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Stock Assessment for the Shark Bay Scallop Fishery

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Executive summary

The Shark Bay scallop fishery is based on a single species *Amusium balloti* and is the most valuable scallop fishery (AUD 10-57 million) in Western Australia. This species is short-lived, has fast growth and highly variable recruitment which is primarily environmentally driven. The scallop fishery consists of two classes of licences, A and B. There are fourteen Licensed Fishing Boats with A Class licences that target scallops and account for approximately 70% of the catch. There are twenty-seven Class B licences, which primarily fish for prawns (in the Shark Bay Prawn Managed Fishery) with scallops a secondary target species. Restructuring and gear amalgamation within the Class B fleet has currently reduced the number of boats actively fishing to 18.

A decision rule framework applies in the fishery which addresses the management objectives:

- Protect scallop spawning stocks when fishing in the early part of the season;
- Retain carryover of residual scallops at the end of the season as a buffer against low recruitment;
- Minimise impact of prawn and scallop boats on each other;
- Optimise size and quality of scallops;
- Allow both fleets access to scallops with equitable catch share and
- Manage the fishery under the principle of ecosystem based fisheries management and in particular:
    - ensure that bycatch, in particular large animals including turtles is minimised and
    - that the effects of fishing do not result in irreversible changes to ecological processes.

Annual scallop surveys, conducted between October and December, have been undertaken in Shark Bay since 1983, and provide size and abundance information from over 90 trawl sites within the bay. These data are used to determine an index of recruitment strength during that year (individuals derived from the current years spawning). They also provide an index of the size of the residual stock (older scallops remaining from the year before and possibly 2 years before, noting the life span is 2-3 years) and together provide the basis for predicting the catch the following year. A strong correlation between the survey index and catch was observed up to the mid 1995. Since 2007, the catch prediction has been determined using only years since 1995 to reflect the changes in fishing practices. The annual survey also provides scallop abundance and distribution that enables the season fishing arrangements of the fishery to be determined that take into account fishing scallops at an optimum size.

The sedentary nature of scallop stocks and the relatively short duration of fishing by the scallop fleet on any fish ground makes them an ideal fish stock to use depletion analysis in stock assessment. Detailed daily logbook information since 2005 has provided the ability to undertake depletion estimation of stock abundance for the Denham Sound and northern Shark Bay fish grounds.

1.0 Introduction

1.1 Description of the Fishery

The Shark Bay Scallop (SBS) fishery exists within the waters of Shark Bay off the mid west coast of Western Australia (WA) (Figure 1.1). The boundary of the fishery is described as:

> *"the waters of the Indian Ocean and Shark Bay between 23°34' south latitude and 26°30' south latitude adjacent to Western Australia on the landward side of the 200m isobath, together with those waters of Shark Bay south of 26°30' south latitude" (Figure 1.2).*

Figure 1.1 Shark Bay Scallop fishery locality map.

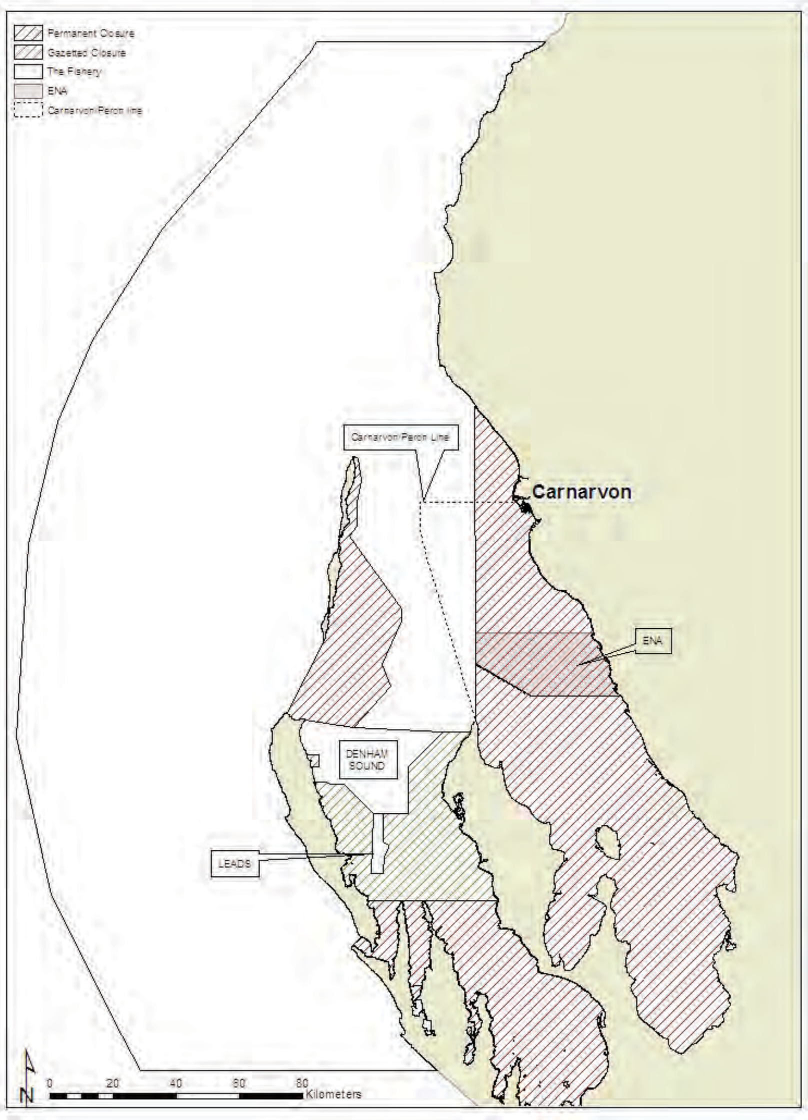


Figure 1.2 SBS fishery indicating closure areas for A class boats and B class temporal closure lines (Carnarvon/Peron line and ENA).

Within the overall management area, scallop trawling only occurs in waters east of the outer islands of Shark Bay, in depths between 16 and 40 m. The state Jurisdiction is to the 200 m isobath and that including those waters within the SB scallop (and Prawn) fisheries effectively controls trawling outside the Bay even if the area trawled is only inside the Bay. Additionally, within the functional area of trawling, there are differences in fishing boundaries according to what type of licence is held. The scallop fishery consists of two classes of licences, A and B. There are fourteen Licensed Fishing Boats with A Class licences that target scallops and account for approximately 70% of the catch. There are twenty-seven Class B licences, which primarily fish for prawns (in the Shark Bay Prawn Managed Fishery) with scallops a secondary target species. Restructuring and gear amalgamation within the Class B fleet has currently reduced the number of boats actively fishing to 18.

The boundaries for the A Class boats are the waters of Shark Bay and Denham Sound west of longitude 113°30’36”E and north of a line running due east from the north extremity of Cape Bellefin to Peron Peninsula. The boats with Class B licences are endorsed to fish the waters of

Shark Bay and part of Denham Sound. While A-class licence holders are not permitted to fish east of a line extending northwards from Cape Peron, B-class licence holders can fish in this area (Figure 1.2). A permanent closure for both licences exists for a reef area eastward of the Naturaliste Channel, between the northern end of Dirk Hartog Island and the southern end of Bernier Island and northwards along the east side of Bernier and Dorre Islands (Figure 1.2).

1.2 Physical Environment

Shark Bay has a semi-arid to arid climate with hot, generally dry summers and mild winters. The waters of Shark Bay cover an area of about 13,000 km^2. It is for the most part a shallow embayment with an average depth of 9 metres and a maximum depth of 29 m. Water depths increase to the north and west where the bay opens into the Indian Ocean reaching a maximum of around 40 m in the Naturaliste and Geographe Channels.

The large seagrass beds in the bay influence the hydrology of the area, slowing water currents as they pass over the beds, and allowing increased deposition of suspended sediments. This has led to the development of large sedimentary banks (e.g. Faure Sill), which create restrictions on water flow. The rainfall is low approximately 20 cm per year while the evaporation rate under the influence of the summer trade winds reaches approximately 220 cm per year. The combination of high evaporation rate with the extensive sand banks that slow water movements into the southern bays results in high salinities of up to 60-70 ppt (twice seawater) in areas such as Hamelin Pool. The temperature range in shallow waters can be between 15 (June/July) and 35°C (Feb/Mar) (Penn and Stalker, 1979). This has resulted in the unusual hydrologic structure in Shark Bay characterised by salinoclines and three major water types namely oceanic (salinity 35-40 ppt), metahaline (40-56 ppt) and hypersaline (56-70 ppt). This distinct salinity pattern influences the distribution of marine flora and fauna within the bay, leading to three biotic zones.

The islands bordering the bay and the seafloor itself are of sedimentary origin, predominantly limestone and sandstones (Logan and Cebulski, 1970). In Shark Bay, water movement is largely influenced by wind and tide. The waters of the Bay are influenced by semi-diurnal tides (two high water per day), which have a maximum range of about 1.5 metres. Stratification of water due to different and elevated salinities has resulted from these influences in Shark Bay.

1.3 Economic Environment

The majority of the annual catch is destined for export as frozen scallop meat to Asia, principally via Hong Kong markets. Very small quantities of scallops are occasionally left 'roe-on', in the shell or in the half-shell to supply the local gourmet seafood market.

Wholesale market prices for scallops have fluctuated markedly over the history of the fishery. In the 1980's the price ranged from $8.50 to $17.00/kg (meat weight) but was generally around $16-$17/kg. In the 1990's the prices increased to around $26 to $28/kg but has declined from 2000 to around $17 to $20 per kg (Table 1.1).

Size and condition of the meat is essential in obtaining high market value for scallop meat, and consequently these factors greatly influence selection of appropriate seasonal opening dates as meat size and condition vary significantly through the year (Joll and Caputi 1995). Higher prices are usually paid for larger scallops, so it is desirable to open the scallop fisheries when meats may reasonably be expected to be in the range of 20 to 40 pieces per pound (454 grams) criterion, as this size is preferred on the export market.

Since 1982, the annual catches and value of the fishery have varied greatly with annual catches ranging from 121 to 4,414 tonnes meat weight (Figure 1.3), depending primarily on the naturally variable strength of recruitment. Consequently, the fishery's value (derived using the beach price provided by Industry and total catch) has also fluctuated on an annual basis, ranging from $2 - 62 million. Despite the highly variable annual catches which is typical of scallop fisheries, the Shark Bay Scallop Managed Fishery is WA's most significant scallop fishery, although in some years large catches have been taken in other scallop fisheries (Sporer and Kangas 2001), such as the Abrolhos Islands and Mid West Trawl Fishery (Table 1.1).

A preliminary economic analysis of the scallop fishery including revenue and cost factors was undertaken for the Shark Bay fisheries review (Department of Fisheries, 2010).

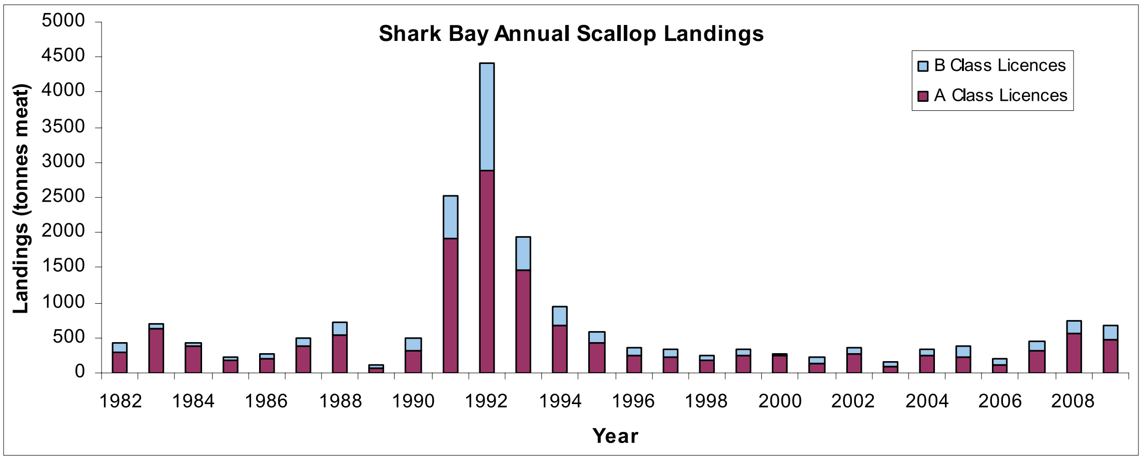


Figure 1.3 Annual landings of scallops by prawn and scallop trawlers during 1982-2009.

Table 1.1 Annual catch and values ($million) for Shark Bay and Abrolhos Islands and Mid West Trawl fisheries, 1985-2009.

Year	Shark Bay $/kg	Shark Bay Catch (t)	Shark Bay Total (million $)	Abrolhos $/kg	Abrolhos Catch (t)	Abrolhos $ Total (million $)	Total (million $)
1985	12.25	232.8	2.9	11.00	10.0	0.1	**3.0**
1986	15.25	259.5	4.0	13.00	74.2	1.0	**4.9**
1987	16.00	490.9	7.9	16.25	67.6	1.1	**9.0**
1988	17.00	731.2	12.4	17.00	23.6	0.4	**12.8**
1989	17.50	121.0	2.1	17.50	43.1	0.8	**2.9**
1990	15.00	486.7	7.3	15.00	25.8	0.4	**7.7**
1991	8.50	2532.0	21.5	8.50	17.5	0.1	**21.7**
1992	14.00	4414.0	61.8	14.00	80.2	1.1	**62.9**
1993	17.00	1934.6	32.9	17.00	292.2	5.0	**37.9**
1994	18.00	957.1	17.2	20.00	526.7	10.5	**27.8**
1995	28.50	596.0	17.0	28.50	317.4	9.0	**26.0**
1996	26.00	364.0	9.5	26.00	228.7	5.9	**15.4**

Year	Shark Bay $/kg	Shark Bay Catch (t)	Shark Bay Total (million $)	Abrolhos $/kg	Abrolhos Catch (t)	Abrolhos $ Total (million $)	Total (million $)
1997	35.00	328.5	11.5	35.00	8.8	0.3	**11.8**
1998	22.00	252.2	5.5	22.00	42.3	0.9	**6.5**
1999	21.75	339.9	7.4	21.75	116.6	2.5	**9.9**
2000	26.25	269.0	7.1	26.25	85.7	2.2	**9.3**
2001	20.50	216.3	4.4	20.50	236.4	4.8	**9.3**
2002	16.50	354.0	5.8	16.50	38.9	0.6	**6.5**
2003	16.80	155.2	2.6	16.80	1168.5	19.6	**22.2**
2004	18.60	332.9	6.2	18.60	28.9	0.5	**6.7**
2005	17.00	384.6	6.5	17.00	1294.0	22.0	**28.5**
2006	17.50	208.8	3.7	17.50	40.7	0.7	**4.4**
2007	18.00	454.6	8.2	18.00	9.6	0.2	**8.4**
2008	19.50	734.8	14.3	19.50	243.2	4.7	**19.1**
2009	18.00	678.2	12.2	N/A	0	0	**12.2**

1.4 Social Environment

The fishery has considerable impact on regional WA with part of the scallop and prawn fleet based in Carnarvon. A Class boats are permitted to operate with 13 crew members while Class B boats for most years have operated with a maximum of 6 crew (but since 2007 up to 8 crew have been allowed). In addition, there is also scallop processing and support staff employed at Carnarvon and Fremantle. The A Class boats generally fish for up to two months a year whereas the Class B boats are operational for approximately eight months of the year (primarily fishing for prawns) and as a result, the SBS fishery (A Class and B boats inclusive) employs in excess of 300 individuals in the Gascoyne region including the fishing fleet, processing and fleet maintenance, plus indirect employment for service providers during the season from March to November.

1.5 Fishing History

Scallops were first identified in WA waters in 1904, when the government survey boat Rip reported finding the saucer scallop, *Amusium balloti*, in several trawls conducted in south-west coastal waters (Gale, 1905; Laurenson et al., 1993). During the late 1950s and early 1960s exploratory trawling was undertaken in the Shark Bay area by the research boats *Lancelin* and *Peron* (Penn and Stalker, 1979). This revealed potential commercial quantities of prawns and scallops, but it wasn't until 1966 that scallop landings from prawn boats fishing in Shark Bay and other boats targeting scallops were first reported. For several years they were taken as a by-product from boats fishing primarily for prawns, and were first targeted for commercial purposes in the Shark Bay area during the late 1960s (Joll, 1989). In 1969 net mesh size (minimum 100 mm) regulations were introduced for scallop fishing. Prawn boats could fish for 24 hours fishing for prawns (although most boats generally fished at night) and a small number of boats changed nets to fish for scallops with 100 mm mesh nets during the day.

No scallop catches were recorded in 1971 and low catches in subsequent years were apparently caused by poor recruitment. Catches increased in 1976 and boat numbers targeting scallops remained stable at around 2 to 5 until 1982. Then from 1982 the number of boats attracted to the fishery escalated dramatically (Joll, 1989). Improvements in techniques for processing the catch at sea, increases in price due to higher product quality and an apparent increase in stocks made scallop fishing in Shark Bay increasingly lucrative (Joll, 1989). In 1982 an increase in the number of dedicated scallop boats (13) and successful scallop recruitment resulted in a high scallop landings. In the following year the number of scallop boats increased to 26 due to an interest from other fishers intending to fish for scallops in Shark Bay and the Abrolhos Islands fisheries. Landing records from Shark Bay showed 705 t of scallops mainly from the dedicated scallop boats. Subsequent increases in fishing pressure mainly by the scallop boats were further compounded by increased targeting by the 35 Shark Bay prawn boats, that since 1966 were retaining scallops caught while targeting prawns. These increases in fishing activity, with a significant increase in fishing effort from 1982 led to a much higher proportion of the resident stock being taken at 0+ and 1+ age class, with fewer scallops surviving to the maximum age of 3 years (Joll, 1989). Commonwealth export regulations at the time prevented much of the scallop catch from being exported, as it was subject to advanced larval nematode infection. As the age composition of the stock was lowered, however, more scallops were caught before serious infection could develop. This increased both the proportion of the catch suitable for export and the value of the product (Joll, 1989).

After unrestricted fishing by dedicated-scallop boats peaked at 26 boats in 1983 the number of scallop boats was limited to 14 in 1984, pending a four-year biological review of the scallop fishery. Following review recommendations, Shark Bay was declared a limited-entry fishery in 1987, with 14 dedicated-scallop boats (A Class) operating together with the 35 boats endorsed to fish the limited-entry prawn fishery (B Class), under a loose catch-sharing arrangement with guidelines with the objective for the prawn boats to take 20% or 60 tonnes of the scallop catch each year (Department of Fisheries 2010).

From the inception of the prawn fishery in 1962 there was no daily time restriction on fishing and this also applied for scallops. In 1988 trawling was limited to a 15-hour period from 1700 hrs to 0800 hrs the following morning for both fleets except for prawn boats in the areas north of Koks Island where 24 hours fishing by prawn boats was permitted (to take prawns in deeper water). At this time there were no crew limits for either fleet. However the 15-hour time limit for trawling was removed for scallop boats in 1991 allowing the catch to be more steadily processed and frozen at sea before being landed and the catch share 80/20% was also removed. Crew limits were introduced in this year limiting the number of crew on scallop boats to 13 and 6 for prawn boats. This trade off was to maintain the catch share arrangement between the two fleets for the scallop resource.

The Shark Bay prawn fleet was reduced to 27 boats in 1990 to reduce the available effort that could be expended on prawn stocks, and to improve economics of the fishery and industry restructures commencing in 2005, has further reduced the fleet to 18 boats.

1.6 Management Objectives

Management arrangements over the past 20 years have aimed for adequate spawning stock levels to be maintained when spawning commences. While the approach has been generally successful in maintaining stocks, annual variations in recruitment seem to be dominated by environmental factors with recruitment inversely correlated with the strength of the Leeuwin Current.

Management of the fishery is also aimed at catching scallops at the best size and condition for the market, thereby maximising the economic return, whilst maintaining breeding stock levels. Because the scallop stock commences spawning in mid-April (continuing through until the end of November) and meat condition declines as spawning continues, the process of setting the opening date of the season balances breeding stock levels and the seasonal decline in meat condition associated with spawning.

The annual scallop survey which estimates recruitment and residual abundance, enabled scallop catch predictions each year and a set of guiding principles (Table 1.2) were used in developing a matrix system in 1987 that determined the season opening time each year according to abundance of scallops (Table 1.3).

Table 1.2 Guiding principles used to help determine an appropriate opening date for the Shark Bay scallop season

1. Adequate abundance of spawning stock scallops in Shark Bay (spawn mid-April to end of November).
2. Marketable meat sizes (high level of <40/lb). New recruits usually reach 40/lb by mid-March to end of April; proportion of 40-60/lb grade may increase later in the season (August onwards) as meat shrinks during spawning; residual stock usually <40/lb by late January.
3. Marketable meat quality (meats not watery, breaking, wormy) meat quality decreases during the year as spawning continues;
   - maximum quality - February/March;
   - ·minimum quality - September/October.
   - increased worm lesions by October/November.

Table 1.3 Schedule (known as Matrix system) linking strength of recruitment and residual scallops determined during the November survey with estimated catch producing an appropriate estimated opening date.

