differences between the two surveys may be attributable to major ecosystem changes in the bay, particularly the introduction and establishment of exotic marine species.

## Introduction

Port Phillip Bay is a large, semi-enclosed marine embayment in south-eastern Australia that supports significant commercial and recreational fisheries, and provides suitable spawning and nursery areas for several fish species (Neira *et al.* 1999). During the past three decades, the ecosystem of this bay has undergone significant, possibly irreversible, long-term changes that have markedly altered the composition and abundance of communities of both macrobenthic invertebrates (Wilson *et al.* 1998; Currie and Parry 1999) and demersal fishes (Hobday *et al.* 1999). Main factors identified as responsible for these changes include a decrease in the overall nutrient load from moderate to low levels (Wilson *et al.* 1998), a decline in seagrass abundance, and the establishment of at least 165 introduced marine species in the bay (Parry *et al.* 1996; Currie and Parry 1999; Hewitt *et al.* 1999; Hobday *et al.* 1999). In addition, changes in the bay's demersal fish communities have been associated with significant increases in fishing pressure, as well as the introduction and establishment of at least four exotic teleost fishes (Hobday *et al.* 1999; Lockett and Gomon 1999).

A few studies have shown the impact of ecosystem changes on plankton communities, as in the case where direct predation by an introduced bivalve was found to be the main cause of the substantial decline in nauplii larvae of estuarine copepods (e.g. Kimmerer *et al.* 1994). However, there are no studies in estuaries or semi-enclosed bays that have attempted to examine whether major ecosystem changes, like those reported for Port Phillip Bay, could be evidenced in changes to the ichthyoplankton assemblages of such systems. One could logically argue that alterations to the benthic community structure over a period of time, including the establishment of exotic invertebrates and the loss of seagrass habitats, will somehow modify available breeding habitats generally used by fishes that are benthic or demersal spawners. This could, in turn, be detected in the composition and abundance of larvae of these species, provided comparable data prior to the event are available. Equally possible is that changes in fishing pressure may affect both demersal and pelagic fish species that spawn within the bay, and hence these may be reflected in the ichthyoplankton composition.

Information on ichthyoplankton of Port Phillip Bay is limited to one study describing the composition, seasonality and distribution of fish eggs and larvae within the bay (Jenkins 1986). Egg catches in the bay were dominated by those of anchovy, *Engraulis australis*, one of the few commercial species that spawn within estuaries, coastal marine lakes and enclosed bays across temperate Australia (Arnott and McKinnon 1985; Jenkins 1986; Neira *et al.*

 10.1071/MF01111 1323-1650/02/020339

1992; Neira and Potter 1992*a*, 1994). The larval assemblage, on the other hand, was dominated by larvae of the Gobiidae and those of other resident bay species, although it also contained a small number of marine-spawned larvae that are passively transported into the bay from Bass Strait waters (Jenkins 1986). The lower incidence of marine-spawned larvae reflects the fact that the majority of the most abundant fishes in Port Phillip Bay, as well as other bays and estuaries across temperate Australia, recruit into these nursery areas as postlarvae and/or juveniles (Neira and Potter 1992*b*; Neira *et al.* 1999).

In 1995/96, an intensive survey was conducted in Port Phillip Bay *(a)* to examine the composition and abundance of ichthyoplankton and *(b)* specifically to ascertain to what extent pilchard, *Sardinops sagax*, were using the bay as a spawning area (see Neira *et al.* 1999 for details). This paper describes the 1995/96 ichthyoplankton assemblage of the bay, and compares the results with those obtained during the first ichthyoplankton survey conducted in this system in 1983/84 (Jenkins 1986). We attempt *(a)* to ascertain whether major changes have occurred in the composition and abundance of fish eggs and larvae since the 1983/84 survey, and *(b)* to determine whether these changes are related to the significant ecosystem changes reported for this bay between 1969 and 1995 (Currie and Parry 1999; Wilson *et al.* 1998; Hewitt *et al.* 1999; Hobday *et al.* 1999). Finally, we briefly discuss the use of ichthyoplankton information as an alternative method to detect, monitor and evaluate long-term ecosystem changes such as those described for Port Phillip Bay.

## Materials and methods

*Study area and selection of sites*

Port Phillip Bay (38°S, 145°E) is a large (1930 km$^2$) sheltered marine embayment connected to the sea of Bass Strait by a relatively narrow, 3 km wide entrance channel (Fig. 1). Tides through the entrance are semi-diurnal, comprising one large and one small tide each day (Harris *et al.* 1996). The narrow entrance, coupled with the extensive shallow sand banks immediately inside the entrance, restricts the water exchange between the bay and the sea resulting in the main body of water having a residence time of 10–16 months. The bay remains vertically well mixed for most of the year owing to its relatively shallow mean depth (13.6 m; maximum 24 m) (Harris *et al.* 1996; Walker 1999).

Since we were interested in comparing our ichthyoplankton data with those obtained during the 1983/84 survey (Jenkins 1986), the bay was divided into the same six geographical areas used in that study. These were Geelong (1), Werribee (2), Melbourne (3), Frankston (4), Central (5) and Southern (6) (Fig. 1). Prior to each cruise, two sites were randomly selected within each of these six areas using a SAS® random number generator program. Random selection of sites using this method was achieved by feeding the program with 728 numbers that resulted from dividing the bay into 728 blocks of 0.8 nm$^2$ (1 min

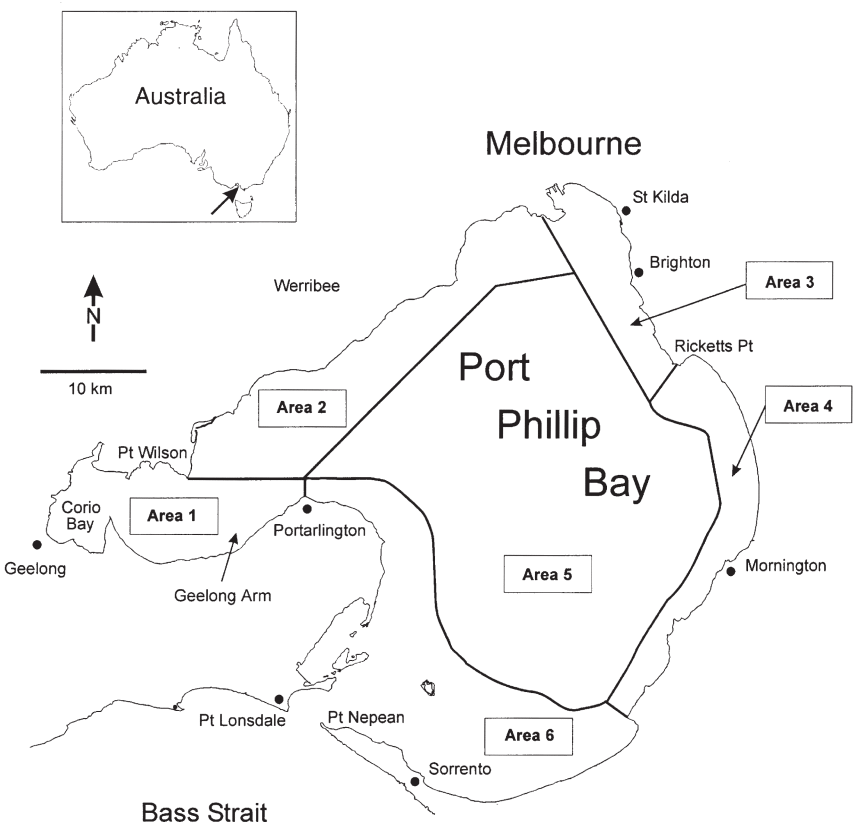


**Fig. 1.** Map of Port Phillip Bay, in south-eastern Australia, showing the areas (1–6) sampled during this study.

latitude × 0.8 min longitude) and allocating a number to each of these (1–728). After two numbers had been obtained for each area ($n$ = 12 sites per sampling cruise), the geographical positions (latitudes and longitudes) at the centre of the selected blocks were obtained and entered into a vessel-mounted DGPS to pinpoint the exact location of the sampling sites. This procedure was repeated before each cruise, with replication then being carried out at the area level, i.e. two replicate samples per area on each sampling cruise.

*Sampling regime and laboratory procedures*

Ichthyoplankton samples were collected fortnightly at night (from one hour after sunset) between September 1995 and September 1996, on both full- and new-moon days. Sampling on those specific days was carried out to test whether fish egg and larval concentrations differed significantly with moon state (see Analysis of Data). Sampling in April 1996 could not be done because of bad weather throughout most of that month. All samples were obtained with a bongo sampler equipped with two nets (length 3 m, diameter 0.6 m) of 500 and 300 µm mesh, respectively. At each site, the sampler was deployed behind a twin-engine vessel, and towed for 5 min at speeds of 1.0–1.5 knots using step-wise and double step-wise oblique tows depending on site depth. Total water volume filtered during each tow was calculated from General Oceanics flowmeters attached to the mouth of each net. Nets were washed after completion of each tow, and the contents of each codend fixed with 4% formaldehyde–seawater and later preserved in 70% ethanol. Water temperatures (°C) and salinities were recorded at each site on each sampling occasion with a YEO-KAL salinity–temperature bridge, and averaged for each site and area to provide mean monthly values.

All samples ($n$ = 276) were sorted under a dissecting stereo-microscope. Fish eggs were separated into those of anchovy (*Engraulis australis*) and those of other teleost fishes (herein referred to as other fish eggs). The total numbers of both anchovy and other fish eggs in each sample were estimated by averaging the numbers counted in four well mixed 25 mL subsamples. All fish larvae were removed from samples, identified to the lowest possible taxon and counted. Identifications were carried out following Neira *et al.* (1998) and references therein. Larval fishes that were identified only to family level belonged mostly to multispecies groups requiring further work to provide accurate species identification (e.g. gobiids, clinids). The distinction between marine- and bay-spawned larvae was based on information on adults (Gomon *et al.* 1994) and/or on studies of larval fishes across temperate Australia (Neira *et al.* 1998, 2000). Larvae that could not be identified to any taxonomic level, i.e. mainly those either at the yolk-sac stage or that were extensively damaged, were placed in the unidentified category. Terminology of larval stages follows Neira *et al.* (1998). Some 1600 larval fishes from several families caught during the 1983/84 ichthyoplankton survey in Port Phillip Bay (Museum Victoria; Melbourne; NMV A15000 series) were re-examined by one of us (FJN) to verify identifications. Unless stated otherwise, all identifications of larvae reported in the publication derived from that earlier survey (Jenkins 1986) were confirmed as correct.

