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Summer and winter plankton fish assemblages around offshore oil and gas platforms in south-eastern Australia

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Abstract

Opportunistic plankton surveys were conducted within a 5-nmi radius of nine offshore oil and gas platforms in Bass Strait, south-eastern Australia, in February 1998 and 1999 (summer) and August 1998 (winter). The 108 day-night samples collected alongside (vertical tows) and nearby (surface and oblique tows) platforms yielded 1526 larval and early juvenile fishes representing 55 taxa from 45 families. Epipelagic/mesopelagic taxa dominated the catches, whereas hard/soft habitat-associated taxa were uncommon. Carangidae (36.2%) and Myctophidae (31.5%) dominated in summer and winter, respectively. The most abundant taxon was *Trachurus declivis* (Carangidae, 35.1%), followed by *Bovichtus angustifrons* (Bovichtidae, 8.7%), *Scomberesox saurus* (Scomberesocidae, 3.7%), *Centroberyx affinis* (Berycidae, 3.0%) and *Arripis trutta* (Arripidae, 1.7%). Fish concentrations (nos. per 100 m^3) alongside platforms did not differ significantly between day and night across all surveys. Likewise, concentrations nearby platforms in February 1999, including those of *T. declivis*, did not vary significantly by tow type (surface vs. oblique) or day vs. night. The far greater diversity and abundance recorded in February 1999 are likely the result of upwelling conditions over the eastern Bass Strait shelf during the sampling period, and which were not detected in February 1998. In the absence of data on adult fishes associated with the Bass Strait platforms, and given the limited availability of reefs directly around the area, it could be argued that some of the taxa caught may originate from spawning around neighboring natural reefs, particularly those off the Gippsland coastline and the south-east corner of mainland Australia. However, the prime position of the platforms almost right in the center of a productivity "hotspot" would have a confounding effect on the potential source(s) of larval fishes in that region of south-eastern Australia. The role of platforms as potential de-facto reefs for juvenile fishes in Bass Strait, as well as spawning areas, is discussed based on the findings of this study, the first on early stages of fishes around oil and gas platforms in Australia.

Keywords: larval fishes; offshore platforms; Bass Strait; south-eastern Australia

1. Introduction

Data on fish assemblages associated with offshore oil and gas production platforms (herein referred to as platforms) are available from several studies in western USA, the Gulf of Mexico and North Sea, undertaken with an array of survey methods that include manned submersibles, ROVs, SCUBA visual surveys, hydro-acoustics and light traps (Hastings et al., 1976; Love and Westphal, 1990; Stanley and Wilson, 1991, 1997; Love et al., 1994, 1999, 2000, 2003; Aabel et al., 1997; Hernandez et al., 2003; Hernandez and Shaw, 2003; Rademacher and Render, 2003). As with fish attraction devices and artificial reefs (Rountree, 1990; Grossman et al., 1997), these studies have primarily focused on the attraction-production issue, i.e. ascertaining whether, and in which way, these structures enhance local and regional fish and fishery production. All fish surveys conducted in platforms to date conclude that these

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function as artificial reef systems, attracting a high diversity of fish species not typically found in the surrounding seafloor or adjacent water column, some in large numbers (Hastings et al., 1976; Stanley and Wilson, 1991, 2000, 2003; Love et al., 1999, 2000, 2003; Hernandez et al., 2003). Furthermore, greater abundances of juvenile and adult fishes have been reported around platforms compared to either adjacent natural reefs or surrounding waters, supporting the view that these artificially complex, de-facto reefs function effectively both as nurseries and marine refuges (Aabel et al., 1997; Stanley and Wilson, 1997, 2003; Love et al., 2003). Survey results are now increasingly being employed to assist in the decision-making process of platform decommissioning, i.e. what to do with these structures once they have ceased producing, which in turn has fuelled the known ''rigs to reefs'' debate.

Several reasons have been proposed to explain why platforms provide such highly productive and optimal microecosystems, especially for juvenile and adult fishes found there either temporarily or permanently: (1) the cross-beams, support struts and vertical pilings of steel jacket platforms offer suitable hard, reef-like surfaces for many sessile invertebrates, including mussels and barnacles, which in turn provide abundant food and shelter; (2) as platforms occupy the entire water column, they provide alternative microhabitats from surface to bottom, including the shell mounds typical of the surrounding seafloor, thereby enhancing habitat partitioning and lowering predation; (3) they may function both as giant ''fixed plankton collectors'', concentrating larval invertebrates and fishes that drift passively with local currents, and giant ''light traps'', by attracting various species from small invertebrates and fishes to large predators; and (4) they serve as visual, tactile and/or auditory reference points in an open water environment which may otherwise be just an unstructured watery space (Hastings et al., 1976; Stanley and Wilson, 1991, 1997; Aabel et al., 1997; Love et al., 1999, 2000, 2003; Hernandez et al., 2003).

Compared to what is known about juvenile and adult fish communities associated with platforms, information on larval and/or early juvenile fish assemblages adjacent to and around these structures worldwide is very limited (e.g. Hernandez et al., 2003). Plankton surveys would be useful to determine which resident species arrive at platforms as larvae/presettlement juveniles, and/or which species use these as temporary larval refuges before moving/settling elsewhere, e.g. pelagic fishes. Another question would be to ascertain whether resident species spawn in the area and then self recruit to the same or adjacent platforms, and if this occurs at the larval or later stages. In the latter context, current research indicates that fish assemblages in platforms far removed from natural reefs are not dependent on immigration of juveniles and adults from these reefs, but more likely on the recruitment of fishes with planktonic larvae and juveniles originated from both adjacent and distant sources (Love et al., 2003).

No data are available on larval, juvenile and/or adult fishes associated with offshore oil and gas platforms operating in Australia. This paper documents for the first time the species composition and abundance of larval and early juvenile fishes around platforms in Bass Strait, south-eastern Australia, from surveys undertaken in February 1998 and 1999 (summer), and August 1998 (winter). Particular emphasis was placed on assessing the prevalence in the surveyed area of early stages of the few species known to reside on these structures. The role of platforms as possible temporary refuges for larvae and early juveniles of coastal fishes is also discussed.

2. Materials and methods

2.1. Study area

Plankton surveys were confined to waters around nine manned, steel jacket/concrete gravity-based platforms in eastern Bass Strait, south-eastern Australia, which form part of the Esso Australia Ltd production system (Figs. 1 and 2b). The entire production field houses a complex of 21 fixed, interconnected offshore installations (comprising platforms, monotowers and subsea completions), which are operated 24 h/day for the extraction and production of crude oil and natural gas. They have been part of eastern Bass Strait seascape since 1968 when the first platform (Barracouta) commenced drilling. The region where the platforms are located is considered a key ''hotspot'' of fisheries productivity in south-eastern Australia, resulting from a combination of topographic and oceanographic features that favour upwelling of deep, nutrient-rich sub-Antarctic water (Harris et al., 1987; Prince, 2001).

Platforms visited during this study are positioned at depths of 46-93 m on the continental shelf, approximately 23–72 km from the Gippsland Lakes, a vast estuarine system comprised by three large interconnected lagoons on east coast of mainland Australia (Table 1; Fig. 1). The substrate where the platforms are placed consist predominantly of soft grounds (muddy sediment flats, bryozoan sands and gravels, and quartzose sandy areas), intermixed with sparse to dense mollusc beds, and almost no natural rock/reef grounds (Bax and Williams, 2001). Main inshore hard ground habitats in the region include an elongate, low-relief outcrop adjacent to the Gippsland coastline (limestone slab and sandstone/granite reefs), some 46 km from the installations, and the Broken Reef and the Howe/Gabo complex (high/low relief sandstone/limestone reefs), about 148–176 km north-east of the platform area on the south-east corner of mainland Australia (Fig. 1).