ESTIMATED CATCH	ABUNDANCE RECRUITS	ABUNDANCE RESIDUALS	OPENING DATE*
Low (<300t)	Low	Low	15 May
	Moderate	Low	1 May
Med (300 - 600t)	Low	Moderate	15 April
	High	Low	15 April
	Moderate	Moderate	15 April
High (600 - 1500t)	Low	High	1 April
	High	Low	1 April
Very high (>1500t)	Low	High	15 March

The timing of opening the scallop seasons and integration of the scallop fishery arrangements with the prawn fishery arrangements, while suitable for protecting the breeding stock, did not necessarily provide the best outcome for maximizing the economic yield for the fishery. Prawn fishing commenced before the scallop season allowing prawn boats to catch but having to discard scallops until the scallop season commenced. The continual capture and discarding of scallops caused nets to tear and may have caused some trawl-induced mortality to scallops. The matrix system did not provide an opportunity to target scallops in February/March when the meat is at its maximum quality.

The matrix system of opening schedule was abolished in 2005 and the management objectives were revised to:

- Protect scallop spawning stocks when fishing in the early part of the season;
- Retain carryover of residual scallops at the end of the season as a buffer against low recruitment;
- Minimise impact of prawn and scallop boats on each other;
- Optimise size and quality of scallops;
- Allow both fleets access to scallops with equitable catch share and
- Manage the fishery under the principle of ecosystem based fisheries management and in particular:
  - o ensure that bycatch, in particular large animals including turtles is minimised and
  - o that the effects of fishing do not result in irreversible changes to ecological processes.

Within this framework a series of Decision Rules apply in the fishery:

- Fishing for scallops in any area will only be undertaken if the expected catch (using the catch prediction) is above a minimum level (different levels set for Denham Sound, northern Shark Bay and Leads areas);
- Fishing for scallops within Denham Sound and northern Shark Bay cease when the catch rate threshold is reached;
- A scallop spawning closure is implemented (no take of scallops) during May to July each year;
- Fishing for scallops will cease when the average meat size is more than 50 pieces per pound (454 grams) and
- A depletion analysis is undertaken to determine standing stock and the stock available (if any) to be taken after the spawning closure period in Denham Sound and northern Shark Bay.

1.7 Management History

The following represents a summary of the management history for the scallop and prawn fishery:

Year/Season	Regulation/Management changes
1962	First recorded catch of prawns from prawn boats (4 boats)
	No season or area closures for prawn boats.
1966	First recorded commercial landings of scallops by prawn boats. Product landed whole and processed ashore.
1969	Increased recruitment of scallops and increased effort by other boats rigged for trawl fishing for scallops
1970 to 1975	Stable landings (low) of scallops mainly from prawn boats
1972	Combination of twin 6 and 7-fathom nets used by prawn boats. Low effort on scallops. Three boats increased nets to 8 and 10 fathom nets and total fleet headrope was 362 fathoms
1978	Introduction of prawn nursery areas and extended nursery area (ENA). ENA opened 15 April each year (otherwise no season set).
1976 to 1979	Scallop landings significantly increased and number of dedicated-scallop boats fishing was stable (2 to 5 boats). Introduction of onboard processing increased viability for scallop boats (shucking on fishing grounds).
1982 to 1983	Significant increase in boat numbers (13 and 26 respectively) and increased effort resulting in high landings by scallop boats. Also targeting of scallops by prawn boats. Scallop recruitment survey implemented.
1982	Increased area of the ENA. January closed for all trawling.
1983	14 prawn boats using 8 fathom nets, 19 using 7.5 fathom nets and 2 using 6 fathom nets increase in total effort (533 fathoms of prawn fleet headrope)
1983 to 1986	Introduction of prawn season opening 1 March and closing 1 November.
1984	The number of dedicated scallop boats limited to 14 using standard size nets (2 x 7 fathom nets)
1985	Moon closures implemented for prawn boats only

Year/Season	Regulation/Management changes
1985	Scallop trawl line introduced. No fishing for scallops east of a line from Cape Peron north.
1986	Scallops permitted to be taken by prawn boats east of scallop line due north of Cape Peron at the commencement of scallop season.
1987	Limited-entry scallop fishery approved. Management Plan introduced. Prawn season opened by lunar phase and season generally between March and November. Introduction of matrix system to open scallop season.
1988	80/20% guideline for scallop take introduced with an allocation of 80% for the dedicated-scallop boats. Introduction of restricted trawl times from 1700 to 0800 hrs the following day, 15 hours trawling for both A and B class boats. Prawn boats trawl 24 hours north of Koks Island
1989	Carnarvon line introduced. The Carnarvon line extended from Carnarvon then due west to the Islands. Fishing was undertaken north of this line by the prawn boats until the scallop season opened. When the scallop season opened, fishing was undertaken throughout the remainder of the bay except for the ENA closure (Figure 1.2).
1990	The Carnarvon line changed to Carnarvon/Peron line coordinates (Figure 1.2) to allow prawn boats access to prawns stocks in the western part of the bay south of Carnarvon. Eight prawn boats and their net headrope entitlement removed from the fishery via a buyback. The net size not standardised and 430 fathoms total headrope remain in the prawn fishery
1991	Removal of 80/20% rule for scallops. Trawl hours amended to 24 hrs for scallop boats and 15 hours for prawn boats. Crew limits introduced, 13 for scallop boats and 6 for prawn boats.
1992	Larger boats for scallop sector permitted. Dorre and Bernier Island trawl (both sectors) closure implemented
1996	Net standardisation with all prawn boats fishing twin 8-fathom nets for a total fleet headrope of 432 fathoms.
2004	Snapper Closure implemented in Denham Sound (Figure 1.2) for both A and B Class boats. Season opened 3 May using matrix system (last year of matrix season opening system)
2005	Fishing scallops in Leads area south of Snapper closure line for A Class boats only. Matrix abolished, fishing for scallop pre-spawning. Catch rate threshold level implemented which stopped the pre-spawning fishing. Threshold level in Denham Sound set at 125 kg/day fishing period. Threshold level in northern Shark Bay set at 400 kg per 24 hrs. Thresholds levels are based on scallop boat fleet catch rates and all boats were required to fish in the same area. Daylight fishing restriction (0600 to 1830 hrs each day) in Denham Sound for A Class boats. Red Cliff area trial closure.
2006	Threshold level in Denham Sound was raised from 280 to 300 kg per day fishing. Red Cliff threshold set at 400 kg per 24 hrs. The remaining part of the northern Shark Bay threshold set at 200 kg per 24 hour fishing.

Year/Season	Regulation/Management changes
2007 and 2008	Threshold level in Denham Sound retained at 300 kg per daytime fishing period. Threshold level in northern Shark Bay was raised to 300 kg per 24 hr. No Red Cliff closure. Trial catch-share arrangement (72/28%).
2009	Threshold level in Denham Sound increased to 400 kg per daytime period and increased to 400 kg per 24 hours in northern Shark Bay.
2010	Threshold level in Denham Sound increased to 450 kg but fishing was allowed at night by both fleets. Northern Shark Bay remained at 400 kg per 24 hours.

1.8 Current Management Strategies

The current management plan for the SBS fishery is a statutory document that provides the framework for the management measures for the fishery. The management framework aims to catch scallops at a size and reproductive condition that maximizes market value (meat weight and condition) while maintaining sustainability of the fishery.

The SBS fishery is an input controlled fishery and these input controls include limited entry, boat size, gear controls, area closures and the timing and duration of the fishery.

Seasonal closure. The fishery has generally closed between November and around April. The closure is generally aligned with the Shark Bay Prawn Managed Fishery but the A-class boats usually cease fishing before the gazetted closure date as the scallop catch rates decline to levels that are not economic for scallop-only boats to continue fishing. Since 2005 the season has opened depending on meat size in late February or early March prior to the main-scallop spawning period.

Area closures. Within Shark Bay only the deeper soft seabed areas are open for scallop trawling. Permanently closed areas are in place for both prawn and scallop boats (Figure 1.2). The Denham Sound area was historically fished by prawn boats in two periods in March-April and then after 1 August for both prawn and scallop boats. Since 2005 Denham Sound has generally only opened for the scallop boats early in the season with prawn boats only fishing after 1 August.

Time closures. During the scallop season A Class boats have been permitted to fish for scallops 24 hours. B Class boats are restricted to fishing between 1700hrs to 0800 hours the following day (15 hour fishing period). Between the years 2005 and 2009 scallop fishing in Denham Sound, by the A Class boats was restricted to daytime hours (sunrise to sunset each day) because of the interaction with prawns in the early part of the season (prawns are mainly active at night).

Crew restrictions. A Class boats are limited to 13 crew. B Class B boats are generally limited to six crew, however the CEO has approved up to eight crew.

Gear controls. (Net size (headrope), board size, net mesh size, size of try gear and bycatch reduction devices). Specifications for these input controls are part of the Management Plan (Appendix 1).

Vessel Monitoring System. Since the 2001 season, a Vessel Monitoring System (VMS) has been in place in the Shark Bay scallop fishery. The VMS enables the Department of Fisheries to monitor a boats location and speed with particular attention paid to the surveillance of closed areas. VMS monitoring of boats is undertaken for the entire season.

Byproduct Species. All retained byproduct are recorded in the daily logbook provided.

1.8.1 Recent Changes to Management arrangements

Since 2005, scallop fishing has commenced earlier with the aim of optimising value of scallops caught by taking them at a time when the meat size is large prior to spawning. However, to ensure that sufficient stock remains for spawning, the fishing arrangements provide a threshold catch rate limit to cease pre-spawning fishing. This catch rate threshold was initially set at relatively low levels based on historical abundance levels left at the end of the season by scallop boats. This catch rate threshold level has been increased since 2005 because fishing for scallops is pre-spawning (refer Table 1.7). When the threshold level is reached (or early May) there is a cessation of scallop fishing during the key spawning period (May to July inclusive).

For the 2007 and 2008 seasons, a catch share arrangement was also in place as part of a two-year trial with the share of 72% and 28% for the A Class and B boats respectively. This catch share was set using the average catch for the two fleets between 1982 and 2006. In 2009 and 2010, the catch share arrangement was not in place and provided an opportunity to evaluate how the fishing arrangements would operate without a catch share but with catch-rate thresholds still in place.

During these years there was a strategy to ensure that residual scallops were left on trawl grounds at the end of season as a carryover for the following season. Since 2009 this strategy has been formally incorporated into the management objectives to ensure some buffer for subsequent spawning stock and catches against low recruitment. The methodology for estimating residual stock and the amount of fishing that can resume after spawning is being reviewed using a variety of depletion estimation techniques.

The Research Division carries out daily monitoring (real-time management) of the scallop fleet catch and effort to provide advice on when to close areas based on the threshold catch rates and determines the amount of stock that can be harvested after the spawning closure to retain carryover of some scallop stock.

2.0 Biology and Life History Parameters

2.1 Distribution

The saucer scallop, *Amusium balloti*, belongs to the family Pectinidae. The western population of *A. balloti* has a distribution spanning most of the WA coast, having been recorded from Broome in the north to Esperance in the south (Figure 2.1). The greatest numbers are found in Shark Bay and around Abrolhos Islands (Joll, 1989). The eastern population of *A. balloti* occurs from Innisfail, Queensland to Jervis Bay, New South Wales (Kailola et al. 1993). Therefore, the distribution of the eastern and western populations of saucer scallops are separated across the northern Australian waters thus resulting in two separate populations.

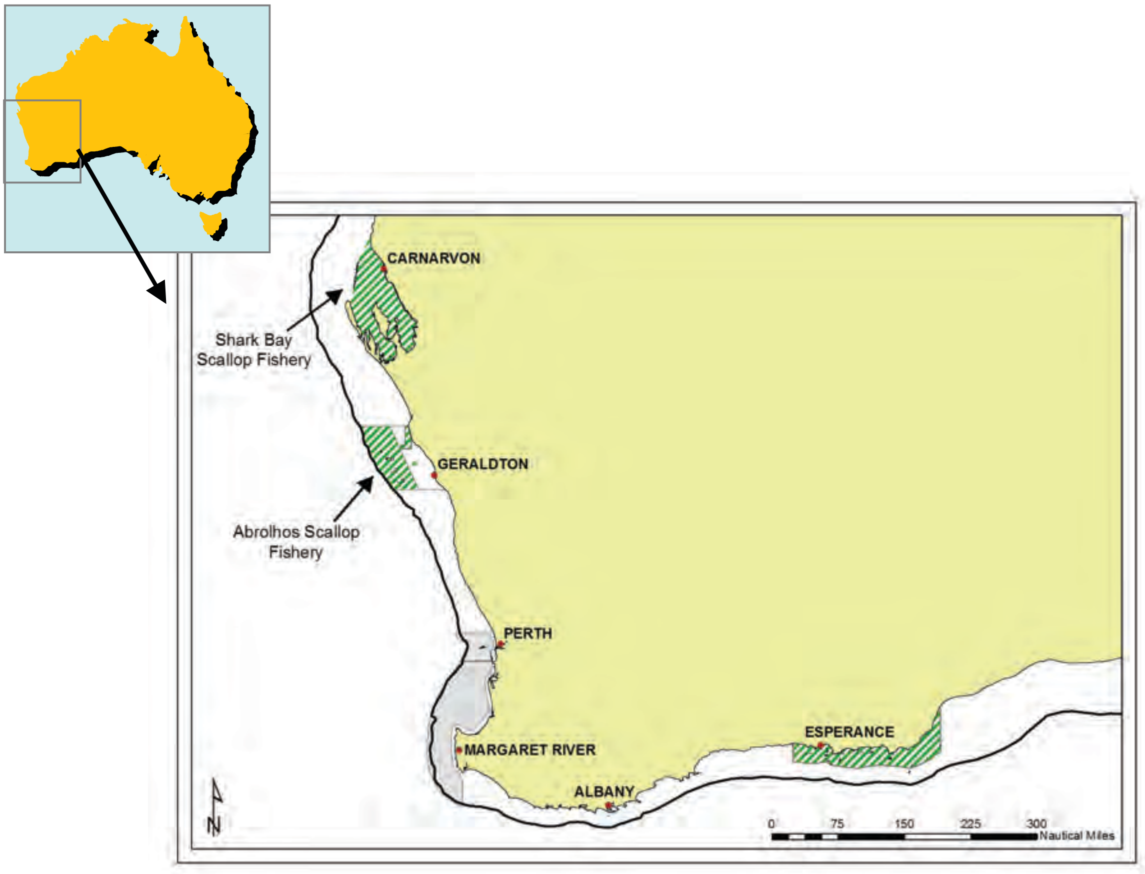


Figure 2.1 Map showing the main areas of distribution of *Amusium balloti* in Western Australia.

Larvae of the *A. balloti* from the east and west coast are morphologically identical (Rose et al. 1988). In Kailola et al. 1993, the eastern and western populations are referred to as separate sub-species (Ballot's saucer scallop in the east and Western saucer scallop in the west) as a result of research conducted in Queensland. This research found that not only were there differences in the genetic make-up of the two populations but the degree of difference indicated that there is probably no interbreeding between the two (Kailola et al. 1993). In more recent research Pulsednik (pers. comm.) found a difference of 3.3% sequence divergence based on 16S ribosomal mtDNA. between the eastern and western populations of *A. balloti* and within WA. She found the largest difference at the 16S gene with 1.1% divergence within populations of WA. These differences are not considered sufficient to treat them as different species.

Although *A. balloti* has an extensive distribution, it tends to be restricted to areas of bare sand in the more sheltered environments found in the lee of islands and reef systems. The species has been reported occurring in depths from 10-75 m in discrete beds, up to 15 km in length, at densities of up to 1 per m^2 (Dredge 1988; Kailola et al. 1993). Joll (1994) recorded average densities in Shark Bay of 2 per m^2 with peak densities of 7 per m^2. Salinity is another ecological factor that clearly limits distribution, but there have been few studies of distribution in relation to salinity or of the salinity tolerance of scallop species (Brand 2006).

2.2 Life History

Early growth of this species is rapid and although saucer scallops have been recorded reaching 140 mm in length and living up to 3-4 years. In Shark Bay most appear to live no more than two years and usually attain a maximum size around 115 mm (Heald, 1978; Dredge, 1988).

The reproductive cycle among Shark Bay scallop stocks begins with the onset of gametogenesis in late March/early April, with spawning occurring 4-8 weeks after the onset of gametogenesis (April/May through to December) (Joll and Caputi, 1995a). The gametogenic cycle of scallops is a genetically controlled response (neurol, hormonal) to the environment (temperature, salinity, light, food) (Sastry 1979) and most year-to-year variation in gametogenesis can be related to environmental factors (Barber and Blake 2006). Gametogenesis is an energy demanding process, as the mobilisation of nutrients to the gonad is essential for gamete development. It is still unclear whether the energy and nutrient demands of gonad development depends on recently ingested food, stored reserves or some combination of the two (Sastry 1979, Barber 1984). Given the energetic demands of reproduction, food availability for adults as well as larvae may be an important factor in determining the timing of the reproductive cycle (Joll and Caputi 1995a).

Although it was originally believed that the reproductive cycle of the saucer scallop was triggered by changes in water temperature in the range of 18°-23°C, research conducted by Joll and Caputi (1995a), has found that the relationship between changes in gonad weight and water temperature is tenuous for *A. balloti* on the WA coast. The timing of spawning is crucial to ensure temperatures and concentrations of phytoplankton are adequate for larval development (Cragg 2006). Wang (2007) found that water temperatures between 18° and 20°C were optimal for larval survival and that they could not survive temperatures above 24°C. Although spawning probably continues for eight to nine months in Shark Bay, most of the recruitment to the populations appears to have arisen from spawning in the first few months (April to July) (Joll 1994, Joll and Caputi 1995b). Changes in environmental patterns may however, lead to different periods of the spawning cycle having a greater importance as contributors to overall recruitment (Joll and Caputi 1995a).

Saucer scallops are broadcast spawners, releasing their eggs and sperm into the surrounding waters for fertilisation to occur in the water column (Kailola et al. 1993). During this period larvae are susceptible to being passively transported by tides and currents whilst in the water column. Larval survival is affected by food availability and predator abundance, and the length of the larval period (assuming survival is enhanced by reducing time in the plankton community) can also be influenced by water temperature. The life cycle for the saucer scallop is depicted in Figure 2.2.

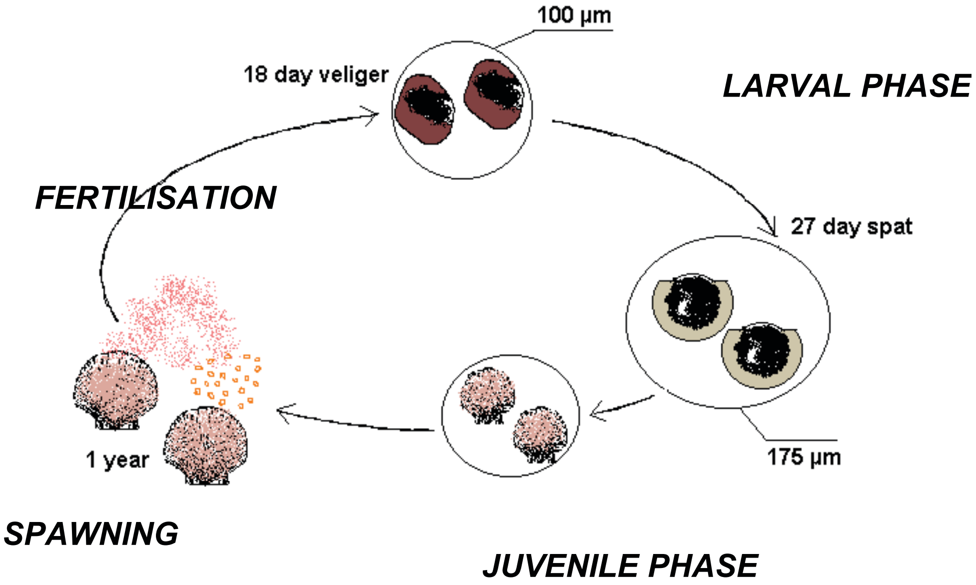


Figure 2.2 Life cycle of the saucer scallop, *Amusium balloti*.

The planktonic, larval phase of the saucer scallop lasts between 12 and 24 days (Rose et al. 1988). Success of the larval phase appears to be governed by prevailing oceanographic events, which greatly influence settlement locations and subsequent recruitment patterns. The predominant oceanographic influence along the WA coast is the Leeuwin Current (LC), a southward flowing current of relatively warm, tropical water that is low in salinity (Joll and Caputi 1995b). While the environmental mechanisms relating to the recruitment variability of *A. balloti* are yet to be fully understood, it appears that in years of strong LC there is an increased likelihood that larvae are flushed away from areas of suitable recruitment habitat.

Larval competency is considered to be the time when larvae develop the ability to respond to external signals that induce metamorphosis (Degnan et al. 1997). Wang (2007) found that this was the time the larvae had developed eyespots (at the fully developed pediveliger stage). No studies have determined exactly what cues induce metamorphosis in *A. balloti* (Wang 2007). Following the larval phase, juvenile scallops settle out as spat over a period of several days (Rose et al. 1988). During this time, they crawl actively using a well-developed, ciliated foot, and do not appear to attach permanently to the substrate (Rose et al. 1988). Growth estimates have been between 5.2 and 6.3 µm day (Rose et al. 1988) and 7.3 µm (Cropp 1993) in shell length from the straight–hinged veliger to the pediveliger stage. Wang (2007) described the settlement process that when the spat reached 1-2 mm the byssus became thicker and could be observed microscopically. If detached by water movement, the spat would initially retract into their shell for several seconds or minutes then they would extend the foot from the byssal notch using it to explore and crawl or attach to the substratum. Spat could explore and crawl for a few minutes before stopping using a byssal filament. He observed that *A. balloti* usually secreted two or three byssal threads, a small number compared to some other bivalves. If disturbed the spat would extend the foot again to explore the surrounding area and secrete another byssus or release existing threads and crawl away. At about 4-5 mm, spat started to swim and appeared to cease byssal production and attachment (Wang et al. 2001, Wang 2007).

