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The Western Australian scallop industry

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Fisheries research in Western Australia
The Fisheries Research Division of Fisheries Western Australia is based at the Western Australian Marine Research Laboratories, P.O. Box 20, North Beach (Perth), Western Australia, 6020. The Marine Research Laboratories serve as the centre for fisheries research in the State of Western Australia.

Research programs conducted by the Fisheries Research Division and laboratories investigate basic fish biology, stock identity and levels, population dynamics, environmental factors, and other factors related to commercial fisheries, recreational fisheries and aquaculture. The Fisheries Research Division also maintains the State data base of catch and effort fisheries statistics.

The primary function of the Fisheries Research Division is to provide scientific advice to government in the formulation of management policies for developing and sustaining Western Australian fisheries.

Contents

The Western Australian scallop industry

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Abstract

Five separate commercial fisheries target the saucer scallop, Amusium balloti *(Bernadi 1861) in Western Australian waters. While the average annual catch from these fisheries is around 600 tonnes of scallop meat, past catches have been highly variable with annual landings ranging from 150 to 4,400 tonnes of meat worth between $2 and $59 million. Consequently, scallops represent one of the larger single-species fisheries operating in Western Australia (WA).*

A. balloti *has a distribution spanning most of the WA coast, from Broome in the north around to Esperance in the south. Despite this extensive distribution, saucer scallops tend to be restricted to areas of bare sand in the more sheltered environments found in the lee of islands and reef systems, and are consequently found in commercially viable amounts in only five locations in WA. The five WA fisheries that target scallops (with average annual landings in brackets) are: the Shark Bay Scallop Managed Fishery (541 t), the Abrolhos Islands and Mid-West Trawl Managed Fishery (121 t), the south coast (15 t), the South-West Trawl Managed Fishery (11 t), and the Nickol Bay Prawn Managed Fishery (4 t).*

The majority of the annual catch is exported as frozen scallop meat to Asia, Europe and the United States of America; while a small portion is marketed directly to the public via local retail outlets. As with catches, wholesale market prices have fluctuated dramatically over the last 10 years, plummeting from $16/kg in 1987 to $8.50/kg by 1991, before steadily improving to peak at $28.50/kg in 1995. This variation has arisen primarily in response to product availability and condition.

The primary scallop fisheries operate in Shark Bay and around the Abrolhos Islands. Commercial fishing commenced in these fisheries in the late 1960s with moderate catches reported. Following a period of low catches in the mid 1970s, landings increased significantly during the late 1970s and early 1980s, mainly due to increased recruitment and fishing effort. Further advancements in processing methods and marketing strategies, and an associated increase in profitability, attracted even more vessels to the fisheries with further increases in effort. Subsequently, both were declared limited entry fisheries (now termed Managed Fisheries under the Fish Resources Management Act 1994). The Abrolhos Islands and Mid-West Trawl Fishery and Shark Bay Scallop Fishery were declared limited entry fisheries in 1986 and 1987 respectively.

As A. balloti *is an active swimmer, otter trawling is favoured. Vessels fishing for scallops in WA employ demersal otter trawl gear with strict controls placed on the vessels (boat units) and associated trawl gear (size restrictions) that can be used in each of the fisheries. These controls are designed to limit the total fishing effort to acceptable levels in order to maintain adequate spawning stocks, and to target those scallops at a size and age when the meat is in a premium condition for market.*

Research into the biological and environmental aspects of WA scallop stocks and their commercial exploitation has been carried out by Fisheries WA since the late 1960s. This research has centred on maximising the economic returns from the available scallop resource, while managing its use and harvesting at ecologically sustainable levels. Research

initiatives have included pre-season surveys to monitor the strength of recruitment to seasonal scallop stocks; the monitoring of environmental influences, such as the Leeuwin Current, and their effects on scallop populations; and the provision of detailed catch data via voluntary logbook programs and statutory monthly fishermen's returns.

1.0 Introduction

Scallops were first identified in Western Australian waters in 1904, when the government survey vessel *Rip* reported finding the saucer scallop, *Amusium balloti* (Bernadi 1861) in several trawls conducted in south-west coastal waters (Gale 1905, Laurenson *et al.* 1993). It was not until the late 1960s, however, that commercial fishing for scallops commenced in WA after exploratory research in the Shark Bay area revealed potentially commercial-sized stocks of prawns and scallops.

1.1 Scallop species

Belonging to the Family Pectinidae, the more common scallop species occurring in WA waters include the saucer scallop, *Amusium balloti* (Bernadi 1861), the commercial scallop, *Pecten modestus* (Reeve 1852), the doughboy scallop, *Chlamys asperrimus* (Lamark 1819) and the leopard scallop, *Chlamys leopardus* (Reeve 1853). However, only *A. balloti*, currently supports a commercial fishery in WA; although a small dredge fishery operating in Cockburn Sound did take several hundred tonnes of *P. modestus* between 1970 and 1973.

1.2 Biology of *Amusium balloti*

The saucer scallop, *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 1). Greatest numbers are found in Shark Bay and around the Abrolhos Islands (Joll 1989). Despite this extensive distribution, saucer scallops tend to be restricted to areas of bare sand in the more sheltered environments found in the lee of islands and reef systems. Dredge (1988a) reported that *A. balloti japonicum* occurs in extensive 'beds' separated by areas of low or zero scallop density, and the occurrence of *A. balloti* in WA follows a similar pattern. The species has been reported occurring in depths from 10 m to 75 m (Dredge 1988b).

The reproductive cycle of the saucer scallop (Figure 2) commences with gametogenesis, originally believed to be triggered by changes in water temperature in the range of 18°C to 23°C (Dredge 1981). Recent research by Joll and Caputi (1995a), however, has found that the relationship between changes in gonad weight and water temperature is tenuous for *A. balloti* on the WA coast. The onset of gametogenesis triggers a rapid increase in gonad weight, with histological examination revealing mature gametes forming within one to two months. Generally, equal numbers of males and females arise in wild stocks (Joll and Caputi 1995a). Histological examinations, however, revealed that a small proportion (< 0.5%) are hermaphroditic, possibly as a transitional stage of a sex change.

Spawning is believed to commence some 4-8 weeks after the onset of gametogenesis (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). Recent research into the cyclical patterns of variation in gonad weight has indicated that saucer scallops are subject to a process of partial spawning, possibly following a lunar cycle (Joll and Caputi 1995a). This process would then provide the developing larvae with multiple opportunities to develop in environments that may support a high larval survival rate.

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, a southward flowing current of relatively warm, tropical water that is low in salinity (Pearce and Phillips 1988). 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 Leeuwin Currents there is an increased likelihood that larvae is flushed away from areas of suitable recruitment habitat. This hypothesis is supported by research data which indicates that in years when the current flow is strong, scallop recruitment in Shark Bay is low and vice versa (Joll and Caputi 1995b). However, Joll and Caputi noted that it is also quite possible that the Leeuwin Current could have some temperature effects on spawning or fertilisation because of associated warmer waters.

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. A week after settlement, a byssal notch and associated threads develop on the dissoconch of the right valve, although attachment to the substrate remains very weak and is never permanent (Rose *et al.* 1988).

Growth of these new recruits is rapid, with scallops reaching 50 mm in shell height some 6-7 months after fertilisation and attaining a size suitable for commercial harvest (> 90 mm shell length) within one year (Joll and Caputi, 1995a). It is around this stage that the recruits mature and enter the breeding stock. Saucer scallops have been recorded reaching 14 cm in length and living for up to 3-4 years, although most appear to live no more than two years and maximum sizes are usually around 115 mm (Heald 1978; Dredge 1988b).

Saucer scallops feed by filtering organic material from the surrounding water. Known predators include pink snapper (*Pagrus auratus*), octopus and various species of turtles.

1.3 Fishing methods

Because *A. balloti* is an active swimmer, otter trawling is employed to fish scallop stocks in WA. The majority of scallops in WA fisheries are taken by dedicated scallop trawlers, although prawn trawlers in Shark Bay are also licensed to catch scallops whilst trawling for prawns. During the 1995 Shark Bay scallop season for example, roughly 70% of the total catch came from dedicated scallop vessels with the remainder landed by prawn trawlers (Figure 3). Prawn trawlers in Shark Bay, however, are restricted to fishing during the night, whereas dedicated scallop vessels may trawl on a 24-hour basis during the fishing season.

Both dedicated scallop vessels and prawn vessels employ demersal otter trawl gear to fish for scallops (Figure 4) and strict controls are placed on the vessel configuration (boat units) and trawl gear (size restrictions) that can be used in each of the fisheries.

Crew numbers aboard trawlers vary between the fisheries, being primarily dependent on the size of catch and the licence endorsements of the particular vessel. Scallop vessels in Shark Bay may carry up to 13 crew to facilitate onboard processing of large catches during the peak of the season, whereas only six crew are allowed on prawn vessels. Along with 24-hour trawling, this gives scallop vessels a greater capacity to fish and process the catch and helps to regulate the catch share. Scallop vessels operating in the smaller fisheries tend to carry the skipper and one to three additional crew.

Processing saucer scallops involves the labour-intensive practice of 'shucking' or removing the adductor muscle (scallop 'meat') from the shell. Various manufacturers are in the process of developing and trialing mechanical shucking machines, however, to date none have been found to be reliable enough for skippers to utilise them as a practical alternative to hand shucking. Originally, all scallops were landed whole and processed ashore using a large, land-based shucking machine. Since 1979, however, the catch has been processed at sea by hand and snap-frozen aboard the vessels.

1.4 Fishing seasons

Trawling for scallops in the Shark Bay and Abrolhos scallop fisheries is restricted to certain periods of the year. While practicalities involved in determining the timing of fishing seasons differ between these two fisheries, both are based on the need to maintain and preserve adequate spawning stocks and to catch scallops at a size and reproductive condition which maximises meat weight and condition. Historical factors also play a part in determining how these biological influences are treated.

Factors taken into account when setting opening and closing dates in Shark Bay include:

- strength of recruitment (pre-season surveys in November give an indication of recruitment; in years of low levels of recruitment, the season is delayed to allow the fewer scallops more spawning time);
- size of meat (larger scallop meats generally attract higher prices);
- meat condition (adductor muscle condition associated with reproductive cycle and nematode infestation associated with age);

The framework for the Abrolhos Island season is set by the period of activity of the Western Rock Lobster fishery (March-June), with the actual operating dates then being determined by meat size.

1.5 Fishing controls

Each of the five separate fisheries that target saucer scallops are regulated by state legislation and operate under stringent input controls. These controls are designed to limit the total fishing effort to acceptable levels in order to maintain adequate spawning stocks, and to ensure that scallops are taken at a premium meat size and condition for market.

Fishing controls employed in managing the scallop fisheries include:

- limiting vessel numbers and licences;
- regulating entry to specific areas within each fishery;
- seasonal time restrictions for specific areas within each fishery;
- trawl gear restrictions describing net head-rope lengths and mesh specifications;
- limits on crew numbers;
- vessel size restrictions.