*Analysis of data*

The total numbers of anchovy eggs, other fish eggs and larvae of each of the taxa caught in the two nets during each cruise were converted to a concentration (numbers per 100 $m^3$) and subsequently summed for each site. Percentage contributions of both families and individual larval taxa to the total assemblage were calculated using concentrations (adjusted numbers) instead of total raw numbers (Table 1). Since preliminary analyses using a general linear model on $\log_{10}$ transformed

**Table 1. Families and taxa of fishes collected as larvae in Port Phillip Bay between September 1995 and September 1996, and their respective ranks by abundance**

Contributions of families and taxa were calculated after addition of the adjusted numbers, i.e. numbers per 100 $m^3$. Percentage contributions of each family and taxon to the total larval fish assemblage are given only when they exceed 0.1%. Families recorded during the 1983/84 survey (Jenkins 1986) are also indicated (right column)

| Rank | Family/Taxon | Taxon rank | Total contribution | | | | Total number | Families identified 1983/84 |
|---|---|---|---|---|---|---|---|---|
| | | | Family | (%) | Taxon | (%) | | |
| 1 | **Gobiidae** | | 7469 | 54.2 | | | | X |
| | Gobiids | 1 | | | 7445 | 54.0 | 8819 | |
| | *Callogobius mucosus* | 21 | | | 24 | 0.2 | 28 | |
| 2 | **Engraulidae** | | 2304 | 16.7 | | | | X |
| | *Engraulis australis* | 2 | | | 2304 | 16.7 | 3108 | |
| 3 | **Clinidae** | | 1378 | 10.0 | | | | X |
| | Clinids | 3 | | | 1378 | 10.0 | 1716 | |
| 4 | **Odacidae** | | 814 | 5.9 | | | | |
| | *Neoodax balteatus* | 4 | | | 773 | 5.6 | 1083 | |
| | *Haletta semifasciata* | 20 | | | 27 | 0.2 | 32 | |
| | *Odax cyanomelas* | 24 | | | 14 | 0.1 | 14 | |
| 5 | **Monacanthidae** | | 388 | 2.8 | | | | X |
| | *Acanthaluteres* spp. | 5 | | | 237 | 1.7 | 304 | |
| | Monacanthids | 12 | | | 88 | 0.6 | 96 | |
| | *Scobinichthys granulatus* | 17 | | | 46 | 0.3 | 63 | |
| | *Brachaluteres jacksonianus* | 28 | | | 10 | 0.1 | 13 | |
| | *Meuschenia* spp. | 31 | | | 8 | 0.1 | 11 | |
| 6 | **Blenniidae** | | 213 | 1.5 | | | | X |
| | *Parablennius tasmanianus* | 7 | | | 207 | 1.5 | 255 | |
| | *Omobranchus anolius* | 34 | | | 6 | | 8 | |

*Continued on next page*

**Table 1.** *Continued*

| Rank | Family/Taxon | Taxon rank | Total contribution | | | | Total number | Families identified 1983/84 |
|---|---|---|---|---|---|---|---|---|
| | | | Family | (%) | Taxon | (%) | | |
| 7 | **Platycephalidae** | | 170 | 1.2 | | | | X |
| | *Platycephalus bassensis* | 8 | | | 152 | 1.1 | 212 | |
| | *Platycephalus speculator* | 22 | | | 16 | 0.1 | 23 | |
| 8 | **Callionymidae** | | 135 | 1.0 | | | | X |
| | *Eocallionymus papilio* | 9 | | | 128 | 0.9 | 170 | |
| | *Foetorepus calauropomus* | 34 | | | 6 | | 9 | |
| 9 | **Syngnathidae** | | 112 | 0.8 | | | | X |
| | *Stigmatopora nigra* | 15 | | | 60 | 0.4 | 79 | |
| | *Stigmatopora argus* | 18 | | | 43 | 0.3 | 55 | |
| | *Vanacampus phillipi* | 39 | | | 5 | | 7 | |
| | *Hippocampus rostratus* | 45 | | | 2 | | 3 | |
| | Syngnathid | 45 | | | 2 | | 2 | |
| | *Pugnaso curtirostris* | 51 | | | 1 | | 1 | |
| 10 | **Pleuronectidae** | | 107 | 0.8 | | | | X |
| | *Rhombosolea tapirina* | 13 | | | 79 | 0.6 | 103 | |
| | *Ammotretis rostratus* | 20 | | | 27 | 0.2 | 38 | |
| 11 | **Scorpaenidae** | | 103 | 0.7 | | | | X |
| | *Neosebastes scorpeanoides* | 11 | | | 92 | 0.7 | 132 | |
| | *Gymnapistes marmoratus* | 26 | | | 13 | 0.1 | 13 | |
| 12 | **Atherinidae** | | 101 | 0.7 | | | | X |
| | *Leptatherina presbyteroides* | 10 | | | 101 | 0.7 | 133 | |
| 13 | **Triglidae** | | 72 | 0.5 | | | | |
| | *Lepidotrigla papilio* | 14 | | | 72 | 0.5 | 85 | |
| 14 | **Gobiesocidae** | | 59 | 0.4 | | | | |
| | Gobiesocid 4 | 22 | | | 16 | 0.1 | 21 | |
| | Gobiesocid 2 | 24 | | | 14 | 0.1 | 19 | |
| | *Alabes* sp. 2 | 28 | | | 10 | 0.1 | 12 | |
| | Gobiesocid 1 | 32 | | | 7 | 0.1 | 9 | |
| | *Alabes* sp. 1 | 34 | | | 6 | | 7 | |
| | Gobiesocid 7 | 45 | | | 2 | | 3 | |
| | Gobiesocid 6 | 45 | | | 2 | | 2 | |
| | Gobiesocid 5 | 51 | | | 1 | | 2 | |
| | Gobiesocid 3 | 51 | | | 1 | | 1 | |
| 15 | **Plesiopidae** | | 52 | 0.4 | | | | |
| | *Trachinops caudimaculatus* | 16 | | | 52 | 0.4 | 72 | |
| 16 | **Hemiramphidae** | | 31 | 0.2 | | | | X |
| | *Hyporhamphus melanochir* | 19 | | | 31 | 0.2 | 37 | |
| 17 | **Clupeidae** | | 17 | 0.1 | | | | X |
| | *Hyperlophus vittatus* | 26 | | | 13 | 0.1 | 17 | |
| | [A]*Spratelloides robustus* | 43 | | | 3 | | 5 | |
| 18 | **Pomacentridae** | | 11 | 0.1 | | | | |
| | [A]*Chromis* sp. | 30 | | | 9 | 0.1 | 9 | |
| | [A]*Parma* sp. | 51 | | | 1 | | 2 | |
| 19 | **Galaxiidae** | | 7 | | | | | |
| | *Galaxias maculatus* | 32 | | | 7 | | 9 | |
| 20 | **Sillaginidae** | | 6 | | | | | X |
| | [A]*Sillaginodes punctata* | 39 | | | 5 | | 6 | |
| | *Sillago bassensis* | 45 | | | 2 | | 2 | |
| | **Tetraodontidae** | | 6 | | | | | X |
| | Tetraodontids | 34 | | | 6 | | 7 | |
| | **Creediidae** | | 6 | | | | | |
| | [A]*Creedia haswelli* | 34 | | | 6 | | 8 | |
| 23 | **Sparidae** | | 5 | | | | | X |
| | [A]*Pagrus auratus* | 39 | | | 5 | | 7 | |
| 24 | **Tripterygiidae** | | 4 | | | | | X |
| | *Norfolkia incisa* | 42 | | | 4 | | 4 | |

**Table 1.** *Continued*

| Rank | Family/Taxon | Taxon rank | Total contribution | | | | Total number | Families identified 1983/84 |
|---|---|---|---|---|---|---|---|---|
| | | | Family | (%) | Taxon | (%) | | |
| 25 | **Apogonidae** | | 3 | | | | | |
| | [A]*Siphamia cephalotes* | 43 | | | 3 | | 4 | |
| 26 | **Ophidiidae** | | 2 | | | | | X |
| | [A]*Genypterus tigerinus* | 45 | | | 2 | | 2 | |
| 27 | **Trachichthyidae** | | 1 | | | | | |
| | [A]*Aulotrachichthys* sp. | 51 | | | 1 | | 2 | |
| | **Carapidae** | | 1 | | | | | |
| | [A]*Echiodon rendahli* | 51 | | | 1 | | 1 | |
| | **Diodontidae** | | 1 | | | | | |
| | [A]*Diodon nichtemerus* | 51 | | | 1 | | 1 | |
| | **Gempylidae** | | 1 | | | | | X |
| | [A]*Thyrsites atun* | 51 | | | 1 | | 1 | |
| | **Leptoscopidae** | | 1 | | | | | |
| | *Leuseurina platycephala* | 51 | | | 1 | | 1 | |
| | **Percophidae** | | 1 | | | | | |
| | [A]*Enigmapercis reducta* | 51 | | | 1 | | 1 | |
| | **Unidentified larvae** | | | | 212 | 1.5 | 268 | |
| | **Totals** | | **13789** | | | | **17157** | |

[A]Known marine spawners

data of fish eggs and larvae showed that moon phase was not significant ($P$ >0.05), the concentration values, including those of all larvae combined, were averaged by area/month for both full- and new-moon days. Thus, data were averaged for the four sites across both days to provide a mean monthly value per area (i.e. four replicate samples per area per month). Homogeneity of variance was examined using the Cochran's test. Concentrations of anchovy eggs and larvae, other fish eggs and all larval fish combined were then $\log_{10}$ transformed for all subsequent ANOVAs to account for variance heterogeneity. To show the trends in seasonal abundance, average concentrations (+ 95% confidence limits) of anchovy eggs and larvae, other fish eggs and of all fish larvae combined were plotted by month. Distributional maps showing these data by area were constructed using SURFER® for those months when they were greatest. For comparisons with the 1983/84 survey, most taxa for which individual accounts are provided in this paper correspond to those for which graphic data were given by Jenkins (1986). Temperatures and salinities obtained at each site during each cruise were pooled for all six areas and averaged by month. Pearson correlations were performed between mean monthly temperatures and salinities, and data on larvae of selected taxa and all larvae combined.

