Projects #95/043 and #98/130
A collaborative investigation on the usage and stock assessment of bait fishes in southern and eastern Australian waters, with special reference to pilchards (*Sardinops sagax*); extension into Queensland and New South Wales

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Objectives

1. To examine the species composition of purse-seine catches in southern Queensland.
2. To describe the size-structure of the species caught by purse-seining and determine the age-structure of the pilchard population in southern Queensland.
3. To identify the location and timing of clupeoid spawning in southern Queensland.
4. To estimate the spawning biomass of pilchards in southern Queensland using the daily egg production method.
5. To examine the potential impacts of a purse-seine fishery in southern Queensland on populations of predators of baitfish, and on other stakeholders.
6. To develop and assess methods for preventing the encirclement and mortality of dolphins in purse-seine nets.
7. To examine the potential yield of a purse-seine fishery for pilchards in southern Queensland.

Non Technical Summary

Australia's pilchard fisheries expanded rapidly during the 1980s and 1990s. The need for biological information to facilitate ecologically sustainable development of the fisheries in South Australia and Victoria led to the initiation of an FRDC-funded collaborative project (#94/029) in December 1994. The primary need identified for Queensland at that time was for quantitative estimates of baitfish usage.

A proposal in 1995 to develop a purse-seine fishery targeting pilchards in southern Queensland brought the state's needs for biological information on pilchards into line with those of the southern states. This need led to the original collaborative project (#94/029) being expanded in September 1995 to include a 3–year project in Queensland (project #95/043). A 3–year developmental fishery commenced in July 1996. The Queensland research project was extended by 18 months in September 1998 (FRDC project #98/130), primarily to encompass the final year of the developmental fishery and to develop and assess methods for reducing the encirclement and mortality of dolphins. This report presents the results of the two Queensland projects.

The single-vessel in the developmental fishery operated between Double Island Point and Cape Moreton. The fishery was highly selective, with 13 different species of fish being recorded by an independent observer, but only four of these (pilchard, maray, yellowtail and blue mackerel) being recorded on more than ten occasions. Pilchards accounted for 85% of the total catch with another 6% made up by maray. Monthly levels of bycatch ranged from 0.5 to 27% of the total catch in months where the total catch was greater than 10 t. Catch-per-unit-effort of pilchards was highest in late winter–early spring (August–November), when water temperatures were coolest and pilchards were aggregated in the fishing area.

Most pilchards caught in the fishery were at least 15 cm (fork length) and 3–6 years old. Preliminary estimates of instantaneous rates of total mortality (Z) ranged from 0.59 to 2.14 and were used as estimates of natural mortality (M) because of the stock's history of light exploitation.

The main spawning season of pilchards was between July and October, with most spawning occurring between Double Island Point and Caloundra. Maray (*Etrumeus teres*) spawned throughout a similar, but slightly larger area to pilchards, and the peak spawning season was between May and December. Most anchovy (*Engraulis australis*) spawning occurred outside the entrances of the estuarine systems at Caloundra and Jumpinpin, and in Hervey Bay in August 1997, although peak spawning appeared to be in the summer months. Sandy sprat (*Hyperlophus vittatus*) and translucent sprat (*Hyperlophus translucidus*) spawned throughout the study area, but no seasonal patterns were determined.

Spawning biomass of pilchards was estimated in 1997 and 1998 using the daily egg production method (DEPM). Parameters for the DEPM were estimated from samples of pilchard eggs and adults collected during August and September. The estimates of biomass were imprecise, but suggest that the size of the pilchard stock was at least 25000 t in both years. The high degree of uncertainty was due mainly to large variability in the estimates of egg production and problems with estimating spawning fraction and batch fecundity.

The potential effects that a conservatively-managed pilchard fishery in southern Queensland would have on predatory fishes, birds and mammals were assessed using the developmental fishery as a model. Potential ecological (i.e. indirect) effects would be limited by a) the opportunistic feeding habits of the region's predatory species, b) the successful targeting of only one (i.e. pilchards) of the region's many species of potential prey and c) the removal of only a small percentage (e.g. 5–10%) of that species' adult biomass. Potential operational (i.e. direct) effects of a purse-seine-based pilchard fishery would include the accidental encirclement and drowning of dolphins. 77 dolphins were encircled in the developmental fishery between September 1997 and October 1998; 68 of these were released alive and nine died. An analysis of data relating to the use of acoustic "pingers" in the fishery found only a tenuous correlation between deploying pingers and reducing the probability of encircling dolphins. More importantly, the pingers did not prevent dolphin encirclement altogether.

Community concerns about the catches of dolphins led to the temporary prohibition of purse-seining in Queensland in February 1999. An expertise-based Working Group led by Dr Peter Hale (University of Queensland) recommended operational changes aimed at reducing dolphin encirclement and avoiding further mortalities. These recommendations were included in a revised permit issued to the fisher in March 1999. At the same time, the temporary prohibition of purse-seining was lifted, but was put in place again in May 1999, before the Working Group's recommendations were tested. Legislation permanently prohibiting purse-seining is now in place.

Estimates of spawning biomass suggest that southern Queensland could support a viable pilchard fishery with an annual sustainable catch in excess of 1000 t. Yield would not be limited by demand as Australian and international markets are large and under-supplied. However, the potential for bad weather to limit yield of a purse-seine fishery in the region was highlighted by the small number of successful commercial catches during August and September 1998. As purse-seining is arguably the only suitable method for commercially fishing pilchards in southern Queensland, the major factor currently limiting yield is Queensland legislation that prohibits the use of purse-seine nets. The objective of this legislation is to prevent dolphin encirclements and mortalities. An alternative approach, which would allow purse-seining and protect dolphins, would be to implement the recommendations of the expertise-based Working Group.

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Chapter 1. General Introduction

1.1 Background

1.1.1 Australian pilchard fisheries

Fisheries biologists have recognised the commercial potential of Australia's pilchard stocks for many years, but development of substantial pilchard fisheries was limited until recently by lack of demand (e.g. Whitley 1937; Dakin 1938; Blackburn 1949; Blackburn and Downie 1955; SCP Fisheries Consultants 1988; Fletcher 1991; Ward *et al.* 1998). Annual Australian landings were below 3000 t prior to 1982 but increased to approximately 8000 t in 1984 and to more than 15000 t in 1995 (Fletcher 1991; Kailola *et al.* 1993; Ward *et al.* 1998). Catches from the Albany and Fremantle regions in Western Australia were the first to increase (Fletcher 1991) and were followed by expansion of the fishery into new areas in Bremer Bay and Esperance. Catches also increased in Port Phillip Bay (Victoria) as well as in Spencer Gulf and the west coast region of South Australia (Fletcher 1990, Ward *et al.* 1998). Annual landings of pilchards did not increase in Queensland or New South Wales during the same period (Dixon *et al.* 1996).

The increase in demand for pilchards was driven initially by recreational and commercial fishers who use pilchards as bait (SCP Fisheries Consultants 1988; Fletcher 1990; Kailola *et al.* 1993). More recently, the quantities of pilchards destined for human consumption and for use as fodder in the tuna mariculture industry have also increased (Simpson 1992; Glaister and Diplock 1993; Dixon *et al.* 1996; Jones *et al.* 1995).

The increasing catches of pilchards throughout Australia raised concerns about sustainability because of the history of collapse of fisheries for small pelagic fishes (e.g. Fletcher 1991; Glaister and Diplock 1993; Fletcher *et al.* 1996a; Kailola *et al.* 1993). The possibility of local depletion of stocks was also identified for areas such as southern Queensland, where demand for pilchards was high but local stocks were relatively unexploited (Glaister and Diplock 1993; Dixon *et al.* 1996).

1.1.2 Recent developments

Mass mortality events in 1995 and 1998 significantly affected pilchard stocks and fisheries throughout Australia, especially in South Australia and Western Australia (Fletcher *et al.* 1997; Griffin *et al.* 1997; Hyatt *et al.* 1997; Jones *et al.* 1997; Whittington *et al.* 1997; Ward and McLeay 1999b; Dan Gaughan pers. comm.). These events led to an increased awareness of the risks of disease introduction associated with using imported frozen pilchards as bait or fodder (Humphrey 1995; Hine and MacDiarmid 1997; Fletcher *et al.* 1997; Jones *et al.* 1997; Ward *et al.* 1999). Ward *et al.* (1999) suggested that sustainable harvesting of Australia's lightly exploited, east-coast stocks may lead to a decrease in the quantity of frozen pilchards imported into Australia as well as helping to alleviate pressure on pilchard stocks in other states.

1.1.3 Queensland

Queensland imports large quantities (e.g. 2000–3000 t annually) of pilchards from Western Australia, New South Wales and California, for use as recreational and commercial bait (approximately 90%) and for human consumption (approximately 10%) (Dixon *et al.* 1996). Local stocks of pilchards in southern Queensland have been exploited only lightly, mainly by ocean beach fishers using seine nets to target other species and have, therefore, received limited attention from scientists and resource managers (SCP Fisheries Consultants 1988; Glaister and Diplock 1993; Dixon *et al.* 1996).

A proposal to develop a purse-seine fishery targeting pilchards in southern Queensland met with considerable opposition. The Queensland Fisheries Management Authority initially rejected the proposal, but a successful appeal to the Fisheries Tribunal resulted in the issuing of a 3–year permit in July 1996. This permit allowed a single purse-seine vessel to take up to 600 t per annum of four species of clupeoids: *Sardinops sagax* (pilchard or sardine), *Etrumeus teres* (maray or big-eye pilchard), *Engraulis australis* (anchovy or frog-mouth pilchard) and *Hyperlophus vittatus* (white pilchard). Other conditions of the permit included carrying an observer onboard the vessel during purse-seining operations and paying a fee to the Queensland Fisheries Management Authority equal to 5% of the gross value of the catch.

1.2 Need

1.2.1 Stage 1 (#95/043)

Commonwealth and State Government legislation and policies require that management strategies for the sustainable use of marine resources are based on quantitative data. Thus there was initially a need for biological information which would facilitate ecologically sustainable development of pilchard fisheries in South Australia and Victoria. This need led to the commencement of the original collaborative project (project #94/029; Ward *et al.* 1998).

The primary need identified for Queensland at that time was for estimates of total baitfish usage (Dixon *et al.* 1996). In accordance with the state's *Fisheries Act 1994*, the proposal to develop a pilchard fishery in southern Queensland brought the state's needs in line with those of South Australia and Victoria, and led to the establishment of project #95/043 in September 1995.

1.2.2 Stage 2 (#98/130)

Logistical difficulties encountered during the first year of the developmental fishery (1996/97) delayed the start of intensive fishing for pilchards until mid–1998, towards the conclusion of project #95/043. The ongoing need to assess the fishery's potential was facilitated by extending the project to cover the last year of the 3–year developmental fishery.

The need to assess inter-annual variations in the stock-size of pilchards was highlighted by studies conducted elsewhere in Australia (Fletcher *et al.* 1996a, 1996b; Ward *et al.* 1998). These variations are potentially large, and have significant implications for management of the resource, especially in regions such as southern Queensland which are close to the geographical limits of the species.

Samples of adult fish are needed to monitor seasonal changes in reproductive status of populations and to estimate population parameters required for estimating spawning biomass using the daily egg production method. Results from the collaborative project (#94/029) and Stage 1 of this project indicated there is a need to supplement samples collected from commercial catches with samples collected independent of the fishery. A multi-mesh gill-net, which was developed during Stage 1 of the project, needed refinement and testing.

Observations made during Stage 1 of the project indicated that dolphins were occasionally encircled and drowned in the developmental fishery. The need to develop and assess mitigating procedures was identified because the incidental capture of dolphins was considered a potential impediment to the establishment of an ongoing fishery.

1.3 Objectives

The original objectives of Stage 1 of the project (#95/043) were:

1. Identify the main clupeoid species accessible in south east Queensland and experimentally determine the seasonal abundance of these species.
2. Define the size- and age-structure and examine the reproductive cycle of the major small pelagic species present in south east Queensland.
3. Estimate egg densities and spawning biomass indices of the small pelagic species present in south east Queensland.
4. Examine methods of estimating potential fishery yields for a limited purse-seine fishery in south east Queensland.
5. Examine the species composition from experimental purse-seining in south east Queensland and comment on areas of possible conflict with other users.
6. Examine the potential impact of developing and existing purse-seine fisheries on predators.

The original objectives of Stage 2 of the project (#98/130) were:

1. To obtain catch-at-age data from a virgin stock in order to compare estimates of spawning biomass of pilchards obtained using the Daily Egg Production Method and age-based simulation models.
2. To describe the inter-annual variations in the spatial and temporal patterns of distribution and abundance of clupeoid eggs/larvae in southern Queensland and northern New South Wales.
3. To develop, apply and assess a new technique for obtaining samples of adult pilchards required to (i) obtain fishery-independent estimates of population structure, (ii) describe seasonal changes in reproductive status and (iii) calculate adult reproductive parameters required for application of the DEPM.
4. To develop and assess methods for preventing bottlenose dolphins (*Tursiops truncatus*) being encircled in purse-seine nets.

1.4 Revised Objectives

As most objectives of Stage 2 of the project were extensions of Stage 1 objectives, they have been combined and revised. This provides a simpler framework within which to discuss the results of the project. The revised objectives were:

1. To examine the species composition of purse-seine catches in southern Queensland.
2. To describe the size-structure of the species caught by purse-seining and determine the age-structure of the pilchard population in southern Queensland.
3. To describe the time and location of clupeoid spawning in southern Queensland.
4. To estimate the spawning biomass of pilchards in southern Queensland using the Daily Egg Production Method.
5. To examine the potential impacts of a purse-seine fishery in southern Queensland on populations of predators of baitfish, and on other stakeholders.
6. To develop and assess methods for preventing the encirclement and mortality of dolphins in purse-seine nets.
7. To examine the potential yield for a purse-seine fishery in southern Queensland.

Chapter 2. Species Composition of Catches in the Developmental Pilchard Fishery

Objective: *To examine the species composition of purse-seine catches in southern Queensland.*

This objective was achieved by monitoring the catches of the developmental fishery. Catch composition data were obtained from the commercial logbook and from reports of an observer. 73 purse-seine shots were carried out; ten before the start of the observer-program, 11 shots during the remainder of 1997 and 52 shots in 1998. All fishing occurred between Double Island Point and Cape Moreton.

The fishery was highly selective. Despite the diversity of fish species present in southern Queensland, only 13 different species were recorded by the observer, and only four species (pilchard, maray, yellowtail and blue mackerel) were recorded on more than ten occasions each. Pilchards accounted for over 95% of the catch (by weight) in nearly half the shots and 85% of the total catch during the observer-program. Maray made up a further 6% of the total catch. Bycatch ranged from 0.5–27% of the total catch during months in which it was greater than 10 t.

The catch-per-unit-effort of pilchards in southern Queensland was highest in late winter–early spring (August–November), and lowest in late summer–autumn (January–May). This seasonality of catch rate reflected the aggregation of pilchards in the fishing grounds. It was also correlated with sea-surface temperature in the region, which was lowest (20–24°C) between July and November.

2.1 Methods

2.1.1 Fishing method

Schools of baitfish were located using sonar and sounders. Once a suitably-sized school was detected, the vessel was anchored and underwater and overhead lights were deployed for 1–5 hours to concentrate the fish, and attract other schools in the area. The lights were transferred to an inflatable tender and moved slowly away from the vessel (e.g. 100 m). The net was set around the tender and fish a short time later, typically an hour or so before dawn.

Schools of baitfish spotted on the surface during daylight were occasionally fished. The position of the school was monitored with side-scanning sonar during the setting of the net.

Captured fish were forced into a cage at the bunt-end of the net during retrieval. The cage and fish were held alongside the vessel during processing (Figure 2.1). Fish were pumped into a hopper on the fishing vessel after the cage was lifted slightly to concentrate fish near the pump's inlet (Figure 2.2). A conveyor belt (Figure 2.3) transported fish from the hopper into and through a freezer where they were "individually quick frozen" (IQF).

2.1.2 Catch compositions

The permit-holder in the developmental fishery was required to complete a commercial logbook, providing dates, locations and sizes of catches of target species between 20 March 1997 and 16 October 1998. Catches of some bycatch species were recorded from May 1998.

An observer-program was initiated by the Queensland Fisheries Management Authority on 17 September 1997 to assist the monitoring of catches and fishing procedures. The observer recorded; the quantity of each species in each shot (estimated from counts of boxes multiplied by the average weight of boxes), the time spent searching for fish (effort) and the sea-surface temperature (SST).

Figure 2.1. The cage for holding fish alongside the vessel during processing.

Figure 2.2. The cage lifted to assist pumping of fish onto fishing vessel.

Figure 2.3. The conveyor belt leading to the "IQF" freezer.

2.2 Results

The Suborder Clupeoidei (Order Clupeiformes) consists of 4 families; Chirocentridae, Clupeidae, Engraulidae and Pristigasteridae. Approximately 350 species of clupeoid have been identified, 60 of which occur in Australia and 16 in southern Queensland (Whitehead 1985; Table 2.1).

Table 2.1. Species of clupeoid in the world, Australia and southern Queensland (SQ). Data from Whitehead (1985) and Whitehead *et al.* (1988).

FAMILY and Sub-family *Australian Genera* (Number of Australian Species)	Number of Species World	 Australia	 SQ	Species in southern Queensland
CHIROCENTRIDAE	2	2	2	
Chirocentrus (2)				*C. dorab*, *C. nudus*
CLUPEIDAE				
Dussumieriinae	13	4	1	
Etrumeus (1), *Spratelloides* (3)				*E. teres*
Clupeinae	68	18	7	
Sprattus (1), *Sardinops* (1), *Herklotsichthys* (8), *Amblygaster* (2), *Sardinella* (4), *Escualosa* (1)				*S. sagax, H. castelnaui, H. quadrimaculatus, A. sirm, S. gibbosa, S. lemuru, E. thoracica*
Pellonulinae	43	3	2	
Potamalosa (1), *Hyperlophus* (2)				*H. translucidus* *H. vittatus*
Allosinae	31	0	0	
Dorosomatinae	22	4	0	
Nematolosa (3), *Anodontostoma* (1)				
PRISTIGASTERIDAE	34	2	0	
Ilisha (1), *Pellona* (1)				
ENGRAULIDAE	139	27	4	
Engraulis (1), *Encrasichola* (3), *Stolephorus* (8), *Thryssa* (11), *Papuengraulis* (1), *Setipinna* (3)				*E. australis, S. carpentariae, T. aestaria, T. baelama*
TOTAL	352	60	16	

2.2.1 Fish catches in the developmental fishery

Purse-seining was carried out between Double Island Point and Cape Moreton (Figure 2.4). 73 shots (21 in 1997 and 52 in 1998) were made on 71 different days between 20 March 1997 and 16 October 1998, in depths of 17–64 m (Figure 2.5 and Figure 2.6). Ten of these shots were made before the observer-program started in September 1997. Pilchard (the main target species) was recorded in most shots and in the largest quantity of all species caught (Table 2.2). Only three other species (maray, yellowtail and blue mackerel) were recorded on more than ten occasions each. Several species of other fish and invertebrate were caught on fewer than five occasions each.

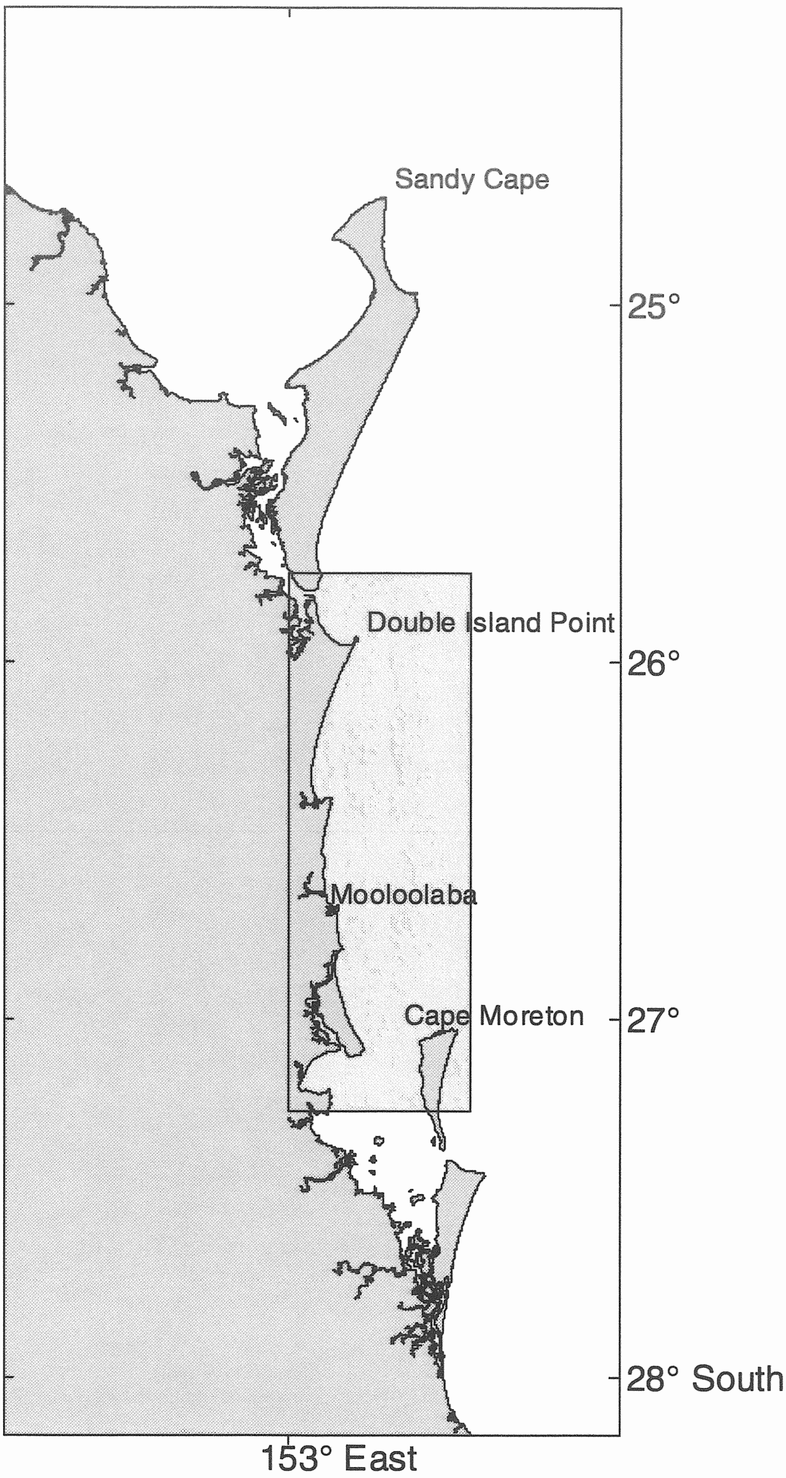


Figure 2.4. Area of commercial purse-seine fishing in southern Queensland in 1997–1998, from Sandy Cape to the state border. Shaded area indicates extent of Figure 2.5 and Figure 2.6.

Table 2.2. Summary of catches (kg) recorded in commercial logbook and observer reports for the developmental fishery in Queensland. The number of occasions each species was caught is shown in parentheses. * The observer-program started in September 1997.

	1997		1998	
	Logbook	Observer* Reports	Logbook	Observer Reports
Sardinops sagax (pilchard)	72 628 (19)	47 261 (11)	170 020 (47)	171 076 (46)
Etrumeus teres (maray)	2 100 (4)	685 (5)	14 527 (12)	15 634 (20)
Engraulis australis (anchovy)	1 472 (3)	68 (2)		
Trachurus novaezelandiae (yellowtail)		318 (6)	7 728 (24)	7 399 (24)
Scomber australasicus (blue mackerel)		929 (8)	8 481 (24)	10 916 (34)
Decapterus spp. (scad)		1 (1)	167 (2)	2 630 (6)
Amblygaster sirm (northern sardine)				1 (1)
Sarda sp. (bonito)				3 (1)
Bothidae (unidentified flatfish)		1 (1)		
Priacanthus macracanthus (bullseye)				1 020 (4)
Squid		5 (2)		4 (2)
Pomatomus saltatrix (tailor)				20 (1)
Sillago sp. (whiting)		1 (1)		1 (1)

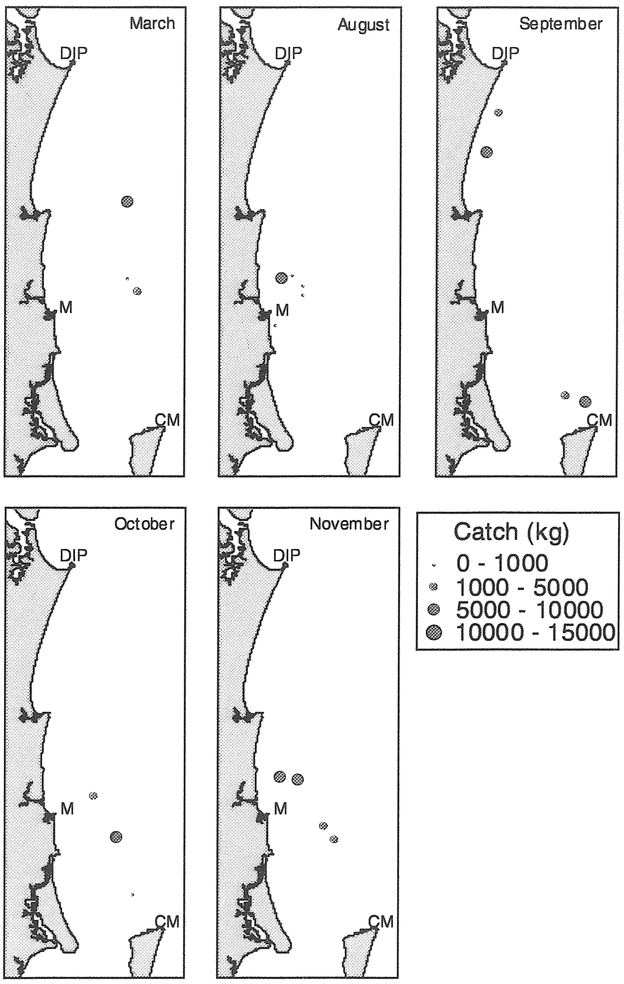


Figure 2.5. Catches of pilchards and maray combined (kg) as recorded in the developmental fishery logbook for 1997. DIP, Double Island Point; M, Mooloolaba; CM, Cape Moreton.

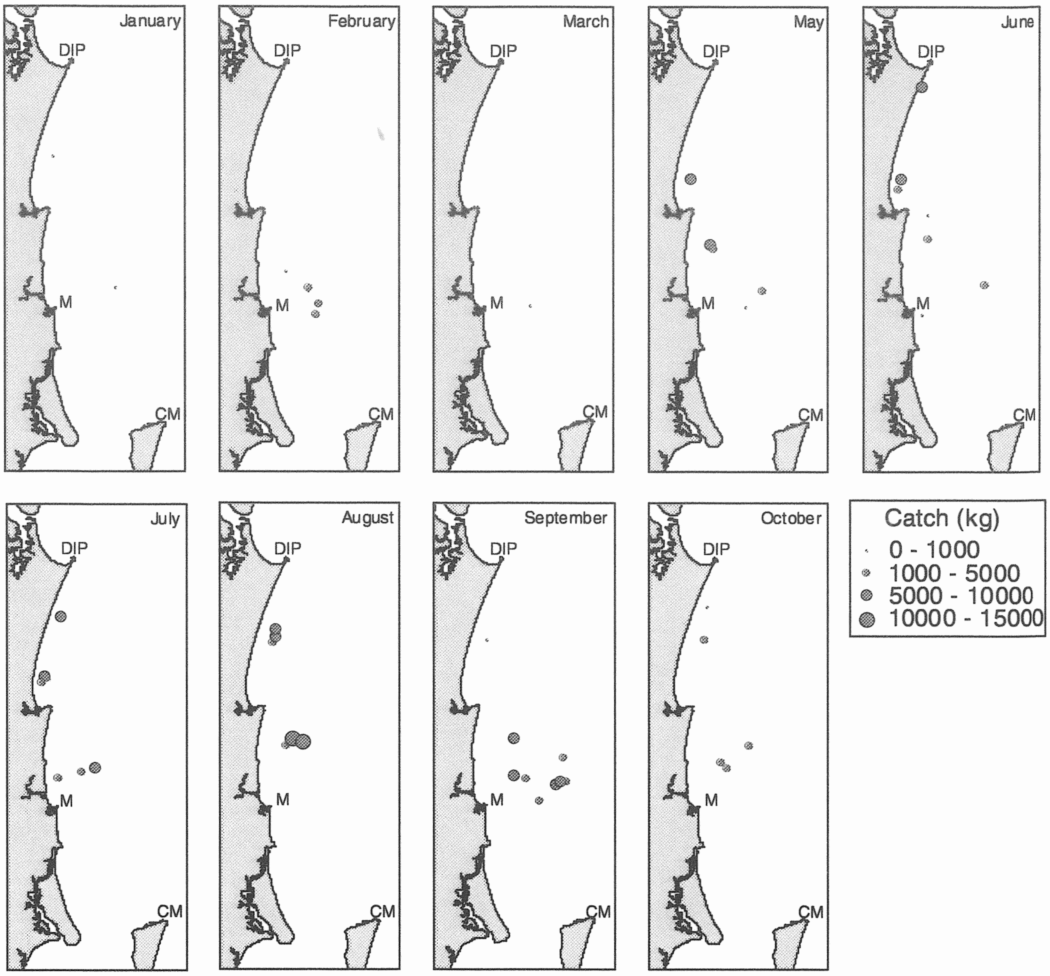


Figure 2.6. Catches of pilchards and maray combined (kg) as recorded in the developmental fishery logbook for 1998. DIP, Double Island Point; M, Mooloolaba; CM, Cape Moreton.

Catches of target species (pilchard, maray) recorded in the commercial logbook differed slightly to those estimated by the observer. Most of these differences were related to inconsistencies in differentiating the catches of the two species, rather than discrepancies in the estimated quantities caught. There were more and larger differences when comparing the catches of bycatch species. Most of these differences are explained by the fisher not differentiating between species (e.g. scad and blue mackerel) and by their being no provision in the logbook to record bycatch.

Pilchards accounted for at least 95% of the catch weight in nearly half (31) of the shots and 85% of the total catch during the observer-program, with another 6% made up by maray. Low catches of pilchards between January and May 1998 coincided with the warmest SST recorded during the year (24–27°C) (Figure 2.7).

Monthly percentages of bycatch (all non-target species, including discards expressed as a percentage of the total catch) ranged from 0.5–75% . The highest percentage occurred in January 1998, when 576 kg of pilchards, 756 kg of blue mackerel and 1000 kg of bullseye were caught in the only successful shot for the month. Bycatch was less common in months where total catches were greater than 10 t, ranging from 0.5–27%.

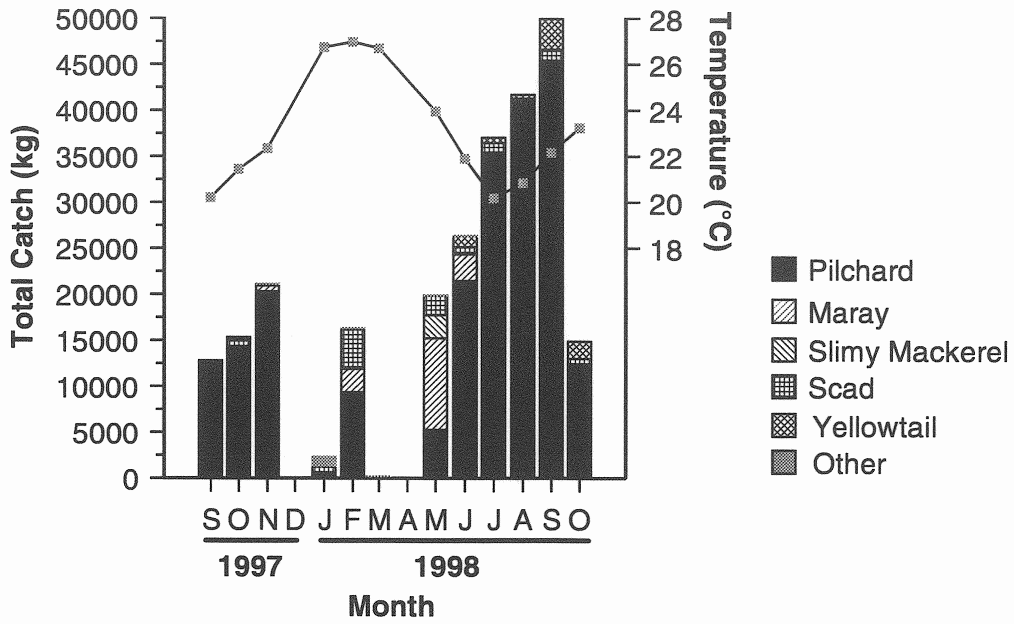


Figure 2.7. Total monthly catches in the developmental fishery, and mean monthly sea-surface temperatures (line) recorded in the observer reports.

2.2.2 *Catch and effort*

There was no fishing in December 1997 or April 1998 (Figure 2.8), due to a combination of lack of demand, lack of fish and bad weather. Extensive effort was expended in January–March 1998, but catches were small. Catch-per-unit-effort (CPUE) was highest in late winter–early spring (August–November), and lowest in late summer–autumn (January–May).

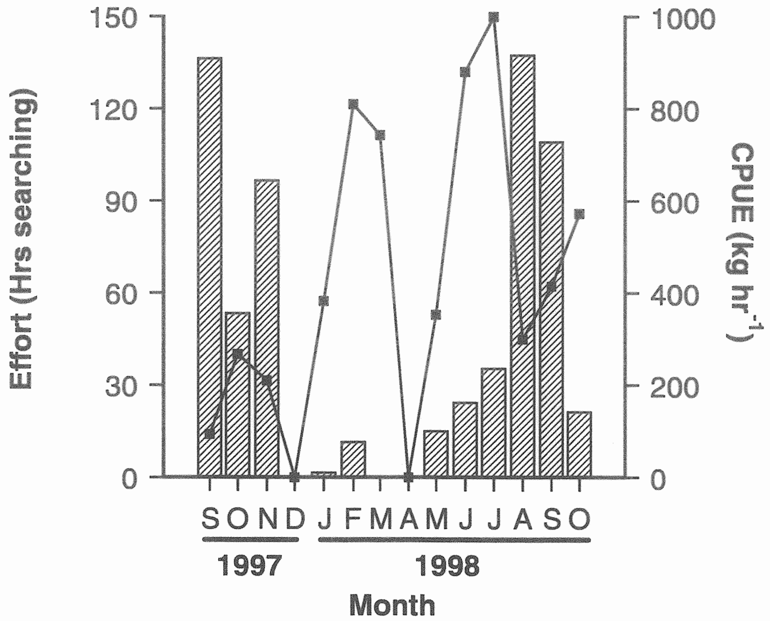


Figure 2.8. Monthly effort (solid squares) and pilchard catch per unit effort (bars) in the developmental fishery, calculated from data recorded in the observer reports.

2.3 Discussion

2.3.1 Accessible species

A diverse assemblage of small pelagic fishes, including clupeoids, carangids and scombrids, exists in the waters of southern Queensland. However, the developmental fishery was highly selective and only a small number of theses species were caught regularly. The selective nature of the fishery can be attributed to two factors; high demand for pilchards, and the ability of the fisher to target pilchards successfully.

There was a high demand for the high-quality pilchards that had been "individually quick frozen" (IQF) on board the fishing vessel (see Chapter 8). Maray were not regarded as highly by the fisher, despite their similar appearance to pilchards, because they were more difficult to keep alive prior to processing and spoilt quickly once dead. Even maray that were processed quickly, resulting in good quality frozen product, were less favoured as bait than pilchards because they were softer and spoilt more quickly when thawed.

Data collected during the observer-program indicated that schools of small pelagic fishes in offshore waters of southern Queensland are not always complex multi-species assemblages, thus assisting the targeting of pilchards. The knowledge that large pilchard schools occurred in the fishing area encouraged the fisher to continue searching, even after he located a significantly-sized school of fish if he believed it was not dominated by pilchards. The fisher assessed the composition of schools by interpreting sonar and sounder output, and by sampling the school with bait jigs or a gill-net.

2.3.2 Seasonal abundance of pilchards

Monthly catches and CPUE of pilchards suggest they are most abundant in southern Queensland during winter and spring (August–November). This period coincides with coolest water temperatures and peak spawning in the region (see Chapter 4) and is consistent with the belief that pilchards migrate from northern New South Wales into Queensland to spawn. An alternative explanation for the high CPUE in winter and spring is that pilchards aggregate, and, thus become more catchable, during their main spawning season. The may then disperse and/or move south during the warmer months resulting in lower CPUE.

Data collected in southern Queensland during annual egg abundance surveys during the peak spawning season (August–September) indicated that most spawning pilchards were concentrated in an area between 26°15' and 26°45'(see Chapter 5). This was also the area where most fishing occurred. The CPUE data, therefore, reflect the abundance of pilchards in this relatively small area rather than throughout southern Queensland. The dangers of relying on trends in CPUE to monitor stocks of schooling pelagic fish have been discussed by many authors (e.g. Butterworth 1981; Lluch-Belda *et al.* 1989; Hilborn and Walters 1992; Kawasaki 1993). The aggregating behaviour or these fish has been shown to result in CPUE remaining high, despite an overall decrease in their abundance (hyperstability), when fishing occurs in the high density areas.

Monthly catches were affected by factors additional to the seasonal patterns of abundance of fish and the amount of effort during the month, such as weather conditions and gear problems. These additional factors affect the accuracy of the CPUE data, especially when only a single vessel is being considered over a short period of time. For example, weather conditions sometimes reduced effort, when strong winds and rough seas prevented the vessel from leaving port. On other occasions, the vessel was able to locate fish (i.e. expend effort), but then unable to shoot the net successfully due to a change in conditions. Similarly, gear problems sometimes reduced the catch directly, when they occurred during the setting of the net (e.g. ropes breaking or the net tearing allowing fish to escape) and sometimes indirectly by reducing fishing effort (e.g. the time required to repair gear).