Growth of the shell is allometric with the height of the shell growing more rapidly than length (i.e. shell height is positively allometric to length). Growth of these new recruits is rapid. Scallops derived from early in the spawning season (April-July) reach sizes around 50-60 mm in shell height by November, some 6-7 months after fertilisation. A size suitable for commercial harvest (>90 mm shell length) is reached by March-April the next year, in less than one year (Joll and Caputi 1995a).

2.3 Size at maturity, fecundity

The anatomically distinct gonad of the scallop allows for easy removal from the rest of the soft tissue and provides a simple but effective means of assessing the timing, duration and extent of gametogenesis in scallops by determining the mean gonad mass –weight on a regular basis throughout the year (Barber and Blake 1981). The gonad index which expresses gonadal mass as a proportion of total body mass is also used extensively to define gametogenic cycles in scallops (Barber and Blake 2006). *Amusium balloti* are mature at around 90 mm shell height at approximately one year (Joll and Caputi 1995a) although scallops as small as 70 mm shell height were found with maturing gonads (Williams and Dredge 1981). The number of oocytes per gonad for *A. balloti* between 85 and 107 mm shell height was 3.20×10^5 to 2.65×10^6 (Dredge 1981).

2.4 Shell Growth

Daily growth rings are visible in juvenile scallops (Joll 1988) but become difficult to read in mature animals (older than 8-9 months). Very fast growth (8-13 mm per month) is observed in the first year of life with scallops attaining a size of 75 mm by 7 months (Williams and Dredge 1981) and to 90-95 mm by 8-9 months (Joll 1988). At this time scallops become mature and their growth rate decreases significantly to only 1-2 mm per month. This slow growth in individuals greater than 95 mm shell height has also been observed with a repeat recapture tagging study in Shark Bay (Chandrapavan et al. in prep.). The von Bertalanffy growth (von Bertalanffy 1938) equation has been used to describe scallop growth using tag-recapture data (Williams and Dredge 1981) and estimates are $L\infty$: 102-109 mm shell height (SH); K (week^{-1}) : 0.0515-0.0588. A recent tagging study in Queensland (Campbell et al. 2010) determined similar estimates of $L\infty$ (103-104 mm SH) and K (0.0307-0.0394 week^{-1}).

Seasonal growth in bivalves including Pectinids is influenced by the interaction of a number of environmental variables particularly water temperature and food supply (Broom and Mason 1978, Bayne and Newell 1983). Food availability has often been found to exert a greater influence on growth rate than temperature in temperate species (Orensanz 1984). Intraspecific variability in growth rates and tissue weight for a given shell height has most frequently been correlated with differences in water depth. Scallops from inshore, shallower waters typically display higher growth rates and maximum sizes than those from deeper waters. This can be related to the higher temperatures and higher food levels in shallow waters (MacDonald and Thompson 1985). In Shark Bay, a slower growth rate is observed during the spawning months (April to July), which is likely due to energy diverted into reproduction (Rogers et al. 1983), although lower temperatures may also play a part.

2.5 Somatic Growth

Seasonal variation in the size and condition of the adductor muscle size for *A. balloti* has been observed in Shark Bay (Joll and Caputi 1995a) and much of this variation is related to the reproductive cycle. The adductor muscle size also varies according to the shell size of the scallop. Short term variation in somatic tissue weight or energy content is a more sensitive indicator of growth fluctuations within the individual than a change in shell dimensions, because unlike the soft tissue the shell cannot shrink rapidly under adverse environmental conditions (MacDonald and Thompson 1985).

2.6 Feeding

Saucer scallops are filter feeders, removing small phytoplankton, organic material and particulates from the surrounding water (Harris et al .1999).

2.7 Movement

Horizontal larval advection is primarily via current and tidal movements whilst larvae may have some control over their vertical distribution (Cragg 2006). For some species, diurnal migration has been documented (Manuel et al. 1996 a, b, Kaartvedt et al. 1987, Maru 1985, Tremblay and Sinclair 1990 a,b and Raby et al. 1994). The behaviour of larval *A. balloti* within the water column is poorly understood and attempts to collect spat of *A. balloti* in Queensland has not been successful (Sumpton et al. 1990, Robins-Troeger and Dredge 1993). No specific studies on larval distributions have been undertaken for *A. balloti*.

Adult scallops differ from most bivalve molluscs because of their ability to swim. This swimming ability is referred to as an adaptation to fleeing from predators. The best scallop swimmers are species of the genus *Amusium* which can swim up to 23 m in a single swim (Joll 1989). When one scallop swims it often induces swimming in others nearby, setting off a chain reaction (Chapman et al. 1979, Vahl and Clausen 1980, Minchin and Mathers 1982, Howell and Fraser 1984). The sensitivity of *A. balloti* to disturbance and its swimming ability allows it to be fished by otter trawls compared to other scallop species that are captured by dredges (Himmelman et al. 2009). Morton (1980) suggests that *Amusium pleuronectes* is sufficiently well developed that is unlikely that the species only used swimming for an escape response but they may also use it for migration.

2.8 Predators and competitors

Known scallop predators within Shark Bay include pink snapper (*Pagrus auratus*) and octopus (Harris et al. 1999). A potential predator of the saucer scallop is the slipper lobster *Thenus orientalis* as it strongly prefers scallops and its foraging behaviour appears to be adapted to hunting and ambushing scallops (Himmelman et al. 2009). Escape response studies by Himmelman et al. (2009) indicated that *A. balloti* showed a consistent and vigorous swimming response to *Thenus orientalis*, blue swimmer crab *Portunus pelagicus* and coral crab *Charybdis cruciata*. Sea stars are generally considered to be key predators of scallops (Thomas and Gruffydd 1971, Wilkens 1981) however, Himmelman et al. (2009) showed that there was no response when the mantle of *A. balloti* was touched by the sea star *Pentaceraster regulus* although several individuals showed a weak swimming response when *P. regulus* was placed on top of them.

The ecological role of competitors is poorly understood. Bivalves (including adults of the same species) and other benthic filter feeders may compete for suspended food particles and may filter out planktonic larvae (Brand 2006) and at very high densities density dependent controls of recruitment may occur (Vahl 1982).

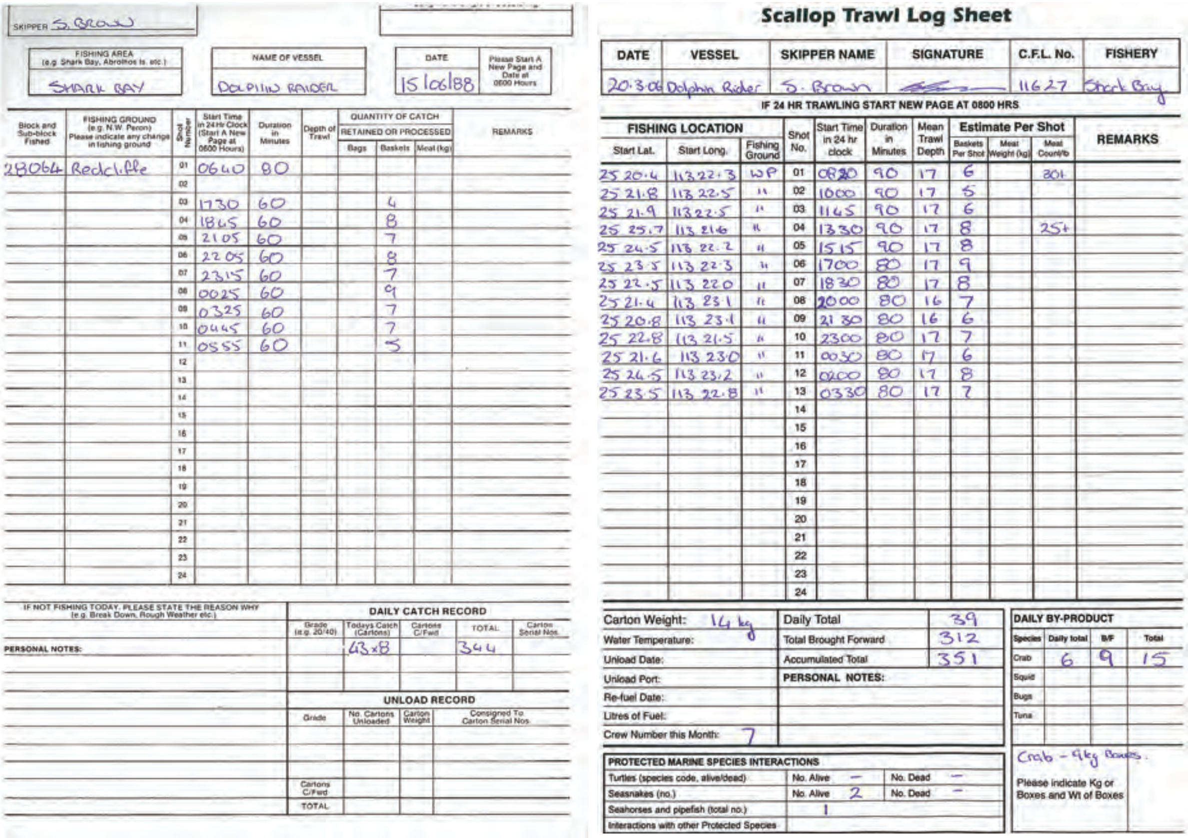
2.9 Parasites

The larval ascaridoid nematode *Sulcascaris sulcata* has been found in *Amusium balloti* (Canon 1978, Lester et al. 1981). This nematode causes lesions in the muscle and reduces marketability although there are no human health implications by this infestation. In addition, a small percentage of scallops sampled (Canon 1978, Lester et al. 1981) also contained a larval gnathostome *Echynocephauls sp*. These parasites are thought to be carried via the loggerhead turtle *Caretta caretta*, which feeds on scallops.

3.0 FISHERIES TIME SERIES DATA

3.1 Daily Logbook Data

Daily logbooks have been completed by commercial scallop fishers since the 1980s. Daily catch and effort were recorded as shot by shot. The spatial information provided was recorded in a 10 x 10 nautical mile block or fishing ground format. The daily catch and effort information was then summarised by day commencing at 0600 hrs each day and by block up to 1997. Since 1998 spatial information has been collected on a shot-by-shot basis with latitude and longitude co-ordinates (Figure 3.1). In addition fishers need to report interactions with protected and threatened species and daily by product. The data quality from individual skippers is variable but has improved in the last five years. Prawn boats can also retain scallops and prawn logbook data did not record the scallop catches fully in the early years of the Fishery as the focus of data collection was prawn catches. Recorded scallop landings by prawn boats from processors commenced in 1982.



SKIPPER S. BROWN

FISHING AREA (e.g. Shark Bay, Abrolhos Is. etc.)	NAME OF VESSEL	DATE	Please Start A New Page and Date at 0600 Hours
SHARK BAY	DOLPHIN RAIDER	15/06/88	

Block and Sub-block Fished	FISHING GROUND (e.g. N.W. Peron) Please indicate any change in fishing ground	Shot Number	Start Time in 24 Hr Clock (Start A New Page at 0600 Hours)	Duration in Minutes	Depth of Trawl	QUANTITY OF CATCH RETAINED OR PROCESSED			REMARKS
						Bags	Baskets	Meat (kg)	
28064	Redcliffe	01	0640	80					
		02							
		03	1730	60			4		
		04	1845	60			8		
		05	2105	60			7		
		06	2205	60			8		
		07	2315	60			7		
		08	0025	60			9		
		09	0325	60			7		
		10	0445	60			7		
		11	0555	60			5		
		12							
		13							
		14							
		15							
		16							
		17							
		18							
		19							
		20							
		21							
		22							
		23							
		24							

IF NOT FISHING TODAY, PLEASE STATE THE REASON WHY (e.g. Break Down, Rough Weather etc.)

PERSONAL NOTES:

DAILY CATCH RECORD

Grade (e.g. 20/40)	Todays Catch (Cartons)	Cartons C/Fwd	TOTAL	Carton Serial Nos.
	43×8		344	

UNLOAD RECORD

Grade	No. Cartons Unloaded	Carton Weight	Consigned To Carton Serial Nos
Cartons C/Fwd			
TOTAL			

Scallop Trawl Log Sheet

DATE	VESSEL	SKIPPER NAME	SIGNATURE	C.F.L. No.	FISHERY
20.3.06	Dolphin Rider	S. Brown		11627	Shark Bay

IF 24 HR TRAWLING START NEW PAGE AT 0800 HRS

FISHING LOCATION			Shot No.	Start Time in 24 hr clock	Duration in Minutes	Mean Trawl Depth	Estimate Per Shot			REMARKS
Start Lat.	Start Long.	Fishing Ground					Baskets Per Shot	Meat Weight (kg)	Meat Count/lb	
25 20.4	113 22.3	WP	01	0820	90	17	6		30+	
25 21.8	113 22.5	"	02	1000	90	17	5			
25 21.9	113 22.5	"	03	1145	90	17	6			
25 25.7	113 21.6	"	04	1330	90	17	8		25+	
25 24.5	113 22.2	"	05	1515	90	17	8			
25 23.5	113 22.3	"	06	1700	80	17	9			
25 22.5	113 22.0	"	07	1830	80	17	8			
25 21.4	113 23.1	"	08	2000	80	16	7			
25 20.8	113 23.1	"	09	2130	80	16	6			
25 22.8	113 21.5	"	10	2300	80	17	7			
25 21.6	113 23.0	"	11	0030	80	17	6			
25 24.5	113 23.2	"	12	0200	80	17	8			
25 23.5	113 22.8	"	13	0330	80	17	7			
			14							
			15							
			16							
			17							
			18							
			19							
			20							
			21							
			22							
			23							
			24							

Carton Weight: 14 kg
Water Temperature:
Unload Date:
Unload Port:
Re-fuel Date:
Litres of Fuel:
Crew Number this Month: 7

Daily Total	39
Total Brought Forward	312
Accumulated Total	351

PERSONAL NOTES:

DAILY BY-PRODUCT

Species	Daily total	B/F	Total
Crab	6	9	15
Squid			
Bugs			
Tuna			

Crab – 9kg Boxes.

Please indicate Kg or Boxes and Wt of Boxes

PROTECTED MARINE SPECIES INTERACTIONS

Turtles (species code, alive/dead)	No. Alive	–	No. Dead	–
Seasnakes (no.)	No. Alive	2	No. Dead	–
Seahorses and pipefish (total no.)	1			
Interactions with other Protected Species				

Figure 3.1 Example of a completed scallop daily logsheet . Left – hitorical version, Right – current version including requirement to report interactions with protected and threatened species.

3.1.1 Methods

The logbook data is used to determine annual catch and effort (Table 3.1), catch each fishing ground and the total swept area for the fleet is calculated as:

Total duration (hours) x Speed (knots) x Head-rope length (feet) x Net 'inefficiency' factor/ No. feet in a nautical mile
where

- Net 'efficiency' factor - 0.6 (i.e. standard otter trawl net only 60% efficient due to curve of net)
- One nautical mile = 6080 ft
- Head-rope length = 84 feet (two seven-fathom nets as in Shark Bay)

Both A Class and Class B boat catches have been recorded on a daily basis since 1983. Scallop boat catches are delineated into three main fishing grounds (Figure 3.2a and b) for comparison with historical information. Since 1998 logbooks information allows more detailed analysis for each trawl with latitude and longitude co-ordinates entered into the database for each trawl shot, allowing catch to be separated by fish ground (H1, H2 and H3). Processor landings are used to weight up the logbook catch for each unload (see section 3.2) and provide a validation check on the logbooks. The logbook information may be aggregated by night or for the whole fleet. As scallop boats can fish 24 hours in some parts of the fishery, each day is represented as 0800 hrs to 0800 hrs the following day.

The shot by shot information provides improved spatial information on fishing patterns, catch and catch rate densities using GIS for catch per hour trawled in 1nm grids (example Figure 3.3). Daily catch rate can be determined for the fleet and provides information for depletion analyses (see Chapter 4).

Prawn boat scallop catches have generally been reported as daily aggregates and these have been entered as Denham Sound or northern Shark Bay historically but in recent years some shot by shot information has been provided by skippers to allow better spatial analysis of prawn boat scallop catches.

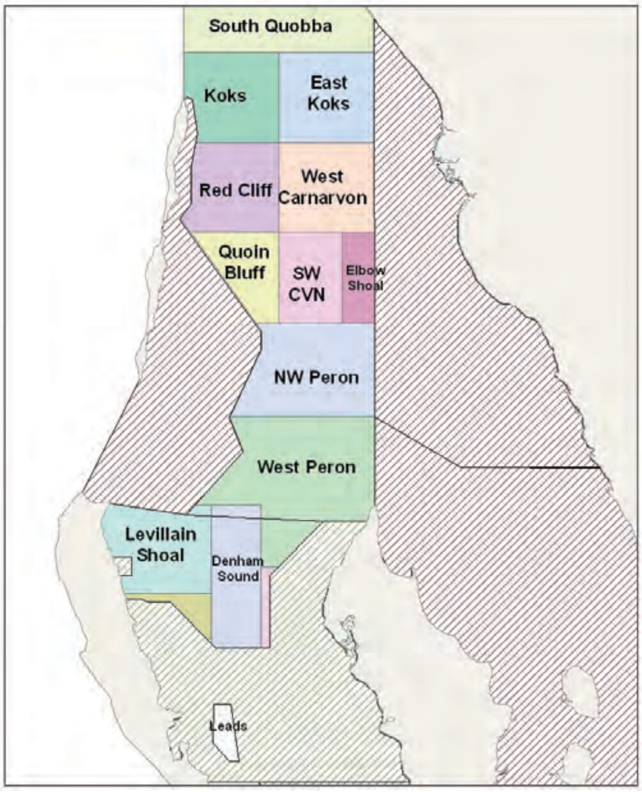


Figure 3.2 a) Fishing grounds in logbooks for the A Class scallop boats.

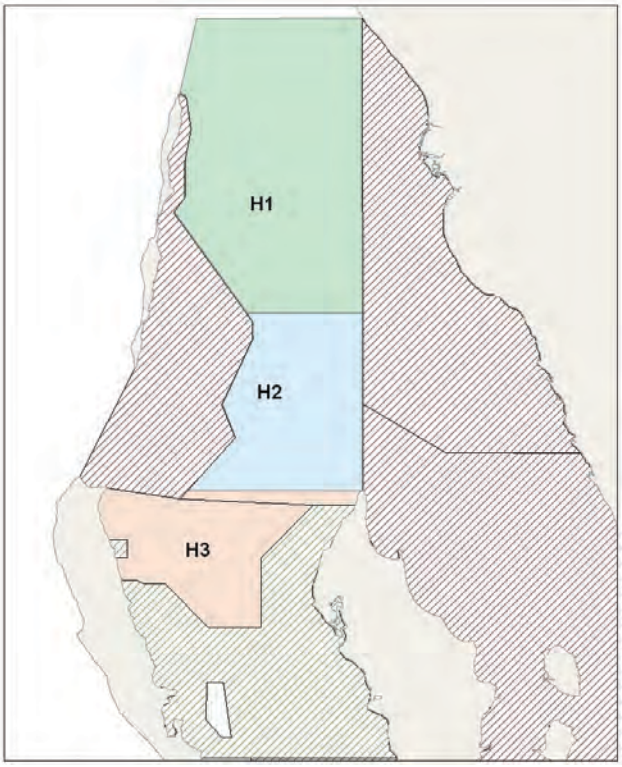


Figure 3.2 b) Three main fishing grounds (H1, H2 and H3) for A Class boats. NB. For H3, the Denham Sound boundary line was amended in 2008 to the lower line to join the permanently closed areas.

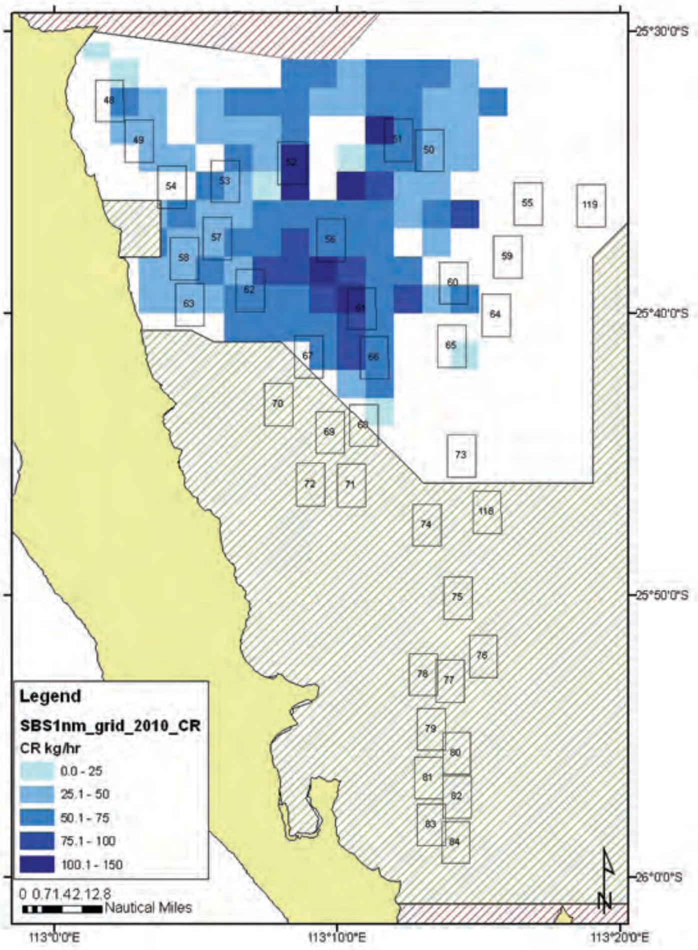


Figure 3.3 Catch rate (kg/hr trawled) of scallops in Denham Sound during 2010 from logbook data. Numbered squares represent annual survey locations.