Classification and Non-metric Multiple Dimensional Scaling (NMDS) ordination analyses were carried out using the Pattern Analysis Package (PATN) to examine similarities between areas sampled during this study (Belbin 1990). Since there were distinct periods of high (October 1995–March 1996) and low (May–September 1996) larval abundances (see Results), these analyses employed the mean concentrations of larvae (numbers per 100 $m^3$) per area ($n$ = 6) and period (high or low) of those fish families present in at least two areas/periods during the study ($n$ = 24). Larvae of families that were caught only in one area and in one period, and that contributed <0.1% to the total catch, were omitted from these analyses ($n$ = 8). The original area × period × family data set was converted into a two-dimensional matrix containing the mean concentrations of larvae of each of the 24 families at each of the six areas during the periods of high and low abundance. Values in this matrix were subjected to the range standardization option of PATN, before it was transformed into an association matrix using the Bray–Curtis (B–C) index of dissimilarity; range standardization was applied to avoid abundant families from greatly influencing the B–C index (Clarke and Green 1988). The resultant association matrix was then subjected to classification using Unweighted Flexible Pair–Group Arithmetic Averaging (UPGMA, $\beta$ = – 0.1) to construct the dendrogram, and to ordination using Semi-Strong Hybrid (SSH) NMDS (Belbin 1990). A B–C percent value of 100 means complete dissimilarity. Stress values between 0.1 and 0.2 indicate a good fit when representing $n$-dimensional ordination relationships in multidimensional space (Clarke 1993). Those fish families that contributed most to the observed groupings identified in the NMDS plot were determined using the Kruskal–Wallis test. ANOSIM (Clarke and Green 1988; Belbin 1990) was employed to determine the statistical significance of the observed NMDS groupings.

## Results

### *Environmental conditions*

Mean temperatures in Port Phillip Bay increased from 11.8°C in September 1995 to a maximum of 19.6°C in January 1996, before declining to a minimum of 10.9°C in July and August 1996 (Fig. 2*a*). Mean salinities in the bay during the survey period ranged from 31.6 in September 1996 to 33.9 in both January and February 1996 (Fig. 2*a*).

### *Family and species composition*

Larvae of 60 taxa belonging to 32 teleost fish families were identified from the 17 157 fish larvae collected from Port Phillip Bay from September 1995 to September 1996 (Table 1). Families with the greatest number of taxa were Gobiesocidae (9), Syngnathidae (6) and Monacanthidae (5).

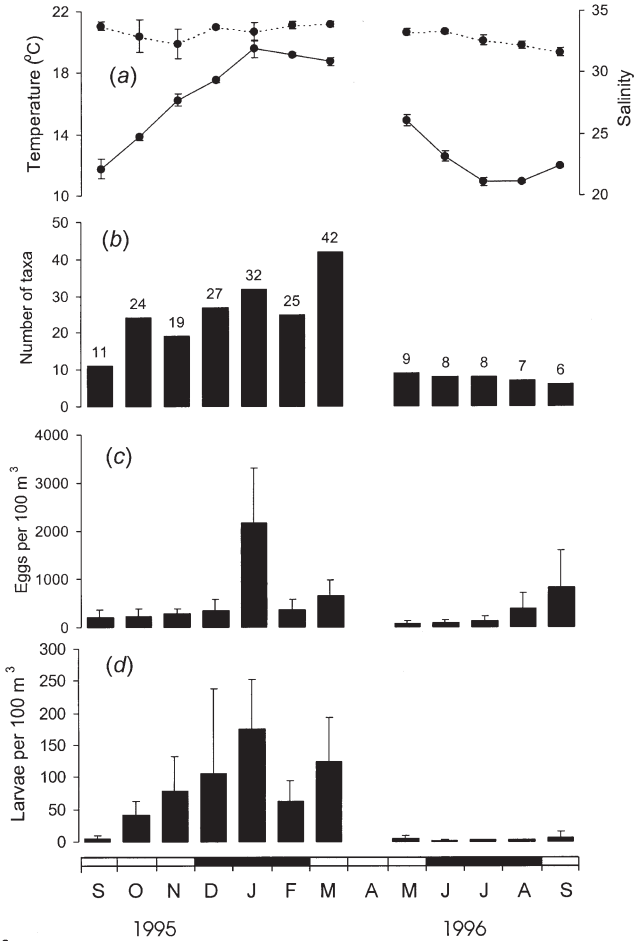


**Fig. 2.** *(a)* Mean monthly temperature (—) and salinity (. . . .) and *(b)* number of taxa, and mean monthly concentrations (numbers per 100 $m^3$ + 95% CI) of *(c)* fish eggs (excluding anchovy eggs) and *(d)* larval fishes in Port Phillip Bay between September 1995 and September 1996. Values above bars in (b) indicate total numbers of taxa. No samples were collected in April 1996. Horizontal axis: open boxes, spring and autumn months; black boxes, summer and winter months.

Several families were represented by only one species, including Triglidae, Sparidae and Gempylidae. In terms of contribution to the overall larval assemblage, Gobiidae accounted for 54.2% of the total (adjusted) number of larvae caught, followed by Engraulidae (16.7%), Clinidae (10.0%) and Odacidae (5.9%). Monacanthidae, Blenniidae, Platycephalidae and Callionymidae contributed 2.8–1.0%, whereas the remaining 24 families each contributed <1.0% (Table 1). The most abundant individual taxa were larval gobiids followed by larvae of *Engraulis australis* (Engraulidae), clinids and *Neoodax balteatus* (Odacidae), which combined accounted for 86.3% of all larvae caught during the study. Larval *Callogobius mucosus* were the only representative of the Gobiidae that could positively be identified to species given their distinct pigment pattern (Neira, unpublished). Species with ≤2 larvae included *Genypterus tigerinus* (Ophidiidae), *Echiodon rendahli* (Carapidae), *Thyrsites atun* (Gempylidae) and *Enigmapercis reducta* (Percophidae) (Table 1).

Of the 60 taxa identified in this survey, 13 (21.6%) belonged to species known to spawn at sea. These included species such as *Sillaginodes punctata* (Sillaginidae), *Creedia haswelli* (Creediidae) and *Aulotrachichthys* sp. (Trachichthyidae) (Table 1). The total (adjusted) number of larvae of all these species combined accounted for only 0.3% of the total caught during the study. The remaining taxa comprised resident species (bay spawners), as well as species known to spawn both in sheltered bays and in inshore coastal waters.

### *Temporal changes in number of taxa and overall ichthyoplankton abundance*

The total monthly number of taxa identified as larvae throughout Port Phillip Bay during this study increased from 11 in September 1995 to a maximum of 42 in March 1996 (Fig. 2*b*). Thereafter, the number of taxa decreased gradually from nine in May 1996 to six in September 1996. Mean concentrations of other fish eggs varied significantly among months during the study ($P$ <0.001; Table 2). Mean

**Table 2. Results of ANOVAs ($log_{10}$ transformed data) for concentrations (numbers per 100 $m^3$) of *(a)* total fish larvae, *(b)* other fish eggs (excluding anchovy eggs), *(c)* anchovy eggs and *(d)* anchovy larvae by area (1–6) and month**

Period in (a) corresponds to periods of high (October 1995–March 1996) and low (May–September 1996) abundance. 'Month' in (b), (c) and (d) corresponds to September 1995 to August 1996 except April 1996 ($n$ = 11), December 1995 to March 1996 and January to March 1996, respectively. NS, $P$ >0.05; *$P$ <0.05; **$P$ <0.001

| Source | df | MS | F-ratio | Significance |
|---|---|---|---|---|
| *(a)* **Total fish larvae** ($n$ = 276) | | | | |
| Area | 5 | 1.17 | 0.63 | NS |
| Period | 1 | 356.47 | 189.87 | ** |
| Area × Period | 5 | 6.86 | 3.66 | * |
| $R^2$ | 0.51 | | | |
| *(b)* **Other fish eggs** ($n$ = 269) | | | | |
| Area | 5 | 431.44 | 86.28 | ** |
| Month | 10 | 779.00 | 77.90 | ** |
| Area × Month | 50 | 1458.07 | 29.16 | ** |
| $R^2$ | 0.52 | | | |
| *(c)* **Anchovy eggs** ($n$ = 96) | | | | |
| Area | 5 | 108.47 | 3.27 | * |
| Month | 3 | 80.65 | 2.43 | NS |
| Area × Month | 15 | 62.92 | 1.89 | * |
| $R^2$ | 0.43 | | | |
| *(d)* **Anchovy larvae** ($n$ = 67) | | | | |
| Area | 5 | 24.48 | 1.04 | NS |
| Month | 2 | 11.46 | 0.49 | NS |
| Area × Month | 10 | 46.19 | 1.96 | NS |
| $R^2$ | 0.34 | | | |

**Table 3. Monthly occurrence of families of fishes collected as larvae in Port Phillip Bay between September 1995 and September 1996. No samples were collected in April 1996. Black rectangles indicate peak abundance months for each family. Mean concentrations of larvae (numbers per 100 m$^3$) during peak month, as well as area of the bay (1–6) where peak occurred, are also shown**