No minimum shell size is set on the taking of scallops in Western Australian waters, however, restrictions are placed on the minimum mesh size that can be used in trawl nets. Only nets with a minimum mesh size of 100 mm (measured as a stretched diagonal) are permitted as these have a very low efficiency for taking scallops less than 80 mm in shell length. They also result in virtually no catch of prawns.

1.6 Markets

The majority of the annual catch is destined for export as frozen scallop meat to Asia, principally via Hong Kong markets, Europe and the United States of America. A small portion is marketed locally via retail outlets. Very small quantities of scallops, predominantly from the Fremantle, Geographe Bay and Esperance fisheries, are occasionally left 'roe-on', in the shell or in the half-shell to supply the gourmet seafood market.

Wholesale market prices for scallops have fluctuated markedly over the last ten years, plummeting from $16/kg in 1987 to $8.50/kg by 1991, before steadily improving to peak at $28.50/kg in 1995 (Table 1). Market variability is primarily in response to product availability and condition, although poor marketing in the face of a large supply and price manipulation by Hong Kong buyers was blamed for the low prices in the early 1990s.

Size and meat condition play an integral part in determining the market value of scallop meat, and consequently these factors greatly influence selection of appropriate seasonal opening dates. Higher prices are usually paid for larger scallops, so the respective scallop fisheries are opened when meats may reasonably be expected to be better than the 40/lb criterion, as sizes better than 40/lb are preferred on the export market. Changes in meat condition and subsequent recovery rates are closely associated with the animal's reproductive cycle (Joll 1987; Joll and Caputi 1995a). Maximum adductor muscle condition occurs during the latter part of the regressed phase of the reproductive cycle (March in Shark Bay and June in the Abrolhos Islands). Muscle condition begins to deteriorate after the onset of gametogenesis as the reproductive process draws on the nutritional resources within the adductor muscle, with minimum meat condition occurring around the time of maximum gonad index (September in Shark Bay, December in the Abrolhos Islands) . The change in wet meat weight between these two extremes is approximately 20% for an animal of 90 mm shell length, although this reduction will be offset to some degree by growth over the time from maximum to minimum gonad condition (Joll 1989).

The wild stocks of scallops targeted in WA waters are also subject to potential infestation by the nematode *Sulcascaris sulcata*, a parasite common to coastal marine habitats. While nematode infestation presents no health concerns for humans, it can spoil the meat's appearance and reduce its value. This proved to be a major problem for scallop fishermen during the early years of the fishery. A solution became apparent in the early 1980s, when stocks became more heavily exploited and the proportion of scallops over two years of age in the stock was heavily reduced. The accompanying fall in the incidence of infestation indicated that the overt signs of nematode parasitism did not become a significant factor until well into the scallop's life. Consequently, the problem of nematode infestation has been largely overcome by taking scallops at a younger age (around 12 months old), before nematode infestations are manifested.

In order to prepare the product for market, the animal is shucked and the meat frozen. This process involves removing one valve of the shell and lifting away and removing the gonad, mantle and digestive gland before removing the 'meat' (the adductor muscle) from the remaining valve. Prior to 1979, all scallops were landed whole and processed ashore by hand or machine, however, improvements in deck layout and refrigeration technology have allowed the catch to be processed at sea and landed as frozen meat. This change in the method of processing had a dramatic impact on the economic attractiveness of scallop fishing. Vessels could now remain at sea and fish for extended periods, rather than have to spend 8-10 hours on a return trip to port to unload every day or other day.

The three main fisheries that target scallops in Western Australian waters are (Figure 5):

- Shark Bay Scallop Managed Fishery;
- Abrolhos Island and Mid-West Trawl Managed Fishery; and
- South-West Trawl Managed Fishery (Fremantle and Geographe Bay).

In addition, scallops are sometimes taken by vessels operating in the Nickol Bay Prawn Managed Fishery and by a few vessels operating in the Esperance area which have trawl access to the South Coast Inshore Fishery as a condition of their fishing boat licence.

2.0 Methods

Research into the biological and environmental aspects of WA scallop stocks and their commercial exploitation has been carried out by Fisheries WA (then the Fisheries Department) since the late 1960s. This research has aimed at maximising the economic returns from the available scallop resource, while managing its use and harvest at ecologically sustainable levels to conserve and protect the State's aquatic ecosystems. Much of the research carried out during the early years of commercial scallop fishing in WA focused on gaining a sound understanding of scallop biology, its interaction with the natural environment, and the effects of fishing on both existing scallop stocks and habitat. As understanding of these aspects grew, specific research programs were tailored to suit each of the scallop fisheries based on their particular environmental concerns and requirements and the magnitude of commercial fishing activity occurring in each fishery.

2.1 Shark Bay

A pre-season survey to monitor the strength of recruitment in Shark Bay has been conducted annually by Fisheries WA since 1982. The survey is designed to measure the abundance of pre-recruits to the Shark Bay population each year, providing an annual index of recruitment which is independent of fishery catch records (Joll and Caputi 1995b). A significant correlation (0.81) has been determined between the abundance of pre-recruits and the following year's catch, and this allows annual management arrangements to be tailored to the expected abundance of scallops. The surveys are conducted aboard the 20 m Fisheries Research vessel, *Flinders*, and involve systematic sample trawling to cover the approximately 1000 km^2 of the main trawl grounds. The survey occurs annually, usually in November, as this is the earliest time that growing juveniles are large enough to be caught by trawls to allow for assessment of the distribution and density of pre-recruits.

Catch data from the fishery are obtained via voluntary log books maintained by skippers in both the Shark Bay Scallop and Shark Bay Prawn fisheries, as well as the statutory monthly Catch and Effort Statistics (CAES) system returns. The logbooks are completed on a daily basis and provide information on hours fished, areas of operation and the estimated catch per trawl, allowing for an accurate assessment of total effort and the distribution of catch (Joll and Caputi 1995b). Data on landings of scallops are also obtained from vessel owners and the various shore-based processors, and are used to cross-check the catch data (Joll 1994).

In 1992, temperature sensors were placed in Shark Bay with the intention of developing a long term database on water temperatures in the area. It is expected that this will provide a more direct measure of the impacts of the Leeuwin Current in Shark Bay.

Recent research is beginning to focus on the use of thermal satellite imagery to obtain accurate sea surface temperatures around the WA coast. Used in conjunction with altimeter data, the satellite imagery is expected to provide a more direct estimate of the strength of the Leeuwin Current (Caputi *et al.* 1996). It is expected that this information will provide a much greater insight into the annual, seasonal and regional variations of the current and assist in improving assessments of the regional impact of the current on scallop recruitment (Caputi *et al.* 1996).

2.2 Abrolhos Islands

For a number of years, a pre-season survey was conducted by Fisheries Research Division in the Abrolhos Islands area (usually during September/October) to determine the abundance and distribution of the scallop stocks in the region. The survey was found to be of limited value as a catch predictor, however, due to the very patchy distribution of scallops in the Abrolhos area which made it very difficult for the survey to cover all areas of potential scallop stocks. Recently, the agency has re-commenced conducting a limited pre-season survey in the known areas of major scallop distribution, with the information gathered from the survey being used by vessel operators and skippers to determine crew numbers, market strategies, and other logistical concerns for the forthcoming season. The survey also assists Fisheries Management to monitor stock levels in the fishery.

2.3 Other scallop fisheries

Catch, effort and catch rates in the smaller fisheries are monitored from statutory monthly CAES returns provided by skippers. With the research resources available, it is not possible to survey stock levels in the smaller fisheries and so catch projections are not made. Breeding stocks in these smaller fisheries vary according to total stock levels, but appear to be adequate to maintain recruitment over the normal range of environmental conditions. As with the larger fisheries, recruitment levels and subsequent catches have fluctuated dramatically from year to year probably due primarily to environmental influences which are not yet fully understood.

Research has been carried out in minor scallop fisheries, however, as an incidental component of research programs being carried out by Fisheries WA. Spawning patterns of the South-West Trawl scallop stocks were investigated by Joll and Caputi (1995a) during a project comparing geographic variation in the reproductive cycle of saucer scallops along the WA coast, while all aspects of the environmental impacts of scallop trawling in the fishery were scrutinised by Laurenson *et al.* (1993).

Although no major studies have been carried out with regard to spawning seasons or recruitment patterns for the scallop stocks off the south coast region, examinations carried out in the late 1980s suggested that spawning patterns of saucer scallop stocks along the region were similar to those found amongst scallop populations off Fremantle.

3.0 Results

3.1 Shark Bay Scallop Managed Fishery

The Shark Bay Scallop Managed Fishery is the primary scallop fishery in Western Australia. Annual catches over the period since the fishery reached full exploitation in 1982, have ranged from 121 to 4,414 tonnes (meat weight) at an average of 938.4 tonnes, and an annual value of between $2 and $58 million (Tables 1 and 2).

3.1.1 Historical perspective

Exploratory trawling was undertaken in the Shark Bay area during the late 1950s and early 1960s, by the research vessels *Lancelin* and *Peron* (Penn and Stalker 1979; D. Wright *pers. comm.*). This action revealed potentially commercial quantities of prawns and scallops, but it was not until 1966 that scallop landings were first reported (Table 2). For several years they were taken as by-product from vessels fishing primarily for prawns, and were first targeted for commercial purposes in the Shark Bay area during the late 1960s (Joll 1989).

Scallop trawling ceased during 1971/72, as a result of low catches caused by apparent poor recruitment. Fishing recommenced in 1973 and vessel numbers gradually increased over the ensuing 10 years (Table 2).

By the early 1980s, the number of vessels 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. Subsequent increases in fishing pressure were further compounded by the efforts of the 35 Shark Bay prawn trawlers, which began to retain scallops caught while targeting prawns. These increases in fishing activity led to a much higher proportion of the resident stock being taken, with fewer scallops surviving into the older age classes (Joll 1989). Federal 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 peaking at 26 vessels in 1983, the size of the scallop fleet was reduced to 14 vessels pending a four-year biological review of the fishery. Following review recommendations, Shark Bay was declared a limited entry fishery in 1987, restricted to 14 dedicated scallop vessels operating alongside the then 35 vessels endorsed to fish the limited entry prawn fishery, under a catch-sharing arrangement (Joll 1989). The Shark Bay prawn fleet was itself reduced to the current 27 vessels in 1990 to limit the available effort which could be expended on prawn stocks, and to improve vessel economics.

To aid in the orderly fishing of scallop stocks by both scallop and prawn vessels, limitations on daily fishing time for scallops were introduced in Shark Bay in 1988. Trawling was limited to a 15-hour period from 1700 hrs to 0800 hrs the following morning, but the practice was abandoned in 1993 in the interests of crew safety and an improved (fresher) product. Twenty four–hour trawling was subsequently reinstated for dedicated scallop trawlers, allowing the catch to be steadily processed and frozen at sea before being landed when convenient.