3.1.2 Results

Annual scallop landings are highly variable (Table 3.1, Figures 3.4) and the proportion of catch from each main area is also variable annually (Figure 3.5). Since 2002, Denham Sound has consistently provided a significant catch of scallops whereas in the previous eight years little catch was taken from this area (Table 3.2).

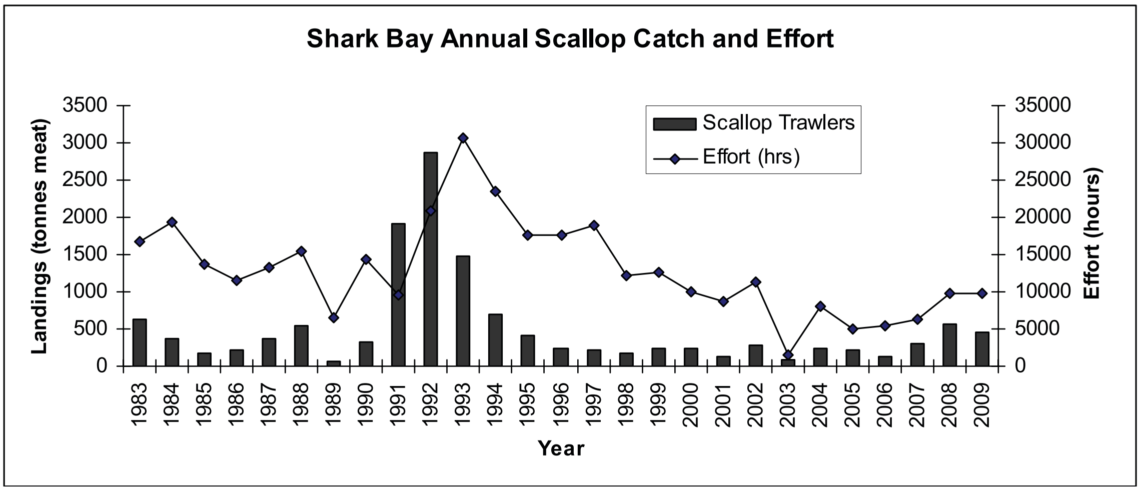


Figure 3.4 Annual scallop landings and hours of trawling by A Class (1983 to 2009)

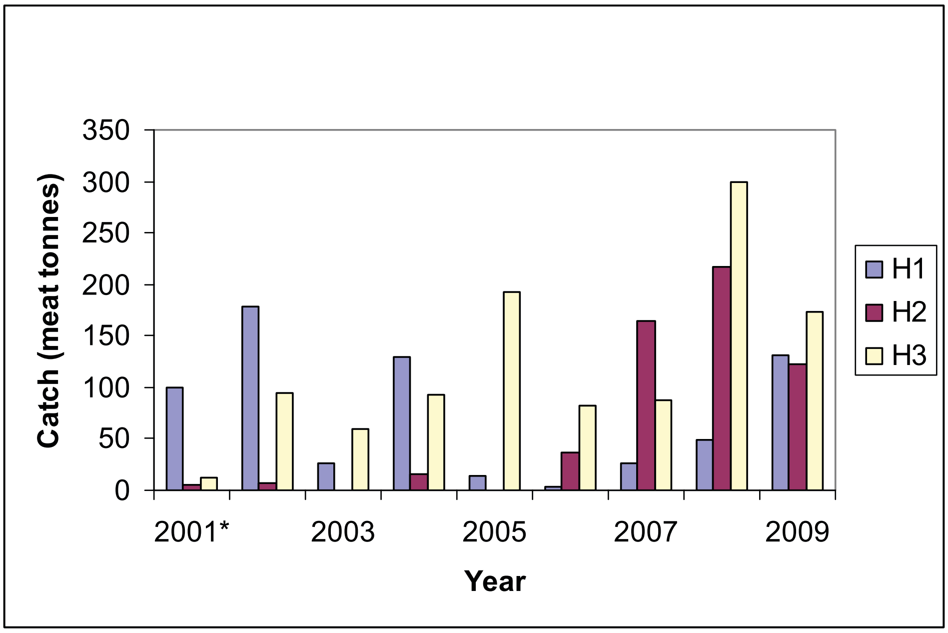


Figure 3.5 Scallop catch divided into the three main fishing grounds (Figure 3.2b – scallop fleet only)
*2001- 22.3t not allocated to an area due to poor location information in logbooks.

Table 3.1 Shark Bay Annual Scallop Landings 1966 – 2009 (A and B class boats)

Shark Bay Scallop Historical Catches

Prawn and Scallo boats					Scallo boats ONLY			
YEAR	Total Landings	Landings by Scallop Trawlers	Prawn Trawlers	% by Prawn T.	Maximum No of vessels	Total Effort (hrs)	Swept Area (nm2)	Catch Rate (kg meat/hr)
1966	1.2	N/A			N/A	N/A	N/A	N/A
1967	N/A	N/A			0	N/A	N/A	N/A
1968	37.8	N/A			N/A	N/A	N/A	N/A
1969	272.8	N/A			7	N/A	N/A	N/A
1970	83.2	N/A			14	N/A	N/A	N/A
1971	N/A	N/A			0	N/A	N/A	N/A
1972	22.3	N/A			0	N/A	N/A	N/A
1973	57.4	N/A			3	N/A	N/A	N/A
1974	31.7	N/A			0	N/A	N/A	N/A
1975	27.4	N/A			0	N/A	N/A	N/A
1976	107.5	N/A			2	N/A	N/A	N/A
1977	158.5	N/A			5	N/A	N/A	N/A
1978	109.3	N/A			4	N/A	N/A	N/A
1979	57.0	N/A			3	N/A	N/A	N/A
1980	101.0	58.6			4	N/A	N/A	N/A
1981	140.7	74.6			5	N/A	N/A	N/A
1982	434.7	295.4	139.3	32.0	13	8930	252	33.1
1983	705.3	640.4	64.9	9.2	26	16790	473	38.1
1984	431.2	379.0	52.2	12.1	14	19430	548	19.5
1985	232.8	175.0	57.8	24.8	14	13730	387	12.7
1986	259.5	211.1	48.4	18.7	14	11500	324	18.4
1987	490.9	377.3	113.6	23.1	14	13210	372	28.6
1988	731.2	544.9	186.3	25.5	14	15500	437	35.2
1989	121.0	71.2	49.8	41.2	14	6430	181	11.1
1990	486.7	318.2	168.5	34.6	14	14290	403	22.3
1991	2532.0	1916.2	615.8	24.3	14	9570	270	200.2
1992	4414.0	2876.2	1537.8	34.8	14	20860	588	137.9
1993	1934.6	1469.6	465.0	24.0	14	30740	866	47.8
1994	957.1	685.5	271.6	28.4	14	23580	665	29.1
1995	596.0	423.4	172.6	29.0	14	17680	498	23.9
1996	364.0	239.3	124.7	34.3	14	17649	497	13.6
1997	328.5	227.6	100.9	30.7	14	18872	532	12.1
1998	252.2	177.4	74.8	29.7	14	12224	345	14.5
1999	339.9	249.8	90.1	26.5	14	12567	354	19.9
2000	269.0	244.1	24.9	9.3	14	9893	279	24.7
2001	216.3	138.7	77.6	35.9	14	8645	244	16.0
2002	354.0	279.8	74.6	21.1	14	11284	318	24.8
2003	155.2	85.5	69.7	44.9	14	1598	45	53.5
2004	332.9	237.1	95.9	28.8	14	8093	228	29.3
2005	384.6	217.5	167.1	43.4	14	4903	138	44.4
2006	208.8	122.4	86.4	41.4	14	5360	151	22.8
2007	454.6	312.4	142.2	31.3	14	6204	175	50.4
2008	734.8	567.3	167.5	22.8	14	9802	276	57.9
2009	678.2	462.9	215.3	31.7	14	9871	262	46.9
Avg	654.7	469.3	194.8	28.3		12828.8	361.0	38.9
Max	4414.0	2876.2	1537.8	44.9		30740.0	866.4	200.2
Min	101.0	58.6	24.9	9.2		1598.0	45.0	11.1
	*Note: From 1980		* Note: From 1982					

Table 3.2 Shark Bay Annual Scallop Landings 1984 – 2009 divided into northern Shark Bay and Denham Sound.

Year	Northern Shark Bay	Denham Sound
1984	346	86
1985	233	0
1986	260	0
1987	491	0
1988	731	0
1989	121	0
1990	472	14
1991	2231	301
1992	4177	237
1993	1216	719
1994	923	34
1995	592	4
1996	354	10
1997	329	0
1998	252	0
1999	336	0
2000	269	0
2001	205	12
2002	264	94
2003	54	101
2004	182	150
2005	87	287
2006	94	120
2007	312	142
2008	417	318
2009	477	180

Detailed analysis of catch rates of scallops within regions also show variation in abundance patterns from year to year (Figures 3.6 a and b).

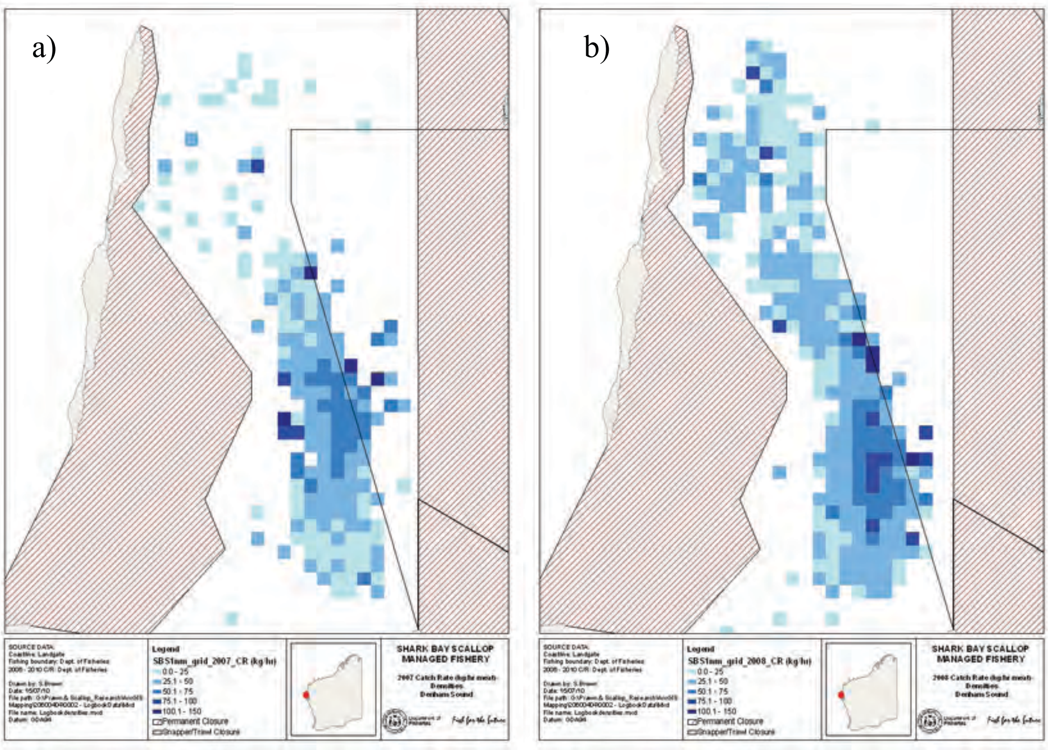


Figure 3.6 Scallop fleet CPUE (kg/hr) per nm block within northern Shark Bay for 2007 and 2008.

3.2 Processor Returns

Catch unload information has been provided by processors since the early 1960's and is used to validate the logbook data. Processor catch landings are used to adjust the daily logbook catch and effort. Both boat unload for target and byproduct species is collected generally on a monthly basis. Beach prices for target species have been collected from processors annually but in recent years, from around 2005, prices were obtained bi annually January and July. Some byproduct prices have been collected but in future, it is intended to collect prices for all retained byproduct species. This information provides the most accurate measure of the total catch and value and has been used to determine the GVP of the fishery.

3.3 Fishery Independent Surveys

Annual scallop surveys have been undertaken in Shark Bay since 1983 and are used to estimate scallop recruit (0+) and residual (1+) abundance. The original focus was to sample both prawn and scallop stocks (Figure 3.7). Over the years there have been some changes to the number of survey shots and the detailed locations, but the survey still occurs over the key scallop grounds.

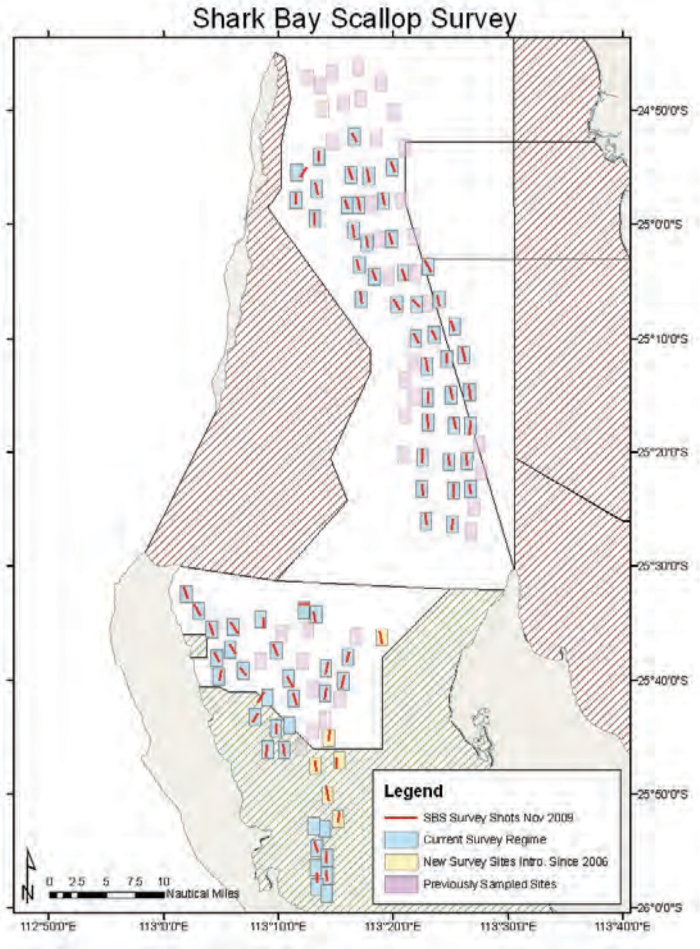


Figure 3.7 Annual scallop survey sampling regime. Displaying previous survey sites (1983 to 2005) and 2006-2009 survey shots. (RV Flinders/Naturaliste 1982 to 2007, FV Palmerston 2008 and 2009)

3.3.1 Methods

The survey is conducted over nine to ten nights, during October/November. Sampling was conducted on the RV Flinders until 2000, then RV Naturaliste from 2001 to 2007 inclusive and a commercial scallop boat was used in 2008 and 2009. Twin six-fathom headrope length flat nets with 50 mm mesh in the panels and 45 mm in the cod-end were used on all surveys. Fishing was undertaken at night, commencing at approximately 19:15 hrs. The duration of each trawl is 20 minutes (trawl period begins when the trawl gear started to fish (winches cease paying out until the commencement of retrieving the trawl gear). Processing each shot involved recording numbers of both recruit and residual scallops (if the basket count was in excess of 2 baskets, only one basket was counted and recruit, residual and total number of scallops obtained by multiplying the number of scallops in one basket for the total basket number. Recruits were generally determined as those with a dorso-ventral length less than 86 mm, however this separating length using the length frequency can vary from each area or year. To obtain dorso-ventral length frequency measurements, samples of 150 to 200 scallops were taken and measured from one net except when there are low numbers and both sides are combined.

Whilst it is recognised that the sites used during the November survey do not necessarily cover all the scallop grounds in Shark Bay, they do, however, cover the main trawl grounds and the objective is to replicate previous surveys in order to allow a comparison with data from previous years.

Data is entered into an Access database and includes abundance of recruits and residual scallops and length frequency data for scallops from each sampling site (81 sites), duration, distance trawled and environmental (depth, water temperature, sea conditions) information for each site.

As the speed at which trawling takes place influences the efficiency of the trawl gear (Figure 3.8) the catch (by category and total) was standardised according to:,

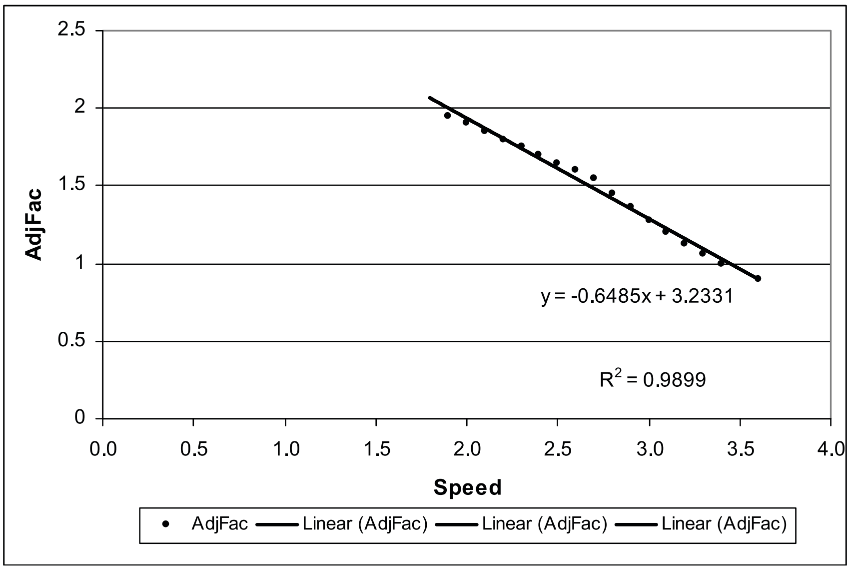


Figure 3.8 Adjustment factor in relation to trawl efficiency with speed compared to a standard 3.4 knot.

$$c_{st} = \frac{c}{3.2331 - 0.6485v}$$

where v denotes the trawl speed in knots and c and c_{st} the catch and the standardised catch respectively. This adjusts the catch to the equivalent catch at a speed of 3.4 knots. The standardised number of residuals, recruits and total number of scallops were further converted to densities taking into account the distance trawled and the number of nets and their spread,

$$d = \frac{c_{st}}{2Tw}$$

Here T and w denote the shot distance and the width per net in nautical miles, assuming a width of six fathoms (10.97 m) head rope for each net.

3.3.2 Results

The recruitment strength in the fishery is annually highly variable (Tables 3.3 and 3.4) and also spatially variable (Figures 3.9) and this variability is reflected in annual catches and residual abundance (Figure 3.10).

Table 3.3 Annual Recruitment and Residual survey indices (mean number per nm) for Shark Bay (Redcliff and NW Peron) 1983- 2010. Index in red is based on additional sites in areas not sampled prior to 2002. Index = Red Cliff recruits and residuals plus NW Peron recruits and residuals, divided by two. Indices from 2005 have been adjusted for 15% efficiency gain from changing the type of nets used during surveys.

	SURVEY CATCH								CATCH FORECAST			
Survey Year	Red Cliff				NW Peron		OVERALL INDEX		Fishing Year	Catch Prediction	Range	Annual Catch
	Recruits		Residuals		Recruits	Residuals						
1983	47		237		32	301	309		1984	544		346
1984	54		73		81	7	108		1985	302		233
1985	134		91		247	2	237		1986	458		260
1986	277		47		75	0.3	200		1987	413		491
1987	598		133		609	35	688		1988	1000		731
1988	18		132		58	49	129		1989	327		121
1989	97		45		192	2	168		1990	375		472
1990	608		77		3756	73	2257		1991	2888		2231
1991	169		2411		50	4253	3442		1992	4313		4177
1992	162		770		157	467	778		1993	1109		1216
1993	209		189		171	196	383		1994	633		923
1994	144		111		339	104	349		1995	592		596
1995	90		113		115	132	225		1996	443		354
1996	108		31		273	23	218		1997	434		329
1997	92		18		70	10	95		1998	287		252
1998	41		23		160	75	150		1999	352		336
1999	347		27		71	9	227		2000	446		269
2000	104		76		112	4	148		2001	268		205
2001	119		48		130	18	158		2002	276		264
2002	138		17		17	15	94		2003	178		54
2003	231	230	23	80	159	43	228	256	2004	348		182
2004	23	30	87	104	56	79	123	135	2005	192		87
2005	41	41	83	82	80	81	142	142	2006	207		94
2006	333	289	47	52	949	45	687	667	2007	905		312
2007	294	215	87	65	578	112	536	485	2008	326	261-391	417
2008	249	203	166	165	303	154	436	412	2009	303	242-363	477
2009	71	113	116	143	121	77	193	227	2010	164	131-196	132
2010	252	211	53	47	353	32	345	321	2011	268	214-322	

Red Includes index based on extra shots in areas not sampled in previous surveys
Index = Red Cliff recruits and residuals plus NW Peron recruits and residuals, divided by two.
2005 to 2010 inclusive Index adjusted by 15%.

Table 3.4 Annual Recruitment and Residual survey indices (mean number per nm) for Denham Sound 1983–2010. Indices in red indicate additional sites sampled since 2003 and indices adjusted for net efficiency by 15% from 2005.

