Resource Assessment Report

No.3

Scallop Resource

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Executive Summary

- Saucer scallops, *Ylistrum balloti* (formerly *Amusium balloti*), are fished using otter trawls in four separate fisheries in Western Australia. The Shark Bay Scallop Managed Fishery (SBSMF) is usually Western Australia's most valuable scallop fishery with boats licensed to take only scallops (11 Class A licenses) and boats that also fish for prawns (18 Class B licenses). The second largest scallop fishery is the Abrolhos Islands and Mid-West Trawl Managed Fishery (AIMWTMF). The South West Trawl Managed Fishery (SWTMF) and the South Coast Trawl fishery (SCTF) are multi-species fisheries that primarily target scallops.

- Management is generally based on limited entry, gear controls and seasonal closures however Shark Bay undertook a catch quota trial between 2014 and 2017 with an allocation between the Class A and B sectors and this has been formalised since 2017. The AIMWTMF is managed according to a “constant escapement policy” designed to ensure that a minimum level of scallop spawning stock is left at the end of each fishing season. This thereby helps to ensure that fishing does not deplete the residual stock to a level that then impacts on recruitment. The harvest strategy for the two key fisheries recognise that scallop recruitment is naturally highly variable and unpredictable. Thus, control rules are in place to provide the spawning stock with a very high level of protection in years when scallops are naturally low in abundance.

- The other two smaller scallop fisheries consist of a small number of licenses and low fishing activity in which fishing effort is related to the abundance of scallop in any given year, which can be highly variable (due to sporadic recruitment). Broader management objectives for all scallop fisheries are to; 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.

- Catches in these fisheries vary widely depending on the strength of recruitment, which is thought to be influenced by the strength of the Leeuwin Current and water temperature. Extreme environmental events, as was observed with a marine heatwave in the summer of 2010/11 had a significant impact on scallop stocks, particularly in Shark Bay and the Abrolhos Islands with closures of 3-5 years and variable recovery in these stocks since.

- In the SBSMF and AIMWTMF annual fishery-independent scallop surveys have been undertaken and provide size and abundance information from standardised sites. These data are used to determine an index of abundance that provides the basis for predicting the catch the following year and for setting the TACC in Shark Bay.

- The stock status of all the scallop fisheries in 2017/18 was sustainable but a significant stock decline was evident in November 2018 in northern Shark Bay to below the reference level requiring consideration for a recovery strategy.
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<tr>
<td>AIMWTMF</td>
<td>Abrolhos Islands and Mid-West Trawl Managed Fishery</td>
</tr>
<tr>
<td>AMM</td>
<td>Annual Management Meeting</td>
</tr>
<tr>
<td>BOM</td>
<td>Bureau of Meteorology</td>
</tr>
<tr>
<td>BRD</td>
<td>Bycatch reduction device</td>
</tr>
<tr>
<td>CAES</td>
<td>Catch and Effort System</td>
</tr>
<tr>
<td>CoA</td>
<td>Commonwealth of Australia</td>
</tr>
<tr>
<td>CPUE</td>
<td>Catch Per Unit Effort</td>
</tr>
<tr>
<td>DoF</td>
<td>Department of Fisheries (Western Australia)</td>
</tr>
<tr>
<td>EBFM</td>
<td>Ecosystem-Based Fisheries Management</td>
</tr>
<tr>
<td>ESD</td>
<td>Ecologically Sustainable Development</td>
</tr>
<tr>
<td>EPBC</td>
<td>Environment Protection and Biodiversity Conservation (Act)</td>
</tr>
<tr>
<td>FHPA</td>
<td>Fish Habitat Protection Area</td>
</tr>
<tr>
<td>FRMA</td>
<td>Fish Resources Management Act</td>
</tr>
<tr>
<td>MFL</td>
<td>Managed Fishery Licence</td>
</tr>
<tr>
<td>MSC</td>
<td>Marine Stewardship Council</td>
</tr>
<tr>
<td>SAFS</td>
<td>Status of Australian Fish Stocks</td>
</tr>
<tr>
<td>SBSMF</td>
<td>Shark Bay Scallop Managed Fishery</td>
</tr>
<tr>
<td>SCTF</td>
<td>South Coast Trawl Fishery</td>
</tr>
<tr>
<td>SWTMF</td>
<td>South West Trawl Managed Fishery</td>
</tr>
<tr>
<td>WA</td>
<td>Western Australia</td>
</tr>
</tbody>
</table>
1 Scope

This document provides a cumulative description and assessment of the Scallop Resource and all of the fishing activities (i.e. fisheries / fishing sectors) affecting this resource in Western Australia (WA). The overall resource comprises one scallop species, *Ylistrum balloti* that inhabit the inshore waters of four separate fisheries operating in the Gascoyne, West coast and South Coast bioregions. This species is captured by demersal otter trawls that operate in each bioregion.

The report contains information relevant to assist the assessment of the resource against Environment Protection and Biodiversity Conservation (EPBC) Act export approval requirements and which were part of pre-assessments for the Marine Stewardship Council (MSC) Principles and Criteria for Sustainable Fishing and for other reporting requirements, e.g. Status of Australian Fish Stocks (SAFS).

2 How the Department Operates

Fisheries management in WA has evolved over the last 40-50 years from a focus on managing catch of target species by commercial fishers to a fully integrated Ecosystem-Based Fisheries Management (EBFM) approach, which ensures that fishing impacts on the overall ecosystems are appropriately assessed and managed (Fletcher et al. 2010). In line with the principles of Ecologically Sustainable Development (ESD; Fletcher 2002), the EBFM approach also recognises that the economic and social benefits of fishing to all users must be considered.

Implementation of EBFM involves a risk-based approach to monitoring and assessing the cumulative impacts on WA’s aquatic resources from all fishing activities (commercial, recreational, customary), operating at a bioregional or ecosystem level. The level of risk to each resource is used as a key input to the Department of Primary Industries and Regional Development (DPIRD) Risk Register, which is an integral component of the annual planning cycle for assigning activity priorities (research, management, compliance, education etc.) across each bioregion. A summary of the Department’s risk-based planning annual cycle that is delivering EBFM in the long-term is provided in Figure 2.1.

To ensure that management is effective in achieving the relevant ecological, economic and social objectives, formal harvest strategies are being developed for each resource. These harvest strategies outline the performance indicators used to measure how well objectives are being met and set out control rules that specify the management actions to be taken in situations when objectives are not being met. The WA harvest strategy policy (DoF 2015) has been designed to ensure that the harvest strategies cover the broader scope EBFM and thus considers not only fishing impacts of target species but also other retained species, bycatch, endangered, threatened and protected (ETP) species, habitats and other ecological components (Fletcher et al. 2016).
3 Aquatic Environment

3.1.1 Shark Bay

The Gascoyne Coast Bioregion (Gascoyne) runs from the Zuytdorp cliffs, north of Kalbarri to the Ashburton River, south of Onslow (27° S to 21°46’ S; Error! Reference source not found.).

The marine environment of the Gascoyne Coast Bioregion represents a transition between the fully tropical waters of the North West Shelf and the temperate waters of the west coast. Offshore ocean temperatures range from about 22°C to 28°C, while the inner areas of Shark Bay regularly fall to 15°C in winter. Mean annual rainfall is low, ranging from 200 mm in the west of the Bay to 400 mm to the east.

The hydrology of Shark Bay is influenced by the Leeuwin Current (LC) which carries warm, low saline water southward down the WA coast. Substantial exchange of oceanic water in the northern waters of Shark Bay occurs through the broad Naturaliste and Geographe channels,
while a lesser exchange occurs in the Western gulf through the narrow South Passage (Figure 3.1).

### 3.1.2 West Coast and South Coast

The AIMWTFM operates within the Abrolhos Islands Ecosystem off the west coast of WA. The Houtman Abrolhos Islands is located in the northern section of the WCB approx. 60 km off the coast of Geraldton. The Abrolhos Islands are a complex of 122 low-lying islands and reefs located on the edge of the continental shelf (Johannes et al. 1983). There are three major island groups, the North Island-Wallabi Group, the Easter Group and the Pelsaert (Southern) Group, separated by the Middle and Zeewijk Channels, respectively.

The Abrolhos Islands are well-known for their high species diversity, coral reefs and unique mixture of temperate and tropical species. The Abrolhos are considered to be an ecological mid-point in a gradient that extends from the tropical ecosystems of Shark Bay, south along the shelf to the temperate communities at Rottnest Island (off Perth). However, being offshore, these islands catch more of the flow of the LC than the adjacent lagoons and shorelines. Due to the strong influence of the LC, the coral reefs of the Abrolhos Islands are the most southern extensive coral community along the west coast (CoA 2008).

Southwest WA has a Mediterranean climate, with most rainfall occurring during the winter months. Coastal water temperatures range from 18°C to about 24°C in the WCB and from approx. 15°C to 21°C in the SCB. The temperatures are generally higher than would be expected at these latitudes, due to the influence of the warm LC. From a global perspective, these waters are generally characterised by low levels of nutrients and high species diversity, including a large number of endemic species. Biological communities are mainly comprised of temperate species, which mix with tropical species in the northern regions of the bioregion. These characteristics are considered to be caused by the influence of the LC, the low level of terrestrial run-off and the relatively stable geological history of the south-west region (Commonwealth of Australia [CoA] 2008).
4 Resource Description

4.1 Scallop Resource

Although *Y. balloti* has an extensive distribution, it tends to be restricted to areas of bare sand in the more sheltered environments found in embayments and in the lee of islands and reef systems. 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 most appear to live no more than two years and usually attain a maximum size around 115 mm (Heald 1978, Dredge 1988). The
Timing of spawning is crucial to ensure temperatures and concentrations of phytoplankton are adequate for larval development and water temperatures between 18 °C and 20°C are optimal for larval survival (Cragg 2006) and that they could not survive temperatures above 24°C (Wang 2007). Spawning is seasonal and the timing is variable for latitudes with spawning occurring up to eight to nine months in Shark Bay and only two to three (summer) months on the south coast. Even with more protracted spawning most of the recruitment to the populations appears to arise from spawning in a few months (i.e. April to July, in Shark Bay). 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, b).

Saucer scallops are broadcast spawners, releasing their eggs and sperm into the surrounding waters for fertilisation to occur in the water column (Dredge 1981). During this period, larvae are susceptible to being passively transported by tides and currents whilst in the water column. Once settled, saucer scallops only move short distances, primarily for predator avoidance but once disturbed can lift themselves off the bottom and swim up to 23 m (Joll 1989) making them available for capture using demersal otter trawl nets.

4.2 Selection of Indicator Species for Resource

Following the adoption by the Department in 2002 of the ESD policy (Fletcher 2002), the process for monitoring and assessing the aquatic resources of WA has involved allocating the species within each bioregion into one of five suites – Estuarine, Nearshore, Inshore Demersal, Offshore Demersal and Pelagic (Department of Fisheries 2011). A risk-based approach is used to quantify the risks to sustainability of the stocks based on biological and other criteria to develop a risk matrix. From the list of species within a suite for a given bioregion, indicator species are then identified based on their vulnerability to fishing and other considerations, such as whether they are target species in major fisheries, and their economic and social values (Lenanton et al. 2006). The status of these indicator species is assumed to represent the status of the entire suite and therefore the resource. The same concept has also been applied to determine appropriate indicator species for the invertebrate resources of WA.

However, for the Scallop Resource, *Ylistrum balloti* is the only indicator species.
5 Species Description

5.1 Saucer scallop (*Ylistrum balloti*)

![Figure 5.1. The saucer scallop, *Ylistrum balloti*.](image)

**5.1.1 Taxonomy and Distribution**

Saucer scallops in Australian waters are now classified as *Ylistrum balloti* (formerly *Amusium balloti*) following a recent revision of the genus *Amusium* (Myrnhardt et al. 2016). This species is distributed from Esperance in Western Australia, across the tropics, to the southern coast of New South Wales.

**5.1.2 Stock Structure**

Saucer scallops occur along most of the coast of Western Australia, but given the vast length of this coastline and the potential for regional differences in recruitment, four functionally independent management units are the SBSMF, AIMWTMF, SWTMF and SCTF.

Saucer scallop larvae from the east and west coast of Australia 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, Puslednik (pers. comm.) found a difference of 3.3% sequence divergence based on 16S ribosomal mtDNA between the eastern and western populations of saucer scallops, and within WA. The largest difference was found at the 16S gene with 1.1% divergence within populations of WA. These differences are not considered sufficient to treat them as different species.

A study of the genetic diversity of saucer scallops between and within the populations in WA was undertaken by O’Brien (2003). Scallops were tested from 3 different locations within the Abrolhos Islands (Wooded Island, Gee Bank and Pelsaert Island) and from Shark Bay but no samples collected from the south-western WA stocks (e.g. Rottnest Island). The study showed
high degree of gene exchange between Shark Bay and the Abrolhos Islands and suggests a single genetic stock. Given the results of hydrodynamic modelling, differences in reproductive cycle (Joll and Caputi 1995a), the relatively short larval life (2-4 weeks), and little inter-annual correlation between relative abundances of this species in these different areas, however, it is unlikely that there is a strong source-sink relationship between adjacent populations in Shark Bay and Abrolhos Islands. Thus, it is appropriate to treat them as functionally distinct stocks for the purpose of management. The results of this earlier work was reinforced by genetic analysis completed in 2016 with samples from Shark Bay, Abrolhos Islands, the south west and south coast trawl which indicated that at least two genetic stocks of *Y. balloti* are present between Shark Bay and Israelite Bay (Lukehurst et al. in prep). There may also be the presence of a third cluster, in the Abrolhos Islands, which appears to be an intermediate location. In addition, we found a significant isolation by distance profile indicating that local recruitment is occurring as a result of ecological barriers to gene flow. However, it is important to note that there is potential for undetected local adaptation because we examined neutral loci. These results have important implications for translocation programs as knowledge of population structure is vital for maintaining genetic variation in wild populations.

5.1.3 Life History

The sub-sections below provide an overview of the life history characteristics of the *Ylistrum balloti* with a summary of the relevant biological parameters used in stock assessments presented in Table 5.1.

5.1.3.1 Life Cycle

The timing of the reproductive cycle varies with latitude in WA (Joll and Caputi, 1995a) with the cycle in Shark Bay being quite different to other key scallop fisheries. Within Shark Bay there is also a difference between northern Shark Bay and Denham Sound which have little connectivity between scallop stocks due to the circulation patterns within the two areas (Kangas et al. 2015). The reproductive cycles from Abrolhos Islands to the south coast are more similar. A current FRDC (2015/016) funded study is underway to deduce if changes in the timing of the reproductive cycles as described by Joll and Caputi (1995a) have occurred in recent years in each of these fisheries and this project will be completed in late 2018. Daily rings counts are counted from small juvenile scallops and are being used to determine an approximate month of spawning, although it should be noted that this only indicates successful spawning and settlement at the time of sampling and not necessarily all spawning events.
Table 5.1. Summary of biological parameters for *Ylistrum balloti*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value(s)</th>
<th>Comments / Source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Growth parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_\infty$ (mm)</td>
<td>102 mm- 109 mm</td>
<td></td>
</tr>
<tr>
<td>$K$ (year$^{-1}$)</td>
<td>0.0515 - 0.0588</td>
<td></td>
</tr>
<tr>
<td>$t_0$ (years)</td>
<td>1 June (Shark Bay)</td>
<td></td>
</tr>
<tr>
<td>Maximum age (years)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Maximum size (mm)</td>
<td>150 mm shell height SH</td>
<td></td>
</tr>
<tr>
<td>Natural mortality, $M$ (year$^{-1}$)</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td><strong>Length-weight parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(mature)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a$</td>
<td>0.552</td>
<td>$W = a \ (SH) - b$, changes seasonally with gonad development</td>
</tr>
<tr>
<td>$b$</td>
<td>32.406</td>
<td></td>
</tr>
<tr>
<td><strong>Reproduction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Generally gonochoristic, broadcast spawners but some</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hermaphrodites</td>
</tr>
<tr>
<td><strong>Maturity parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A_{50}$ (years)</td>
<td>8 months</td>
<td></td>
</tr>
<tr>
<td>$A_{95}$ (years)</td>
<td>10 months</td>
<td></td>
</tr>
<tr>
<td>$L_{50}$ (mm)</td>
<td>80 mm SH</td>
<td></td>
</tr>
<tr>
<td>$L_{95}$ (mm)</td>
<td>89 mm SH</td>
<td></td>
</tr>
<tr>
<td><strong>Fecundity</strong></td>
<td>3.20 x 10^5 to 2.65 x 10^6 (at 85 to 107 mm SH)</td>
<td>Batch / Annual fecundity</td>
</tr>
<tr>
<td><strong>Size-fecundity parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F = (a \ SH - b)^3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a$</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>$b$</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Spawning frequency</strong></td>
<td></td>
<td>Potentially multiple spawners, spawning period 3-8 months</td>
</tr>
</tbody>
</table>

Joll and Caputi (1995a) found that in 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 to December). 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. 1995a).

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 °C and 20 °C were optimal for larval survival and that they could not survive temperatures above 24 °C. Research conducted by Joll and Caputi (1995a), has found that the relationship between changes in gonad weight and water temperature to be fairly tenuous. However, our recent study has found that the spawning period for *Y. balloti* in WA appears to be driven by water temperatures where 19 to 24°C appears to be the optimal temperature range. This supports the protracted spawning months in the northern regions of the State in Shark Bay and Abrolhos Islands and the reduced spawning months in the southern regions of Rottnest Island and the South Coast.

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 1995 b). 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). In the current study protracted spawning is evident in Shark Bay. In the northern scallop grounds, spawning is predominantly between May and September when temperatures begin to decline from 25 to 20°C. In Denham Sound, there appears to be two distinct spawning peaks during July/August when temperatures are at their lowest ~ 21°C and also during February/March at the peak of summer (~25°C).