Asterisk indicates families whose mean larval concentrations were significantly greater in the period of high (October 1995–March 1996) than the low (May–September 1996) abundance ($P$ <0.005)

| Family | Sep-95 | Oct-95 | Nov-95 | Dec-95 | Jan-96 | Feb-96 | Mar-96 | Apr-96 | May-96 | Jun-96 | Jul-96 | Aug-96 | Sep-96 | Peak concentration (No. per 100 m$^3$) | Bay area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gobiidae* | X | X | X | ■ | X | X | X | | X | X | X | X | X | 1410.9 | 3 |
| Engraulidae* | | | | X | X | X | ■ | | X | X | X | X | | 343.4 | 6 |
| Clinidae* | X | ■ | X | X | X | X | X | | | | X | X | X | 153.3 | 2 |
| Odacidae | | X | X | X | ■ | X | X | | | | | | X | 229.9 | 2 |
| Monacanthidae* | X | X | X | X | X | X | ■ | | X | | | | | 75.9 | 6 |
| Blenniidae* | | X | X | ■ | X | X | X | | | | | | | 22.6 | 3 |
| Platycephalidae* | | | | X | X | X | ■ | | | | | | | 69.8 | 6 |
| Callionymidae* | | X | X | X | X | ■ | X | | X | | | | | 19.7 | 1 |
| Syngnathidae | | X | X | X | X | X | ■ | | X | X | X | | | 19.5 | 6 |
| Pleuronectidae | X | X | | | | X | ■ | | X | X | X | X | X | 8.9 | 6 |
| Scorpaenidae | X | X | | | | | ■ | | | | X | X | X | 62.9 | 6 |
| Atherinidae | | X | ■ | X | X | X | X | | | | | | | 37.1 | 1 |
| Triglidae | | | | ■ | X | X | X | | | | X | | | 37.0 | 2 |
| Gobiesocidae | X | X | X | ■ | X | X | X | | | | | | | 15.2 | 6 |
| Plesiopidae* | | X | X | ■ | | | | | | | | | | 39.6 | 3 |
| Hemiramphidae | | | | X | ■ | X | X | | | | | | | 8.5 | 3 |
| Clupeidae | | | | | X | X | ■ | | X | X | | | | 2.7 | 6 |
| Pomacentridae | | | | X | ■ | | | | | | | | | 8.5 | 3 |
| Galaxiidae | ■ | X | X | | | | | | | X | | | | 1.5 | 2 |
| Tetraodontidae | | | | X | X | ■ | X | | X | | | | | 1.5 | 3 |
| Sillaginidae | | X | ■ | X | X | | X | | | | | X | X | 0.9 | 2 |
| Creediidae | | | | | | | ■ | | | | | | | 4.1 | 6 |
| Sparidae | | | | | ■ | X | | | | | | | | 2.0 | 2 |
| Tripterygiidae | | | | ■ | | | X | | | | X | | | 1.3 | 3 |
| Apogonidae | | | | X | ■ | | X | | | | | | | 1.4 | 1 |
| Ophidiidae | ■ | | | | | | | | | | | | | 1.0 | 1 |
| Trachichthyidae | | | | | | | ■ | | | | | | | 1.4 | 6 |
| Carapidae | | | | | | | ■ | | | | | | | 0.7 | 6 |
| Gempylidae | ■ | | | | | | | | | | | | | 0.7 | 6 |
| Diodontidae | | | | ■ | | | | | | | | | | 0.7 | 2 |
| Leptoscopidae | | | | | | | ■ | | | | | | | 0.7 | 6 |
| Percophidae | | | | | | | ■ | | | | | | | 0.7 | 6 |
| Anchovy eggs | | | | X | ■ | X | X | | | | | | | 8028.0 | 2 |
| Other eggs | X | X | X | X | ■ | X | X | | X | X | X | X | X | 1694.0 | 2 |

concentrations ranged from 215 to 340 eggs per 100 m$^3$ between September and December 1995, and reached a peak of 2175 eggs per 100 m$^3$ in January 1996 (Fig. 2*c*). Mean concentrations decreased markedly in February and March 1996 to <650 eggs per 100 m$^3$, before gradually increasing again from about 80 to 830 eggs per 100 m$^3$ between May and September 1996. The highest single concentration of other fish eggs in a sample was recorded in Area 2 (Werribee) in January 1996, i.e. 8028 eggs per 100 m$^3$ (Table 3).

The trend in mean monthly concentrations of all larval fish combined showed two distinct periods during the survey: a high-abundance period from October 1995 to March 1996, and a low-abundance period from May to September 1996 (Fig. 2*d*). Mean larval fish concentrations during these periods differed significantly ($P$ <0.001; Table 2). Mean concentrations increased gradually from 5 larvae per 100 m$^3$ in September 1995 to a maximum of 175 larvae per 100 m$^3$ in January 1996, then declined to 63 larvae per 100 m$^3$ in February 1996 before reaching a second, smaller peak at 125 larvae per 100 m$^3$ in March 1996 (Fig. 2*d*). Mean concentrations remained <7 larvae per 100 m$^3$ thereafter. The trend in mean larval fish concentrations closely followed that of mean temperatures, with the peak larval concentrations in January 1996 occurring at the time when mean temperatures were highest (19.6°C; Fig. 2*a*).

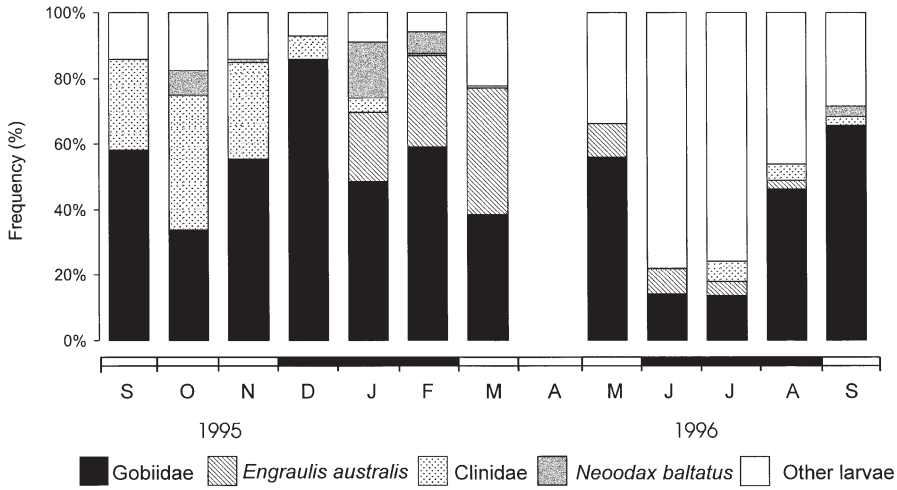


**Fig. 3**. Monthly percentage contributions of the four most abundant taxa collected as larvae in Port Phillip Bay between September 1995 and September 1996. No samples were collected in April 1996. Contributions (%) are based on total adjusted numbers. Horizontal axis: open boxes, spring and autumn months; black boxes, summer and winter months.

Mean monthly larval concentrations were significantly correlated with mean temperatures ($r = 0.71$, $P < 0.001$) but not with mean salinities.

Gobiids and clinids dominated the larval fish assemblage from September to December 1995, with both taxa contributing >75% to the total (adjusted) caught in those months (Figs 3 and 7). By contrast, larval gobiids and anchovies dominated the assemblage from January to March 1996 (>70%), with larval *N. balteatus* also making a significant contribution (17%) in January 1996. The winter (June–August) assemblage was dominated by larvae of species such as the pleuronectids *Rhombosolea tapirina* and *Ammotretis rostratus* and, to some extent, gobiid larvae in August (Figs 3 and 7).

*Spatial distribution of taxa and overall ichthyoplankton*

Larval concentrations of 14 of the 32 families recorded during this study were highest in Area 6 at the southern end of the bay, including Engraulidae, Monacanthidae, Platycephalidae, Pleuronectidae and Gobiesocidae (Table 3). Larvae of another six of the 14 families, namely Creediidae, Trachichthyidae, Carapidae, Gempylidae, Leptoscopidae and Percophidae, were caught exclusively in Area 6, and were each represented by <8 specimens (Tables 1 and 3). Peak concentrations of larvae of the remaining 18 families were recorded mostly in Areas 1 to 3, whereas no peaks were observed in Areas 4 or 5 (Table 3).

Of the 32 taxa caught in January 1996, 21 came from Area 2 on the northern section of the bay, whereas 36 of the 42 taxa caught in March 1996 occurred in Area 6 (Fig. 4*a*). Total taxa caught in Area 5 at the centre of the bay remained <8 in all six months comprising the period of high abundance (October 1995–March 1996) except in January 1996, when it reached 10. Other fish eggs occurred in all areas during that period and were generally more abundant in the three northern-most areas, particularly in January 1996 (Fig. 4*b*). Significant differences were found in the mean concentrations of other fish eggs among areas ($P < 0.001$; Table 2). Egg concentrations in the three northern bay areas in January 1996 averaged 3745 eggs per 100 $m^3$, whereas they remained <1500 eggs per 100 $m^3$ in all other areas during the October 1995–March 1996 period (Fig. 4*b*).

Larval fishes occurred in all areas of the bay, and showed no clear distributional pattern during the six-month period of high abundance (Fig. 4*c*). Two-way ANOVA of mean larval fish concentrations in the periods of high and low abundance showed no significant differences among areas, but a significant area × period interaction ($P < 0.05$; Table 2). Larval fishes were predominantly abundant along the three northern-most areas of the bay between November 1995 and January 1996, and on the bay's eastern half in March 1996, with Area 3 in December 1995 yielding the highest mean larval concentration recorded during that period, i.e. 462 larvae per 100 $m^3$ (Fig. 4*c*). During the period of high abundance, mean larval fish concentrations by area ranged from 54 larvae per 100 $m^3$ in Area 5 to 170 larvae per 100 $m^3$ in Area 3.