3.1.2 Boundaries and access

The Shark Bay fishery covers "*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 200 m isobath, together with those waters of Shark Bay south of 26°30′ south latitude.*" (Figure 6)

The Shark Bay scallop fleet now consists of 14 trawlers issued with A class licences (to fish exclusively for scallops) and 27 vessels carrying B class licences (to take both prawns and scallops). The 27 B class vessels comprise the Shark Bay Prawn Managed Fishery fleet. In recent years, they have accounted for 25-35% of the annual scallop catch (Figure 3).

Class A vessels are restricted from taking scallops east of 113°30′36″E (*i.e.* east of Cape Peron) while all vessels are restricted from trawling in areas permanently closed to trawling (Figure 6).

3.1.3 Landings

As with most scallop fisheries, catches have varied dramatically in Shark Bay over the last 15 years from 121 to 4,414 tonnes meat weight (Table 2), depending primarily on the strength of recruitment from the breeding season of the previous year. Consequently, fishery values have also fluctuated on an annual basis, ranging from $2 to $58 million (Table 1). Traditionally, the majority of the annual catch has come from two main fishing areas, Red Cliff and North-West Peron, although the scallop beds in Denham Sound contributed almost 50% of the total catch for 1993 (Figure 7).

3.1.4 Fishing season

The framework for the timing and duration of the scallop season in Shark Bay has been greatly influenced by the adjacent Shark Bay Prawn Managed Fishery. Scallops have remained an important by-product for the prawn fleet, especially in the latter part of the season when prawn catches decline. Consequently, since 1983 the scallop season has been set to close with the Shark Bay prawn season in November, however, dedicated scallop vessels usually cease fishing well before the end of the defined season as catch rates of scallops alone become economically unviable.

The opening date for the scallop season, however, is determined independently of the prawn fishery, and is regulated by principles that have been developed as understanding of the breeding biology and annual variations of stock abundance improved. These opening date principles are:

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 - Feb/March;
     - minimum quality - Sept/October.
   - scallops begin to show increased larval nematode lesions by October/November.

From this information, an opening date schedule has been developed to assist in determining an appropriate opening date for the scallop season (Table 3).

3.1.5 Spawning season

The reproductive cycle amongst Shark Bay scallop stocks begins with the onset of gametogenesis in late March/early April, with spawning occurring from April/May through to December (Joll and Caputi 1995a). Growth is rapid amongst new recruits. Scallops derived from early in the spawning season (April-July) reach sizes around 50-60 mm in shell height by November, and a harvestable size (90 mm) by March-April the next year. These newly recruited scallops also reach sexual maturity at about this time and enter the breeding stock (Joll and Caputi 1995a).

3.1.6 Environmental influences

Scallop populations world-wide have been acknowledged as being highly susceptible to environmental influences on recruitment (Hancock 1973). Consequently, much research has been carried out investigating the environmental influences that affect recruitment to scallop stocks in Shark Bay. The predominant environmental event considered to affect Shark Bay recruitment is the Leeuwin Current, a southward flowing current of relatively warm, tropical water that is low in salinity (Pearce and Phillips 1988). While the environmental mechanisms relating to the recruitment variability of *A. balloti* are yet to be fully understood, it appears that in years with a strong Leeuwin Current there is an increased likelihood that larvae are flushed away from areas of suitable recruitment habitat. This hypothesis is supported by research data which indicates that in years when the current flow is strong, scallop recruitment in Shark Bay is low and vice versa (Joll and Caputi 1995b). It is also quite possible that the Leeuwin Current could have some effect on spawning or fertilisation because of associated variations in water temperature (Joll and Caputi 1995b). Reid and Mantlya (1976) indicated that the strength of the Current should be reflected in the coastal sea level and, as described by Pearce and Phillips (1988), the sea level measurements from the Fremantle tide gauge have been monitored as an index of the Leeuwin Current since 1983 (Joll and Caputi 1995b).

3.2 Abrolhos Island and Mid-West Trawl Managed Fishery

The Abrolhos Islands and Mid-West Trawl Managed Fishery targets saucer scallops (using 100 mm mesh nets), in the waters around the Abrolhos Islands, and prawns (using 50 mm mesh nets), in the waters off Port Gregory (Figure 8).

3.2.1 Historical perspective

As with Shark Bay, the Abrolhos Islands area was first fished commercially for scallops during the late 1960's, although no fishing occurred in the region between 1969-1972 (Joll 1989). The fishery then operated intermittently over the next five years, with catches ranging from 0.3 to 6.7 tonnes of meat landed by between three and six vessels. After a poor season in 1977 (0.8 t meat), fishing for scallops again ceased during 1978/79 (Joll 1989).

With just two vessels in operation, the Abrolhos fishery recommenced in 1980. Both catches and vessel numbers increased over the next few years, primarily due to an increase in scallop price, improvements in operating efficiency and an apparent increase in scallop stocks (Joll 1989). Following a freeze on vessel numbers in Shark Bay in 1983, a large number of operators transferred their efforts to the Abrolhos grounds causing vessel numbers to escalate dramatically (Table 4). This increase in fishing pressure greatly reduced the catch share amongst vessels in the fishery, causing individual profitability to become severely jeopardised. Because of this large influx of vessels and the associated impacts on catch share and commercial viability, the entry of further vessels was restricted in 1985 (Joll 1989). In 1986, the fishery was moved from an open entry to a limited entry fishery with a maximum of 30 licences available. Following this decision, the maximum number of vessels allowed to operate in the fishery was gradually reduced through a two-for-one net reduction on transfer of licence. The two-for-one reduction has since been removed from the Management Plan and there are currently 17 licences operating in the fishery.

3.2.2 Boundaries and access

The Abrolhos Island and Mid-West Trawl Fishery covers "*all the waters of the Indian Ocean between 27°51' south latitude and 29°03' south latitude on the landward side of the 200 metre isobath*".

The main fishing grounds associated with the Abrolhos scallop fishery have traditionally centred on the waters surrounding the core Abrolhos Islands area. This region is encompassed in the A zone of the Western Rock Lobster Managed Fishery, and the original schedule of the area for the limited entry scallop fishery, used the boundaries of this A zone (at that time) as the legal boundaries for the scallop fishery (Dibden and Joll 1998). The Rock Lobster A zone was subsequently amended, but the eastern boundary of the trawl area reflects the old A zone boundary line that ran in a south-easterly direction from 27°51′S, 113°46′E to 29°03′S, 114°18′E (Figure 8). Trawling for scallops is not permitted east of this line.

Further changes were made to the boundaries of the Abrolhos Islands fishery in 1987. The legal area of the fishery was extended from the eastern A zone boundary to the coast, as this provided a higher level of protection against illegal trawling in this area. The area remained closed to trawling, however, except for a coastal zone that formalised and limited access to a small prawn fishery off Port Gregory, south of Kalbarri (Joll 1988). The fishery primarily targets western king prawns (*Penaeus latisulcatus*), using nets with 45 mm mesh in the cod-ends and 51 mm mesh in the remainder, and is limited to vessels with Mid-West Trawl Fishery endorsements (Joll 1988).

In recent years, a strong demand for scallop meat together with improvements in navigational technology (depth sounder, GPS, etc.), have led to an expansion in the areas trawled in the Abrolhos fishery as fishermen seek potential new scallop grounds (Dibden and Joll 1998). This expansion generally occurred within the traditional Abrolhos fishing grounds, although some exploratory trawling took place in previously untrawled locations around the Abrolhos Islands region as well as (illegally) in the closed waters south of the Port Gregory trawl zone (Dibden and Joll 1998). Locations suitable for scallop trawling were believed to exist within these closed waters in areas known as the "North Kidney Patch" and "South Kidney Patch" (Figure 8). Some illegal fishing activity in 1993 led to the discovery of a high concentration of scallops in the South Kidney Patch, and subsequent requests for vessels to be given permission to fish the area (Dibden and Joll 1998). Following Fisheries WA trawl and echo sounder surveys which supported indications of a large stock of scallops in an area predominantly suitable for trawling, the South Kidney Patch area was opened for a period of two weeks in late March, 1994, resulting in a catch of more than 160 tonnes of scallop meat (Dibden and Joll 1998).

As mentioned, there are currently 17 licences issued for the Abrolhos Islands fishery. The majority of the fleet also have endorsements to operate in other fisheries.

3.2.3 Landings

Prior to 1983, annual catches of scallop meat from the Mid-West Trawl fishery ranged from just 0.3 to 47.0 tonnes (Table 4). Following the 1983 freeze on vessel numbers in Shark Bay, the large number of operators who transferred their efforts to the Abrolhos grounds caused a dramatic increase in fishing effort to occur. Coupled with an apparent increase in stock levels, significant increases in catch resulted. The region quickly became heavily fished, and after two above-

average years, the catch plummeted to just 10 tonnes for the 1985 season. The Abrolhos Islands and Mid-West Trawl Managed Fishery was declared a limited entry fishery in 1986 and subsequent catches ranged from 17.5 to 80.2 tonnes between 1986 and 1992. Following this period, there appeared to be another significant increase in stock levels. Consequently, fishing effort and subsequent landings increased significantly, peaking in 1994 with a record catch of 526.7 tonnes (Table 4).

Most scallops are caught in the area immediately to the east of the Abrolhos Islands (Figure 8). The vast majority of the total annual catch is usually taken during the first two to three weeks of the season. In years when the Shark Bay scallop fishery does not open until early-mid May, vessels with appropriate endorsements leave the Abrolhos fishery to operate in Shark Bay.

3.2.4 Fishing season

As with Shark Bay, the framework for the Abrolhos Island scallop season is also influenced by another fishery operating in the same area, in this case the much larger Western Rock Lobster Managed Fishery. Since 1984, the Abrolhos scallop season has been run in conjunction with the rock lobster season primarily due to the cost-effectiveness of using fishery patrol vessels already present in the area to monitor the rock lobster fishery. In earlier years, when much smaller scallop vessels were used which were unable to operate continuously at sea, the timing also allowed rock lobster fishermen to police the use by scallop fishermen of jetties and other facilities owned by rock lobster fishermen.

The season generally opens on the first Tuesday in April, and closes on 30 June in conjunction with the Western Rock Lobster Managed Fishery.

3.2.5 Spawning season

The spawning season in the Abrolhos area begins approximately three months after that of Shark Bay. Gonad development commences during June/July, with the subsequent spawning period lasting from August until the following February/March (Joll and Caputi 1995a). As a result, catches consist only of post-spawning stock so there is no concern regarding security of the breeding stock.