2.3.3 Management Considerations

The results presented in this chapter show that a fishery targeting pilchards with minimal bycatch could be established successfully in southern Queensland. If one were to develop, the logbook design would need to be reviewed to ensure that accurate data are collected in the absence of an observer-program. For example, the fisher did not always differentiate between pilchards and maray or scad and blue mackerel, as they were generally packaged together and the total number of boxes was used to estimate the total catch. Only occasionally, did the fisher estimate and record the relative percentages of two co-packaged species. The logbook would also need to be changed to record bycatch for each shot formally, as this was done on an *ad hoc* basis in the developmental fishery. Finally, there is a need to collect information that may be useful in interpreting effort data, such as reasons for not setting the net. In particular, it would be useful to be able to identify occasions when the lack of fish was the primary reason.

Chapter 3. Size- and Age-Structure of Pilchards, and other Small Pelagic Species

Objective: *To describe the size-structure of the species caught by purse-seining and determine the age-structure of the pilchard population in southern Queensland.*

This objective was achieved using fish collected from commercial purse-seine, beach-seine, prawn-trawl and fish-trawl catches, and caught by fishery-independent gill-netting and bait-jigging. Ages of pilchards were estimated by counting annual growth increments in whole otoliths.

Most pilchards caught in southern Queensland were at least 15 cm and 3–6 years old. Fish smaller than 10 cm were caught on only two occasions. The most likely explanation for the general absence of very small/young fish in catches is that they do not occur on the fishing grounds.

Linearised catch-curves of pilchards in southern Queensland and northern New South Wales were used to estimate instantaneous rates of total mortality (Z). Total mortality ranged from 0.59 to 2.14 and was used as preliminary estimates of natural mortality (M) because of the stock's history of light exploitation.

3.1 Methods

3.1.1 Collection of samples

Samples were obtained using a variety of techniques: commercial purse- and beach-seining, commercial prawn- and fish-trawling, experimental gill-netting and bait-jigging. The gill-net used in this study was made of multiple panels consisting of three different mesh sizes; 25 mm (1 inch), 29 mm (1.125 inches) and 32 mm (1.25 inches) (see Chapter 5). Prior to the commencement of the developmental fishery in Queensland, samples of target and bycatch species were collected from commercial purse-seine catches in New South Wales and fish-trawl and beach-seine catches in southern Queensland. Between 1997 and 1998, samples of 100–200 pilchards were collected by the observer from most shots in the developmental fishery. Gill-netting and bait-jigging were carried out during the annual egg surveys (Chapter 5) and during monthly egg surveys (Chapter 4).

All fish were measured (fork length, FL; ± 1 mm), put into 0.5 cm size classes and the first 3–5 fish in each size class kept for further analyses (age determination and reproductive studies).

3.1.2 Age-determination (pilchards)

Sagittal otoliths were extracted from pilchards, cleared of adhering tissue in water and dried at room temperature (approximately 25°C) for at least one week. They were then packaged and sent to the Central Ageing Facility at the Marine and Freshwater Research Institute in Victoria for age-determination.

Whole otoliths were immersed in water and viewed at 16× magnification against a black background with reflected light. Customised image analysis software enabled on-screen video digitising of each otolith. Otoliths that were difficult to read on the monitor were examined directly under the microscope. Ages were not estimated for broken, deformed or crystallised otoliths.

The number of translucent (dark) zones was counted along a transect from the primordium to the posterior edge on the distal (concave) face of the otolith. The distal surfaces of whole otoliths exhibited a central core area which was predominantly opaque, but had between one and three faint translucent zones. These inner zones were considered to form during the larval or juvenile stages and were not counted for age estimation.

Preliminary marginal increment analysis indicated that formation of translucent zones occurred mainly in winter. This was similar to the situation reported by the Central Ageing Facility for South Australian and Victorian pilchards (Ward *et al.* 1998). Otoliths of fish caught a short time before 1 July were examined assuming they were approaching ring formation; evidence of a zone at the edge of the otolith was ignored. Likewise, otoliths of fish caught a short time after 1 July were examined assuming they had formed a zone recently; a zone at the edge of the otolith was assumed even if it was not present. A 1 July birthday was assumed for all pilchards, which allowed the estimation of ages in decimal years.

3.1.3 Growth parameters (pilchards)

Growth of fish was defined using the von Bertalanffy growth equation:

$$L_t = L_\infty \times (1 - e^{(-K \times (T - T_0))})$$

where L_t is the length at time t (mm), L_∞ is the asymptotic length (mm), K is the growth coefficient (years^{-1}) and T_0 is the initial condition parameter (years). Parameters were estimated by a nonlinear least-squares method using Marquardt's algorithm (SAS Institute Inc. 1989).

Growth curves were calculated for each year separately (1995–1999). No small/young fish (< 1 year old) were caught in 1995 or 1996, so lengths-at-age of six small/young fish (85–92 mm, 0.66–0.72 years) caught in 1997 were added to the 1995 and 1996 sets of data, and growth parameters were estimated using the combined data.

3.1.4 Age-structure (pilchards)

Age-length data were pooled into two periods each year, period–1 (January–June) and period–2 (July–December). Eight age-length keys (proportions) were constructed, one for each year × half-year-period combination (see Appendices).

Length-frequency data were pooled by state (Queensland or New South Wales), year, period and gear. Length-frequencies of fish caught by purse-seining in Queensland in 1997 and 1998 were analysed twice, once weighted by the size of the catch and once unweighted. Length-frequencies were converted to age-frequencies by multiplying by the appropriate age-length keys and summing the number of fish in each age-class.

Estimates of the instantaneous rate of total mortality (Z) were obtained from linearized catch curves (Sparre and Venema 1992). Mortality rate was assumed to equal the negative slope of the regression of the natural logarithm of frequency on age for age-classes that had fully recruited to the fishery.

3.2 Results

3.2.1 Pilchards

3.2.1.1 Size-structure

A total of 20919 fish, belonging to nine species, were collected and measured between 1995 and 1998 (Table 3.1). Pilchards were collected more often, and in greater numbers than any other species.

Table 3.1. Numbers of samples collected from commercial beach-seines (BS), purse-seines (PS) prawn-trawls (PT) and fish-trawls (FT) and fishery-independent gill-netting (GN) and jigging (J) in northern New South Wales and southern Queensland between 1995 and 1998. Total numbers of fish collected and measured are shown in parentheses.

	Queensland						New South Wales	
	BS	PS	FT	PT	GN	J	BS	PS
Pilchard	3 (235)	64 (11241)	23 (1645)	1 (66)	12 (931)	3 (69)	2 (366)	18 (3329)
Maray		15 (702)	6 (383)		5 (234)	3 (24)		4 (87)
Blue mackerel		15 (347)	1 (9)		2 (7)	3 (13)		
Yellowtail		7 (159)	2 (2)			1 (1)		1 (1)
Slender scad		7 (246)	1 (31)		1 (20)			
Indian scad		5 (23)	1 (1)					
Anchovy		2 (531)	1 (3)				1 (78)	
Northern sardine		3 (37)						
Gold stripe sardine		1 (98)						

Two general size-classes were evident in the monthly size-distributions of pilchards collected from commercial beach- (Figure 3.1) and purse-seine (Figure 3.2) catches in New South Wales. The smaller size-class was approximately 12–15 cm and the larger class was approximately 15–18 cm. Samples from beach-seines contained the larger-sized fish only, whereas samples from purse-seines contained both size-classes with the smaller class predominating in most months.

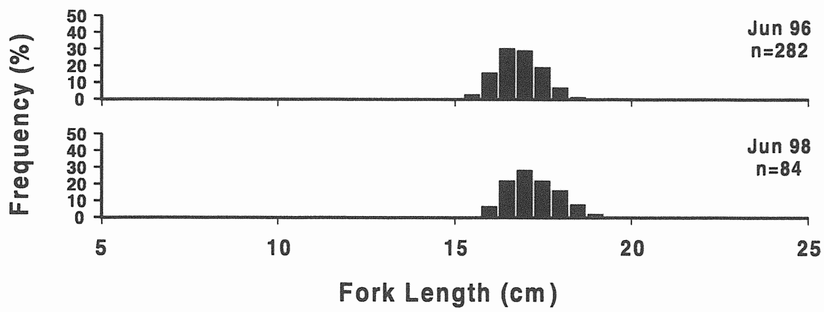


Figure 3.1. Length-frequencies of pilchards collected from commercial beach-seine catches in northern New South Wales.

The size-distributions of fish collected from beach-seine catches in Queensland in July 1996 and June 1998 (Figure 3.3) were similar to those samples caught by the same method in New South Wales at approximately the same time. They were also similar to those of samples caught by purse-seining in Queensland during most months (Figure 3.4).

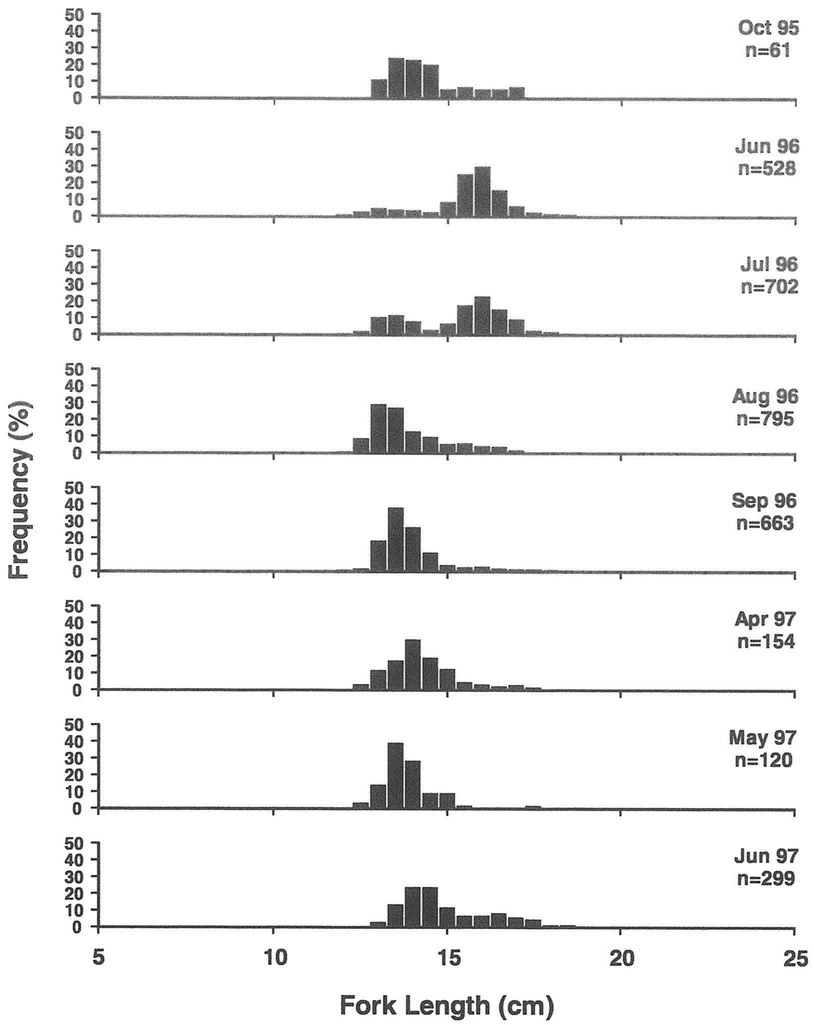


Figure 3.2. Length-frequencies of pilchards collected from commercial purse-seine catches in northern New South Wales.

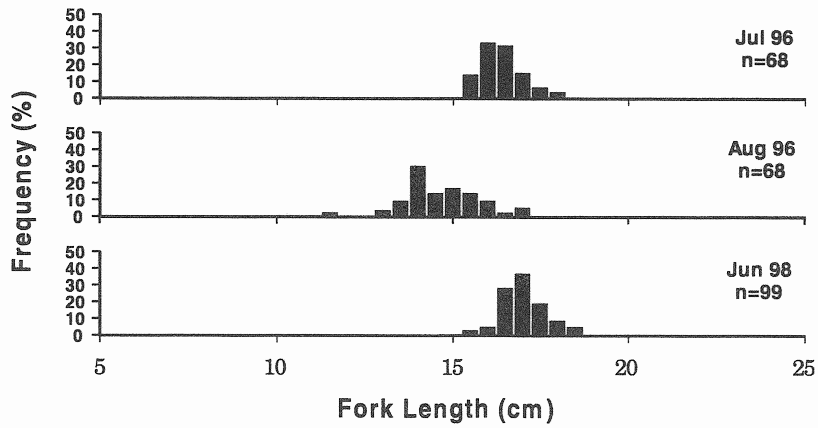


Figure 3.3. Length-frequencies of pilchards collected from commercial beach-seine catches in southern Queensland.

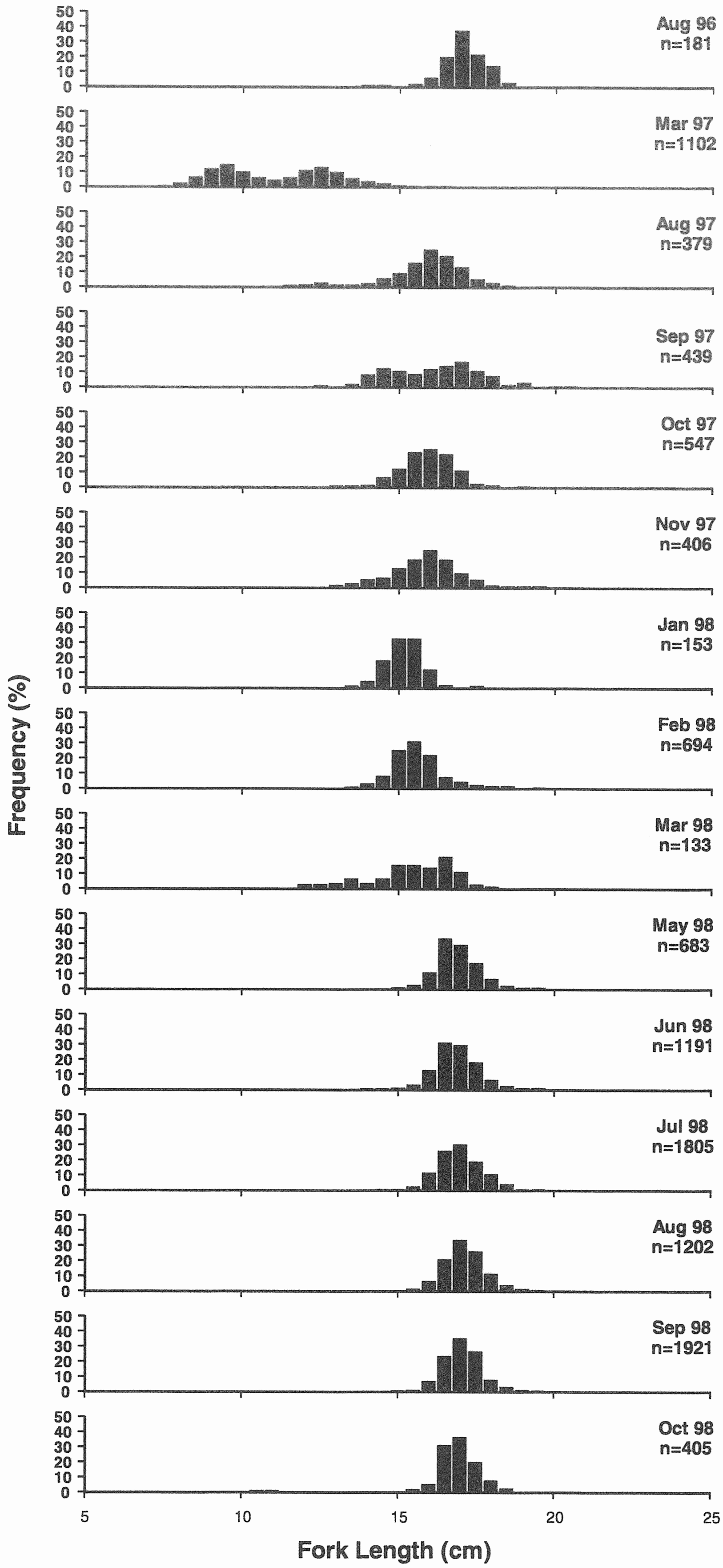


Figure 3.4. Length-frequencies of pilchards collected from commercial purse-seine catches in southern Queensland.

Most fish collected from purse-seine catches in Queensland were in a single size class, approximately 15–18 cm, which is the same size as fish in the larger of the two size-classes evident in purse-seine catches from New South Wales. The most obvious exception to this general pattern was the size-distribution of fish collected from two catches in March 1997. Fish collected during that month were much smaller and formed two size classes, one approximately 8–11 cm and the other approximately 11–14 cm.

The size-distributions of fish collected from fish-trawl catches in Queensland during most months were similar to those caught by purse-seining in New South Wales during the same months (Figure 3.5). Most fish were between 12 and 18 cm in length, although smaller fish (<10 cm) were collected in February 1997. This was approximately the same time that small fish were collected from purse-seine catches in Queensland.

A single sample of pilchards between 15 and 19 cm in length was collected from a prawn-trawl in Queensland in March 1998 (Figure 3.6).

Pilchards between 11 and 19.5 cm were caught in the experimental gill-net in 1997 and 1998 (Figure 3.7). Most monthly size-distributions of samples were similar to those of samples from purse-seine catches during the same months, except in November 1997. A bimodal size-distribution was evident in the gill-net samples during that month, with one size class of fish at 11–13 cm and the other at 14–16 cm. This was in contrast to the wide ranging, but unimodal size-distribution of the samples from purse-seine catches.

Few pilchards were caught by jigging. The size-distributions of samples in September 1997 and 1998 were similar to those of samples from purse-seine catches during the same months.

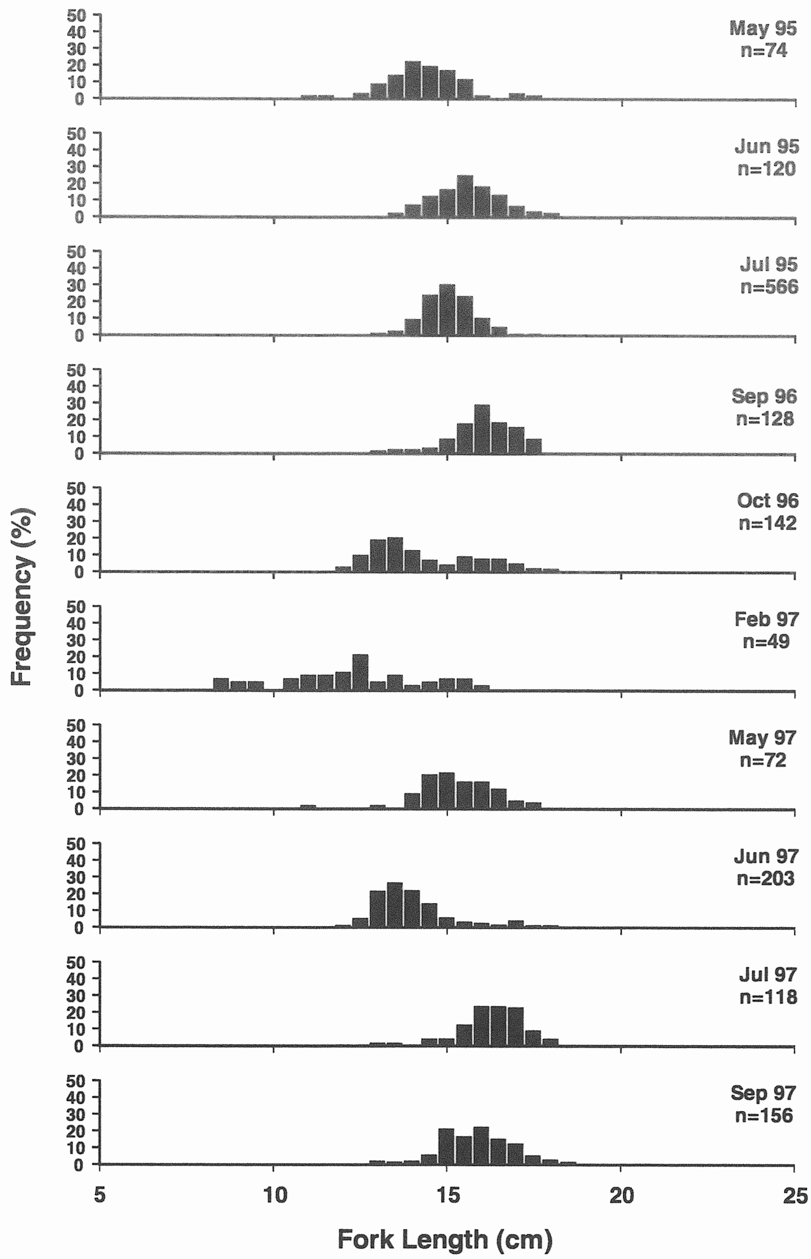


Figure 3.5. Length-frequencies of pilchards collected from commercial fish-trawl catches in southern Queensland.

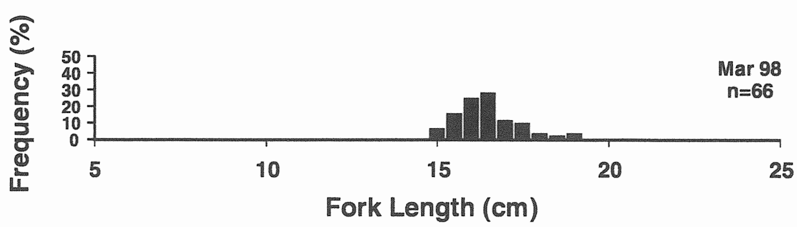


Figure 3.6. Length-frequencies of pilchards collected from a commercial prawn-trawl catch in southern Queensland.

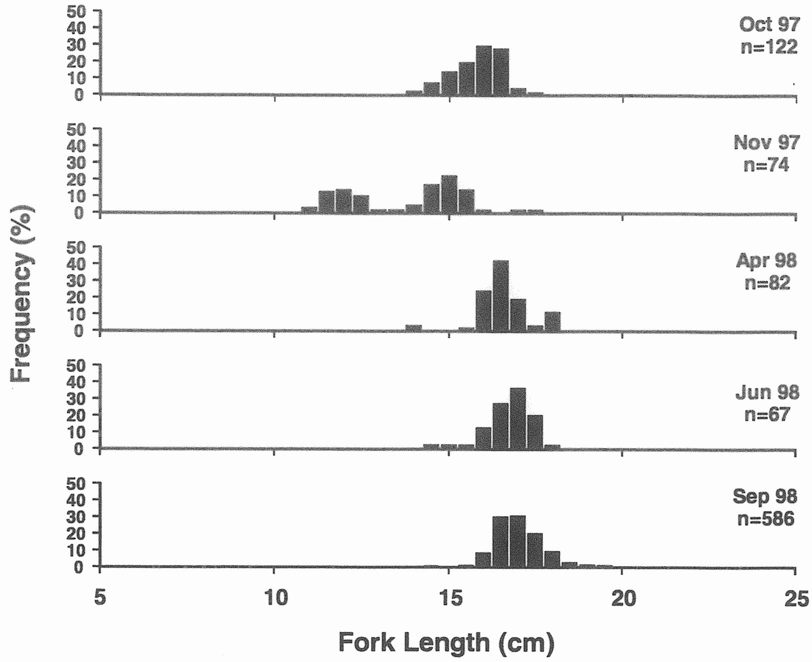


Figure 3.7. Length-frequencies of pilchards caught by gill-netting in southern Queensland.

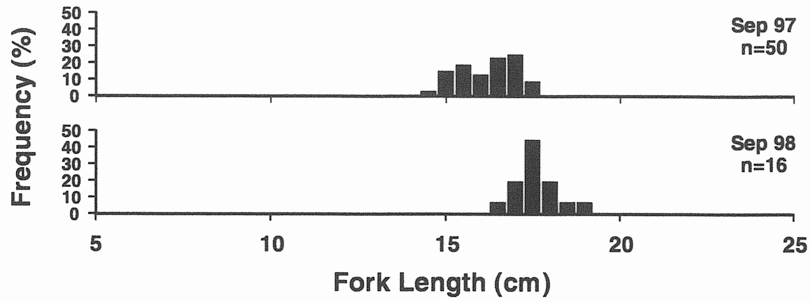


Figure 3.8. Length-frequencies of pilchards caught by jigging in southern Queensland.

3.2.1.2 *Growth rate*

The ages of 1591 pilchards, caught between 1995 and 1998, were estimated (Table 3.2). The number of rings observed on otoliths interpreted as annuli varied from zero to eight. There was a large amount of variation in both length-at-age and age-at-length (Figure 3.9). There was no consistent difference between male and female growth patterns.

Table 3.2. Number of pilchards aged from different years and caught using different gear types in Queensland and New South Wales. BS, beach-seines; PS, purse-seines; PT, prawn-trawls; FT, fish-trawls; GN, gill-net; J, jigging.

	New South Wales		Queensland					
Year	BS	PS	BS	PS	PT	FT	GN	J
1995		38				115		
1996	29	464	62	52		91		
1997		67		206		130	20	9
1998	6		5	271	8		17	1

Growth curves and parameters were generally similar for fish caught in 1996–1998 (Figure 3.10, Table 3.3). Growth was rapid in the first two years, by which time most fish had reached approximately 120–150 mm. However, all of the few fish caught in 1996 that were older than 5.5 years were relatively small compared with similar aged fish caught in other years. This resulted in the estimation of a smaller L_∞ (but larger K) in 1995 compared with other years.

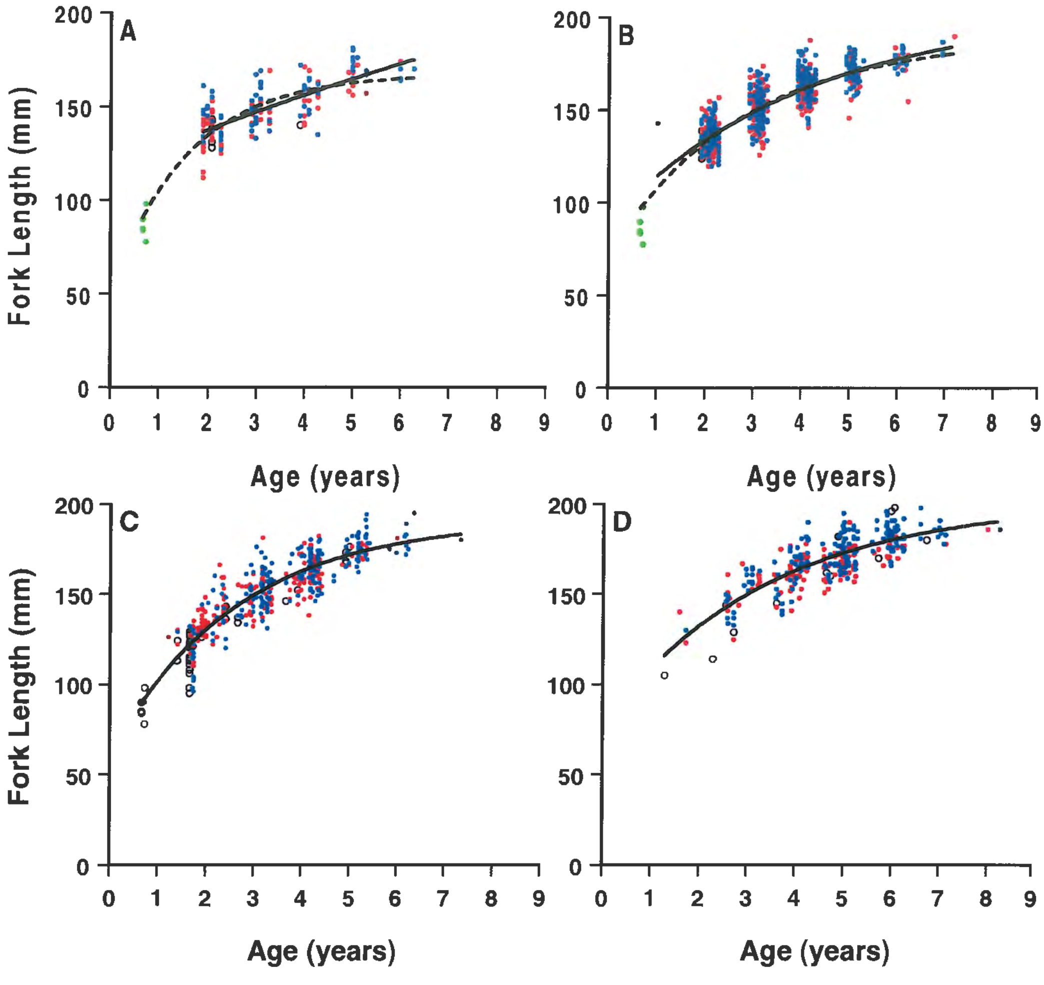


Figure 3.9. Length-at-age of pilchards; male (red circle), female (blue circle) and undetermined sex (open circle). A, 1995; B, 1996; C, 1997; D, 1998. Von Bertalanffy growth curves shown (solid lines). Dashed lines in A and B show von Bertalanffy growth curves fitted to combined sets of data including young fish (< 1 year old) caught in 1997 (green circles).

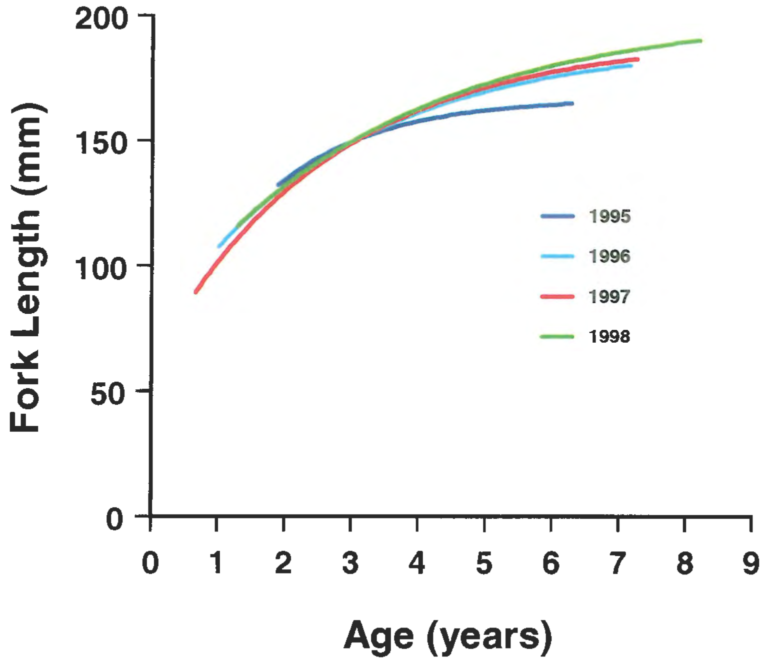


Figure 3.10. Von Bertalanffy growth curves of pilchards in southern Queensland and northern New South Wales.

Table 3.3. Von Bertalanffy growth parameters of pilchards (males, females and undetermined-sex combined). 1995 and 1996 data include six young fish (< 1 year old) caught in 1997.

Year	n	Parameter		95% Confidence Interval Lower	Upper
		L_∞	167	162	173
1995	159	K	0.633	0.495	0.771
		T_0	-0.575	-0.926	-0.224
		L_∞	189	183	196
1996	704	K	0.360	0.295	0.428
		T_0	-1.330	-1.739	-0.915
		L_∞	191	184	199
1997	432	K	0.378	0.309	0.448
		T_0	-1.009	-1.351	-0.667
		L_∞	201	188	214
1998	308	K	0.297	0.193	0.402
		T_0	-1.604	-2.636	-0.573

3.2.1.3 Age-structure

Approximately two thirds of fish that were aged were caught during the second half of the year, between July and December (Table 3.4). Ages of fish caught during the first half of the year ranged from 0^+ to 7^+ years, with more than 85% ranging from 1^+ to 4^+ years. Ages of fish caught during the second half of the year ranged from 1^+ to 8^+, with more than 90% ranging from 2^+ to 5^+ years.

Table 3.4. Number of pilchards assigned to each age-class.

Age-Class	Jan–Jun	Jul–Dec
0^+	7	
1^+	128	9
2^+	115	262
3^+	130	260
4^+	106	288
5^+	50	165
6^+	11	52
7^+	1	6
8^+		1

Age-classes 3^+–5^+ were common in beach-seine samples from New South Wales in 1996 and 1998, although the relative frequencies were slightly different between years (Figure 3.11). Fish caught by purse-seining tended to be one year younger, with the 2^+ age-class dominating most year×period combinations (Figure 3.12). The samples collected in January–June 1996, however, were dominated by the 3^+ and 4^+ age-classes, which made them similar in age-structure to the beach-seine samples. Fish in the 1^+ age-class were caught during January–June 1997 only.

Age-classes 3^+–5^+ were common in samples collected from commercial beach-seine (Figure 3.13) and purse-seine (weighted (Figure 3.14) and unweighted (Figure 3.15)) catches and prawn-trawl catches (Figure 3.16) and in samples collected by gill-netting (Figure 3.18). The 2^+ age-class was also present in small, but varying percentages at most times in these samples. Samples from purse-seine and fish-trawl (Figure 3.17) catches in January–June 1997 included significant numbers of fish in the 1^+ age-class and were the only ones that included fish in the 0^+ age-class.

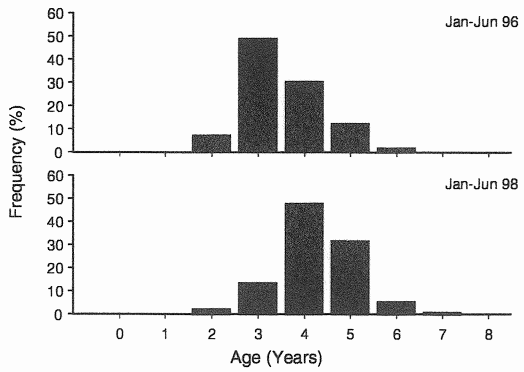


Figure 3.11. Age-structure of pilchard samples collected from commercial beach-seine catches in northern New South Wales.

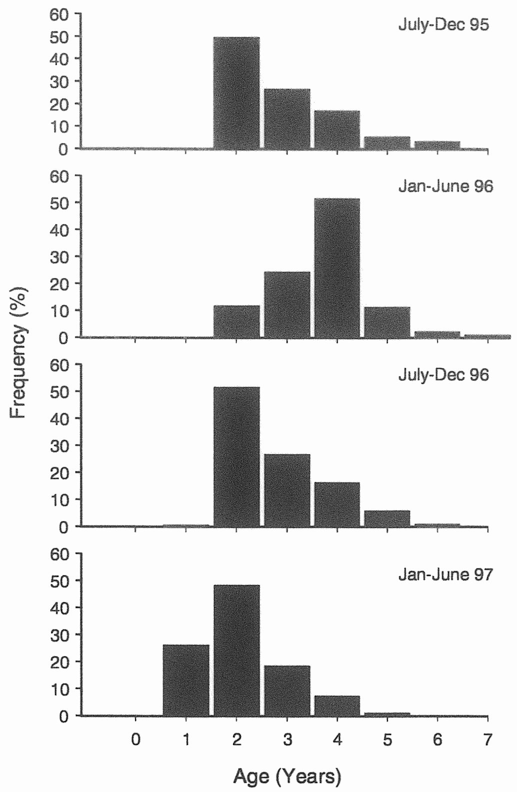


Figure 3.12. Age-structure of pilchard samples collected from commercial purse-seine catches in northern New South Wales.

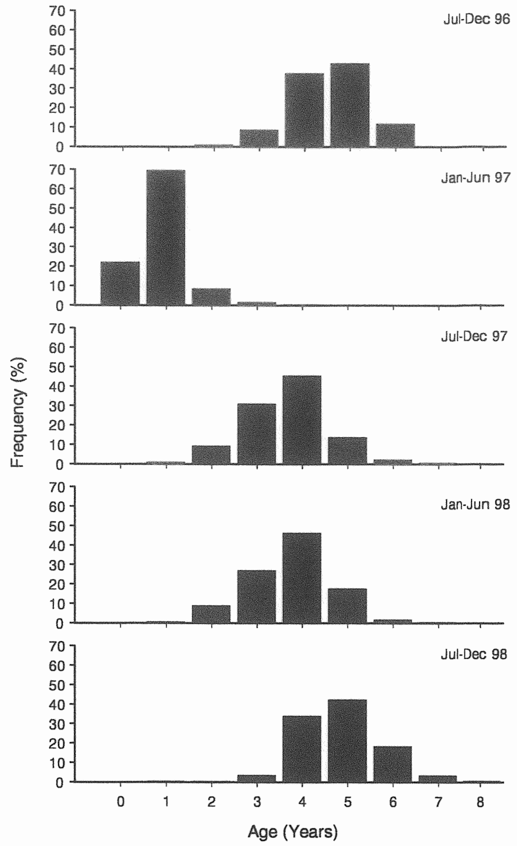


Figure 3.14. Age-structure of pilchard samples collected from commercial purse-seine catches in southern Queensland.

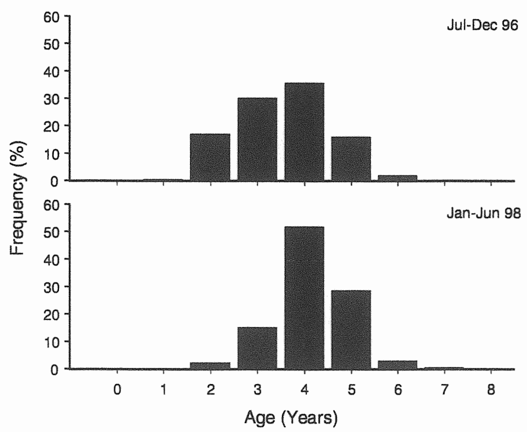


Figure 3.13. Age-structure of pilchard samples collected from commercial beach-seine catches in southern Queensland.