Previous research has indicated that the reproductive cycle of scallops in the Abrolhos Island begins with the onset of gametogenesis from August to March/early April, with spawning occurring 4–8 weeks after the onset of gametogenesis (Joll and Caputi 1995a). Ongoing research (FRDC 2015/026) has focused on estimating the month of spawning from daily ring count information, supported by the gonadal developmental staging and length frequency data, which suggests a protracted spawning period from September to May, which can be separated into early (Sep-Jan) and late (Feb-May) spawning phases (Figure 5.2).

The early spawning over the summer months is likely to produce recruits five months later between February and May. Some of the faster growing individuals may also spawn towards April/May. The recruiting juveniles are detected during February (< 60 mm SH), but they appear to be more catchable during May and has been observed by fishers during the latter part of their fishing season who actively avoid concentrations of small scallops when detected. Early spawned recruits grow rapidly and become the larger sized mature adults (>90 mm SH) (residual scallops) and are observed during the November survey and these come into spawning condition between September and January. This cohort is the larger residuals fished the following year.

The later spawning between February and May produces 0+ recruits that are captured during the November survey at around 6-8 months of age (~60-80 mm SH) (Figure 5.2). These late spawned recruits mature over summer and become mature adults by April/May and come into spawning condition. A proportion of this cohort will also be harvested during the fishing season.
prior to spawning (pre-spawned scallops) and the rest will grow through to be sampled during the November survey as 1+ residual scallops.

The commercial fishery in the Abrolhos Islands historically operated between April and June and therefore it appears that fishers targeted the older, already spawned individuals as well as scallops at their optimal meat condition just prior to spawning. The proportion of scallops which resulted from either an early or late spawning progeny is likely to vary between years as observed with differences in size composition of scallops during November surveys. Thus the timing of spawning between September and May and larval developmental/juvenile period in the following six/eight months are the critical periods when environmental factors can significantly influence larval survival, retention, settlement and growth and survival of juveniles.

In the SWTMF, the spawning period extends between October and March when temperatures are between 19 and 22°C. On the South Coast, the spawning period ranges between November and February and peaking over the summer months (December/January) when temperatures are between 19 and 20°C.
Figure 5.2. Estimated month of spawning indicated by daily ring counts from scallops (30-60 mm SH) collected between 2012 and 2016 from stocks in the Northern Shark Bay, Denham Sound, Abrolhos Islands, Rottnest Island and the South Coast regions (solid bars). This is overlayed with mean monthly sea surface temperatures from these regions for the periods 1981-2009 (green) and 2010-2016 (red).

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 below in Figure 5.3.
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 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 *Y. 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 *Y. 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 *Y. 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).
5.1.3.2 Habitats and Movements

Although *Y. 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 m² (Dredge 1988; Kailola et al. 1993). Joll (1994) recorded average densities in Shark Bay of 2 per m² with peak densities of 7 per m². Salinity is another ecological factor that clearly limits distribution and fairly clearly delineates scallop distribution in Shark Bay to areas of oceanic salinities whereas oceanic conditions prevail in all of the other scallop fisheries in WA. In Shark Bay, scallop distribution is generally in 10 to 30m whilst in the Abrolhos Islands scallops generally occur in depths of 20-40 m.

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 and b and Raby et al. 1994). The behaviour of larval *Y. balloti* within the water column is poorly understood and collection spat of *Y. balloti* has not been successful (Sumpton et al. 1990, Robins-Troeger and Dredge 1993).

Adult scallops differ from most bivalve molluscs because of their ability to swim. This swimming ability is thought to be an adaptation from fleeing predators. The best scallop swimmers are species of the genus *Amusium/Ylistrum* 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 *Y. 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.

5.1.3.3 Age and Growth

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 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, within approximately one year (Joll and Caputi 1995a). Saucer scallops have been recorded reaching 150 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).

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 75mm 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 Pectinidae, 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.

Seasonal variation in the size and condition of the adductor muscle size for *Y. balloti* has been observed in Shark Bay (Joll and Caputi 1995a; Figure 5.) 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).

![Figure 5.4](image-url) Seasonal changes in adductor muscle wet weight from Shark Bay and the Abrolhos Islands between 1983 and 1986 (from Joll and Caputi 1995a.).
The information on the seasonal variation of the adductor muscle weight has been important for refining the harvest strategy to optimise the value of the catch. In particular this information was used since 2005 as the basis for opening the scallop fishing season earlier to enable fishers to focus on scallops when the meat weight (and quality) was at its maximum.

Given the importance of understanding the seasonal and spatial variation in meat weight the Department initiated several research studies since 2005. Opportunistic meat samples have been obtained from scallop surveys and from commercial boats during fishing operations. These scallop adductor muscle samples are individually weighed and recorded and this provides meat weights in grades compared to the length (shell height) frequency distribution at different times of the year. Grades are adductor muscle ‘pieces per 454 g’ (= 1 pound) graded as < 20, 21/30, 31/40, 41/50 and 50+. The grades of scallop meat are taken from scallops ≥ 83 mm SH. Over the last three years, meat weight samples have been collected in Shark Bay during fishery independent surveys which indicate that the seasonal cycles (Figure 5.5 and 5.6) in gonad condition (and adductor muscle weights) generally reflects that observed by Joll and Caputi (1995).

Figure 5.5 Changes in meat size in Denham Sound between November 2015 and November 2018.
Figure 5.6 Changes in meat size in Norther Shark Bay between November 2015 and November 2018.

During an 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 adductor muscle weight for a given shell height apparently becomes much larger (Figure 5.7).

Figure 5.7 Relationship between *Y. balloti* shell height (mm) and adductor meat weight in Denham Sound during February 2008 for mature (square) and immature scallops (diamond)
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) focusing 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. (2015) indicated 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 in the time they were at liberty. 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 shell height showed a monthly growth rate around 3 mm whilst individuals between 90 and 105mm 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).

Recently returned tagged scallops from an ongoing translocation tagging project in the Abrolhos Islands has shown fast growth in small individuals with scallops in the size range 50 – 70 mm SH growing approximately 20 to 30 mm between March and July 2017. Further sampling will occur in November 2017 to determine longer term growth rates if scallops are recovered.

5.1.3.4 Natural Mortality

The natural mortality coefficient, $M$, of the saucer scallop $Y. balloti$ 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 three years and 0.6 % after 4 years (Dredge 1985).

Since 2005, the daily catch rate data have been used to determine estimates of weekly harvest rates (which provide an approximation to weekly mortality rates) to gain an understanding of the rates of mortality of scallops in different years. The initial or highest catch rate within the first five days (allowing initial searching) is compared with the last day (or one or two days earlier if not all fleet still fishing) as the final catch rate and the difference between the two (decline in catch rate) is calculated for the days fished and converted as a weekly decline by

$$\frac{(CPUE_{\text{initial}}-CPUE_{\text{final}})/CPUE_{\text{initial}}}{\text{(days fished/7)}}$$
show annually variable weekly harvest rates between 0.15 and 0.39 wk\(^{-1}\) in Denham Sound and 0.16 and 0.31 wk\(^{-1}\) in northern Shark Bay (Table 5.2). Similarly, Dredge (1985) determined that Z (total mortality) for a given statistical fishing block in central Queensland did not exceed 0.16 wk\(^{-1}\).

Table 5.2 Weekly harvest rates (by scallop boats) for Denham Sound and northern Shark Bay 2005 to 2010.

<table>
<thead>
<tr>
<th>Year</th>
<th>Denham Sound</th>
<th>Northern Shark Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.15</td>
<td>NA</td>
</tr>
<tr>
<td>2006</td>
<td>0.22</td>
<td>0.33</td>
</tr>
<tr>
<td>2007</td>
<td>0.39</td>
<td>0.25</td>
</tr>
<tr>
<td>2008</td>
<td>0.19</td>
<td>0.17</td>
</tr>
<tr>
<td>2009</td>
<td>0.28</td>
<td>0.18</td>
</tr>
<tr>
<td>2010</td>
<td>0.30</td>
<td>0.31</td>
</tr>
</tbody>
</table>

With resumption of fishing in Shark Bay in 2015, under a trial quota arrangement and a restructure in the scallop fleet and much reduced number of boats fishing, this methodology is not comparable. However, scallop fishing within a small spatial area within the Hummocks fishing grounds in the Abrolhos Islands in 2017, by four boats, provided an opportunity to determine a weekly harvest rate for this region of 0.17. A significant depletion in abundance was evident over the 40 days of fishing (Figure 5.8)

![Graph of daily cumulative catch and catch rate for four boats fishing within the Hummocks area of the Abrolhos Islands during 2017](image)

\[ y = -0.0009x + 173.18 \]
\[ R^2 = 0.8033 \]

Figure 5.8 Daily cumulative catch and catch rate for four boats fishing within the Hummocks area of the Abrolhos Islands during 2017. Red line indicates approximate industry limit for cessation of fishing.
As *Y. balloti* has a very short life-cycle with highly variable abundance it is appropriate for most scallop fisheries to operate under an escapement policy i.e. fish the stock down to a certain level leaving a residual stock for the following year. As expected, the estimated mortality rates are variable between years. These estimates can be calculated using daily commercial catch rate information as they are considered to be informative but are not currently used as part of the formal stock assessment.

Short-term, repeat recapture survival of scallops varies seasonally with higher mortality over summer and survival around 90% in winter (Chandrapavan et al. 2012). 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.

Between 2005 and 2011 discard mortality in Shark Bay was likely to be lower than historically due to changes to management arrangements (see Appendix 10.1). From 2005 both the prawn and scallop fleets could retain scallops during the warmer pre-spawning months at a time when discard mortality is higher compared to earlier years when the scallop season would not generally open until April/May resulting in the prawn fleet discarding scallops in March/early April since they could not retain them. The revised strategy since 2005 was for both fleets to retain scallops from when their respective fisheries opened and aimed to optimally utilise the scallop stocks resource. Some discarding still occurs, particularly by the prawn fleet during the scallop spawning closure period between May/June and July (when scallop boats do not operate and prawn boats cannot retain scallops) but this is during a cooler period with associated discard mortality at its minimum.

Since the re-opening of fishing for scallops in 2015 after the extreme heatwave of 2010/2011, the Shark Bay scallop fishery has been operating under a trial quota harvesting arrangement and therefore there is higher potential for discarding as operators choose when to retain and optimise the size and quality (and value) of the scallops when operating outside the current mandatory spawning closure period (June to July/August).

All other scallop fisheries still operate under an escapement policy.

### 5.1.3.5 Reproduction

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). *Ylistrum balloti* are mature at around 90 mm shell height at approximately one year (Joll and Caputi 1995a) although smaller scallops (~70 mm shell height) were found with maturing gonads (Williams and Dredge 1981). The number of oocytes
per gonad for *Y. balloti* between 85 and 107 mm shell height was $3.20 \times 10^5$ to $2.65 \times 10^6$ (Dredge 1981). Further evaluation of reproductive condition and cycles of scallops in Shark Bay and Abrolhos Islands have been undertaken between 2015 and 2017.

Variations in gonad weight are highly cyclical, with minimum gonad weight in Shark Bay between January and March and maximum gonad weights occurring around July to August (Joll and Caputi 1995a, Figure 5.4). Gonad weight continue to increase over a period of three to four months following the end of the resting period and variations in gonad weight during this period indicated that partial spawning may occur before the time of peak gonad weight. Joll and Caputi (1995a) suggested that spawning may follow a lunar cycle. The key spawning periods as currently understood are described in section 5.1.4.1 and a current FRDC project (FRDC 2015/026) due for completion in 2019 is providing an increased understanding of the reproductive cycles of scallops within WA.

5.1.3.6 Factors Affecting Year Class Strength and Other Biological Parameters

Recruitment is highly temporally and spatially variable (Mueller et al. 2012). There is a weak correlation between recruitment strength and both water temperature (May to August) and LC strength (May to August). Lenanton et al. 2010 and Caputi et al. 2010 suggested that if both of these environmental indices are low then there is an increased probability of good recruitment however the main factors influencing recruitment success remain poorly known (Heald and Caputi 1981, Joll 1994, Joll and Caputi 1995b). Larval advection and retention, temperature, food availability and spawning stock abundance are likely to be key factors. It is also quite possible that the LC may affect spawning or fertilisation success because of associated warmer waters (Joll and Caputi 1995b).

Generally, high sea levels corresponding to strong LC correlate with poor recruitment of scallops. Although the LC is likely to weaken over the coming century, it has experienced a strengthening trend during the past two decades, likely due to natural variability (Feng et al. 2012). The strong La Niña conditions have generally resulted in below-average scallop recruitment, and the marine heat wave event off the WA coast (centred on the Gascoyne and Mid-West regions) in February-March 2011 contributed to the record low recruitment levels and high mortality of residual scallops in Shark Bay and Abrolhos Islands (Pearce et al. 2011). Similar extreme events may occur more often in the future with the trend of rising ocean temperatures.

The flow of the LC may impact larval movement dynamics as it influences the water temperatures and current strength which are critical factors for passive particles such as scallop larvae which stay in the water column two to four weeks (Rose et al. 1988). In Shark Bay, the water temperatures generally increase from $-19^\circ$C to $-24^\circ$C during the spawning period. The adverse effects of temperatures higher than the optimal range, as experienced during the heat wave event can result in poor spawning success due to high larval mortality. However the impact of cooler temperatures outside of this range is not as clear, although increased stock recovery during 2016 in Shark Bay and Abrolhos Islands does support a positive influence of
cooler than average temperatures. After spawning, prevailing oceanographic conditions can greatly influence settlement patterns evidenced annually by varying settlement strength and locations in all scallop fisheries. The spawning period between May and September is when the LC is normally at its weakest. The strong El Niño event of 2014/15 resulted in average to below average sea levels and overall a very weak LC, coinciding with the strongest stock recovery since 2011 despite low spawning stock levels.

Highly variable settlement of saucer scallops been observed in the AIMWTMF with very high settlement in the fishery area observed in 2002 and 2004 and more recently in the Hummocks region of the Abrolhos Islands in 2017. An examination of the likely environmental factors in recruitment variability is currently underway with the FRDC 2015/026 project.

The wind regime is stronger during the spawning months and weaker during the post-spawned months during settlement and growth of juveniles. This suggests that wind dynamics and surface currents can also significantly influence larval movement and flushing. Stronger southerlies can also drive the inshore Capes Current further north and inundate the Abrolhos Islands. The seasonal dynamics of the Capes Current is not well understood at present. The increased concentration of Chlorophyll A between April and July due to the strengthening of the LC aligns with increased food source for the newly settled and/or juvenile scallops.

An extreme marine heatwave in 2010/11 caused high mortality and apparent recruitment failure of Y. balloti in Shark Bay and Abrolhos Islands (Caputi et al. 2015) with subsequent unprecedented low stock levels resulting in the closure of these fisheries to allow recovery. Prior to the heatwave there was a very weak relationship between the spawning stock and recruitment but a stock recruitment relationship is now evident in both Shark Bay and the Abrolhos Islands however overall abundance is still strongly influenced by environmental factors when stock levels rise above the limit reference levels (see Stock Assessment Section).

See Section 7.3.2 for information on how climate change may affect recruitment, growth etc. of the resource.

5.1.3.7 Diet and Predators

Scallops are active suspension-feeding bivalves, which rely on suspended detrital material and phytoplankton as their food source (MacDonald et al. 2006). They are non-siphonate, ciliary suspension feeders. Water enters the mantle cavity along the ventral and anterior edge and exits through the posterior exhalent openings (Hartnell 1967). The food is trapped through ciliary action within the gills and the food is transported towards the mouth.

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/Abacus sp. 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 Y. balloti showed a consistent and vigorous swimming response to Thenus orientalis, blue swimmer crab Portunus armatus 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 *Y. 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).

### 5.1.3.8 Parasites and Diseases

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

### 5.1.4 Inherent Vulnerability

The biology and behaviour of scallops makes them low to moderately vulnerable to fishing. Depletion estimates generally indicate that their catchability is around 30-40% and their escape response and catchability varies with size with small animals being less vulnerable to the gear as well as escaping through net mesh openings. Scallop growth is rapid with scallops attaining sexual maturity within one year, generally harvested at around 1 year of age and living not much beyond their second year. They are highly fecund with a short planktonic larval stage (approx. 3-4 weeks) usually with low to moderate dispersal. Because they are broadcast spawners, they may require a threshold density level in order to achieve spawning success.

Scallops are able to swim but they fatigue quickly (Joll 1989) and therefore generally have limited movement or mixing amongst regions. Modelling of larval advection in Shark Bay indicated low connectivity between areas with entrainment within areas due to the circulation patterns and eddies (Kangas et al. 2015). Similar processes are likely to occur in the Abrolhos Islands as well as the smaller southern scallop fisheries.

The only method of capture is by demersal trawl. There is a risk of hyper-stability in catch rates as aggregations of scallops are normally targeted. Major stock declines that have occurred have followed extreme environmental events with recovery after management intervention (or cessation of fishing due to uneconomic abundances) has been between 3 and 5 years in Western Australia. The major stock declines in Shark Bay and the Abrolhos Islands indicated spawning stock abundance levels at which recruitment can be impaired, the first for this species. There is evidence however that strong recruitment can occur following significant reductions in spawning biomass indicating that the key recruitment driver in most years is environmental. Further, whilst the level of recruitment often varies annually, associated with environmental conditions, there is generally some recruitment in most years.
6 Fishery Information

6.1 Fisheries / Sectors Capturing Resource

Scallops are fished in Shark Bay by dedicated scallop trawlers and by prawn trawlers and solely by scallop trawlers in the Abrolhos Islands and the South Coast, whilst the SWTMF is a multispecies fishery primarily targeting scallops. All boats use low-opening demersal otter trawls and each fleet has a standard net size and gear configuration. No recreational or traditional fishers target saucer scallops.