SURVEY CATCH							CATCH FORECAST			
Survey Year	Denham Sound				OVERALL INDEX		Yea	Catch redictio	Range	Annual Catch
	Recruits		Residuals							
1983	65		158		111.5		1984			86
1984	33		0.1		16.55		1985			0
1985	30		0.5		15.25		1986			0
1986	51		0.7		25.85		1987			0
1987	32		7		19.5		1988			0
1988	12		2		7		1989			0
1989	32		1		16.5		1990			14
1990	631		21		326		1991			301
1991	100		683		391.5		1992			237
1992	761		439		600		1993			719
1993	34		91		62.5		1994			34
1994	11		11		11		1995			4
1995	34		1		17.5		1996			10
1996	7		8		7.5		1997	0		0
1997	15		1		8		1998	0		0
1998	6		1		3.5		1999	0		0
1999	14		1		7.5		2000	0		0
2000	55		5		30		2001	20		12
2001	84		5		44		2002	35		94
2002	85		57		71		2003	45		101
2003	168	290	146	138	157	214	2004	110		150
2004	106	185	175	178	141	182	2005	126		287
2005	59	75	172	150	115	113	2006	140		120
2006	350	338	34	38	192	188	2007	197		142
2007	573	581	312	246	442	414	2008	477	382-572	318
2008	137	150	118	128	128	139	2009	180	144-216	180
2009	160	149	23	16	91	82	2010	116	93-139	186
2010	50	133	7	5	29	69	2011	31	25-37	

Red Includes index based on extra shots in areas not sampled in previous surveys
Index = recruits plus residuals, divided by two.
2005 to 2010 inclusive Index adjusted by 15%.

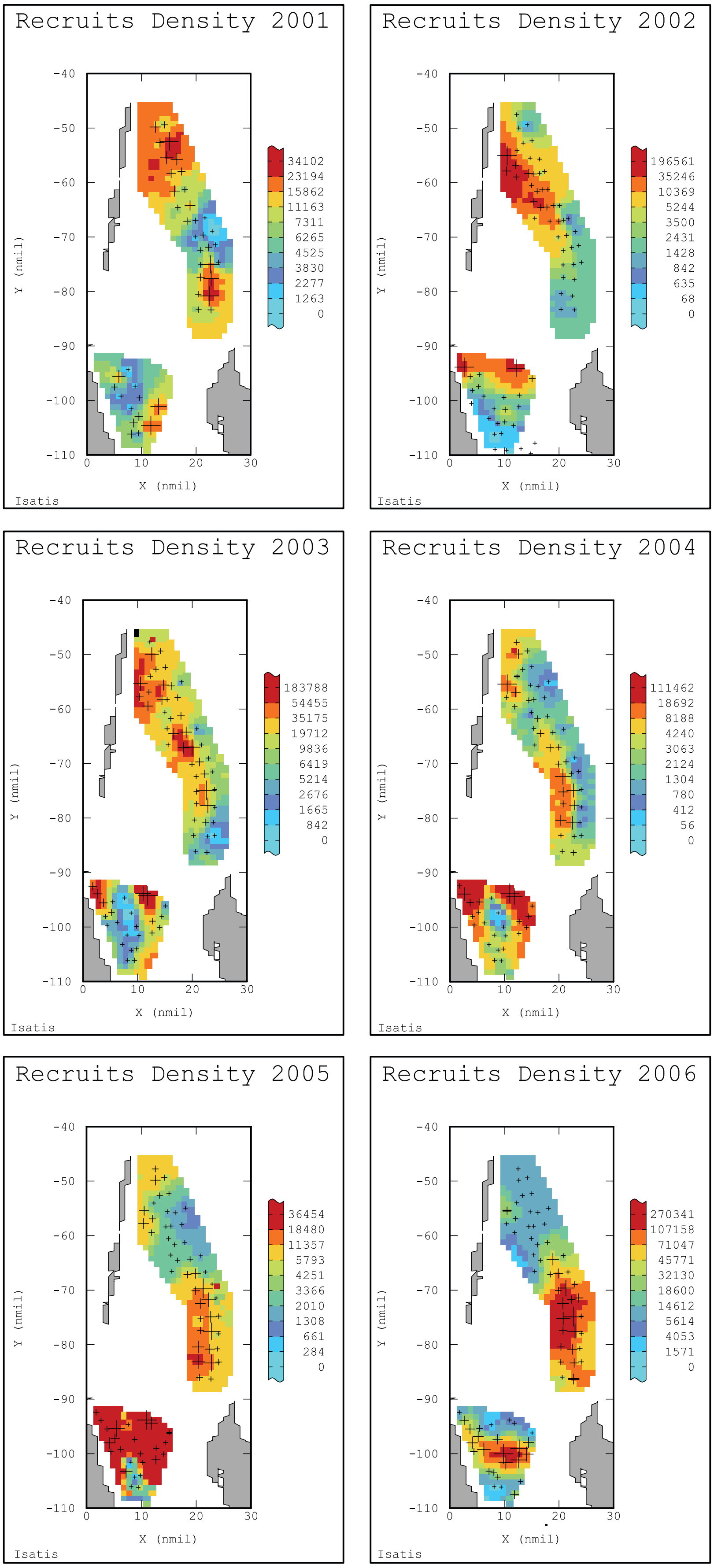


Figure 3.9 Spatial recruit density variation between 2001 and 2006 (Mueller et al. 2008). The crosses indicate the survey sites.

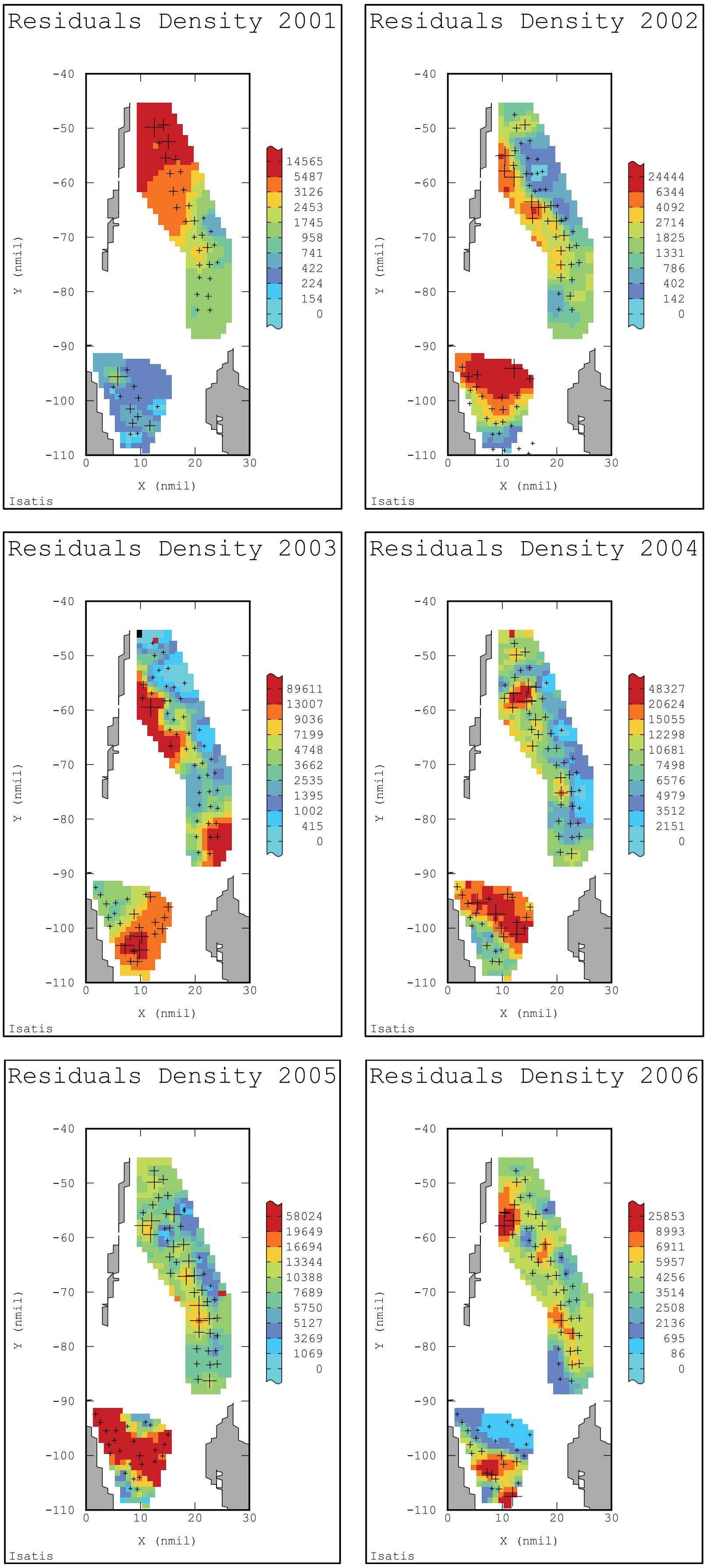


Figure 3.10 Spatial residual density variation between 2001 and 2006 (Mueller et al. 2008). The crosses indicate the survey sites.

3.4 Environmental Data

Environmental conditions such as Leeuwin Current strength and water temperature influence recruitment strength for *Amusium balloti* and information on these environmental parameters is sourced from the Australian Government's Bureau of Meteorology (BOM) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) as well as the Department of Fisheries monitoring within Shark Bay. The current FRDC project is investigating additional environmental factors such as currents and tides within Shark Bay in relation to the larval advection and recruitment settlement.

3.4.1 Methods

Water Temperature

Data Loggers

A temperature data logger was in place on Uraine Bank [25° 16.84 'S 113° 13.09 'E] between December 1992 and February 2006 when the logger was lost and not replaced. During this period, several large gaps in the data occurred (August 1995 to March 1996, November and December 1996, April to August 1998, July – September 2000, November 2000 to June 2001 and December 2001 to November 2003) due to loss of data loggers, malfunction and inability to retrieve the loggers at reasonable time intervals.

A temperature data logger was placed in Broadhurst Bight [25° 32.80 'S 113° 25.17 'E] in April 2005 and data retrieval from this Onset logger is continuing.

Reynolds Satellite Sea Surface Temperature (SST)

Monthly Reynolds SST have been obtained since January 1982. Temperature is recorded for 1-degree blocks and the blocks used for Shark Bay are centered on 24.5° and 25.5° S and 113.5 ° E.

Sea Level

Sea level data for the west coast is obtained from BOM recordings at Hillarys (http://www.bom.goe.au/oceanography/projects/abslmp/abslmp.shtml), and from the National Tidal Centre for Fremantle sea level. This provides hourly sea level data as well as data on water temperature, air temperature, barometric pressure, wind direction, wind gust, and wind speed. Archived data is available from 1992 with current data updated six monthly.

Southern Oscillation Index (SOI)

The SOI is calculated from the monthly air pressure difference between Tahiti and Darwin and is an indicator of El Nino events (BOM website, http://www.bom.gov.au/climate/current/soi2.shtml).

Winds Strength and Direction

Daily wind strength and direction is available from the BOM website, on a three hourly basis. Data is available from 1945 to present.

3.4.2 Results

The temperature range recorded at Uraine Bank (Figures 3.11 and 3.12) has been between 17° and 27° C and at Broadhurst Bight (Figure 3.13) between 18° and 26° C. As the Broadhurst Bight site is shallower than Uraine Bank a lag in temperature response is seen for temperature rises and decreases. The Reynolds sea surface temperatures values are generally slightly higher than what is observed for data obtained from loggers positioned close to the sea bed (Figure 3.14).

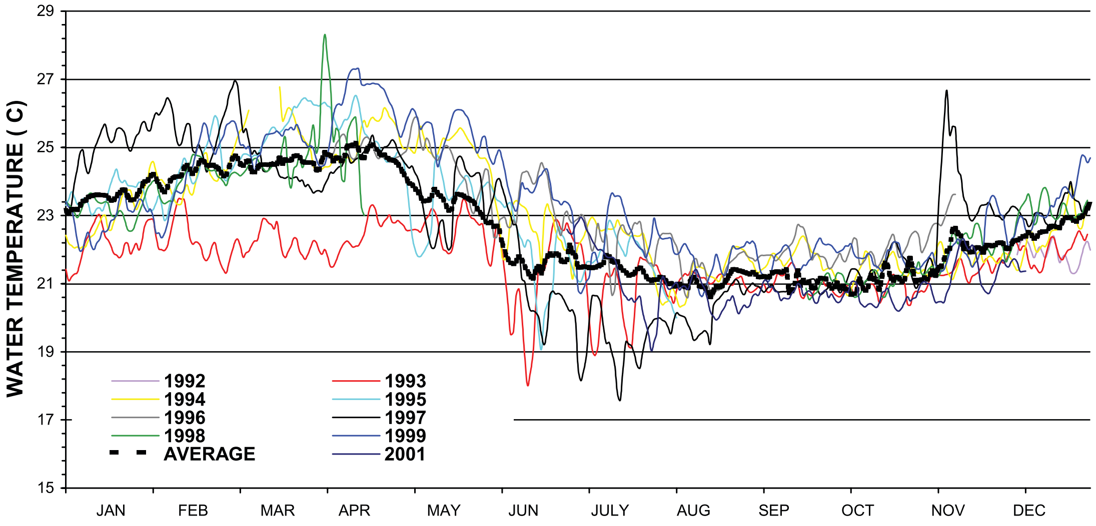


Figure 3.11 Daily bottom water temperature at Uraine Bank, 1992 to 2001 (2000 missing)

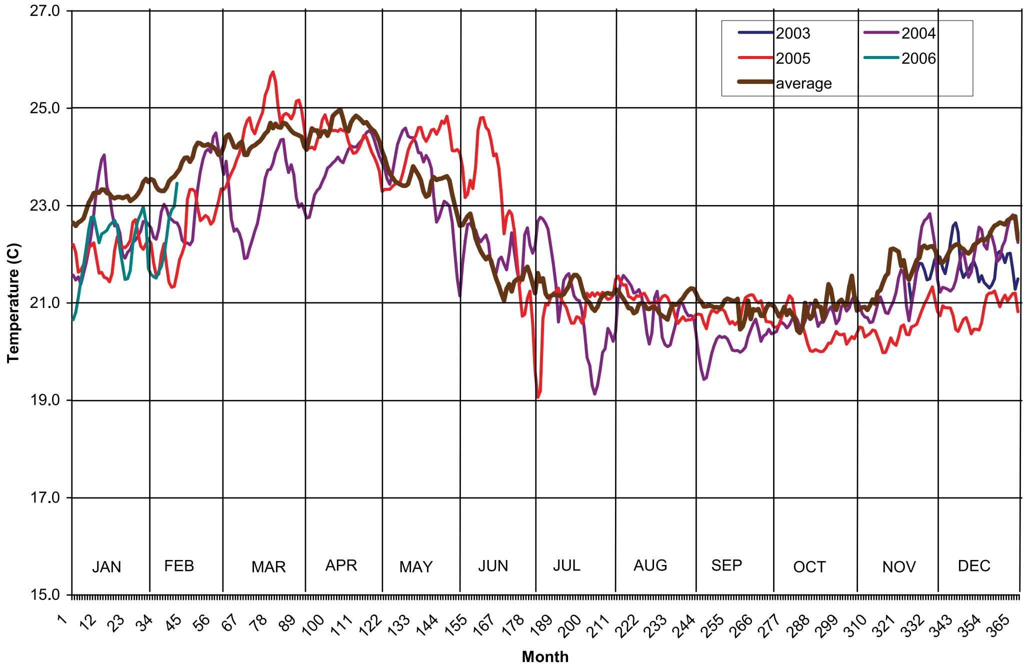


Figure 3.12 Daily bottom water temperature at Uraine Bank 2003 to February 2006 (after which time the logger was lost and not replaced at this site).

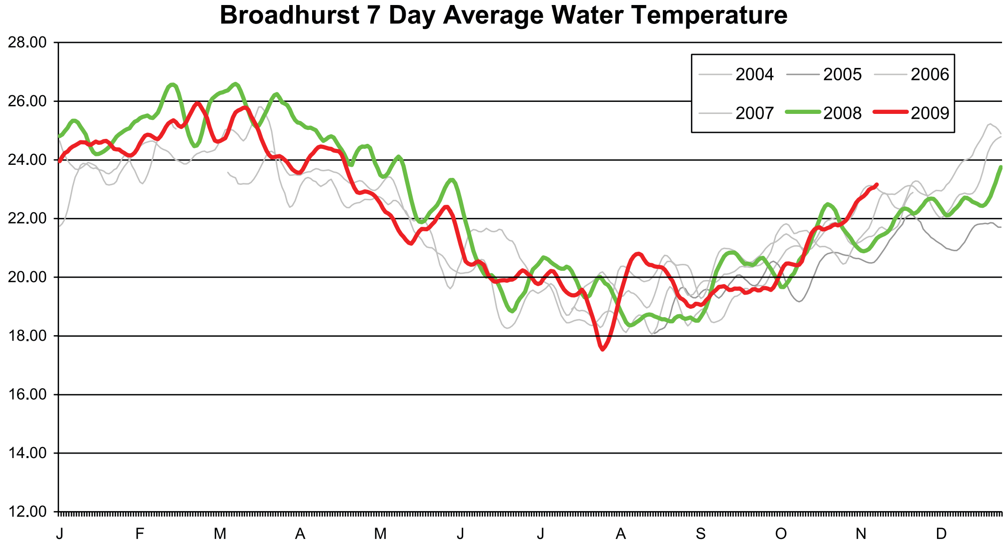


Figure 3.13 Bottom water temperature (°C) at Broadhurst Bight, 2004 to 2009

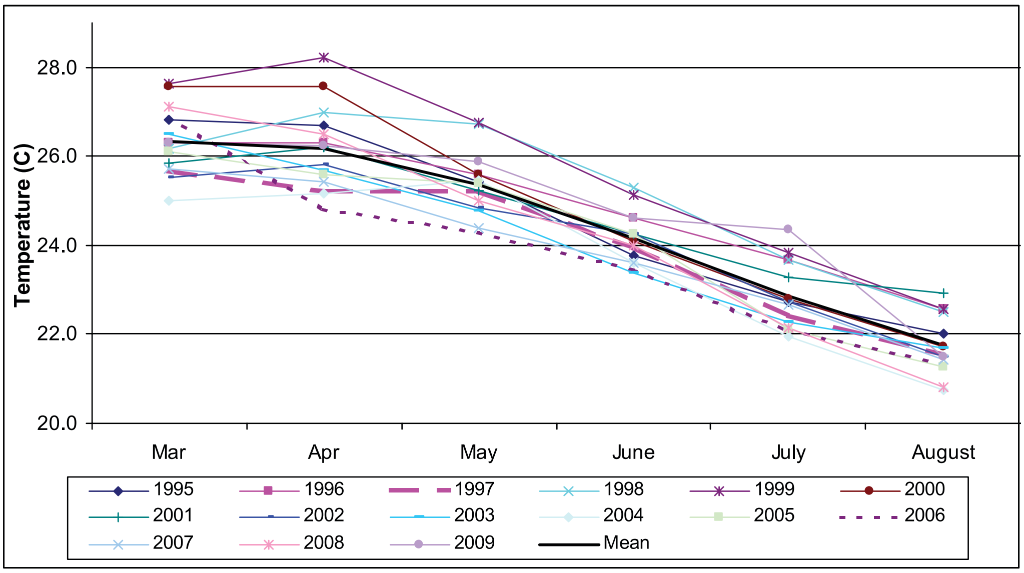


Figure 3.14 Reynolds sea surface temperature between 1995 and 2009 for March to August in Shark Bay.

The Fremantle sea level is used as a proxy for the strength of the Leeuwin Current (LC) and the LC strength has been inversely correlated to the strength of recruitment in Shark Bay (r =-0.85, p<0.05, RMS 0.145, Joll and Caputi 1995b). The strength of this current is strongly influenced by El Nino/Southern Oscillation (ENSO) events. The SOI is another environmental feature that may be used to correlate with recruitment strength in Shark Bay (Figure 3.15)

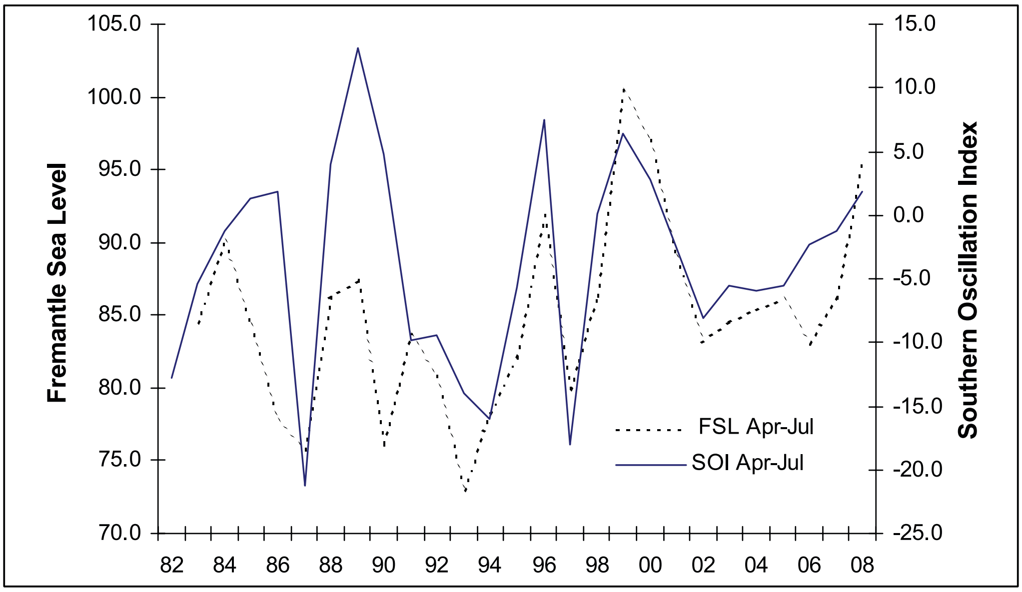


Figure 3.15 Mean Southern Oscillation Index and Fremantle sea level between April and July 1982 to 2008.