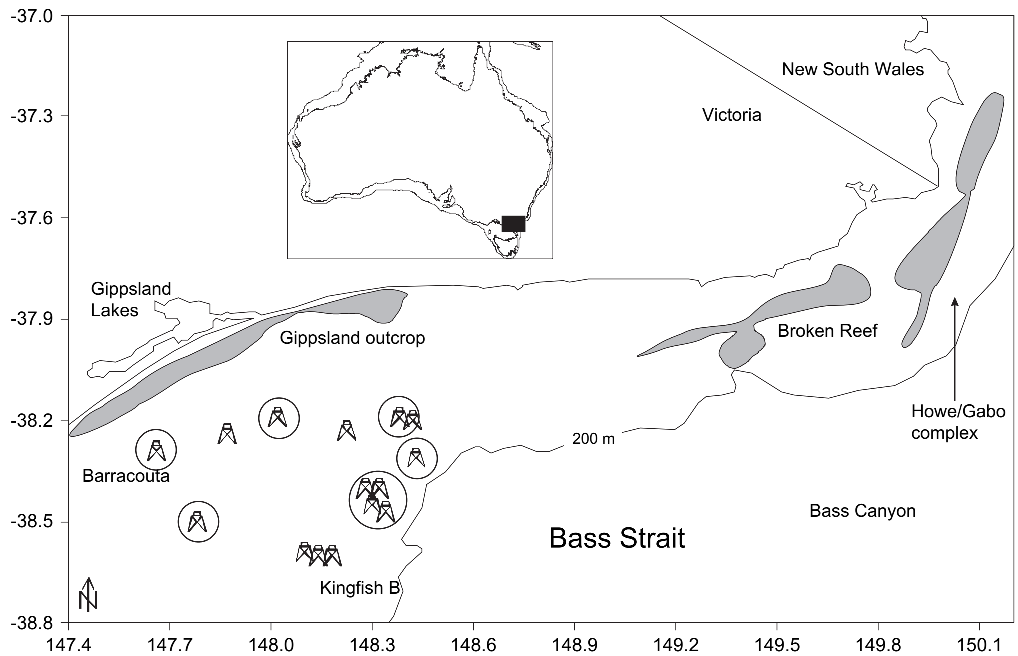

Fig. 1. Approximate location of the 16-manned offshore oil and gas production platforms of Esso Australia Ltd in Bass Strait, in south-eastern Australia (monotowers and subsea installations have been omitted). Encircled platforms (9) indicate those visited during surveys. Approximate shape and position provided for the Gippsland outcrop, Broken Reef and Howe/Gabo complex for reference were adapted from Bax and Williams (2001) (see text for details).

2.2. Sampling regime and laboratory procedures

Surveys were carried out on 10–11 February 1998, 4–5 August 1998 and 23–24 February 1999 on board large supply vessels which operate around platforms. Sampling during each survey comprised surface plankton tows at random sites located at or just inside a 5-nmi radius (nearby) from platforms, as well as 3–6 replicate vertical tows some 20 m (alongside) form each platform, obtained with the vessel completely stationary while loading and off-loading supplies. Sampling in February 1999 included additional random oblique tows at sites nearby platforms. Time of day and sequence in which samples nearby and alongside platforms were obtained during each survey followed the vessel's scheduled stopovers at that time. For the purpose of data analyses (see below), all samples collected during the study have been regarded as random within the platform area, and have been divided into day or night depending on the time and season (summer vs. winter) when they were taken. Details of platforms, sampling dates, times and methods for each survey are provided in Table 1.

Nearby surface and oblique samples were taken with a bongo sampler consisting of two 500-μm mesh nets, each 3 m in length and 0.6 m in diameter. For surface tows, the sampler was deployed from the starboard and towed at the surface at speeds of 1.0–1.5 knots for 10 minutes. For oblique tows, the sampler was lowered directly to about 5 m above the sea floor and brought back in a step-wise mode. Samples alongside platforms were obtained using a single, conical 500-μm mesh net, 3 m in length and 0.5 m in diameter. This net was deployed from the starboard side to within 5 m from the sea floor, and immediately brought back on board. Total water volume filtered during each tow (m^3) was calculated from counts obtained with 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 in 4% formaldehyde-seawater and later preserved in 70% ethanol.

All samples ($n = 108$; Table 1) were sorted under a dissecting stereomicroscope, and all fish removed, identified to the lowest possible taxon and counted (Table 2). Identifications were carried out using the larval fish guides of Moser (1996), Neira et al. (1998) and Leis and Carson-Ewart (2000), and references therein. Fishes identified only to family level belonged mostly to multispecies groups whose adult taxonomy needs revision, and/or to those for which further work is required to provide precise species identifications (e.g. myctophids). For the purpose of this paper, the term "larva" includes preflexion through to postflexion stage, whereas "early juvenile" includes transforming/settlement stages (Neira et al., 1998); the term "fishes" comprises both larvae and early juveniles. The broad distinction between fishes belonging to epipelagic (coastal, schooling)-, meso-benthopelagic (oceanic)-, soft substrate- and rock/reef-associated taxa was based on known habitats provided by identification guides of adult fishes from temperate Australia (Last et al., 1983;

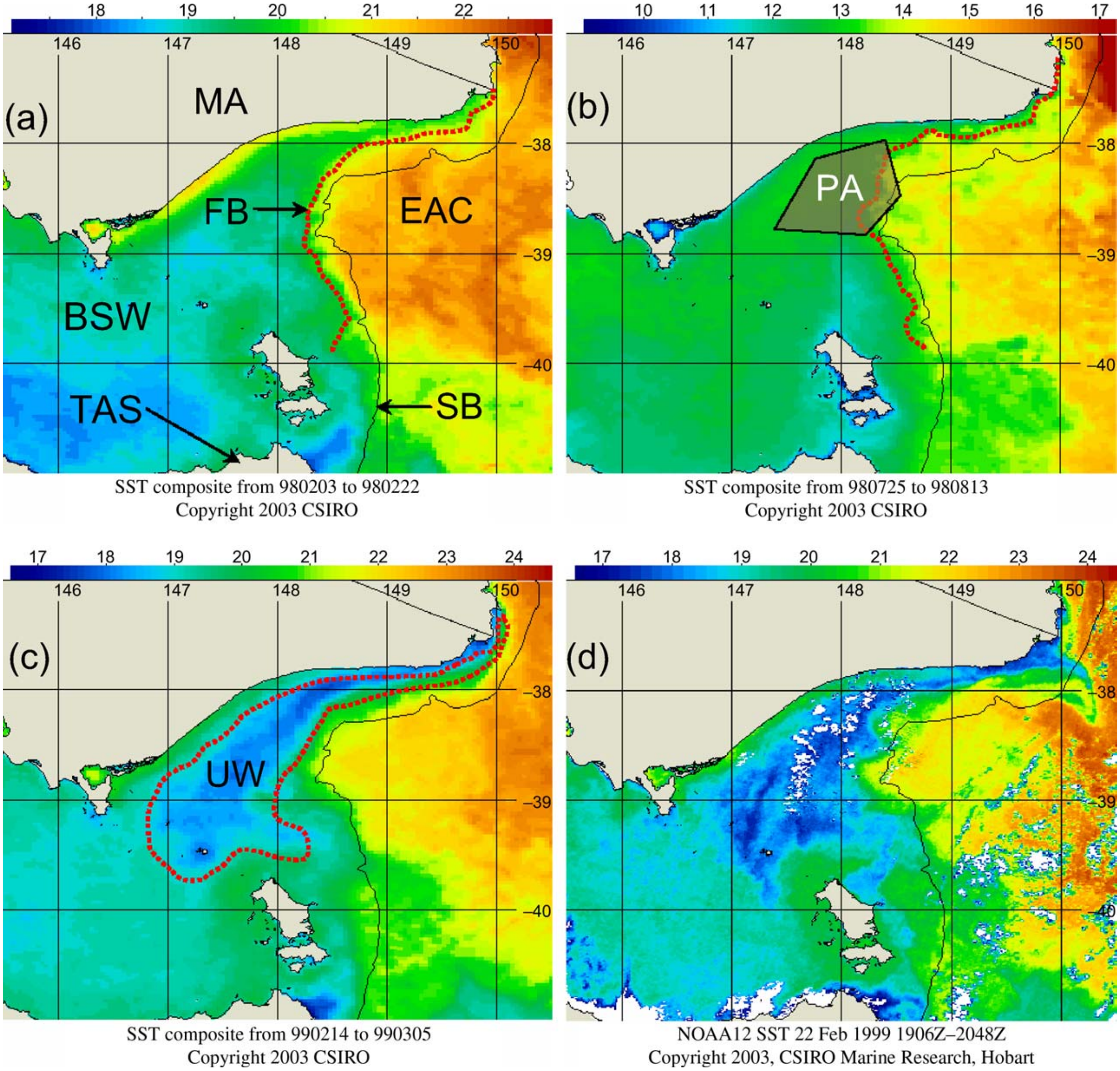

Fig. 2. Sea surface temperatures (SST) images of south-eastern Australia for (a) February 1998; (b) August 1988; and (c), (d) February 1999; (a), (b) and (c) correspond to composite SST images constructed from 20-day averages centered around the sampling days; (d) corresponds to a single image pass on 22 February 1999. Abbreviations: BSW – Bass Strait Water; EAC – East Australian Current; FB – frontal boundary (approximate position shown by red dotted line); MA – mainland Australia; SB – shelf break; PA – platform area; TAS – Tasmania; UW – upwelling.