In 2002, bycatch reduction device (BRD) trials were commenced in SBSMF and the AIMWTMF to test different turtle exclusion devices (TEDs) or grids in the nets. Since 2003, no fishing for scallops or prawns may be carried out in these fisheries unless all otter trawl nets, except for try nets, are fitted with a BRD when in use. Specifically, a rigid inclined barrier (installed at an angle no greater than 60°), which comprises vertical bars spaced a minimum of 200 mm apart, must be attached to the circumference of the net (DoF 2004; Figure 6.1). This will guide animals and/or objects (including turtles) towards an escape opening forward of the grid, which must be at least 750 mm wide transversely across the net and 500 mm along the net from the mid-point of the width measurement.

![Diagram](https://example.com/diagram.png)

**Figure 6.1.** Diagrammatic representation of the type of bycatch reduction device used in the scallop trawl fisheries (Source: DoF 2004).

Four licences are permitted to trawl for scallops and demersal scalefish of the Class Osteichhtyes (except Australian salmon *Arripis trutta*, small pelagic fish as defined in the *South Coast Purse Seine Management Plan 1994* and any fish specified under Commonwealth control or management in the *Offshore Constitutional Settlement 1995*).

Trawling takes place at night, in waters less than 40 m and each tow can last in duration from 20 minutes to up to 120 minutes, depending on scallop abundance. Tow speed is around 2.5 to
3.5 knots. Boats that operate as demersal fish trawlers are rigged with a single net that has a larger mesh than the scallop nets.

Trawling is only permitted between 1 May and 31 October in any one year with total area closures near population centres.

6.2 SBSMF

6.2.1 History of Development

The history of the scallop fishery is outlined in Joll 1989, Harris et al. 1999 and Kangas et al. 2011 with limited entry and the Management Plan developed in 1987. At its effort maximum, fourteen scallop boats and at the time 35 prawn boats could operate in Shark Bay although scallops were retained by prawn trawlers earlier than the establishment of the SBSMF since the prawn fishery commenced in the early 1960’s.

Restructuring of the prawn fleet (see Shark Bay prawn RAR) through VFAS programs saw reduction from 35 to 27 boats in 1991 and then a further reduction with gear configuration changes in 2006/07 to 18 boats. In 2010, a VFAS was also implemented with the removal of 3 scallop licenses so the 2017 fleet composition is 18 prawn (B Class) and 11 (A Class boats). Due to internal company restructures not all 11 scallop boats operate, with on four boats fishing during 2017 and seven in 2018.

The SBSMF is based on a single species, *Ylistrum balloti* and is the most valuable scallop fishery in WA. Since 1987, fishing effort for the dedicated scallop fleet has generally reflected the abundance (and economic efficiency) of scallops whereas prawn boats could retain scallops by either targeting or as incidental catch (Figure 6.2). In 1988, a guideline of 80%:20% scallop take by the scallop and prawn fleets respectively was introduced and in 2010, the catch share arrangement was formalised. In 2015 a trial quota arrangement was implemented.
Figure 6.2. Annual total retained catches (tonnes whole weight) for scallop and prawn fleet and scallop fleet fishing effort (hours trawled) in the SBSMF between 1982 and 2017/18. Fishery was closed between 2012 and 2014. Since 2015 the fishery has been operating under a quota trial arrangement.

6.2.2 Current Fishing Activities

A summary of key attributes of the current SBSMF and the fishing fleet is provided in Table 6.1. 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. 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 6.3).

Historically the fishery generally closed between November and around April. The closure generally aligned with the seasonal closure of the Shark Bay Prawn Managed Fishery but the A-class boats usually ceased 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 opened depending on meat size in late February or early March prior to the main-scallop spawning period until the fishery closure in 2012. Since 2015 a trial quota arrangement has been in place combined with a two/three month spawning closure period between May/June and August. In 2016/17 the A Class boats fished in December to February whilst prawn fishers retained scallops during their prawn season other than during the scallop spawning closure. In 2017/18 A Class Boats fished in January to June with a few B Class boats also fishing for scallops using A Class nets during this period whilst the rest of the B Class boats fished during their prawn season.
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 6.2). 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. Between 2005 and 2010 Denham Sound generally opened for the scallop boats early in the season with prawn boats only fishing this area after 1 August. During the scallop season A Class boats were 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). However, between the years 2005 and 2010 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). A Class boats have been limited to 13 crew and B Class B boats are generally limited to six crew members, however, the CEO approved up to eight crew members since the catch share arrangement. After moving to individual transferable quotas from 2015, boats using A Class scallop nets have been able to fish for 24 hours in any area.

Historically, scallop trawling by A Class boats has normally been undertaken during both day and night. Trawl shots typically vary from 30 minutes up to three hours, depending on the catch rates. Trawling tow speed is around three knots. Scallops are shucked and processed at sea and frozen and majority is exported with lesser quantities sold locally or as half shell. In the last two years, several licensees have brought a proportion of their landed catch as whole shell and processed the meat in interstate or local factories.

Table 6.1. Summary of key attributes of the commercial SBSMF 2017

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing methods</td>
<td>Demersal otter trawl</td>
</tr>
<tr>
<td>Fishing capacity</td>
<td>Scallops: 280.7m (154 ftm), 11 licenses, 4 boats in 2017</td>
</tr>
<tr>
<td></td>
<td>Prawns: 724 m total headrope, 18 boats, 4 x 5.5 ftm (10.1 m) nets</td>
</tr>
<tr>
<td>Number of licences</td>
<td>18 prawn 11 scallop (100/36% respectively active)</td>
</tr>
<tr>
<td>Number of vessels</td>
<td>18 prawn 4 scallop</td>
</tr>
<tr>
<td>Size of vessels</td>
<td>22.0-24.9m</td>
</tr>
<tr>
<td>Number of people employed</td>
<td>80-90 directly</td>
</tr>
<tr>
<td>Value of fishery</td>
<td>2017: $18.4M Level 3</td>
</tr>
</tbody>
</table>
Fishing Methods and Gear

The total net headrope capacity for the scallop fleet was 358.4 metres (196 fathoms). Scallop boats are authorised to operate with two 12.8 metre nets (7 fathoms [ftm]) and there were 14 scallop licenses in the fishery. In 2010, a VFAS was approved for the fishery and three licences were removed, reducing the scallop fleet 11 licenses. The restructure also resulted in the total net headrope capacity of the scallop fleet being reduced to 281.6 m (154 fathoms; Sporer et al. 2012b). The scallop fleet uses a 100 mm diamond mesh codend to select for scallops greater than 85 mm shell height, while the prawn fleet uses a 50 mm diamond mesh codend to select for prawns (Kangas et al. 2012). Mesh selectivity (traditional diamond mesh) experiments were undertaken in WA (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 WA (Chandrapavan et al. 2012, Kangas et al. 2012) and in Queensland (Courtney et al. 2007, 2008) indicating that improved scallop size selectivity can be achieved using square mesh cod-ends.

For the prawn fleet, historically the regulations allowed the boats to tow two 8 fathom nets. However, four, 10.97 m (6 ftm) or three 14.83 m (8 ftm) otter trawl nets, each with a headrope length of greater than five metres, but not exceeding 10.97 m (six ftm net) or 14.83 m (8 ftm net) respectively were permitted (by Exemption) to generate improved economics. In 2018, the regulations were changed to allow unitisation of net headrope with the total allocation.
remaining as per existing limit but setting unit allocations to each licence holder. This may result in operators trialling alternative net size and gear configurations in the future and may result in further restructuring within the fleet.

Otter boards should not exceed 2.44 metres in length and 0.91 metres in breadth. One otter trawl try-net can also be used with a headrope not exceeding five metres in length (but see below for new initiative in the use of quad gear). Boats also fish under an exemption to use ‘bison’ otter boards outside the prescribed dimensions.

The otter boards are attached to the extremities of each net at the opening (Figure 6.4). The height of the fishing gear is set by the height at the point where they are connected to the otter boards. Forces produced by water flowing over the otter boards open the trawl nets laterally. The lateral spread is vital to the catching efficiency of trawl gear and determines the area swept. Generally, the headrope and ground rope is spread between 75 % and 85 % of their length. Attached to the footrope is the ground chain, which is limited to 10 mm diameter. The ground chain travels across the sea floor and disturbs prawns and scallops so they rise from the seafloor and into the oncoming net. Low opening nets have the headrope as a lead-ahead, which acts as a net veranda and is set in front of the footrope to ensure that the prawns disturbed by the ground chain do not pass over the headrope. This also maintains the catch efficiency of the nets. Generally each tow by scallop boats is between 20 and 150 minutes depending on scallop abundance and prawn trawls are approximately 50 to 180 minutes in duration depending on prawn/scallop abundance.

![Figure 6.4 a) Standard twin-rig otter trawl; b) Standard quad-rig otter trawl (Source: adapted from Sterling, 1998).](image)

The scallop and prawn fleet is currently using bycatch reduction devices (BRDs) in the form of large object excluders (i.e. grids), and the prawn fleet also use finfish excluders (such as square mesh panels). BRDs were made mandatory throughout the fleet in 2002/2003. The whole prawn fleet also has ‘hopper’ or ‘well’ sorting systems on board. This system allows for
the catch to remain in recirculating seawater for an extended period thereby maximising the survival of discarded species.

6.2.3 Illegal, Unreported or Unregulated Fishing
Negligible.

6.3 AIMWTFM

6.3.1 History of Development

The Abrolhos Islands area was first fished commercially for scallops during the late 1960; however, no fishing occurred in the region between 1969 and 1972 (Joll 1989a). The fishery then operated intermittently over the next five years, with catches ranging from 0.3 to 6.7 t of scallop meat landed by between three and six vessels. After a poor season in 1977 (0.8 t meat weight), fishing for scallops again ceased during 1978 – 1979 (Joll 1989a) but recommenced in 1980, with just two vessels in operation. Both catches and vessel numbers increased over the next few years, primarily due to an increase in scallop price, improvements in operating efficiency, an apparent increase in scallop stocks, and a decrease in the problems associated with larval nematodes (Joll 1989a).

Following a freeze on vessel numbers in the Shark Bay fishery in 1983, a large number of operators transferred their efforts to the Abrolhos grounds causing vessel numbers to escalate dramatically (DoF 2004). This increase in fishing pressure greatly reduced the catch share among 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 1989a). In 1986, the fishery was moved from an open-entry to a limited-entry fishery, with a maximum of 30 licences available (Joll 1989a). Following this decision, the maximum number of boats allowed to operate was gradually reduced through a two-for-one net reduction on transfer of license until there were 17 licenses operating in the Fishery.

There are currently 10 licensees in the AIMWTFM, after an industry-funded buyback in late-2010. Scallop landings have varied dramatically over the last few decades, and are dependent on sporadic recruitment, which appears to be strongly influenced by environmental conditions (Figure 6.25). The extreme marine heatwave in 2010/11 resulted in a significant stock decline at the end of 2011 and the fishery was closed for 5 years until 2017.
Figure 6.5. Annual total retained catches (tonnes whole weight) and fishing effort (standard hours trawled) in the commercial AIMWTMF between 1967 and 2018 (no fishing between 2012 and 2016).

6.3.2 Current Fishing Activities

A summary of key attributes of the current AIMWTMF and the fishing fleet is provided in Table 6.12.

The AIMWTMF exists within the waters of the Abrolhos Islands off the mid-west coast of WA and is based on the take of saucer scallops, with a small component targeting western king prawns in the Port Gregory area (Kangas et al. 2017). The fishery operates using low-opening otter trawl systems.

The physical area of the Fishery includes the waters of the Indian Ocean between 27° 51’ S and 29° 03’ S, on the landward side of the 200 m isobath (Figure 6.6). The licenced Fishery area extends out into Commonwealth waters, however, many of the principal fishing grounds are within State waters (DoF 2004). Within the fishery boundary, historically established fishing grounds are known as traditional fishing grounds (Figure 6.7) where fishing with main gear is permitted anytime in the season whereas any other areas need to tested with ‘try-gear’ to determine scallop abundance prior to fishing (refer to Industry Code of Conduct in Appendix x).

Historically the fishery operated from the second Tuesday in April (to fit in with the rock lobster fishery in the region) and generally lasted between one and eight weeks, with the length of season dependent on scallop distribution and abundance. In 2003 and 2005 the season was extended due to high scallop abundance. In 2017, the first year fishing was permitted after the severe stock decline after the marine heatwave in 2010/11. The fishing season was set at five months (1 March to 1 August) to allow industry to optimise the meat size and quality.
Table 6.2. Summary of key attributes of the commercial AIMWTMF

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing methods</td>
<td>Demersal otter trawl</td>
</tr>
<tr>
<td>Fishing capacity</td>
<td>256 m total headrope (140 ftm)</td>
</tr>
<tr>
<td>Number of licences</td>
<td>10 (40% active)</td>
</tr>
<tr>
<td>Number of vessels</td>
<td>Up to 10 (4 in 2017)</td>
</tr>
<tr>
<td>Size of vessels</td>
<td>22.5-24.9 m</td>
</tr>
<tr>
<td>Number of people employed</td>
<td>40-50</td>
</tr>
<tr>
<td>Value of fishery</td>
<td>Highly variable: 2017: $4.5 million</td>
</tr>
</tbody>
</table>

Figure 6.6. Boundaries and extent of the AIMWTMF. Traditional areas of the fishery are detailed in figure 6.7.
Figure 6.7. Traditional areas of the AIMWTMF, red hatched areas are permanently closed Reef Observation Areas (ROAs).

### 6.3.3 Fishing Methods and Gear

The fishery currently operates under a maximum total net headrope capacity restriction of 256.1 m. Recent amendments to the management plan have seen the removal of the headrope unitisation scheme in favour of a standardised net headrope allocation where each Managed Fishery Licence (MFL) has an equal allocation of net headrope length. Each licensed vessel is permitted to fish for scallops or prawns, using an otter trawl net or nets with a headrope length not exceeding 25.61 m in scallop fishing areas. This provides for each vessel to operate using two 12.8 m (7ftm) nets in twin gear configuration. Vessels operating in the prawn fishing area (Port Gregory) are permitted to use a maximum of two otter trawl nets, with each net having a maximum headrope length of 14.62 m (8ftm).
The boats tow two otter boards, each being no greater than 2.29 m in length and 0.91 m in breadth (DoF 2004). The mesh size of nets must not be less than 100 mm and chafers or liners may not cover more than the bottom half of the cod end. The vessels which target western king prawns in the Port Gregory area of the fishery are permitted to tow nets with mesh no less than 45 mm in the cod end, and 51 mm in the remainder of the net. The trawlers carry the skipper and up to 12 crew.

Scallop trawling is undertaken during both day and night. Trawl shots typically vary from 30 minutes up to three hours, depending on the catch rates. Trawling tow speed is around three knots. Scallops are shucked and processed at sea and frozen and majority is exported with lesser quantities sold locally or as half shell.

6.4 Illegal, Unreported or Unregulated Fishing

Negligible.

6.5 SWTMF

6.5.1 History of Development

The SWTMF includes two of the State’s smaller scallop fishing grounds; Fremantle and north of Geographe Bay. Being a multi-species fishery, the SWTMF has not only targetted saucer scallops and western king prawns, but also retained whiting (Sillago spp.), blue swimmer crabs (Portunus armatus), squid and various other scalefish species (Sporer et al. 2014), however in the last few years, scallops has been the primary focus of any fishing activity.

Trawling for scallops by Shark Bay prawn trawlers north-west of Fremantle, which represented the forerunner to the SWTMF, started in the late 1960s (Laurenson et al. 1993). Following the conversion of a number of ex-rock lobster vessels to small trawlers to fish for western king prawns and saucer scallops in the late 1970s and early 1980s, the fisheries resources between Fremantle and Cape Naturaliste became more consistently exploited. In 1982/1983 three small trawlers began targeting prawns in this region (Laurenson et al. 1993). After reports of good prawn catches during that first fishing season, a further six vessels from the Geraldton-based trawler fleet also commenced fishing these grounds. In response to conflicts between the original and new trawler operators in this relatively restricted inshore region of Comet Bay, and growing concerns about depletion of western king prawn and blue swimmer crab stocks, a small limited-entry fishery was established in WA waters in 1983 (Laurenson et al. 1993). Although 16 applications seeking licence endorsements to fish in the restricted area were received, the WA Minister for Fisheries approved access only for five small trawlers. At this same time, trawling was prohibited within 800 m of the high water mark between the mouth of the Moore River and Cape Naturaliste (Laurenson et al. 1993). The restrictions placed on the Comet Bay fishery led to a limited southern expansion of the trawl fishery, primarily by those vessels which did not gain access to the Comet Bay prawn fishery (Laurenson et al. 1993). Commercial catches were first reported in the Geographe Bay region in 1984, with two trawlers undertaking some exploratory fishing for scallops and, to a lesser extent, southern school whiting. By 1989, trawling in Geographe Bay was being undertaken in a more consistent
pattern, with three vessels more or less consistently fishing areas where saucer scallops occurred regularly (Laurenson et al. 1993). This level of exploitation peaked during 1990, when 1,066 boat days were spent fishing in the area. The fishing effort in this fishery has since declined.

In February 1989, the *South West Trawl Management Plan 1989* was released (Moore 1989), with the final plan gazetted in October of that year. Annual scallop catches in the SWTMF declined substantially between 1990 and 1993, and remained relatively low until 2010 when a catch of 217 t (whole weight) was reported. Catches of scallops have since declined, with 82 and 40 t landed in 2011 and 2012, respectively. Since 2004, annual prawn landings by the SWTMF have been low, in the range of 3 to 14 t (Sporer et al. 2014) Figure 6.2.8.