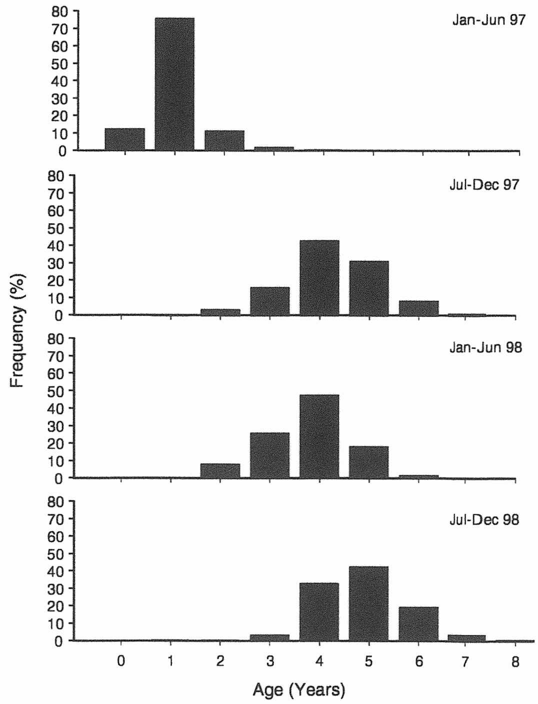


Figure 3.15. Age-structure of pilchard samples, weighted by catch size, collected from commercial purse-seine catches in southern Queensland

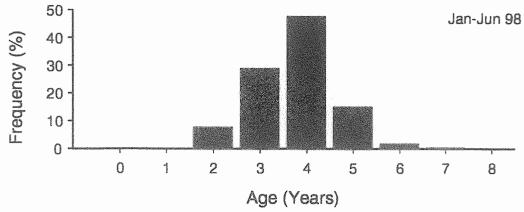


Figure 3.16. Age-structure of pilchard samples collected from commercial prawn-trawl catches in southern Queensland.

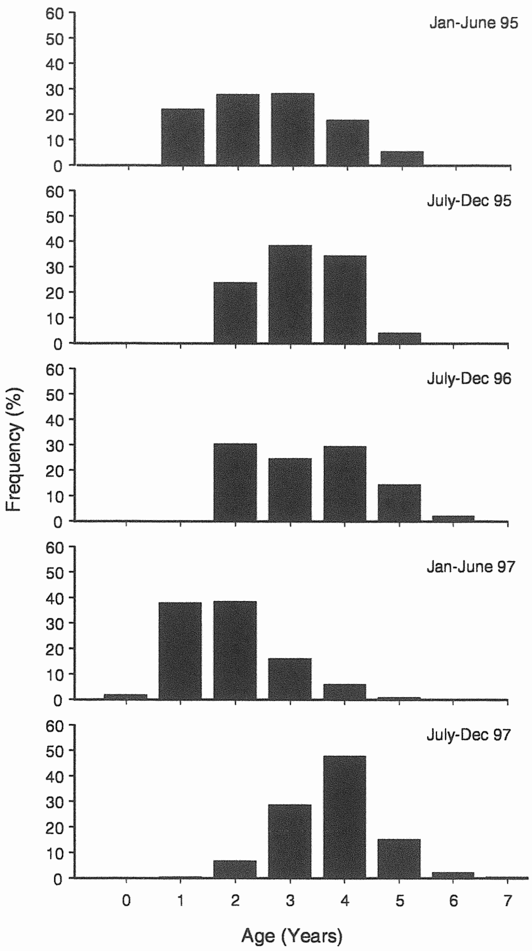


Figure 3.17. Age-structure of pilchard samples collected from commercial fish-trawl catches in southern Queensland.

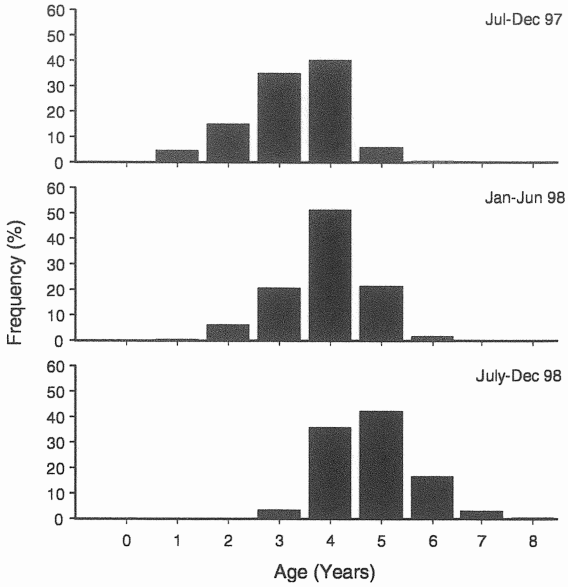


Figure 3.18. Age-structure of pilchard samples collected by gill-netting in southern Queensland.

3.2.1.4 Catch-curves and estimates of total mortality (Z)

Catch-curves were completed for the age-structures of most combinations of gear × year × half-year-period (Figure 3.19–Figure 3.26); the catch-curve for purse-seine catches in July–December 1996 was the only exception.

Fish were assumed to be fully recruited at 2-years of age for the purse-seine fishery in New South Wales and 3-years old for the remaining fisheries at all times other than in January–June 1997, at which time fish were assumed to be fully recruited at 1–year old for the purse-seine fishery (Queensland) and 2-years old for the fish-trawl fishery (Queensland).

25 estimates of rates of instantaneous rate of total mortality ranged from 0.59 (weighted Queensland purse-seine, July–December 1998) to 2.14 (unweighted Queensland purse-seine, January–June 1997). Total mortality was not estimated using the catch-curve of the Queensland purse-seine fishery in July–December 1996 because there was no downward trend in the frequencies of fish in the 3^+–6^+ age-classes. The catch-curves of the purse-seine catches in Queensland were similar when samples were weighted or unweighted.

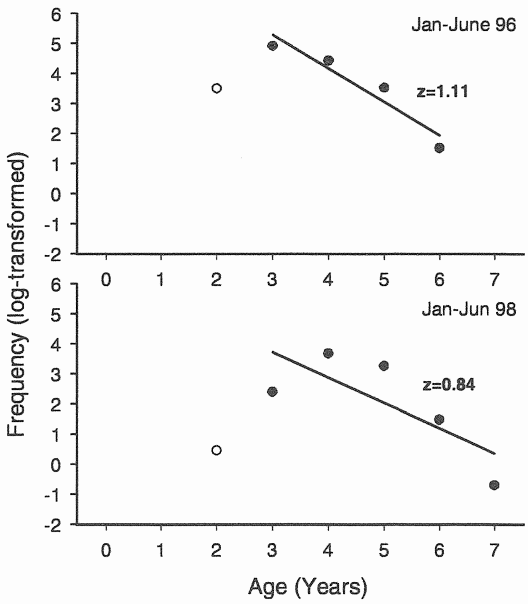


Figure 3.19. Catch curves for pilchard samples collected from commercial beach-seine catches in New South Wales. Open circles indicate data not included in the calculation of Z.

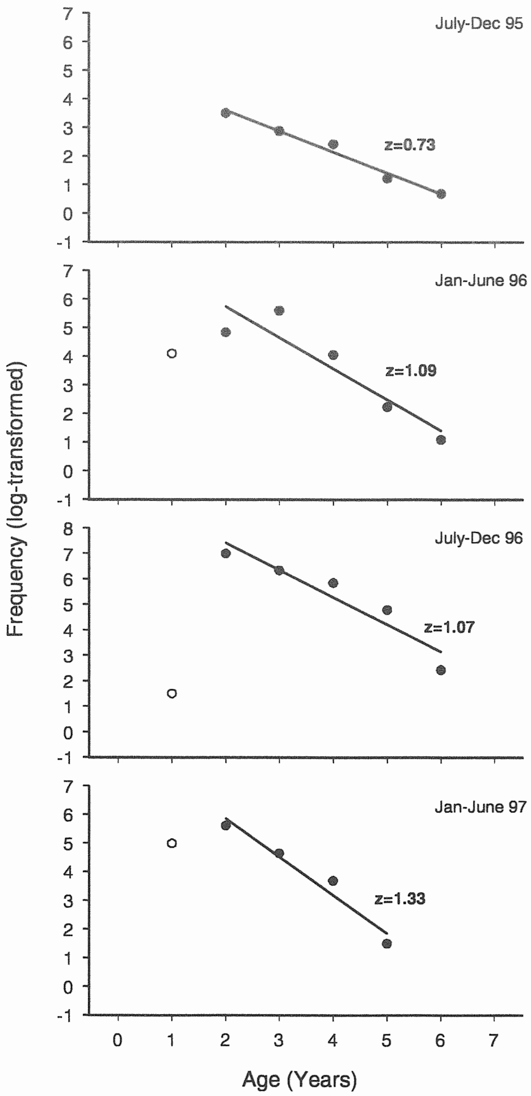


Figure 3.20. Catch curve for pilchard samples collected from purse-seine catches in New South Wales. Open circles indicate data not included in the calculation of *Z*.

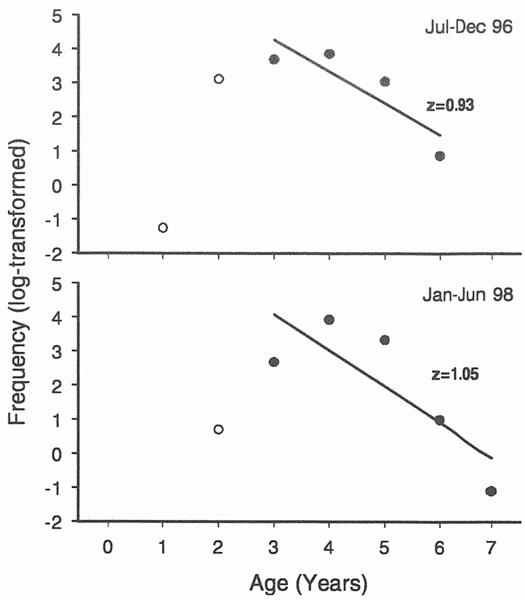


Figure 3.21. Catch-curves for pilchard samples collected from commercial beach-seine catches in Queensland. Open circles indicate data not included in the calculation of *Z*.

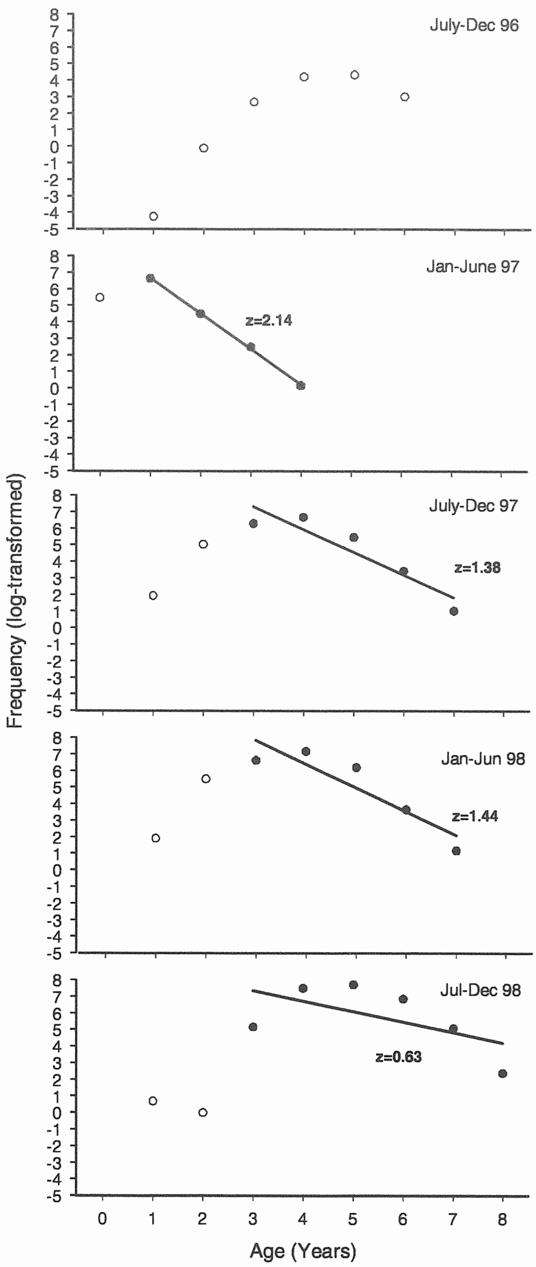


Figure 3.22. Catch curves for pilchard samples collected from commercial purse-seine catches in Queensland. Open circles indicate data not included in the calculation of *Z*.

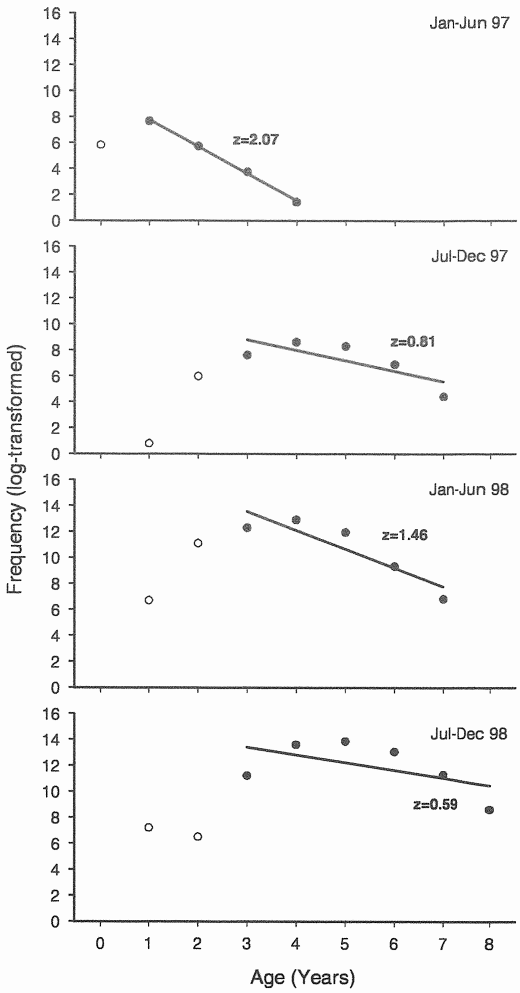


Figure 3.23. Catch-curves for pilchard samples, weighted by catch-size, from commercial purse-seine catches in Queensland. Open circles indicate data not included in the calculation of *Z*.

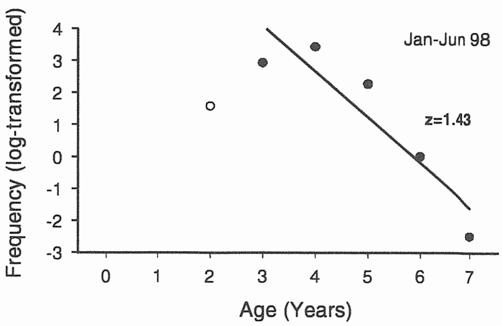


Figure 3.24. Catch-curves for pilchard samples collected from commercial prawn-trawl catches in Queensland. Open circles indicate data not included in the calculation of *Z*.

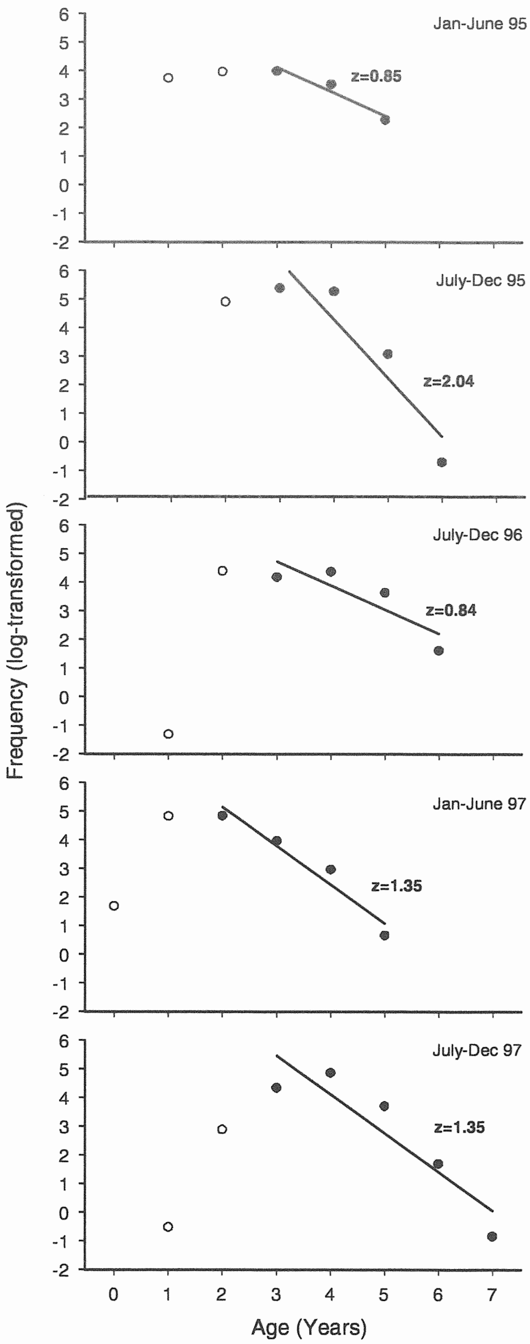


Figure 3.25. Catch curves for pilchard samples collected from commercial fish-trawl catches in Queensland. Open circles indicate data not included in the calculation of *Z*.

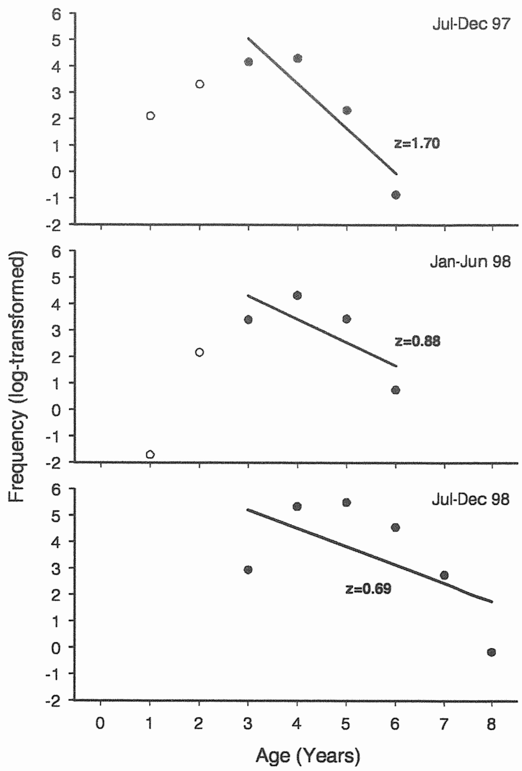


Figure 3.26. Catch-curves for pilchard samples collected by gill-netting in Queensland. Open circles indicate data not included in the calculation of *Z*.

3.2.2 Species other than pilchards

3.2.2.1 Maray

Maray, ranging from 12 to 15.5 cm, were collected from a New South Wales purse-seine catch in October 1995 (Figure 3.27). These fish were smaller than most fish collected from Queensland purse-seine catches (Figure 3.28) and fish-trawl catches (Figure 3.29) in most months other than May 1995 and March 1997; the size range of fish caught during May 1995 was 11.5–17.5 cm and during March 1997 was 9–17 cm. Gill-netting caught fish of a large range of sizes, between 10 and 19 cm (Figure 3.30). Few fish were caught jigging (Figure 3.31).

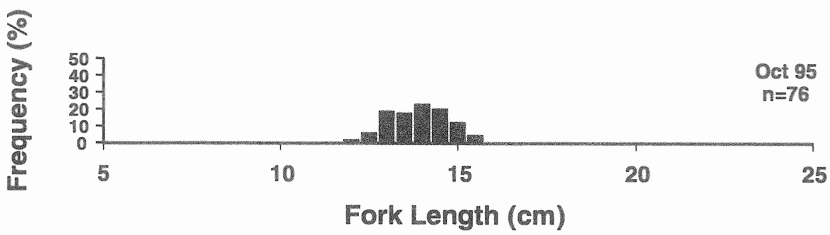


Figure 3.27. Length-frequencies of maray collected from commercial purse-seine catches in northern New South Wales.

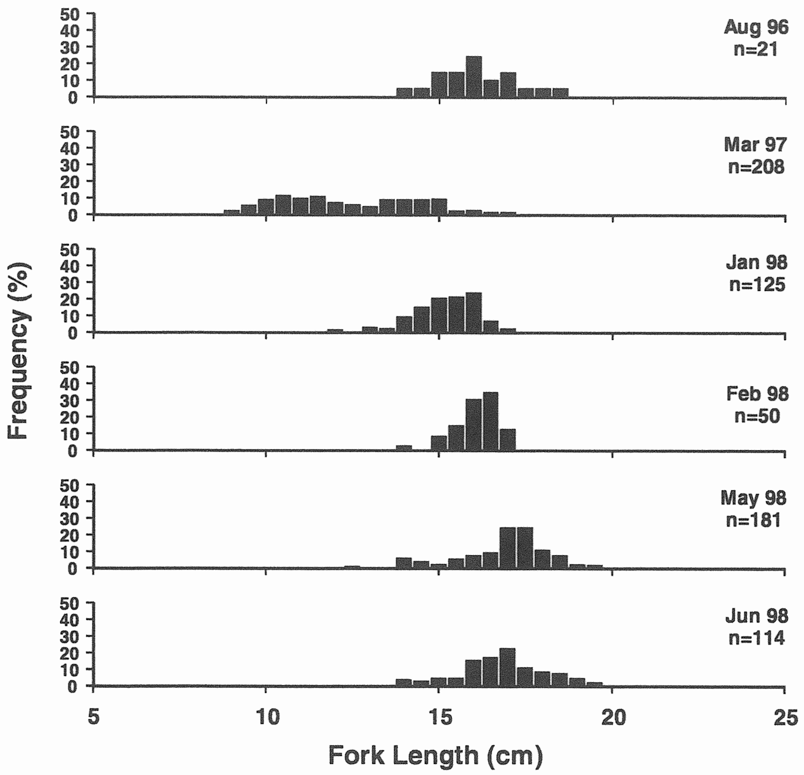


Figure 3.28. Length-frequencies of maray collected from commercial purse-seine catches in southern Queensland.

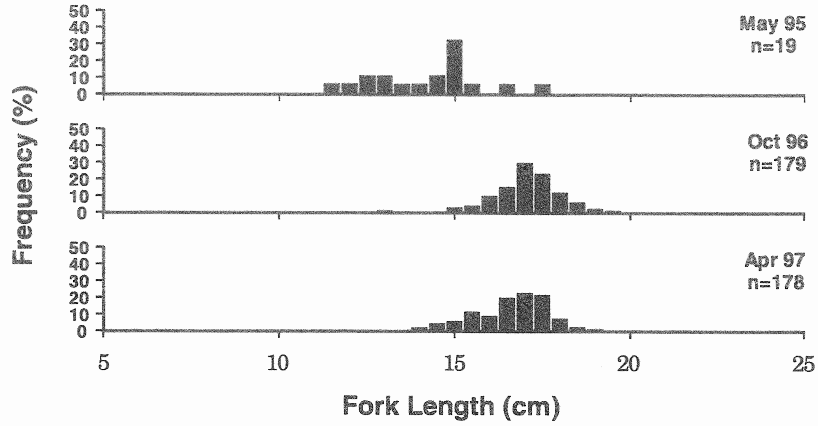


Figure 3.29. Length-frequencies of maray collected from commercial fish-trawl catches in southern Queensland.

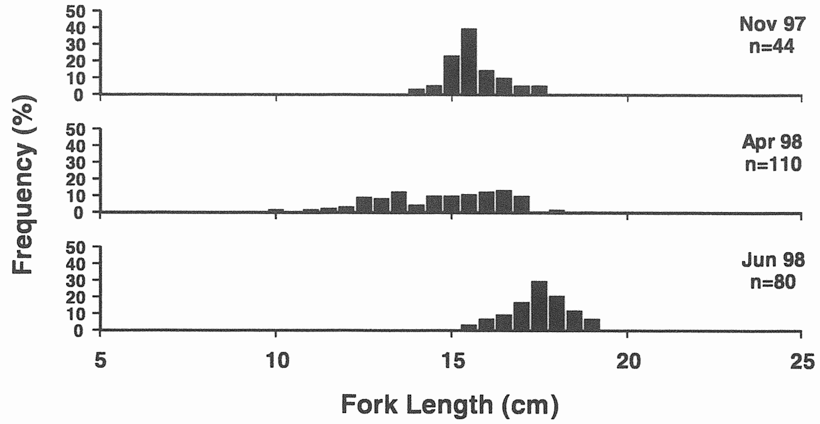


Figure 3.30. Length-frequencies of maray collected by gill-netting in southern Queensland.

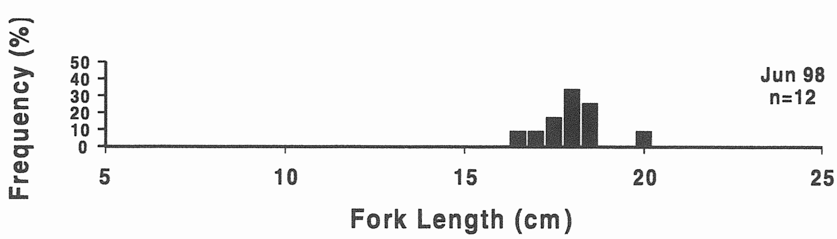


Figure 3.31. Length-frequencies of maray caught by jigging in southern Queensland.

3.2.2.2 *Blue mackerel*

Blue mackerel collected from purse-seine catches in Queensland in 1996 were mostly smaller (15.5–18 cm) than those collected between May and August 1998 (18–23 cm) from purse-seine catches (Figure 3.32) and by jigging (Figure 3.33).

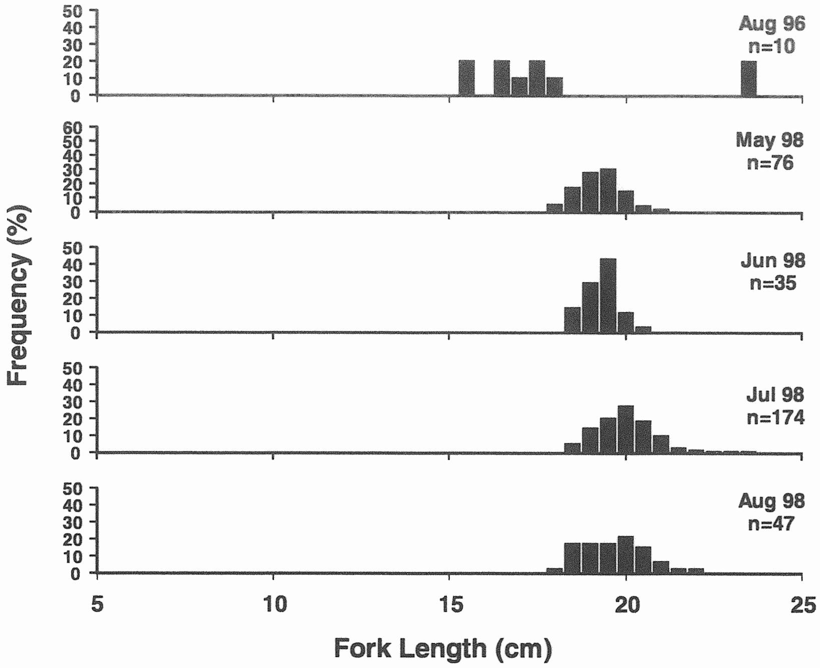


Figure 3.32. Length-frequencies of blue mackerel collected from commercial purse-seine catches in southern Queensland.

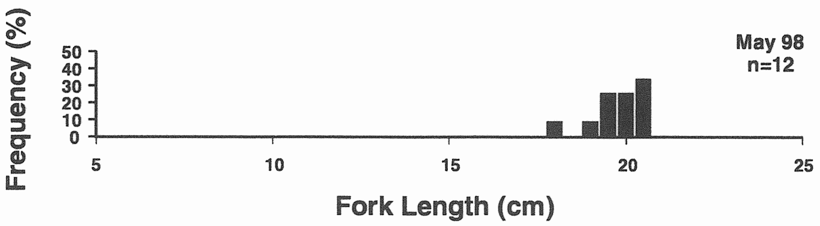


Figure 3.33. Length-frequencies of blue mackerel caught by jigging in southern Queensland.

3.2.2.3 Yellowtail

Yellowtail collected from purse-seine catches in Queensland varied in length from 13 to 20 cm, with most fish between 14 and 17 cm (Figure 3.34).

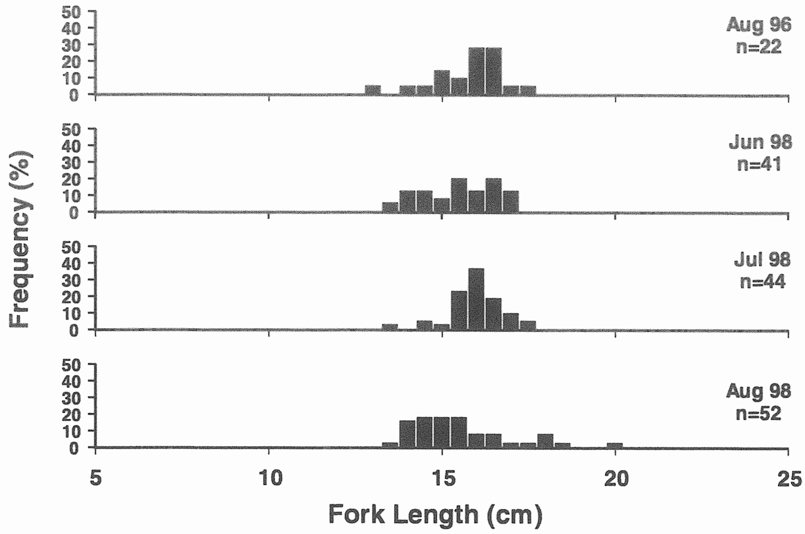


Figure 3.34. Length-frequencies of yellowtail collected from commercial purse-seine catches in southern Queensland.

3.2.2.4 Slender scad

The smallest slender scad (11–14 cm) were collected from a commercial fish-trawl catch in May 1995 (Figure 3.35). Slender scad were also collected from seven commercial purse-seine catches between May and July 1998 (Figure 3.36). There was an increase in the modal size of fish during these months, from approximately 15–15.5 cm in May to 17.5–18.5 cm in July. Fish collected by gill-netting during April 1998 (Figure 3.37) were smaller (13–15 cm) than those collected from purse-seine catches.

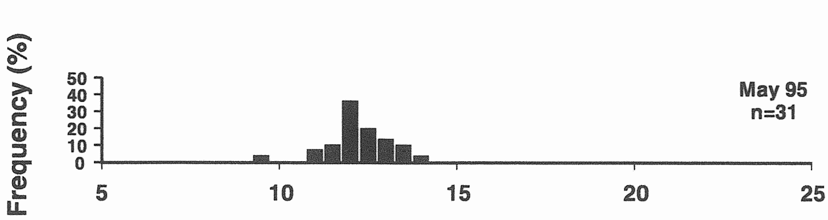


Figure 3.35. Length-frequencies of slender scad collected from commercial fish-trawl catches in southern Queensland.

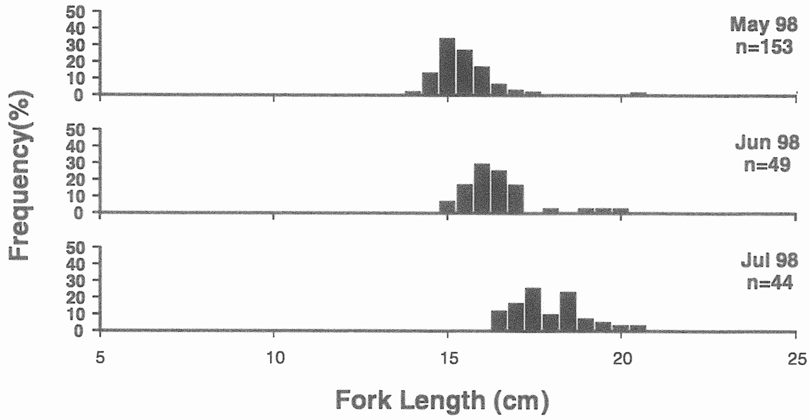


Figure 3.36. Length-frequencies of slender scad collected from commercial purse-seine catches in southern Queensland.

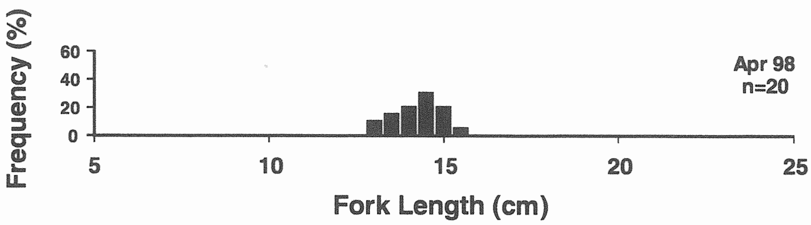


Figure 3.37. Length-frequencies of slender scad caught by gill-netting in southern Queensland.

3.2.2.5 *Indian scad*

Most Indian scad were collected from commercial purse-seine catches that also contained similar sized slender scad (14.5–17 cm; Figure 3.38). Indian scad, however, were much less common.

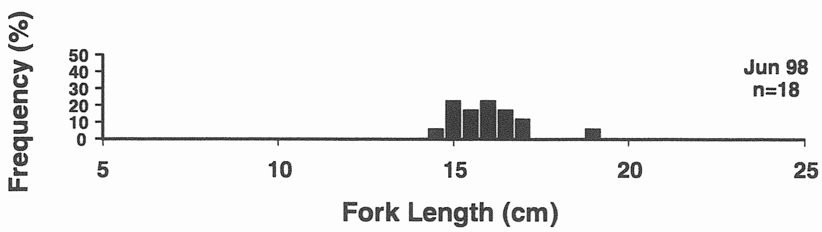


Figure 3.38. Length-frequencies of Indian scad collected from commercial purse-seine catches in southern Queensland.

3.2.2.6 Anchovy

Anchovy were collected from commercial catches in January and March 1997. The fish collected from beach-seine catches in northern New South Wales (Figure 3.39) were larger (9.5–12.5 cm) than those collected from purse-seine catches in Queensland (6–10 cm; Figure 3.40).

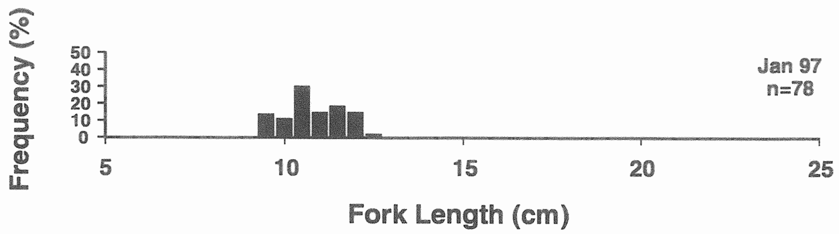


Figure 3.39. Length-frequencies of anchovy collected from commercial beach-seine catches in northern New South Wales

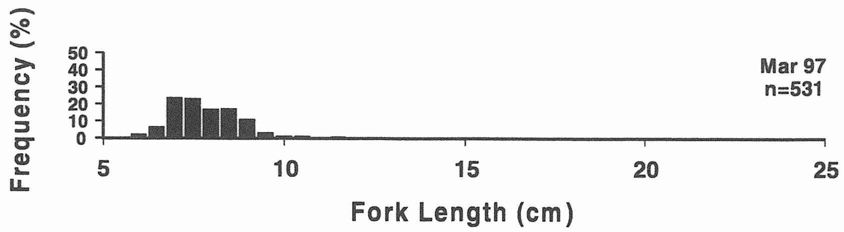


Figure 3.40. Length-frequencies of anchovy collected from commercial purse-seine catches in southern Queensland.

3.2.2.7 Northern sardine

Northern sardines were collected from commercial purse-seine catches during August 1996 (one fish, not shown) and May 1998 (Figure 3.41). The fish were similar in length (approximately 18–20 cm) and appearance to the largest pilchards caught in the same shots and were not distinguished easily by the vessel's crew.

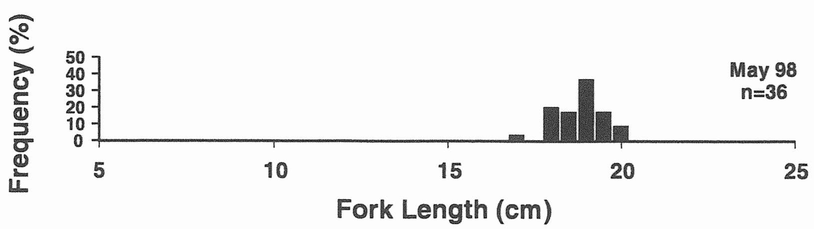


Figure 3.41. Length-frequencies of northern sardines collected from commercial purse-seine catches in southern Queensland.

3.2.2.8 Gold stripe sardine

Gold stripe sardine, ranging from 11.5–16.5 cm, were collected from a single experimental purse-seine catch in August 1996 (Figure 3.42).

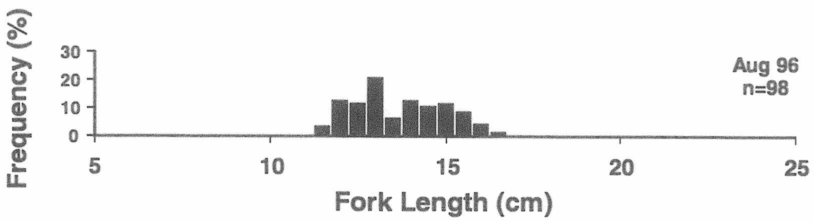


Figure 3.42. Length-frequencies of gold stripe sardine collected from a commercial purse-seine catch in southern Queensland.