*Occurrence of fish eggs and larvae of selected taxa*

*Engraulis australis* (*Engraulidae*)

Anchovy eggs occurred from December 1995 to March 1996, whereas anchovy larvae were mainly caught from January to March 1996, with very few also occurring in December 1995 and in May–August 1996 (Fig. 5; Table 3). Mean concentrations of anchovy eggs between December

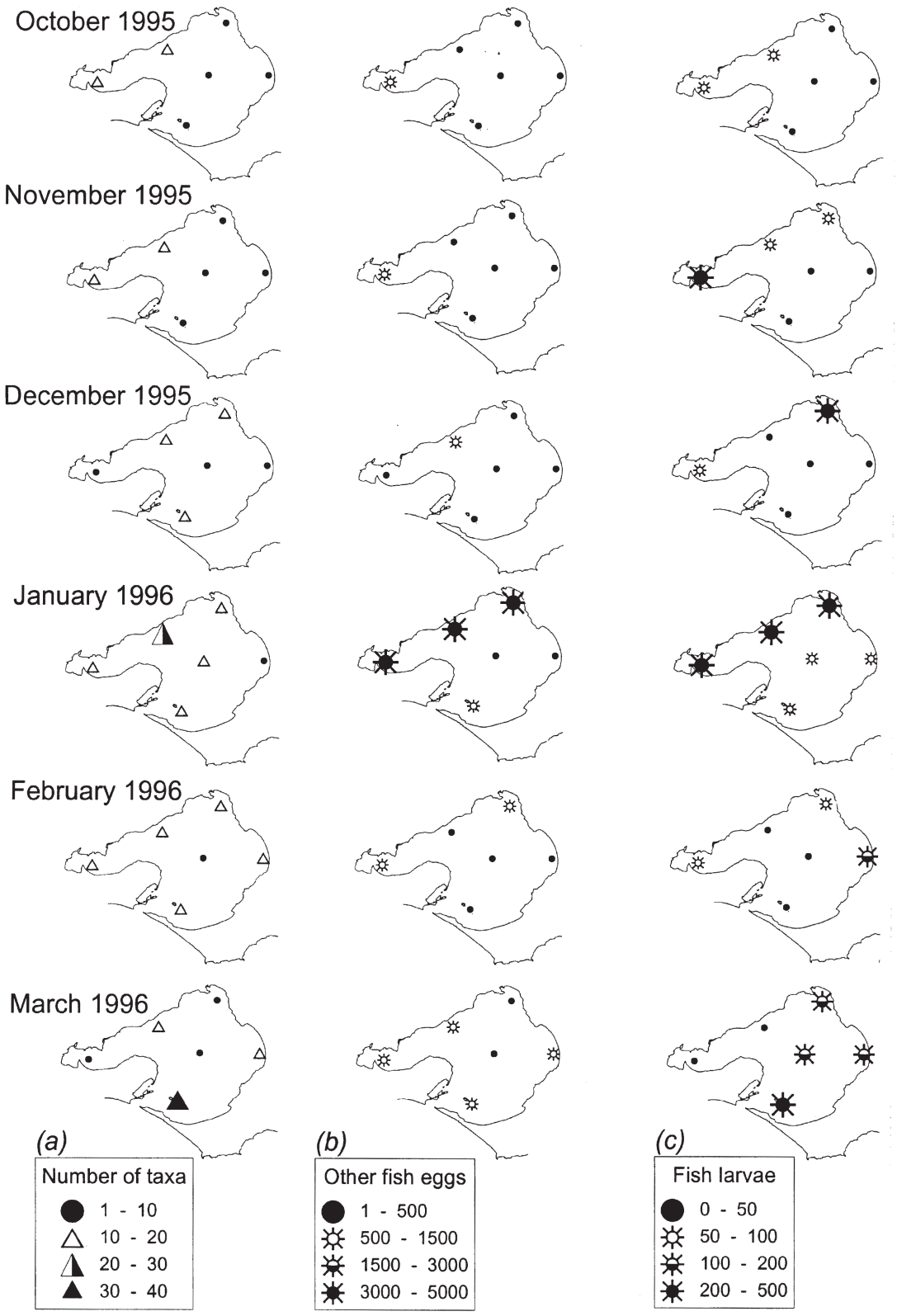


**Fig. 4**. *(a)* Total number of taxa, and mean monthly concentrations (numbers per 100 $m^3$) of *(b)* fish eggs (excluding anchovy eggs) and *(c)* larval fishes by area in Port Phillip Bay between September 1995 and March 1996. In this and in Figs 6 and 8, values provided for each area correspond to monthly means obtained after sampling two randomly selected sites in each area over two days (full and new moon); position of each symbol in each map shows location of each bay area (see Fig. 1 for area limits).

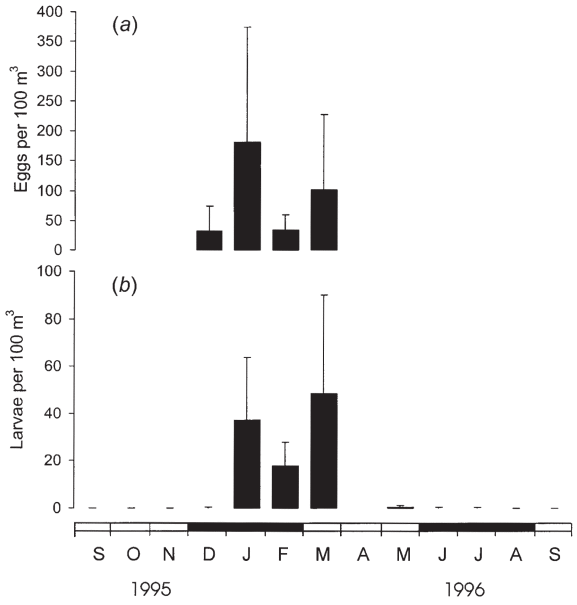


**Fig. 5.** Mean monthly concentrations (numbers per 100 $m^3$ + 95% CI) of *(a)* eggs and *(b)* larvae of anchovy (*Engraulis australis*) in Port Phillip Bay between September 1995 and September 1996. No samples were collected in April 1996. Horizontal axis: open boxes, spring and autumn months; black boxes, summer and winter months.

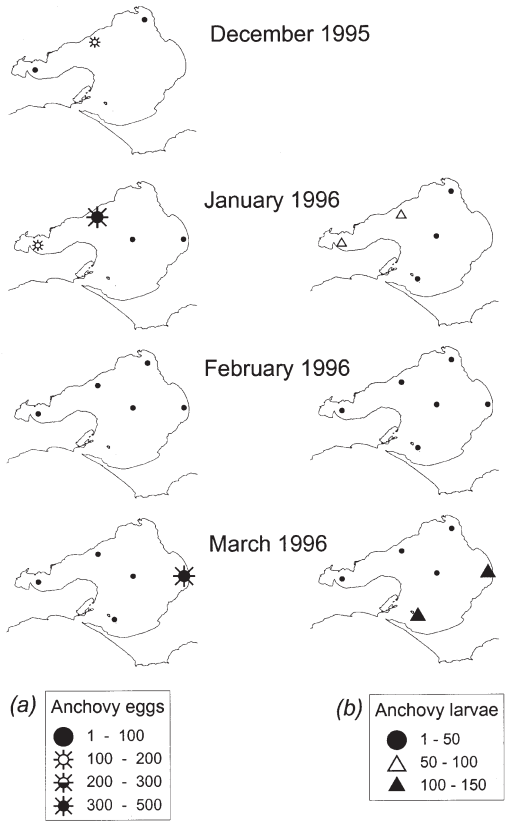


**Fig. 6.** Mean monthly concentrations (numbers per 100 $m^3$) of *(a)* eggs and *(b)* larvae of anchovy (*Engraulis australis*) by area in Port Phillip Bay between December 1995 and March 1996.

1995 and March 1996 did not differ significantly among months, but differed significantly among areas, and area × month interaction ($P$ <0.05; Table 2). By contrast, no significant differences were found in the mean concentrations of anchovy larvae among areas, months or area × month interaction in the period January–March 1996 (Fig. 6*b*; Table 2). Bay-wide mean concentrations of anchovy eggs were highest in January (180 eggs per 100 $m^3$) and March 1996 (101 eggs per 100 $m^3$), which resulted from the high egg abundances recorded in Areas 2 and 4 during those months, respectively (Fig. 6*a*). The highest single concentration of anchovy eggs in a sample was recorded in Area 2 (Werribee) in January 1996, i.e. 1694 eggs per 100 $m^3$ (Table 3). As with eggs, bay-wide mean concentrations of anchovy larvae were highest in January (37 larvae per 100 $m^3$) and March 1996 (48 larvae per 100 $m^3$). The January and March peaks resulted from the high abundances recorded in areas on the northern (1, 2) and south-eastern (4, 6) regions of the bay, respectively (Fig. 6*b*). Mean monthly concentrations of anchovy larvae were significantly correlated with mean temperatures ($r$ = 0.61, $P$ <0.001) but not with mean salinities. The spatial distribution of both anchovy eggs and larvae showed no clear pattern during the period of occurrence, except their greater concentrations in Areas 4 and 6 in March 1996 (Fig. 6).

*Gobiidae*

Larvae occurred in all months of the study. Bay-wide mean concentrations increased gradually from 3 larvae per 100 $m^3$ in September 1995 to a peak of 90 larvae per 100 $m^3$ in December 1995, before gradually decreasing to <1 larva per 100 $m^3$ in June and July 1996. About 63% of the larvae were caught in Areas 1 and 3 (Fig. 7*a*). Mean larval concentrations during the period of peak abundance were greatest (200–500 larvae per 100 $m^3$) in Area 3 both in December 1995 and in January 1996 (Fig. 8).

*Clinidae*

Larvae occurred in all months except September 1996, with the highest concentrations (16–33 larvae per 100 $m^3$) being recorded between September and November 1995. Over 50% of the larvae were caught in Areas 2 and 3 (Fig. 7*b*).

*Neoodax balteatus* (*Odacidae*)

Larvae occurred from October 1995 to February 1996, and in September 1996, with mean concentrations reaching a maximum of 63 larvae per 100 $m^3$ in January 1996. Over 90% of the larvae came from Areas 1 and 2 (Fig. 7*c*). Greatest mean concentrations were 70 larvae per 100 $m^3$ in Areas 1 and 2 in January 1996.

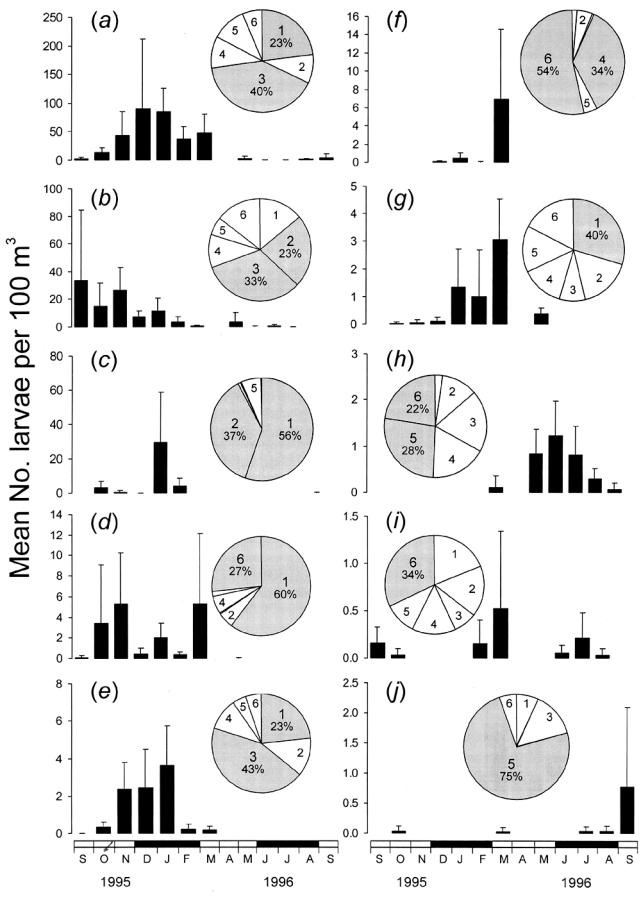


**Fig. 7.** Mean monthly concentrations (numbers per 100 $m^3$ + 95% CI) of larvae of selected taxa caught in Port Phillip Bay between September 1995 and September 1996. No samples were collected in April 1996. Each pie represents the overall percentage contribution (adjusted numbers) of each taxon by area sampled (1–6) in the bay. Horizontal axis: open boxes, spring and autumn months; black boxes, summer and winter months. *(a)* Gobiidae; *(b)* Clinidae; *(c) Neoodax balteatus*; *(d)* Monacanthidae; *(e) Parablennius tasmanianus*; *(f)* Platycephalidae; *(g)* Callionymidae; *(h) Rhombosolea tapirina*; *(i) Ammotretis rostratus*; *(j) Gymnapistes marmoratus*.