![Figure 6.8. Annual total retained catches (tonnes) of scallop and western king prawn and fishing effort (boat days) in the commercial SWTMF between 1990 and 2017. No fishing in 2015 and 2016 and one boat fished in 2017 so no catch provided.](image)

### 6.5.2 Current Fishing Activities

A summary of key attributes of the current SWTMF and the fishing fleet is provided in Table 6.13.

The fishery extends across waters of the Indian Ocean between 31°43.38”2’S and 115°08.08’E where it intersects the high water mark at Cape Leeuwin, and on the landward side of the 200 m isobath (Figure 6.9). It is divided into four Management Zones, with large areas of the fishery (Rottnest Island, Cockburn Sound, Warnbro Sound and inshore Geographe Bay) closed to trawling to protect sensitive coastal habitats (including seagrass beds) and nursery areas.

The SWTMF is a gear-based managed fishery that operates under an input control system that limits boat numbers, gear sizes and fishing areas. There are a total of 10 MFLs, in this fishery, however, three boats that have access to Zone A (one of which has dual access to Zone B) and
seven boats are also permitted to operate in Zone B. The fishing season operates between 1 January and 15 November in Zone A and Northern Zone B as described in item 2 (a) of Schedule 2 in the Management Plan. There were three licenses in Zone D, however these were removed from the fishery through a VFAS in 2014 and access to Zone D ceased, while access to Zone C ceased in 2002. The management plan also includes large permanent closures to protect sensitive coastal habitats (including seagrass beds) and nursery areas such as Cockburn Sound, Warnbro Sound, and inshore Geographe Bay (Figure 6.9). For the 2014 season voluntary temporal closures were in place in Zone A from 01 January 2014 until 28 February 2014, and in the Geographe Bay region of Zone B from 01 to 31 January 2014. No fishing occurred in 2015 and 2016 and one boat operated in 2017.

Table 6.3. Summary of key attributes of the commercial SWTMF

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Fishing methods</th>
<th>Number of licences</th>
<th>Number of vessels</th>
<th>Size of vessels</th>
<th>Number of people employed</th>
<th>Value of fishery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demersal otter trawl</td>
<td>10 (10% active)</td>
<td>1 active</td>
<td>22.5 - 24.9m</td>
<td>5</td>
<td>Variable, 2017: N/A due to confidentiality</td>
</tr>
</tbody>
</table>
Figure 6.9. Boundaries of the commercial SWTMF and its Management Zones

6.5.3 Fishing Methods and Gear

Total headrope capacity and configuration varies for each Zone: Zone A: 87.84 m of headrope; Zone B: 351.36 m of headrope; and Zones A and B are permitted up to three otter trawl nets with a headrope length not exceeding 29.25 m. The management plan for the SWTMF also dictates a maximum otter board dimension to be used (2.29 m length and 0.91 m breadth, with shoes that do not exceed 150 mm width and 38 mm depth); however, an Exemption is currently in place to commercial fish using Bison boards with specifications greater than those provided in the management plan.

Trawling is undertaken during both day and night. Trawl shots typically vary from 30 minutes up to three hours, depending on the catch rates. Trawling tow speed is around three knots. Scallops are shucked and processed at sea or brought ashore as half or whole shell and primarily sold at local/niche markets.

6.6 Illegal, Unreported or Unregulated Fishing

Negligible.
6.7 SCTF

6.7.1 History of Development

During the mid-1980s, a number of small trawlers operating out of Esperance and Albany discovered beds of saucer scallops in south coastal waters, particularly within the Recherche Archipelago (Anonymous 1987). The WA Minister for Fisheries approved a Notice limiting trawling in State waters on the south coast and 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 SCTF released in November 1987 (Anonymous 1987). 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, DoF, pers. comm.). The four licences remaining are effectively owned by two operators, who either operate the licences themselves or lease them to other fishers (Harris et al. 1999).

As with the other scallop fisheries in WA, the annual landings are highly variable with environmental conditions being the main drivers for spawning and the subsequent strength of recruitment to these fishing grounds (Figure 6.10). The level of fishing activity in the SCTF has also been variable. A peak scallop catch of 544 t meat weight (2722 t whole weight) was observed in 2000 (Figure 6.10). This is believed to have resulted from optimal environmental conditions to provide for successful settlement and survival of scallops in this region (DoF 2005) and further examination of the drivers is being completed as part of FRDC 2015/026.

The SCTF is currently managed primarily by limited entry, gear specifications and a seasonal closure.
Figure 6.10. Annual total retained catches (tonnes) and fishing effort (boat days) in the commercial SCTF between 1990 and 2017 (no fishing in 2017).

6.7.2 Current Fishing Activities

A summary of key attributes of the current SCTF and the fishing fleet is provided in Table 6.14.

Although the boundaries of the SCTF covers a large section of the south coast of WA (115°30’E to 125°E; Figure 6.11) the fleet are effectively restricted to very small areas of higher scallop abundance (Sporer et al. 2013). Trawling typically occurs in three key areas, including Bremer Bay, the Recherche Archipelago outside Esperance and Israelite Bay. The SCTF principally targets scallops, although in years of low scallop catches licensees historically used other trawl gear to target finfish species (DoF 2005). The present fleet only targets scallops.

Figure 6.11 Fishery boundary of the SCTF.
Table 6.4. Summary of key attributes of the commercial SCTF

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing methods</td>
<td>Demersal otter trawl</td>
</tr>
<tr>
<td>Fishing capacity</td>
<td>Number of licenses</td>
</tr>
<tr>
<td>Number of licences</td>
<td>4 (100% active)</td>
</tr>
<tr>
<td>Number of vessels</td>
<td>4</td>
</tr>
<tr>
<td>Size of vessels</td>
<td>22.4-24.9 m</td>
</tr>
<tr>
<td>Number of people employed</td>
<td>20-30 historically, now up to 20.</td>
</tr>
<tr>
<td>Value of fishery</td>
<td>Variable: 2017 Nil as no fishing</td>
</tr>
</tbody>
</table>

6.7.3 Fishing Methods and Gear

There are four Fishing Boat Licences (FBLs) which are authorised to operate under the Exemption framework currently in place for the SCTF. The Exemption prohibits the retention of any fish other than scallops and demersal scalefish of the Class Osteichthyes (except Australian Salmon, small pelagic fish as defined in the South Coast Purse Seine Management Plan 1994 and any fish specified under Commonwealth control or management in the Offshore Constitutional Settlement 1995), taken in trawl nets.

All trawl nets are required to have a fitted rigid barrier grid (see specifications in Section 6.1). Trawl nets must have a minimum mesh size of 100 mm, unless the headrope length is less than five metres. The use of trawl nets with a headrope length greater than 36.58 m is prohibited. Fishing vessels have a maximum length of 32 m.

Fishers use a net with 100 mm mesh in less than 40 m depth. Trawling takes place day and night, and each tow can last in duration from 20 minutes to up to 120 minutes, depending on scallop abundance. Tow speed is around 2.5 to 3 knots. Boats that operated as demersal fish trawlers historically were rigged with a single net that has a larger mesh than the scallop nets. Trawling is prohibited from 1 November to 31 March of the following year. Implementing a closure across the summer months reduces the overall potential fishing effort, may increase economic efficiency by allowing scallops (and other retained species) to recover condition during the post spawning period and the seasonal closure will protect some of the breeding stock as spawning occurs during spring and summer.

6.7.4 Illegal, Unreported or Unregulated Fishing

Negligible.
7 Fishery Management

7.1 Management System

The SBSMF has, since 2015, been managed using a constant catch harvesting strategy, which involves harvesting a fixed tonnage from each stock each year. The harvesting will vary depending on stock abundance.

Up to the closure of the fishery in 2012 the fishery was managed according to a “constant escapement policy”, which was designed to leave a minimum level of saucer scallop spawning stock during each breeding season to ensure that recruitment the following year is not compromised. There was a target predicted catch (based on annual fishery independent surveys) which determined in an area (Denham Sound or northern Shark Bay) could be fished. For each area, there was also a target catch rate (scallop fleet) at which fishing would cease as well as a closure during the key spawning period (May – July). In addition, in 2011 a catch share arrangement of 70:30% between the scallop and prawn fleets was implemented for the total landings. The performance of the fishery in the first part of the year was then analysed using the Leslie method (depletion analysis) to estimate stock size; the size of the remaining stock dictated if and when fishing could commence after the spawning closure.

Equitability with the prawn sector and expected economic performance based on meat quality are secondary considerations in deciding whether to resume fishing after the spawning closure. If fishing recommences, it continues for the scallop fleet until the catch rate declines to uneconomic levels for the scallop fleet whilst prawn fishers continued to take small amounts scallops until the end of the prawn fishing season if they had not taken their 30% share of the catch allocation.

The implementation of the catch share arrangement in 2011 has facilitated the restructure of the scallop fleet (reduction in the number of boats from 14 to 11) and both sectors now have certainty over their share of the catch (irrespective of the actual annual abundance available) and have increased the efficiency of the remaining boats or chosen to operate less than the number of boats licensed commensurate with the level of catch allocated. Also leasing of units of allocation between licensees has occurred in 2017.

The AIMWTMF, the SWTMF and SCTF are managed using a constant escapement harvest strategy.

7.2 Harvest Strategy

The SBSMF is presently developing a draft Harvest Strategy (HS) based on an ITQ Management System which outlines the long- and short-term objectives for management (DPIRD, 2019). It also provides a description of the performance indicators used to measure performance against these objectives, reference levels for each performance indicator, and associated control rules that articulate pre-defined, specific management actions designed to maintain the resource at target levels.
The HS is responsive to the state of the stock as measured through fishery independent surveys and monitoring of the commercial scallop (and prawn) fleet catches and catch rates.

Prior to 2015, the annual scallop survey provided the catch predictions for the following year, the implementation of catch rate targets to determine timing of the spawning closure, the application of the depletion analysis to estimate remaining stock in the current year to determine re-opening and the economic limit catch rate are all aimed at ensuring there is sufficient breeding stock left in the water (see Section 7.1.2 below). The critical element of this approach was that the stock levels being left have been shown to be sufficient to generate very strong recruitment in some years. However, recruitment variability is primarily driven by environmental factors and there was not a strong relationship between breeding stock size and recruitment.

A formal catch share arrangement (70 % scallop fleet: 30 % prawn fleet) was implemented in 2011 after the trial in 2007 and 2008 (when percentages of 72 and 28 were attributed to the scallop and prawn fleets based on historical catch data) which also constrains the overall catch. The change from 72:28 % to 70:30 % was based on an appeal by the prawn sector and agreed to by Government. The scallop catches taken by the scallop and prawn fishers, which are monitored during the season, are compared against the predicted catch for the full season (as predicted by the fishery independent survey and adjusted as necessary based on catches during the season). If one of the sectors was likely to exceed their catch allocation then fishing for that sector ceases. The catch share arrangement therefore reduced the potential for resource sharing conflict and for the ‘race to fish’ between sectors which could result in not utilizing the resource at optimal size, quality and value. The business rules associated with the catch share arrangement were still in development and consideration was to be given as to whether the sector can carry over the percentage or amount of catch not taken in one season to the next at the time of the fishery closure in 2012.

A key feature of this harvesting strategy was its ability to deal with the very large variation in annual scallop abundance, for example in very high abundance years (e.g. 1991) the management system allowed fishers to maximize the harvest of the resource (i.e. fishing was for all of the year) whereas in times of low abundance (below the limit level) the stock is given a high level of protection with no retention of scallops (e.g. in 2012 and 2013). Discarding by the prawn fleet during their operations would still occur resulting in some repeat recapture/discard mortality as shown by recent research (Chandrapavan et al. 2013, Kangas et al. 2012). A small-scale spatial closure around a relatively high scallop abundance area in Denham Sound in 2013 has been implemented to avoid recapture/discard mortality.

With recovery of stocks, scallop fishing resumed in 2015 under trial quota management arrangement and was determined by the Deputy Director General in 2017 to be the way forward in managing the scallop stocks in Shark Bay. A draft Harvest Strategy for ITQs will be developed in 2018/19.
AIMWTMF

A draft HS for the AIMWTMF is being developed in 2019. Scallop catch rates can be monitored daily through the season and scallop fishing can cease within 48 hours if the target catch rate (150 kg/day) is reached.

SWTMF

There is presently no formal HS for the SWTMF.

SCT

The annual effort expended in this fishery is an outcome of initial fishing surveys used by operators to estimate stock abundance and likely benefits of continued fishing. For the SCTF, the amount of fishing that takes place annually is economically driven with fishers stopping at around 150 kg/day.

7.3 External Influences

7.3.1 Environmental Factors

Scallops are strongly influenced by environmental factors in relation to growth, spawning cycles, recruitment success, spatial larval settlement patterns and natural mortality. Key environmental parameters examined to date as part of FRDC 2015/026 are sea surface temperature, Leeuwin Current strength, winds, tides and primary production. Long-term climate change impacts are covered in a separate sub-section below.

7.3.2 Climate Change

A risk assessment of WA’s key commercial and recreational finfish and invertebrate species has demonstrated that climate change is having a major impact on some exploited stocks (Caputi et al. 2015). This is primarily occurring through changes in the frequency and intensity of El Niño Southern Oscillation (ENSO) events, decadal variability in the LC, increase in water temperature and salinity, and change in frequency and intensity of storms and tropical cyclones affecting the state (Caputi et al. 2015). In 2010/11, a very strong LC resulted in unusually warm ocean temperatures in coastal waters of south-western WA (Pearce et al. 2011). This extreme marine heatwave altered the distribution and behaviour (e.g. spawning activity and migration) of some species and caused widespread mortalities of others, including scallops. Shark Bay, in particular, has been shown (Caputi et al. 2015) to be experiencing changing environmental stressors and shifts in ecosystem productivity and function which will likely significantly impacts of scallops stocks that will need to be factored into future Harvest Strategies.

7.3.3 Introduced Pest Species

The majority of the states scallop fisheries exist in relatively pristine waters with small population sizes and very little urban development. The SWTMF is adjacent to Perth with the main scallop fishing ground occurring between Perth and Rottnest Island and therefore may be somewhat influenced by runoff from the Swan River catchment, port facilities and local metropolitan coastline.
The key threat of introduced pests to scallop stocks would be the introduction of major aquaculture developments (including increased vessel movements) in proximity to the fisheries which is a potential in the Abrolhos Islands which has dedicated aquaculture zones within the scallop fishing grounds and possibly in Shark Bay with potential aquaculture activities in the future.

**7.3.4 Market Influences**

Scallops are a high value commodity. Market competition for the same species exists with the Queensland and Tasmanian scallop fisheries and with imported scallops (i.e. Canada). 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 left, in the shell or in the half-shell to supply the local gourmet seafood markets. 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.

High precedence of lesions in the adductor muscle due to a nematode infestation reduces marketability and value of the scallop meat and has been significant in scallops in Shark Bay historically and in 2017/18.

**7.3.5 Non-WA Managed Fisheries**

N/A.

**7.3.6 Other Activities**

Other activities within the Shark Bay region include, mining, tourism, shipping and maritime activities and currently, low levels of aquaculture activities and are summarised in Kangas et al (2015). These activities also apply within the Abrolhos Islands (refs, aquaculture or other?) and SWTMF other than mining but in the SCTF only tourism and low levels of maritime activities primarily occur. The introduction of marine parks has impacted these fisheries to variable extents.

**8 Information and Monitoring**

**8.1 Range of Information**

There is a range of information available to support the assessment and harvest strategy for the Scallop Resource in WA (see Table 8.1). The extent of information for the Shark Bay Scallop fishery and Abrolhos Islands and Mid-West Trawl fishery is more comprehensive than for the two small scale scallop fisheries (SWTMF and SCTF) which are primarily reliant on commercial catch and effort (daily logbook) information and observations.
## Table 8.1 The range of information available to support the assessment and harvest strategy for the Scallop Resource

<table>
<thead>
<tr>
<th>Data type</th>
<th>Fishery dependent or independent</th>
<th>Analyses used in stock assessment</th>
<th>Additional analysis and purpose</th>
<th>Areas of data collection</th>
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<tr>
<td>Daily scallop logbook data</td>
<td>Fishery dependent</td>
<td>Annual catches and catch rates as indicators of abundance</td>
<td>Analysis of area fished for habitat impact assessment (EPBC)</td>
<td>Detailed shot latitude and longitude</td>
<td>Daily</td>
<td>Since the fishery began</td>
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<tr>
<td>Daily prawn logbook data</td>
<td>Fishery dependent</td>
<td>Annual catches and catch rates as indicators of abundance</td>
<td>Analysis of area fished for habitat impact assessment (EPBC/MSC)</td>
<td>Detailed shot latitude and longitude</td>
<td>Daily scallop landings</td>
<td>Since the SBP began</td>
</tr>
<tr>
<td>Processor unloads</td>
<td>Fishery dependent</td>
<td>Validates the estimated catches</td>
<td></td>
<td>Shark Bay</td>
<td>Monthly</td>
<td>Since the fishery began</td>
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<tr>
<td>Pre-season surveys</td>
<td>Independent</td>
<td>Catch prediction and abundance of recruits and residuals</td>
<td>Size composition used for setting when to start fishing and area openings (economics)</td>
<td>Denham Sound and northern Shark Bay Abrolhos Islands</td>
<td>November</td>
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<tr>
<td>Gear usage</td>
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<td></td>
<td>Shark Bay</td>
<td>Fishing season</td>
<td>2001</td>
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<tr>
<td>VMS</td>
<td></td>
<td>Verify boat locations for logbook analysis</td>
<td></td>
<td>Shark Bay Abrolhos Islands SST for SWTMF and SCTF only</td>
<td>Monthly</td>
<td>Since the fishery began</td>
</tr>
<tr>
<td>SST and Leeuwin Current strength</td>
<td></td>
<td>Correlations between environmental variables and stock abundance</td>
<td></td>
<td>Monthly (accessed from websites). More detailed data loggers for some years.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 8.2 Monitoring

#### 8.2.1 Commercial Catch and Effort

Fishery removals are monitored with a high degree of certainty through daily logbooks which are validated through processor unloads for all fisheries. The Shark Bay prawn and scallop fleets and the AIMWTFM, SWTMF and SCTF are the only sectors that harvest scallops (i.e. no removals by recreational, indigenous or other commercial fishers). The monitoring information is comprehensive with regard to fisheries removals as the information is available for all boats (prawn and scallop fleets) operating in each fishery. These data are complemented
by the fishery-independent surveys that have been undertaken for 35 years. Since the implementation of trial quota, landings are further verified using catch and disposal records (CDR’s).