3.2.6 Environmental considerations

A strong demand for scallop meat, together with improvements in navigational technology, led to an expansion in the areas trawled in the Abrolhos fishery during the early 1990s, as fishermen sought potential new scallop grounds (Dibden and Joll 1998). Concerns were raised by rock lobster fishermen in the Abrolhos Islands area that scallop trawlers in the region may cause damage to lobster habitats when they fished in areas containing both reef and sandy bottoms. In response, the Fisheries Research Division conducted a survey between Geraldton and the Abrolhos Islands in 1994, using an underwater camera to film the sea-floor and GPS navigational equipment to provide exact locations. The survey work was designed to define which areas are appropriate for scallop trawling (flat sandy bottoms) and which are not.

3.3 Other scallop fisheries

Several smaller fisheries also contribute to the Western Australian scallop catch, namely the South-West Trawl Managed Fishery and the Nickol Bay Prawn Managed Fishery. Scallop landings also result from a small amount of trawl activity that takes place off the south coast of WA.

Each fishery takes saucer scallops (*A. balloti*) by otter trawling. Landings are derived from statutory monthly returns provided by skippers for the Catch and Effort Statistics (CAES) system. With the current research resources available, it is not possible to closely monitor stock levels in the smaller fisheries so catch projections are not made. Breeding stocks in these smaller fisheries vary according to total stock levels but appear to be adequate to maintain recruitment over the normal range of environmental conditions. As with the larger fisheries, recruitment levels and subsequent catches have fluctuated dramatically from year to year, due primarily to environmental influences on recruitment.

3.3.1 The South-West Trawl Managed Fishery

The South-West Trawl Managed Fishery includes two of the state's smaller scallop fishing grounds, Fremantle and Geographe Bay.

3.3.1.1 Historical perspective

The first trawl surveys in south-west coastal waters were conducted in 1904 by the government survey vessel, *Rip* (Gale 1905; Laurenson *et al.* 1993). Nine trawls were attempted south of Mandurah and a further 17 directly off Fremantle, but results of the trawls were not particularly encouraging. Although quantities of saucer scallops were taken, gear damage and low catches of other valued species also resulted. Consequently, it was not until the late 1960s that saucer scallops were first targeted commercially in the region, with Shark Bay prawn trawlers beginning to fish in the vicinity of Bell Buoy, north-west of Fremantle (Laurenson *et al.* 1993).

Consistent commercial trawling between Fremantle and Cape Naturaliste began in the late 1970s and early 1980s. This development followed the conversion of a number of ex-rock lobster vessels to small trawlers, enabling them to target saucer scallops and western king prawns, predominantly in the waters north-west of Fremantle (Laurenson *et al.* 1993).

During the mid 1980s, reports of good catches of western king prawns from Comet Bay off Mandurah, led to as many as nine vessels regularly fishing the relatively, restricted inshore region. As a result, conflicts arose between original and the newer trawler operators over catch shares and profitability, as well as with the Mandurah community who were concerned about noise from working trawlers and suggestions that trawling in the area would deplete prawn and blue swimmer crab (*Portunis pelagicus*) numbers while damaging the inshore habitat. In response, management measures were introduced in 1983, including a near-shore closure to trawling and the establishment of a small, restricted-entry fishery with access limited to five small trawlers (Laurenson *et al.* 1993).

With access to the Comet Bay fishery restricted to all but five vessels, limited exploration of the waters south of Mandurah commenced, principally undertaken by the vessels that failed to receive Comet Bay endorsements. Scallop landings were reported by two vessels undertaking 'exploratory fishing' in the Geographe Bay region in October 1984, and by a third vessel (in the same area) in October of the next year. The increased activity in this region led the Minister for Fisheries to inform trawl operators, in November 1985, that their continued access to the fishery could not be guaranteed, and, that if access was restricted, only those vessels with a history of full-time fishing in the area might be eligible for future entry to the fishery. As a result of this action, together with a joint statement issued by the Western Australian Minister and the Federal Minister for Primary Industry in 1987 to the same effect, low level exploratory fishing continued in the

Geographe Bay area. By 1989, a consistent pattern of trawling in Geographe Bay had begun to emerge with three vessels more or less consistently fishing areas where saucer scallops regularly occurred (Laurenson *et al.* 1993).

In April 1988, the WA Government obtained jurisdiction from the Commonwealth Government over the waters from three nautical miles out to the 200 m isobath between 120°E to the north and 125°E to the south. This allowed for the establishment of the current management rules for the limited entry South-West trawl fishery. The South-West Inshore Trawl Management Plan (Moore 1989) was subsequently gazetted in October 1989, although it has since been renamed The South-West Trawl Management Plan.

3.3.1.2 Boundaries and access

The South-West Trawl Managed Fishery covers "*All the waters of the Indian Ocean adjacent to Western Australia between 31°43'27″ south latitude and 115°08' east longitude where it intersects with the high watermark at Cape Leeuwin, and on the landward side of the 200 metre isobath, excepting those waters lying within the boundaries of the Marmion Marine Park Reserve No. 1.*"

This area is then divided into four management zones (Figure 9):

Zone A - from 31°43′27″S to 32°16′S;
Zone B - from 32°16′S to 115°08′E;
Zone C - a seasonally closed scallop region to the north-east of Cape Naturaliste;
Zone D - the Mandurah inshore trawl fishery limited to Comet Bay.

Although most of the waters between Fremantle and Cape Naturaliste are open to trawling, commercial activity is usually restricted to several small fishing grounds; largely fished for either western king prawns or saucer scallops (Laurenson *et al.* 1993). Consequently, of the 18,000 km^2 of available sea bed, only around 250 km^2 or 1.4% of the total area represents actively fished ground (Laurenson *et al.* 1993).

The South-West Trawl Managed Fishery was declared a limited entry fishery in 1989, and a total of 14 vessels have licences to operate; two vessels with Zone A licences, four vessels with Zone B, one vessel with both A and B licences, four with B and C licences, and another three vessels have B and D endorsements.

3.3.1.3 Landings

The Fremantle fishery incorporates Zone A, and has operated for many years as a mixed-trawl fishery taking scallops along with prawns, bugs (Scyllaridae) and a variety of fish. Fishing involves otter trawling using 50 mm mesh nets. As with other fisheries, annual scallop landings have fluctuated, falling to 0.2 tonnes (meat weight) in 1986 before peaking at almost 16 tonnes in 1992 (Table 5).

The Geographe Bay fishery is primarily concerned with the region covered by Zone C, located to the north-east of Cape Naturaliste, but also includes some areas of the southern part of Zone B. This fishery has operated since 1984, after exploratory fishing located a small stock of scallops at a fishable density. Annual landings peaked at 32.4 tonnes (meat weight) in 1990 but have fallen dramatically since 1992, ranging between 0.1 and 1.6 tonnes (Table 5).

3.3.1.4 Seasonal dates

Zone C in Geographe Bay is open to licence holders during the three-month period commencing 1 July and ending 30 September. The Fremantle fishery does not have a set 'season' as such, and fishermen endorsed to operate in Zones A and B may fish all year round. Instead, fishing effort in these areas is regulated by limiting the number of vessels with access to each management zone, environmental factors such as unsuitable wind and sea conditions experienced during most winter and some summer months, and market influences regarding prices obtained for target species.

3.3.2 The Nickol Bay Prawn Managed Fishery

The Nickol Bay Prawn Managed Fishery (NBPMF) primarily targets western king prawns (*Penaeus latisulcatus*) and banana prawns (*P. merguiensis*), while saucer scallops are sometimes retained as a by-product. The fishery is relatively unproductive for scallop fishing when compared with the fisheries operating in Shark Bay and around the Abrolhos Islands.

3.3.2.1 Historical perspective

Trawling activities first took place in Nickol Bay during 1966, when exploratory fishing produced good catches of banana prawns. Subsequently, vessel numbers increased over the next five years, with as many as 22 trawlers targeting banana prawns in the area in any one month (Bowen and Hancock 1982). Many of these were WA-based Northern Prawn Fishery (NPF) vessels fishing the area whilst in transit to or from the NPF.

In 1971, the then Department of Fisheries and Fauna stabilised the fishery by restricting entry in Nickol Bay to operators issued with annual permits. Between 1975 and 1980, up to 16 vessels worked the fishery before it was declared a full limited entry fishery in 1980. Currently, 14 vessels are endorsed to fish in the NBPMF.

3.3.2.2 Boundaries and access

The Nickol Bay fishery covers "*All the waters of the Indian Ocean and Nickol Bay between 116°45' east longitude and 120° east longitude on the landward side of the 200 metre isobath*" (Figure 10). Access to the fishery is limited to 14 vessels currently licensed to fish for prawns in the NBPMF.

3.3.2.3 Landings

Historically, scallop landings have principally resulted from incidental by-catch taken by prawn trawlers operating in the NBPMF. Annual landings have varied dramatically, from nearly 21 tonnes (meat weight) in 1988 to less than 0.1 tonnes in the 1992 and 1994-96 seasons (Table 6). Catches can also vary sharply from year to year, as illustrated by the drop from 13 tonnes in 1991 to less than 0.1 tonnes the following year. Some of this decline may also be the result of the major activities of the prawn fishery not being in areas of scallop abundance.

3.3.2.4 Seasonal dates

The Nickol Bay Prawn Managed Fishery generally opens in April and runs until mid-November. The opening date, to a large extent, is determined by the size and strength of recruitment of banana prawns to the fishery.

3.3.3 The south coast

Fishing for scallops is also undertaken by up to four vessels which hold non-transferable endorsements to trawl in an area off the south coast (Figure 11). Based in Esperance, these vessels employ demersal otter trawling to target saucer scallops, although a small amount of scalefish is also retained (Mant *pers. comm.*). The fishery is relatively unproductive for scallop fishing when compared with the fisheries operating in Shark Bay and around the Abrolhos Islands.

3.3.3.1 Historical perspective

During the mid 1980s, several small trawlers operating out of Esperance and Albany discovered potentially commercial beds of saucer scallops in south coastal waters, especially within the Recherche Archipelago (Anonymous 1987). As a result, interest developed amongst WA fishermen to exploit this resource, with some concerns raised regarding the potential for excessive fishing capacity, as had been experienced in other Australian trawl fisheries (Anonymous 1987).

Following advice recommending management practices be introduced at an early stage to control development of any inshore trawl fishing, the Minister for Fisheries approved a Notice limiting trawling in State waters on the south coast, east of 115°E. A Ministerial statement was then issued on 1 July 1986, advising interested parties that a development plan was being considered for the region and that future access would be restricted to those vessels currently trawling in the area. This date was used as the benchmark for eligibility to obtain an interim endorsement to continue trawling in the region, with 11 vessels subsequently being judged eligible (Anonymous 1987).

Draft proposals for a development plan were circulated for comment by interested parties in September 1987, with the finalised plan for the south coast fishery released in November of the same year (Anonymous 1987). The region is currently managed by non-transferable licence conditions issued pursuant to *Fisheries Notice No.* 287 of October 1987 and Fisheries Notice No. 586 (*Trawling for Scallops, South Coast, Notice*) of December 1992.