Kuiter, 1993; Gomon et al., 1994) and ecological work adjacent to the survey area (Williams and Bax, 2001).

2.3. Data analyses

Both the total numbers of fishes and those of individual taxa caught after each tow during each survey were converted to concentration, i.e. numbers per 100 m^3, using data on water volume filtered. Overall contributions (%) of individual taxa and families to the assemblage across all three surveys were derived from concentrations (Table 2). Length-frequency histograms were constructed for four selected species to illustrate their size ranges present in the survey area. Length measured corresponded to body length (BL, mm), i.e. notochord length (snout tip to notochord tip) in preflexion and flexion larvae, and standard length (snout tip to posterior hypural margin) in postflexion larvae and transforming stages (Neira et al., 1998); all lengths provided correspond to BL unless stated otherwise. The approximate age (days after first feeding) of *Trachurus declivis* was estimated from the regression of ln BL (mm) against age ($y = 0.054x + 1.132$) published by Jordan (1994) for early stages of this species caught along shelf waters of eastern Tasmania in 1990. The use of this relationship was deemed appropriate given that

Table 1
Bass Strait oil and gas production platforms visited during February 1998, August 1998 and February 1999, and total number of surface, vertical and oblique plankton samples obtained during each survey

	Distance from shore kilometres (nautical miles)	Depth (m)	Survey 1	Survey 2	Survey 3
Date/year			10–11 February 1998	4–5 August 1998	23–24 February 1999
Time (hr)			03:39–05:45	02:00–03:00	03:20–16:02
Platform visited					
Barracouta	23 (12.4)	46	+		
Bream A	46 (24.8)	59			+
Cobia	68 (36.7)	78		+	+
Fortescue	62 (33.5)	69	+	+	+
Flounder	58 (31.3)	93		+	+
Halibut	63 (34.0)	73	+	+	+
Mackerel	72 (38.9)	93	+	+	++
Snapper	32 (17.3)	52	+	+	+
West Tuna	45 (24.3)	61	+	+	+
Samples obtained					
Surface			8	13	5
Vertical			18	32	27
Oblique			–	–	5
Total samples			26	45	37

Crosses (+) refer to the number of visits made to a particular platform. Data on distance from shore and depth of platforms were obtained from Esso Australia Ltd.

populations of this species in eastern Bass Strait, southern New South Wales and eastern Tasmania are believed belong to the same stock (Williams and Pullen, 1986).

Fish concentrations (nos. per 100 m^3) from samples alongside platforms were averaged for each survey, and the means (+95% C.I.) plotted both for day and night to show variability across the sampling period (see Fig. 6); one-way ANOVA was carried out using STATISTICA® to determine whether concentrations differed significantly between sampling time (day vs. night). Concentrations from nearby sites in February 1999, as well as of the most abundant species (*Trachurus declivis*), were subjected to two-way ANOVA to determine whether concentrations varied significantly between tow type (surface vs. oblique) and sampling time (day vs. night). Data for all analyses were log-transformed ($\log_{10}[n+1]$) to account for heterogeneity of variance following Cochran's test.

Classification and Multiple Dimensional Scaling (MDS) ordination analyses were carried out to examine similarities between fish assemblages across all three surveys. These analyses used mean fish concentrations (numbers per 100 m^3) of taxa which were recorded in at least two tows during the study ($n=25$); taxa regarded as rare, i.e. those which occurred only once and in very low concentrations (<0.2%), were excluded from the analyses ($n=20$). Concentration values in the resultant taxa (25)×sample (44) matrix were log-transformed ($\log_{10}[n+1]$) to account for zeros and avoid abundant taxa from greatly influencing the result. The final matrix was transformed into an association matrix using the Bray-Curtis (B-C) dissimilarity index, and subsequently subjected to classification (not presented) using Unweighted Flexible Pair-Group Arithmetic Averaging (UPGMA, $\beta=0.1$), and to ordination using Semi-Strong Hybrid (SSH) MDS. Stress values of 0.1–0.2 indicate a good fit when representing n-dimensional ordination relationships in multidimensional space (Clarke, 1993).

2.4. Environmental variables

Data on water temperature (°C), and current (total) velocity (vector-averaged over 8.5 minutes; m/sec) and direction (°T), were obtained daily for the period 22–25 February 1999 (07 am–23 pm) with a SeaData 624XP directional, wave, tide and current meter installed 10 m below MSL at the Kingfish B (KFB) platform (38.6°S; 148.2°E). These data were unavailable for the February and August 1998 surveys due to meter malfunction. The SeaData meter is equipped with temperature and electromagnetic current (Marsh McBirney Industries) sensors. Data on wind velocity (m/sec) and direction (°T) were obtained for the same period with a wind sensor (R.M. Young) placed 44 m above MSL on the same platform. Temperatures were averaged per hour and plotted for the sampling days; velocity and direction of currents and winds were averaged per hour and plotted using the polar coordinate system available with the 2-D scatterplot option of STATISTICA®. Due to the proximity between platforms, data on currents, winds and temperatures from KFB were considered to be representative of the entire area for the period 22–25 February 1999. Composite and single-pass sea surface temperature (SST) images of the study

Table 2
Families and taxa of fishes collected as larvae/early juveniles around Bass Strait oil and gas production platforms in February 1998, August 1998 and February 1999, arranged by family in descending order of contribution (%)

	Family/texa	February 1998			August 1998			February 1999				Total no. larvae		Overall taxa contribution (%)
		S	V	Total survey	S	V	Total survey	S	V	O	Total survey	Family	Taxa	
1	Carangidae											862		
	Trachurus declivis		7	7				536	26	279	841		848	35.1
	Pseudocaranx dentex	14		14									14	1.1
2	Myctophidae											267		
	Myctophids				1	260	261		3	3	6		267	31.5
3	Bovichtidae											46		
	Bovichtus angustifrons				46		46						46	8.7
4	Scomberesocidae											91		
	Scomberesox saurus	18		18				52		21	73		91	3.7
5	Triglidae											28		
	Lepidotrigla mulhalli	3	8	11					2	9	11		22	2.7
	Lepidotrigla modesta		2	2					1		1		3	0.6
	Chelidonichthys kumu									2	2		2	0.1
	Lepidotrigla vanessa									1	1		1	<0.5
6	Berycidae											43		
	Centroberyx affinis							5	8	30	43		43	3.0
7	Arripidae											26		
	Arripis trutta	25		25					1		1		26	1.7
8	Bothidae											25		
	Arnoglossus muelleri	1		1				4	2	12	18		19	1.3
	Pseudorhombus sp.									6	6		6	0.1
9	Monacanthidae											11		
	Monacanthids	1	3	4				4		3	7		11	1.1
10	Galaxiidae											10		
	Galaxias maculatus				10		10						10	1.0
11	Pomacentridae											18		
	Chromis sp.							4		13	17		17	0.5
	Parma sp.		1	1									1	0.3
12	Engraulidae											3		
	Engraulis australis								2	1	3		3	0.8
13	Diodontidae											4		
	Diodon nicthemerus	2	2	4									4	0.7
14	Gonostomatidae											10		
	Cyclothone sp.								2	7	9		9	0.6
	Vinciguerria sp.									1	1		1	<0.5
15	Syngnathidae											2		
	Hippocampus sp.		1	1									1	0.4
	Syngnathid								1		1		1	0.3
16	Cheilodactylidae											7		
	Cheilodactylus nigripes	5		5	2		2						7	0.5
17	Centrolophidae											7		
	Seriollela punctata				2	3	5						5	0.5
	Psenes sp.							2			2		2	0.1
18	Callionymidae											5		
	Foetorepus calauropomus	1	1	2						3	3		5	0.4
19	Gobiidae											2		
	Gobiid		1	1						1	1		2	0.4
20	Platycephalidae											3		
	Platycephalus bassensis								1	2	3		3	0.3
21	Moridae											2		
	Pseudophycis breviuscula		1	1	1		1						2	0.3
22	Girellidae											1		
	Girella tricuspidata		1	1									1	0.3
23	Macroramphosidae											7		
	Macrorhamphosus scolopax							2		5	7		7	0.2
24	Acropomatidae											7		
	Apogonops anomalus									7	7		7	0.2
25	Microcanthidae											1		
	Atypichthys strigatus	1		1									1	0.2