For Shark Bay and the AIMWTMF depletion analysis of fishery-dependent catch and effort on daily catch rates and cumulative catch are conducted if appropriate. This is combined with daily catch monitoring to ensure that fishing ceases around the target levels in these two fisheries. The moderate uncertainty around the initial catch prediction is understood and accounted for through comparisons early in the season with fishery-dependent catch rate information and fisher observations.

8.2.1.1 Daily logbooks

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 was initially 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 8.1) for the start of the trawl. In Shark Bay, until 2017, majority of scallops have been shucked at sea and all weights recorded as meat weight (meat weight is on average approximately 20% of the whole weight). For catch, the skippers record the estimated number of baskets of shell (i.e. whole animal) and what the estimated meat weight for that basket of shell is. By comparing the recorded nightly meat weight and the number of baskets of whole shell, the estimated meat weight can be weighted up or down as appropriate. Since 2017, some operators have landed whole shell (and lesser quantities of half shell) and this weight has been recorded and converted into meat weight by a standard formula.

The data quality (completeness, shot by shot detail for location, trawl start time and duration and water depth and catch amount) from individual skippers is variable but has improved in the ten years (i.e. more accurate estimate when compared to processor unloads). In addition, fishers need to report interactions with protected and threatened species. Since 2015 with a move to trial quota and in 2017/18 with individual ITQs, fishers are also required to fill in Catch and Disposal Records (CDRs, see Compliance Section).
Figure 8.1 Example of a hypothetical completed scallop daily log sheet. Left: historical version, Right: current version including requirement to report interactions with protected and threatened species.

Although prawn boats in Shark Bay retain scallops (now as ITQs), in the early years (prior to 1982) of the Fishery prawn logbook data did not record the scallop catches fully as the focus of data collection was on prawn catches. Prawn boats now record all scallop landings on a daily basis (not shot by shot as with prawn catches and by scallop boats) as well as processor returns. Since 2015/16 prawn boats have also been required to fill in CDRs for scallop landings.

The daily logbooks are checked, entered and validated by the trawl science staff on a monthly basis and any possibly erroneous entries or gaps are checked directly with skippers or the fishing company. Annual spatial data validation is undertaken using GIS and random checks of data entry is made through using VMS location records for all fisheries.

8.2.2 Processor Returns

Catch unload information has been provided by processors since the early 1960’s and is used to validate the logbook data. Licensee catch landings (processor returns) collected generally on a monthly basis and are used to adjust the daily logbook catch estimates. Licensee catch landings are considered to provide an accurate representation of actual landings because there is a high degree of consistency between these records and daily logbook records. Note that there is no evidence of substantial illegal catches of scallops in any of the fisheries that could affect the accuracy of licensee catch landings data.
8.2.2.1 Fishery-dependent abundance indices

Information of scallop daily catch rates are derived from logbooks (catch/nominal effort) and this is aggregated and used for an annual mean catch rate for the scallop fleet as well as daily catch and catch rate information used to determine when it is appropriate to cease fishing (i.e. when catch rates are approaching the target). Although there has not been any major gear change (i.e. in number of nets or headrope length) there have been changes in fishing efficiency (i.e. GPS, contour mapping technology and bigger boats) but these have not been incorporated into the fishery catch rate indices. Also the provision of annual survey information (for the first time) to skippers since 1998 has allowed them to focus on higher abundance areas and to locate them with less searching, increasing overall efficiency. For these reasons, the comparison of fishery-dependent catch rates are only made for recent years (e.g. last 10 years) to provide an indication of changes in abundance levels. It is assumed that the fishing efficiency does not change markedly within a season when using the daily catch rate information. For Shark Bay and the Abrolhos Islands, a far stronger reliance is based on the fishery independent survey data when comparing changes in catch rates over the history of the fishery.

In Shark Bay, both scallop and prawn boat scallop catches have been recorded on a daily basis since 1983. 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. As scallop boats can fish up to 24 hours in general (other than restrictions to daylight fishing only in a few years within Denham Sound), each day is represented as 0800 hrs to 0800 hrs the following day. Processor landings are used to weight up the total catch for each unload and provide a validation check on the daily logbooks.

The catch rate data are also aggregated into three broad regions of Shark Bay (Figure 8.2) with areas H1 and H2 constituting northern Shark Bay and H3 being Denham Sound. The catch rate targets differ between northern Shark Bay and Denham Sound. The abundances of scallops between these two regions are also quite different with the northern grounds being more consistent in catch but in recent years’ scallop catches in Denham Sound have been a major contributor to total scallop catches.

In the Abrolhos Islands, the fishery is separated in traditional trawl grounds and non-traditional trawl grounds (Figure 6.7) and fishers nominate the fishing grounds they are fishing in as well as providing latitude and longitude co-ordinates to assign catch to each fishing ground. For the SWTMF and SCTMF fishers also nominate trawl fishing grounds and provide latitude and longitude co-ordinates to enable spatial mapping of catch and effort.
Figure 8.2 Three main scallop fishing areas in Shark Bay, H1 and H2 form northern Shark Bay and H3 is Denham Sound.

8.2.2.2 Independent surveys of abundance

Regular fishery independent surveys undertaken in Shark Bay (Figures, 8.3 and 8.4a and b) and the Abrolhos Islands in November (Figure 8.5) and February (and June in SB) each year since with the November survey having a long-term data series in Shark Bay since 1983 and in the Abrolhos since 2001. A standardised survey regime (Figure 8.6) has been adopted in the SWTMF on an opportunistic basis between 2010 and 2017 but is not a regular annual survey. No fishery independent sampling is conducted in the SCTF.

8.2.2.2.1 Site selection in Shark Bay

Annual scallop surveys have been undertaken in Shark Bay since 1983 and are used to estimate scallop recruit (0+) and residual (1+) abundance. Initially about 60 sites were placed in the areas with known scallop abundance based on information gained through extensive surveys undertaken in 1974-1976 to determine the distribution of prawns and scallops throughout Shark Bay (Penn pers comm.) from bottom type, i.e. sandy substrates (Logan and Cebulski 1971) and asking the commercial fishers to ensure the full area was covered (Figure 8.3). The sites are approximately evenly spread throughout the main scallop trawl grounds.

Initial trawl transects were selected to be horizontal bands are approximately two nautical miles apart and each trawl track was in a north-south direction. The intent was to replicate the trawl
transect from year to year. In practice this was not possible due to the weather and radar positioning was used to locate the trawl sites. The ability of the boat to trawl the same location from year to year has improved due to plotter technology and in recent years skippers have tended to closely repeat the previous years’ trawl transect, but there is still some variation around the actual trawl path given the weather and sea state (swell and wave height) and other factors.

Over the years some sites were added (with few removed due to consistently low abundance and habitat sensitivity) and changes to the detailed locations (expanded the overall area covered based on more detailed spatial analysis of fishing activity) to 82 sites in total. In 1999 the trawl transects were more formally defined as an area (box) with associated latitude and longitude positions for the extremities of the site (Figure 8.3).

For statistical reasons (adequately estimating the variability) in the future there might be value in having complete random sampling within the box (site) i.e. sensu stricto stratified random survey but due to the weather conditions (predominantly southerly winds means it is generally very difficult to trawl in anything but north/south direction).

Figure 8.3 Annual scallop survey sampling regime. Displaying previous survey sites (1983 to 2005) and 2006-2012 survey shots. (RV Flinders/Naturaliste 1982 to 2007, and 2010 to 2018, FV Palmerston 2008 and 2009)
Figure 8.4 Expanded survey sites conducted since 2012 in Shark Bay a) November b) February and June.

8.2.2.2.2 Site selection in Abrolhos Islands

Annual scallop surveys have been undertaken in their current form (larger number of trawls within designated fishing grounds) since 1997 and are used to estimate scallop abundance (mainly 1+ residuals) and size composition and data on meat size and quality. Typically 20 – 25 sites are sampled within the key fishing grounds, the locations of which were based on fisher knowledge and some earlier research surveys (conducted in 1980s) (Figure 8.38.5). Within the fishing grounds there are designated ‘boxes’ which are approximately 1x1 nm (except the main ground in the Hummocks fishing area which is 2x2 nm) and within which trawls need to be undertaken. Up to five trawls can occur within a fishing ground, usually with a minimum of two.

Within the boxes there will be variation annually around the actual trawl paths given the weather and sea state (swell and wave height) but only one trawl is done in one box. The industry sometimes seeks to do further sampling to investigate areas outside the survey boxes such as areas that they caught scallops in the previous fishing year to see if they still contain scallops at reasonable abundances. These additional sites are not included in the survey index but are used by industry to guide their fishing strategies. If a large abundance of scallops is found outside traditional survey sites, they are noted in the Status of Fisheries and considered as supporting information for stock assessment. The numbers of trawls undertaken within a
fishing ground are largely consistent among years particularly for the more southern fishing grounds where traditionally scallops are found more regularly in abundance. In the northern fishing grounds sometimes only one trawl is undertaken if the abundance is very low. This will reduce the overall mean of the total index value but leads to a more conservative catch prediction.

The annual fishery independent survey is conducted over two days/night, mostly during November. Although sampling has been conducted by industry boats up to 2013 (under direction of Departmental staff on-board the RV Naturaliste has undertaken sampling (using the same nets/gear) from 2014 due to changes in boat charter costing arrangements between the Department and industry and the closure of the fishery. Twin six-fathom headrope length flat nets with 50 mm mesh in the panels and 45 mm in the cod-end are used on all surveys (and this configuration does not change from year to year). 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) and the start and end latitude and longitude are recorded to calculate distance trawled. Processing each shot involves recording numbers of scallops (if the catch is in excess of 2 baskets, only one basket is counted and the total number of scallops obtained by multiplying the number of scallops in one basket for the total number of baskets). To obtain dorso-ventral length frequency measurements, samples of 100 to 150 scallops are taken and measured from one net except when there are low numbers and both sides are combined.

Environmental data (depth, water temperature, sea conditions) are also collected for each site. All of these data are entered (with manual checking) into an Access database.

8.2.2.2.3 Site selection in the SWTMF

A standardised sampling program has been attempted in the SWTMF between 2010 and 2018, (Figure 8.6) however availability of a suitable vessel and time has meant that fishery independent data collected in this fishery is limited.
Figure 8.5 Survey sites conducted in November 2017 in the Abrolhos Islands.

Figure 8.6 Survey sites conducted in the SWTMF on an opportunistic basis between 2010 and 2017. a) indicates 2014 trawls and b) standardised sites based on main abundance of scallops.
8.2.2.3 **Sampling protocol**

The annual fishery independent survey is conducted over nine to ten nights, during October/November. Sampling was conducted on the Research Vessel (RV) Flinders until 2000, then RV Naturaliste (larger and more powerful boat) from 2001 to 2007 inclusive and a commercial scallop boat was used in 2008 and 2009 (similar boat to research vessel and using the standard gear). Sampling with the RV Naturaliste was re-established in 2010. Twin six-fathom headrope length flat nets with 50 mm mesh in the panels and 45 mm in the cod-end are used on all surveys. Fishing is 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 involves recording numbers of both recruit and residual scallops (if the basket count was in excess of 2 baskets, only one basket is 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 are generally determined as those with a dorso-ventral length (shell height) less than 86 mm. To obtain dorso-ventral length frequency measurements, samples of 150 to 200 scallops are taken and measured from one net except when there are low numbers and both sides are combined.

The survey provides data abundance of recruits and residual scallops (number per nautical mile) and length frequency data for scallops from each sampling site (82 sites), trawl duration, distance trawled and environmental (depth, water temperature, sea conditions) information for each site. All of these data are entered (with manual checking) into an Access database.

8.2.2.4 **Adjustment of abundance data**

As the speed at which trawling takes place influences the efficiency of the trawl gear (Figure 8.4, L. Joll, unpublished data, Department of Fisheries) the catch (by recruit, residual and total) was standardised according to:

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

where \(v\) denotes the trawl speed in knots and \(c\) and \(c_{st}\) the catch and the standardised catch respectively (see also Mueller et al. 2007). 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.
Figure 8.4 Adjustment factor in relation to trawl efficiency with speed compared to a standard 3.4 knot.

8.2.3 Catch from Other Sectors
There is negligible removals by any other sector (recreational, charter and/or indigenous catches) because most of the scallop grounds are offshore, in deep water (20-40m) and largely inaccessible. Note that the Abrolhos Islands are about 60 km west of the mainland from Geraldton.

8.2.4 Illegal, Unreported or Unregulated Catch
Negligible.

8.2.5 Environmental Monitoring
Databases with environmental variables (e.g. water temperature, wind and sea level) are continuously updated and extended as new data become available from collections by the Department, internet sources and from other agencies (see Caputi et al. 2015 a, b). The environmental variables from these databases have been used in analyses of correlations with biological parameters of species and allow for the examination of long-term trends. These data are used to explore the extent to which these factors affect recruitment strength (Lenanton et al. 1991, 2009, Chandrapavan et al. in prep.). Although these data are not directly used in stock assessment they have been used to provide an indication as to whether the environmental conditions are likely to be conducive for good recruitment which can influence harvesting strategies. The extreme marine heatwave (Caputi et al. 2015 a, b, Caputi et al. in prep.) significantly impacted scallop stocks in Shark Bay and the Abrolhos Islands and therefore extreme events and climate change continues to be a key focus for these fisheries. The environmental data are also used to assess the stock-recruitment-environmental relationship. The final report for FRDC project (2015/026) examining the influence of environmental factors on scallop recruitment in Shark Bay and the other scallop fisheries within WA will be completed by mid-2019.
9 Stock Assessment

9.1 Assessment Principles

The different methods used by the Department to assess the status of aquatic resources in WA have been categorised into five broad levels, ranging from relatively simple analysis of catch levels and standardised catch rates, through to the application of more sophisticated analyses and models that involve estimation of fishing mortality and biomass (Fletcher and Santoro 2015). The level of assessment varies among resources and is determined based on the level of ecological risk, the biology and population dynamics of the relevant species, the characteristics of the fisheries exploiting the species, data availability and historical level of monitoring.

Irrespective of the types of assessment methodologies used, all stock assessments undertaken by the Department take a risk-based, weight of evidence approach (Fletcher 2015). This specifically requires consideration of each available line of evidence, both individually and collectively, to generate the most appropriate overall assessment conclusion. The lines of evidence include the outputs that are generated from each available quantitative method, plus any qualitative lines of evidence such as biological and fishery information that describe the inherent vulnerability of the species to fishing. For each species, all of the lines of evidence are then combined within the Department’s ISO 31000 based risk assessment framework (see Fletcher 2015; Error! Reference source not found.) to determine the most appropriate combinations of consequence and likelihood to determine the overall current risk status.

9.1 Assessment Overview

A range of fishery-dependent and independent indices are used to assess the Shark Bay scallop stocks. The stocks are assessed annually as well as within the fishing season, an approach that recognises that fishing (or other factors) can deplete the scallop stock. The stocks are assessed in the following manner:

9.1.1 Inter-annual assessments

A range of annual fishery-dependent and independent measures are used to assess the status of the scallop stock each year. These fishery-dependent measures include annual landings (retained catch), nominal effort (hours trawled) and mean annual catch rate (kg/hr). These are not compared over the long term time series due to changes in fishing efficiency but can provide informative comparisons over the last five to ten years prior to moving to quota and noting the fishery was closed 2012 to 2014. Since quota management, fisher behaviour and changes to the fishing season do not allow long-term commercial catch rate comparisons but the proportion of the quota that has been achieved provides a secondary measure of stock status.

Fishery-independent data are derived from a comprehensive annual standardised survey (82 scallop sites) to provide an annual index of abundance of recruit (0+) and residual (1+) scallops (using 52 of the 82 sites, as these 52 sites represent sites that have been sampled for most of
the years in the total time series, noting that in the future more sites may be included in the indices when there is a sufficient time series for a broader set of sites. Due to the high spatial variability in annual distribution of scallop stocks within Shark Bay (Mueller et al. 2005), the extensive survey sampling which covers the full extent of area where scallops are known to occur throughout the history of the fishery provide the most reliable index of abundance. However, in Denham Sound, the introduction of the Snapper Trawl Line (STL) in 2004, a number of scallop sites, although still sampled some historical sites are not in areas open to trawling, so indices are now based on those sites that are in the areas open to fishing. These indices are the key measures by which the stock status can be compared between years.

The fishery-independent annual survey indices as described below for different years are used to obtain catch predictions for each season (separately for Denham Sound and northern Shark Bay) based on the relationship between the catches of one year on the index of recruits and residuals the year before. The catch predictions were used in setting the season arrangements (i.e. opening date and approximate season duration) and now are the basis of determining the quota settings for the season (currently 1 March to 28 February).