*Monacanthidae*

Larvae occurred from September 1995 to May 1996, with the greatest concentrations recorded in October–November and in March 1996. Most larvae came from Area 1 (60%) and, to a lesser extent, Area 6 (Fig. 7*d*).

*Parablennius tasmanianus* (*Blenniidae*)

Larvae occurred from October 1995 to March 1996, and reached a maximum of 3.6 larvae per 100 $m^3$ in January 1996. Larvae were caught in all areas, particularly in Areas 3 and 1 (Fig. 7*e*).

*Platycephalidae*

Larvae occurred from December 1995 to March 1996, the latter month yielding the greatest mean concentration during the study, i.e. 7 larvae per 100 $m^3$. Almost 90% of the larvae were caught in Areas 4 and 6 (Fig. 7*f*).

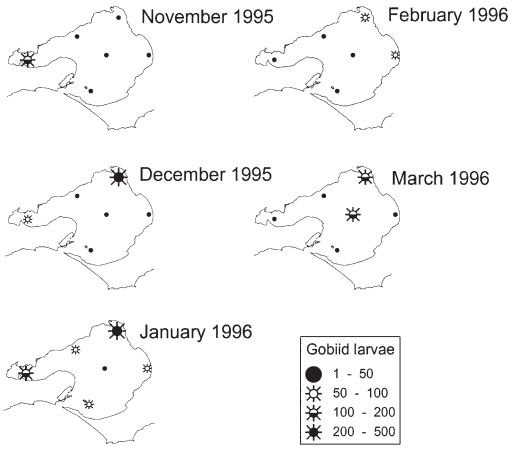


**Fig. 8.** Mean monthly concentrations (numbers per 100 $m^3$) of gobiid larvae by area in Port Phillip Bay between November 1995 and March 1996.

*Callionymidae*

Larvae occurred from October 1995 to May 1996, with maximum mean concentrations (1–3 larvae per 100 $m^3$) recorded in January–March 1996. Larvae were caught in all areas, particularly in Area 1 (Fig. 7*g*).

*Rhombosolea tapirina and Ammotretis rostratus* (*Pleuronectidae*)

Larvae of both species were caught in all areas but in very low numbers, their combined contributions accounting for <1% of the total number of larvae caught during the study (Table 1). Larval *R. tapirina* occurred mostly between May and July 1996 and came largely from Areas 5 and 6 (Fig. 7*h*). Larval *A. rostratus* occurred in several months, particularly in March 1996, and a high proportion came from Area 6 (Fig. 7*i*).

*Gymnapistes marmoratus* (*Scorpaenidae*)

Larvae occurred in very low numbers (Table 1), the greatest mean concentration being 0.8 larvae per 100 $m^3$ in September 1996. No larvae were caught in Areas 2 or 4, and the few that were caught came mostly from Area 5 (Fig. 7*j*).

*Classification and ordination of areas*

Classification of areas of Port Phillip Bay, based on mean larval concentrations of 24 fish families during the periods of high (October 1995–March 1996) and low (May–September 1996) larval abundance clearly separated all six areas in both periods at about the 100% level of dissimilarity (Fig. 9*a*). During the period of high abundance, Areas 1–2 and 4–6 clustered together below the 50% dissimilarity level, whereas Area 3 showed the lowest degree of similarity. During the period of low abundance, Areas 2–6 were very

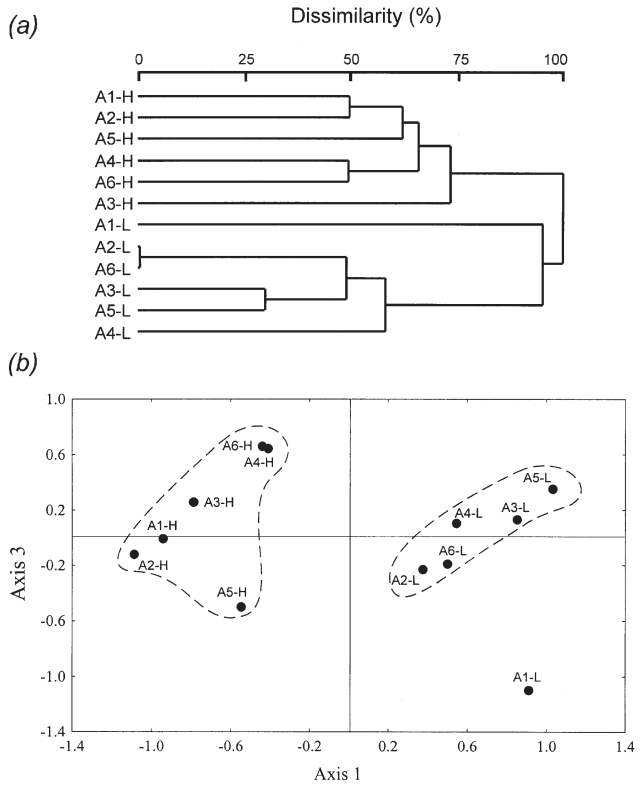


**Fig. 9.** *(a)* Classification and *(b)* non-metric multidimensional scaling ordination plot of areas (A1–6) in Port Phillip Bay, based on mean concentrations of larval fishes caught during the periods of high (H; October 1995 – March 1996) and low (L; May–September 1996) abundance. Scale (%) in dendrogram corresponds to the Bray–Curtis dissimilarity index. Stress value in the NMDS was 0.11.

similar and Area 1 was the most dissimilar, clustering with the other five areas at the 95% level of dissimilarity. The NMDS ordination supported the classification (Fig. 9*b*), with all areas during the high-abundance period clustering together and separately from the same areas during the low-abundance period, the two periods being significantly different (ANOSIM $P$ <0.005). In addition, the classification is supported by the clear separation of Area 1 from the other five areas in the NMDS ordination plot for the low-abundance period, which possibly reflects the very low concentrations of larvae of only five families caught at that time. The Kruskal–Wallis test showed that mean concentrations of larvae of eight families (Table 3) were significantly greater in the high- than in the low-abundance period ($P$ <0.005).

## Discussion

### *Species composition*

Results of this study show that the composition of the larval fish assemblage of Port Phillip Bay is similar to that described for estuaries and other protected inshore marine embayments elsewhere in temperate Australia. As in those systems, the assemblage is dominated by bay-spawned larvae, including those of the Gobiidae, Engraulidae, Clinidae, Monacanthidae and Blenniidae. Gobiid larvae dominated the assemblage of the bay during this study, as they did during the 1983/84 survey (Jenkins 1986). This parallels the fact that gobiid larvae constitute a major contributor to larval fish assemblages in other temperate bays and estuaries in Australia (Neira *et al.* 1992; Neira and Potter 1992*a*, 1994). In addition, the abundance of gobiid larvae is reflected in the fact that adults of at least 21 species of the Gobiidae have so far been recorded in the bay, including two that were introduced before 1995, making it one of the most speciose families in the bay together with the Clinidae (21) and Syngnathidae (17) (Lockett and Gomon 1999).

In terms of families and species composition, results of this study differed to some extent from those reported for the 1983/84 survey. Larval fishes of 60 taxa from 32 families were collected in this study, whereas larvae of 39 taxa from 26 families were recorded in 1983/84 (Jenkins 1986). Although the higher number of taxa and families during this study could well be attributed to greater sampling intensity, it may also reflect the presence of essentially different larval assemblages in the two surveys. In terms of families for example, this study collected larval fishes from 13 families that were not caught during the earlier survey (see Table 1). Conversely, larvae from seven families caught during the earlier survey were absent from this study, i.e. Carangidae, Dinolestidae, Gonorynchidae, Mullidae, Mugilidae, Moridae and Pegasidae.

Larvae of anchovy, *Engraulis australis*, were the second most abundant taxon during this study but ranked very low in the 1983/84 survey. However, a detailed re-examination of several summer samples from the 1983/84 survey revealed significant numbers of newly hatched anchovy larvae, which most likely correspond to those reported as ‘unidentified clupeoids’ by Jenkins (1986; Table 1, $n$ = 2166). Had these been identified to species, engraulids would have accounted for nearly 30% of the total larvae caught in 1983/84, which would have been consistent with the considerable quantity of eggs of this species found during that survey (Jenkins 1986). Like gobiids, anchovies are also a major contributor to larval fish assemblages of bays and estuaries in temperate Australia since they are capable of breeding within these systems (Arnott and McKinnon 1985; Neira *et al.* 1992; Neira and Potter 1992*a*, 1992*b*, 1994).