3.5 Day-Night Catch Comparisons

Limited data sets are available, comparing day and night catch rates for scallops from the annual scallop surveys in November 2005, 2006 and 2008 (Table 3.5). In addition, day, night commercial catches using daily logbook data (shot by shot basis) were compared for March 2006 and April 2007.

Table 3.5 Data collected for day-night scallop catch comparisons in Shark Bay

Date	# Trawls	Locations	Comment
November 2005	9	Leads, Denham Sound	Comparisons 10 days apart
November 2006	6	North West Peron	
November 2008	9	North West Peron	
18–29 Mar 2006	Whole fleet	Northern Shark Bay	24-hour fishing
20 Mar-10Apr 2007	Whole fleet	Northern Shark Bay	24- hour fishing
April 2010		Abrolhos Islands	

3.5.1 Methods

For 2006 and 2008, the same trawl sites were sampled during the day and night within the same 24-hour period. In 2005 the sites sampled at night on 20 November were repeated on 30 November during the daytime. The abundance of residual and recruit scallops was recorded for both time periods. In 2006 sampling was undertaken: Day 0600-1000hrs Night 2300-0400hrs, and in 2008 Day 1100-1500 Night 0000-0400hrs.

3.5.2 Results

A significant reduction in catch rates was observed during daytime trawls compared to nigh-time trawls (39-57%) during the survey and differences in catchability were observed between recruit and residual scallop catches. The daytime catchability of recruits was much lower (57-80%) than night-time compared to only a 15-46% reduction in daytime catch rates for residual scallops (Table 3.7). This was also observed during commercial square mesh codend trials in the Abrolhos Islands in April 2010 where recruit numbers (<80 mm SH) were down by 63% in daylight trawls whereas there was no difference in catches of residual scallops between day and night.

Commercial logbook daily catch rate analyses in 2007 indicated reduced catch rates between daytime and night time trawling in northern Shark Bay (only daytime fishing in Denham Sound) with a reduction around 20% but this was not significant and in 2006 no difference was observed due to overall lower catch rates. This may in part be due to less accurate recording of scallop catch per trawl shot and due to variability in differences in catch rates between daytime and nigh-time trawls and overall abundance (Figure 3.16).

Table 3.6 Mean recruit and residual catch rates for day and night trawls in Shark Bay during surveys in 2005, 2006 and 2008.

	Recruits		Residuals		% Difference	
YEAR	Night	Day	Night	Day	Recruits	Residuals
2005	8	2	752	312	75.0	58.5
	29	3	730	383	89.7	47.5
	0	2	1884	1238		34.3
	7	3	397	300	57.1	24.4
	0	0	3420	387		88.7
	2	0	314	1228		-291.1
	0	0	1647	761		53.8
	0	0	1450	1040		28.3
	5	0	160	112		30.0
total 05	**51**	**10**	**10754**	**5761**	**80.4**	**46.4**
2006	3331	1774	78	59	46.7	24.4
	707	166	57	44	76.5	22.8
	997	1415	28	35	-41.9	-25.0
	2169	300	102	46	86.2	54.9
	4191	1480	25	34	64.7	-36.0
	1613	373	125	50	76.9	60.0
total 06	**13008**	**5508**	**415**	**268**	**57.7**	**35.4**
2008	182	105	240	213	42.3	11.3
	1204	678	361	306	43.7	15.2
	626	548	431	380	12.5	11.8
	1266	563	374	294	55.5	21.4
	536	139	677	580	74.1	14.3
	1138	356	356	322	68.7	9.6
	524	137	387	344	73.9	11.1
	522	128	108	108	75.5	0.0
	422	105	306	211	75.1	31.0
total 08	**6420**	**2759**	**3240**	**2758**	**57.0**	**14.9**

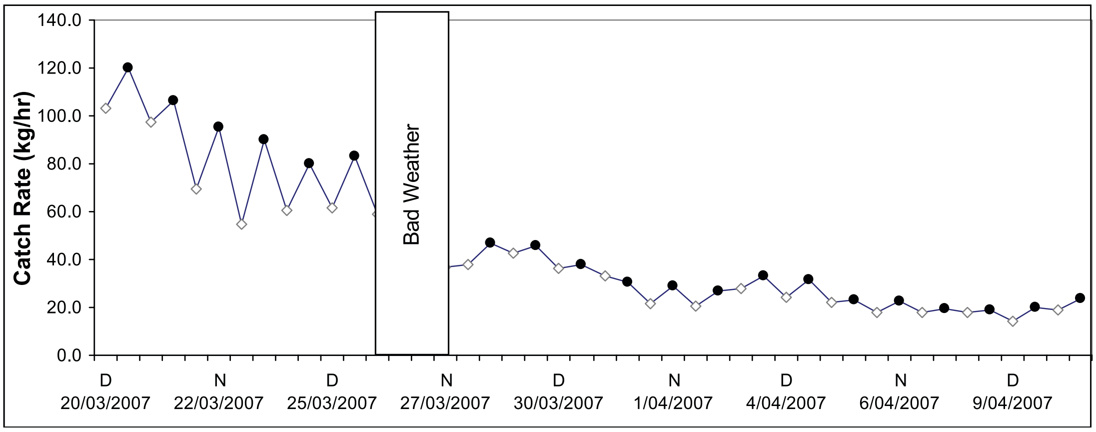


Figure 3.16 Daytime (open diamond) and night time (closed circles) catch rates for the Shark Bay scallop fleet betweem 20 March and 12 April 2007.

3.6 Bycatch Reduction

Initial grid trials were undertaken in 1998/99 using grids used in other Australian trawl fisheries. Further grid trials were undertaken between 2000 and 2002 as part of a FRDC project (FRDC 200/189, Kangas and Thomson 2004). These grids were modified to function appropriately in the Shark Bay trawl fishery.

When implementation occurred in 2003, fishers were given the opportunity to undertake further experimentation of grids under commercial fishing conditions (three grids were used within the fleet). Each fishery is using grids suitable for their fishing operations but all grids fit within generic specifications as part of Fishery License conditions. For the Shark Bay scallop fishery, the use of 100 mm mesh in scallop trawl nets precluded them from having to implement secondary bycatch reduction devices, Fish Escape Devices (FEDs), as there is very little fish bycatch retained in scallop trawl nets.

The key findings were; grids were shown to exclude nearly all (95-100%) large animals including sharks, rays and turtles. Sponges and rocks are also significantly reduced. Smaller individuals of shark and ray species are still retained as these pass through the bar spacings. No significant differences between grids were observed and overall scallop catches were up by 12% in nets with grids compared to control nets.

There was a 9% reduction in scallop catch for the Shark Bay prawn boats in nets with grids compared to the control net. Both prawns and scallops would be available for capture after escaping through the opening. Square mesh codends reduced finfish and prawn bycatch to very low levels.

Bycatch selectivity of square-mesh codends was trialled in February 2008 and November 2009. All three square-mesh codends (50, 55 and 60 mm) achieved greater than 80% reductions in the total catch of the different bycatch groups relative to the standard 100 mm diamond mesh codend but there were no differences in catch rates of bycatch among the square mesh codends (Kangas et al. in prep; Chandrapavan et al. in prep).

3.7 Meat size/quality sampling

The meat condition (size and quality) of scallops are closely linked to their reproductive cycle. Meat condition has been shown to be variable from season to season (Joll and Caputi 1995a, Figure 3.17) and between areas within a season. Opportunistic sampling has been undertaken during scallop surveys and collections from commercial fishers during several seasons to increase the knowledge of adductor meat quality and size throughout the year and within different areas of Shark Bay. In future pre-season surveys meat size and quality analysis will be undertaken and a more systematic commercial sampling needs to be implemented.

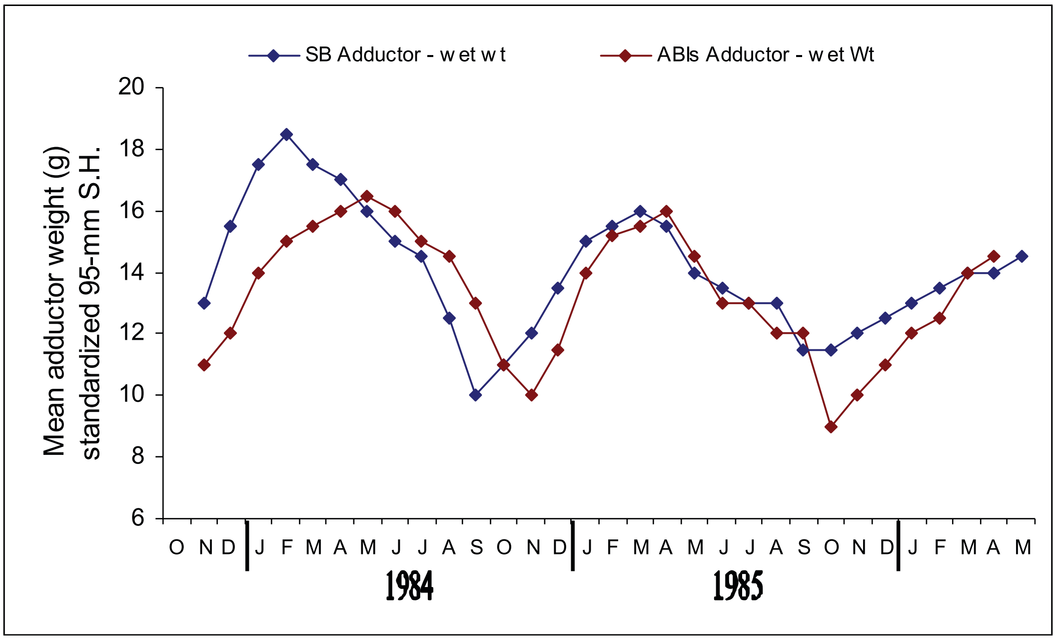
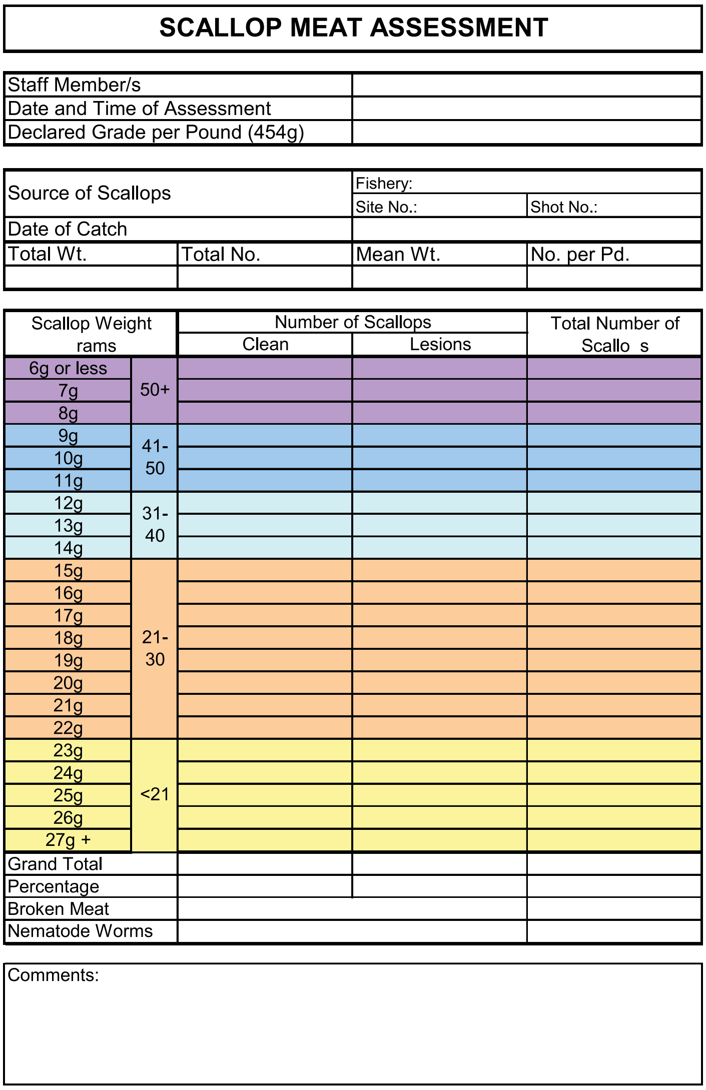


Figure 3.17 Seasonal changes in adductor muscle wet weight from Shark Bay and the Abrolhos Islands between 1983 and 1986 (Joll and Caputi 1995a.)

3.7.1 Methods/Results

Opportunistic meat samples have been obtained, from the scallops measured when length frequencies are completed during the surveys and a representative sample from commercial boats during fishing operations. These scallop meats are individually weighed and recorded and this provides meat weights in grades compared to the length frequency distribution at different times in the fishery (Figure 3.18). Grades are pieces per 454 gm (lb) graded as < 20, 21/30, 31/40, 41/50 and 50+. The grades of scallop meat are taken from scallops >83 mm SH. At present insufficient sampling has occurred to allow any analysis of seasonal/spatial differences within Shark Bay.

During the FRDC (2007/051) project, a sample of scallops and their meat weight was analysed during February 2008. Adductor meat size increases with increasing shell size and at the size of maturity (>90 mm SH) the relationship of adductor weight to shell height is more pronounced (Figure 3.19).



SCALLOP MEAT ASSESSMENT

Staff Member/s	
Date and Time of Assessment	
Declared Grade per Pound (454g)	

Source of Scallops		Fishery:	
		Site No.:	Shot No.:
Date of Catch			
Total Wt.	Total No.	Mean Wt.	No. per Pd.

Scallop Weight rams		Number of Scallops		Total Number of Scallo s
		Clean	Lesions	
6g or less	50+			
7g				
8g				
9g	41-50			
10g				
11g				
12g	31-40			
13g				
14g				
15g	21-30			
16g				
17g				
18g				
19g				
20g				
21g				
22g				
23g	<21			
24g				
25g				
26g				
27g +				
Grand Total				
Percentage				
Broken Meat				
Nematode Worms				

Comments:

Figure 3.18 Example of scallop meat assessment data sheet.

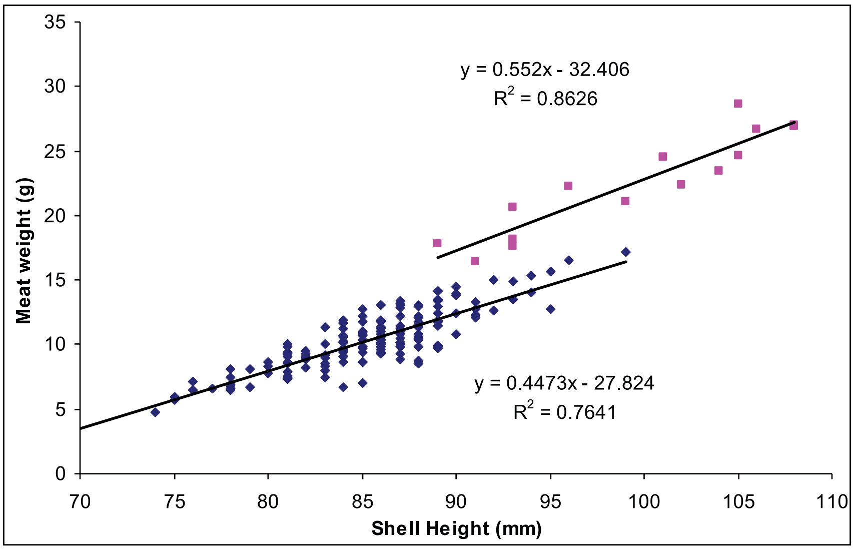


Figure 3.19 Relationship between *A.balloti* shell height (mm) and adductor meat weight in Denham Sound during February 2008 for mature (square) and immature scallops (diamond) .

3.8 Tagging

Tagging programs for scallops have been undertaken in the 1980s (Heald and Caputi 1981, Joll 1988) and some tagging of scallops was undertaken as part of a FRDC project (2007/051) focussing on minimising resource sharing conflicts during 2008. The short-term tagging project had a primary focus of estimating repeat recapture mortality, however tagged scallops were returned to the water after experimentation and tagged scallops were retained by commercial skippers during the 2009 season to enable an assessment of survival and growth.

Results of the short-term recapture mortality experiments are described in Chandrapavan et al., (in prep). The main feature was that there was high short-term repeat recapture survival of scallops during September with survival greater than 90% for both air and hopper treatments whereas survival in summer was more variable and much lower at around 20-30% for both treatments.

Growth estimates from scallops returned by commercial fishers was limited due to most tagged scallops (that have sufficient information provided by skippers) being over 85 mm and hence these showed very little growth. Only one scallop that was released at 67 mm SH was returned a month later with a growth of 8 mm between February and March. Scallops between 75 and 88 mm SH showed a monthly growth rate around 3 mm whilst individuals between 90 and 105 mm showed growth rates between 1 and 2 mm per month and scallops greater than 105 mm grew 0.5 to 1 mm per month. These scallops had generally been at liberty for approximately seven months and no seasonal differences in growth rates could be determined. The growth rates are in line with other estimates of scallop growth (Heald and Caputi 1981, Williams and Dredge 1981, Joll 1988).

4. Stock assessment and data analyses

4.1 Catch predictions

Annual scallop surveys, conducted between October and December, have been undertaken in Shark Bay since 1983, and provide size and abundance information from over 90 trawl sites within the bay (Figure 3.8). These data are used to determine an index of recruitment strength during that year (individuals derived from the current years spawning). They also provide an index of the size of the residual stock (older scallops remaining from the year before and possibly 2 years before, noting the life span is 2-3 years) and together provide the basis for predicting the catch the following year (Joll and Caputi 1995a), (Tables 3.3 and 3.4). The annual survey also provides scallop abundance and distribution that enables the season fishing arrangements of the fishery to be determined that take into account fishing scallops at an optimum size.

A FRDC collaborative project with the Department and Edith Cowan University was completed in mid 2008 (Mueller et al. 2008). One component of this study was to assess the correlation of commercial scallop catches and high abundance areas delineated in surveys. The study indicated that the annual survey was a good indicator of ‘high’ and ‘low’ scallop abundance areas within the fishery. As part of this project, an honours study (Dickson 2007) made a preliminary analysis between the effort applied by the B class fleet prior to scallop fishing commencing and the scallop landings from the A class fleet in the 2000 and 2005 fishing seasons. No clear statistical significance was observed for the level of fishing activity of the B class fleet over the entire season, during the spawning period or prior to the start of the scallop fishing on the scallop catch achieved by the A class fleet.

A strong correlation between the survey index and catch was observed up to the mid 1995. Since 2007, the catch prediction has been determined using only years since 1995 (Figure 4.1b) to reflect the changes in fishing practices. The abundance indices have been adjusted to take into account an estimated 15% increase in trawl efficiency of the RV Naturaliste (compared to RV Flinders) due to the improved performance of the boats and replacement of the type of nets used. In 2008 and 2009, a commercial boat undertook the surveys and at this stage no correction has been made for any efficiency increase in this boat, however the 15% increase in efficiency incorporated for the RV Naturaliste was used as the nets used by the commercial boat are the same as that used by RV Naturaliste.

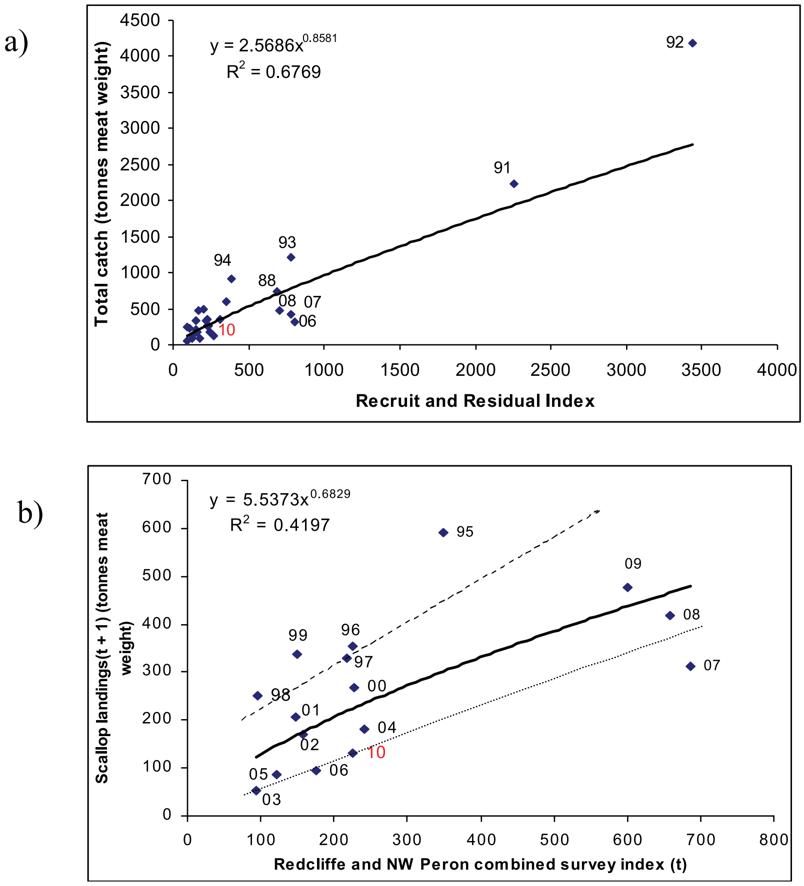


Figure 4.1 Relationship between recruit and residual index from the annual scallop survey against scallop landings a) 1983 to 2010 b) 1995 to 2010.

The catch prediction has been overestimating the catch taken for years between 2003 and 2008 (Figure 4.1b – lower dashed line) and therefore a review of the methodology is being undertaken to improve the catch prediction by taking into account the fishing effort and changes in fishing practices.