Following completion of the developmental plan, the 11 vessels granted interim access to the fishery had their endorsements formalised and were granted access. Over the ensuing years, however, the number of vessels carrying appropriate licences has gradually been reduced to four vessels on the basis of non-performance (Mant *pers. comm*). These remaining four licences are effectively owned by two operators, who either operate the licences themselves, or lease them to other fishermen.

3.3.3.2 Boundaries and access

The legislated trawl zone off the south coast covers "*All Western Australian waters between 115°08' east longitude and 125° east longitude and on the landward side of the 200 metre isobath.*". This area includes a specific scallop zone within the Recherche Archipelago which incorporates the waters between 121°30′E and 123°30′E and on the mainland side of 34°20′S (basically the area from Esperance to Israelite Bay within the Recherche Archipelago) as shown in Figure 11.

Access to the south coast trawl zone is limited, with only four vessels currently endorsed to take scallops in the fishery. These endorsements are governed by two Fishing Boat Licence (FBL) Conditions. Condition 73 authorises the use of trawl nets off the south coast of WA in State

waters east of 115°E and is attached to all four FBLs. Condition 79 authorises demersal trawling for scallops within the Recherche Archipelago and is attached to only three of the current licences. Due to very poor catches in recent years, trawling has been intermittent.

3.3.3.3 Landings

As with other scallop fisheries, annual landings from the south coast fishery have fluctuated greatly, ranging from 0.2 to 27.6 tonnes meat weight (Table 7). Typically, annual effort in scallop fisheries such as that off the south coast is an outcome of initial fishing effort, which is used by operators to estimate stock abundance and the likely benefits of continued fishing. The very low catches in 1993 and 1994, for example, resulted from very low fishing effort because it was considered not viable to keep fishing the season after initial efforts were unproductive.

3.3.3.4 Seasonal dates

Current management measures in the fishery revolve around a closed season during the three-month period from 1 December to 1 March, for waters in the scallop zone within the Recherche Archipelago. No seasonal closures currently apply to scallop trawling in areas outside of the Archipelago.

4.0 Conclusion

The southern saucer scallop, *Amusium balloti* (Bernadi 1861) has been targeted by commercial fishermen in WA waters since the mid 1960s. From humble origins involving exploratory fishing in south-west coastal waters and Shark Bay, the state's scallop stocks are now fully exploited with some 78 operators currently carrying various fishery-specific licences endorsing them to take scallops in the five WA fisheries. While the average annual catch from these fisheries is around 600 tinnes of meat, past catches have been highly variable with annual landings ranging from 150 to 4,400 tonnes of meat worth between $2.6 and $59 million. On a live weight basis, landings have ranged from 650 tonnes to well over 20,000 tonnes in 1992, making it the second largest single-species fishery for that year in Australia after greenback jack mackerel (Joll 1994). Consequently, scallops represent one of the more important single-species fisheries operating in Western Australia.

The biology of *A. balloti* has been comprehensively studied over the past 30 years, resulting in a sound understanding of scallop biology, the animal's interaction with the natural environment and the effects of fishing on both existing scallop stocks and habitat. In recent years, scientific research on this species has focused on the dramatic annual variations that arise in recruitment to scallop stocks and subsequent seasonal catches. As the data show no relationship between spawning stocks and subsequent recruitment at the levels of breeding stock which have been experienced, these irregularities are likely to relate more to environmental influences on recruitment affecting the larval or juvenile stages of scallop development (Joll 1988).

Research programs investigating environmental influences on recruitment have focused predominantly on the effects of the Leeuwin Current with regard to the hydrological flushing of larvae away from areas suitable for spat settlement and development, and the possible influence of associated variations in water temperature on spawning stimulus (Joll and Caputi 1995b).

Recent research is beginning to focus on the use of thermal satellite imagery to obtain accurate sea surface temperatures around the WA coast. Used in conjunction with altimeter data, the satellite imagery is expected to provide a more direct estimate of the strength of the Leeuwin Current (Caputi *et al.* 1996). It is expected that this information will provide a much greater insight into the annual, seasonal and regional variations of the current and assist in improving assessments of the regional impact of the current on scallop recruitment (Caputi *et al.* 1996).

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6.0 References

Anonymous. 1987. A developmental plan for the South Coast Inshore Trawl Fishery, *Fisheries Department of Western Australia, Fisheries Management Paper* **13,** 10p.

Bowen, B.K. & Hancock, D.A. 1982. The limited entry prawn fisheries of Western Australia: research and management, *Fisheries Research Bulletin, Western Australia,* **27**: 1-20.

Caputi, N., Pearce, A., Fletcher, R., Chubb, C. & Joll, L.M. 1996. El Niño and the Leeuwin Current, *Western Fisheries,* Autumn 1996, Fisheries Western Autralia, p.p 17-22.

Dibden, C.J. & Joll, L.M. 1998. A research vessel survey of bottom types in the area of the Abrolhos Islands and mid-west trawl fishery, *Fisheries Research Report No 110,* Fisheries WA, 21p.

Dredge, M.C.L. 1981. Reproductive biology of the saucer scallop *Amusium japonicum balloti* (Bernadi) in central Queensland waters, *Australian Journal of Marine and Freshwater Research*, **32**: 775-787.

Dredge, M.C.L. 1988a. 'How far can a scallop population be pushed?'. in *Proceedings of the Australasian Scallop Workshop,* ed by M.L.C. Dredge, W.F. Zacharin and L.M. Joll, July 1988, Hobart, Tasmania, pp. 68-79.

Dredge, M.C.L. 1988b. Recruitment overfishing in a tropical scallop fishery? *Journal of Shellfish Research*, **7**(2): 233-239.

Gale, C.F. 1905. Report on the fishing industry and trawling operations for the year 1904, Fisheries Department of Western Australia, 57p.

Hancock, D.A. 1973. The relationship between stock and recruitment in exploited invertebrates, *Rapports et proces-verbeaux des Reunions, Conseil Internationale pour l'exploration de la mer*, **164**: 113-131.

Heald, D. 1978. A successful marking method for the saucer scallop, *Amusium balloti* (Bernadi), *Australian Journal of Marine and Freshwater Research*, **29**: 845-851.

Joll, L.M. 1987. The Shark Bay scallop fishery, *Fisheries Management Paper 11*, Fisheries Department of Western Australia, 123p.

Joll, L.M. 1989. History, biology and management of Western Australian stocks of the saucer scallop *Amusium balloti*, in *Proceedings of the Australasian scallop workshop*, ed by M.L.C. Dredge, W.F. Zacharin and L.M. Joll, July 1988, Hobart, Tasmania, pp. 30-41.

Joll, L.M. 1994. Unusually high recruitment in the Shark Bay saucer scallop (*Amusium balloti*) fishery, *Memoirs of the Queensland Museum*, **36**(2): 261-267.

Joll, L.M. & Caputi, N. 1995a. Geographic variation in the reproductive cycle of the saucer scallop, *Amusium balloti* (Bernadi, 1861)(Mollusca: Pectinidae), along the Western Australian coast, *Marine and Freshwater Research*, **46**: 779-792.

Joll, L.M. & Caputi, N. 1995b. Environmental influences on recruitment in the Shark Bay saucer scallop (*Amusium balloti*) fishery of Shark Bay, Western Australia, *ICES Marine Science Symposia*, **199**: 47-53.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A. & Grieve, C. 1993. 'Australian Fisheries Resources', Bureau of Resource Sciences and the Fisheries Research and Development Corporation, Canberra, 422p.

Laurenson, L.J.B., Unsworth, P., Penn, J.W. & Lenanton, R.C.J. 1993. The impact of trawling for saucer scallops and western king prawns on the benthic communities in coastal waters off south-western Australia, *Fisheries Research Report 100*, Fisheries Department of Western Australia, 93p.

Moore, N. 1989. Management of the south-west inshore trawl fishery, *Fisheries Management Paper 23*, Fisheries Department of Western Australia, 10p.

Pearce, A.F. & Phillips, B.F. 1988. ENSO events, the Leeuwin Current, and larval recruitment of the western rock lobster, *Journal du Conseil Internationale pour l'exploration de la mer*, **45**: 13-21.

Reid, J.L. & Mantlya, A.W. 1976. The effect of the geostrophic flow upon coastal sea elevations in the northern North Pacific Ocean, *Journal of Geophysical Research*, **81**: 3100-3110.

Rose, R.A., Campbell, G.B. & Sanders, S.G. 1988. Larval development of the saucer scallop *Amusium balloti*, Bernadi (Mollusca:Pectinidae), *Australian Journal of Marine and Freshwater Research*, **39**: 133-160.

7.0 Tables

Table 1 Historical annual values ($Am) for each of the Western Australian scallop fisheries, 1985-1997.

YEAR	AVG.	FISHERY VALUE (A$m)					
	PRICE/KG *	*Shark Bay*	*Abrolhos*	*South Coast*	*South West*	*Nickol Bay*	TOTAL
1985	11.00	2.5	0.1	0.03	0.01	0.0	**2.64**
1986	15.50	3.5	1.0	0.25	0.03	0.01	**4.79**
1987	16.00	8.0	1.1	0.36	0.4	0.01	**9.87**
1988	17.00	12.0	0.4	0.47	0.07	0.36	**13.30**
1989	17.50	2.1	0.8	0.22	0.1	0.05	**3.27**
1990	14.50	7.0	0.4	0.03	0.6	0.18	**8.21**
1991	8.50	21.5	0.2	0.19	0.2	0.11	**22.20**
1992	14.00	58.0	1.1	0.27	0.2	0.01	**59.58**
1993	17.00	32.9	4.7	0.01	0.1	0.02	**37.73**
1994	20.00	17.2	10.0	0.01	0.07	0.01	**27.29**
1995	28.50	17.0	9.1	0.79	0.1	0.01	**26.91**
1996	28.25	10.1	6.5	0.49	0.1	0.01	**17.20**
1997	30.00	9.9	0.3	0.78	0.04	0.01	**11.03**

* Average price/kg is processed meat from Shark Bay.

Table 2 The catch history of the Shark Bay Scallop Managed Fishery (1966-1997).

Year	Total landings[1] (tonnes meat) (incl. prawn trawlers)	Dedicated scallop trawlers				
		Landings (tonnes meat)	*Maximum no. of trawlers*	*Total effort[2] (hours)*	*Swept area[3] (n miles²)*	*Catch rate (kg meat/hr) (n miles²)*
1966	1.2	N/A	N/A	N/A	N/A	N/A
1967	N/A	N/A		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	13	8,930	259	33.1
1983	705.3	640.4	26	16,790	487	38.1
1984	431.2	379.0	14	19,430	564	19.5
1985	232.8	175.0	14	13,730	398	12.8
1986	259.5	211.1	14	11,500	334	18.4
1987	490.9	377.3	14	13,210	383	28.6
1988	731.2	544.9	14	15,500	450	35.2
1989	121.0	71.2	14	6,430	187	11.1
1990	486.7	318.2	14	14,290	415	22.3
1991	2,532.0	1,916.2	14	9,570	278	200.2
1992	4,414.0	2,876.2	14	20,860	605	137.9
1993	1,934.6	1,469.6	14	30,740	892	47.8
1994	957.1	685.5	14	23,580	684	29.1
1995	596.0	423.4	14	17,680	513	23.9
1996	364.0	239.3	14	17,649	513	13.6
1997	328.5	227.6	14	20,593	548	11.1

[1] **Conversion of shell to meat**: Landings as shell weight have been converted to meat weight using the approximate relationship: meat weight = 0.2 shell weight.