Larvae of the Odacidae and Gobiesocidae were recorded during this study but not in 1983/84, a fact that was evident after our re-examination of 1983/84 summer samples. This finding is even more surprising if we consider that in 1995/96 these families were represented by the larvae of at least three and nine taxa, respectively. The re-examination of 1983/84 samples also discounted the possibility of

misidentification of odacid larvae by Jenkins (1986), as these can easily be confused with early cupleoid larvae (Neira *et al.* 1998). The fact that *N. balteatus*, the most abundant of the three odacids, ranked fourth in terms of total larval abundance during this study implies that a population of this species became well established within the bay some time after 1983/84. This observation is consistent with the finding of Hobday *et al.* (1999) of a significant increase in the biomass of this species in Port Phillip Bay between 1972/75 and 1990/91. Hobday *et al.* (1999) further suggested that such biomass increase was related to the establishment of the exotic sabellid polychaete *Sabella spallanzanii*, first detected in Corio Bay in 1987, which has been found to provide an important habitat for adult *N. balteatus* (Parry *et al.* 1995, 1996; Currie and Parry 1999; Currie *et al.* 1999). In this context, it is relevant that 93% of *N. balteatus* larvae caught during this study came from Areas 1 and 2 in the north-western region of Port Phillip Bay, which is also the region that supported large numbers of this polychaete in 1995/96 (Currie and Parry 1999). Given the close association of adult *N. balteatus* with *S. spallanzanii*, there is evidence that the abundance of this odacid has been steadily increasing as the polychaete spreads further into the bay (Parry *et al.* 1995).

Besides odacids and gobiesocids, larvae of two species of Pomacentridae and one species each of the Creediidae, Trachichthyidae, Carapidae, Diodontidae, Leptoscopidae and Percophidae were caught during this study but not in 1983/84. Since these larvae were caught in very low numbers (≤9 specimens each) and mostly in Area 6 just inside the bay's entrance, it is likely they would have been passively transported from Bass Strait. This is supported by the fact that larvae of all these species have previously been caught in Bass Strait waters (Neira *et al.* 2000), where their adults are commonly found (Gomon *et al.* 1994). Moreover, the influx of marine-spawned larval fishes from coastal waters into Port Phillip Bay would be greatly facilitated by the typically strong incoming tides (>2.5 m $s^{-1}$) through the bay's entrance (Walker 1999).

Larvae of one species each of the Triglidae and Plesiopidae were also caught during this study but not in 1983/84. The presence of relatively high numbers of larval *Lepidotrigla papilio* (Triglidae) during 1995/96 suggests bay spawning, as indicated by the fact that most larvae came from those areas within Port Phillip Bay where adults are abundant (Hobday *et al.* 1999). However, passive transport of larvae into Port Phillip Bay cannot be entirely discounted as both larvae and adults of this triglid are common in Bass Strait waters outside the bay (Gomon *et al.* 1994; Neira *et al.* 2000). As with *L. papilio*, the occurrence of larval *Trachinops caudimaculatus* (Plesiopidae) in 1995/96 is consistent with the fact that this species is known to reside in the bay (Lockett and Gomon 1999). As larvae of neither *L. papilio* nor *T. caudimaculatus* were found in re-examined 1983/84 samples, it is possible that their absence during that survey could be attributed to sampling intensity.

Both eggs and larvae of pilchard, *Sardinops sagax* (Clupeidae), were recorded in 1983/84 but not in 1995/96. Although eggs in 1983/84 were recorded (albeit in small numbers) throughout the bay (Jenkins 1986), no pilchard larvae were found in any of the several summer samples that were re-examined from the earlier survey. Instead, some of those samples contained larvae of the clupeid *Spratelloides robustus*, which are very similar to those of pilchard (Neira *et al.* 1998) and which also occurred in this study. The absence of pilchard eggs and larvae in the present study is consistent with the fact that this clupeid is known to spawn in shelf waters in southern Australia, with eggs and larvae occurring from inshore waters to the shelf's edge (Fletcher and Tregonning 1992; Hoedt and Dimmlich 1995; Neira *et al.* 2000). The lack of eggs and larvae in 1995/96, together with the findings of a 3-year study of the pilchard fishery in Port Phillip Bay, led to the conclusion that they do not spawn within the bay but use it as a nursery area, entering mostly as juveniles in late spring/early summer before returning to sea the following winter (Neira *et al.* 1999).

Larvae of two abundant commercial species in Port Phillip Bay, *S. punctata* and *Pagrus auratus* (Sparidae), were caught in very small numbers during this study. The low numbers of the former are consistent with the fact that this species is known to enter the bay at the late postflexion stage from late September, following a winter spawning in coastal waters (Jenkins and May 1994; Jenkins *et al.* 1997). By contrast, little is known about the recruitment processes of *P. auratus*, and specifically whether this sparid breeds within the bay or recruits from Bass Strait as larvae, or both. Although the small numbers of larvae of this species caught both in 1995/96 and 1983/84 (Jenkins 1986) suggest some low intensity spawning within the bay, it is possible that a significant percentage of the bay population originates from larvae spawned outside. The latter hypothesis is supported by the recent findings of early postflexion *P. auratus* larvae in flood-tide samples at the entrance of Port Phillip Bay (P. Hamer, personal communication), which parallel those of transport studies elsewhere in southern Australia that have reported postflexion larvae of this species entering similar systems (e.g. Miskiewicz 1986; Neira and Potter 1992*b*).

Larvae of several other marine species that are abundant as adults in Port Phillip Bay were not found during this study, including *Aldrichetta forsteri* (Mugilidae) and *Pseudocaranx* sp. (Carangidae). Larvae of these species, however, together with those of species such as *Dinolestes lewini* (Dinolestidae), *Acanthopegasus lancifer* (Pegasidae), *Gonorynchus greyi* (Gonorynchidae), *Upeneichthys* sp. (Mullidae) and *Pseudophycis barbata* (Moridae), were recorded in the 1983/84 survey (Jenkins 1986). Their presence in 1983/84 was attributed to these larvae being transported into the bay from coastal waters (Jenkins 1986),

which is consistent with the fact that they occur predominantly in Bass Strait and coastal waters elsewhere in south-eastern Australia (Neira *et al.* 2000). As none of these species are known to spawn in bays or estuaries, the absence of their larvae in 1995/96 may be due to factors such as little or no transport and/or their low abundances outside the bay.

*Ichthyoplankton abundance*

The seasonal trend in ichthyoplankton concentrations recorded during this study is typical of that described for other Australian temperate systems, i.e. highest in summer and lowest in winter, with mean concentrations closely following mean water temperatures (Neira *et al.* 1992; Neira and Potter 1992*a*, 1994). Larval fishes showed distinct periods of high (October 1995 – March 1996) and low (May–September 1996) abundances, which were supported by classification and NMDS analyses. However, the timing and magnitude of peaks in overall mean concentrations of fish eggs and larvae during this study, as well as that of larvae of several taxa, differed from those described for the 1983/84 survey of Port Phillip Bay. Both fish eggs and larvae during this study reached maximum concentrations in January 1996 when mean temperatures were 19.6°C, and were lowest in winter/spring. By contrast, concentrations during 1983/84 peaked in winter (August) for larval fishes and again in early summer (December) for fish eggs and larvae, the latter when water temperatures had reached 19.7°C (Jenkins 1986). The absence of a winter peak in 1995/96 resulted from the overall lower concentrations of larval fishes during that period, including scorpaenids, gobiids and pleuronectids, which were mostly responsible for the peak in August 1983 (Jenkins 1986). Moreover, the January 1996 peak was mostly due to gobiids, engraulids and odacids, whereas the December 1983 peak was produced mainly by gobiid and clupeoid (most likely engraulid) larvae (Jenkins 1986). A second, slightly lower peak in larval fishes occurred in March 1996 but not in 1983/84, due to a combination of gobiids, engraulids and, to a lesser extent, to the influx of marine-spawned larvae of several taxa that occurred just inside the bay's entrance (Area 6) at that time.

A high percentage of the larval fishes during the summer of 1995/96 were caught in the three northern-most areas of the bay (1–3), particularly in Areas 2 and 3, and included gobiids, odacids and blenniids. In the case of gobiids, almost 40% of the larvae caught during this study came from Area 3, which is also the area where adults of two of the exotic gobiids recorded before 1996, i.e. *Tridentiger trigonocephalus* and *Acanthogobius flavimanus*, mostly occur (Lockett and Gomon 1999). Although only postflexion larvae of these two introduced gobiids could be identified with certainty (Neira, unpublished), it is highly probable that they have become bay residents. Moreover, it is also highly likely that future surveys will find larvae of these gobiids as well as those of the third introduced gobiid, *Acentrogobius pflaumi*, which is now distributed throughout most of the bay (Lockett and Gomon 1999).

Apart from gobiids, larvae of *G. marmoratus* made a substantial contribution to the winter peak in August 1983, with mean concentrations during that month reaching ~85 larvae per 100 $m^3$ (Jenkins 1986). By contrast, mean concentrations of larval *G. marmoratus* during this study did not exceed 0.8 larvae per 100 $m^3$ during the peak month (September 1996), i.e. a decline of almost one order of magnitude from the earlier survey. It is possible that the low concentrations of larval *G. marmoratus* in 1995/96 could reflect the significant decline in the adult biomass of this scorpaenid in Port Phillip Bay (–85.5%) between 1972–75 and 1990/91 (Hobday *et al.* 1999). Furthermore, their major decline in biomass is thought to be linked to the undocumented loss of seagrass habitats where this species is commonly found (Gomon *et al.* 1994), which apparently resulted from the extensive scallop dredging in the north-western region of the bay (Geelong Arm) in the early 1970s and in 1985 (Hobday *et al.* 1999). In this context, it is perhaps relevant that nearly 75% of larvae of this scorpaenid were collected in Area 5 at the centre of the bay, whereas very few were caught in Area 1 in the Geelong Arm.

The sharp peak in mean egg concentrations in January 1996 resulted from the considerably higher contribution of eggs of teleosts other than anchovy during this study. By contrast, overall egg concentrations in 1983/84 were highest from December to February, with peaks in December and January mostly due to anchovy eggs (Jenkins 1986). Anchovy eggs in 1995/96 were collected from December to March, whereas in 1983/84 they occurred from September to March (Jenkins 1986). In terms of abundance, mean concentrations of anchovy eggs during the peak month in December 1983 reached >10 000 eggs per 100 $m^3$, whereas they did not exceed 180 eggs per 100 $m^3$ during the January 1996 peak. The much lower concentrations and shorter occurrence of anchovy eggs in 1995/96 is surprising given the greater spatio–temporal sampling intensity employed during this study. Although this may be attributed to several factors, including natural interannual variability, increased egg mortality and/or the presence of a smaller spawning biomass in the bay compared with that in 1983/84, these results need to be interpreted with caution. For example, there is no evidence that anchovy in Port Phillip Bay belong to a discrete, self-recruiting population, although it seems likely given that they also spawn within other systems in temperate Australia (Arnott and McKinnon 1985; Neira *et al.* 1992; Neira and Potter 1992*a*, 1994). It is equally possible, however, that they belong to a much larger stock in south-eastern Australia, in which case changes in egg production would be linked to fluctuations of the anchovy stock in coastal waters outside the bay.