3.3 Discussion

3.3.1 Size- and age-structure of catches

The most important finding from this part of the project was that most pilchards caught in southern Queensland and northern New South Wales were large. Pilchards less than 10 cm in length were caught on only two occasions; most fish were greater than 15 cm in length and 3–6 years old.

There are three simple explanations for the absence of large numbers of small/young pilchards in samples. The most likely is that the smallest/youngest fish usually occur in areas away from the fishing grounds, such as in deep offshore waters or in protected estuaries and bays. This supports the conclusions of Blackburn (1949) who stated that pilchard post-larvae move into bays and inlets in New South Wales where they remain for approximately one year. Ward *et al.* (1998) also reported catching very small pilchards (5–8 cm) in Port Phillip Bay in Victoria.

The second explanation for the absence of small pilchards in commercial catches is that recruitment in recent years may have been extremely poor, resulting in small numbers of young fish in commercial catches. Although unlikely, this hypothesis cannot be discounted completely as pilchard recruitment and stock sizes are known to be highly variable (e.g. Blaxter and Hunter 1982; Csirke 1988).

The third explanation is that small fish are not caught because of targeting or selectivity of the fishing gear. Whilst targeting did occur in the developmental fishery, it was related more to species composition than fish size. Gear selectivity is also unlikely to have explained the absence of small pilchards in purse-seine catches, as the mesh is generally small (e.g. 12 mm), which would allow the direct escapement of only extremely small fish.

The codends of the fish-trawl nets used in southern Queensland are designed to capture stout whiting (*Sillago robusta*), and thus they are less than ideal for capturing the smaller and more slender pilchards or maray. However, fish-trawl fishers believe that pilchards and maray are generally caught during deployment or retrieval of the net, when the trawl-boards are not fully spread and the net-mesh is not fully open. Despite the problems of using fish-trawling to collect pilchards, there were no consistent differences between the size-structures of samples from fish-trawl catches compared with purse-seine catches taken at approximately the same time.

Gill-netting is usually considered the most size-selective fishing method, as mesh sizes need to be large enough to allow fish to become entrapped but small enough so that they cannot escape easily. The gill-net used in this study was designed specifically to capture adult pilchards (Chapter 5). The use of panels constructed with three different sizes of mesh increased the size range of fish vulnerable to capture. The large size-range of pilchards and maray caught by gill-netting, and the similarity of size-structures with those of samples from purse-seine catches, suggested that this method was suitable for capturing these two species in the size-ranges that were present (i.e. adults).

Ideal conditions for comparing quantitatively the size-selectivity of gill-netting with other methods, especially purse-seining, would occur when a wide range of sizes of fish was present, and if the same school was sampled using the different methods. This level of rigorous testing of the net was planned for 1999, but was not possible due to the prohibition of purse-seining in Queensland. The gill-net did prove ideal for sampling adult pilchards, which were used to calculate DEPM parameters during the spawning season (Chapter 5). Fisheries scientists at SARDI have used a similar net in their DEPM studies and have also proposed a project investigating the distribution and abundance of juvenile pilchards in the state which will make use of a modified design incorporating panels of mesh smaller than 25 mm.

The suggestion that the size- and age-structure of commercial catches are not representative of the entire population, has significant implications for the management of the fishery based on fishery-dependent collection of samples. For example, age-structures are frequently used in models for stock assessment and monitoring of commercial fish populations, especially when the population is exploited at "high" levels. These models assume that catches are representative of the population and samples are representative of the catches. In this study, sufficient samples were collected from the developmental fishery to allow the age-structure of the catch to be estimated accurately, especially in the period between September 1997 and October 1998 when 100–200 fish were collected from each individual catch. There is some doubt, however, about the degree to which the total catch was representative of the entire population because of the likelihood that small/young fish occur in areas away from the fishing grounds and also because of the possible migratory behaviour of adult pilchards in southern Queensland and northern New South Wales.

3.3.2 Age/growth

The growth pattern of fish caught in Queensland in 1997 was very similar to that reported by Ward *et al.* (1998) for fish caught between 1995 and 1997 in South Australia (Figure 3.43). In Victoria, however, fish had grown larger by 5–6 years of age than in the other states and grew larger in total (greater than 200 mm).

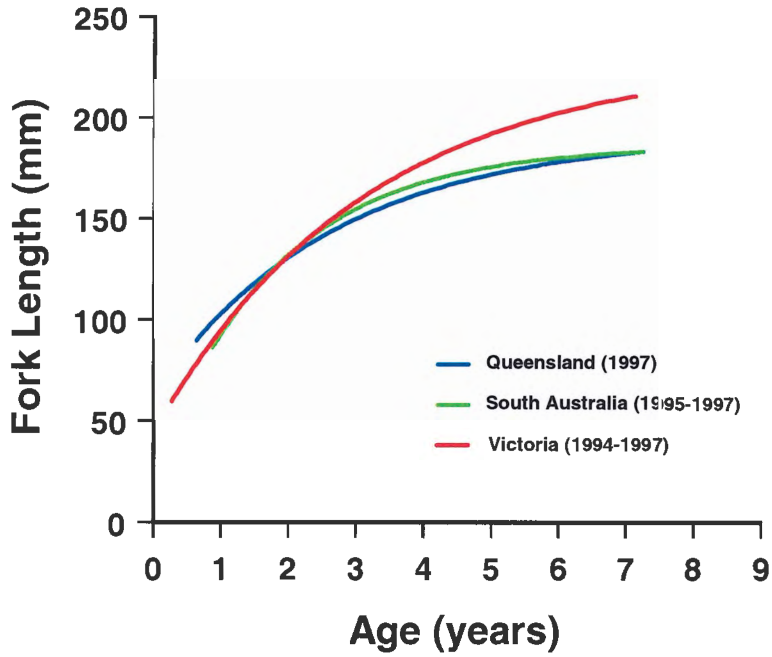


Figure 3.43. Von Bertalanffy growth curves of pilchards. South Australian and Victorian curves from Ward *et al.* (1998).

The size-frequencies in May–October 1998 provide the longest consecutive sequence of pilchard samples. There was no evidence, however, of any modal progression during that period, as a narrow and consistent size-distribution persisted for the 6–month period. The most parsimonious explanation for this observation is that growth rate of pilchards is very slow by the time they reach 16–18 cm in length. This is supported by the estimates of L_∞ which ranged from 167 to 204 mm.

3.3.3 Mortality rates

The pilchard population in southern Queensland and northern New South Wales has been exploited only lightly, thus estimates of total mortality approximate natural mortality. The instantaneous rates of natural mortality estimated in this study (0.59–2.14) are higher than that estimated by Joseph (1981) for pilchards in Jervis Bay (0.47). A fishery of several hundred tonnes per year was well established in Jervis Bay by the time Joseph's estimate was made and the rate of natural mortality is unlikely to have remained at the same levels as it was in the virgin stock (Shepherd 1988).

Estimating instantaneous rates of mortality (total or natural) from linearized catch-curves may not be appropriate for small pelagic fishes as this approach relies on several assumptions that are rarely met for these types of fish. The first is that recruitment is constant, so that declines in relative numbers of fish in successive age-classes are due to fish dying, rather than differences in the initial number of fish in each cohort. The second is that age-structures are representative of the population, an issue which has been discussed already. The third is that mortality is assumed constant in all age-classes and all years. Clupeoid populations are renowned for their natural, high variability (e.g. Blaxter and Hunter 1982; Csirke 1988) and it is unlikely that either recruitment or mortality are constant between years.

Chapter 4. Clupeoid Reproductive Cycles

Objective: *To describe the time and location of clupeoid spawning in southern Queensland.*

This objective was achieved by monitoring; a) the size and development of fish gonads between 1995 and 1998 and b) the abundance of clupeoid eggs and larvae in the coastal waters of southern Queensland in 1997 and 1998.

Male and female pilchards matured at a minimum size of approximately 120 mm. The peak spawning season was in winter–early spring (July–October) when water temperatures were coolest. Most spawning in the peak season occurred in the area between Double Island Point and Caloundra in 1997 but was limited to a much smaller area in 1998. Small-scale patterns in water temperature did not fully explain the spatial distribution of spawning.

Maray eggs and larvae were collected during most months, with highest densities between May and December and lowest values between February and April. This pattern was supported by changes in the size of gonads during the year. Spawning occurred throughout a similar, but slightly larger, area to pilchards in August during both years.

Anchovy spawning during August 1997 occurred at sites along transects out from the entrances of two estuarine systems at Caloundra and Jumpinpin and in Hervey Bay. The main spawning season appeared to be in the summer months, however, as egg abundance was highest between February and March.

Sandy sprat spawning was limited in August 1997 but was scattered throughout the survey area. Translucent sprat spawning was spread more evenly throughout the survey area, especially north of Cape Moreton.

4.1 Methods

4.1.1 Adults (pilchard and maray)

Adult pilchards and maray were collected in Queensland using a variety of techniques: commercial purse- and beach-seining, commercial prawn- and fish-trawling, experimental gill-netting and bait-jigging (see Chapter 3). All fish were measured for length-frequency composition (0.5 cm size classes), and the first 3–5 fish in each size class were kept for further analyses. Fish were measured (± 1 mm) and weighed (± 0.01 g), and their gonads removed and weighed (± 0.01 g). Pilchard gonads were staged (macroscopic stage) according to criteria in Table 4.1. Gonosomatic index (GSI) was calculated for pilchards and maray using the formula:

$$GSI = \frac{W_{gonads}}{(W_{whole} - W_{gonads})}$$

where W_{gonads} is the weight of the gonads (g) and W_{whole} is the whole wet weight of the fish.

Table 4.1. Criteria for macroscopic-staging of pilchard gonads.

	Description	Criteria
Stage–1	Inactive	Small ovaries, less than half the body cavity length, narrow but firm, pale pink. Testes flat and leaf-like, pink or transparent.
–2	Inactive/active	Ovaries beginning to enlarge, slightly longer and up to 5 mm thick, dark pink. Testes beginning to thicken and elongate, white colour developing.
–3	Active	Ovaries longer than one half body cavity length, noticeably thicker, and yellow, vascular. Testes elongated to over half body cavity length, thickened, opaque white, with wavy edges.
–4	Active/ripe	Ovaries distended, almost completely filling body cavity, bright yellow, vascular; Eggs discrete, becoming transparent at posterior end. Testes filling most of body cavity, opaque white, milkiness apparent at posterior end.
–5	Ripe	Ovaries at maximum size, darker yellow and semi-transparent eggs throughout gonads. Testes at maximum size, posterior half milky.
–6	Ripe/running	The same as previous stage, but pressure on belly causes extrusion of eggs or sperm.
–7	Spent	Ovaries elongated, but flat, hollow and bloodshot; no large eggs present, except occasionally a few in oviduct. Testes elongated, strap-like, and bloodshot
–8	Spent/inactive	Ovaries or testes spent, but showing signs of recovery to inactive stage; showing shrinkage, and are firmer and less bloodshot than stage–7 gonads; pale pink.
–9	Spent/inactive/active	Ovaries or testes still showing signs of having been spent recently, but recovering to active stage.

Ovaries of pilchards caught during the adult sampling for the biomass estimates using the daily egg production method (August–September 1997 and 1998) were sent to Adelaide University for histological analyses. They were sectioned, stained with haematoxylin and eosin and staged (microscopic stage) according to the most advanced oocytes present (criteria in Table 4.2).

Table 4.2. Criteria for staging oocytes in sectioned and stained ovaries.

	Description	Criteria
Stage–1	Oogenesis	Primordial follicles are polygonal in shape, homogenous in size and comprised of an oocyte surrounded by a single elongated layer of follicular cells. The developing oocyte possesses a single round, prominent and centrally-located nucleus with numerous peripherally located nucleoli. The cytoplasm is basophilic and homogenous in appearance.
–2	Partially yolked	Follicles have increased in diameter, comprising of an oocyte surrounded by two somatic sell layers – and inner cuboidal granulosa layer and an outer elongated thecal layer. The oocyte possesses a prominent nucleus with several peripheral nucleoli. The cytoplasm is basophilic with lipid yolk droplets (empty appearing) dispersed throughout. An acellular layer, the vitelline envelope, is present between the oocyte and the granulosa layer appears basophilic.
–3	Yolked	Follicles further increased in diameter comprising of an oocyte surrounded by the granulosa and thecal layers. The oocyte possesses a prominent and centrally-located nucleus. In the nuclear-migrating stage (NMS) the nucleus is observed to traverse to the cortex of the oocyte. The cytoplasm is basophilic, and in addition to the lipid yolk droplets which fuse to form an oil droplet upon NMS, eosinophilic striations are observed to extend its matrix.
–4	Hydrated/ripe	Follicles further increased in size. Numerous eosinophilic yolk plates are present within the oocyte in between which reside narrow bands of cytoplasm. The vitelline envelope and enveloping cell layers are greatly stretched.

4.1.2 Eggs and Larvae

12 cruises were conducted between 28 August 1997 and 17 September 1998. Two "annual" cruises sampled sites along 19 (1997) and 15 (1998) transects covering a large area of the coastal waters of southern Queensland, and ten "monthly" cruises sampled two transects only, one offshore from Coolum (26°30') and one offshore from Caloundra (26°45') (Figure 4.1). Sites along two transects (26°15' and 26°30') were sampled twice during the 1998 annual survey.

Methods of sample collection are given in detail in Chapter 5. All teleost eggs and larvae were removed from plankton samples and species of clupeoid were identified using the criteria outlined in Table 4.3. Densities of eggs and larvae (100 m^{-3}) were estimated for each site by dividing counts by the volume of water filtered. Mean densities were calculated for each transect and cruise, weighting sites according to the area of ocean they were assumed to represent (see Chapter 5).

Table 4.3. Criteria used to identify clupeoid eggs and larvae collected in plankton tows in southern Queensland between 28 August 1997 and 17 September 1998 (Tregonning *et al.* 1996; Neira *et al.* 1998).

	Eggs	Larvae
Pilchard (*Sardinops sagax*)	• Egg diameter (1.32 – 1.7 mm, Av 1.53 mm) • Does have an oil globule • Yolk diameter (0.71 – 0.83 mm) • Perivitelline space as a percentage of egg diameter (42.2 – 57.9 %, Av 49.4)	• 48–53 myomeres • Cross-hatched pattern of muscle fibres visible until 14 mm • Anus migrates anteriorly from myomere 42 to 36 between 3.9 and 25.1 mm • Posterior end of dorsal fin 4–6 myomeres in from origin of anal fin • Series of internal melanophores dorsally along hindgut in preflexion larvae
Maray (*Etrumeus teres*)	• Egg diameter (1.24 – 1.48 mm, Av 1.35 mm) • Does not have an oil globule • Yolk diameter (0.99 – 1.28 mm, Av 1.12 mm) • Perivitelline space as a percentage of egg diameter (7.1 – 22.6 %, Av 18.7)	• 53–55 myomeres • Cross-hatched pattern of muscle fibres visible until 14 mm • Long snout and elongate jaws bearing teeth • Anus lies under myomeres 41–43 throughout development • Posterior end of dorsal fin 2–3 myomeres in front of origin of anal fin • Paired series of internal melanophores dorsolaterally over hindgut in postflexion larvae
Anchovy (*Engraulis australis*)	• Elliptical in shape and measure 1.06 – 1.40 x 0.48 – 0.62 mm	• 44 – 47 myomeres • Cross-hatched pattern of muscle fibres visible until 12 mm • Anus migrates anteriorly from myomere 33 to 26 between 2.9 and 32.2 mm • Posterior end of dorsal fin overlaps anterior end of anal fin by up to 3 myomeres • No melanophores along dorsal surface of hindgut prior to flexion stage
Translucent sprat (*Hyperlophus translucidus*)	• Pham (unpublished)	• 40–42 myomeres • Cross-hatched pattern of muscle fibres visible until 12 mm • Gut striations extend from posterior of foregut to entire hindgut • Sheath of tissue on foregut in larvae up to about 15 mm • Anus migrates anteriorly from myomere 30 to 24 between 3 and 30.6 mm • Posterior end of dorsal fin initially 2 myomeres in front of origin of anal fin, and overlapping origin of anal fin by 1–2 myomeres in transforming stage • 5–9 small melanophores above and below notochord tip in preflexion larvae • No melanophores dorsally along gut prior to postflexion stage
Sandy sprat (*Hyperlophus vittatus*)	• Egg diameter (0.83 – 0.95 mm, Av 0.93 mm) • Does have an oil globule • Yolk diameter (0.50 – 0.87 mm, Av 0.83 mm) • Perivitelline space as a percentage of egg diameter (8.6 – 30.9 %, Av14.5)	• 46–48 myomeres • Cross-hatched pattern of muscle fibres visible until 13 mm • Anus migrates anteriorly from myomere 36–33 between 4.7 and 30.7 mm • Posterior end of dorsal fin 1–3 myomeres in front of origin of anal fin, not overlapping anal fin • 2–5 melanophores above and below notochord tip

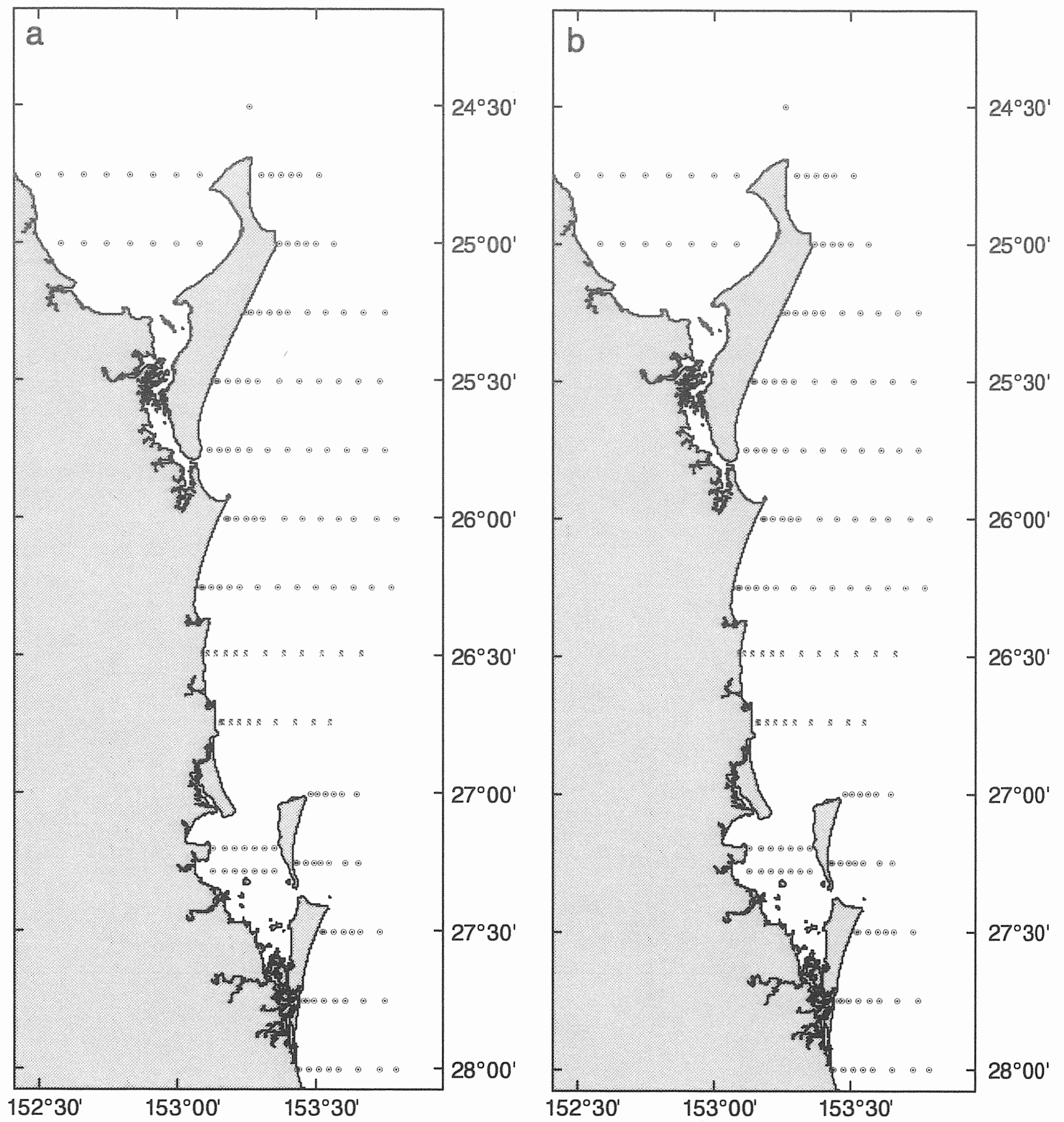


Figure 4.1. Plankton collection sites in (a) 1997 annual survey and monthly surveys (⊙ = annual survey sites; + = 1997 annual and monthly survey sites) and (b) 1998 annual survey (⊙ = sites sampled once; + = sites sampled twice).

4.1.3 Calculation of reproductive parameters

4.1.3.1 Minimum length at maturity

The minimum length at maturity of pilchards was calculated using two methods. First, the minimum lengths of male and female fish classed as stage–2 or above (microscopic and macroscopic stages separately) were identified. Next, the minimum GSIs of maturing fish (stage–2 or above) was estimated and the minimum size of fish with GSI greater than this threshold value was identified.

4.1.3.2 Spawning season

Patterns in the reproductive activity of fish were based on: 1) the mean monthly GSIs (pilchard and maray), 2) the proportions of gonads at stage–3 and above (macroscopic stage; pilchard) and 3) the mean densities of eggs and larvae (m^{-2}) along the two transects sampled regularly (pilchard, maray and anchovy).

4.1.3.3 Spawning location

The identification of spawning locations was based on the distribution of fish eggs collected during the annual surveys. Egg densities at sites along the two transects that were sampled twice during the 1998 survey were averaged to give a single value for each site.

4.2 Results

4.2.1 Pilchard

4.2.1.1 Length at first maturity

4.2.1.1.1 Macroscopic staging

The results of macroscopic staging of gonads during the spawning season indicate that all fish examined were adult-sized. The gonads of 951 female (124–197 mm) and 611 male (122–193 mm) pilchards caught during the spawning season (between June and October) were staged macroscopically. All females less than 148 mm (n=29) and all males less than 141 mm (n=17) were classed as stage–2 or above. The small number of female stage–1 fish identified ranged from 148–186 mm (n=42) while the male stage–1 fish ranged from 141–177 mm (n=10).

4.2.1.1.2 Microscopic staging

The results of microscopic staging of ovaries during the spawning season were similar to those in section 4.2.1.1.1, in that they indicated all pilchards examined were adult-sized. Histology was carried out on 459 ovaries collected in August to October 1997 and on 534 ovaries collected in September 1998. Fish ranged from 124–206 mm. The ovaries of all fish between 124 and 168 mm (n=430) were classed as stage–2 or above. Eight females, ranging from 169–189 mm were classed as stage-1.

4.2.1.1.3 GSI

The gonads of 711 male and 1457 female pilchards were weighed but not staged, both during and outside the spawning season. Most of these fish had GSIs in the range expected of gonads classed as stage–2 or above, when compared with GSIs of known-stage fish (Figure 4.2). These fish included some slightly smaller than the minimum lengths of maturity determined by methods involving staging fish (see above); both males and females as small as 120 mm had GSIs high enough to indicate they had gonads at stage–2 or above.

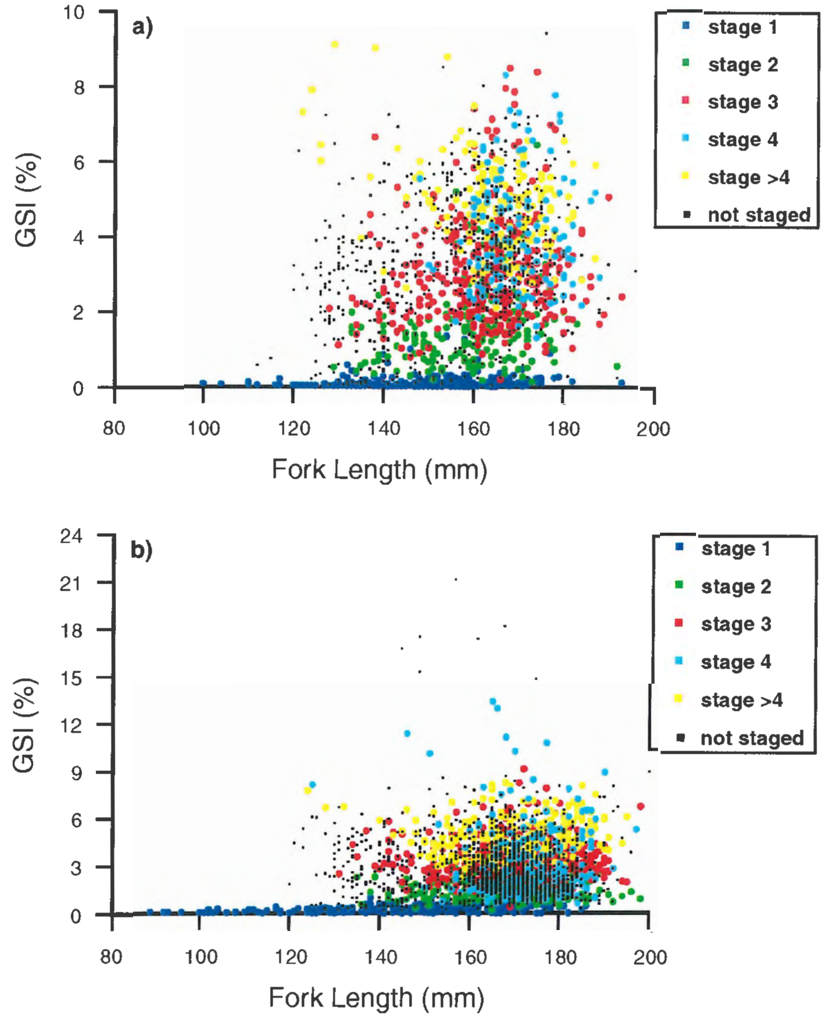


Figure 4.2. GSI of (a) male and (b) female pilchards at different stages of reproductive development (determined macroscopically).

4.2.1.2 Spawning season

4.2.1.2.1 GSI

GSIs were determined for 2448 female and 1342 male pilchards between July 1996 and October 1998. Patterns of GSI were similar for both sexes (Figure 4.3). Values were consistently lowest between January and April and highest between July and October during the 28–month period when data were collected.

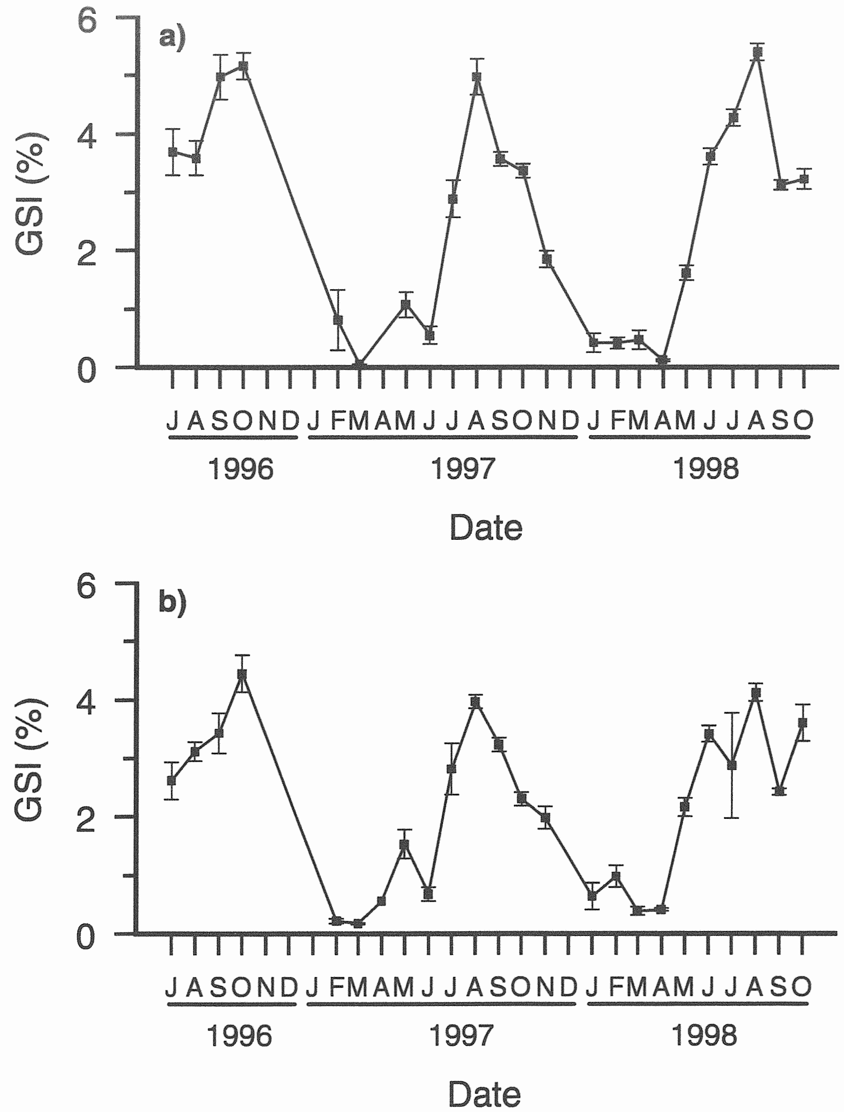


Figure 4.3. Mean GSI (± SE) of (a) male and (b) female pilchards.

4.2.1.2.2 Macroscopic stage of gonads

The gonads of 937 males and 1277 females were staged macroscopically between February 1997 and October 1998. Seasonal patterns in the relative abundance of the different stages of development were similar to the patterns of potential reproductive activity indicated by GSI (Figure 4.4). Stage–1 and –2 fish dominated the months between January and April, whereas gonads at or above Stage–3 were common between June and November.

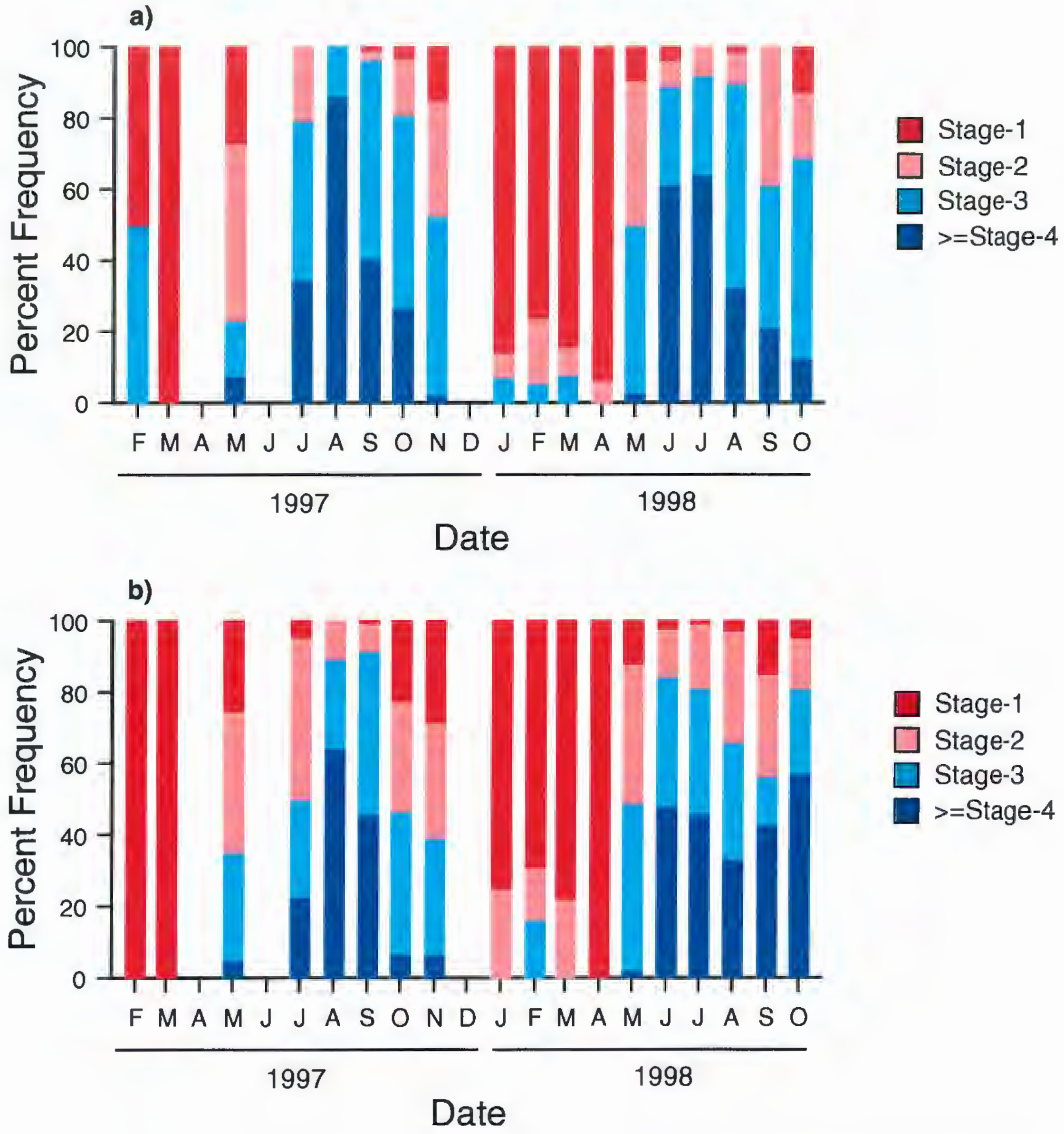


Figure 4.4. Percentages of different stages of reproductive development (determined macroscopically) for (a) male and (b) female pilchards.

4.2.1.2.3 Changes in densities of eggs and larvae

3645 pilchard eggs and 803 larvae were caught during the monthly plankton surveys. High densities of pilchard eggs and larvae were observed during September and October 1997 and July–September 1998 (Figure 4.5). Very small numbers of larvae, but not eggs, were caught during February–April. Very few eggs or larvae were caught in mid-September 1998, despite the high densities observed earlier in the same month.

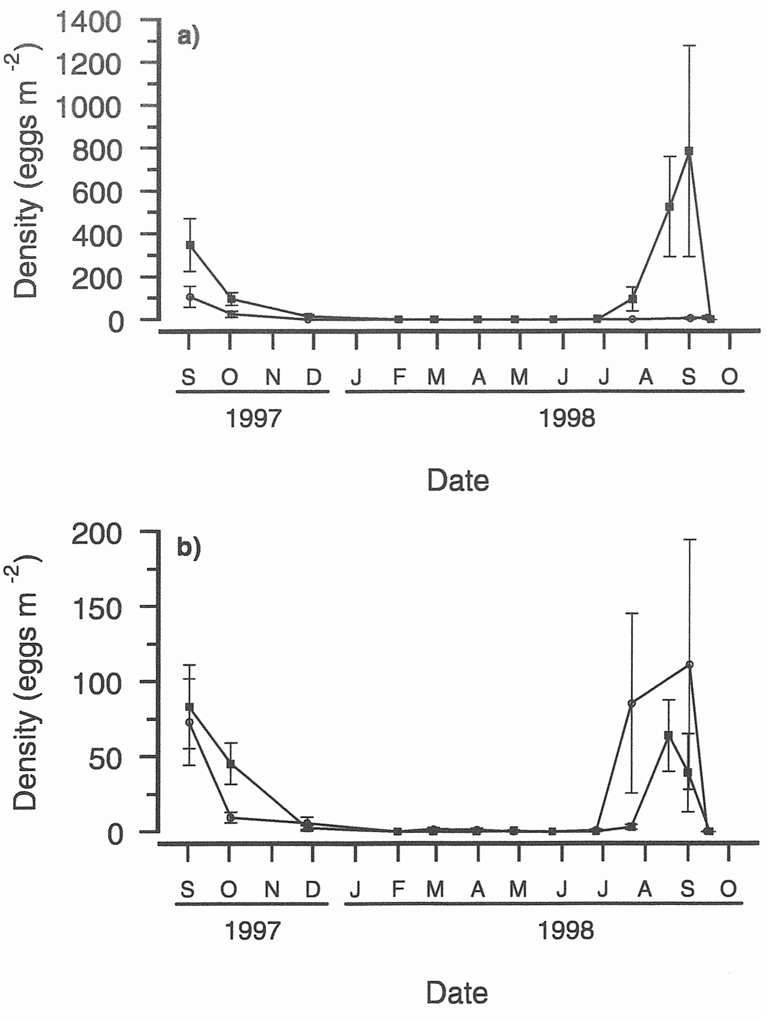


Figure 4.5. Mean density (eggs m^{-2}) of pilchard (a) eggs and (b) larvae along 2 transects (26°30' and 26°35').

4.2.1.3 Spawning location

1352 eggs were captured at 51 sites throughout the survey area during the 1997 annual egg-abundance survey. Most eggs were captured in the area between Double Island Point (26°) and Caloundra (26°45'), with highest densities at sites along the transect at 26°30' (Figure 4.6). More eggs were caught during the survey in 1998 (2487) than in 1997, though at a smaller number of sites (22). Highest densities were at sites along the same transect as in 1997.