Table 2 (*continued*)

	Family/texa	February 1998			August 1998			February 1999				Total no. larvae		Overall taxa contribution (%)
		S	V	Total survey	S	V	Total survey	S	V	O	Total survey	Family	Taxa	
26	Pinguipedidae											3		
	Parapercis sp.									3	3		3	0.2
27	Pempherididae											5		
	Pempheridid							3		2	5		5	0.1
28	Sillaginidae											4		
	Sillago flindersi							1		3	4		4	0.1
29	Mullidae											3		
	Upeneichthys vlamingii	2		2				1			1		3	0.1
30	Coryphaenidae											3		
	Coryphaena hippurus							2		1	3		3	0.1
31	Scorpaenidae											3		
	Neosebastes sp.									2	2		2	0.1
	Scorpaenid									1	1		1	<0.5
32	Gempylidae											2		
	Gempylid									2	2		2	0.1
33	Clupeidae											2		
	Sardinops sagax							1		1	2		2	0.1
34	Callanthidae											2		
	Callanthias australis							1		1	2		2	0.1
35	Carapidae											1		
	Echiodon rendhali									1	1		1	0.1
36	Leptoscopidae											1		
	Crapatalus?								1		1		1	0.1
37	Cynoglossidae											1		
	Cynoglossidae									1	1		1	<0.5
38	Exocoetidae											1		
	Cheilopogon sp.	1		1									1	<0.5
39	Gerreidae											1		
	Gerres subfasciatus							1			1		1	<0.5
40	Labridae											1		
	Labrid									1	1		1	<0.5
41	Serranidae											1		
	Acanthistius sp.									1	1		1	<0.5
42	Sparidae											1		
	Pagrus auratus									1	1		1	<0.5
43	Synodontidae											1		
	Synodus sp.									1	1		1	<0.5
44	Terapontidae											1		
	Terapontid									1	1		1	<0.5
45	Trachichthytidae											1		
	Trachichthyid									1	1		1	<0.5
	Total larvae	74	28	102	62	263	325	619	50	430	1099	1526	1526	
	Number of taxa identified	12	11	19	6	2	6	15	12	36	43	45	55	

Total number of specimens caught in surface (S), vertical (V) and oblique (O) tows is provided for each survey, as well as totals for each family and taxa for entire study. Overall contributions (%) from each family and taxa were calculated after adding the concentrations (numbers per 100 m^3) across the three surveys.

area in south-eastern Australia (NOAA AVHRR) were obtained from the CSIRO Marine Research Remote Sensing Facility for February 1998 and 1999, and August 1998. Images were taken from 20-day averages centered around the sampling dates, and processed for cloud cover. Average sea-surface temperatures (±1 °C) were obtained from these images using specifically-designed image software. Composite images, and a single-pass image for 22 February 1999, are provided to illustrate important oceanographic processes.

3. Results

3.1. Temperatures and water current conditions

Average sea-surface temperatures obtained from the SST images for the study area were 19–21 °C in February 1998, 12–14 °C in August 1998, and 17–22 °C in February 1999. All images show a frontal boundary between cooler, northward-moving Bass Strait water and warm water (>22.0–23.5 °C) derived from the south-flowing East Australian Current (EAC), which roughly follows the shelf break contour (Fig. 2). A distinct upwelling of presumably slope water (<18 °C) is visible over the mid shelf in the study area February 1999, which continues eastwards along the inner shelf just past the Victoria/New South Wales border (Fig. 2d). This plume of cooler water is also visible in the single-pass image of 22 February, a day before sampling started, and its presence coincided with a marked drop in average temperatures recorded at a depth of 10 m during 22–25 February 1999 (Fig. 3). Average water temperatures during those days decreased rapidly from 21.0 °C at 18 pm to 17.8 °C between 20 pm on 22 February and 14 pm on 24 February (includes sampling period), before increasing to 20.2 °C by 23 pm on 25 February.

Hourly current direction and velocity plots for the period 22–25 February 1999 clearly show current vectors mainly in the SE (90–180°) and SW (180–270°) quarters (Fig. 4). The strongest currents in any given day ran mainly SSW-SW (200–250°) at velocities of up to 1.0 m/s (1.9 knots), whereas currents in the SE quarter did not exceed 0.25 m/sec (0.5 knots). Examination of raw data reveals that current direction varied hourly following an anti-clockwise pattern, with most SE and SW current vectors gradually shifting south to east (05 am–13 pm) and west to south (12–19 pm), respectively (time for main SW vectors shown in Fig. 4). For example, current bearings (velocity) on 23 February shifted from 181° (0.33 m/s) to 113° (0.23 m/s) between 05 and 08 am (SE quarter), and from 258° (0.39 m/s) to 181° (0.65 m/s) between 14 and 18 pm (SW quarter). Changes in flow direction SE to SW during that period occurred between 9 am and 13 pm, and lasted from one (25 February) to five (23 February) hours. Prevailing winds during 22–25 February 1999 shifted from ENE-NE (078–058°; 22–23 February) to SW (228–231°; 23–24 February), and to SSE (154–147°; 24–25 February) (Fig. 4). Hourly average wind velocities during the entire period ranged from 1.1 to 17.4 m/sec, i.e. 2–34 knots; extreme averages within a day ranged from 4.4 m/sec (8 knots) at 0 am–12 pm on 24 February to 14.0 m/sec (27 knots) at 13–23 pm on the same day (Fig. 4).

3.2. Species composition

The 108 plankton samples collected in day-night, nearby and alongside tows during this study yielded 1526 fishes from 45 families and 55 taxa (Table 2). Fishes from eight families accounted for ca. 91.0% of the total caught during the study (numbers adjusted to 100 m^3), with Carangidae (36.2%) and Myctophidae (31.5%) dominating the summer and winter catches, respectively; individuals of one or more species of the Bovichtidae, Scomberesocidae, Triglidae, Berycidae, Arripidae, Bothidae and Monacanthidae made up the other 23.0%. The remaining 37 families (9.3%) each contributed <1% to the total collected, with 13 being represented each by one specimen. In terms of individual species, the most abundant were *Trachurus declivis* (35.1%), followed by *Bovichtus angustifrons* (8.7%), *Scomberesox saurus* (3.7%), *Centroberyx affinis* (3.0%) and *Arripis trutta* (1.7%). Species represented by one individual included *Atypichthys strigatus*, *Echiodon rendhali*, *Girella tricuspidata* and *Pagrus auratus*, all of which occurred in summer (Table 2).

Overall, 48 taxa were recorded in the summer surveys (42 families), five of which occurred only in February 1998, including *Pseudocaranx dentex* and *Girella tricuspidata*. The total number of taxa identified in February 1999 ($n=43$) was more that twice that recorded in February 1998 ($n=19$), and considerably greater than that in August 1998 ($n=6$). The total numbers of taxa from surface and vertical tows in February 1998 and 1999 were relatively similar, i.e. 11–15, but noticeably

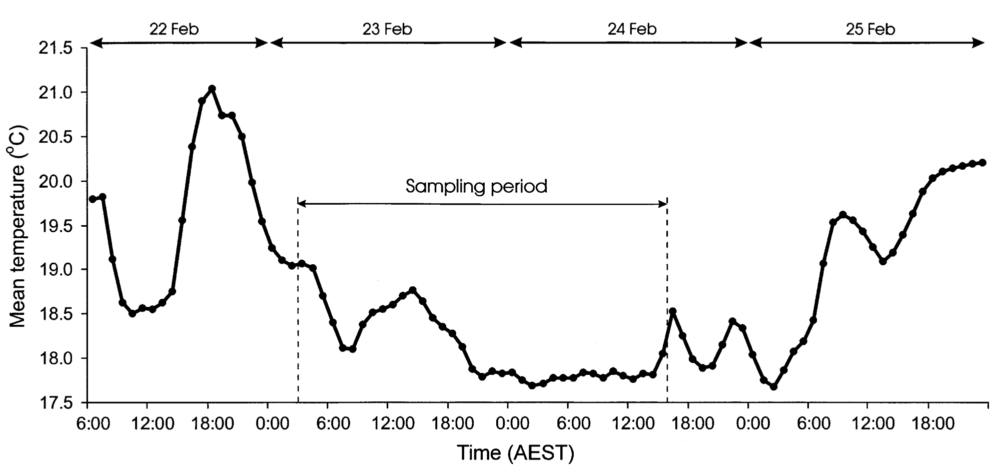

Fig. 3. Mean temperature (°C) recorded hourly at a depth of 10 m from "Kingfish B" during the period 22–25 February 1999. "Time" in this and in figures 4 and 6 corresponds to summer Australian Eastern Standard Time (AEST).