*Concluding remarks*

We have provided persuasive evidence of significant differences between the 1995/96 and 1983/84 ichthyoplankton assemblages, in terms of composition and abundance of larval fishes, and abundance of anchovy eggs. Although some of these differences may be attributed to natural interannual variability and/or other factors, some are likely to be associated with the major ecosystem changes reported for the bay for the period 1969–95 (Wilson *et al.* 1998; Currie and Parry 1999; Hewitt *et al.* 1999; Hobday *et al.* 1999). Perhaps the most overwhelming evidence of a linkage between ecosystem changes and the bay's ichthyoplankton was the finding of high concentrations of larvae of the odacid *N. balteatus* during this study. The most plausible explanation for their presence in such concentrations in 1995/96, but not in 1983/84, is the establishment of a population of this odacid following the introduction to the bay of the exotic, sessile sabellid polychaete *S. spallanzani* in the late 1980s (Parry *et al.* 1995, 1996; Hobday *et al.* 1999).

Although our comparisons are limited to results from two surveys carried out some 11 years apart, it is evident that ecosystem changes in Port Phillip Bay have had an effect on the bay's ichthyoplankton assemblage. However, the extent of the impact of such changes is difficult to interpret, since differences between 1983/84 and 1995/96 may be confounded by a number of factors, including improved accuracy in identifying larvae, differing sampling intensity, differences in spatio–temporal distribution of fish eggs and larvae, recruitment variability, and/or environmental factors. Despite the limitations of this study, and the uncertainties of the data obtained with these types of studies, plankton surveys appear to be a useful alternative method of detecting and evaluating ecosystem changes. Ichthyoplankton surveys, using a similar design to that employed during this study, should be conducted regularly in Port Phillip Bay to monitor long-term changes in this system. Moreover, future ichthyoplankton surveys, together with concurrent demersal-trawl and benthic monitoring surveys, should strengthen the current approach to evaluate ecosystem changes in Port Phillip Bay as well as in other similar aquatic systems.

## Acknowledgments

We are very grateful to D. McKeown and the skippers of the sharkcat '*Gratis'*, T. Sheehan, M. Ferrier and D. Beyer, for their dedication and hard work with sampling during this project. Special thanks to S. Berry for her assistance with sampling and the sorting all the samples. We also thank Pam Oliveiro and several other staff from the Marine and Freshwater Resources Institute (MAFRI) in Victoria who helped with sampling, including D. Reilly, T. Ryan, K. Smith, B. Waters, D. Forbes and S. Conron. Many thanks also to D. Bray (Museum of Victoria, Melbourne), for providing the 1983/84 larval fish samples. G. P. Jenkins and G. D. Parry (MAFRI) provided valuable suggestions and editorial comments. This project was partially funded by the Fisheries Research and Development Corporation project No. 94/029.

## References

Arnott, G. H., and McKinnon, A. D. (1985). Distribution and abundance of eggs of the anchovy, *Engraulis australis antipodum* Günther in relation to temperature and salinity in the Gippsland Lakes. *Australian Journal of Marine and Freshwater Research* **36**, 433–9.

Belbin, L. (1990). 'PATN Technical Reference Manual.' (CSIRO Division of Wildlife and Ecology: Canberra.)

Clarke, K. R. (1993). Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* **18**, 117–43.

Clarke, K. R., and Green, R. H. (1988). Statistical design and analysis for a 'biological effects' study. *Marine Ecology Progress Series* **46**, 213–26.

Currie, D. R., and Parry, G. D. (1999). Changes to benthic communities over 20 years in Port Phillip Bay, Victoria, Australia. *Marine Pollution Bulletin* **38**(1), 36–43.

Currie, D. R., McArthur, M. A., and Cohen, B. F. (1999). Exotic marine pests in the Port of Geelong, Victoria. In 'Marine Biological Invasions of Port Phillip Bay, Victoria.' (Eds C. L. Hewitt, M. L. Campbell, R. E. Thresher and R. B. Martin.) pp. 227–46. Centre for Research on Introduced Marine Pests, Technical Report No. 20. (CSIRO Marine Research: Hobart.)

Fletcher, W. J., and Tregonning, R. J. (1992). Distribution and timing of spawning by the Australian pilchard (*Sardinops sagax neopilchardus*) off Albany, Western Australia. *Australian Journal of Marine and Freshwater Research* **43**, 1437–49.

Gomon, M. F., Glover, C. J. M., and Kuiter, R. H. (Eds) (1994). 'The Fishes of Australia's South Coast.' (State Print: Adelaide.)

Harris, G., Batley, G., Fox, D., Hall, D., Jernakoff, P., Molloy, R., Murray, A., Newell, B., Parslow, J., Skyring, G., and Walker, S. (1996). 'Port Phillip Bay Environmental Study Final Report.' (CSIRO: Canberra.)

Hewitt, C. L., Campbell, M. L., Thresher, R. E., and Martin, R. B. (1999). Marine Biological Invasions of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests, Technical Report No. 20. (CSIRO Marine Research: Hobart.)

Hobday, D. K., Officer, R. A., and Parry, G. D. (1999). Changes to demersal fish communities in Port Phillip Bay, Australia, over two decades, 1970–91. *Marine and Freshwater Research* **50**, 397–407.

Hoedt, F. E., and Dimmlich, W. F. (1995). Egg and larval abundance and spawning localities of the anchovy (*Engraulis australis*) and pilchard (*Sardinops neopilchardus*) near Phillip Island. *Marine and Freshwater Research* **46**, 735–43.

Jenkins, G. P. (1986). Composition, seasonality and distribution of ichthyoplankton in Port Phillip Bay, Victoria. *Australian Journal of Marine and Freshwater Research* **37**, 507–20.

Jenkins, G. P., and May, H. M. A. (1994). Variation in settlement and larval duration of King George whiting, *Sillaginodes punctata* (Sillaginidae), in Swan Bay, Victoria, Australia. *Bulletin of Marine Science* **54**(1), 281–96.

Jenkins, G. P., May, H. M. A., Wheatley, M. J., and Holloway, M. G. (1997). Comparison of fish assemblages associated with seagrass and adjacent unvegetated habitats of Port Phillip Bay and Corner Inlet, Victoria, Australia, with emphasis on commercial species. *Estuarine, Coastal and Shelf Science* **44**, 569–88.

Kimmerer, W. J., Gartside, E., and Orsi, J. J. (1994). Predation by an introduced clam as the likely cause of substantial declines in

zooplankton of San Francisco Bay. *Marine Ecology Progress Series* **113**, 81–93.

Lockett, M. M., and Gomon, M. F. (1999). Occurrence and distribution of exotic fishes in Port Phillip Bay. In 'Marine Biological Invasions of Port Phillip Bay, Victoria.' (Eds C. L. Hewitt, M. L. Campbell, R. E. Thresher and R. B. Martin.) pp. 178–92. Centre for Research on Introduced Marine Pests, Technical Report No. 20. (CSIRO Marine Research: Hobart.)

Miskiewicz, A. G. (1986). The season and length at entry into a temperate Australian estuary of the larvae of *Acanthopagrus australis*, *Rhabdosargus sarba* and *Chrysophrys auratus* (Teleostei : Sparidae). In 'Indo-Pacific Fish Biology: Proceedings of the Second International Conference on Indo-Pacific Fishes.' (Eds T. Uyeno, R. Arai, T. Taniuchi and K. Matsuura.) pp. 740–7. (Ichthyological Society of Japan: Tokyo.)

Neira, F. J., and Potter, I. C. (1992*a*). The ichthyoplankton of a seasonally closed estuary in temperate Australia. Does an extended period of opening influence species composition? *Journal of Fish Biology* **41**, 935-53.

Neira, F. J., and Potter, I. C. (1992*b*). Movement of larval fishes through the entrance channel of a seasonally open estuary in Western Australia. *Estuarine*, *Coastal and Shelf Science* **35**, 213-24.

Neira, F. J., and Potter, I. C. (1994). The larval fish assemblage of the Nornalup–Walpole Estuary, a permanently open estuary on the southern coast of Western Australia. *Australian Journal of Marine and Freshwater Research* **45**, 1193–207.

Neira, F. J., Potter, I. C., and Bradley, J. S. (1992). Seasonal and spatial changes in the larval fish fauna within a large temperate Australian estuary. *Marine Biology* **112**, 1–16.

Neira, F. J., Miskiewicz, G. A., and Trnski, T. (1998). 'Larvae of Temperate Australian Fishes. Laboratory Guide for Larval Fish Identification.' (University of Western Australia Press: Nedlands.)

Neira, F. J., Sporcic, M. I., and Longmore, A. (1999). Biology and fishery of pilchard, *Sardinops sagax* (Clupeidae), within a large south-eastern Australian bay. *Marine and Freshwater Research* **50**, 43–55.

Neira, F. J., Jenkins, G. P., Longmore, A., and Black, K. (2000). Spawning and larval recruitment processes of commercially important species in coastal waters off Victoria 1997–1998. Final Report, Fisheries Research and Development Corporation, Project No. 96/116.

Parry, G. D., Hobday, D. K., Currie, D. R., Officer, R. A., and Gason, A. S. (1995). The distribution, abundance and diets of demersal fish in Port Phillip Bay. CSIRO INRE Port Phillip Bay Environmental Study, Technical Report No. 21. (CSIRO: Canberra.)

Parry, G. D., Lockett, M. M., Crookes, D. P., Coleman, N., and Sinclair, M. A. (1996). Mapping and distribution of *Sabella spallanzanii* in Port Phillip Bay. Final Report, Fisheries Research and Development Corporation, Project No. 94/164.

Walker, S. J. (1999). Coupled hydrodynamic and transport models of Port Phillip Bay, a semi-enclosed bay in south-eastern Australia. *Marine and Freshwater Research* **50**, 469–81.

Wilson, R. S., Heislers, S., and Poore, G. C. B. (1998). Changes in benthic communities of Port Phillip Bay, Australia, between 1969 and 1995. *Marine and Freshwater Research* **49**, 847–61.

Manuscript received 21 May 2001; revised 25 September and 21 December 2001; accepted 21 December 2001