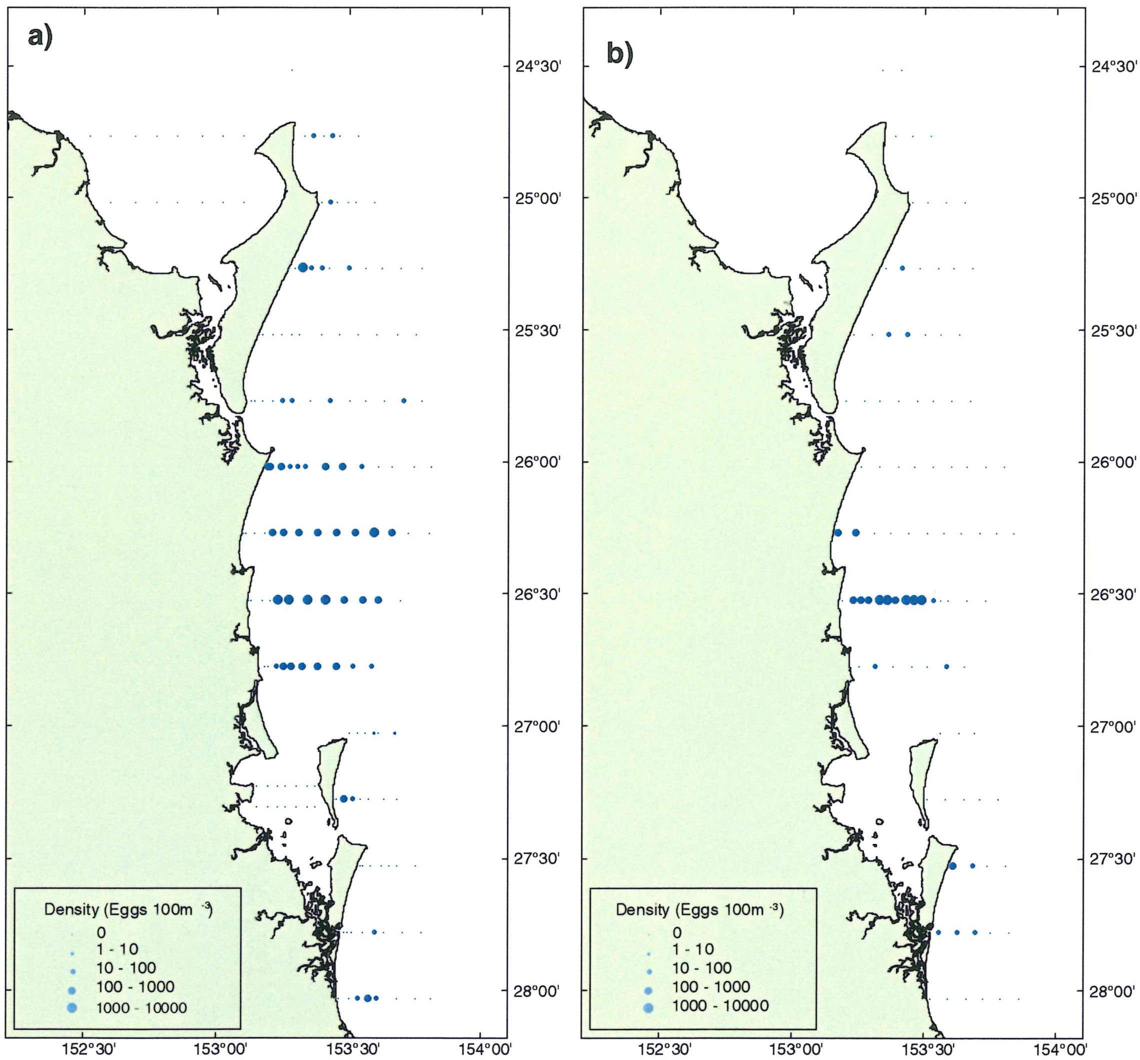


Figure 4.6. Density (eggs 100 m^{-3}) of pilchards eggs in August–September (a) 1997 (b) 1998.

4.2.1.4 Water temperature

Water temperatures during the 1997 annual survey were, on average, approximately 1° cooler than at the same sites during the 1998 annual survey (Figure 4.7). Moreton and Hervey Bays contained the coolest water in 1997; the temperature at most sites was less than 20°C. The highest temperatures were recorded at sites at the northern end of Fraser Island, especially in 1998 when there was a pool of warm water (greater than 23°C) extending approximately halfway down the island's eastern coast.

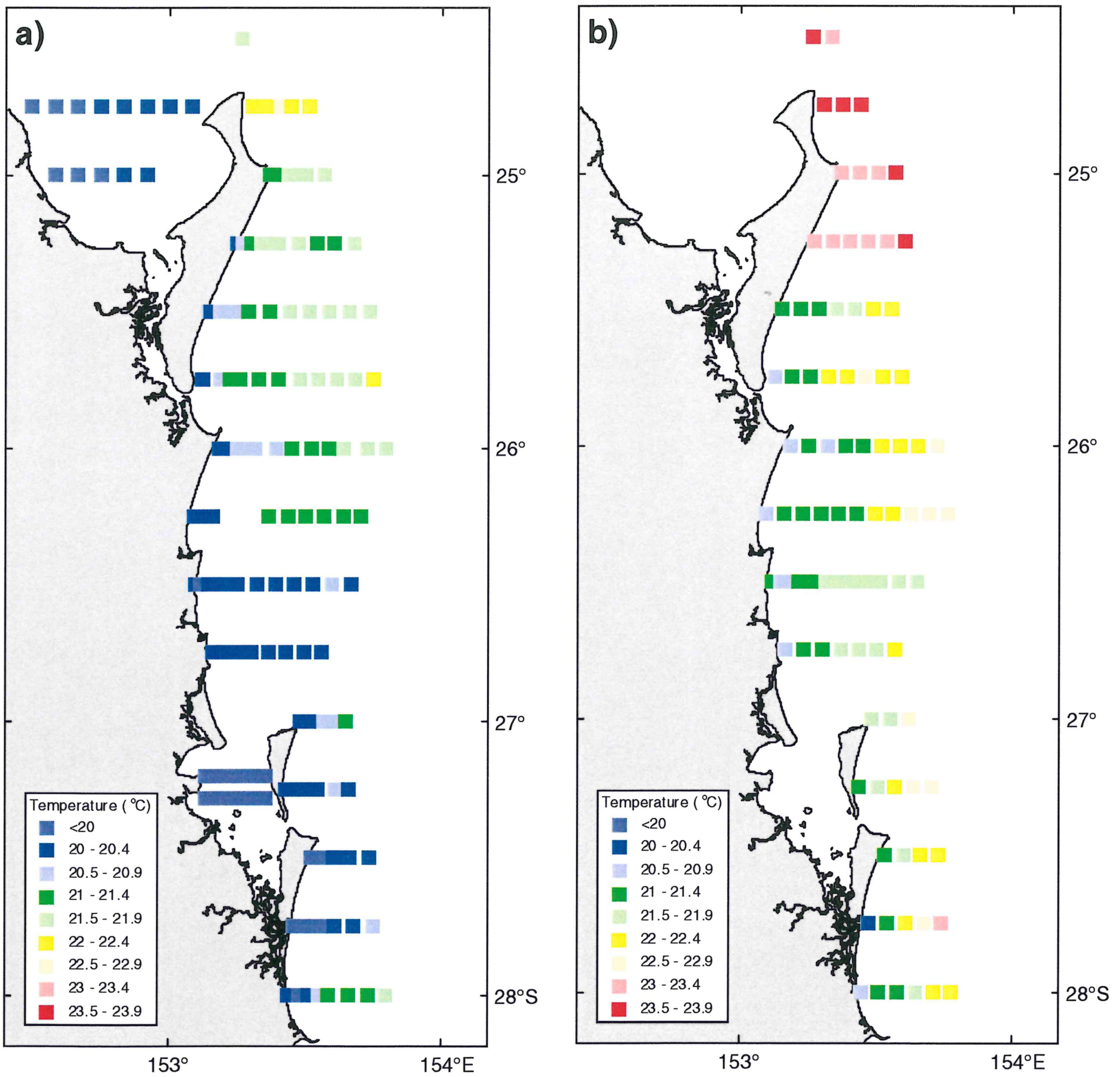


Figure 4.7. Surface water temperature (°C) at plankton-collection sites in August–September (a) 1997 and (b) 1998.

4.2.2 Maray

4.2.2.1 Reproductive season

4.2.2.1.1 GSI

GSIs were determined for 246 male and 315 female maray between October 1996 and June 1998. Data from the different years were pooled, so that a single chart could be plotted showing general monthly variations, independent of years. Patterns of GSI were similar for male and female maray, with low values between January and April, and highest values between May and November (Figure 4.8). No GSI data were available for June or December.

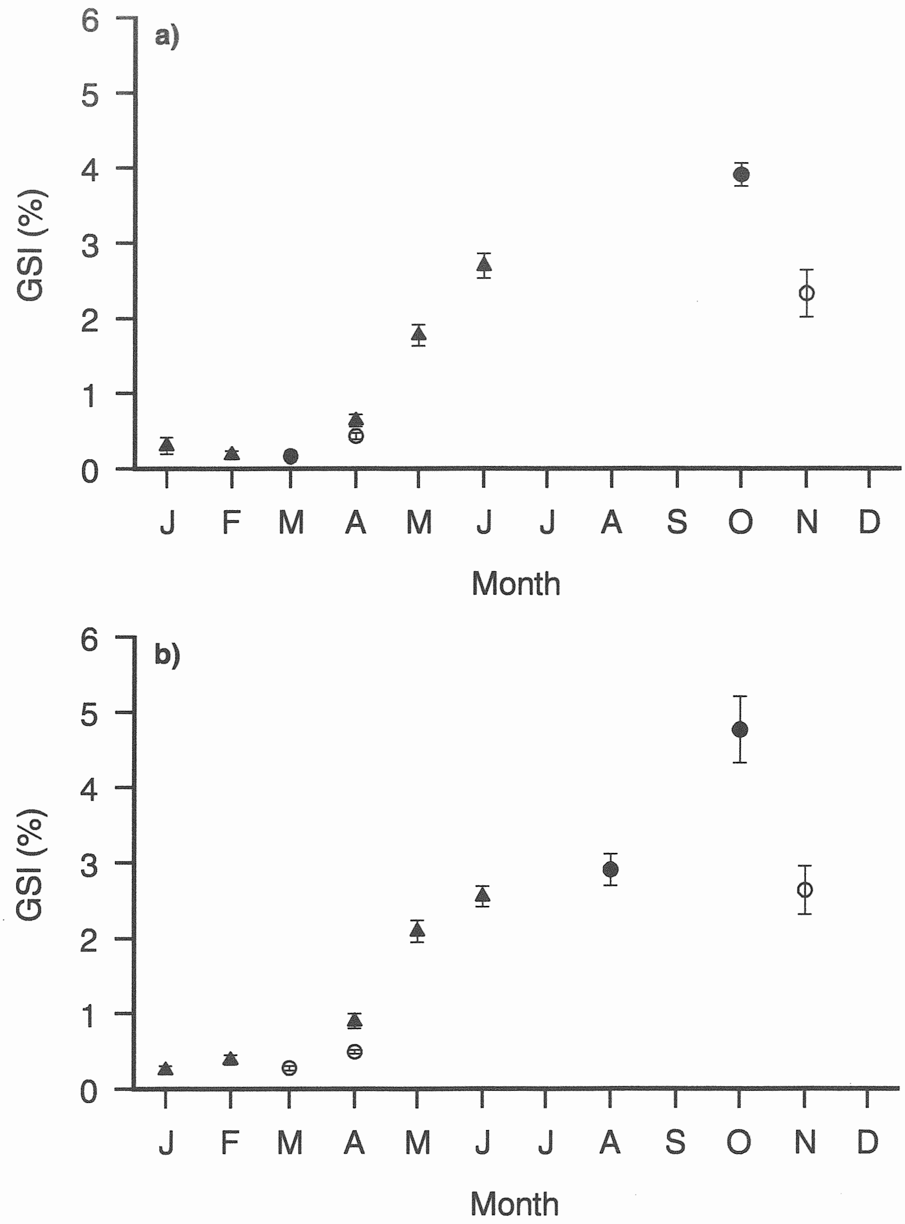


Figure 4.8. Mean GSI (± SE) of (a) male and (b) female maray. Closed circle=1996; Open circle=1997; Closed triangle=1998.

4.2.2.1.2 Changes in densities of eggs and larvae

244 maray eggs and 55 larvae were captured during the monthly plankton sampling. Small numbers of eggs and larvae were caught throughout the year (Figure 4.9). Egg densities were highest between late-May and late-November, and lowest between early-February and late-April.

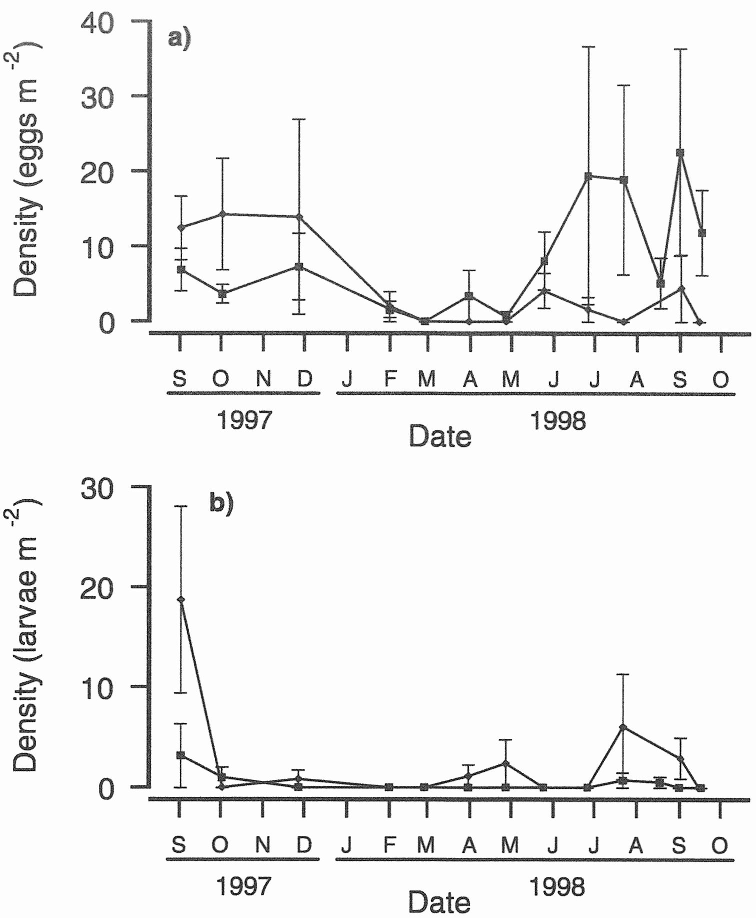


Figure 4.9. Mean density (eggs m^{-2}) of maray (a) eggs and (b) larvae along 2 transects (26°30' and 26°35').

4.2.2.2 *Spawning location*

135 eggs were captured during the annual egg-abundance survey in 1997, mainly at sites spread throughout the area between the southern end of Fraser Island and Cape Moreton (Figure 4.10). Fewer eggs (96) were collected at fewer sites during the 1998 survey, mainly in the same area as in 1997.

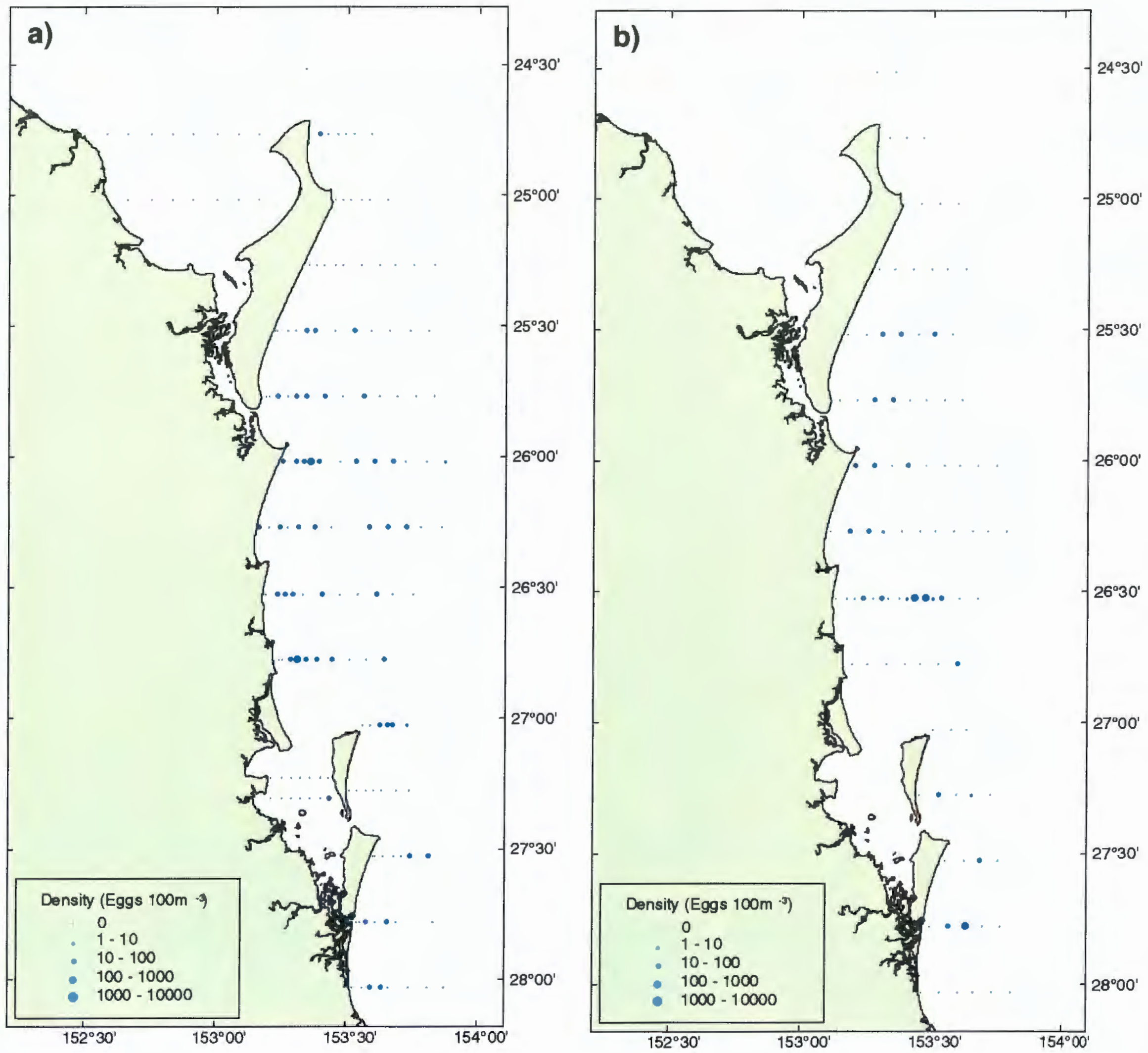


Figure 4.10. Density (eggs 100 m^{-3}) of maray eggs in August–September (a) 1997 and (b) 1998.

4.2.3 Anchovy

4.2.3.1 Spawning season

4.2.3.1.1 Changes in densities of eggs and larvae

411 anchovy eggs and 60 larvae were captured during the monthly plankton sampling. Egg densities were highest between early February and late March (Figure 4.11). Some eggs were also collected in August 1997. The highest densities of anchovy larvae were recorded in early September 1997 and August and September 1998. Some larvae were also caught between January and March 1998, though in smaller numbers than eggs.

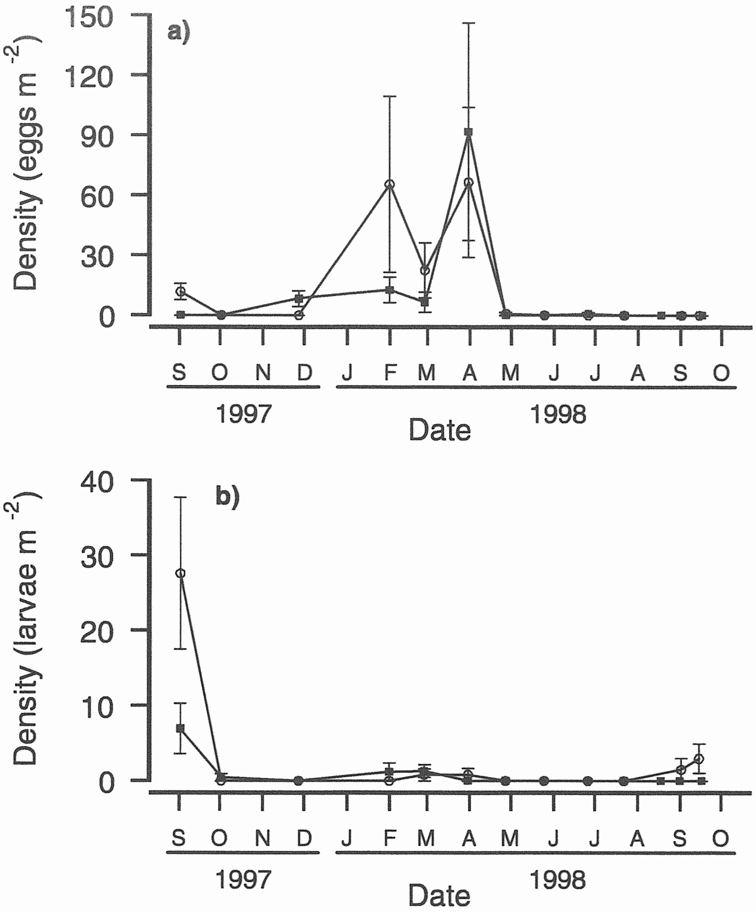


Figure 4.11. Mean density (eggs m-2) of anchovy (a) eggs and (b) larvae along 2 transects (26°30' and 26°35').

4.2.3.2 Spawning location

59 anchovy eggs were captured at 22 sites during the 1997 annual egg-abundance survey (Figure 4.12), but only 5 eggs were captured at one site during the 1998 survey. Most sites in 1997 were along transects near the mouth of Pumiscestone Passage (26°45') and Jumpinpin (27°45'), near Indian Head on Fraser Island (25°00') and in Hervey Bay.

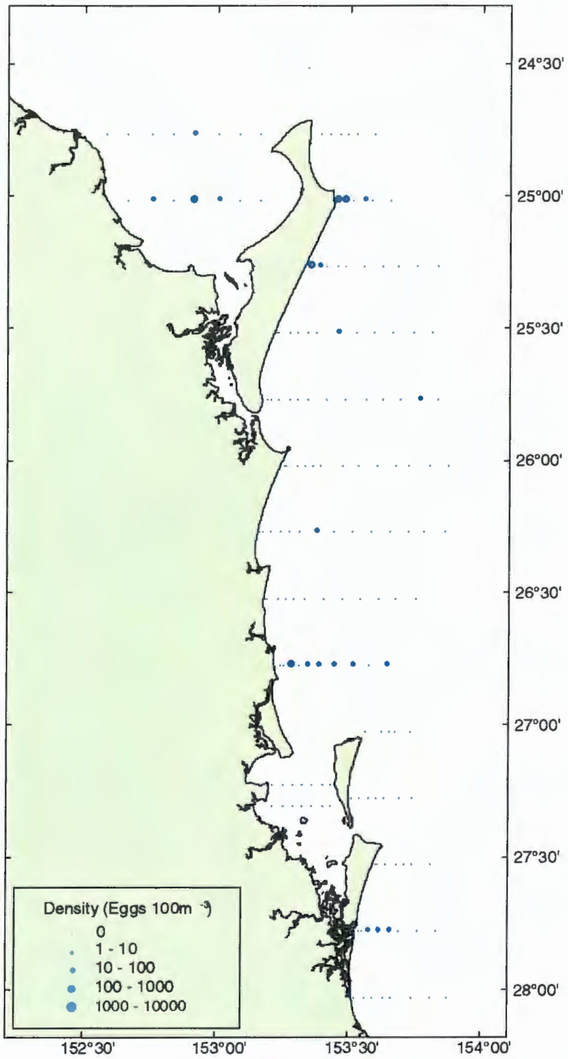


Figure 4.12. Density (eggs 100 m^{-3}) of anchovy eggs in August–September 1997.

4.2.4 Sandy Sprat

4.2.4.1 Spawning location

45 sandy sprat eggs were caught at 17 sites spread throughout the survey area during the 1997 annual egg-abundance survey (Figure 4.13). Sprat eggs were not identified in 1998.

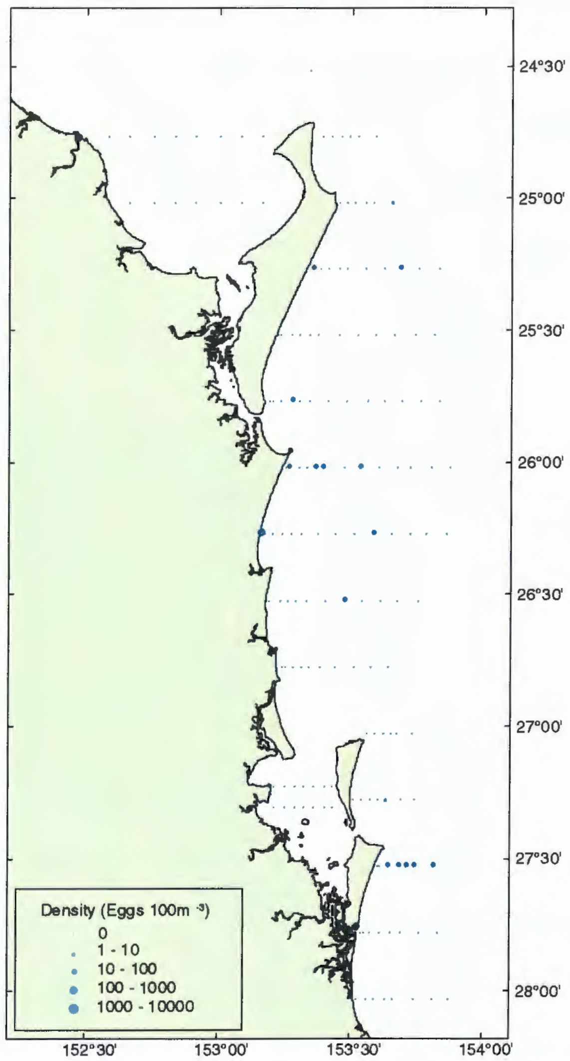


Figure 4.13. Density (eggs 100 m^{-3}) of sandy sprat eggs in August–September 1997.

4.2.5 Translucent Sprat

4.2.5.1 Spawning location

997 translucent sprat eggs were captured during the 1997 annual egg-abundance survey (Figure 4.14). These eggs were spread throughout the entire survey area, with the exception of Hervey and Moreton Bays. Sprat eggs were not identified in 1998.

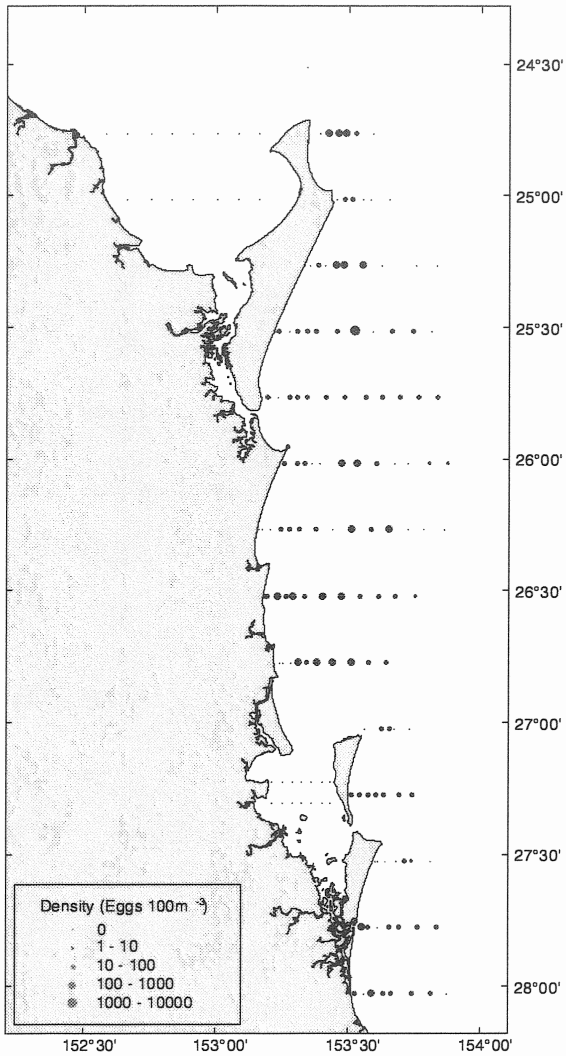


Figure 4.14. Density (eggs 100 m^{-3}) of translucent sprat eggs in August–September 1997.

4.3 Discussion

4.3.1 Pilchard reproduction

Results of macroscopic staging of ovaries and testes, histology of ovaries and observations of male and female GSI, suggest that pilchards reach sexual maturity at a minimum size of approximately 120 mm in Queensland. These results are within the range (70 mm Standard Length–150 mm FL) reported in other studies of pilchards throughout Australia (eg. Blackburn 1941, 1950; Ward *et al.* 1998). The method employed in this study differed slightly to the method in these other studies, which designated length at first maturity as the size at which 50% of fish were mature (determined by macroscopic or microscopic staging) during the spawning season. The main reason for using the GSI data in this study was because of the paucity of fish in the size range where maturity was first occurring (e.g. between 110 and 130 mm), especially during the peak spawning season. All these fish had their gonads weighed, but only a portion of them were staged (macroscopically or microscopically). Thus the GSI data were used to extend the results obtained from staging a relatively small number of gonads.

Pilchard spawning appears to be linked to water temperature, although the nature of the relationship is not clear (Blackburn 1960; Fletcher 1990; Fletcher and Tregonning 1992). Consequently, pilchard spawning has been reported in most seasons in Australia, varying with locality (eg. Blackburn 1941, 1950; Fletcher 1990; Fletcher and Tregonning 1992; Hoedt and Dimmlich 1995; Ward *et al.* 1998). Fletcher and Tregonning (1992) reported two peaks in pilchard spawning each year in the Albany region of Western Australia, one in July and one in December. The peak spawning season for pilchards in Queensland is during winter–early spring (July–October), which is the same time of year that Blackburn (1941) collected pilchard eggs in northern New South Wales and southern Queensland. This period corresponds to coolest water temperatures in the region, approximately 18–22°C (see Chapter 2), and is consistent with previous findings that pilchards spawn at water temperatures of 14–21°C (e.g. Blackburn 1960; Fletcher and Tregonning 1992). Small numbers of larvae were collected throughout the year, suggesting an extended spawning season, with at least some spawning occurring during summer. The annual pattern of pilchard spawning, including the timing of peak spawning, may depend on the characteristics of the east Australian Current, which is one of the main oceanographic influences along the Queensland and New South Wales coast.

Patterns in water temperature alone do not explain fully the concentration of pilchard spawning in a relatively small part of the shelf waters of southern Queensland in both years. Although these concentrations occurred in some of the coolest waters in the area (excluding the Bays), water of the same temperature was spread through a much larger area than spawning. The slightly warmer temperatures in 1998 compared with 1997 added more weight to the argument that temperature was not the only factor affecting spawning location. Ward and McLeay (1999b) also found that water temperatures in South Australia seemed to have regional but not local significance in defining favoured spawning areas of pilchards.

4.3.2 Maray reproduction

Very little information exists about maray spawning in Australia. Blackburn (1941) collected maray larvae in southern Queensland and northern New South Wales in autumn–spring and concluded that the spawning season was in winter–spring in that region. The results from this study support an autumn–spring peak spawning season for maray in southern Queensland.

4.3.3 Anchovy reproduction

Anchovy spawning peaks in summer in Australia's southern states, with a more protracted season in southern Queensland and northern New South Wales, where it extends from spring to autumn (Blackburn 1941, 1950b; Hoedt and Dimmlich 1995; Tri Pham unpublished). Pham (unpublished data) collected anchovy larvae, but very few eggs, in Pumicestone Passage, an estuarine system that opens into the ocean near Caloundra. The absence of eggs suggested that spawning occurred elsewhere (e.g. in waters offshore from Caloundra) and that young larvae migrated or were transported into the Passage. The hypothesis of offshore spawning sites in an area from where transport of larvae into the Passage would be likely is supported by the results of plankton sampling in this project during August/September 1997; high densities of eggs were found at sites along transects out from the Passage entrance, but no eggs were collected at sites along the transect to the north or south of the one off Caloundra. A similar situation also existed at Jumpinpin (27°45'South), which is the opening to another estuarine system at the south end of Moreton Bay. Hoedt and Dimmlich (1995) also reported the same general pattern in Victoria, where anchovies seemed to spawn mainly at the entrances to Western Port.

4.3.4 Sandy sprat reproduction

Sandy sprat spawning peaks between May and September in south Western Australia, although some spawning occurs in most other months as well (Gaughan *et al.* 1996). Gaughan *et al.* (1996) reported that most spawning occurred in nearshore waters, within 5.5 km of the coast. Blackburn (1941) reported that large shoals of sandy sprat occur in the bays and along the sandy beaches of southern Queensland in winter, but only hinted that these were spawning aggregations of some kind. The results of this study support the comments of Blackburn (1941), as some spawning occurred during winter. They do not support his comments regarding spawning location, however, because they suggest that spawning was not restricted to areas closest to the shore and was not occurring in Moreton or Hervey Bays, at least during winter.

4.3.5 Translucent sprat reproduction

No published information exists regarding the spawning patterns of translucent sprat. Whitehead (1985) describes the geographical distribution of the species as southern Queensland and New South Wales, and its preferred habitat as shallow sandy parts of bays and estuaries. The results of this study suggest that the species occurs throughout a much wider range of habitats, as it appeared to spawn throughout the shelf waters in southern Queensland in late-August 1997.

Chapter 5. Estimates of Spawning Biomass of Pilchards

Objective: *To estimate the spawning biomass of pilchards in southern Queensland using the Daily Egg Production Method.*

The parameters required to achieve this objective were estimated from samples of pilchard eggs and adults collected during August/September 1997 and 1998. Most eggs were collected in the same small area in both years, although the total spawning area was larger in 1997 (6376 km^2) than in 1998 (3368–3691 km^2). Mean egg production was 250 eggs m^{-2} in 1997 and 311–323 eggs m^{-2} in 1998. Mean weight of mature females was 44.10 g in 1997 and 47.84 g in 1998. Mean fecundity was 20268 eggs in 1997 and 20506 eggs in 1998. Sex ratio was 0.63 in 1997 and 0.64 in 1998. A range of spawning fractions (0.1–0.2) were used in 1997 because of problems estimating this parameter. A mean spawning fraction of 0.15 was estimated in 1998.

Estimates of spawning biomass were imprecise, but suggest that the size of the pilchard stock was at least 25000 t in both years. The high degree of uncertainty was due mainly to the large variability in the estimates of egg production, problems estimating spawning fraction in 1997 and the small number of observed fecundities. Egg production can be estimated more precisely by increasing the number of plankton samples collected in the major spawning area and by collecting the samples between dawn and mid-morning. Increased fishery-independent collection of adult pilchards using a multi-mesh gill-net should result in the capture of sufficient female fish with hydrated oocytes to ascertain more accurately the relationship between fecundity and fish size.

5.1 Methods

5.1.1 Daily Egg Production Method Model

The daily egg production method (DEPM) is becoming widely accepted as the favoured method for estimating the biomass of small pelagic fishes (e.g. Lasker 1985; Somerton 1990; Alheit 1993; Milton *et al.* 1995; Lo *et al.* 1996). Biomass of spawning adults is calculated from estimates of the number of eggs produced per day within the spawning area (daily egg production) and number of eggs produced per unit weight of pilchards per day (daily fecundity). Successful application of the method depends on several criteria: fish must be multiple spawners; eggs must be pelagic and able to be caught in plankton nets without significant losses; and spawning and non-spawning adults must be equally catchable (Lasker 1985). Pilchards meet these criteria and the DEPM has been used recently to obtain estimates of the spawning biomass of this species in Western Australia and South Australia (Fletcher *et al.* 1996a, 1996b; Ward *et al.* 1998; Ward and McLeay 1998, 1999b).

Spawning biomass (B) was estimated using Parker's (1985) model:

$$B = \frac{P_0 . A . W}{R . F . S}$$

where P_0 is the daily egg production per unit area (eggs m^{-2} day^{-1}), A is the spawning area (m^2), W is the average weight of mature females (g), R is the sex ratio (proportion of females in the population, by weight), F is the average batch fecundity (eggs female^{-1} day^{-1}) and S is the spawning fraction (proportion of mature females spawning day^{-1}).

5.1.2 Sample Collection

5.1.2.1 *Egg Survey Cruises*

Surveys to estimate the abundance of pilchard eggs were carried out during the 1997 and 1998 pilchard spawning season using the DPI research vessel RV *Warrego*. Plankton tows were performed during the day (approximately 7:00–18:00 EST) at sites along east-west aligned transects between latitudes 24°30'S (slightly north of Sandy Cape) and 28°S (slightly north of the Queensland / New South Wales border). Most transects extended from depths of approximately 15 to 180 m.

154 sites were sampled along 19 transects between 28 August and 5 September 1997 (Figure 5.1). Sites were spaced approximately 2 or 4 nm apart. Two transects, with sites spaced 4 nm apart, were sampled inside Hervey Bay and two transects, with sites spaced 2 nm apart, were sampled inside Moreton Bay.

A single cruise was planned for the second half of August 1998 to collect plankton samples as far south as Iluka in northern New South Wales. The weather in August and September was unusually bad, resulting in the planned cruise being broken up into three short trips of three to four days duration, with gaps of 10 and 11 days between each. The bad weather also prevented the collection of any samples from New South Wales.

95 sites were sampled along 15 transects between 18 August and 17 September 1998 (Figure 5.2). Two transects (26°15'S and 26°30'S) within the major 1997 spawning area were sampled twice in 1998 (referred to as Area 1). The first sampling of the transects (Replicate A) was the day before starting to sample all transects to their north, and the second (Replicate B) was the day before starting to sample all transects to their south. The remaining area, which was sampled only once, is referred to as Area 2.