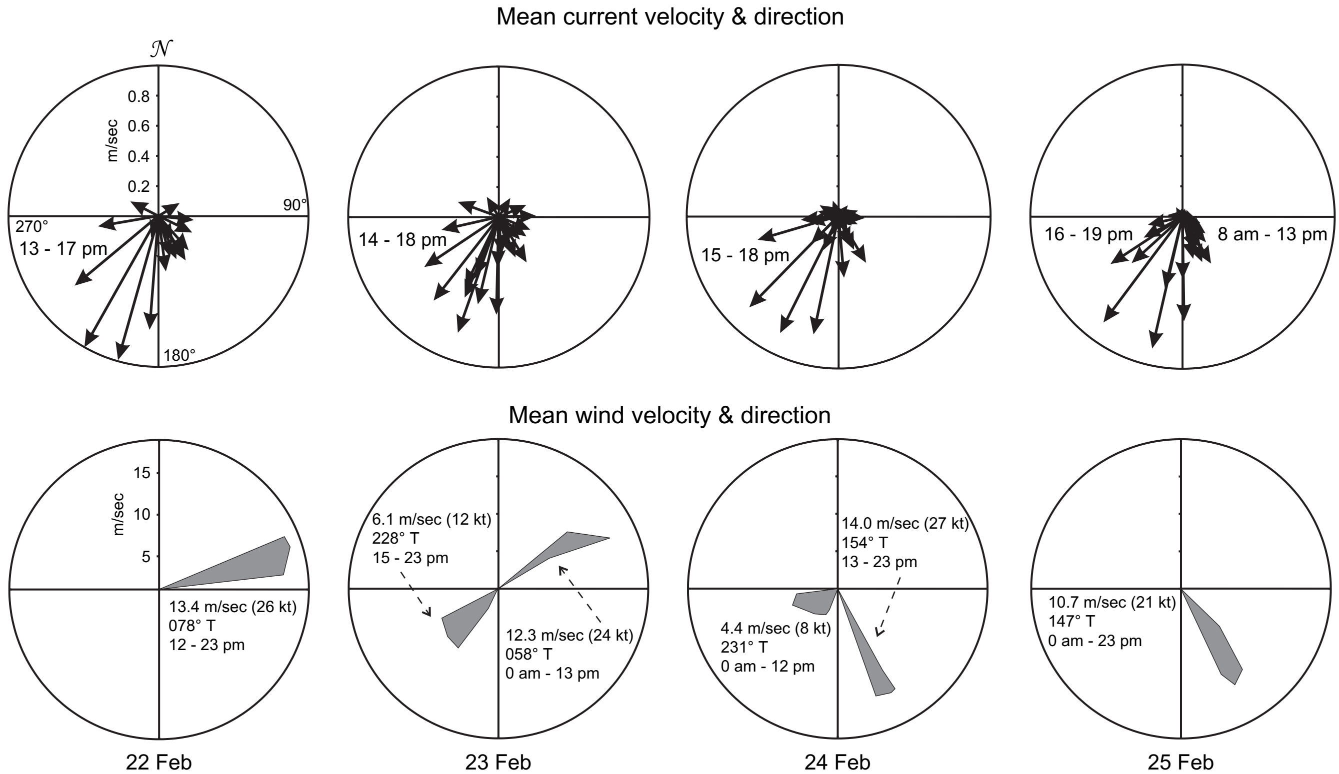

Fig. 4. Polar coordinate representations of mean hourly water current and wind velocities (m/sec) and direction (°T) obtained daily for the period 22–25 February 1999 at Kingfish B (center of plot) in Bass Strait. Current and wind data were obtained with sensors placed 10 m below MSL and 44 m above MSL, respectively. In current plots (top row), arrow heads of each vector represent current flow direction away from platform, while length of each vector represents magnitude; time period (hours, AEST) when strongest currents were observed is provided for each day in the respective quarters. In wind plots (bottom row), opaque shapes represent direction of wind flow towards platform (pointed end), bearing range (wider end), and magnitude (length); mean speed and bearing, and time period (hours, AEST) of prevailing winds associated with each of the opaque shapes are provided for each day in the respective quarters.

fewer than the 36 recorded in the additional oblique tows conducted in February 1999 (Table 2); overall, 16 taxa (29.1%) were caught only in oblique tows during the study. Beside myctophids, *Bovichtus angustifrons*, *Galaxias maculatus*, *Cheilodactylus nigripes*, *Seriollela punctata* and *Pseudophycis breviuscula* were also collected in winter (August 1998), the first three species occurring exclusively during that survey (Table 2).

Epipelagic/schooling coastal taxa (e.g. carangids, scomberesocids, arripids) dominated the February 1998 and 1999 assemblages, contributing 47% and 79% to the total caught in those surveys, respectively (Fig. 5). Taxa associated with soft substrate and rock/reef habitats ranked second (e.g. bothids, triglids) and third (e.g. pomacentrids, monacanthids) overall, and were distinctly more prevalent in February 1998. Meso-benthopelagic (oceanic) taxa (e.g. gonostomatids, myctophids) were only present in February 1999 and contributed <3% to the total caught (Fig. 5).

3.3. Fish concentrations

Mean concentrations alongside platforms remained <50 fish per 100 m^3 in February 1998 and 1999, whereas they exceeded 50 fish per 100 m^3 on three occasions in August 1998 (Fig. 6). Peak mean concentrations of 10.2, 87.3 and 25.1 fishes per 100 m^3 were recorded in February 1998, August 1998 and February 1999, respectively, with myctophids accounting for

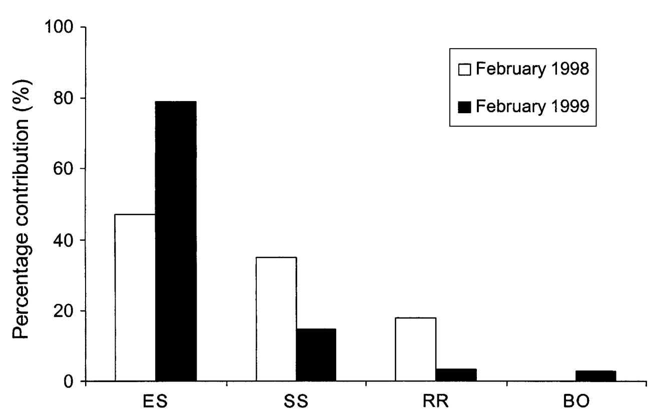

Fig. 5. Overall contribution (%) of early stages of epipelagic/schooling (ES), soft substrate (SS), rock/reef (RR) and meso-benthopelagic/oceanic (BO) fishes to the total caught during the surveys carried out around Bass Strait oil and gas production platforms in February 1998 and 1999.

almost 99% of the captures in August 1998 (Table 2). Mean fish concentrations alongside platforms did not differ significantly with sampling time (day vs. night) across all surveys ($P > 0.05$). Likewise, overall mean fish concentrations from sites nearby platforms in February 1999 did not differ significantly with sampling time (day vs. night), tow type (surface vs. oblique) or interaction time×tow type ($P > 0.05$). Multidimensional scaling ordination clearly separated samples collected in August 1998 from those collected in February 1998 and 1999, but did not separate between samples collected in February of both years (Fig. 7).

3.4. Species accounts

Trachurus declivis (Carangidae – Fig. 8a): 848 individuals were caught in the summer surveys, 99% in February 1999 (Table 2). Most came from sites nearby platforms and comparatively few from alongside platforms. Mean concentrations in February 1999 did not differ significantly with sampling time (day vs. night), tow type (surface vs. oblique) or time×tow type interaction ($P > 0.05$). Of the 556 fish measured (3.0–26.7 mm), 28% were preflexion/flexion (<7.0 mm), 27% postflexion (7–13 mm), and the remaining 45% early juveniles. The approximate age of these fish (days after first feeding) ranged from 2 to 40 d, with 42% in the 25–31 d age class corresponding to the 12–16 mm class interval (Figs. 9a,b).