4.2 Depletion analysis – Biomass and catchability

The sedentary nature of scallop stocks and the relatively short duration of fishing by the scallop fleet on any fish ground makes them an ideal fish stock to use depletion analysis in stock assessment. Detailed daily logbook information has provided the ability to undertake depletion estimation of stock abundance for the Denham Sound and northern Shark Bay fish grounds. The depletion analyses have been undertaken since 2005 but could be extended to some years prior to this where the daily logbook information is sufficiently good for analysis.

For *A. balloti*, changes in catchability may arise from either changes in response or start up time, a change in threshold stimulus required to initiate swimming or any combination of these factors (Joll 1989). Variations in catchability are primarily related to size and to a lesser extent season (Joll 1989). Joll (1994) postulated that the catchability of recruit sized scallops (50-60 mm SH) would be about 30-40% of that of residual sized scallops due to their lower swimming capacity and the higher latency of their response to a stimulus to swim.

A Leslie-DeLury depletion experiment (Leslie and Davis 1939, DeLury 1947) was completed by Joll and Penn (1990) in northern Shark Bay and they estimated the efficiency of a prawn trawl (50 D mesh net) to catch scallops to be 64 and 60% during two trials in March 1986. Depletion experiments conducted as part of a biodiversity sampling program in Denham Sound during February and June 2003 showed prawn trawl efficiency for scallops of 40-42% (Kangas et al. 2007, Kangas and Morrison in prep.).

4.2.1 Methods

The DeLury depletion model has:

$C_t/F_t = q\ B_t$ where B_t is the biomass present at time t. We use C_t = mean fleet catch (kg) per day; F_t = mean daily/nightly fleet fishing effort (hours), q is catchability.

The depletion is based on the assumption that the CPUE changes reflect changes in abundance, there is no movement in (through immigration or recruitment) or out of the area and that there is no major environmental effects on catchability (even though we do observe reduced catch rates during strong swell conditions). There is also an assumption that the area fished by the fleet is relatively consistent.

The basic DeLury method for estimating catchability and populations size is based on a relationship between the decline in CPUE and the cumulative catch that is removed fro the fishery (Ricker 1975). The slope of this (linear) relationship provides an estimate of the catchability of the unit of fishing. The extrapolation of the relationship down to the point where the CPUE is zero (Ricker 1975) provides an estimate of the population size. Assessment indices generated by this analysis include annual trends in harvest rate, total population estimate and residual biomass after the completion of fishing, and catchability of the fishing effort that reflects the efficiency of effort applied by the fleet.

A Class boats daily logbook data provides daily catch rate and cumulative catch information and B Class boat daily catches are included which can be used to determine trawl efficiency using a depletion analysis.

4.2.2 Results

Due to the short-term nature of scallop fishing within Shark Bay and in recent years the scallop fleet fishing as a fleet on a fishing ground (eg. Northern Shark Bay, Figure 4.2a and Denham Sound, Figure 4.2b) depletion estimates can be determined for the two fishing grounds separately.

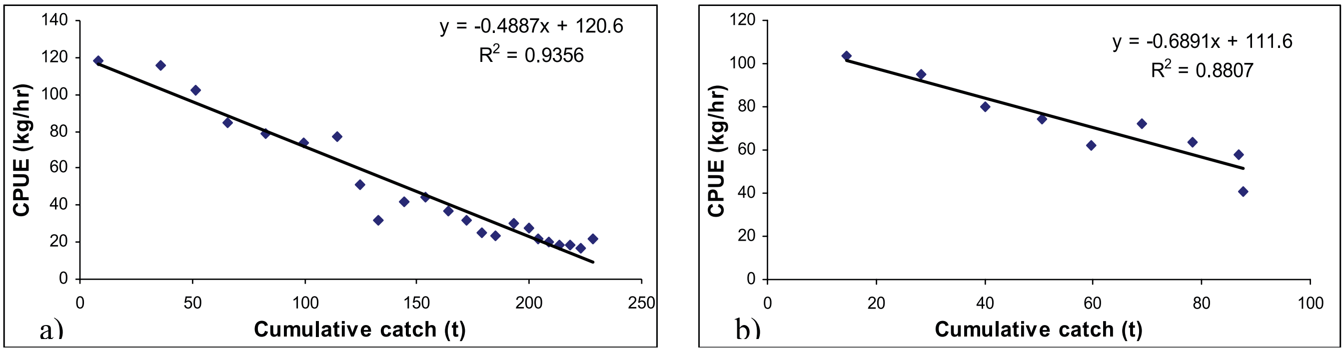


Figure 4.2 Scallop boat CPUE (kg/hr) on cumulative catch (both prawn and scallop boats) for a) northern Shark Bay b) Denham Sound 2007

Estimates of catchability and total biomass for the last five years show annual and spatial variability (Table 4.1)

Table 4.1 Annual estimates of catchability and total biomass for northern Shark Bay and Denham Sound between 2005 and 2010.

	Northern Shark Bay		Denham Sound	
Year	Catchability	Biomass estimate	Catchability	Biomass estimate
2005	NA	NA	19.3	364.4
2006	33.9	76.5	35.5	138.1
2007	48.9	246.8	68.9	162.0
2008	34.3	379.4	39.6	405.2
2009	17.9	443.6	57.2	231.6
2010	20.3	180.6	69.1	225.1

Scallop trawl efficiency between 2006 and 2010 for northern Shark Bay varied between 17.9 and 48.9% (Figures 4.3a-c, 2008-2010) and between 35.5 and 69.1% (Figures 4.4 a-c 2008 to 2010) for Denham Sound between 2005 and 2010.

Differences in catchability have also been observed between day and night catches as well as for regions (Chapter 3). Scallop catchability is also influenced by swell conditions with reduced catches during strong northerly swells (Figure 4.2c and 4.4 a).

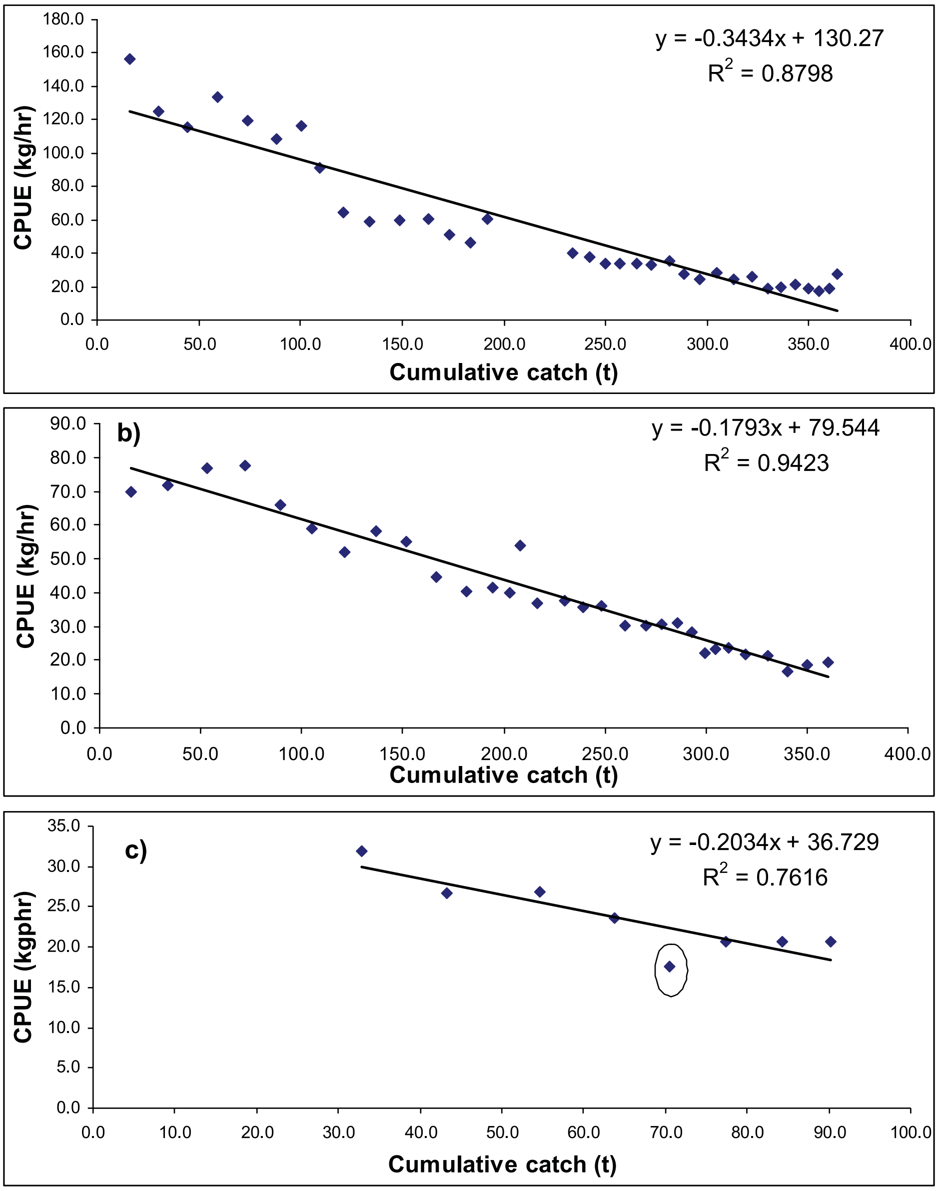


Figure 4.3 CPUE (kg/hr) versus cumulative catch for A Class scallop and B Class catch in northern Shark Bay a) 2008, b) 2009 and c) 2010. The day circled in c) indicates a bad weather day with depressed catch rates.

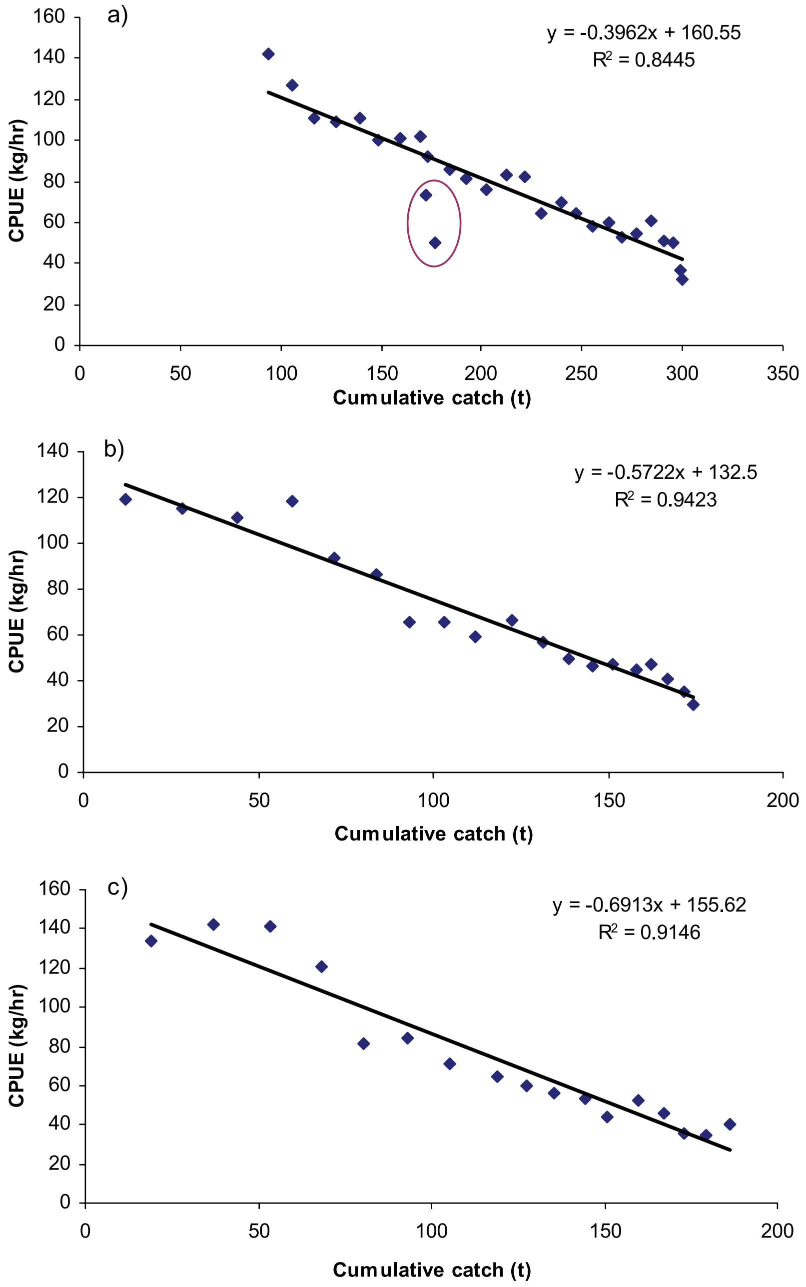


Figure 4.4 CPUE (kg/hr) versus cumulative catch for A Class scallop catch in Denham Sound a) 2008, b) 2009 and c) 2010. The days circled in a) indicates bad weather days with depressed catch rates.

4.3 CPUE trends

4.3.1 Annual CPUE

Exceptionally high catch rates (kg/hr) of scallops were observed in 1991 and 1992 due to very high recruitment in 1990. In years prior to this the mean catch rate (± se) was 24.3 (3.3) kg/hr and between 1994 and 2004 the mean catch rate was 24.5 (3.5) kg/hr. Significantly higher catch rates have been observed since 2005 (mean 44.5 (5.9) kg/hr (Figure 4.5).

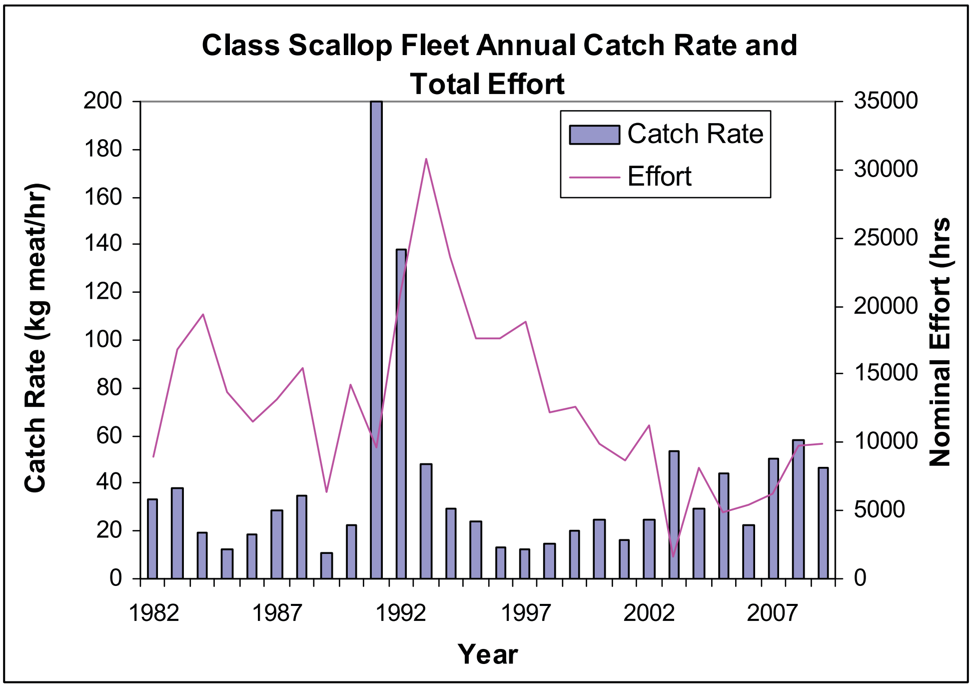


Figure 4.5 Annual catch rate trends and nominal effort for A Class scallop fleet since 1982.

The regime of fishing pre-spawning scallops and fishing to a threshold cut off-catch rate level (Figure 4.6) allow scallops to be taken efficiently with improved economics by taking scallops at desired market size and reducing fishing hours. The differences in the current harvesting strategy compared to pre 2005 also allows more carry over of residual scallops into the following season whereas in prior years, scallops were fished to lower levels at the end of the prawn season which generally ceased November each year. This has effectively reduced overall trawl hours of the scallop boats.

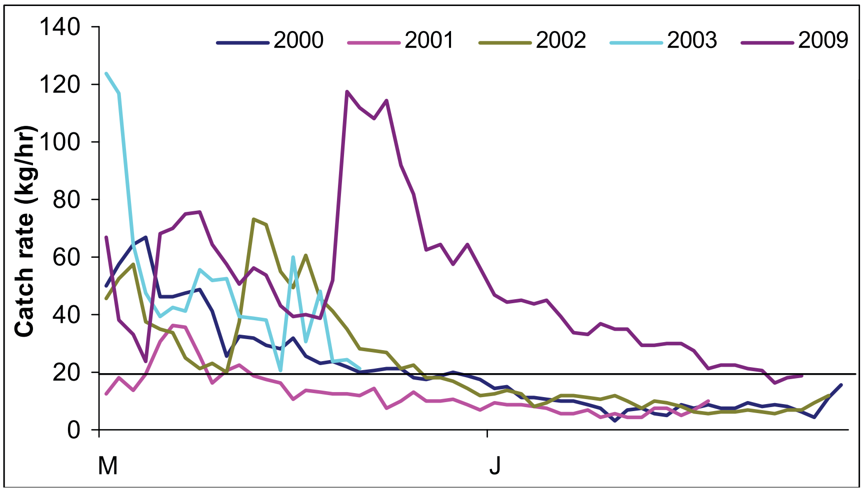


Figure 4.6 Mean daily catch rate for the scallop fleet between 2000 and 2003 between May and June and for 2009 (new fishing regime, commencing Feb/March)

The ways in which the catch rate data can be used needs to be reviewed. The current effort is not reflecting abundance levels compared to before 2005 when economics allowed boats to fish to lower catch rates with no regard to carry over scallops stock.

4.4 Stock Recruitment -Environmental Relationships

The effect of the spawning stock on the recruitment level was examined by Joll and Caputi (1995a) for data in the 1980s using a Ricker stock-recruitment relationship with an environmental variable (sea level) incorporated, and resulted in the model

$R_t = 387.4\ 10^6\ S_t \exp(-0.905\ S_t - 0.168\ FSL_t)$

This had a high multiple correlation of 0.91 with an inverse relationship between the spawning stock and recruitment over the range of spawning stocks observed though the effect of spawning stock was not significant ($p > 0.5$) after the sea level was taken into account. They considered that the environmental conditions played a significant role in recruitment success rather than breeding stock levels but recognised the management of the fishery was designed to prevent excessive fishing on breeding stock.

Caputi et al. (1998) updated the relationship including 1990-1994 and resulted in:

$R_t = 239\ 10^6 \exp(-0.174\ FSL_t)$. The model fitted using a logarithmic transformation resulted in a correlation of –0.79 ($P = 0.002$) and a RMS of 0.506.

It was apparent that in years of weaker LC flow, higher recruitment success was observed and vice versa (Lenanton et al. 1991). A more recent analysis of LC strength and scallop recruitment in Shark Bay using data between 1982 and 2006 indicates a much weaker negative correlation (Figure 4.7) than the one reported for the 1980s (Lenanton et al. 2009). Similarly, a relatively weak negative correlation was observed between scallop recruitment and surface water temperature (Figure 4.8). There is some indication that a weak LC flow and/or cooler water temperatures benefit recruitment but are not sufficient in themselves to always result in good recruitment. Other factors (e.g. water current movements during larval phase) may also be influencing recruitment.

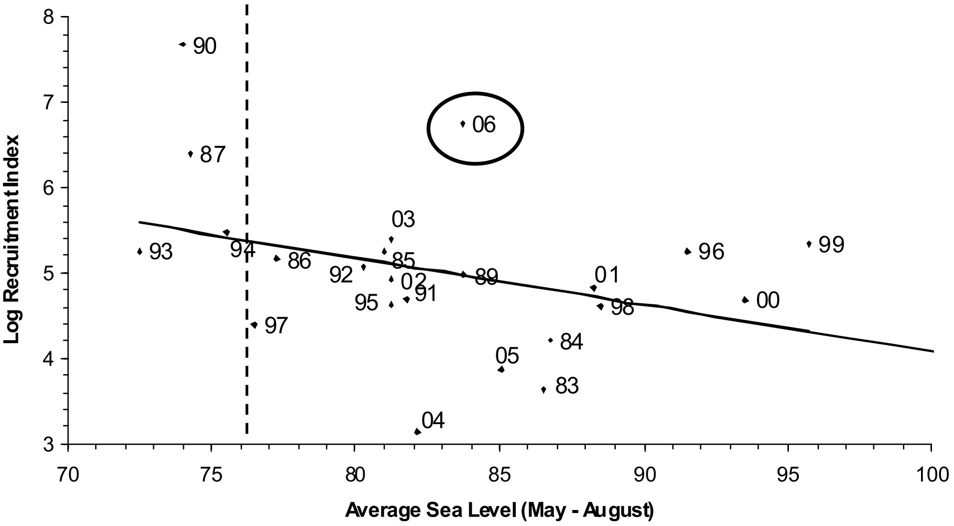


Figure 4.7 Correlation (log (Recruitment) = 9.6- 0.06FSL, $R^2 = 0.14$) between recruitment index in the Shark Bay scallop fishery (northern ground) and Leeuwin Current strength (FSL) between May and August (1983-2006). Dashed line indicates low average FSL conditions where some recruitment was observed to be high. Note 2006 is highlighted as a year with higher recruitment even though FSL was average.