5.1.2.2 Plankton Collection

Plankton samples were collected using paired conical plankton nets (internal diameter 0.285 m) deployed to within 5 m of the substratum (in waters <70 m deep) or to a depth of 70 m (in waters >70 m deep). The net was retrieved vertically at a speed of approximately 1 m s^{-1}. The distance travelled by the net was calculated using calibrated flowmeters. Samples from each net were stored in 5% buffered formalin. Preliminary analyses showed little difference between nets, so samples from the two nets were pooled at each site. Surface water temperature (± 0.1 °C) was measured at each site.

5.1.2.3 Adult Sampling

Samples of adult pilchards were collected in 1997 from three commercial fish trawl catches (2/9/97–3/9/97), from five purse-seine catches (22/8/97–24/9/97) and by jigging (3/9/97) (Figure 5.1). Samples were collected in 1998 from five purse-seine catches (1/9/98–20/9/98) (Figure 5.2). Samples from the fish trawl catches were frozen and other samples were fixed in 5% buffered formalin.

Samples of adult pilchards were also collected once in 1997 (1/10/97) and six times in 1998 (1/9/98–16/9/98) using a multi-mesh gill-net deployed from the FV *Warrego*. The gill-net was made of nine panels of double diamond nylon dyed brown, with three panels of each of three mesh sizes; 2.5 mm (1 inch), 29 mm (1.125 inches) and 32 mm (1.25 inches) (Figure 5.3). The headline and footrope were hung at a ratio of 1:2. Lead weights of approximately 1 kg were attached to the footrope at the two ends and below the two vertical seams.

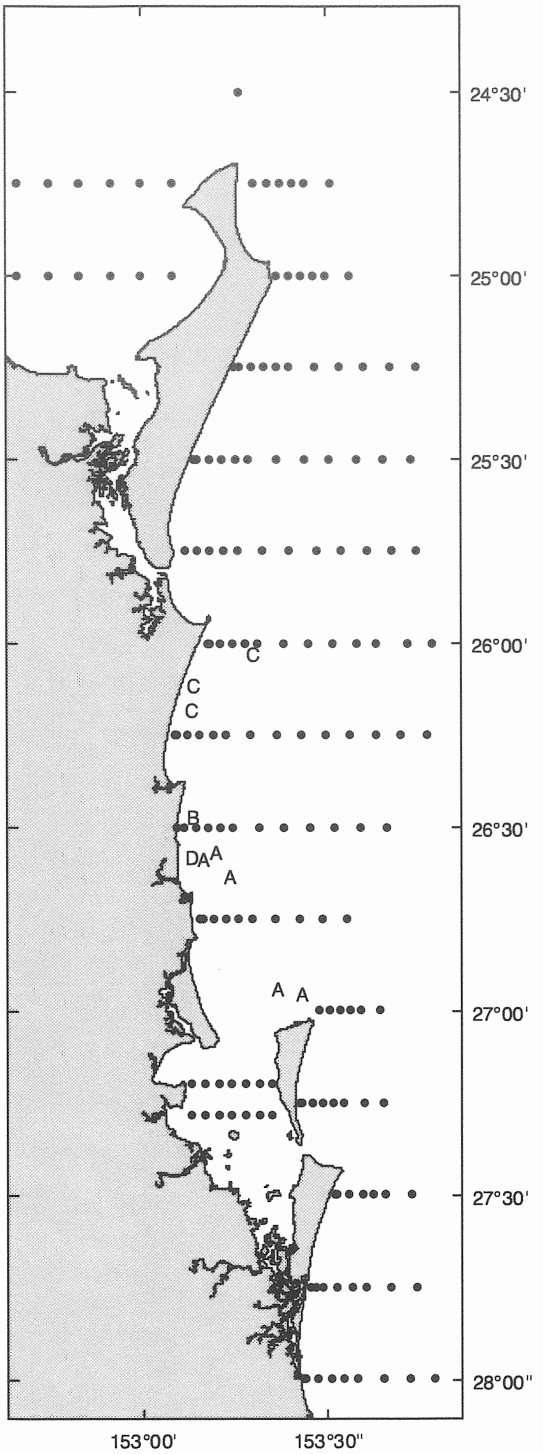


Figure 5.1. Sites for collection of plankton (28 August–5 September) and adult pilchards (22 August–1 October) during 1997 annual egg survey. ●, plankton sites; A, purse-seine sites; B, gill-net site; C, fish-trawl sites; D, jigging site.

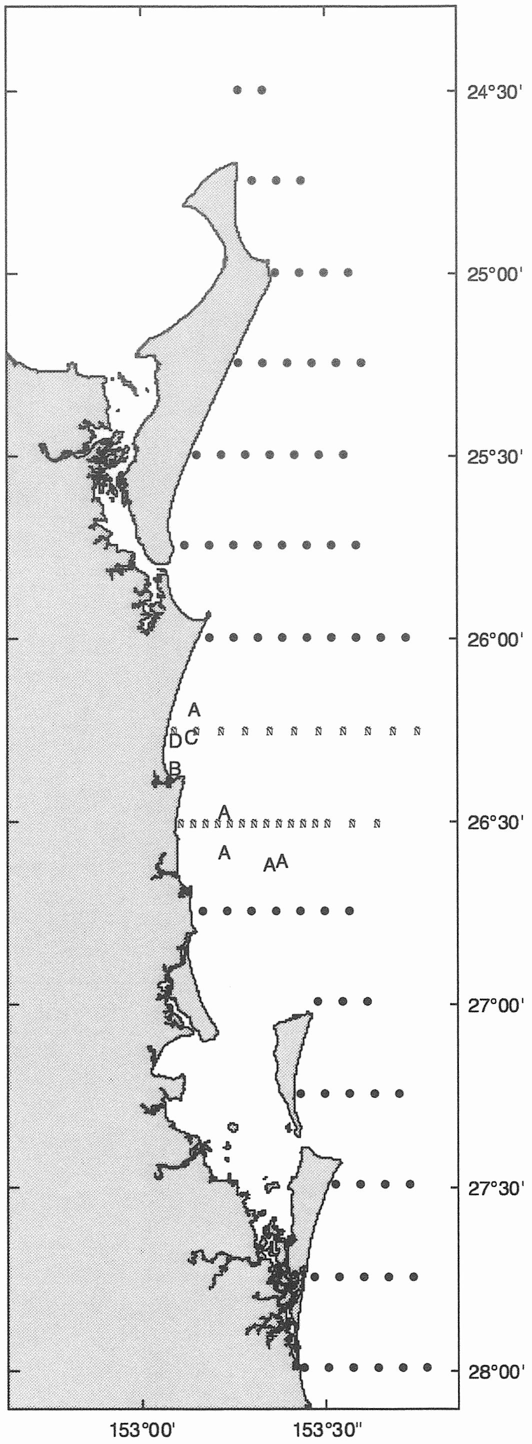


Figure 5.2. Sites for collection of plankton (18 August–3 September) and adult pilchards (1–20 September) during 1998 annual egg survey. ●, plankton sites (Area 2); +, plankton sites sampled twice (Area 1); A, purse-seine sites; B, gill-net sites (1 sample); C, gill-net sites (2 samples); D, gill-net sites (3 samples).

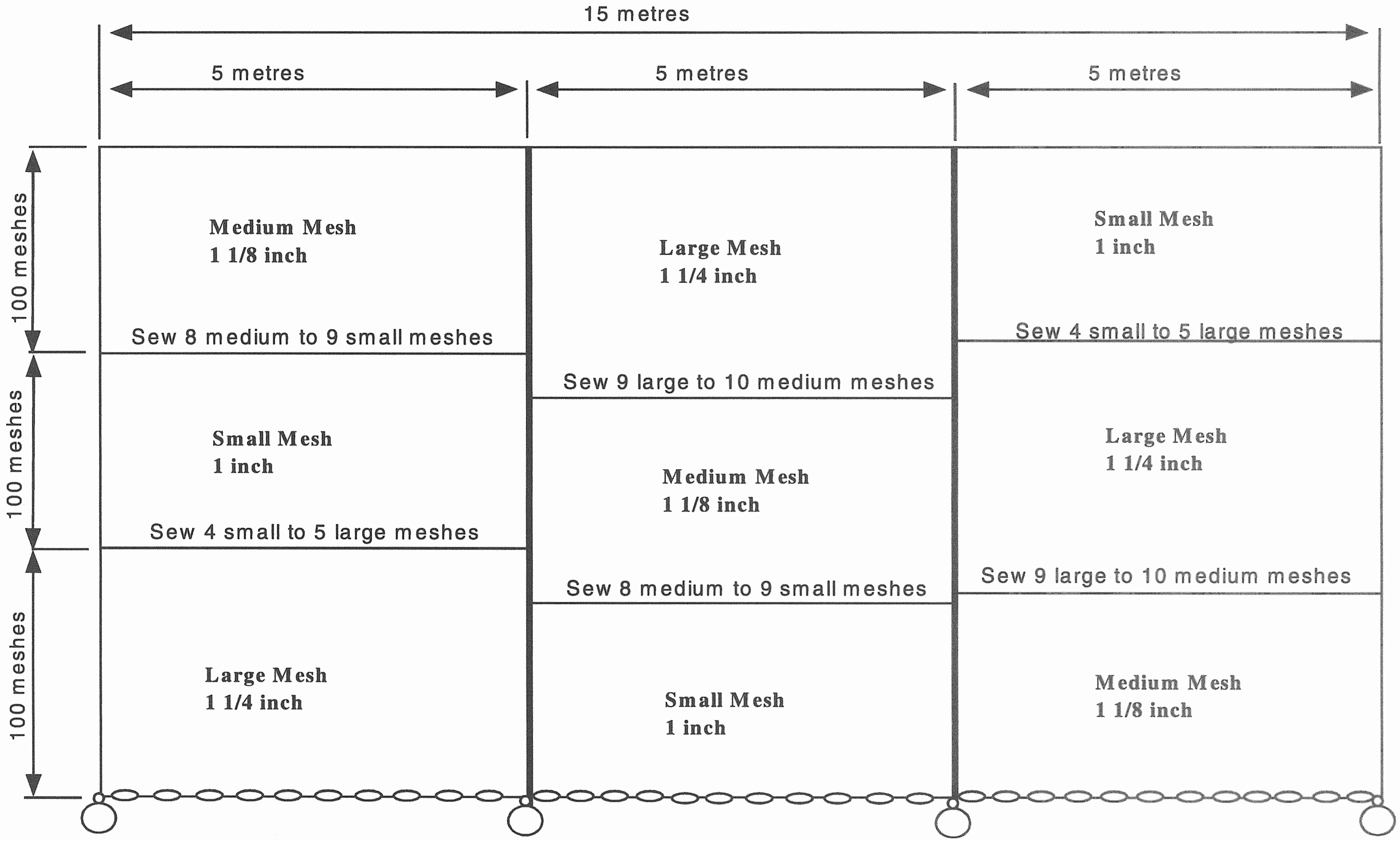


Figure 5.3. Design of multi-mesh gill-net used to catch adult pilchards

5.1.3 Sample Processing

5.1.3.1 Plankton

Pilchard eggs in each plankton sample were identified and staged according to their internal structure (White and Fletcher 1998), and the number in each stage was counted.

5.1.3.2 Adults

Adult pilchards were measured (± 1 mm FL) and weighed (± 0.01 g) and their gonads were removed and weighed (± 0.01 g). Ovaries were sent to the University of Adelaide for sectioning and staining with haematoxylin and eosin, for the examination of sections for post-ovulatory follicles and for the estimation of batch fecundity. Batch fecundity was only estimated for females with hydrated oocytes. Sub-samples of each ovary were weighed, and the number of hydrated oocytes counted. The total batch fecundity was estimated by multiplying the number of oocytes per gram in the sub-sample by the total weight of the ovary.

5.1.4 Analyses

5.1.4.1 Spawning Area (A)

The survey area was divided into a series of contiguous grids, centred approximately on each site. The spawning area was estimated as the sum of the areas containing sites where day–1 eggs (<24 hours old) were collected (positive sites), plus a few sites where day–1 eggs were absent but might be reasonably expected to occur (embedded negative sites) because they were adjacent to at least three other positive sites.

5.1.4.2 Egg Production (P_0)

The number of eggs spawned was estimated taking into account the observed numbers of eggs collected, the approximate time of day when pilchards spawned and an hourly rate of egg mortality.

A range of possible spawning times was estimated for each batch of day–1 eggs using a range of ages for pilchard eggs of the same stage of development in water of the same temperature (see Table 1, White and Fletcher 1998). The sea-surface-temperature at each collection site was used as an approximation of the temperature experienced by the egg during its development. The frequency of each possible spawning time (after pooling all batches of day–1 eggs) was plotted and the time of peak frequency identified and used as spawning time.

Each plankton sample was assigned a day–1 age by subtracting the assumed spawning time from the sample's collection time and a day–2 age by adding 24 hours to the day–1 age. This allowed samples to be assigned ages, even if no eggs were collected (i.e. for embedded negative sites and sites where day–2 eggs were not collected). Day–2 observations were not included in the analyses if their estimated age was ≥ 37 hours, by which time most eggs could be reasonably expected to have hatched.

Counts of eggs (*C*) were converted to densities (*P*; eggs m^{-2}) using the formula:

$$P = \frac{C}{V} \times D$$

where V is the volume filtered and D is the depth. In depths >70 m, D was set to 70 m, the maximum depth to which the plankton net was deployed. Densities were weighted according to the area of the grid they represented.

Mean egg production (the density of eggs released into the sea) can be estimated by regressing egg density on age using the exponential mortality model (Piquelle and Stauffer 1985):

$$P_t = P_0 e^{(-Zt)}$$

where P_t is the abundance of eggs at age t and Z is the instantaneous rate of daily egg mortality, which is assumed to remain constant throughout the development of the eggs.

In this study, the linear version of the model was used to estimate P_0 (Picquelle and Stauffer 1985):

$$\ln(P_t + C) = \ln(P_0 + C) - Zt$$

where C was a constant to allow inclusion of zeros from embedded negative sites. The linear method was chosen because of the extremely non-normal distribution of the residuals using the non-linear method. The values of the constant C were 4 in 1997 and 8 in 1998. These values were the minimum observed densities in the respective years, and resulted in approximately normally distributed residuals.

The unbiased estimate of P_0 was approximated using the following formula:

$$P_0 = e^{(\ln(P_0 + C) + s^2/2)} - C$$

where s^2 is the residual variance from the regression.

5.1.4.3 Adult Parameters (W, R, F and S)

The batch fecundity (F) of all mature females was estimated using the parameters derived from a regression of batch fecundity on ovary-free weight for females with hydrated oocytes. Mean F and weight of mature females (W) were estimated for each sample.

Stained sections of ovaries were examined for the presence of post-ovulatory follicles (POFs) indicating recent spawning. POFs were classified as day–0 (<24 hours old), day–1 (24–48 hours old) or day–2 (>48 hours old) according to published criteria (Goldberg *et al.* 1984; Akkers *et al.* 1996). Spawning fraction (S) of each sample was estimated as the mean proportion of day–1 and day–2 POFs.

Sex ratio (S) was estimated for each sample as the proportion of the total weight of the sample apportioned to mature females.

Population-mean values for W, R, F and S were estimated, having weighted individual sample values (or sample means) according to sample size (Picquelle and Stauffer 1985).

5.1.4.4 Bootstrapping

Coefficients of variation of individual parameters (P_0, W, F, R and S) and the 95% confidence interval of the biomass estimates, were estimated using bootstrapping methods. Each parameter was estimated 10000 times using the same methods outlined above. The bootstrap data sets contained randomly-chosen individuals (with replacement) from randomly-chosen samples (with replacement). The number of samples, and sample sizes were the same as for the original data set. Where regressions were used to calculate parameters (P_0 and F), bootstrap data sets consisted of randomly-chosen residuals from the original regression added to each expected value. In the case of regressions of bootstrap data sets resulting in negative values of Z (i.e. positive slope) or negative relationship between fecundity and ovary-free weight, slopes were assumed to equal zero, and intercepts to equal the mean of the bootstrap data. The 95% confidence intervals of biomass estimates were estimated using the percentile method.

5.2 Results

5.2.1 Spawning Area

Most eggs were collected at sites along two transects; one at 26°15' (1997) and the other 26°20 (1997 and 1998). Positive sites, plus five embedded negative sites, represented an area of 6376 km^2 in 1997 (Figure 3). The estimated spawning areas in 1998 were 2337 km^2 (Area 2; Figure 5.5), 1030 km^2 (Area 1, Replicate A; Figure 5.6a) and 1354 km^2 (Area 1, Replicate B; Figure 5.6b). No pilchard eggs were found in either Hervey Bay or Moreton Bay in 1997, hence these bays were not sampled in 1998.

5.2.2 Egg Production

In 1997, all estimated spawning times were between 17:30 and 05:30 h, with 50% occurring between 21:30 and 2:30 h (Figure 5.7). The frequency of possible spawning times peaked between 22:30 and 00:30 h. The midpoint of this period, 23:30 h, was designated as the time of spawning for estimating egg ages. In 1998, more than 50% of possible spawning times occurred between 18:00 and 22:00 h, with highest frequency, and designated spawning time, being at 21:00 h.

A total of 1321 pilchard eggs, 985 of which were less than 24 hours old, were identified from the plankton samples collected in 1997. Most samples contained fewer than 5 day–1 eggs. However, 9 samples contained more than 50 day–1 eggs, and 2 of these samples contained more than 100 day–1 eggs. Weighted densities of these samples varied from zero to 1690 eggs m^{-2} (Figure 5.8).

A total of 2486 pilchard eggs, including 2434 (98%) day–1 eggs, were collected in 1998, mostly from Area 1. Nine samples, each containing between one and nine day–1 eggs, were collected in Area 2. Nine (Replicate A) and 12 (Replicate B) samples collected in Area 1 contained day–1 eggs, usually between 20 and 100 eggs per sample. One sample in Replicate B of Area 1 contained 895 eggs. Weighted densities ranged from zero to 4397 eggs m^{-2} (Figure 5.9).

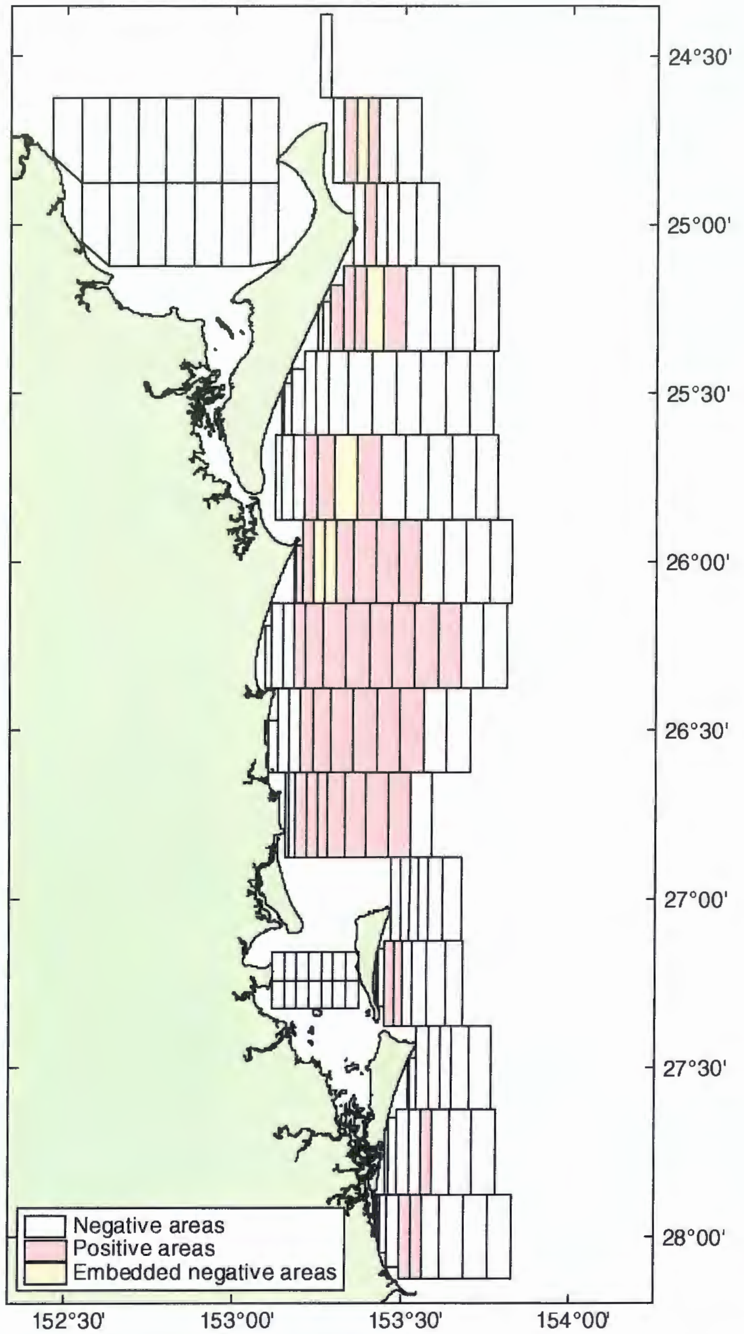


Figure 5.4. Spawning area of pilchards determined from the distribution of day–1 eggs during the 1997 annual egg survey (28 August–5 September).

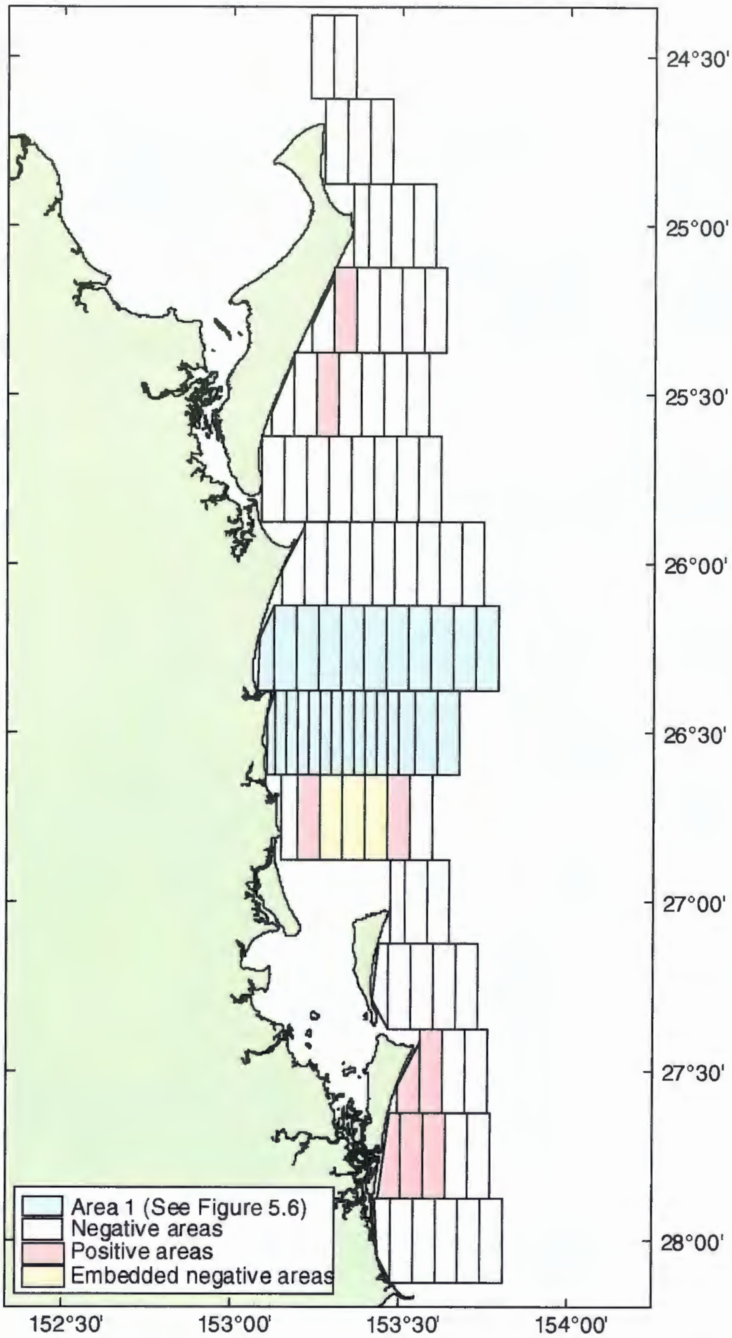


Figure 5.5. Spawning area of pilchards (Area 2) determined from the distribution of day–1 eggs collected during the 1998 annual egg survey (18 August–3 September). Results from Area 1 are shown in Figure 5.6.

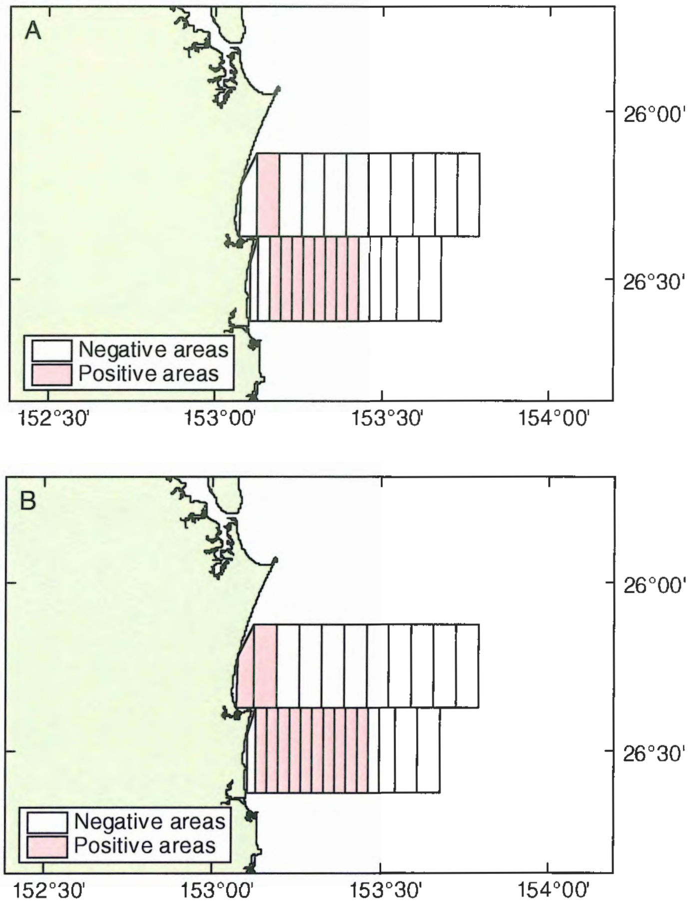


Figure 5.6. Spawning area of pilchards (Area 1) determined from the distribution of day–1 eggs collected during the 1998 annual egg survey. (A) Replicate A (18–19 August), (B), Replicate B (1 September).

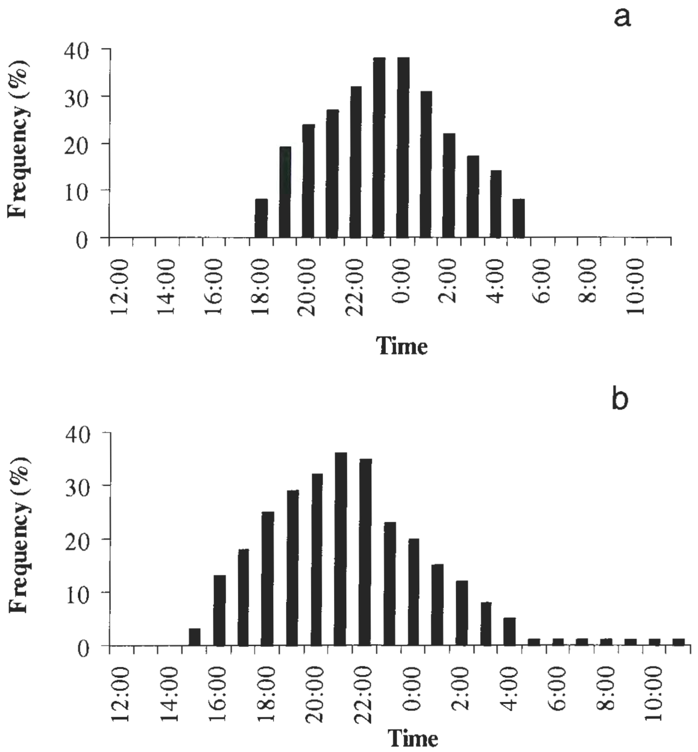


Figure 5.7. Frequency of possible spawning times for pilchards during (a) 1997 and (b) 1998 annual egg surveys, back-calculated from range of possible ages of eggs and collection times.

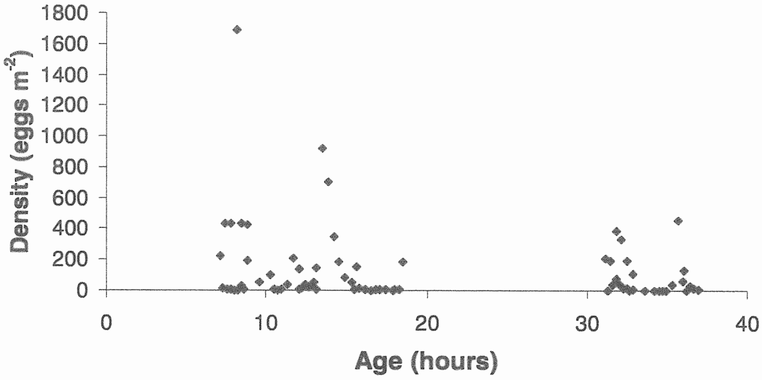


Figure 5.8. Weighted densities (eggs m^{-2}) of day–1 and day–2 pilchard eggs collected during 1997 annual egg survey.

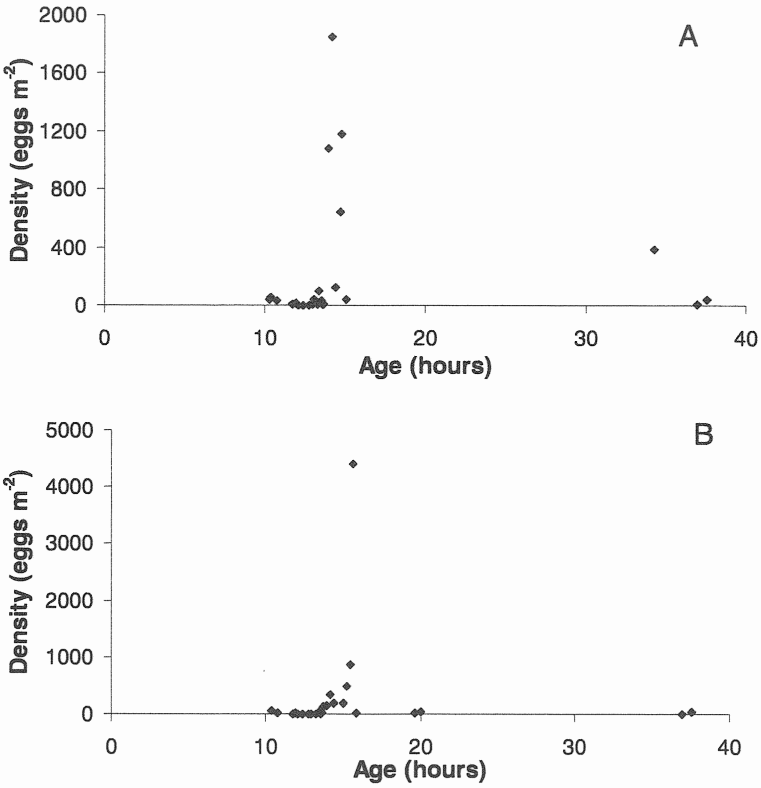


Figure 5.9. Weighted densities (eggs m^{-2}) of day–1 and day–2 pilchard eggs collected during 1998 annual egg survey (Area 1 and Area 2 combined). (A) Area 2 + Replicate A, (B) Area 2 + Replicate B.

The linear regression of the log-transformed densities in 1997 resulted in a slope of -0.025 (i.e. Z=0.025 hr^{-1} or 0.6 day^{-1}), intercept of 4.14 and residual variance of 2.81 (Figure 5.10). The unbiased estimate of P_0 was 250.25 eggs m^{-2} (CV=46%).

The lack of day–2 eggs in 1998 meant that a reasonable estimate of egg mortality (*Z*) could not be obtained using the linear regression of log-transformed egg densities. Instead, the *Z* value of 0.025 $hour^{-1}$ (0.6 day^{-1}), which was estimated from the 1997 density data, was used for 1998 also. Straight lines with slope of -*Z*, were fitted to the log-transformed data from Area 1 (Replicates A and B separately) combined with Area 2 (Figure 11). The intercepts of the lines were 4.34 and 4.42 and residual variances of 2.92 and 2.69 for Area 2 plus Replicates A and B respectively. The unbiased estimates of P_0 were 323.02 eggs m^{-2} (CV= 75%) and 311.39 eggs m^{-2} (CV=80%).

5.2.3 *Female Weight*

A total of 455 mature female fish were weighed in 1997 and 688 were weighed in 1998. The mean weight of these fish, weighted by sample size, was 44.10 g (CV=4%) in 1997 and 47.84 g (CV=3%) in 1998 (Table 5.1).

5.2.4 *Sex Ratio*

The mean sex ratio, weighted by sample size, was 0.63 (CV=12%; Table 5.1) in 1997 and 0.64 (CV=8%) in 1998.

5.2.5 *Fecundity (F)*

The regression of fecundity on ovary-free weight (*W**) was $F = 17788 + 58.13W^*$ (Figure 5.12). The relationship was not significant because only four females with hydrated oocytes were collected (F = 0.14, *df* = 2, p=0.747), Fecundity was estimated using this equation for 455 mature females in 1997, with a mean, weighted by sample size, of 20268 (CV=8%; Table 5.1).

None of the females collected in 1998 contained ovaries with hydrated oocytes. Therefore, the equation relating fecundity to ovary-free weight in 1997 was used to estimate fecundity of 676 mature females in 1998. The mean fecundity, weighted by sample size, was 20506.09 (CV=8%; Table 5.1).

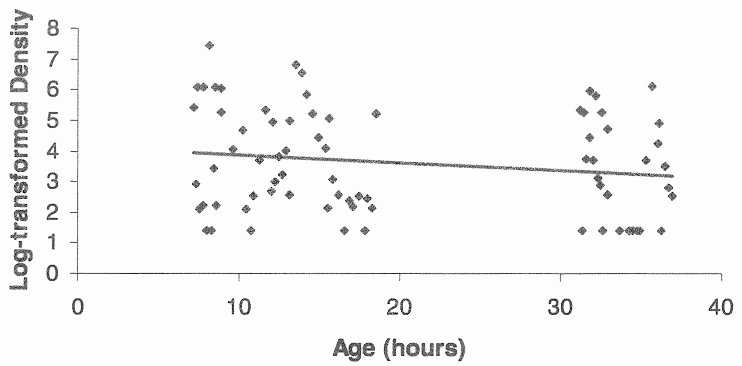


Figure 5.10. Weighted log-transformed (Log (X+4)) densities of day–1 and day–2 pilchard eggs collected during 1997 annual egg survey. Solid line is linear regression.

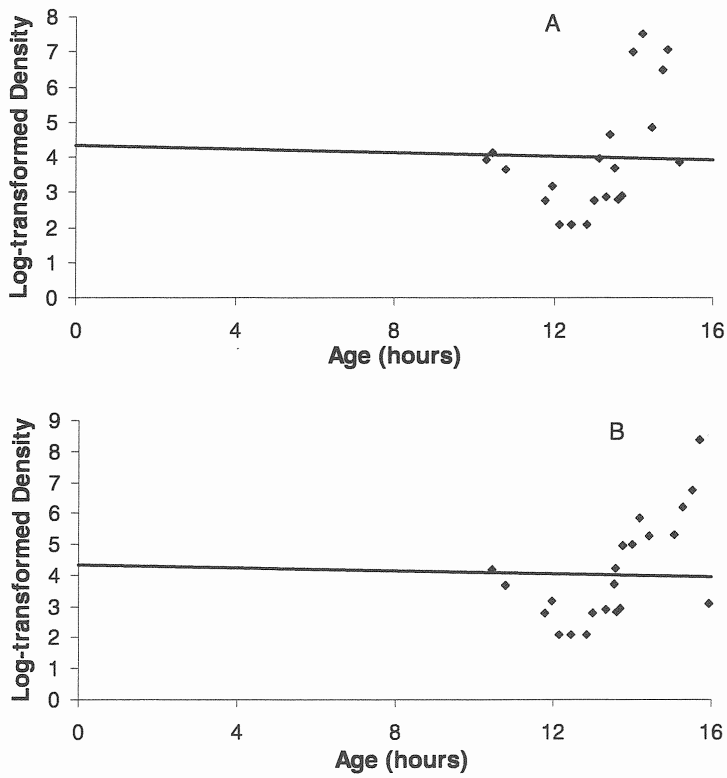


Figure 5.11. Log-transformed weighted densities of day–1 pilchard eggs collected during 1998 annual egg survey . Solid line is linear regression with assumed slope of -0.025. (A) Replicate A, (B) Replicate B.

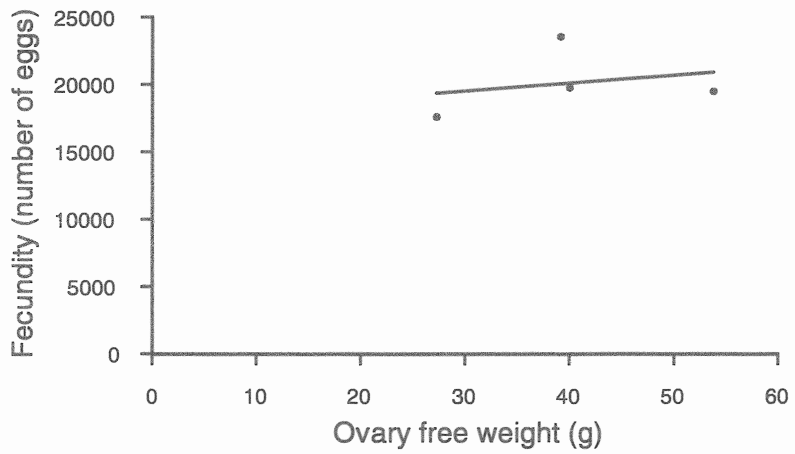


Figure 5.12. Relationship between fecundity (number of eggs) and size (ovary free weight (g) of ripe pilchards. Note: regression was non significant (F = 0.14, *df* = 2, p=0.747) because of the small sample size.