[2] **Effort values**: In the past, a number of vessels in the fishery have towed nets of varying headrope length. Consequently, all effort values have been converted to hours trawled for a vessel towing 14-fathom headrope gear, using the formula: $\frac{\text{\# hrs x headrope length}}{14}$

[3] **Swept area** = $\frac{\text{total duration (hrs) x speed (kts) x head-rope length (ft) x net 'drag' factor}}{\text{No ft in a nautical mile}}$

N/A Not available

Table 3 Schedule linking strength of recruitment and residuals determined during the November survey, with estimated catch producing an appropriate estimated opening date between mid-March and mid-May.

Estimated catch (meat wt.)	Abundance recruits	Abundance residuals	Opening date *
Low (<300t)	Low	Low	15 May
Med (300-600 t)	Moderate	Low	1 May
	Low	Moderate	15 April
High (600-1,500 t)	High	Low	15 April
	Moderate	Moderate	15 April
	Low	High	1 April
Very high (> 1,500 t)	High	Low	1 April
	Low	high	15 March

* Or nearest suitable day.

Table 4 Historical landings for the Abrolhos Islands and Mid-West Trawl Managed Fishery (1967-1997).

Year	Catch* (tonnes)	No. of vessels	Year	Catch* (tonnes)	No. of vessels
1967	4.6	3	1983	158.2	22
1968	25.9	8	1984	219.1	40
1969	NF	-	1985	10.0	27
1970	NF	-	1986	74.2	28
1971	NF	-	1987	67.6	16
1972	NF	-	1988	23.6	20
1973	0.3	3	1989	43.1	14
1974	4.2	4	1990	25.8	20
1975	6.7	6	1991	17.5	12
1976	2.9	4	1992	80.2	8
1977	0.8	3	1993	292.2	12
1978	NF	-	1994	526.7	19
1979	NF	-	1995	317.4	19
1980	12.3	2	1996	228.7	17
1981	28.5	6	1997	8.8	7
1982	47.0	9			

* Catches are recorded in tonnes meat weight. Data other than 1984-86 are compiled from monthly CAESS returns. 1984-86 data compiled from daily logbook returns.

NF No fishing

Table 5 Historical landings for the South-West Trawl Managed Scallop Fishery (1985-1997). Landings are recorded as tonnes meat weight.

Season	Fremantle	Geographe Bay
1985	0.4	0.8
1986	0.2	1.7
1987	1.0	24.4
1988	1.1	12.8
1989	0.7	5.9
1990	11.7	32.4
1991	8.0	10.7
1992	15.6	1.6
1993	4.5	0.8
1994	3.3	0.4
1995	3.0	0.5
1996	4.3	0.1
1997	1.3	0.1

Table 6 Historical scallop landings for the Nickol Bay Prawn Managed Fishery (1985-1997). Landings are recorded as tonnes meat weight.

Season	Landings
1985	0.0
1986	< 0.1
1987	< 0.1
1988	21.0
1989	2.9
1990	12.7
1991	13.0
1992	< 0.1
1993	1.2
1994	< 0.1
1995	< 0.1
1996	< 0.1
1997	< 0.1

Table 7 Historical landings for the south coast region (1985-1997). Landings are recorded as tonnes meat weight.

Season	Landings
1985	2.7
1986	16.2
1987	22.7
1988	27.6
1989	12.7
1990	2.1
1991	21.8
1992	19.3
1993	0.2
1994	0.3
1995	27.6
1996	17.3
1997	26.1

8.0 Figures

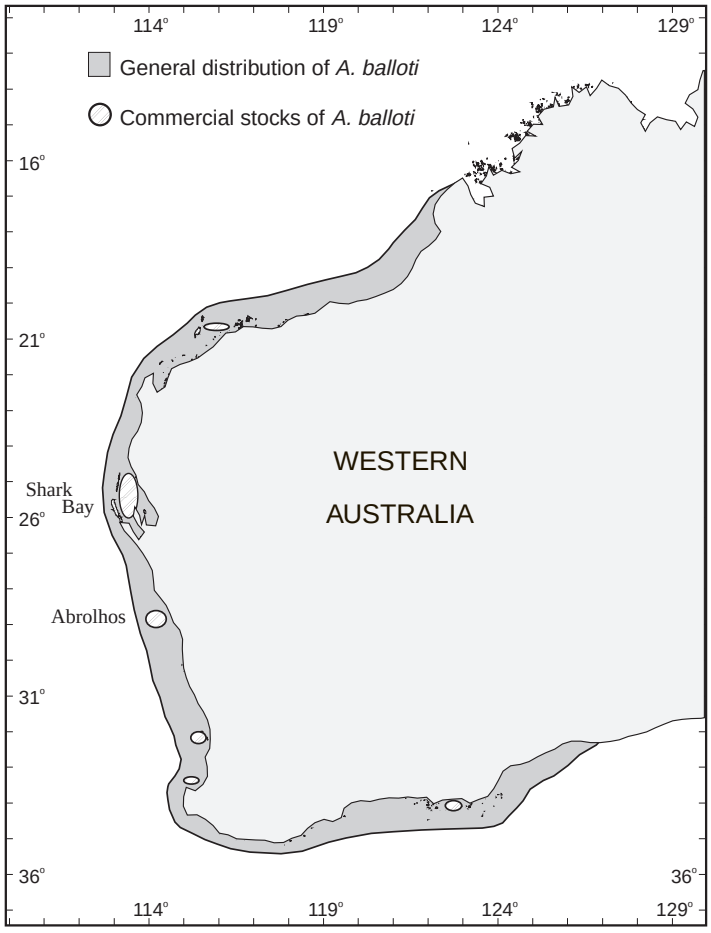

Figure 1 Map showing the distribution of *Amusium balloti* in Western Australia.

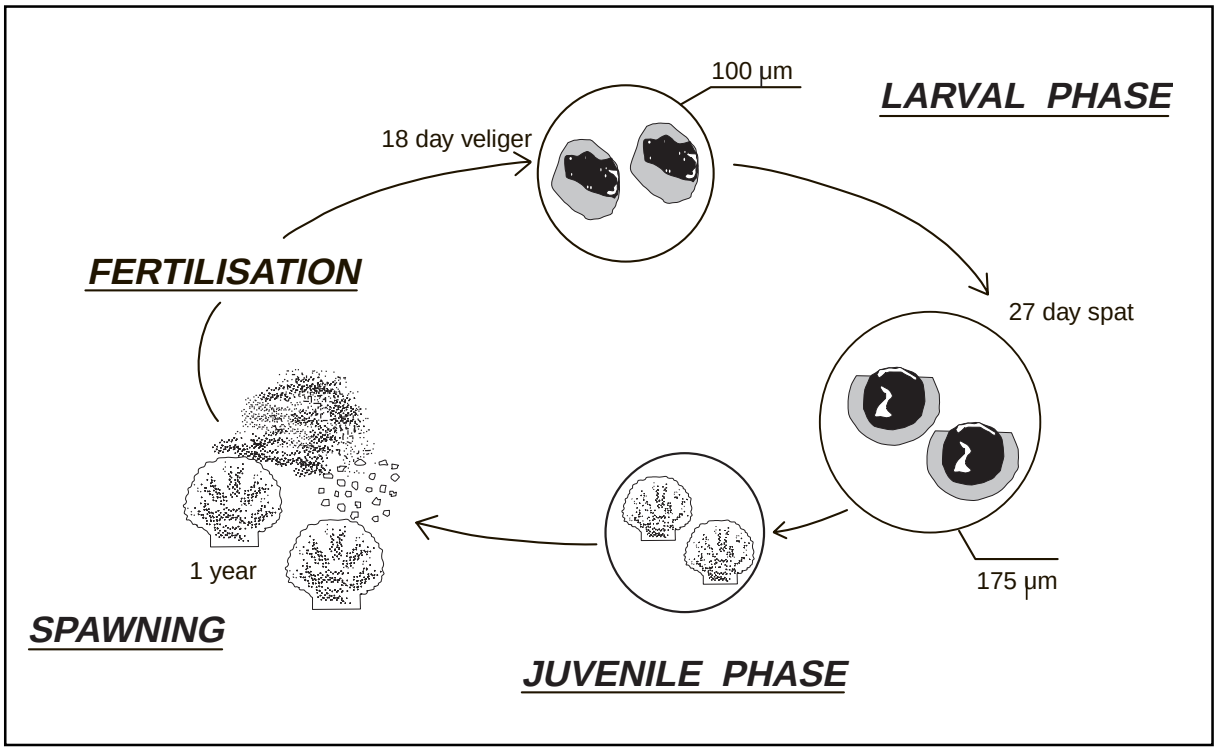

Figure 2 Life cycle of the saucer scallop, *Amusium balloti*.

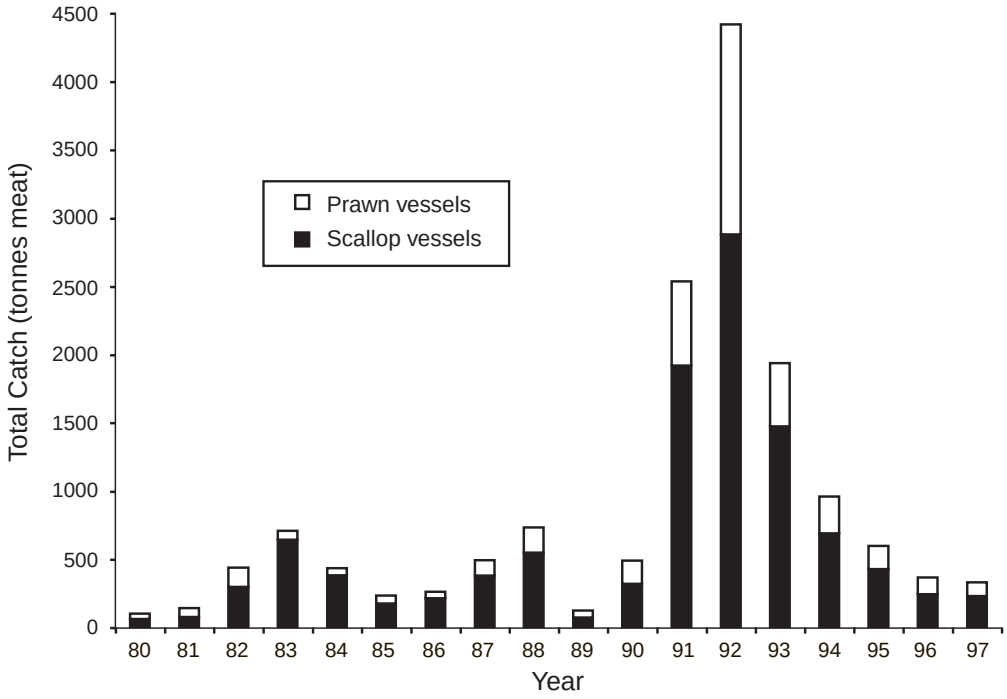

Figure 3 Historical comparison of catch (meat weight) recorded by dedicated scallop vessels and prawn vessels in Shark Bay (1980-97).