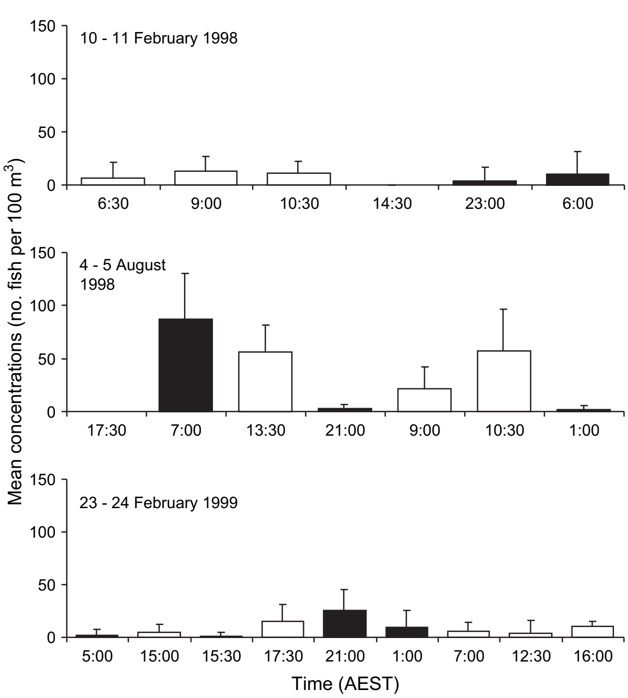

Fig. 6. Mean concentrations (+CI) of fishes (all taxa combined) from vertical tows alongside Bass Strait oil and gas production platforms in February 1998, August 1998 and February 1999. No bars means no fish caught. Black and white bars represent night and day samples, respectively; note that sunrise is much earlier during summer.

Bovichtus angustifrons (Bovichtidae – Fig. 8b): 46 larvae were caught in August 1998, all in surface tows (Table 2). Of the 38 in reasonable conditions to be measured (7.0–15.4 mm), 14 were preflexion/flexion (<10.8 mm) and the remaining postflexion, 45% in the 10–11 mm class (Fig. 9c).

Centroberyx affinis (Berycidae – Fig. 8c): 43 larvae were caught in February 1999 (3.3–13.7 mm), 30 in oblique tows (Table 2). Of these, 25 were preflexion/flexion (<6.0 mm), and the rest postflexion (Fig. 9d).

Arripis trutta (Arripidae – Fig. 8d): 26 individuals were caught in the summer surveys (Table 2). All those caught in February 1998 ($n=25$) came from surface samples and were all early juveniles (11.9–30.2 mm), 58% in the 14–16 mm class (Fig. 9e). A single flexion larva (5.3 mm) was caught in a vertical tow in February 1999.

Other species: Late postflexion larvae/early juveniles of seven other species were caught in the survey area, albeit most in small numbers (Table 2). Species caught in summer included *Pseudocaranx dentex* ($n=14$; 16.5–35.5 mm), *Coryphaena hippurus* (17.8, 18.1 mm), *Upeneichthys vlamingii* (26.5, 27.5 mm), *Chromis hypsilepis* (13.8 mm) and *Diodon nichthemerus* (13.1 mm); winter species were *Cheilodactylus nigripes* (18.2 mm) and *Pseudophycis breviuscula* (27.5 mm).

4. Discussion

4.1. Composition of fish assemblages

This study constitutes the first descriptive account of larval and early juvenile fishes from around offshore oil and gas platforms in Australia to date, and indeed Australasia. Unfortunately, no comparable data are available on the fish diversity associated with the Bass Strait platforms, except for a handful of species identified from ROV-acquired video footage obtained during routine structural inspections (F.J. Neira, pers. observ.). The only existing fish species checklist from the eastern shelf region of Bass Strait comes from demersal trawl and gill net surveys conducted during a large habitat study close to the platform area (Williams and Bax, 2001). Thus, all inferences regarding adult fishes from that area in this discussion are based primarily on that list. In addition, comparisons of the actual study findings are limited to published accounts of larval and adult fish assemblages associated with platforms elsewhere in the world, particularly those from southern and central California (Love et al., 1999, 2000, 2003), and northern Gulf of Mexico (hereafter referred to as Gulf platforms) (Hastings et al., 1976; Stanley and Wilson, 1991, 1997, 2000, 2003; Hernandez et al., 2003).

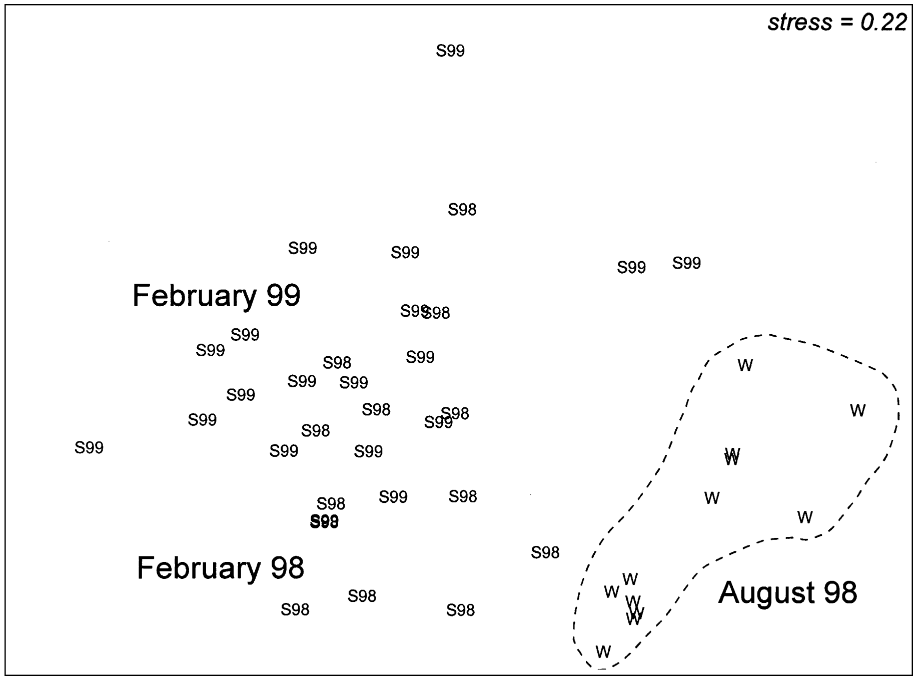

Fig. 7. Two-dimensional MDS plot of plankton fish samples obtained around Bass Strait oil and gas production platforms in February 1998 (S98), August 1998 (W) and February 1999 (S99). Each assemblage contains log-transformed data on mean fish concentrations of 25 taxa selected for the ordination (see Data analyses for details).

The plankton surveys undertaken during this study yielded a taxonomically diverse fish assemblage containing 55 taxa from 45 families. The summer-winter assemblages differed markedly in terms of family and taxa richness: 42 families occurred in both summers combined compared to only six in winter, despite the greater sampling effort in August 1998 than in February 1998 or 1999. This marked seasonal difference was supported by MDS ordination, and reflect the fact that fishes in coastal waters across temperate Australia, including enclosed bays and estuary entrances, spawn primarily during spring/summer (Gaughan et al., 1990; Neira et al., 1992, 1998, 2000). Similarly, early stages of very few taxa were caught at Gulf platforms during the Northern Hemisphere winter (Hernandez et al., 2003).

The number families reported during this study fell within the 34–54 range obtained from passive plankton net collections alongside offshore (22–219 m deep) Gulf platforms (Hernandez et al., 2003). Besides families exclusive to each area, which presumably reflect the more tropical location of the Gulf platforms (~29.5°N; 91.0°W) compared to those in Bass Strait (~38.4°S; 148.0°E), both these studies shared early stages of fishes belonging to cosmopolitan, species-rich groups like carangids, myctophids, triglids and pomacentrids (Hernandez et al., 2003). However, groups which consistently dominate coastal assemblages in temperate Australia, including estuary entrances and enclosed bays, were either rare (e.g. gobiids, engraulids, clupeids, monacanthids) or absent (e.g. blenniids, clinids) during this study (Gaughan et al., 1990; Neira et al., 1992, 1998, 2000; Trnski, 2001; Neira and Sporcic, 2002). This was surprising given the number of species and abundance of adults of these groups in shelf habitats across south-eastern Australia (Gomon et al., 1994; Williams and Bax, 2001), and the proximity of platforms to the Gippsland coastline outcrop (Bax and Williams, 2001). In contrast, larval engraulids, clupeids, gobiids and blenniids were frequent in plankton net samples alongside Gulf platforms, with clupeiforms being by far the most abundant group (Hernandez et al., 2003).