5.2.6 Spawning Fraction

79 females from 6 samples collected in 1997 had ovaries containing POFs; four samples contained no recently-spawned females. Day–2 POFs were extremely rare, occurring in two samples only. The low spawning fractions observed (Table 5.1) seemed unrealistically low, and were possibly related to problems of sampling adult fish. Therefore, values of 0.1, 0.15 and 0.2 were used to estimate possible spawning biomass. These values reflect spawning fractions estimated in previous DEPM studies in Australia (Fletcher *et al.* 1996a, 1996b; Ward *et al.* 1998).

196 females ovaries from 10 samples collected in 1998 had ovaries containing POFs; only one sample contained no recently-spawned females. The mean spawning fraction (mean of day–1 and day–2 POFs), weighted by sample size, was 0.15 (CV=16%; Table 5.1).

5.2.7 Biomass Estimate

A summary of the parameters *P, A*, *W*, *R* and *F* is shown in Table 5.2. The most conservative estimate of spawning biomass in 1997, assuming a spawning fraction of 0.2, was 27 553 t , while the least conservative estimate, assuming a spawning fraction of 0.1, was 55 106 t (

Table 5.3). The two estimates of spawning biomass in 1998 were 25 747 t (Replicate A) and 27 205 t (Replicate B). The distributions of the bootstrapped estimates of *B* were extremely skewed, a pattern which was a consequence of the approximately log-normal distribution of *P* (Figure 5.13).

Table 5.1. Adult parameters of individual samples of pilchards caught by fish-trawling (FT), gill-netting (GN) jigging (J) and commercial purse-seining (PS) for use in spawning biomass calculations in 1997. Sample sizes in parentheses.

Date	Time	Gear	Mean Female Weight (g)	Mean (estimated) Fecundity (eggs)	Sex Ratio	Spawning Fraction
02/09/97	2:35	FT	43.21 (32)	20200.89 (32)	0.33 (57)	0 (32)
03/09/97	1:25	FT	44.50 (16)	20290.99 (16)	0.78 (21)	0 (16)
03/09/97	19:30	FT	40.33 (33)	20062.20 (33)	0.80 (78)	0 (33)
01/10/97	23:30	GN	40.44 (70)	20084.44 (70)	0.62 (117)	0.26 (70)
03/09/97	–	J	46.44 (13)	20420.03 (13)	–	0.08 (13)
22/08/97	dawn	PS	40.61 (41)	20052.70 (41)	0.79 (94)	0 (41)
30/08/97	dawn	PS	44.35 (70)	20272.48 (70)	–	0.06 (70)
31/08/97	dawn	PS	41.17 (66)	20094.75 (66)	–	0.19 (66)
11/09/97	dawn	PS	51.85 (88)	20700.56 (88)	–	0 (26)
24/09/97	dawn	PS	44.55 (26)	20322.57 (26)	0.44 (60)	0.02 (88)
01/09/98	18:45	GN	47.80 (158)	20500.17 (157)	0.79 (204)	0.17 (79)
01/09/98	20:45	GN	47.71 (83)	20496.79 (83)	0.82 (102)	0.24 (50)
02/09/98	4:30	GN	51.64 (104)	20708.21 (104)	0.75 (143)	0.13 (75)
15/09/98	23:30	GN	56.25 (37)	20950.14 (37)	0.81 (46)	0.01 (37)
15/09/98	5:30	GN	62.88 (12)	21302.90 (12)	0.64 (20)	0 (12)
16/09/98	21:15	GN	51.50 (52)	20717.38 (52)	0.73 (72)	0.08 (51)
01/09/98	19:45	PS	45.23 (43)	20354.19 (41)	0.44 (101)	0.22 (43)
03/09/98	3:00	PS	39.77 (50)	20051.14 (50)	0.50 (101)	0.25 (50)
14/09/98	3:45	PS	47.66 (56)	20537.37 (50)	0.58 (101)	0.25 (50)
17/09/98	4:30	PS	43.31 (41)	20241.60 (41)	0.42 (101)	0.11 (41)
20/09/98	4:30	PS	41.17 (52)	20137.86 (49)	0.52 (100)	0.07 (50)

Table 5.2. Summary of pilchard DEPM parameter values (mean (CV)) in 1997 and 1998. * assumed values.

		1998	
Parameter	1997	Replicate A + Area 2	Replicate B + Area 2
Egg Production (eggs m^{-2})	250.25 (0.46)	323.02 (0.75)	311.39 (0.80)
Spawning Area (km^2)	6376	3368	3691
Female Weight (g)	44.10 (0.04)	47.84 (0.03)	
Sex Ratio	0.63 (0.12)	0.64 (0.08)	
Batch Fecundity (eggs $female^{-1}$ $batch^{-1}$)	20268 (0.06)	20506 (0.06)	
Spawning Fraction	0.1, 0.15, 0.2 *	0.15 (0.16)	

Table 5.3. Spawning biomass (t) estimates and 95% confidence intervals for pilchards in 1997 and 1998.

	1997			1998	
	S=0.1	*S*=0.15	*S*=0.2	Replicate A	Replicate B
Lower 95% CI	20 813	13 875	10 406	5 240	6 981
Mean Estimate	55 106	36 737	27 553	25 747	27 205
Upper 95% CI	119 250	79 500	59 625	102 528	110 161

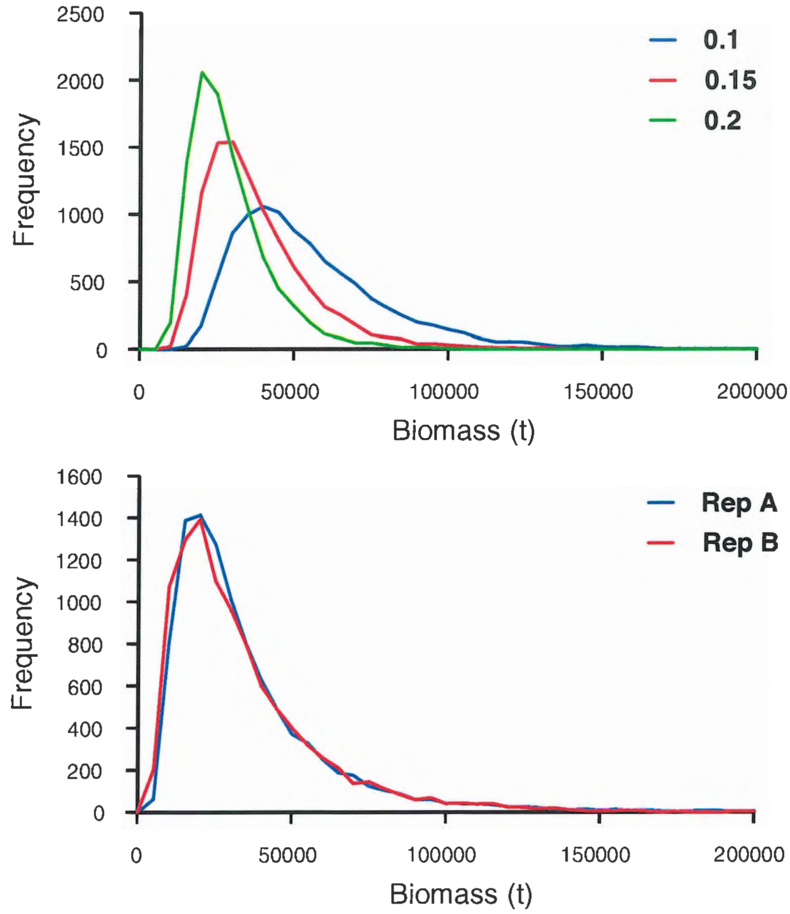


Figure 5.13. Frequency distribution of bootstrapped biomass estimates of pilchards in (a) 1997, assuming 3 different values for egg mortality (*Z*; 0.1–0.2) and (b) 1998.

5.3 Discussion

5.3.1 Spawning biomass of pilchards in Queensland

The results from 1997 and 1998 suggest that the spawning biomass of pilchards during the spawning season in both years was in excess of 25000 t. The precision of these estimates was low, due to the large variability of some of the parameters and the uncertainty of the estimate of spawning fraction in 1997. The low precision resulted in large 95% confidence intervals.

Coefficients of variation (CV) of most parameters were less than 10%. Egg production was the most variable parameter, as indicated by the large CVs of 46% in 1997, and 75% and 80% in 1998. The large variability was due partly to the small number of samples containing eggs and the occurrence of a few very high egg densities. These high values occur when plankton samples are collected within a high density patch of eggs that has not had time to disperse within the water column. The resulting samples can contain several hundred eggs, compared with most samples that contain between 0 and 50 eggs. Future CVs of egg production should be reduced by further increasing the sampling effort in the area of highest density spawning. This stratification of sampling effort will need to be balanced with the unknown annual variability in the size and location of the major spawning area which requires the entire region to be sampled each year. The distribution pattern of day–1 eggs in 1997 and 1998 suggests that most spawning occurs in the area between Double Island Point (26°S) and Cape Moreton (27°S). This pattern could vary annually, however, as spatial distribution of pilchards is influenced by both stock-dependent (e.g. abundance) and -independent (e.g. environment) factors (e.g. Csirke 1988; Hilborn and Walters 1992; Kawasaki 1993).

The method used to estimate rates of egg mortality and egg production can have a large influence on their values. Values estimated using the non-linear method of fitting the exponential mortality model are influenced greatly by outlying high densities of young eggs. By log-transforming the observed densities and using the linear version of the model, as was done in this study, the influence of extremely high densities of young eggs on estimates of egg production and egg mortality is minimised. Log-transformed data also fit the assumptions of the model better, by having approximately normally-distributed residuals. In this study, the 1997 dataset was the only one suitable for estimating egg mortality and egg production simultaneously (i.e. the standard analysis). Although not presented here, the non-linear method of analysing the data would have resulted in significantly higher estimates of both parameters compared with those estimated using the linear method and log-transformed data.

Likewise, the estimates of egg production from the data in 1998 were lower (i.e. more conservative) when estimated from log-transformed data, compared with using untransformed data.

An estimated time of peak spawning before midnight, fast development of eggs in the warm water (20–21°C) and daytime collection of plankton samples were all probable factors in the paucity of day–2 eggs collected during the study. The abundance of these eggs is critical to the estimation of egg mortality and, therefore, egg production. Future estimates of egg production will be more precise if plankton sampling is conducted between dawn and mid-morning, thus increasing the occurrence of samples containing young day–2 eggs (i.e. stage–10 and –11 eggs).

The CVs of fecundity in both 1997 and 1998 were low (6%). The small variability in the 10000 bootstrap values of fecundity resulted in part from the small variability in the estimates of mean ovary-free weight for samples in both years. A tight fitting relationship between ovary-free weight and fecundity would also contribute to low CVs. This was not the case in this study as only a small number of ripe females (four) were used to establish the relationship. The low CVs were not, therefore, accurate indicators of the uncertainty with which fecundity was estimated. Confidence in future estimates of fecundity will benefit from an increase in the number of observations used to regress fecundity on ovary-free weight. This objective could be attained by collecting a larger number of samples soon after dusk, thus maximising the probability of catching ripe females prior to pre-midnight spawning.

Further investigations of the spawning localities of pilchards in southern Queensland, extending into northern New South Wales, are required. The data relating to abundance of pilchards presented in this report (Chapter 2) support, but do not necessarily confirm, the anecdotal evidence (e.g. Whitley 1937) that large quantities of pilchards migrate from northern New South Wales to southern Queensland to spawn. Blackburn (1941) collected large numbers of pilchard eggs at sites on the continental shelf near Cape Byron and Coffs Harbour during September, indicating that some spawning occurs in northern New South Wales at the same time as spawning in Queensland. It is impossible, however, to establish the relative amounts of spawning biomass in the waters off the two states with the available information. An extension of the area sampled to include plankton collection at sites in northern New South Wales would be an essential part of any future research program.

5.3.2 Comparison with other states

The estimates of pilchard stock size in southern Queensland were of similar magnitude in 1997 and 1998. They are, therefore, comparable to estimates of pilchard stock-size from similar sized regions in Western Australia (Albany, Bremer Bay, Esperence) where established fisheries have existed for a number of years (Fletcher *et al.* 1996a, 1996b). Recent estimates of pilchard spawning biomass in South Australia (1995–1999) have fluctuated annually, due in part to two large-scale mortality events caused by a herpes virus (Ward *et al.* 1998, 1999; Ward and McLeay 1998, 1999a, 1999b). Estimates of biomass have varied from approximately 18000 to 100000 t spread throughout a spawning area approximately 10–20 times as large as the spawning area in southern Queensland.

5.3.3 Management Implications

Estimates of spawning biomass should be an important component in the process of setting appropriate total allowable catches (TACs) for small pelagic fish fisheries (Ward *et al.* 1998; Cochrane 1999). These and other issues relating to the potential for the development of a pilchard fishery in southern Queensland are discussed in Chapter 8.

Chapter 6. Potential effects of a purse-seine fishery on predatory species and other user groups

Objective: *Examine the potential impacts of a purse-seine fishery in southern Queensland on populations of predators of baitfish and on other stakeholders.*

This objective was achieved by identifying: i) the species of small pelagic fishes found in southern Queensland, ii) the quantities of these fishes caught in the developmental pilchard fishery, iii) the species of marine predators found in southern Queensland, iv) the potential effects of the fishery on predatory species and v) the concerns raised by other user groups. The chapter complements the wide-ranging review of available literature presented in Ward *et al.* (1998).

Coastal waters of southern Queensland support a diverse assemblage of small planktivorus pelagic fishes. Despite this diversity, pilchards accounted for approximately 85% of the total catch in the developmental fishery between September 1997 and October 1998 and relatively few other species were caught. There is also a diverse assemblage of predatory birds, mammals and fish, all of which are opportunistic feeders on a wide variety of small pelagic fishes and invertebrates. Recreational anglers have expressed concern that the development of a pilchard fishery in southern Queensland will have adverse effects on the predatory fishes, many of which are considered prime angling species. However, the potential ecological effects of a conservatively-managed, sustainable pilchard fishery would be limited by a) the opportunistic feeding habits of the predatory species, b) the successful targeting of only one (i.e. pilchards) of the region's many species of potential prey and c) the removal of only a small percentage (e.g. 5–10%) of that species' adult biomass.

Potential operational (i.e. direct) effects of a purse-seine-based pilchard fishery would include the accidental encirclement and occasional drowning of dolphins. However, adoption of recommendations outlined in a report written by an expertise-based Working Group may assist the minimisation of rates of encirclement and mortality of dolphins. These recommendations remain untested due to the prohibition of purse-seining in Queensland waters.

6.1.1 Introduction

Ward *et al.* (1998) provided an extensive review of available literature regarding the potential impacts of purse-seine fisheries for clupeoids in southern and eastern Australia on populations of predatory fishes, seabirds and marine mammals. This chapter compliments, but does not replicate, the review by Ward *et al.* (1998) by focusing on the potential consequences of purse-seine fishing on the diverse assemblages of predatory fish, birds and mammals that occur in southern Queensland. It also expands the discussion by considering the potential effects of the purse-seine fishery on other user groups.

This chapter examines five topics:

(i) the species of small pelagic fishes found in southern Queensland;

(ii) the quantities of these fishes caught by purse-seining in southern Queensland;

(iii) the species of marine predators found in southern Queensland;

(iv) the potential effects of the fishery on predatory species;

(v) the concerns raised by other user groups.

The chapter concludes with a discussion of the implications of these issues for management of the a purse-seine fishery in southern Queensland.

6.1.2 Small pelagic fishes found in southern Queensland

Coastal and shelf waters of southern Queensland support a rich pelagic ecosystem that includes a diverse assemblage of small planktivorus pelagic fishes. This comprises approximately 16 species of clupeoids (Chapter 2), as well as several species of small scombrids (e.g. blue mackerel), carangids (e.g. yellowtail scad, slender scad), atherinids (hardyhead), hemiramphids (garfish) and mugilids (mullet). Collectively, these fish species convert large quantities of plankton into a form that is available to higher-order predators. Few data are available on the biology or ecology of most of these species, and their relative abundance and ecological importance are poorly understood.

6.1.3 Small pelagic fishes caught by purse-seining in Southern Queensland

Despite the large number of small pelagic fish species that occur in the waters of southern Queensland, relatively few were caught in the developmental fishery (Chapter 2). Pilchard was the primary target species and constituted approximately 85% of the total weight of all catches between September 1997 and October 1998. Only three species other than pilchard were caught in significant quantities (>5 t): maray, blue mackerel and yellowtail. Anchovies were caught on three occasions (total 1472 kg), twice when targeted and once as bycatch in a shot aimed at pilchards. The small quantity of bycatch reflects the highly selective nature of the fishery resulting from high demand for pilchards and the ability to successfully identify and target schools dominated by pilchards.

6.1.4 Marine predators found in southern Queensland

Diverse assemblages of predatory fish, birds and mammals are found in the waters off southern Queensland. Some of the species that are thought to feed frequently on juvenile or adult small pelagic fishes and that have some degree of economic, ecological or social significance are listed in Table 1.

The effects of fisheries on predator populations can be divided into two groups, operational (i.e. direct) and ecological (i.e. indirect) (Ward *et al.* 1998). Operational effects on predators include their incidental capture in fishing gear, whereas ecological effects are defined as those that result from fishing-induced depletion of prey species. While this division is convenient and widely accepted (Muck and Fuentes 1987; Croxall 1987; Blaber *et al.* 1996), it is not complete; operational effects can also have ecological implications. For example, feeding on encircled and discarded fish is generally considered an operational effect, but this practice can also have ecological consequences (e.g. changes in reproductive success).

6.1.4.1 Ecological effects

Few quantitative data are available on the diet of southern Queensland's predatory marine species. However, results from the limited number of these studies suggest that most of the species listed in Table 6.1 are opportunistic predators that consume a wide variety of prey types, including numerous species of small pelagic fishes and invertebrates (e.g. Blackburn 1949, 1957; Baker 1966; Colman 1972; Bade 1977; MacPherson 1987; Glaister and Diplock 1993; Kailola *et al.* 1993; Young and Cockroft 1994; Begg and Hopper 1996).

The total allowable catch (TAC) of the developmental pilchard fishery was 600 t per annum, which equates to less than 3% of conservative estimates of spawning biomass of this species obtained in 1997 and 1998 (Chapter 5). Actual annual pilchard catches did not exceed 172 t, or 0.7% of the estimated spawning biomass (see Chapter 2 and 5). Harvesting such a small proportion of the adult stock of only one potential prey species in the region seems unlikely to have significantly reduced the quantities of food available to opportunistic predators. Furthermore, harvest rates of 10–20% are considered conservative and sustainable (see Chapter 8). In any future pilchard fishery in southern Queensland, adoption of harvest strategies of approximately half the levels applied in other states (i.e. 5–10%), especially in the early stages of the fishery's development, would help to minimise the potential impacts on assemblages of predatory fishes, mammals and seabirds

Populations of many predatory fishes (e.g. mackerel, tuna, and tailor) have been reduced by commercial and recreational fishing. In other ecosystems, the removal of top predators has been shown to increase the abundance of prey species (e.g. Pauly 1979; Christensen 1996). It is possible that moderate usage of several trophic levels is a better option for maintaining ecological sustainability than exclusive utilisation of upper level predators (Ward *et al.* 1998).

Cairns (1987) reviewed the effects of depleted food supplies on seabirds, and concluded that only extreme food shortages cause significant adult mortality. Poor to moderate availability of food can reduce adult body weight, clutch size, breeding success, growth rates of chicks, colony attendance and guano production (Cairns 1987, 1992). The potential impacts of sustainable baitfish fisheries on seabird populations are, therefore, minimal. They are even less in southern Queensland, as there are no significant breeding colonies of seabirds located between Lady Elliott Island (southern Queensland) and Coffs Harbour (northern New South Wales).

6.1.4.2 Operational effects

The bycatch of the developmental fishery included only a small number of predatory species. For example, small tailor (*Pomatomus saltatrix*; 20 kg total), squid (8.75 kg total) and bonito (*Sarda australis*; 2.5 kg total) were caught occasionally. Dolphins were the most commonly-caught predator, occurring in approximately 20% of shots (see Chapter 7). A report by an expertise-based Working Group (Hale *et al.* 1999) recommended changes to the fishing operation intended to minimise rates of encirclement and mortality while purse-seining in the region. These recommendations remain untested because of the prohibition of purse-seining in Queensland waters.

Terns, boobies, gulls, gannets and shearwaters were observed feeding on encircled, escaping or discarded baitfish. Purse-seining thus appears to increase the availability of prey species to seabirds. However, other implications of these on breeding success and the learning patterns of juveniles are poorly understood (see Montevecchi and Myers 1997).

6.1.5 Concerns raised by other user groups

The concerns of other user groups prior to the developmental purse-seine fishery were highlighted in numerous media articles about the fishery. The most common concern appeared to be that interference with the annual 'pilchard run' would adversely affect populations and catches of marlin, snapper, mackerel, billfish and tailor, as these species feed on the pilchards (e.g. Spann 1995; Orr 1996; Middap 1996). Tombs (1995) noted that this would be most likely to occur if mismanagement led to over-exploitation of the resource.

Other concerns included the potential for unknown quantities of bycatch in the fishery (e.g. Middap 1996) and the potential for the fishery to impact heavily on the ecology of waterways such as Pumicestone Passage (Spann 1995). Bycatch of other species of fish proved of little concern due in the developmental fishery due to the highly selective nature of the purse-seine technique. The link between a pilchard fishery and Pumicestone Passage is unclear, as the fishery would be located offshore and well north of the Passage's opening.

There was also concern that there may have been pressure to expand the fishery into other areas. For example, Cridland (1995) reported that recreational fishers in northern Queensland were concerned that the success of a fishery in the south may lead to the granting of permits to harvest baitfish on northern billfish grounds (e.g. Cape Bowling Green). However, the dominant species of baitfish in northern Queensland (*Decapterus* spp., *Amblygaster sirm*, *Sardinella* spp.; Cappo 1995) are different to those dealt with in this study. The results of this research program should not be used to justify the development of fisheries for other species in other areas.

The potential for dolphins to be killed in the fishery was not highlighted by the local media prior to the commencement of the developmental fishery, but was a concern to some groups and individuals, mainly due to the history of international purse-seine fisheries for tuna and also the common association of dolphins and pilchards in southern Queensland. Community concern over the incidental capture of dolphins led to the developmental fishery's closure and permanent prohibition of purse-seining in Queensland waters. Chapter 7 discusses this issue in detail.

Table 6.1. Some of the potential predators of baitfish in southern Queensland that have economic, ecological or social significance .

Teleost Fishes	
Thunnus albacares	Yellowfin Tuna
Thunnus obesus	Bigeye tuna
Thunnus tonggol	Longtail Tuna
Thunnus alalunga	Albacore
Katsuwonus pelamis	Skipjack Tuna
Sarda spp	Bonito
Seriola lalandi	Yellowtail Kingfish
Euthynnus affinis	Mackerel Tuna
Scomberomorus commerson	Spanish Mackerel
Scomberomorus semifasciatus	Grey Mackeral
Scomberomorus munroi	Spotted Mackerel
Scomberomorus queenslandicus	School Mackerel
Rachycentron canadus	Black Kingfish
Coryphaena hippurus	Mahi Mahi
Makaira indica	Black Marlin (juvenile)
Makaira mazara	Blue Marlin
Tetrapturus audax	Striped Marlin
Istiophorus platypterus	Sailfish
Xiphias gladius	Broadbill Swordfish
Pagrus auratus	Snapper
Pomatomus saltatrix	Tailor
Argyrosomus hololepidotus	Mulloway
Atractoscion aequidens	Teraglin
Pristipomoides spp	King Snapper
Glaucosoma scapulare	Pearl Perch
Lutjanidae	Sea Perch
Lethrinidae	Emperors
Plectropomus spp	Coral Trout
Sharks	
Carcharhinus spp	Whaler Sharks
Carcharadon carcharias	Great White Shark
Galeocerdo cuvieri	Tiger Shark
Marine Mammals	
Tursiops truncatus	Bottlenose Dolphin
Delphinus delphis	Common Dolphin
Sousa chinensis	Humpback Dolphin
Birds	
Puffinus pacificus	Wedge-tailed Shearwater
Puffinus caneipes	Fleshy-footed Shearwater
Puffinus tunuirostris	Short-tailed Shearwater
Puffinus huttoni	Hutton's Shearwater
Puffinus gavia	Fluttering Shearwater
Sula leucaster	Brown Booby
Sula dactylatra	Masked Booby
Sterna bergii	Crested Tern
Hydroprogne caspia	Caspian Tern
Fregata minor	Greater Frigate
Fregata ariel	Least Frigate

Chapter 7. Incidental Bycatch of Dolphins in the Developmental Pilchard Fishery

Objective: *To develop and assess methods for preventing dolphins being encircled in purse-seine nets.*

This objective was achieved by monitoring the use of acoustic "pingers", which were deployed from the fishing vessel in the developmental fishery in an attempt to deter dolphins from the vicinity of the vessel prior to setting the net.

A total of 77 dolphins were encircled between 17 September 1997 and 16 October 1998; 68 of these were released alive, but nine died. There was a tenuous correlation between deploying six pingers and reducing the probability of encircling dolphins. More importantly, the deployment of pingers did not prevent dolphin encirclement altogether. This was highlighted by the Queensland Fisheries Management Authority Board's decision to prohibit purse-seining in February 1999 while an investigation of the issue was undertaken. Dr Peter Hale led a Working Group which recommended changes to the fishing operation aiming to decrease the number of dolphins encircled and avoid the drowning of any encircled dolphins. The procedures were included in a revised permit issued in March 1999. However, purse-seining was prohibited again in May 1999, prior to the re-commencement of fishing and before these procedures were tested. Permanent prohibition of purse-seining in Queensland waters was legislated in March 2000.

7.1 Introduction

7.1.1 Dolphin species present in southern Queensland

Several species of dolphin occur in southern Queensland, including the bottlenose dolphin (*Tursiops truncatus* and *T. cf. aduncus*), the Indo-Pacific hump-backed dolphin (*Sousa chinensis*), the spinner dolphin (*Stenella longirostris*) and the common dolphin (*Delphinus delphis*). Increases in the size of human populations living at or near the coast, and the expansion of Queensland's fisheries have increased the potential for interactions between humans and dolphins. Human activities that could potentially affect Australian dolphin populations adversely include: incidental mortality resulting from entanglement in nets (offshore and inshore gill-nets, shark-control nets, nets around fish farms and trawl nets); reduction in prey species due to over-fishing and habitat destruction; disturbance by vessels; effects of pollution; and direct killing of dolphins (Anderson 1995; Hale 1997). Dolphins can also become entangled in abandoned fishing equipment, such as fishing line discarded by fishers (Pirzl and Anderson 1997; Wells *et al.* 1998).

Dolphins (sub-order Odontoceti) and whales (sub-order Mysticeti) are protected in Commonwealth waters under the Whale Protection Act 1980, which prohibits the killing, injuring, taking or interfering with cetaceans. However, commercial fishers have not committed an offence if they catch cetaceans accidentally during licensed fishing activities. Under the requirements of the Act, fishers must report the capture of cetaceans to the Minister for the Environment as soon as possible, and should retain carcasses for scientific study. Cetaceans are also protected within 3 nautical miles of the coast by State and Territory laws that reflect the Commonwealth legislation (Ovington 1986; Hale 1997)

7.1.2 Interactions with Australian Fisheries

Paterson (1979) presented statistics on the number of dolphins caught in gill-nets which are set to catch sharks at popular tourist beaches along the coast of Queensland. He reported that 317 dolphins were caught between 1962 and 1977, mostly in southern Queensland. Recent incidental catches of dolphins by the Queensland Shark Control Program (QSCP) have been presented in annual reports to the International Whaling Commission (IWC) (e.g. Anderson 1995; Anderson and Pirzl 1996). In response to recommendations of a ministerial Committee of Enquiry, the QSCP began a series of initiatives in 1992 to reduce the incidental capture of bycatch species in the protective shark nets (Gribble *et al.* 1998). For example, sonic warning beacons attached to some shark-nets have been trialed as a method for reducing the incidental catch of dolphins and whales.

The annual reports to the IWC from the Commonwealth have been the only consistent source of information regarding the incidental catches of dolphins in other fisheries around Australia, although the magnitude of unreported catches remains difficult to estimate. Anecdotal evidence indicates that under-reporting of catches is common in the absence of independent observers on fishing vessels, a pattern found in commercial fisheries throughout the world (e.g. Stone *et al.* 1997; Cox *et al.* 1998). Recent reports indicate that dolphins are caught occasionally in the shark gill-net fishery in Western Australia and in the inshore gill-net fishery for barramundi and threadfin bream in northern Queensland (e.g. Anderson 1995; Anderson and Pirzl 1996; Pirzl and Anderson 1997). The Commonwealth's 1996 report presents the only available information on the catch of dolphins in an Australian pilchard fishery, with the deaths of two bottlenose and one common dolphin being reported from the pilchard purse-seine fishery in Western Australia in 1994 (Anderson and Pirzl 1996).

7.1.3 Dolphin bycatch in the eastern Pacific tuna purse-seine fishery

Dolphin bycatch in the United States-based tuna purse-seine fishery in the eastern tropical Pacific Ocean (ETP) was the focus of concern in the 1960's and 1970's (Hall 1998). Incidental mortality of dolphins during that period was estimated to occur in more than 85% of sets at an average rate in excess of 40 deaths per set (Coe *et al.* 1984). This rate of mortality was not sustainable, and led to declines in the dolphin populations (Hall 1998). The Marine Mammal Protection Act 1972, which led to the establishment of a mandatory observer-program on United States' boats, came about partly as a result of public concern about the mortalities. The observer-program assisted directly (in the development of certain fishing techniques) and indirectly (by putting pressure on ship's captains) in decreasing the mortality of dolphins. By 1980, the rate of mortality of dolphins had dropped to an average of 4 per set, with between 60 and 70% of sets resulting in no dolphins being killed. It was estimated that mortality for the entire fishery in 1996 was approximately 2500 dolphins (Coe *et al.* 1984; Hall 1998).

7.1.4 The developmental purse-seine fishery in Queensland

The potential for incidental capture of dolphins was confirmed early in the history of the developmental purse-seine fishery in Queensland. The fisher sought advice from the QSCP on ways to deter dolphins from the fishing area before and during the setting of the net. It was suggested that hydro-acoustic deterrents ("pingers"), similar to the ones used by the QSCP, could be trialed. The aim of this chapter is to assess the effectiveness of pingers in reducing the rate of dolphin encirclement. Discussion of the report written by the expertise-based Working Group (Hale *et al.* 1999) is also included.

7.2 Methods

7.2.1 Data Collection

An observer was employed by the Queensland Fisheries Management Authority between 17 September 1997 and 16 October 1998, to accompany each fishing trip made in the developmental fishery. It was the observer's duty to record information supplementary to that recorded in the vessel's logbook, such as interactions with dolphins including the use of deterrent devices. From 31 July 1998, the observer recorded other extra information pertaining to the use of deterrent devices, such as the length of time for which the pingers were deployed and whether dolphins were sighted prior to setting the purse-seine net.

7.2.2 Fishing Methods

The general fishing procedures employed in the developmental fishery are outlined in Chapter 2. In addition to these procedures, three or six pingers (Dukane NetMark 1000) were frequently deployed from the fishing vessel prior to setting the net. The pingers emitted a 10 kHz broadband signal at approximately four second intervals.

7.2.3 Analysis

The probability of capturing dolphins was analysed using general linear modelling, using the logit link and binomial distribution. The terms considered in the analyses were; time of set (day verses night), fishing method (lights or sonar), preventative method (no pinger, 3 pingers, 6 pingers), geographic area (15 by 15 minute grids), season (January–March and May–November) and catch composition (proportion of total catch of 4 baitfish species). All terms were screened and only significant terms ($p < 0.10$) were included in the final model. Fitted means were calculated, adjusting for all other terms.

7.3 Results and Discussion

The observer collected data from 63 sets between 20 September 1997 and 16 October 1998. The locations of each set are shown in Figure 1. Most sets were at night using the light attraction method, and most involved deployment of pingers (Table 1). Between one and 12 dolphins were encircled on 15 occasions, resulting in a total of 77 dolphins being caught, nine of which died. Carcasses were not retained, and the species of live and dead dolphins was not established, though it is probable that they were bottlenose or common dolphins.

The exact cause of the deaths was difficult to determine. Coe *et al.* (1984) reported that dolphin deaths in purse-seines occur usually by suffocation (dry-drowning) due to being unable to reach the surface o breathe after becoming entangled (e.g. by fin or beak) in the net or more frequently after becoming entrapped in net-folds. Entrapment in net folds is believed to be the more likely cause of deaths in the Queensland purse-seining operation, given the very small mesh size of the net, which would make entanglement unlikely.

Table 7.1. Number of sets using light attraction and sonar fishing methods, during day and night, with and without pingers. Numbers in parentheses indicate the number of sets that caught dolphins.

Fishing Method:	Light Attraction Method			Sonar	
	No Pingers	3 Pingers	6 Pingers	No Pingers	6 Pingers
Day Sets	-	-	-	4 (0)	1 (1)
Night Sets	12 (5)	29 (7)	16 (2)	1 (0)	-

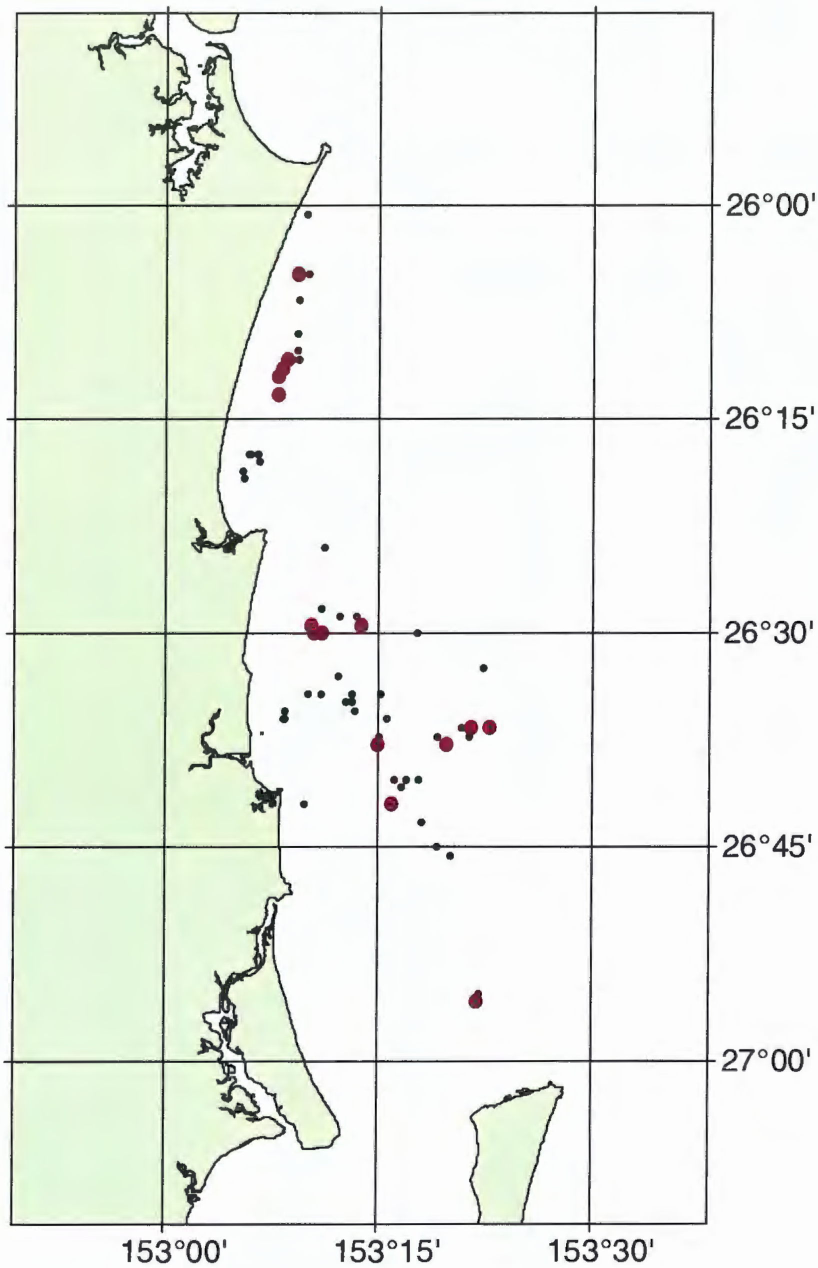


Figure 7.1. Location of all purse-seine shots between 20 September 1997 and 16 October 1998. •; shots where no dolphins encircled. ⊙; shots where dolphins were encircled

7.3.1 Analysis

The screening process indicated that the best model (*df*=57, χ^2=57.35) describing the probability of dolphin capture was one that included the terms fishing method ($p = 0.038$), season ($p = 0.080$) and preventative method ($p = 0.045$). The results should be treated cautiously, due to the limited data and the lack of experimental design. Mean probabilities of capture (adjusted for all other terms) were lower using the sonar method (0.017) than the light attraction method (0.302), lower between May and November (0.209) than between January and March (0.752) and lower if six pingers were deployed (0.030), compared with deploying three (0.313) or zero pingers (0.455).