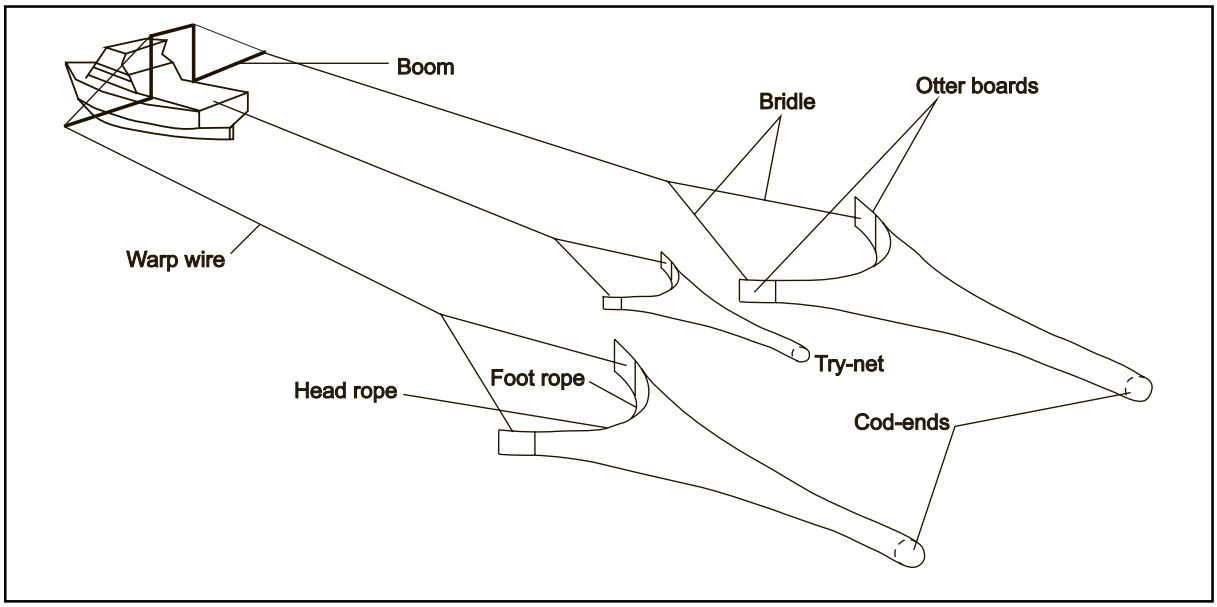

Figure 4 Diagram illustrating the demersal otter trawl gear used by scallop trawlers.

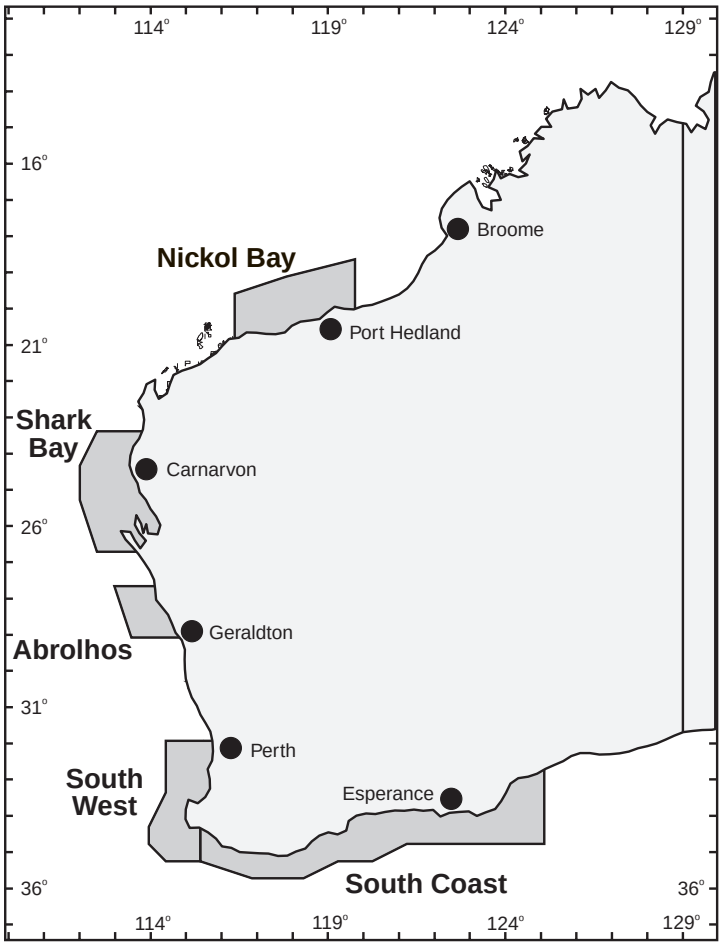

Figure 5 Boundaries of the fisheries operating in Western Australia that take scallops.

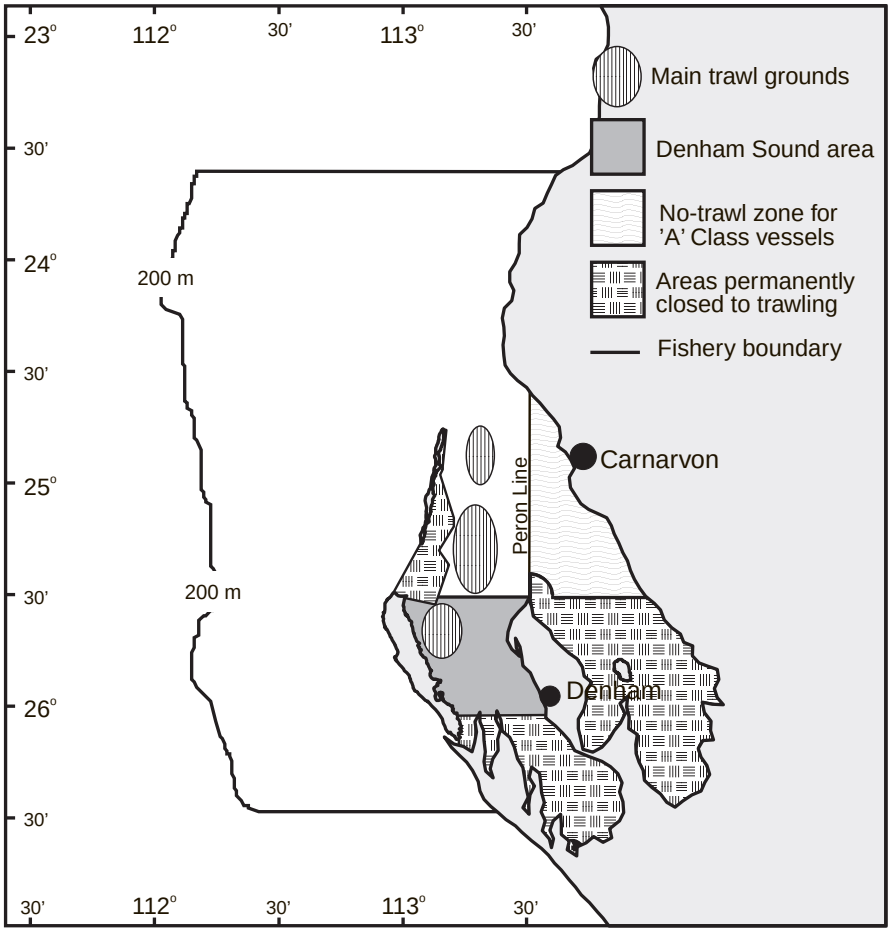

Figure 6 Map showing the general boundaries of the Shark Bay Scallop Managed Fishery.

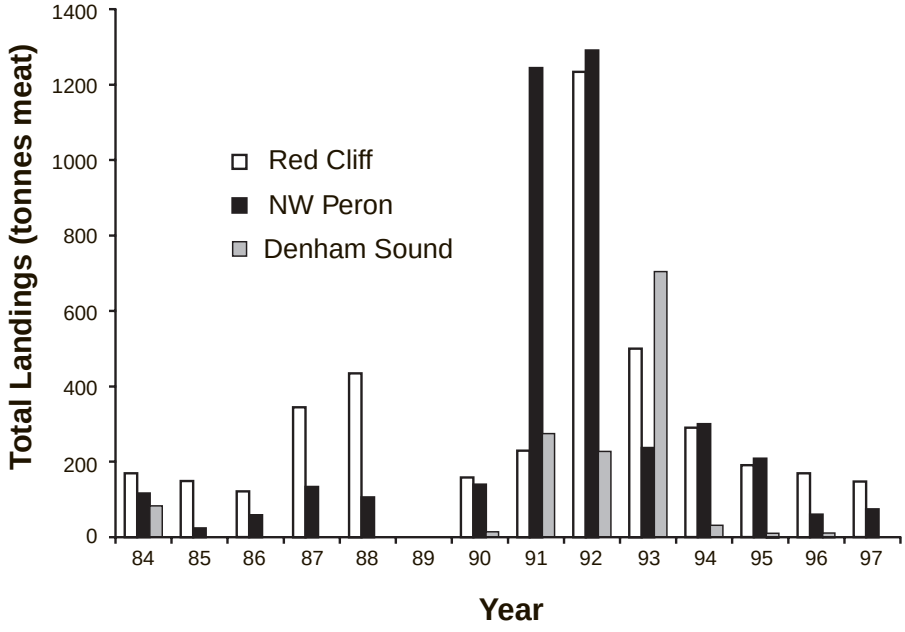

Figure 7 Historical annual catches from dedicated scallop trawlers for each area of Shark Bay.