In addition, since 2012, two additional surveys, sampling a sub-set of the total number of sites have been undertaken in February/March and June to determine scallop size and abundance during the peak recruitment and spawning season, respectively. These data will be considered as secondary indicators in the Harvest Strategy.

9.1.2 Intra-annual assessment

9.1.3 Pre 2015 (non-quota)

At different times during the season fishery-dependent indices were used to assess the scallop stocks in Shark Bay.

The fishery-dependent daily catch rate data from the scallop fleet, collected up to the initial spawning closure (approximately June/July) can be analysed using the Leslie depletion method (Leslie 1957) to obtain an estimate of the biomass. The catch that has been taken up this point can be subtracted from the initial biomass (prediction) estimate to determine the spawning biomass during the closure.

As there is some uncertainty around the initial catch prediction and lower uncertainty associated with the depletion model, the biomass estimate from the depletion analysis was then used to refine the season arrangements, which in some years meant that fishers can take scallops after the spawning closure if there was sufficient stock. Note that if the daily catch rates were reduced to the target level prior to May (see above) then fishing would cease early.

The approaches taken to assess the stocks are well suited to the biology of the species and nature of the fishery. As scallops are short-lived and recruitment levels fluctuate very markedly between years, exploitation needs to be tailored around these variations. This requires real-time monitoring of fishery-dependent catch rates and rapid management responses to changes in stock status indices, to protect the breeding stock, whilst allowing industry to maximise profits.
Because the number of boats in this fishery was low it is relatively easy to get the daily information required for this type of assessment and management approach.

Although the assessments made are simple and easy to calculate, they allow for the real-time monitoring of this fishery which ensures the indices are reflecting the current stock status. Any method more complex and difficult to calculate would not be practicable and would not give the rapid response required.

9.1.3.1 Quota (from 2015)

Since the fishery re-opened in 2015 under a trial quota, fishing in 2015 to 2018 has been from 1 March in one year to end of February the following and therefore fishing has occurred before and after the spawning closure. This has required a modified approach to estimating spawning biomass using fishery-independent methods to supplement fishery dependent data and has proved not be as informative in some years compared to pre quota years. Depletion estimation can inform on the quantity of removals prior to a spawning closure if there is a demonstrable reduction in catch rates (Figure 9.1a). In some years since 2015, stock depletion has not been evident from commercial scallop boat daily catch rates. This is due to fewer boats operating (5-6 boats compared to fleet of 14 boats previously) and thereby maintaining their daily catch rates to what was achieved historically (Figure 9.1b). Due to changes in scallop catchability during the season (i.e. growth of recruiting scallops between November and February) scallop abundance indices from fishery independent surveys in February and June will be incorporated into assessments in the future.
Figure 9.1 Scallop fleet mean daily catch on cumulative catch (both prawn and scallop boats) for a) Denham Sound 2015 b) fleet daily catch rate for Denham Sound 2017 indicating a slight decline until 28 March then an increasing daily catch rate for the rest of the fishing period.

9.1.4 Assessment approach relative to reference points

9.1.4.1 Pre Quota

The assessment approach involved comparing indices of stock abundance (through daily scallop fleet average catch rates) to the catch rate based reference points (threshold) to cease fishing whilst the limit reference point assessment was derived from the annual fishery independent survey catch prediction. Within-season monitoring was also supplemented through depletion estimates.

9.1.4.2 Quota

The assessment approach involves comparing annual fishery independent indices against limit and threshold reference levels derived from the spawning stock recruitment environment relationships recently developed for the saucer scallop in northern Shark Bay and Denham Sound (Caputi et al. 2015a). Historically there were no clear spawning stock recruitment relationships evident for either stock, with the environment appearing to be the main driver of recruitment strength, however, after the significant decline in spawning stock following the marine heatwave, very low spawning stock resulted in very low recruitment and therefore it has been possible to determine the point (or index level) at which recruitment can be impaired due to low spawning stock levels. These points are considered to be the limit reference level for Denham Sound and northern Shark Bay (Figure 2.2). These index levels (limit, threshold) can be incorporated onto the catch prediction assessments to determine the stock status in relation to reference levels.
9.1.5 Evaluation of uncertainty in assessments

A range of measures are taken to account and reduce uncertainty in assessment information. These include:

- Determining confidence intervals of survey abundance indices
- The additional surveys in Feb/March and June provide a basis for comparison with the long-term November survey.
- The catch prediction has a high level of uncertainty. The November survey-catch relationship appears to have changed over the years, particularly in northern Shark Bay and even more so, since the heatwave event. To reduce uncertainty, within season information is used to evaluate stock abundance and status. However, the initial catch prediction, using the index of 0+ and 1+ individuals is fairly robust in determining whether fishing should commence or not i.e. that the stock is above or below the limit.
- Fishery-dependent information provides real-time catch rate data on which to base within-season assessments and these data are continually verified against fishery independent measures. The spatial extent of the catch rate data can vary between years and this can influence the abundance of the spawning stock and breeding stock protection can be supplemented by small scale spatial and temporal closures.
- Accounting for uncertainty in fishery dependent data is by validating catch information against processor returns and CDR’s and regular communication with fishers.

9.1.6 Evaluation of assessment

The previous assessment approach includes multiple indices of abundance and these measures tend to provide a similar signal with regard to the stock status. For example, prior to the two years (2011 and 2012) when there was none or very limited fishing, the fishery independent (catch predictions were declining) and dependent measures of abundance (catch rates declined to threshold levels rapidly) both provided a strong indication of declining scallop abundance. The converse is true for years of higher abundance e.g. 2008 and 2009.

The assessment of abundance also involves the analysis of the spatial distribution of fishing effort to evaluate the possibility that fishing may be concentrated on small, high abundance aggregations and that the overall catch rates do not provide a good measure of overall stock abundance. If there is any indication that this is true in any year, more conservative management may be undertaken.

9.1.7 Peer review of assessment

Annual internal reviews were undertaken as part of the process for completing (and updating) the annual Status Reports of the Fisheries and Aquatic Resources in Western Australia and as part of the Status of Australian Fish Stock Reports (FRDC 2017).
The Department had a schedule for peer review of assessments for all fisheries; with a “rolling” schedule aimed to generate major reviews of 5-8 fisheries per year, employing a mix of internal and external (e.g. universities, CSIRO, inter-state fisheries departments) fisheries experts. An external review for Shark Bay scallop was undertaken in August 2010 by Dr Jim Penn (former Director of Research, Department of Fisheries and working as a consultant). A Stock Assessment report for this fishery (Kangas et al. 2011) was internally reviewed by the Department of Fisheries before publication. This fishery in conjunction with the Shark Bay Prawn Managed Fishery is scheduled to be independently reviewed in 2019.

The Department of the Environment for the Australian Government, assessed the fishery in 2015 as being sustainable under the provisions of the Environment Protection and Biodiversity Conservation (EPBC) Act 1999. This has provided the export accreditation for the fishery for a period of ten years until May 2025[^1].

The Shark Bay Scallop Managed Fishery has undergone MSC pre-assessment in 2014 and is considering full assessment and third party certification against the Marine Stewardship Council (MSC) standard for sustainable fishing (V2.1) in 2020.

9.2 Analyses and Assessments in Shark Bay

9.2.1 Data Used in Assessment

| Logbook / Processor returns / CDRs/VMS data |
| Economic data |
| Environmental data |
| Fishery-dependent data |
| Fishery-independent survey data |

9.2.2 Catch and Effort Trends

9.2.2.1 Commercial Catches

Annual scallop catches (both prawn and scallop boats) are highly variable (Figure 9.1), with high catches observed in 1991 to 1994 and then relatively low overall catches until 2007 when slightly increased catches were observed for three years, until 2009. The catches in 2010 returned to lower levels and were extremely low in 2011 following the marine heatwave. No scallop fishing occurred between 2012 and 2014 by either the scallop or prawn fleets due to low scallop abundance and any incidental catch of scallops by the prawn fleet was returned to the sea. Up until 2011, it was believed that stock was well above the point where recruitment could be impaired, particularly northern Shark Bay, but in 2012 the low abundance levels had dropped to levels where there was concern that recruitment could be impaired particularly if the stock was to be fished. Therefore, the strongest management action taken was to close the fishery. Past experience had shown that the stock can recover from very low abundance levels given favourable environmental conditions. However, due to the unprecedented low scallop abundance supplementary small scale spatial closures for the prawn fleet were also implemented. By 2015 a low quantity of catch was permitted and has moderately increased to 2017 under a quota trial arrangement (see below for further discussion on effort trends).

The proportion of catch from each main area (northern Shark Bay and Denham Sound) is also variable annually. Before 2005 (in the time series shown), northern Shark Bay contributed most to the scallop catch whereas the contribution of catches from Denham Sound increase in 2007 to 2009 and has made a major contribution to catches since 2015. These broad trends highlight the importance of obtaining higher resolution spatial data on the scallop catch and effort each year to understand stock status in each area.
Figure 9.2. Annual total catch (tonnes) of saucer scallop in northern Shark Bay and Denham Sound by A and B Class boats (combined) that target the Shark Bay Scallop Resource between 1984 and 2017/18.

9.2.2 Commercial Effort

During the early years of the fishery (1983 to 1989) the scallop fleet effort remained relatively high (11500 to 19430 hours). After 1992, effort increased sharply to a peak of 30 740 hours in 1993, one year after the highest ever recorded abundance of scallops. Following that year, effort progressively declined until about 2002. Since 2002, the effort and catch have been more closely correlated (Figure 9.3). This is due to a combination of factors including increased provision of survey information on stock abundance and distribution to fishers and the changing managing arrangements which curtail fishing when the target catch rate is reached. After the fishery closure (between 2012 and 2014), the fishery changed to quota management with changes in the fishing season and a reduction in the number of boats operating although they are still towing the same gear as prior to the closure, with recent effort not fully comparable before and after the introduction of quota.

The trends shown in Figure 0.2 provide some evidence that the low abundance of scallops in 2011 was not likely to be due to excessive fishing effort since the effort levels in the years preceding 2011 were not higher than experienced throughout most of the history of the fishery. Indeed, during 1996 to 2002 the overall scallop fleet effort was much higher than between 200003 and 2010. The scallop fleet effort in 2017 was similar to effort levels observed for similar total catches between 2002 and 2009 even though the number of scallop boats operating have reduced. The remaining boats individually fish for more days compared to when a larger fleet operated.
Figure 9.3 Annual scallop landings and hours of trawling by the scallop fleet (1983 to 2017/18). Note the fishery was closed between 2012 and 2014.

9.2.2.3 **Recreational / Charter Catches**

No recreational fishing occurs the Shark Bay or any other scallop fishery in Western Australia.

9.2.3 **Fishery-Dependent Catch Rate Analyses**

Throughout the history of the fishery, the fishery dependent catch rates have generally ranged between 10 and 50 kg meat/hour (Figure 9.4). Exceptionally high catch rates (kg meat/hr) of scallops were observed in 1991 and 1992 due to very high recruitment in 1990. Between 2003 and 2010 the catch rates remained above 40 kg meat/hour. The higher catch rates since 2005 almost certainly reflect in part the management change introduced in 2005 that ensured catch rates remained above target levels which in 2011 was 400 kg meat/24 hr in northern Shark Bay and 450 kg/hr daylight fishing in Denham Sound. The trends in the relatively high fishery dependent catch rates indicate that management strategy prior to the severe decline in scallop abundance due to the marine heatwave was more conservative than in the past, i.e. leaving increased stock at the end of a fishing season. Since the re-opening of the fishery the scallop fleet mean annual commercial catch rates have been between 30 and 40 kg meat/hour.
Figure 9.4 Annual scallop fleet mean catch rates (kg meat/h) 1982 to 2017/18. Note fishery was closed between 2012 and 2014.

Fine scale annual catch rates
Since the introduction of detailed shot by shot daily fisher logbooks in 1998 fine scale data on the catch rates of scallops throughout the fishery have been available. Although not used directly for stock assessment (i.e. against reference points) these data are used to provide secondary information on the spatial extent of the stock, of fishing effort and to supplement the knowledge on factors that may be affecting the overall catch rate. The areas of scallop abundance and thus catch rates vary between years for example in 2007 most of the catch and higher catch rates in northern Shark Bay were recorded in the central and southern part of northern Shark Bay (Figure 9.5a) whilst in 2008 good catch rates were recorded in all of northern Shark Bay as well as in Denham Sound (Figure 9.5b). The spatial data may raise concerns about mean catch rates if the fleet was focussing on a very small aggregation of stock. In a recent FRDC funded study fine scale fishery dependent catch rate information was compared with fine scale fishery independent survey catch rates and the analysis showed a high level of correspondence between fishery dependent catch rates and survey catch rates at corresponding locations (Mueller et al. 2008). Therefore, the fishery dependent indices can be used with a high level of confidence as long as the spatial distribution is taken into account.
Figure 9.5  Scallop fleet CPUE (kg/hr) per nm block within northern Shark Bay and Denham Sound a) 2007 and b) 2008.

9.2.4 Depletion analysis – Biomass estimates

The daily logbook catch rate data were used in depletion analyses (2005-2010) to estimate the biomass of the scallop stock at the beginning of the fishing season. This information was used to complement the catch prediction estimate using the fishery-independent survey indices.

Using the Leslie method (Ricker 1975), the catch per unit of effort (CPUE at time t) is linearly related to the cumulative catch up to that time-1 (days);

\[ CPUE_t = qN_0 - qK_{t-1} \]

where \( K_{t-1} \) is the cumulative catch up to the previous day, \( q \) is the catchability coefficient (the magnitude of the slope), and \( qN_0 \) is the intercept which is used to determine initial biomass i.e. by dividing the estimated intercept by \( \hat{q} \). Note that until present, the analyses have differed from the above description as the catch rate was regressed against cumulative catch at time t instead of t-1. However, impact of this has been explored and shows almost negligible effect on the biomass estimate. In the future the analysis will be based not just on the description given but also using an alternative method including the Ricker adjustment (Ricker 1975).

Hilborn and Walters (1992) note that the index of abundance for the Leslie method can be either catch or CPUE. Furthermore, they note that the data used as an index of abundance in the Leslie method can be independent of the data used to measure cumulative catch. For scallops the cumulative catch is the total removals by the prawn and scallop fleets whilst the CPUE is derived from the scallop fleet only.
The Leslie method for estimating the initial biomass is built upon six assumptions:

1. The population is closed (i.e. closed to sources of animals such as recruitment and immigration and losses of animals due to natural mortality and emigration). As scallops in Shark Bay constitute a functionally separate stock (see Section 4.2), scallops are sedentary and the fishing season is short (less than two months), this assumption is likely to be true. There is also an assumption that the area fished by the fleet is relatively consistent.

2. Catchability is constant over the period of removals. For the short period of fishing there are no major seasonal environmental effects on catchability. Some reduced catch rates have been observed during the season because of strong swell conditions.

3. Enough fish must be removed to substantially reduce the catch-per-unit-effort. The historical catch data clearly demonstrate for this to be true.

4. The catches remove more than 2 % of the population. As above.

5. All fish are equally vulnerable to the method of capture. The net mesh size that is permitted by scallop (and prawn) fishers is of a size that ensures that the scallops are fully vulnerable to the fishing gear (Anon. 1969). Changes in the spatial distribution of effort can affect this assumption; however, the fleet would generally focus on the area identified by the survey as providing a reasonable abundance.

6. *The units of effort are independent.* The catch rates are based on the scallop fleet only and the fishers are assumed to operate relatively independently of each other and thus the individual units of effort (for each boat) are assumed to be independent. Because the prawn fleet do not directly target scallop effort from this sector is excluded from the analysis. In addition, the usual assumptions of simple linear regression also apply.

Due to the short-term nature of scallop fishing within Shark Bay prior to 2012 and a number of years when the scallop fleet fished together within the same fishing region, depletion estimates were determined for northern Shark Bay and Denham Sound separately (Figure 9.6).

![Figure 9.6 Scallop boat CPUE (kg/hr) on cumulative catch (both prawn and scallop boats) for a) northern Shark Bay 2007 and b) Denham Sound 2007.](image-url)
The fishery was closed between 2012 and 2014 due to low abundance with fishing resuming in Denham Sound in August 2015 and both parts of the fishery opened in 2016 with a combined quota for the two areas. The historical fishing patterns and number of boats operating has markedly changed and depletion estimates have not, at this stage, been incorporated into the current stock assessments.

9.2.5 Fishery-Independent Data Analyses

9.2.5.1 Annual indices of recruit (0+) and residual (1+) abundance

The annual abundance of recruits (0+) and residuals (1+) determined from the annual fishery independent survey correlate well with the fishery dependent catch rates the following year (Mueller et al. 2008). The observed recruit (0+) and residual (1+) abundances are highly variable from year to year (for example 2001 to 2006 in Figure 9.7).
Figure 9.7 Spatial recruit density variation between 2001 and 2006 (Mueller et al. 2008). The crosses indicate the survey sites.
In northern Shark Bay the combined recruit and residual index has usually ranged between 100 and 500 scallops per nm but has been above this for five years with two exceptionally high years in 1990 and 1991. The index was below this level for a period of five years following the heatwave and then returned to historical levels in 2016 and 2017, and then fell again to very low levels in 2018 (Error! Reference source not found. 1). Although the indices are variable, this region still has experienced considerable (> 50 t) commercial catches of scallops in this part of the fishery in all years prior to 2012. Northern Shark Bay remained closed until 2016. This marked change in this part of the fishery is of concern to the Department and has led to the strongest possible management response.