The results of this study indicate that the deployment of pingers was not sufficient to prevent dolphin encirclement altogether. At best, they suggest only a tenuous correlation between the preventative measure adopted and the probability of encircling dolphins; they fall a long way short of demonstrating causality. Some recent studies suggest that pingers may act as alerting devices, while some suggest that they act as deterrents, especially when they emit complex broadband signals rather than simple pings emitted at regular intervals at relatively low frequencies (e.g. Goodson *et al.* 1997a, 1997b; Stone *et al.* 1997). Stone *et al* (1997) reported some degree of displacement behaviour by Hector's dolphins in Akaroa Harbour in New Zealand in the presence of 10 kHz pingers, similar to the ones used in this study.

7.3.2 Expertise-based Working Group Report

In early February 1999, the Board of the Queensland Fisheries Management Authority was made aware of the nine dolphins killed in the developmental fishery. The Board decided to take immediate action, and on 9 February issued the *Fisheries (Purse Seine Net emergency Closed Waters) Declaration No. 1 of 1999.* The declaration put in place a temporary prohibition on purse-seining in Queensland while an investigation into the deaths could take place. Dr Peter Hale, Executive Director of the Centre for Conservation Biology at the University of Queensland, was asked to lead an expertise-based Working Group to make recommendations about ways in which dolphin mortalities might be minimised or avoided in a purse-seine fishery in southern Queensland. The Group comprised Dr Hale, Mr Jonathan Staunton-Smith, Mr Tim Ward, Dr Burke Hill (CSIRO Marine Research), Dr Col Limpus (Queensland Environmental Protection Agency) and Dr Daryl McPhee (Queensland Commercial Fishermen's Organisation) (Hale *et al.* 1999). Other persons consulted during the preparation of the report included Dr Rick Fletcher (New South Wales Fisheries, formerly

Western Australian Fisheries), Mr Gary Pinzone (fisher in developmental pilchard fishery), Mr Norman Craig (South Australian Pilchard Fishermen's Association) and Mr Bob Dayman (observer in developmental pilchard fishery).

Six recommendations were made in the report, the adoption of which, it was argued, would contribute to a decrease in the number of occasions dolphins were encircled, and avoid the drowning of any encircled dolphins. The recommendations were:

1. avoid long delays between finding the school and setting the net;
2. maintain the shape of the float line by backing up the vessel and bunching the float line;
3. haul the net so that folds do not develop underwater;
4. sink a small section of the outer edge of the net to enable dolphins to exit;
5. shine lights in the water near the cage to attract pilchards away from the dolphins at the outer edge of the net;
6. consider aborting the set if any dolphins are encircled.

The background and reasoning behind these recommendations are outlined below.

1. Anecdotal evidence from the South Australian fishery, where fishers no longer use lights to attract and "tether" pilchards, suggested that few dolphins are encircled when the net is set around schools of fish soon after they are detected. The Group surmised that avoiding long delays between detecting schools and setting the net would decrease the likelihood of dolphins being around the vessel when the net was set. The long delays in the developmental fishery were mainly related to the aim of concentrating fish near the surface and to safety aspects of setting and retrieving the net in the dark; it was safer to set the net near dawn, when prevailing south east winds were weaker, and so the inflatable tender could be seen from the mother ship.

2. Collapse of the float line was believed to have resulted in folds appearing in the net, where dolphins could have become trapped. Backing-up the vessel, and bunching the float line near the vessel, were considered strategies to minimise folding, and keeping any folds close to the vessel.

3. The Working Group considered formation of a fold at the surface of the net ("verandah") indicative of folds in the net underwater, although this was not confirmed by direct observation. Hydraulic rams can alter the direction and angle of tilt of one of the

powerblocks used to haul the net. Changes to the tilt of the powerblock affect the relative speeds with which the foot and float ropes are retrieved, and thus can be used to prevent formation of the verandah.

4. Anecdotal evidence from the South Australian fishery suggested that dolphins would swim through a sunken section of the net. A section of the net (approximately 3 m wide and 1 m deep) could be sunk using lead weights or a steel bar. Dolphins could be assisted through the sunken section by crew in the inflatable tender.

5. The Working Group discussed the possibility of dolphins being held underwater by the mass of large quantities of pilchards, especially after 50% of the net had been retrieved. It was considered feasible that shining lights in the water near the cage would attract pilchards away from the edge of the net, thus encouraging dolphins to swim away from the cage.

6. The procedure of aborting sets, by opening the net and releasing the entire catch, including dolphins, occurred at least once during the fishery. The Working Group considered that it was unlikely that dolphins would have been entangled in folds and drowned before 70% of the net had been retrieved. Therefore, in the event that other recommendations did not appear to be working, or if a large number of dolphins were encircled in a single shot, consideration could be given to aborting sets before 50–60% of the net had been retrieved.

7.3.3 Events following the report

The *Fisheries (Purse Seine Net emergency Closed Waters) Declaration No. 1 of 1999* was repealed in mid-March and the recommendations of the Working Group were included as conditions in a revised permit which was issued to the fisher. It was also suggested that daytime trials of the changes to the fishing operation be carried out prior to recommencing commercial fishing.

A second Emergency Fisheries Declaration (*Fisheries (Purse Seine Net Emergency Closed Waters) Declaration. No. 4 of 1999*) was made on 27 May because of the belief that the conditions included in the revised permit were not sufficient to remove the risk of further dolphin captures and mortality due to purse-seining, although they were untested. The 2–

month duration of the Declaration prohibited purse-seining until a time beyond the expiration date of the original 3–year permit (19 July), thus closing the developmental fishery.

A temporary amendment to *Fisheries Regulation 1995* (*Fisheries Amendment Regulation (No. 5) 1999*) was made on 17 September 1999, prohibiting purse-seining until 10 December 1999. During that period, a Regulatory Impact Statement (RIS) was released, notifying the community of proposed legislation to permanently prohibit the use of purse-seine nets in Queensland waters. It was decided to proceed with the proposed legislation, and thus *Fisheries Amendment Regulation (No. 2) 2000* was gazetted on 23 March 2000.

Chapter 8. Potential Yield of a Purse-Seine Fishery Targeting Pilchards in Southern Queensland

Objective: *To examine the potential yield for a purse-seine fishery in southern Queensland.*

This objective was achieved by considering four factors that affect yield: i) the size and distribution of the stock, ii) fishing-related issues, iii) stock assessment procedures and uncertainty and iv) management strategies.

The size of the pilchard stock in southern Queensland was estimated as at least 25000 t during the spawning seasons in 1997 and 1998. During the pilchard spawning season, most of this stock occurred in the same area where most fishing occurred in the developmental fishery. The distribution of fish outside the fishing area and spawning season are unknown.

Demand for the high quality product of the developmental fishery exceeded supply and would be unlikely to limit yield in any future pilchard fishery in the region. However, bad weather during a time when large catches were being made (August/September 1998) resulted in few successful fishing trips and highlighted the reliance of the fishing operation on good weather.

The DEPM is currently the favoured technique for stock assessment of small pelagic fishes. Estimates of spawning biomass are used to calculate annual total allowable catches (TAC) of pilchards in South Australia and Western Australia. Harvest rates of 10–20% of spawning biomass are considered sustainable. An even-more conservative approach could be adopted in southern Queensland by establishing harvest rates of 5–10%, to acknowledge the importance of the species as a food source for predatory fishes. This approach suggests an appropriate TAC in 1997 and 1998 would have been 1250–2500 t.

Management of fisheries in Queensland requires an appropriate balance between the different objectives of the *Fisheries Act 1994* through consultation of all stakeholders. However, despite the potential for an ecologically sustainable pilchard fishery, community concerns relating to mortality of dolphins led to the fishery's closure in 1999 and permanent prohibition of purse-seining in Queensland waters. Consequently, potential yield in any future pilchard fishery in the state will be reduced as purse-seining is arguably the only suitable fishing method that has been used in southern Queensland to capture large quantities of pilchards consistently. An alternative approach, which would continue to protect dolphins, would be to ensure future purse-seine fisheries adopt and develop the recommendations made by the expertise-based Working Group.

8.1 Introduction

Many factors affect the yield of fisheries, either directly or indirectly. This chapter discusses factors that would affect a purse-seine fishery for pilchards in southern Queensland, some of which relate to the developmental fishery (1996–1998) and some to the potential fishery that may exist some time in the future. The main factors are discussed under four main headings; the stock, the fishery, research and management (see Figure 8.2 for summary).

8.2 The Stock

The size of the stock is the primary determinant of the potential yield of all fisheries. Estimates of spawning biomass using the daily egg production method in Australia have usually indicated that regional stocks are in the order of tens of thousands of tonnes (Fletcher *et al.* 1996; Ward *et al.* 1998; Ward and McLeay 1998, 1999b; Chapter 6). These stocks are, however, small in comparison with those in South Africa, South America, California and Japan, where fisheries in the order of hundreds of thousand to millions of tonnes per year have existed at various stages this century (e.g. Whitehead 1985; Csirke 1988). Three factors (other than fishing) that affect the size of pilchard stocks throughout Australia are environmental conditions, predation and episodic mass mortality events.

8.2.1 Environmental conditions

Large pilchard stocks occur in regions where pelagic productivity is enhanced by the upwelling of nutrient rich waters, such as the coastal waters of southern Africa and western North America (e.g. Parrish *et al.* 1989; Kailola *et al.* 1993). Australia's seas are characterised by relatively low nutrient levels, although it is notable the Australia's largest pilchard stock may be located in shelf waters of central and western South Australia that are enriched by upwelling events that occur in inshore waters during summer-autumn (Ward and McLeay 1998).

8.2.2 Predation

Predation on small pelagic fishes such as pilchards affects the stock size. All predator species discussed in Chapter 5 are opportunistic feeders likely to consume juvenile and/or adult pilchards in addition to a wide range of other species of fish and invertebrates. Attempts to quantify the effects of these predators on the pilchard populations in southern Queensland would be complicated by the large number of predator and prey species. Preliminary estimates of natural mortality rates of pilchards (Chapter 3) are very high, but these estimates should be treated with caution and predation is only one component of mortality. It is notable that rates of predation may have decreased in recent times because the populations of many predatory fish species (e.g. mackerel, snapper, tuna, tailor) have been reduced by significant commercial and recreational fisheries.

8.2.3 *Mass mortality events*

Australian stocks of pilchards have been significantly affected in recent years by two mass mortality events, the first in 1995 and the second in 1998–1999. The mortalities in 1995 started in South Australia in March and spread rapidly in both directions along the coast, reaching the central coast of Western Australia and the southern coast of Queensland by the end of June. Fletcher *et al.* (1997) estimated that stocks in Western Australia were reduced by thousands of tonnes, representing 10–15% of the population. The mass mortality in 1998 also started in South Australia, in October and spread to the central coast of New South Wales by mid-January and the central coast of Western Australia by mid-May. Ward and McLeay (1999b) estimated that stocks in South Australia were reduced by up to 60%. Both mass mortalities were believed to have been caused by an exotic strain of herpesvirus, recently introduced into the Australian populations.

8.2.4 *Stock distribution*

The spatial and temporal distribution of the stock throughout and beyond the fishing grounds is an important determinant of potential yield. The main fishing grounds in the developmental fishery were in a relatively small area between Double Island Point and Mooloolaba (Chapter 2), which was also the area where more than 90% of the spawning biomass of pilchards in southern Queensland occurred during the peak spawning season in 1997 and 1998 (Chapter 5). This distribution was not consistent throughout the year, however, as low catch rates of fish in summer and anecdotal evidence of northward spawning migrations from New South Wales during autumn/winter suggest a much wider distribution of pilchards outside the spawning season.

The restriction of the fishery and egg abundance surveys to Queensland waters has left several distribution-related issues unresolved. In particular, the proportion of the pilchard population that remains in New South Wales during the spawning season, and the spatial distribution of the stock outside the spawning season are not known. These issues are important because pilchard fisheries in northern New South Wales and southern Queensland potentially exploit the same stock.

8.3 The Fishery

The yield of the fishery is affected by some factors directly related to the fishing operation, such as problems with gear and developing fishing technique, dependence on good weather and demand for product.

8.3.1 Gear, fishing technique and weather

The developmental fishery was affected by a number of gear-related delays. For example, several months were lost at the start of the fishery due to delays in importing materials with which to construct a suitable purse-seine net. Development, construction and/or installation of equipment used in the fishery, such as net-hauling powerblocks and the cage for holding fish alongside the vessel, also caused yield-reducing delays. Most of these delays were one-off events, and would not affect yield in a future fishery in which vessels were already fully operational. Similarly, at the start of the developmental fishery, the crew was unfamiliar with the purse-seining technique, resulting in occasional unsuccessful shots. By the end of 1998, the crew's fishing skills had increased to the extent that it was unlikely to be a major factor in reducing catches.

Even as the proficiency of the crew improved, the purse-seining technique relied on favourable weather conditions, especially light winds and small swell. Good weather was important because it ensured the safety of crew during the operation, especially at night and because strong winds (e.g. $\geq$ 15 knots) made it difficult to maintain the open shape of the net during its retrieval. Furthermore, the fisher's experience was that pilchards did not aggregate around the underwater lights when the swell was large (e.g. $\geq$ 2 m), possibly because they were unsettled by the large vertical movement of the lights.

Wind and swell in southern Queensland during autumn/winter, when pilchard abundance is highest, are generally considered favourable to purse-seining close to shore. However, the potential for bad weather to reduce yield became evident in winter 1998 when unseasonally-strong south-easterly winds and large swell resulted in only two catches being landed between 16 August and 13 September. Seven catches in the week prior to the onset of bad weather had resulted in total landings of approximately 41 t. The inability to catch fish during this period because of unfavourable weather reduced the potential total catch during 1998.

8.3.2 Demand

Lack of demand has been cited as the major factor limiting the early development of Australia's pilchard fisheries (Fletcher 1991; Kailola *et al.* 1993). Markets have expanded in the last 20 years, initially through the requirements of commercial and recreational fishers who use pilchards as bait and more recently due to increased usage for human consumption and as fodder for caged marine fish (SCP fisheries Consultants 1988; Fletcher 1990; Glaister and Diplock 1993; Jones *et al.* 1995). However, recent mass mortalities of pilchards have resulted in severe decreases in the quantity of fish caught and supplied to existing markets. The gap left by decreased supply of fish from Western Australia has been filled partly by the importation of large quantities of pilchards from other sources, especially from California. South Australia's pilchard fishery, which has developed during the last ten years to supply the tuna mariculture industry with fish suitable for fodder, has undergone some recent strategic changes in response to market opportunities for bait and value-added product for human consumption. However, there remains high demand for pilchards throughout Australia.

The processing technique employed in the developmental fishery, whereby pilchards were kept alive until just prior to being "individually quick frozen" on board the fishing vessel, resulted in very high quality product. The fisher had little difficulty in finding a market for this product locally within Queensland, interstate (Melbourne) and overseas (New Zealand and Western Samoa). Demand grew to the point where it exceeded supply by an order of magnitude by the middle of 1998. The permit-holder built a factory with large storage capacity to assist reliable supply, and also purchased equipment to fillet pilchards automatically to take advantage of opportunities of value-adding to the product. There was a great deal of interest in the pilchard fillets, but significant quantities of this product were never available, due to the lack of fishing between October 1998 and March 1999, and the closure of the fishery in May 1999. However, it is clear that demand is unlikely to limit yield in any future pilchard fishery in southern Queensland.

8.4 Research

The outcomes of fisheries research can also affect potential yield. Fisheries scientists provide resource managers with scientific data on the status of the stock and recommend harvesting strategies designed to ensure sustainability. Over-estimates of actual stock size can result in over-exploitation of resources, reductions in long-term yields and ecological damage.

Conversely, under-estimates of stock size can lead to under-exploitation of resources and the loss of potential economic benefits.

8.4.1 Fishery-dependent methods

Fisheries researchers have historically used data obtained from the fishery (i.e. fishery-dependent data) as the basis for managing stocks, but these methods have consistently resulted in over-exploitation. For example, CPUE has been used as an index of fish abundance and downward trends in CPUE have, therefore, been used to identify declining stock sizes. CPUE of schooling pelagic species is known to exhibit hyperstability as a result of at least two factors. First, catches may remain high in periods when the stock is severely depleted, because these species tend to continue schooling in high concentrations, but remain spread throughout a smaller area than when the stock is not depleted (e.g. Butterworth 1981; Lluch-Belda *et al.* 1989; Hilborn and Walters 1992). Second, catch can be limited in periods of highest abundance, by the limitations of the fisher to process large quantities of fish.

There are also problems with using nominal effort (e.g. time searching for fish, days fishing, number of shots performed). Significant effort can be expended in searching for fish, without any shots carried out or fish caught, because of factors other than the absence of fish (e.g. strong wind or current). This can bias "hours searching" as a measure of effort. Likewise, "shots done" can be biased by the fisher targeting large schools only. Also, decrease in abundance may result in fewer schools in the fishing area, but individual schools may remain the same size. It is extremely important, therefore, to identify at the earliest possible stage the ancillary information that is required (e.g. reasons for not setting the net) to allow interpretation of effort data.

8.4.2 Fishery-independent methods

Stock assessment of many pelagic fishes throughout the world (e.g. California, South Africa, Western Australia, South Australia) currently involves the estimation of spawning biomass using the fishery-independent DEPM (e.g. Alheit 1993; Hunter and Lo 1993; Cochrane 1999; Ward and McLeay 1999a). The advantages of applying the DEPM to pilchards include its reliance on a single vessel from which plankton and adult fish can be collected and the determination of an associated measure of precision for each parameter (Lasker 1985). An additional advantage is that the technique facilitates the collection of detailed information on the distribution and reproductive biology of pilchards. The main disadvantages are the high cost involved in collecting and processing samples, the reliance on a period of reasonable weather coinciding with vessel availability and peak spawning season and the imprecise final estimates of biomass.

8.4.3 Sustainability

The preferred objective for managing a stock of small pelagic fish sustainably should be the avoidance of a stock-recruit collapse by maintaining a stable spawning stock biomass (Patterson 1992). The probability of avoiding such a collapse, while taking into account that stocks will fluctuate naturally, can be maximised by making conservative management decisions. This is especially true in the early stages of a fishery (i.e. developmental stage), when a long time series of data is unavailable.

Patterson (1992) related changes in stock biomass to exploitation rate (E) for 28 stocks of 11 species of small pelagic fish. He defined E as:

$$E = \frac{F}{Z}$$

where F is fishing mortality, and Z is total mortality (F plus M). He found that exploitation rates above 0.4 frequently led to declines in stocks of small pelagic fish, whereas rates below 0.3 frequently led to increases. Thus, exploitation rates less than 0.3 can be considered conservative in terms of minimising the chance that stocks will collapse due to the effects of fishing.

Using the previous definition of E, it is straightforward to work out what the value of F is at a given E and M. Exploitation rate can also be expressed in terms of proportion of the population harvested (h) by the formula:

$$h = E(1 - e^{-Z}) .$$

Therefore, it is possible to work out h at any given E and M. Figure 8.1 shows that h approaches the value of E at high values of M (e.g. M>1).

Linearised catch-curves were used to estimate total mortality rates for pilchards in southern Queensland and northern New South Wales during this study. Chapter 3 presents these results and discusses the shortcomings of this simplistic approach with respect to small pelagic schooling fish that undergo variable recruitment and possible seasonal migrations. The assumption that total mortality of pilchards in southern Queensland and northern New South Wales is approximately equal to natural mortality because of the low level of exploitation is also discussed in Chapter 3. The estimated values of mortality, ranging from approximately 0.59–2.14, provide a reasonable starting point to assess appropriate and conservative levels of harvesting, in the absence of a more comprehensive analysis from a long time series of age-structure data.

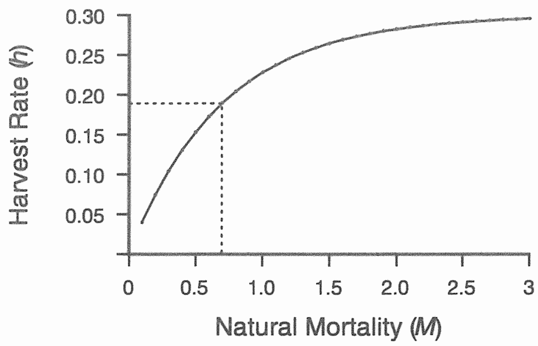


Figure 8.1. Relationship between Natural Mortality (*M*) and Harvest Rate (*h*) when Exploitation Rate (*E*) is kept constant at 0.3.

The lowest estimates of natural mortality should be assumed when establishing harvest strategies in the early years of a new fishery for small pelagic fish, thus contributing to conservative management. Using Figure 8.1, *h* is 0.17 (i.e. 17% of total biomass) at *M* of 0.59 and *E* of 0.3. When it is considered that estimates of spawning biomass only take into account mature adult fish in the area sampled, unlike total biomass which includes juvenile fish, then this rate is higher than the range (i.e. 10–20% of spawning biomass) considered sustainable and appropriate for pilchard fisheries in South Australia (Ward and McLeay 1999a, b), Western Australia (Cochrane 1999) and California (Barnes *et al.* 1992; Jacobson and MacCall 1995). Setting harvest rates at even-more conservative levels (i.e. 5–10%), to acknowledge the importance of pilchards as an important prey species in the region, can also be considered.

8.4.4 Setting a total allowable catch

Once appropriate harvest rates have been determined, they can be combined with estimates of stock size to set TACs. We estimated conservatively the spawning biomass of pilchards in southern Queensland was in excess of 25000 t in 1997 and 1998 (Chapter 6). Based on these estimates, and using the most conservative harvesting rates proposed (i.e. 5–10%), TACs could have been set at 1250–2500 t in 1997 and 1998. Similar TACs would only affect yield if several vessels were involved in the fishery, as a single vessel would be unlikely to attain such a high annual catch. However, if pilchard fisheries were to develop and expand in northern New South Wales and Queensland to an extent requiring the setting of TACs, then some consideration would also need to be given to the fact that these fisheries may be exploiting the same stock.

8.4.5 Future Research

Long term aims of management-related pilchard research in South Australia and Western Australia involve simulation modelling incorporating a substantial time-series of catch-at-age, catch and effort data from the fishery as well as fishery-independent data, such as biomass estimates. It would be some time before there would be sufficient data from any future fishery in Queensland to facilitate a similar approach. However, it would be provident to ensure as much appropriate information as possible is collected so that future models would not be compromised by a paucity of quality data.

8.4.6 Costs of research

Costs of fisheries research are the result of a trade-off between the cost of research that is taking place, and the research that can be done at a certain cost. For example, the collection of commercial logbook data is inexpensive, because data need only to be collated and entered into a database. Sampling commercial catches is reasonably inexpensive, although the level of sample processing influences the final costs.

Fishery-independent research is expensive as it entails the use of research or charter vessels, and requires significant resources to process samples. The trend for cost recovery in fisheries research is increasing in Australia. If the Queensland fishery were to develop fully, it would need to contribute funds for essential research, as was the case with developmental fishery when fees were paid to Queensland Fisheries Management Authority to offset the cost of employing an observer on board the fishing vessel during all fishing trips.

8.5 Management

Fisheries management affects yield through legislation. Queensland's *Fisheries Act 1994* specifies that fisheries resources must be used in an ecologically sustainable way that also optimises community and economic benefits. These objectives would be the starting point for establishing a specific management plan for any future pilchard fishery in southern Queensland. The formulation of management plans involves extensive consultation with all stakeholders, including fisheries scientists, the fishing industry, and the wider community. Scientific advice is needed to assist sustainable use of the resource. Industry representation is required to ensure that consideration is given to economic viability of the fishery.

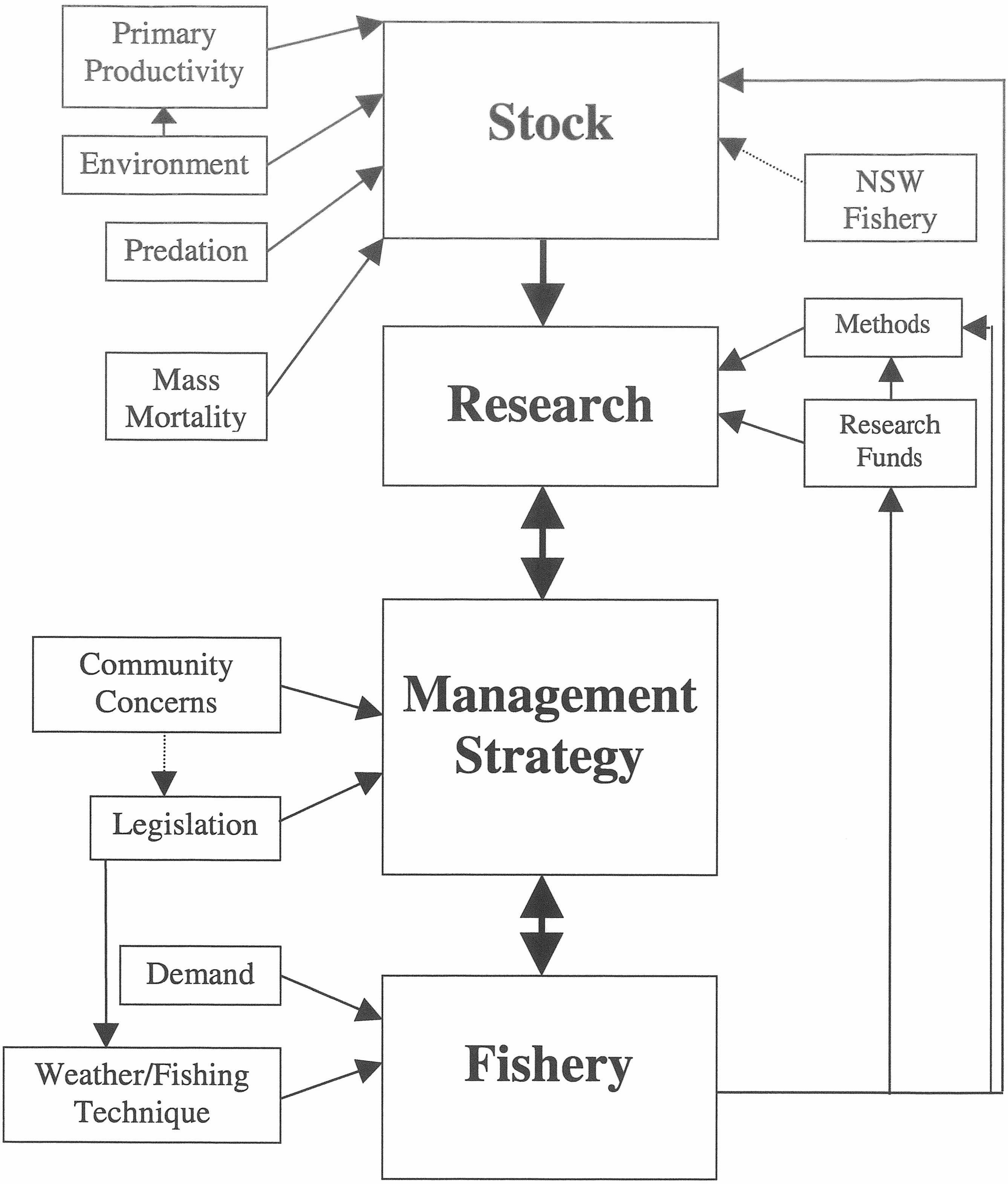
Representatives of the community, especially recreational fishers and conservation groups, are required to ensure that community concerns are taken into account.

Yield of the developmental fishery was directly affected by management decisions on several occasions. The proposal to develop a pilchard fishery was rejected initially by the Queensland Fisheries Management Authority, but the decision was appealed successfully to the Fisheries Tribunal and a 3–year permit was issued. The 600 tonne annual TAC imposed by the permit did not affect yield, as it was far in excess of the total landings during the fishery's short existence. However, community concerns relating to incidental dolphin mortalities in the fishery led the Queensland Fisheries Management Authority to close the fishery before the fisher's permit expired. The use of purse-seine nets in Queensland waters was prohibited permanently in March 2000. Consequently, yield in any future pilchard fishery in the state will be reduced as purse-seining is the only suitable fishing method that has been used in southern Queensland to consistently capture large quantities of pilchards.

An alternative approach to prohibiting purse-seining was recommended in a report to Queensland Fisheries Management Authority from the expertise-based Working Group. The Group recommended changes to fishing methods that would minimise the number of times dolphins were encircled, and avoid mortality of any dolphins that were encircled. These changes to the fishing operation were included in a revised permit issued to the fisher after the first Emergency Fisheries Declaration was repealed. They were not tested, however, before the issuing of the second Emergency Fisheries Declaration, which prevented purse-seining in Queensland until a date after the expiry of the developmental fisheries permit.

Any future pilchard fishery should be established in conjunction with a suitable structure for the ongoing consideration of the views of different user-groups. Such forums usually consist of committees comprising representatives from each group. For example, a Management and Scientific Advisory Committee (MSAC) for the developmental fishery was formed in March 1999. The closure of the fishery prevented the assessment and further development of this system as a means of ensuring appropriate management. A similar system is in place in South Australia, where management of the pilchard fishery is based on recommendations from that state's Pilchard Working Group. Scientific data and recommendations are presented to the Working Group, which consists of representatives of industry, management and recreational fishers. The group makes recommendations to the Minister, who is responsible for the final decisions regarding management of the fishery.

Figure 8.2. Relationships between Some of the main issues that affect the yield of a purse-seine fishery targeting pilchards in southern Queensland.



Benefits

The baseline biological information collected during this study, which was conducted in conjunction with the developmental pilchard fishery, will be most beneficial if a fully-licensed fishery were to develop in southern Queensland and northern New South Wales. This type of information, especially relating to stock sizes, age-structure and levels of bycatch, is rarely available before the onset of intensive fishing. When it is available, fisheries should be able to develop in a controlled and sustainable way.

This study indicated spawning biomass of pilchards can be estimated successfully in southern Queensland using the daily egg production method, because of the significant level of spawning in the region during August–September. However, the results highlighted the need for future surveys of egg abundance to continue into northern New South Wales to ascertain the relative amounts of spawning in the two states. The results also supported results elsewhere that have found egg production to be the parameter estimated with the least precision, although this imprecision can be reduced in future studies mainly by increasing sampling effort in the major spawning area.

The multi-mesh gill-net developed during this project was used successfully to collect adult pilchards, which were used to estimate parameters for the daily egg production method. The net has been used for the same purpose at SARDI, where it also been modified slightly to collect juvenile pilchards and anchovies. Size composition of samples collected with the gill-net was similar to samples collected using other methods (e.g. purse-seining), although further testing of the size-selectivity of the net would be beneficial.

The incidental capture and mortality of dolphins in the developmental fishery lead to its closure and the permanent prohibition of purse-seining in Queensland waters. Changes to the fishing operation aimed at reducing the encirclement and mortality of dolphins, were recommended by the expertise-based Working Group's, but remain untested.

Further Development

Development of the results of this study, especially the estimates of spawning biomass, include the use of this information for assessing the potential for a sustainable pilchard fishery in southern Queensland, and setting a conservative total allowable catch at the start of any future fishery.

Recommendations from the expertise-based Working Group remain untested. It is feasible that they could be tested in other purse-seine fisheries that target small pelagic fishes, such as pilchards and anchovies, both in Australia and overseas. Detailed information relating to problems in applying the recommended techniques, and their success or otherwise, need to be recorded so they can be assessed and modified where necessary.

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Appendices

Appendix 1. Intellectual Property

There is no intellectual property arising from this project. All information generated is in the public domain.

Appendix 2. Staff

Staff employed on the project were:

Jonathan Staunton-Smith (Fisheries Biologist, 1998–1999)
Tim Ward (Fisheries Biologist, 1997)
Adam Butcher (Fisheries Biologist, 1995–1997)
Wayne Hagedoorn (Fisheries Technician, 1995–1998)
Mark Tonks (Fisheries Technician, 1998–1999)

Appendix 3. Pilchard Age-Length Keys

1. Pilchard age-length keys for period–1 (January–June) and period–2 (July–December) 1995.

	Period–1						Period–2					
Length Class	1	2	3	4	5	Total	2	3	4	5	6	Total
11	1	.	.	.	.	1	.	.	.	.	.	.
11.5	1	.	.	.	.	1	.	.	.	.	.	.
12	.	.	.	.	.	.	.	.	.	.	.	.
12.5	3	.	.	.	.	3	5	.	.	.	.	5
13	4	3	.	.	.	7	7	.	.	.	.	7
13.5	1	1	.	.	.	2	7	2	1	.	.	10
14	6	6	3	.	.	15	9	4	.	.	.	13
14.5	4	7	2	.	.	13	3	5	3	.	.	11
15	1	2	2	.	.	5	1	4	1	.	.	6
15.5	.	1	4	2	.	7	2	.	7	1	.	10
16	1	.	2	1	1	5	.	3	5	.	.	8
16.5	.	1	.	4	1	6	.	2	2	2	.	6
17	.	.	2	2	2	6	.	.	.	1	1	2
17.5	.	.	.	1	.	1	.	.	.	1	.	1
18	.	.	.	2	.	2	.	.	.	.	.	.
Grand Total	22	21	15	12	4	74	34	20	19	5	1	79

2. Pilchard age-length keys for period–1 (January–June) and period–2 (July–December) 1996.

	Period–1							Period–2							
Length Class	1	2	3	4	5	6	Total	1	2	3	4	5	6	7	Total
12	2	.	.	.	.	.	2	.	10	.	.	.	.	.	10
12.5	9	.	.	.	.	.	9	.	29	1	.	.	.	.	30
13	7	1	.	.	.	.	8	.	45	5	.	.	.	.	50
13.5	8	3	.	.	.	.	11	.	40	10	.	.	.	.	50
14	4	5	.	.	.	.	9	1	38	28	3	.	.	.	70
14.5	2	4	.	1	.	.	7	.	15	31	4	.	.	.	50
15	1	1	7	.	.	.	9	.	9	27	13	.	.	.	49
15.5	.	9	7	.	.	.	16	.	2	23	31	3	1	.	60
16	.	2	12	1	.	.	15	.	.	15	27	10	.	.	52
16.5	.	1	7	6	.	.	14	.	.	9	32	14	.	.	55
17	.	1	7	4	3	.	15	.	.	3	20	20	2	.	45
17.5	.	.	4	5	3	.	12	.	.	.	2	12	5	.	19
18	.	.	3	2	3	2	10	.	.	.	4	9	4	.	17
18.5	.	.	.	.	.	1	1	.	.	.	1	.	1	.	2
19	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1
Grand Total	33	27	47	19	9	3	138	1	188	152	137	68	13	1	560

3. Pilchard age-length keys for period–1 (January–June) and period–2 (July–December) 1997.

	Period–1							Period–2							
Length Class	0	1	2	3	4	5	Total	1	2	3	4	5	6	7	Total
7.5	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.
8	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.
8.5	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.
9	3	.	.	.	.	.	3	.	.	.	.	.	.	.	.
9.5	1	4	.	.	.	.	5	.	.	.	.	.	.	.	.
10	.	3	.	.	.	.	3	.	.	.	.	.	.	.	.
10.5	.	2	.	.	.	.	2	.	.	.	.	.	.	.	.
11	.	7	.	.	.	.	7	2	.	.	.	.	.	.	2
11.5	.	6	.	.	.	.	6	.	.	.	.	.	.	.	.
12	.	11	.	.	.	.	11	2	4	.	.	.	.	.	6
12.5	.	15	.	.	.	.	15	2	3	.	.	.	.	.	5
13	.	12	3	.	.	.	15	1	3	1	.	.	.	.	5
13.5	.	4	8	.	.	.	12	.	9	3	1	.	.	.	13
14	.	5	5	1	.	.	11	.	7	9	.	.	.	.	16
14.5	.	1	11	4	.	.	16	.	5	13	4	.	.	.	22
15	.	.	7	4	.	.	11	.	3	16	10	.	.	.	29
15.5	.	.	2	11	1	.	14	.	3	17	12	.	.	.	32
16	.	.	3	3	1	.	7	.	1	10	18	1	.	.	30
16.5	.	.	1	1	6	.	8	.	1	2	18	5	.	.	26
17	.	.	.	4	8	1	13	.	.	2	19	13	1	.	35
17.5	.	.	.	2	2	1	5	.	.	1	6	11	3	.	21
18	.	.	.	.	1	1	2	.	.	1	3	8	3	1	16
18.5	.	.	.	.	.	.	.	.	.	.	.	1	1	.	2
19	.	.	.	.	.	.	.	.	.	.	.	2	.	.	2
19.5	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1
Grand Total	7	70	40	30	19	3	169	7	39	75	91	41	9	1	263

4. Pilchard age-length keys for period–1 (January–June) and period–2 (July–December) 1997.

	Period–1								Period–2								
Length Class	1	2	3	4	5	6	7	Total	1	2	3	4	5	6	7	8	Total
10.5	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1
11	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1
11.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12	1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
12.5	.	3	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.
13	1	2	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.
13.5	.	2	1	.	.	.	.	3	.	.	.	.	.	.	.	.	.
14	1	7	3	.	.	.	.	11	.	.	.	.	.	.	.	.	.
14.5	.	6	5	.	.	.	.	11	.	.	.	1	.	.	.	.	1
15	.	2	6	2	.	.	.	10	.	.	2	1	.	.	.	.	3
15.5	.	1	6	6	.	.	.	13	.	.	6	2	2	.	.	.	10
16	.	3	8	8	.	.	.	19	.	.	4	9	6	.	.	.	19
16.5	.	1	4	14	3	.	.	22	.	.	1	12	10	.	.	.	23
17	.	.	2	9	7	.	.	18	.	.	.	9	10	3	.	.	22
17.5	.	.	3	10	4	.	.	17	.	.	.	2	10	8	2	.	22
18	.	.	.	3	8	3	.	14	.	.	.	4	6	7	2	.	19
18.5	.	.	.	3	5	3	1	12	.	.	.	.	5	8	.	1	14
19	.	.	.	.	5	1	.	6	.	.	.	1	2	2	.	.	5
19.5	.	.	.	1	2	1	.	4	.	.	.	.	.	1	.	.	1
Grand Total	3	27	38	56	34	8	1	167	1	1	13	41	51	29	4	1	141