The assemblages obtained during the present study contained larvae and early juveniles from an assortment of epipelagic/coastal-, meso-benthopelagic/oceanic-, soft substrate- and rock/reef-associated taxa. The summer assemblages were dominated by epipelagic schooling species such as *Scomberesox saurus* and *Arripis trutta* (February 1998), and *Trachurus declivis* and *S. saurus* (February 1999), all of which are known to abound in the region (Gomon et al., 1994; Williams and Bax, 2001). In contrast, the overall summer contribution of early stages of hard/soft-habitat associated taxa was comparatively low, even of locally dominant taxa such as *Lepidotrigla* spp. and *Centroberyx affinis* (Gomon et al., 1994; Williams and Bax, 2001). Furthermore, early stages of several fishes that have been observed amongst platforms in the area were notably absent, as was the case of *Caesioperca lepidoptera*, a serranid which aggregates in schools around supporting legs and deep crossbeams at the base of some platforms (F.J. Neira,

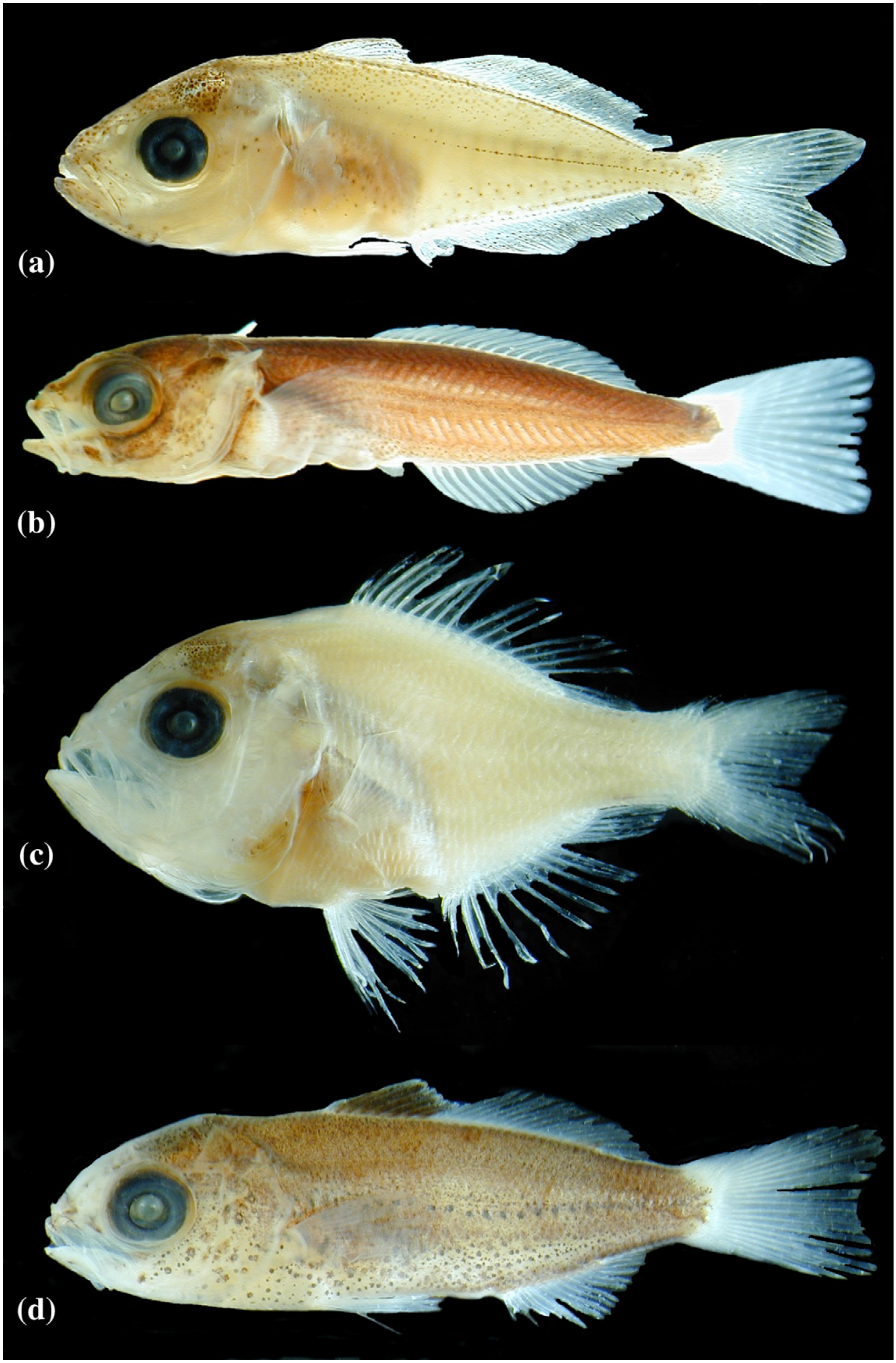

Fig. 8. Selected late postflexion (LP) and early juvenile (EJ) stages of fishes caught during this study: (a) *Trachurus declivis* (16.2 mm EJ); (b) *Bovichtus angustifrons* (14.3 mm LP); (c) *Centroberyx affinis* (13.9 mm LP); and (d) *Arripis trutta* (12.3 mm EJ). (a), (c) and (d) were caught in February 1999; (b) in August 1998.

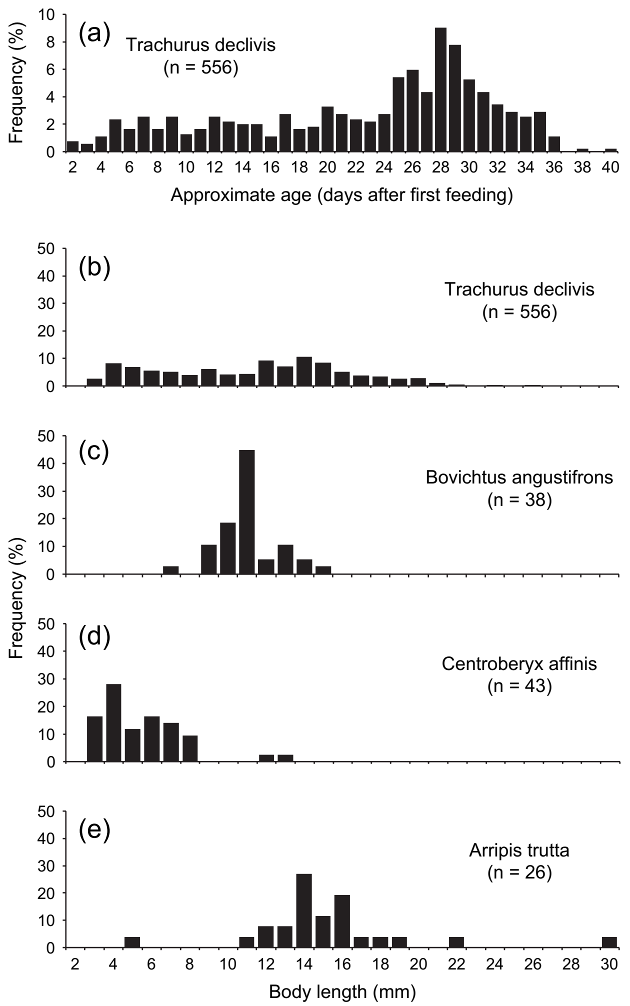

Fig. 9. Length-frequency histograms (b–e; mm BL) and age-frequency histogram (a; days after first feeding) of selected fishes caught during this study: (a) (b), *Trachurus declivis*; (c), *Bovichtus angustifrons*; (d), *Centroberyx affinis*; (e), *Arripis trutta*.

pers. observ.), and which are known to inhabit nearby rock/reef outcrops (Gomon et al., 1994; Williams and Bax, 2001). The overall low contribution of early stages of hard/soft-habitat associated taxa during this study parallels findings in Gulf platforms, where reef-dependent and reef-associate fishes made up a small percentage of the total plankton net collections (Hernandez et al., 2003).