In northern Shark Bay in November, the abundance of recruits is generally higher than that of residuals which primarily is related to fishing during the season (Figure 9.8). At the time of the heatwave the severe decline in abundance affected both residual and recruiting scallops and by 2012 the abundance of residuals was extremely low and they remained extremely low for a further five years. There was low level of recruitment during these five years but these scallops did not translate into residual stock in subsequent years until 2016. Recruitment dipped to the lowest level in 2014 and with increasing residual abundance after 2014 recruitment also increased and returned to historical levels between 2015 and 2017. Recruitment in 2018 was the second lowest recorded in a year that experienced lower than average temperatures during peak spawning times.
Table 9.1 Annual November Recruitment and Residual survey indices (mean number per nm) for Shark Bay (Redcliff and NW Peron) 1983-2018. Index in red is based on additional sites in areas not sampled prior to 2002. Overall Index = Red Cliff plus 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. The adjustment was not applied for 2011 to 2014 due to very low abundance overall.

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70
Figure 9.8 Recruit (0+) and residual (1+) scallop densities from fishery independent surveys in northern Shark Bay in November between 1984 and 2018. The timing of the extreme marine heatwave and the fishery closure is indicated.

In Denham Sound, the survey indices are even more variable than in northern Shark Bay and have ranged between seven and 1200 scallops per nm (Table 9.2). This variability has also been reflected in more years of very low (or close to zero) catches from this region including an extended number of years in the mid to late 1990s which followed very high scallop abundance between 1990 and 1992. In the history of this region when the stock is at very low levels, it takes up to three years for the stock to rebuild (when environmental conditions become favourable). This was also the case after the extreme marine heatwave. The number of recruits have generally been higher than residual scallops, particularly in the low abundance years and there is generally a year’s lag between higher numbers of recruits followed by an increase in the number of residuals (Figure 9.9).
Table 9.2 Annual November Recruitment (0+) and Residual (1+) survey indices (mean number per nm) for Denham Sound 1983-2018. Indices adjusted for net efficiency by 15% from 2005. The adjustment has not been applied for 2011 and 2014 due to very low abundance.

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Figure 9.9 Recruit (0+) and residual (1+) scallop densities from fishery-independent surveys in Denham Sound in November between 1984 and 2018. The timing of the extreme marine heatwave and the fishery closure is indicated.

### 9.2.5.2 Conclusion

Recruitment in 2018 in northern Shark Bay was the second lowest recorded in a year that experienced lower than average temperatures during peak spawning times. The residual scallop abundance had declined from the previous year with very little catch taken but residual abundance was still within the lower end of the historical range. The scallop stock abundance overall however, was below the limit reference level and this part of the fishery will be closed for 2019/20.

Recruitment and residual scallop stock in Denham Sound in November 2018 was lower than the previous two surveys but the overall scallop abundance being above the threshold level.

### 9.2.6 Catch Predictions

The annual scallop survey data have been used to determine an index of recruitment (0+) strength for the survey year (i.e. individuals derived from the current year’s spawning over April to June/July). These data also provide an index of the size of the residual stock (older scallops remaining from the year before and possibly two 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). A strong correlation between the survey index and catch was observed up to 1995 (Figure 9.; Joll and Caputi 1995a) but this relationship has been less evident after 1995.

For northern Shark Bay, survey indices mirror the actual landings (Figure 9.10) but predictions tend to over-estimate the catch. Two obvious exceptions were in 2007 when landings were about a third of the relatively high catch prediction (around 900 t) and in 2011. For 2007, examination of the residual abundance the following two years suggests that the prediction index correctly indicated there was a high abundance of scallop in the fishery at the time but that fishers did not take a substantial proportion of the available stock. This was because the fishers focused on small localized areas (using higher resolution spatial catch and effort data) of higher catch rate rather than fishing the full fishing grounds. Thus in 2008 and 2009 a
substantial proportion of the survey abundance was residual scallops. In 2011 the predicted catch was not achieved but this is believed to be due to the extreme marine heatwave that increased mortality of scallops and reduced the meat quality (hence yield). The prediction for 2012 was very low leading to the closure of the fishery and since 2015, although the catch prediction is used to inform quota setting, fisher behaviour and fleet composition has changed making historical comparisons difficult.

Figure 9.10 **Annual catch prediction and actual catch in northern Shark Bay, 1984 to 2015**

Until the severe decline in scallop abundance in 2011/12 the catch prediction was determined between 2007 and 2011 using only the years from 1995 (Figure 9.9.11) to reflect the changes in management/fishing practices. Separate catch prediction indices were developed for northern Shark Bay and Denham Sound because these two areas have low connectivity in terms of larval advection and recruitment processes. The survey abundance indices have been adjusted from 2005 onwards 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 the 15% increase in efficiency was also incorporated as the nets used by the commercial boat were the same as that used by RV Naturaliste.
For Denham Sound the time-series for the survey index-catch prediction used prior to trial quota was comparatively short as Denham Sound has historically displayed very low scallop abundance and catch years (Figure 9.12). The survey index compared with landings has both under and over predicted landings, particularly in 2005 and 2008 (Figure 9.13). The low catch predictions for 2011 to 2014 resulted in closure of this part of the fishery as there was concern that the stock was at a very low level. From 2015, as part of trial quota, catch predictions were used to inform quota setting with a precautionary approach.
Figure 9.12 Denham Sound survey index (year t) and annual landings (year t+1) in the area open to fishing between 1997 and 2009 (closed in 2011 to 2014). The graph indicates the derived limit and threshold reference levels from the stock-recruit-environment relationship and the lowest realised catch line (red) which has been used to determine the TACC for Denham Sound since 2016.

Figure 9.13 Annual catch prediction and actual catch in Denham Sound 2001 to 2010. Note no fishing in Denham Sound between 2011 and 2014.

A further review of the methodology and the appropriateness of the current prediction methods have been undertaken in 2016/17 and how these estimates could be used in annual quota setting.

A collaborative project with the Department and Edith Cowan University funded by FRDC 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 and the information disseminated to fishers after surveys was useful for them locating aggregations of scallops. 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 second FRDC project (Kangas et al. 2012) included as one of its objectives to further examine whether historical (1987-1990) and more recent (1991-1994) fishing effort and intensity of effort by both the scallop and prawn fleets combined had impacted recruitment dynamics. This examination of historical data compared the overall effort between these two time-series. The second time series represented a time when additional spatial management was incorporated to manage early season prawn catches through implementation of a trawl closure line referred to as the Carnarvon Peron Line (CPL). The CPL was introduced in 1991 to protect brown tiger prawns and scallop fishers questioned whether this closure line changed the fishing pattern of prawn boats on historical scallop grounds before the scallop fishery opened (usually after the prawn season had already opened). The examination of the spatial effort data for these two time periods indicated that the implementation of the CPL did not significantly shift prawn fishing effort onto scallop grounds prior to the scallop fishery opening. This was however somewhat confounded by very high scallop abundance in 1992 to 1994 which prevented prawn boats trawling in some areas and they had to reduce the length (and time) of their trawls due to excessive scallop catches.

### 9.2.6.1 Conclusion

Fishery independent survey indices provide a mean abundance index for northern Shark Bay and Denham Sound and the survey index-annual catch relationship informs, with some uncertainty the likely catches in the following year. The fishery independent survey index for northern Shark Bay in 2018 indicated a low catch and this part of the fishery remains closed for 2019/20. The survey index in Denham Sound indicated a moderate catch and with fishing occurring in February 2019 to complete the 2018/19 season. Fishing is likely to occur in 2019/20. Supplementary information is available from additional surveys conducted in February in both parts of the fishery and in June in northern Shark Bay. These are yet to be incorporated into stock assessment.

### 9.2.7 Empirical Stock-Recruitment Relationships

#### 9.2.7.1 Northern Shark Bay

The stock-recruitment-environment relationship (SRR-E) for northern Shark Bay and Denham Sound was examined in Caputi et al. (2015a) and more recently by Chandrapavan et al. (in prep.). For northern Shark Bay, prior to the severe decline in stock abundance after the marine heatwave (2010/11), there was no strong evidence of a stock recruitment relationship (SRR) (Figure 9.14). Post-heatwave and with very low spawning stock abundance, it was evident that a SRR was significant and a limit reference level was set at the point (survey index) where recruitment appears to be impaired due to spawning stock abundance.
Figure 9.14 Relationship (log transformed) between the scallop survey recruitment index (November year y) with the estimated spawning stock (year y) based on the total scallop abundance in November year y-1) for northern Shark Bay. The year of recruitment is shown. The November 2018 spawning stock index that will be part of the 2019 spawning and contribute to recruitment in 2019 is also indicated.

9.2.7.2 Denham Sound

In Denham Sound, there is a clear relationship between SST and spawning stock abundance where the spawning stock has fallen to low levels in a number of years (Figure 9.15). The limit and threshold levels have been set at the mid-point of the relationship where recruitment is more likely to be influenced by the environment rather than the spawning stock abundance.
Figure 9.15 Relationship (log transformed) between the scallop survey index (November year y) with the estimated spawning stock (year y) based on the total scallop abundance in November year y-1) for Denham Sound. The year of recruitment is shown as well as the mean SST April - August (y). The 2018 spawning stock index that will contribute to recruitment in 2019 is also indicated.

9.2.7.3 Conclusion

The spawning stock recruitment relationships indicate that the northern Shark Bay scallop stocks are below the limit reference level in 2018/19 requiring a recovery strategy to be implemented in 2019/20, Denham Sound scallop stocks are above the threshold.

9.2.8 Quota setting – lowest realised catch and recruit and residual index

The relationship between annual fishery-independent survey indices and the annual landings are currently used to inform the season quota setting. A precautionary approach in quota setting is adopted. This is due to uncertainty in the catch predictions, changes in fishing dynamics since quota and environmental changes within Shark Bay. A joint Departmental/industry working group, was formed to provide advice to the Deputy Director General (DDG) on quota setting. Currently the working group has adopted using the lowest realised catch relative to a specific survey index value to determine the annual quota, This is combined with a within season review process (see Management section).

The quota setting uses a subset of the full time series of data where the lowest catch has been achieved based on the November-survey index for northern Shark Bay and Denham Sound separately (for example Figure 9.16 for Denham Sound). A within-season review of catches and catch rates is made along with mapping the distribution of effort in the two areas. In addition, scallop abundance information from a February survey, (after some fishing/catches
have been achieved in the fishery) enable the quota to be adjusted from the initial setting, either up or down (see Harvest Strategy). Alternative models for setting the quota (and the cycle of a fishing season) will be explored, supplemented by the information from the additional surveys undertaken in February and June.

Figure 9.16 Relationship between recruit and residual index from the annual scallop survey in Denham Sound against scallop landings between 2000/01 and 2009/10, the historical relationship (and equation) used to predict catches is shown as the black line and the lowest realised catch line for the lowest three catch years in the time series is shown in orange. This relationship has been used in 17/18 and 18/19 to set the quota for Denham Sound. The red vertical line is the limit reference level and the yellow the threshold reference level for this part of the fishery (reference levels established from SRR for Denham Sound).

9.2.9 Trends in Size Structure

Saucer scallops are short-lived (maximum of 2-3 years) and seasonal spawning events (primarily over winter months), generally result in two size cohorts in November surveys (Figure 9.17) representing recruit (0+) and residual (1+) animals. Reproductive cycles in northern Shark Bay and Denham Sound are described in Chandrapavan et al. 2019 (in prep.) and are slightly different although winter spawning is the key spawning period in both parts of Shark Bay. Annual variability in the relative abundance of recruits and residuals are evident as a result of; variable recruitment success, fishing and variable survival of residual stock. In some years several recruiting cohorts are evident reflecting settlement pulses. The impact of the heatwave on scallop stocks between 2011 to 2015 in both northern Shark Bay and Denham Sound is clearly evident. Since recovery, Denham Sound and northern Shark Bay have responded differently in scallop size distributions for example low levels of recruitment in combination with poor survival of scallops into residuals until 2015 in Denham Sound but this was apparent up to 2017 in northern Shark Bay.
Figure 9.17 Shell height (SH) frequencies of *Ylistrum balloti* in northern Shark Bay (black) and Denham Sound (blue) from November surveys between 2004 and 2017. Broadly, scallops <86 mm SH are classed as recruits (0+) whilst residuals (1+) are those scallops ≥ 86m SH.

### 9.2.10 Productivity Susceptibility Analysis

Productivity Susceptibility Analysis (PSA) is a semi-quantitative risk analysis originally developed for use in Marine Stewardship Council (MSC) assessments to score data-deficient stocks, i.e. where it is not possible to determine status relative to reference points from available information (Hobday et al. 2011; MSC 2014). The PSA approach is based on the assumption that the risk to a stock depends on two characteristics: (1) the productivity of the species, which will determine the capacity of the stock to recover if the population is depleted, and (2) the extent of the impact on the stock due to fishing, which will be determined by the susceptibility of the species to fishing activities (see Appendix ).
Although a valuable tool for determining the overall inherent vulnerability of a stock to fishing, the PSA is limited in its usefulness for providing stock status advice. This is because of the simplicity and prescriptiveness of the approach, which means that risk scores are very sensitive to input data and there is no ability to consider management measures implemented in fisheries to reduce the risk to a stock (Bellchambers et al. in prep.). Consequently, the PSA is used by the Department to produce a measure of the vulnerability of a stock to fishing, which is then considered within the overall weight of evidence assessment of stock status.

### 9.2.10.1 PSA Scores

Updated scores: Average age at maturity (1), Average maximum age (1), Fecundity (1), Reproductive strategy (1), trophic level (1), density-dependence (2), Availability (3), Encounterability (3), Selectivity (3) Post-capture mortality (2), MSC PSA-derived score (98), Risk category (Low –>80).

The scores, in part, reflect this species being short-lived (maximum age ~2-3 years), highly fecund, broadcast spawning strategy, medium trophic level, but being highly-selected by the fishing gear and exhibiting low to moderate post-capture mortality.

### 9.2.10.2 Conclusion

The PSA analysis indicates that the saucer scallop stock in Shark Bay would be susceptible to overfishing/unacceptable depletion if appropriate management was not in place.

### 9.2.11 Per-Recruit Analysis

Refer to Kangas et al. 2011. Yield is maximised between 80 and 90 mm SH.

#### 9.2.11.1 Conclusion

The fishery targets scallops above 80mm SH up to 110 mm SH and therefore scallops are at or above maximum yield. Yield is also variable due to the change in size and quality of the adductor muscle due to reproduction.

### 9.2.12 Bio-Economic Assessment
9.3 Stock Status Summary

Presented below is a summary of each line of evidence considered in the overall weight of evidence assessment of the stocks that comprise the Shark Bay scallop resource, followed by the management advice and recommendations for future monitoring of the species. In each section, northern Shark Bay and Denham Sound are addressed separately when appropriate.

9.3.1 *Ylistrum balloti* – Northern Shark Bay and Denham Sound

9.3.1.1 Weight of Evidence Risk Assessment

Summary of lines of evidence used to assess risk to sustainability of the Shark Bay scallop fishery.

<table>
<thead>
<tr>
<th>Category</th>
<th>Lines of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>Northern Shark Bay</td>
</tr>
</tbody>
</table>
| Annual catch (% of quota)       | The current landed weight of scallops for 2018/19 from northern Shark Bay was 61.5 t and therefore was only ~35% of the specific TACC from this area. Surveys conducted on standard sites in the northern Shark Bay scallop grounds during November 2017 indicated that scallop abundance had returned to historical levels and a TACC for this area of 250 t was initially set (but revised 287.5 t) however only ~62 t was caught for the season from this area. Therefore, the expected catch for this season, even at the lowest realised catch line was not met. In addition, the November 2018 survey indicated very low stock abundance in northern Shark Bay indicating a high mortality of 1+ individuals during 2018 combined with low recruitment (0+ as measured in November). A subsequent survey in February 2019 confirmed the low abundance levels with only two small areas of recruit abundance.
|                                 | This line of evidence suggests the level of stock recovery observed in 2017 did not continue into 2018 and current stock abundance is below the limit reference level with only two small areas of recruit abundance in northern Shark Bay. |
| Denham Sound                    | The current landed weight of scallops for 2018/19 from Denham Sound was 178 t. Since the northern Shark Bay and Denham Sound quota allocations were combined for a total TACC of 271 t the majority of catch for the year was taken from Denham Sound with this catch well above the area specific TACC that was set. The actual catch taken more closely reflected the historical survey index annual landings expectation rather than the lowest realised catch that is used for TACC setting.
|                                 | This line of evidence suggests the level of stock abundance in Denham Sound was higher than the lowest realised catch line that was used to determine the TACC and reflected the historical survey catch prediction. |
### Annual commercial fishing effort

Most of the targeted effort on scallops was in Denham Sound by both the A and B Class boats with only one area in part of NW Peron in northern Shark Bay being fished for scallops by A Class boats in February/March 2018.

**This line of evidence indicates that fishing effort and effort distribution reflected the abundance and distribution of scallops within Shark Bay.**

### Catch distribution

Scallops were primarily caught within Denham Sound on the traditional scallop grounds. The logbook information indicates that most scallops were retained from areas that indicated higher catch rates of scallops during the November 2017 survey.

**There is no evidence to indicate that the fishery exploited aggregations of scallops in areas not previously identified by surveys.**

### Annual fishery-dependent catch rates

Commercial catch rate data for this fishery can only be based on the A Class boat catch rates as B Class boats generally target prawns and the low level of permitted catch of scallops per boat influences fisher behaviour. The annual commercial catch rate in 2017/18 (and preliminary 2018/19 catch rate) which was mainly focused on Denham Sound, indicate catch rates are within the higher end of the historical range apart from very high catch rate years in the early 1990s.

**Annual scallop fleet trawl catch rates are in the upper range of the historical catch rates but may not be informative due to; changing to quota, a different season structure and the reduction of boats operating in the fishery.**

### Within-season (pre and post spawning) fishery-dependent catch rates

The key spawning period for scallops is between April and July with spawning continuing into spring/summer at lower levels. A spawning closure (no retention of scallops) was set between June and August 2018. With both parts of the fishery showing scallop abundance levels above the threshold levels during the November 2017 survey, no pre-spawning catch limit was set for the 2018/19 season.