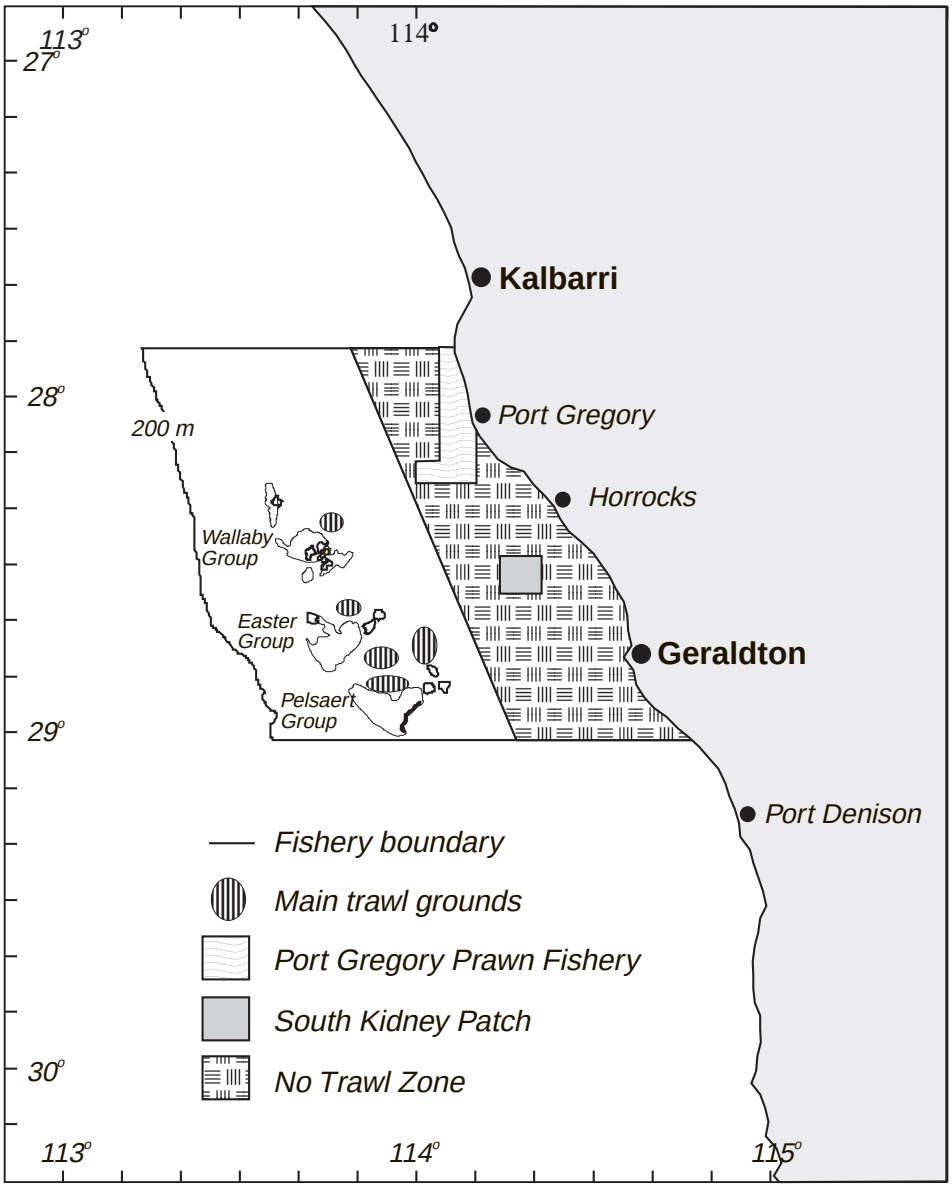

Figure 8 Map showing the boundaries of the Abrolhos Islands and Mid-West Trawl Managed Fishery.

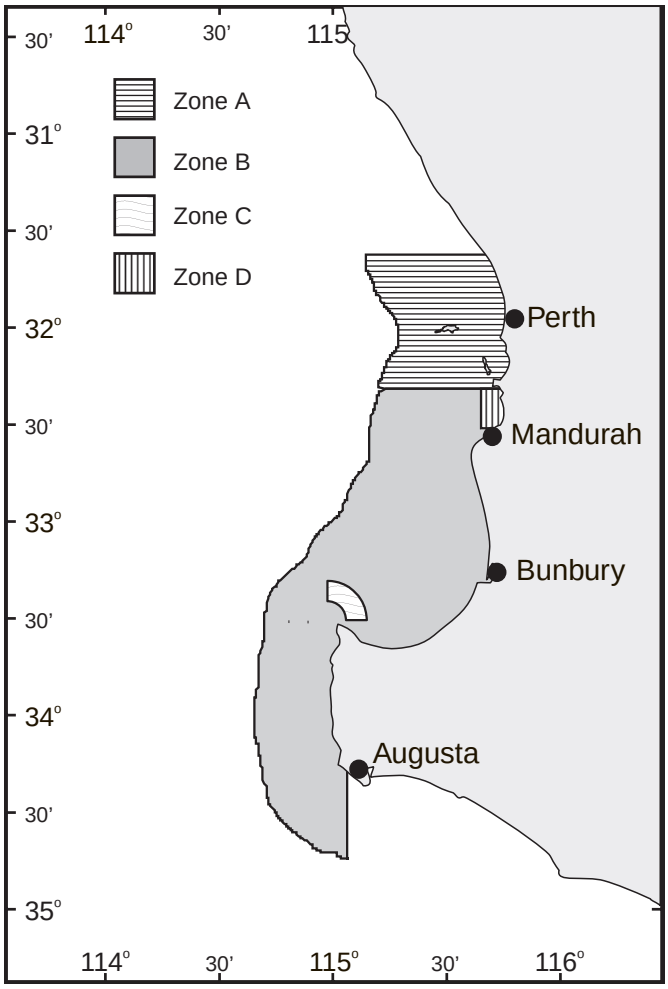

Figure 9 Map showing the boundaries of the South West Trawl Managed Fishery.

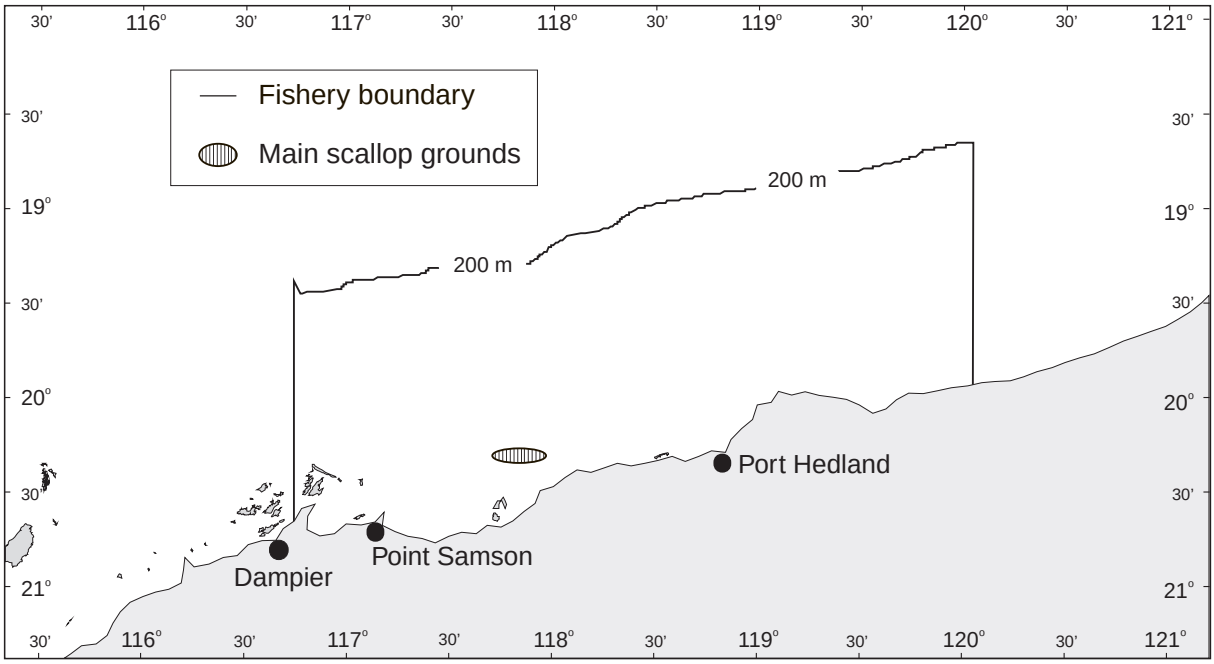

Figure 10 The boundaries of the Nickol Bay Prawn Managed Fishery.

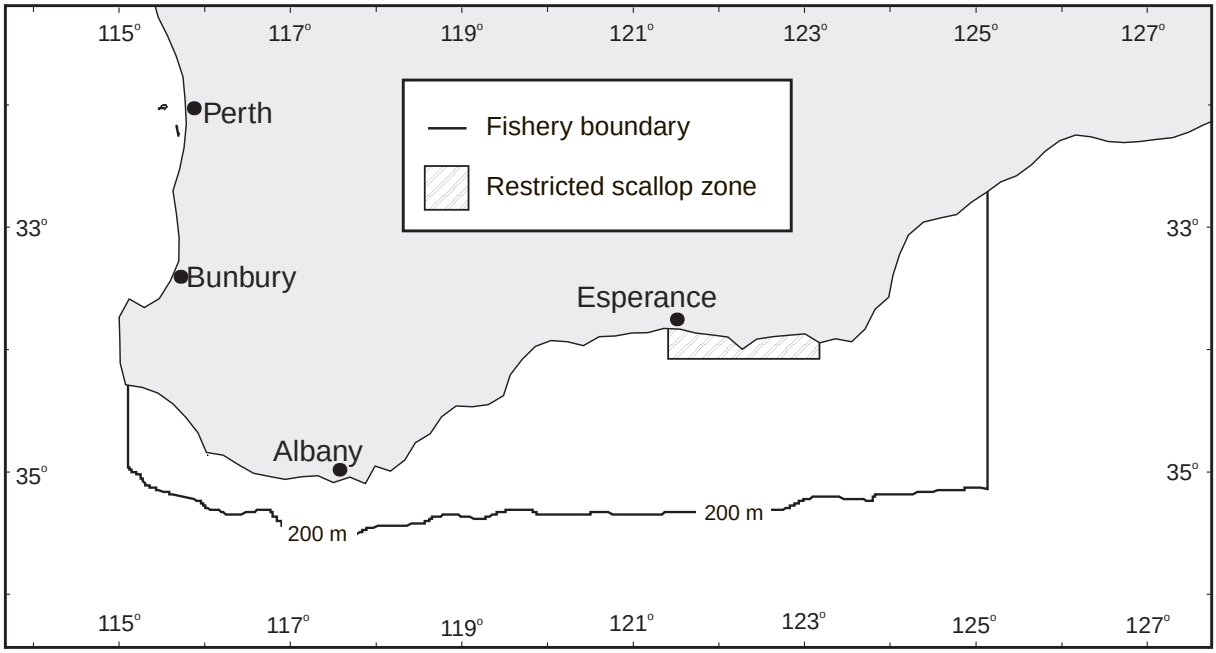

Figure 11 Map showing the boundaries of the trawlable areas off the south coast.