The most abundant taxon in February 1999, and indeed the entire study, was *T. declivis*, one of the most common small pelagics in shelf waters throughout south-eastern Australia (Williams and Pullen, 1993), and by far the most abundant carangid in terms of biomass following surveys nearby the Bass Strait platforms (Williams and Bax, 2001). The Carangidae is usually one of the most speciose platform-associated families both in terms of species richness and abundance (Hastings et al., 1976; Stanley and Wilson, 1991, 1997; Hernandez et al., 2003). The capture of a relatively high percentage (28%) of preflexion/flexion larvae of this species (<7.0 mm BL, about 2–15 days old) implies that spawning takes place in the vicinity of the survey region. Moreover, the capture of the full range of pelagic sizes of this species, i.e. 3 mm preflexion to ~27 mm early juveniles (2–40 days old), suggests an extended spawning period about the same area unless older larvae/early juveniles actively migrate from other regions. Given the wide distribution of this species in south-eastern Australia, it is highly likely that these stages have originated from the same stock that spawns along shelf waters off southern New South Wales and eastern Tasmania in summer (Jordan, 1997; Jordan et al., 1995).

Myctophids (representing *Diaphus* spp., *Hygophum* spp., *Symbolophorus* spp. and others) dominated in August 1998, but were absent and rare in February 1998 and 1999, respectively. Their presence is likely to be a consequence of passive transport via the northwards intrusion of sub-Antarctic water over the shelf typical of the region in winter (Gibbs et al., 1991). While larval myctophids are common in eastern Bass Strait in winter (Neira et al., 2000), they have also been found to greatly contribute to summer (January) and autumn (April) assemblages elsewhere in south-eastern Australia (Smith and Suthers, 1999). Unique to the winter assemblage was *Bovichtus angustifrons*, a cryptic species endemic to Australasia and common in rock pools, jetty pylons and rock ledges to 15 m (Last et al., 1983; Gomon et al., 1994). Capture of larvae of this typically inshore species suggests that adults may also occur offshore around shallow (top) sections of platforms, although this needs to be confirmed. Either way, it is likely that this bovichtid settles after an extended pelagic larval phase, an observation based on the gap between the length range of the larvae caught (7.0–15.4 mm) and their much larger estimated length at settlement, i.e. >30.1 mm (Sutton and Bruce, 1998). Larvae of *S. punctata* also occurred only in winter, matching the known July-August spawning season of this centrolophid in south-eastern Australia (Bruce et al., 2001).

4.2. Early pelagic juveniles

Pelagic juveniles (transforming/settlement stages) of nine species were captured in this study within a 5-nm radius from the platforms, albeit in very small numbers. This included epipelagic, coastal/oceanic species like *Trachurus declivis, Arripis trutta*, and *Coryphaena hippurus*, and hard/soft habitat-associated species such as *Pseudocaranx dentex*, *Upeneichthys vlamingii* and *Didon nicthemerus*. Whereas the occurrence of the latter species does not necessarily imply that they settle around platforms after completing their pelagic larval life, their proximity rises questions about the importance of these artificial structures as prime offshore real estate for juvenile fishes. Given the limited availability of hard habitats directly around the Bass Strait platform area (Williams and Bax, 2001), it could be argued that they may provide suitable alternative settlement habitats for early juveniles of some species. The opposite argument is that platforms may not be as ideal for settling juveniles compared to smaller, low-relief natural reefs, given their large size, high vertical profile (steep relief), lack of structural complexity and low porosity, coupled with high predation pressures among other factors (Hernandez et al., 2003). However, there is ample field-collected evidence from platforms off California showing that no less than 45 fish species are capable of settling and taking up residence around these structures directly from plankton, notably rockfishes *Sebastes* spp. (Love et al., 2000, 2003). Moreover, late larvae of several coral-reef taxa have been recorded to settle at subsurface artificial-reef moorings positioned 1 km from natural reefs, with apogonids, blenniids and gobiids being among the settlers (Leis et al., 2002). The view that platforms are important de-facto reefs for juveniles of some fishes (Aabel et al., 1997; Stanley and Wilson, 1997, 2003; Love et al., 2000, 2003) clearly contrasts with the argument that their main value is confined only to the increased carrying capacity for adult fishes, and role as potential spawning habitats (Hernandez et al., 2003).

4.3. Influence of summer upwelling

Early stages of nearly twice as many fish taxa occurred in February 1999 ($n = 43$) than February 1998 ($n = 19$). This unexpected finding may be due in part to the slightly greater sampling effort in February of 1999 than 1998 (37 vs. 26 samples). However, it is more likely that the greater number of taxa in February 1999, as well as the far greater number of larvae and early juveniles caught (1099 vs. 102), is linked to the upwelling conditions observed in the region during the sampling days, and which were not detected during the February 1998 survey. Upwelling in the area during 23–24 February 1999 was evident in SST images as a distinct plume of cold, presumably slope water over most of the eastern Bass Strait shelf, and was accompanied by a distinct drop in average water temperature (21.0 to 17.8 °C), as well as strong, upwelling-favourable NE and SE winds (21–27 knots) that lasted for up to 12 hours. Short-lived wind-driven upwelling events bringing cool (down to 14–15 °C), nutrient-rich subantarctic water to the surface are persistent features of eastern Bass Strait during February–March (Rochford, 1977; Gibbs et al., 1986), and contribute to augment the region's primary productivity (Prince, 2001). Evidence of coastal upwelling in February 1999 is further supported by the occurrence of coastal, shelf-spawned larvae of a large number of taxa together with mesopelagic, slope-spawned larvae of taxa such as myctophids and gonostomatids. Although the assemblage was largely dominated by *Trachurus declivis*, the influx of shelf-spawned larvae reflects surface water moving offshore during upwelling, as indicated by the dominant SW current flow recorded during the February 1999 survey, while slope-spawned larvae reflect the concurrent shoreward intrusion of deeper water. The occurrence of such mixed assemblage parallels the larval dynamics in the Sydney shelf during upwelling, and supports the view of considering larval fish diversity as proxy to elucidate local hydrographic processes (Smith and Suthers, 1999).

4.4. Possible source(s) of fishes

While this study has demonstrated that early life stages of a large suite of teleost fish families abound nearby and alongside offshore platforms, the current available data are insufficient to conclude as to the source and/or settlement destination of these stages. However, it is likely that both species composition and abundance around the Bass Strait platforms are closely linked to the ichthyofauna inhabiting hard/soft megahabitats off the Gippsland coastline and, to a lesser extent, those at the south-east corner of mainland Australia (e.g. Howe/Gabo complex) (Bax and Williams, 2001). For example, under the strong SW (offshore) current flow conditions of February 1999 (1.5–1.9 knots at 10 m), advection of larval fishes from the Gippsland outcrop and the Howe/Gabo complex to the center of the platform area would have taken between 13–16 hours and <3 days, respectively. Furthermore, the nearly anticlockwise, tidally-driven flow recorded during those days, i.e. a weak SE-NE-NW flow during morning followed by a much stronger SW flow by early afternoon, could well have enhanced their retention in the area.

As with most ongoing platform fish research (e.g. Hernandez et al., 2003; Love et al., 2003; Stanley and Wilson, 2003), the question of which fishes originate from platforms and which are settlers from adjacent/distant natural reef-habitats requires specific field-based research. This would have to include an assessment of the many features that are likely to make platforms attractive to fishes (e.g. pylons, light, shelter, food availability), and what cues (e.g. visual, auditory, olfactory) do larvae/early juveniles employ to orient and swim towards the structures when originating from distant sources (Aabel et al., 1997; Leis et al., 2002). For example, since the Bass Strait platforms remain brightly lit all the time, it is possible that they may act as giant light traps at night, although the lack of significant day-night differences in larval fish concentrations alongside platforms across all surveys suggests otherwise. In terms of attraction, it may be correct to assume that some of these species behave in a similar manner to late larvae of coral-reef fishes, which are believed to employ a combination of olfactory and auditory cues to locate and settle onto artificial reefs (Leis et al., 2002). The question of whether the Bass Strait platforms constitute an important spawning area cannot be answered with data from this study. Their prime location almost right in the center of a productivity "hotspot" (Prince, 2001), and the presence of both artificial (platforms) as well as adjacent natural reefs, would undoubtedly have confounding effects on the potential source(s) of larval fishes found in this region of south-eastern Australia.

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