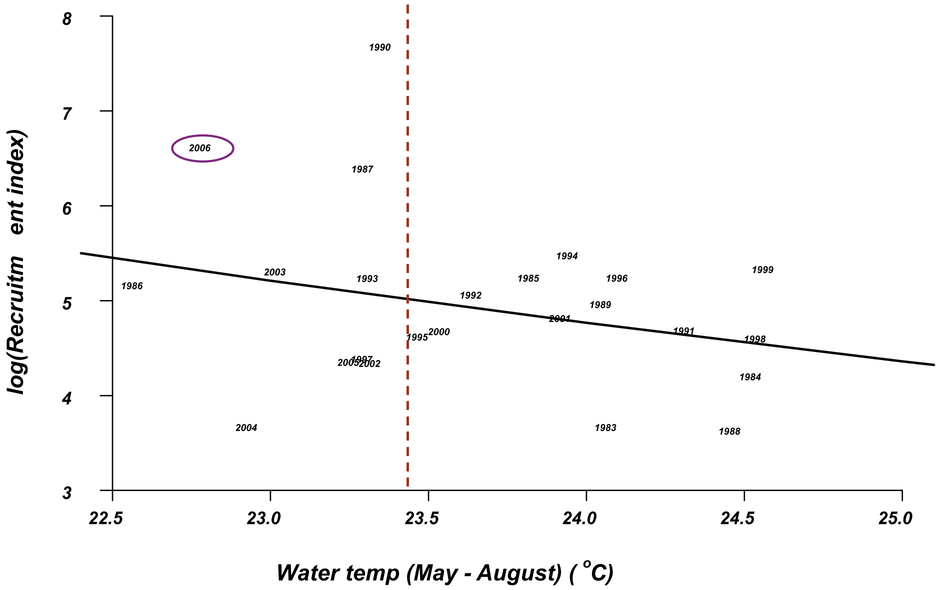


Figure 4.8 Correlation (log (Recruitment) = 15.8-0.46 SST, R^2 = 0.08) between recruitment index in the Shark Bay scallop fishery and surface water temperature (°C) between May and August (1983-2006). The dashed line indicates years when higher recruitment has been observed when Reynolds water temperature in waters of Shark Bay have been less than 23.5°C on average between May and August (when larvae in water column). Also 2006 is highlighted, as high recruitment when LC flow was stronger than for 1987 or 1990.

A current FRDC project is examining hydrodynamic features of Shark Bay for good and poor recruitment years and this modelling may elucidate other environmental parameters that are important in recruitment dynamics.

4.5 Mortality

Natural Mortality

The natural mortality coefficient, M, of the saucer scallop *Amusium balloti* within its central Queensland distribution has been estimated from the survival of tagged scallops to be approximately 0.025 per week (Dredge 1985). The analysis used to obtain this estimate of M incorporates a correction for tag shedding. The high natural mortality coefficient which if constant over the scallop's life span would mean only a 2% survival in an unfished population after 3 years and 0.6 % after 4 years (Dredge 1985).

Total Mortality (Fishing and Natural mortality)

Dredge (1985) determined that Z (total Mortality) for a given statistical fishing block in central Queensland did not exceed 0.16 wk^{-1}.

Total mortality calculated from declines in daily catch rates using daily logbooks between 2005 and 2010 indicate variable weekly mortality rates between 0.15 and 0.47 in Denham Sound and 0.16 and 0.31 in northern Shark Bay (Table 4.2).

Table 4.2 Weekly Total scallop mortality (Z) rates – scallop boats

Year	Denham Sound	Northern Shark Bay
2005	0.15	NA
2006	0.22	0.33
2007	0.47	0.25
2008	0.19	0.17
2009	0.28	0.18
2010	0.30	0.31

A tagging experiment, conducted to assess the survival of saucer scallops exposed to air for varying periods of time, showed that scallops exposed to air for periods of two hours were recaptured at the same rate as controls exposed to air for less than 2 minutes (Dredge 1987). Saucer scallops exposed for longer than 150 mins were recaptured at significantly reduced rates. These results suggest that saucer scallops can survive exposure to air for up to 2 hours without suffering significant mortality (Dredge 1987).

The short-term repeat recapture survival of scallops varies seasonally with higher mortality over summer and survival around 90% in winter (Chandrapavan et al., in prep.). Similar results were observed from a repeat trawl/tumbler study in Queensland where generally survival rates greater than 80% were observed for scallops trawled over four nights (Campbell et al. 2010). Campbell et al. (2010) also observed seasonal differences in survival but they did not undertake any trials during summer.

4.6 Yield Per Recruit

Dredge (1985) calculated that yield to the Queensland fishery would be maximized if age at recruitment of 28 to 36 weeks were harvested (approximately 80-90 mm shell height) (Dredge 1985). A preliminary YPR analysis using parameters from the literature and meat condition values from (Joll and Caputi 1995 a) support that yield is maximised at between 80 and 90 mm SH, however these calculations do not take into account variable meat condition with size nor egg production.

4.7 Selectivity

Mesh selectivity (traditional diamond mesh) experiments were been undertaken in Western Australia (Anon. 1969) and as a result 100 mm diamond mesh nets were legislated. More recently, square mesh cod-end selectivity trials have been undertaken in Queensland (Courtney et al. 2007, 2008) and has been trialled in WA (Chandrapavan et al. in prep.) indicating that improved scallop size selectivity can be achieved using square mesh cod-ends.

The 50 mm square mesh cod-end performed poorly with relatively high retention of small scallops, while the 55 and 60 mm square mesh codends retained 22 – 33 % less smaller scallops than the diamond mesh codend. A mean of 5% loss in commercial sized scallops across all three square mesh cod-ends and significant bycatch reductions of up to 95% occurred when operating square mesh cod-ends compared to the diamond mesh. The ratio of small sized scallops retained by the square to that of the diamond mesh codend decreased with increasing square mesh sizes and was lowest in the 60 mm square mesh codend.

Further testing of the 60 mm square mesh codend against the standard scallop and prawn nets also resulted in reduced retention of small scallops and finfish bycatch. Catch rate of prawns by the square mesh codend was less than 2% of that of the standard prawn net. Thus the performance of the 60 mm square codend in the experimental trials presents a good basis for its use in commercial trials in the Shark Bay scallop trawl fishery. A move to square mesh cod-ends could result in a significant reduction of discards (both small scallop and bycatch) and may in fact increase the catches of commercial sized scallops due to improvements in water flow and net efficiency. The scallop industry has indicated they were open to more extensive trialling of square mesh cod-ends in 2011, which may lead to an adoption by industry of this type of gear in the future.

5.0 Biological Reference Points and Stock Status

5.1 Management Decision-rule Framework

5.1.1 Background

Since 2005, in addition to the input controls on the fishery, a decision-rule framework to address management objectives are set in place. These management objectives are:

1. Biological objective: that management arrangements maintain adequate breeding stock.
2. Ecological objective: that management arrangements are consistent with the principle of ecosystem-based fisheries management and in particular:
   - Ensure that bycatch, in particular large animals including turtles is minimised;
   - That the effects of fishing do not result in irreversible changes to the ecological processes.
3. Commercial objectives:
   - That management arrangements maximise the opportunity for optimum economic returns to the Western Australian community from the scallop resource in Shark Bay
   - That management arrangements for the support and development of regional communities while not unnecessarily restricting normal business practice.

5.1.2 Decision Rules

Between 1987 and 2004, a Matrix management system was used (see Chapter 1) that determined the time of the start of the scallop season to ensure adequate spawning stock. This decision rule framework was abolished in 2004 as it did not allow the targeting of scallops at the optimum meat condition between February-March.

The current fishing season allows for some fishing pre-spawning and then some fishing post-spawning. The decision rules deals with the biological objective of having an adequate breeding stock but at the same time allowing fishing at the optimum meat condition. A catch rate threshold is set for northern Shark Bay and Denham Sound that aims to provide adequate breeding stock levels during the key spawning period each season. Fishing ceases at a threshold level or at a prescribed date that coincides with the key spawning period for scallops (May to July/August).

The concept of fishing to catch rate thresholds prior to the key spawning period to optimise meat yield and quality and improve efficiency has been evolving since 2005 with threshold levels increasing over time. In conjunction with the catch rate threshold to cease fishing pre-spawning at a 'safe' level of spawning stock, there is a strategy of leaving some carryover stock as a buffer against low recruitment and this also provides some scallops to survive into next season to be taken at larger meat size. The assessment of how much carryover is required is still a work in progress.

A scallop abundance estimation table using the pre-season survey and depletion estimates has been used for the last two years to estimate the catch that can be taken after spawning (usually by the prawn boats) and still ensure some carryover of stock (Table 5.1).

5.1.3 Stock Status

The performance measure is to ensure adequate breeding stock levels. Since 2005, a catch rate threshold level is used to cease fishing and maintain breeding stock during the key spawning period. In the 2009 fishing season the threshold catch rate applied for the fishery (based on daily scallop fleet average catch rate) was 400 kg/boat day in both northern Shark Bay and in Denham Sound. This threshold catch rate has continued to be adjusted upwards since being implemented and the threshold levels for both areas (Shark Bay north and Denham Sound) and needs to be further assessed to determine if they are adequate to provide recruitment in the acceptable range given 'normal' environmental conditions.

In 2010 the catch rate level was adjusted upward (450 kg per night time period) because both fleets fished Denham Sound at night (1700 to 0800 hrs the following day) and the overall fishing efficiency is higher. The threshold catch rate levels should be continued for a further three years to determine if it ensures adequate breeding stock.

5.1.4 Environmental Performance

The Australian Government Department of Sustainability, Environment, Water, Population and Communities has assessed the Shark Bay Scallop Managed Fishery under the provisions of the Environment Protection and Biodiversity Conservation Act 1999 and has accredited the fishery for a period of five years (re-assessment in 2013), allowing product from the fisheries to be exported from Australia. The comprehensive Ecological Sustainable Development assessment (Kangas et al. 2006) of these fisheries has also identified issues requiring direct management action. These were; the breeding stock levels of scallop species, bycatch species impacts, protected species interactions (including loggerhead turtles), habitat effects and provisioning effects be addressed annually.

Comparisons between the biodiversity of trawl catches in trawled and untrawled areas of Shark Bay were made during 2002 and 2003 (Kangas et al. 2007). One of the main objectives of this study was to compare the faunal composition between trawled and untrawled areas and if the faunal composition was similar, then it was highly likely that closed areas act as refuges for the majority of those species impacted by trawling. Faunal composition was similar in trawled and untrawled areas in general and therefore it is sufficient that the principal form of monitoring (and indeed management) of species diversity matters in the Shark Bay trawl fisheries is the extent of the trawled areas. Differences in diversity measures were observed both between sites and within assemblages at a given point in time (spatial differences), and from year to year at each sample location (temporal differences). However these differences were not consistent and were not attributable to whether a site was trawled or not. This indicates that many other factors in addition to trawl impacts are important in species richness and diversity.

Table 5.1 Estimation of residual scallop abundance at the end of each season between 2005 and 2010 for Denham Sound and Shark Bay

DENHAM SOUND

Year	Survey Catch (t) Prediction (Year-1)	Range (±20%)	Depletion abundance Estimate (t)	Range (±20%)	kg/fishing period left at cessation of fishing	Scallop boat pre-spawning catch (t)	Prawn boat pre-spawning catch (t)	Est. t of scallops remaining during spawning closure	Scallop boat post-spawning catch (t)	Prawn boat post-spawning catch (t)	Scallops left at end of season (t)	Survey Residual Index (Y)	Survey Recruit Index (Y)
2005	190	152-228	364	292-437	333	192	0	**172**	0	92	80	202	70
2006	166	133-199	138	110-166	224	82	0	**56**	0	35	21	40	410
2007	142	114-170	162	130-194	684	88	0	**74**	0	47	27	508	900
2008	305	244-366	405	324-486	458	300	0	**105**	0	18	87	198	255
2009	234	187-281	232	180-270	436	179	0	**53**	0	0	53	36	260
2010	148	118-178	225	186-278	454	165	20	**40**	0	0	40	7	50

NORTHERN SHARK BAY

Year	Survey Catch Prediction (Year-1)	Range (±20%)	Depletion Estimate	Range (±20%)	Kg/fishing period left at cessation of fishing	Scallop boat pre-spawning catch (t)	Prawn boat pre-spawning catch (t)	Estimated t of scallops remaining during spawning closure	Scallop boat post-spawning catch (t)	Prawn boat post-spawning catch (t)	Scallops left at end of season (t)	Survey Residual Index (Y)	Survey Recruit Index (Y)
2005	117	94-140	NA		300	15	40	**62**	0	35	27	97	80
2006	135	108-162	77	60-89	232	40	13	**82**	0	39	43	54	750
2007	313	250-376	247	197-296	344	191	83	**39**	0	12	27	116	660
2008	444	355-533	379	303-455	304	267	118	**59**	0	32	27	260	450
2009	446	357-535	444	380-570	331	262	189		0	27		133	130
2010	187	150-224	181	145-218	352	58	33	**91**	0	42	54	43	303

6.0 Current and future research

6.1 Summary of historical research completed

Research into the biological and environmental aspects of WA scallop stocks and commercial exploitation, has been carried out by the Department of Fisheries since the late 1960s. This research was aimed at determining basic biology of the species to ensure that the scallops are being harvested at ecologically sustainable levels whilst achieving the best economic returns from the available scallop resource.

The Department has been conducting pre-season surveys that monitor the strength of recruitment in Shark Bay since 1982. These surveys measure the abundance of residuals and recruits to the Shark Bay population each year and provide an annual fisheries-independent index of recruitment (Joll and Caputi, 1995b). As a result, annual management arrangements can be tailored to the expected abundance of scallops due to the significant correlation (0.81) that was determined between the abundance of recruits and the following year's catch (Joll and Caputi, 1995b).

The fleet has provided a detailed record of all the scallops taken since the 1980s in research logbooks completed by all vessels. This collection of fisheries-dependent data (voluntary daily logbooks, monthly catch and effort system (CAES) and processor unload records) for stock assessment and monitoring of the scallops will continue with the daily logbook being mandatory since 2008.

Fleet interaction issues have been, and continue to need to be, addressed including snapper bycatch issues (Moran & Kangas 2003) and scallop-prawn interactions and more recently crab-trawl interaction. For example, the earlier opening of the scallop fishery since 2004 has proven successful in improving size and market price of the scallop meat and reducing some prawn and scallop fleet conflicts and will be continued on a trial basis for a few years. Other 'experimental' approaches to harvesting and protection of spawning stock and newly settled scallops are being investigated, including, refining catch rate thresholds and further temporal and spatial closures.

Between 2002 and 2004 bycatch reduction devices (BRDs) were implemented in this fishery and the implementation process included an observer program documenting the efficiency of BRD (Kangas & Thomson 2004). A Fisheries and Research Development Corporation (FRDC) funded project was finalised on the biodiversity of bycatch in trawled and untrawled areas within Shark Bay in 2007 (Kangas et al. 2007).

A FRDC project, in collaboration with Edith Cowan University was completed in 2008 (Mueller et al. 2008). This study analysed scallop logbook and survey data using geostatistics to provide a better understanding of stock and fleet dynamics and to assess the spatial correlation of commercial catches and high abundance areas delineated in surveys. The study indicated that the annual survey was a good indicator of 'high' and 'low' scallop abundance areas within the fishery.

6.2 Current Research Focus

Research for monitoring the status of the scallop stock is based on detailed logbook records and factory receivals provided by industry. In addition, an annual research survey is carried out in November, which, together with existing detailed biological knowledge, enables an annual catch forecast to be provided. These survey data are also used as the basis for the management arrangements in the following year.

Fishing for scallops now commences pre-spawning which requires real-time monitoring (daily) of catch rates so fishing can cease at the agreed threshold catch rate.

Research will continue investigating the environmental influences that affect recruitment to scallop stocks in Shark Bay. More specifically, research into the effects that the Leeuwin Current, temperature and other environmental factors have on the scallop recruitment and spawning or fertilisation activities will be further investigated.

A two-year FRDC project on prawn/scallop gear interactions, scallop and prawn larval movement patterns in Shark Bay and usefulness of area closures in scallop/prawn management commenced in March 2008 and is due for completion by 2011.

6.3 Future Research Directions

The annual surveys need to continue to provide an annual catch prediction and provides industry with spatial abundance information allowing them to tailor their harvesting strategies. Some additional analyses for stock assessment include:

- Update catch prediction relationship taking into account effort and changes in management arrangements;
- Examine spawning stock recruitment and environment relationships, particularly for Denham Sound, to investigate why the two regions (Denham Sound and northern Shark Bay) appear to have had different recruitment trends in recent years;
- Continue investigating catch thresholds to determine the level to cease pre-spawn fishing in both Denham Sound and northern Shark Bay;
- Determine the catch levels that may be taken post-spawning and still enable sufficient residuals being left behind at the end of the fishing season to allow for a buffer against low recruitment years; and
- Refining the depletion analyses to estimate the total and residual biomass and taking into account spatial areas of fishing

To optimise the value of scallop meat harvested, a pre-season survey (at a smaller scale) focusing on key areas could be undertaken to pin-point the most appropriate time to commence fishing.

A systematic sampling program to monitor meat quality and yields over three years is required to assist with determining optimum fishing periods and to determine how variable meat quality is between years and regions. The Denham Sound area has meat quality issues with a ‘milky’ residue coming from scallops which detracts from their marketability and this needs to be investigated. This sampling program could be combined with a sampling program in the Abrolhos Islands where poor meat quality and stunted growth of scallops have been observed over the last two years in the northern part of that fishery.

Continuing commercial trials of square mesh cod-ends is urgently required in Shark Bay as preliminary results from the Abrolhos Islands in 2010 were positive in significant reduction of small scallops but no appreciable loss of sized scallops. Trials to test the durability and applicability of square mesh other larger mesh or T90 codends needs to be determined before implementation.

7.0 Acknowledgments

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Table 6.1 Summary of current and future research.

Key to symbols in the matrix/summary tables:

■ Indicates that the activity is funded and planned to occur.

O Indicates that the activity is part of a proposal but is not yet funded.

Shark Bay Scallop Fishery Research Projects	Research Status	2010/11	2011/12	2012/13	2013/14	2014/15	Comments
1. Retained Species Stock Analysis							
1.1 Basic Biology of indicator species (Growth, Reproduction, Diet, Natural mortality)							
Scallop Biology	Completed						Competed in the 1970s and 1980
		■	■				Additional information on spatial and temporal differences in meat size and quality will be collected on an opportunistic basis
1.2 Other Biology							
Recruitment Dynamics	Completed						Studies Completed in the 1980's
Larval Advection	Underway						FRDC project UWA PhD student
1.3 Stock Assessment							
Stock-recruit-environ effects	Ongoing	■	■	■	■	■	
Fishery independent surveys and monitoring	Ongoing	■	■	■	■	■	
Survey indices-catch relationships	Ongoing	■	■	■	■	■	Review of methodology in 2010/11
Modelling/Depletion exp.	Ongoing	■	■	■	■	■	Partly Completed
Spatial GIS	Ongoing	■	■	■	■	■	
Spatial analysis	Completed						ECU FRDC project completed in 2008
Catchability	Underway						Partly Completed including day-night trials
Mesh selectivity trials	Underway						FRDC project

Shark Bay Scallop Fishery Research Projects	Research Status	2010/11	2011/12	2012/13	2013/14	2014/15	Comments
1.4 Fishery Monitoring							
Logbooks	Ongoing	■	■	■	■	■	
Pre-season skipper briefings	Ongoing	■	■	■	■	■	
Fishing power monitoring	Ongoing	■	■	■	■	■	
Processor returns	Ongoing	■	■	■	■	■	
Database maintenance	Ongoing	■	■	■	■	■	
Effort impact assessment (GIS)	Ongoing	■	■	■	■	■	EPBC requirement
Spatial analysis of survey and logbook data	Completed						ECU collaboration – student project
2. Habitat & Ecosystem							
2.1 Bycatch							
BRD Implementation	Completed						Completed in 2003
Bycatch monitoring	Periodic	■					Review every 5 years
2.2 Listed Species							
Listed species interactions - logbooks	Ongoing	■	■	■	■	■	EPBC requirement/MOU with DEWHA underway
2.3 Habitat							
Habitat/effort impacts	Ongoing	■	■	■	■	■	EPBC requirement
Closure of sensitive habitats	Possible						Consultation required
2.4 Ecosystem/Environment							
Biodiversity of trawled and untrawled areas	Completed		■				Review every 5-10 years
Formal risk assessment	Periodic						EPBC requirement
Marine Park Monitoring	Possible						
2.5 Oceanography							
Leeuwin Current monitoring	Ongoing	■	■	■	■	■	
Temperature loggers	Ongoing	■	■	■	■	■	
Modelling of currents	Underway	■					FRDC UWA Masters project
2.6 Other impacts on fishery							
Spatial closures	Possible	O					Component of FRDC project

Shark Bay Scallop Fishery Research Projects	Research Status	2010/11	2011/12	2012/13	2013/14	2014/15	Comments
3. Management Analysis							
3.1 Socio-economic							
Social assessment	Possible						Partly completed during SB Review 06/07
Economic Analysis – average price data	Ongoing	■	■	■	■	■	Bio-economic modeling revisited in 09/10
Fuel consumption/expenses	Ongoing	■	■	■	■	■	Bio-economic modeling revisited in 09/10
3.2 Resource Access (Shares)							
Prawn – Scallop- fleet interactions and catch share - Snapper	Ongoing	■	■	■	■	■	Needed for the review of the three fisheries
Prawn-Scallop gear interactions	Underway	■					FRDC Project
4. Industry Development							
4.1 Production Technology							
Aquaculture /reseeding	Completed						Completed in 1990s
4.2 Post Harvest							
4.3 Marketing							
5. Priority Setting	Periodic	■		■			Regular Industry Departmental meetings
6. Science Review	Periodic	■			■		Will be held in July 2010

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