**If the A class fleet fish in the pre-spawning period, their mean daily catch rate may inform on the scallop depletion rates prior to the spawning closure and may provide an estimate of standing stock in the areas fished based on a depletion analysis.**

### Fishery independent spawning stock indices

The November fishery-independent survey is presently used to determine the spawning stock abundance for the following year. The spawning stock in Denham Sound in 2018 was above the threshold level and with cooler than average winter temperatures observed within Shark Bay successful recruitment may occur in 2019. The spawning stock in northern Shark Bay in November 2018 was lower than the limit level.

**The lines of evidence indicate that the spawning stock within Denham Sound is adequate but that in northern Shark Bay is below the limit and requires a recovery strategy to be implemented.**
## Fishery independent recruitment indices

The November 2018 survey confirmed a moderate level of recruitment in Denham Sound however the February 2019 survey indicated high recruitment levels in a number of survey sites indicating that a late recruitment had occurred. Conversely in northern Shark Bay in November very low recruitment levels were observed and in February 2019 only two sites sampled showed high recruit abundance.

**The lines of evidence indicate that the recruitment in Denham Sound is good but that in northern Shark Bay only two small localised areas are showing recruitment and these may require protection as part of a stock recovery strategy.**

## Size composition data

Generally during November surveys, two primary cohorts are evident, the residual stock (1+) and the recruits (0+) derived from the spawning stock. The residuals in November are those that have survived the year and not been harvested. Each year, some variability is observed in the strength, mean size of each cohort and after extreme events the absence of one or both of the primary cohorts have been observed. In November 2017 both areas had good numbers of both residual and recruit scallops. In November 2018 there were at least two cohorts evident in all areas but those in northern Shark Bay were in very low abundance compared to Denham Sound. With very little commercial take in northern Shark Bay, the expectation had been for more residuals in the area, but it appears these did not survive from the November 2017 survey to November 2018. In Denham Sound in November 2017, three distinct cohorts were evident indicating two strong recruitment events and moderate residual abundance.

**This line of evidence indicates low survival of residual scallops in northern Shark Bay in 2018 and also low recruitment levels. Conversely the size composition information indicates good recruitment in Denham Sound showing different responses in the two areas.**

## Stock-recruitment analysis

A stock recruitment relationship (SRR) is evident for both northern Shark Bay and Denham Sound and these relationships have been used to set the limit and threshold reference levels in the draft HS for each part of the fishery. SSTs have also been incorporated into the analysis as environmental factors (and extreme events) have clearly been the main driver of recruitment in years when spawning stock abundance has not been impaired. This was particularly evident in northern Shark Bay, until the marine heatwave of 2010/11 after which spawning stock abundance was also important. In 2018, the SRR indicates that Denham Sound is above the threshold levels whereas northern Shark Bay is below the limit reference level. requiring management action.

**These lines of evidence indicate that the low spawning stock level in northern Shark Bay requires management action.**

## PSA analysis

The PSA score is Low for this species. The score reflects this species being short-lived (maximum age ~2-3 years), highly fecund, broadcast spawning
strategy, medium trophic level, but being highly selected by the fishing gear and exhibiting low to moderate post-capture mortality.

| Environmental factors | Shark Bay experienced the hottest summer SSTs on record in 2010/11 and 2011/12, which is considered to have led to a significant effect on recruitment over 2011-13 resulting in very low spawning stock. Water temperatures in Shark Bay have since returned to within historical ranges however cooler than average winter persist within Shark Bay and summer temperatures being below average in the last 3 summers. The cooler winters are favourable for scallop recruitment. The winters of 2017 and 2018 have been the coldest since the marine heatwave. Scallops are ranked “high risk” under the current climate change scenario impacting the WA coastline and particularly in Shark Bay. **Recruitment levels in Shark Bay may improve with the current SST conditions but there appear to be other factors that are affecting the survival and recruitment of stocks in northern Shark Bay.** |
| Climate change | |

| Catch-MSY Stock assessment | A Catch-MSY model (Martell and Froese, 2013), implemented within the “simpleSA” R package (Haddon 2018) was attempted for the saucer scallop stock in Shark Bay. The Catch-MSY model is a “data-poor” stock assessment method that can been used to estimate biomass and fishing mortality trends based on a catch history and inputs relating to the assumed productivity of the stock. Note that the method makes some strong assumptions and biomass estimates typically exhibit large uncertainty (variation). but the high variability in annual scallop catches precludes this method being suitable. **The Catch-MSY model was not suitable for scallop annual catch data.** |
### Shark Bay Scallop Risk Matrix

#### Northern Shark Bay

<table>
<thead>
<tr>
<th>Consequence (stock sustainability) Level</th>
<th>Likelihood</th>
<th>Risk Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1 Remote (≤5%)</td>
<td>L2 Unlikely (5-30%)</td>
</tr>
<tr>
<td>C1 Minimal (Measureable but minor levels of depletion of fish stock)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>C2 Moderate (Maximum acceptable level of depletion of stock)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>C3 High (Level of depletion of stock unacceptable but still not affecting recruitment level of the stock)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4 Major (Level of depletion of stock are already or will definitely affect future recruitment potential level of the stock)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5 Catastrophic (Permanent or widespread and long-term depletion of fish stock, close to extinction levels)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**C1 (Minimal stock depletion): L1 – Not plausible**

**C2 (Maximum Acceptable Depletion): L2 – All lines of evidence for the status of scallop stocks in northern Shark Bay indicate that stock depletion has occurred with stocks below the limit level which may impact the level of recovery.**

**C3 (Unacceptable Depletion): L3 – The lines of evidence indicate that it is possible that unacceptable stock depletion has occurred for the scallop stocks in northern Shark which may impact the level of recovery. There are only two areas of higher abundance of recruit scallops observed in February. The reasons for this unacceptable depletion is uncertain.**

**C4 (Unacceptable): L4 – All the lines of evidence support that there has been a major impact on the scallop stocks with the abundance below the limit level which will affect stock recovery even with favourable environmental conditions.**

87
C5 (Catastrophic) – Not plausible under current circumstances.

**Summary of risk to stock recovery in northern Shark Bay**

In assessing the overall the risk to stock recovery in northern Shark Bay the lines of evidence indicate a **Severe risk level** (maximum score of 16). Any level of catch is likely to deplete the stock and could impede further stock recovery even under favourable environmental conditions. A stock recovery strategy is appropriate including consideration of spatial and temporal closures.

**Shark Bay scallop risk matrix**

<table>
<thead>
<tr>
<th>Consequence (stock sustainability) Level</th>
<th>Likelihood</th>
<th>Risk Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L1</strong> Remote (&lt;5%)</td>
<td>X</td>
<td>2</td>
</tr>
<tr>
<td><strong>L2</strong> Unlikely (5-30%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>L3</strong> Possible (30-50%)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>L4</strong> Likely (50-90%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>L5</strong> Certain (90-100%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consequence (stock sustainability) Level</th>
<th>Likelihood</th>
<th>Risk Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C1</strong> Minimal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Measureable but minor levels of depletion of fish stock)</td>
<td>X</td>
<td>2</td>
</tr>
<tr>
<td><strong>C2</strong> Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Maximum acceptable level of depletion of stock)</td>
<td>X</td>
<td>8</td>
</tr>
<tr>
<td><strong>C3</strong> High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Level of depletion of stock unacceptable but still not affecting recruitment level of the stock)</td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td><strong>C4</strong> Major</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Level of depletion of stock are already or will definitely affect future recruitment potential level of the stock)</td>
<td>X</td>
<td>4</td>
</tr>
<tr>
<td><strong>C5</strong> Catastrophic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Permanent or widespread and long-term depletion of fish stock, close to extinction levels)</td>
<td>na</td>
<td></td>
</tr>
</tbody>
</table>

C1 (Minimal stock depletion): **L2** – All the lines of evidence support that there has been an unlikely likelihood of minimal scallop stock depletion during 2018 because X t was caught from this part of the fishery in 2018/19 and was higher than the TACC set for this area, however was around the historical expectation in relation to the fishery independent survey index in November 2017.
C2 (Maximum Acceptable Depletion): **L4** – Lines of evidence indicate that a maximum acceptable depletion occurred in Denham Sound in 2018/19 as there was no evidence of recruitment impairment.

C3 (Unacceptable Depletion): **L2** – The lines of evidence indicate that it is unlikely that unacceptable stock depletion has occurred for the scallop stocks in Denham Sound.

C4 (Unacceptable): **L1** – All the lines of evidence support that is a remote likelihood that fishing has caused a major risk to recruitment impairment.

C5 (Catastrophic) – Not plausible under current circumstances.

**Summary of risk to stock recovery in Denham Sound**

In assessing the overall the risk to scallop stocks in Denham Sound the lines of evidence indicate a Medium risk level (maximum score of 8). Harvesting of scallops from Denham Sound can occur in 2019/20 at quantities that retain overall stock abundance above the threshold level.

### 9.3.1.2 Current Risk Status

The Shark Bay Scallop Managed Fishery was considered to have recovered in 2017 with both parts of the fishery having survey indices within historical levels and Denham Sound having high scallop abundance. A trial quota system with a conservative total allowable commercial catch (TACC) and target reference levels for resumption of fishing was implemented in 2015 to provide protection for the breeding stock and aid in recovery. Conservative management measures have been implemented each year since 2015. For the 2018/19 season, a total TACC of 350 t meat weight (1650 t whole weight) was initially implemented and but fishing in late 2018 indicated that catches that were expected in northern Shark Bay would not be realised whereas catches in Denham Sound were as expected from the catch prediction. The initial TACC was reduced to 263 t.

The November 2018 survey indicated very low stock abundance in northern Shark Bay, lower than the limit reference level, and this was verified by a February 2019 survey. Conversely, Denham Sound scallop stocks continue to be fully recovered. Based on the information available, the current risk level for scallops in northern Shark Bay is estimated to be SEVERE (C4 × L4). The Severe Risk (see Error! Reference source not found.) reflects unacceptable level of relative spawning biomass. All the lines of evidence are consistent with a severe level of risk, hence the overall Weight of Evidence assessment indicates the status of the scallop stock in northern Shark Bay is inadequate and that precautionary management settings are required including implementing a recovery strategy to assist stocks returning to acceptable levels.

The November 2018 survey indicated moderate stock abundance in Denham Sound, above the threshold level. The February 2019 survey indicated a much higher stock abundance than observed in November, primarily due to a pulse of late recruitment of scallops (not observed in November due to poor selectivity of small scallops). Based on the information available, the current risk level for scallops in Denham Sound is estimated to be MEDIUM (C2 × L4). The Medium Risk (see Error! Reference source not found.) reflects acceptable/adequate level of relative spawning biomass. All the lines of evidence are consistent with a medium level
of risk, hence the overall Weight of Evidence assessment indicates the status of the scallop stock in Denham Sound is adequate and that management settings should be based around the draft Harvest Strategy.

9.3.1.3 Future Monitoring

- Monitor the changing environmental conditions and how they are affecting the timing of spawning and recruitment of the scallop stocks
- Identify what stage in the life cycle stock impairment is happening for scallops (particularly in NSB) to clarify the ideal times for harvest/no harvest (protection) in each area.
- Further investigate influence of catch and discard of scallops on natural recovery and recruitment
- Investigate fishery-independent (February, June and November) survey/catch relationship to support TACC and ancillary management settings for NSB and DS scallops.
- Assess selectivity of alternative gear (T90/square mesh) if/when adopted by industry.

References


Department of Fisheries (DoF). (2011). Resource Assessment Framework (RAF) for finfish resources in Western Australia. Fisheries Occasional Publication No. 85. Department of Fisheries, WA.


Fletcher, W.J. (2002). Policy for the implementation of ecologically sustainable development for fisheries and aquaculture within Western Australia. Fisheries Management Paper No. 157. Department of Fisheries, WA.


Fletcher, W.J. and Santoro, K. (eds.) (2015). Status reports of the fisheries and aquatic resources of Western Australia 2014/15: State of the fisheries. Department of Fisheries, WA.


Appendix 1

Consequence, Likelihood and Risk Levels (based on AS 4360 / ISO 31000) modified from Fletcher et al. (2011) and Fletcher (2015)

CONSEQUENCE LEVELS

As defined for major target species

1. Minor – Fishing impacts either not detectable against background variability for this population; or if detectable, minimal impact on population size and none on dynamics
   Spawning biomass > Target level ($B_{MEY}$)

2. Moderate – Fishery operating at maximum acceptable level of depletion
   Spawning biomass < Target level ($B_{MEY}$) but > Threshold level ($B_{MSY}$)

3. High – Level of depletion unacceptable but still not affecting recruitment levels of stock
   Spawning biomass < Threshold level ($B_{MSY}$) but > Limit level ($B_{REC}$)

4. Major – Level of depletion is already affecting (or will definitely affect) future recruitment potential/levels of the stock
   Spawning biomass < Limit level ($B_{REC}$)

LIKELIHOOD LEVELS

These are defined as the likelihood of a particular consequence level actually occurring within the assessment period (5 years was used)

1. Remote – The consequence has never been heard of in these circumstances, but it is not impossible within the time frame (Probability of <5%)

2. Unlikely – The consequence is not expected to occur in the timeframe but it has been known to occur elsewhere under special circumstances (Probability of 5 - <20%)

3. Possible – Evidence to suggest this consequence level is possible and may occur in some circumstances within the timeframe. (Probability of 20 - <50%)

4. Likely – A particular consequence level is expected to occur in the timeframe (Probability of ≥50%)
### Consequence x Likelihood Risk Matrix

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor (1)</td>
<td>Negligible</td>
</tr>
<tr>
<td>Moderate (2)</td>
<td>Negligible</td>
</tr>
<tr>
<td>High (3)</td>
<td>Low</td>
</tr>
<tr>
<td>Major (4)</td>
<td>Low</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Levels</th>
<th>Description</th>
<th>Likely Reporting &amp; Monitoring Requirements</th>
<th>Likely Management Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Negligible</td>
<td>Acceptable; Not an issue</td>
<td>Brief justification – no monitoring</td>
<td>Nil</td>
</tr>
<tr>
<td>2 Low</td>
<td>Acceptable; No specific control measures needed</td>
<td>Full justification needed – periodic monitoring</td>
<td>None specific</td>
</tr>
<tr>
<td>3 Medium</td>
<td>Acceptable; With current risk control measures in place (no new management required)</td>
<td>Full Performance Report – regular monitoring</td>
<td>Specific management and/or monitoring required</td>
</tr>
<tr>
<td>4 High</td>
<td>Not desirable; Continue strong management actions OR new / further risk control measures to be introduced in the near future</td>
<td>Full Performance Report – regular monitoring</td>
<td>Increased management activities needed</td>
</tr>
<tr>
<td>5 Severe</td>
<td>Unacceptable; If not already introduced, major changes required to management in immediate future</td>
<td>Recovery strategy and detailed monitoring</td>
<td>Increased management activities needed urgently</td>
</tr>
</tbody>
</table>

### References


# Appendix 2

**Productivity Susceptibility Analysis (PSA) Scoring Tables**

<table>
<thead>
<tr>
<th>Productivity attribute</th>
<th>High productivity (Low risk: Score = 1)</th>
<th>Medium productivity (Medium risk: Score = 2)</th>
<th>Low productivity (High risk: Score = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average maximum age</td>
<td>&lt;10 years</td>
<td>10-25 years</td>
<td>&gt;25 years</td>
</tr>
<tr>
<td>Average age at maturity</td>
<td>&lt;5 years</td>
<td>5-15 years</td>
<td>&gt;15 years</td>
</tr>
<tr>
<td>Average maximum size</td>
<td>&lt;1000 mm</td>
<td>1000-3000 mm</td>
<td>&gt;3000 mm</td>
</tr>
<tr>
<td>Average size at maturity</td>
<td>&lt;400 mm</td>
<td>400-2000 mm</td>
<td>&gt;2000 mm</td>
</tr>
<tr>
<td>Reproductive strategy</td>
<td>Broadcast spawner</td>
<td>Demersal egg layer</td>
<td>Live bearer</td>
</tr>
<tr>
<td>Fecundity</td>
<td>&gt;20,000 eggs per year</td>
<td>100-20,000 eggs per year</td>
<td>&lt;100 eggs per year</td>
</tr>
<tr>
<td>Trophic level</td>
<td>&lt;2.75</td>
<td>2.75-3.25</td>
<td>&gt;3.25</td>
</tr>
<tr>
<td>Density dependence</td>
<td>Compensatory dynamics at low population size demonstrated or likely</td>
<td>No depensatory or compensatory dynamics demonstrated or likely</td>
<td>Depensatory dynamics at low population sizes (Allele effects) demonstrated or likely</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Susceptibility attribute</th>
<th>Low susceptibility (Low risk: Score = 1)</th>
<th>Medium susceptibility (Medium risk: Score = 2)</th>
<th>High susceptibility (High risk: Score = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areal overlap</td>
<td>&lt;10% overlap</td>
<td>10-30% overlap</td>
<td>&gt;30% overlap</td>
</tr>
<tr>
<td>Encounterability</td>
<td>Low encounterability / overlap with fishing gear</td>
<td>Medium overlap with fishing gear</td>
<td>High encounterability / overlap with fishing gear (Default score for target species in a fishery)</td>
</tr>
<tr>
<td>Selectivity of gear type</td>
<td>a) Individual &lt; size at maturity are rarely caught</td>
<td>a) Individual &lt; size at maturity are regularly caught</td>
<td>a) Individual &lt; size at maturity are frequently caught</td>
</tr>
<tr>
<td></td>
<td>b) Individual &lt; size can escape or avoid gear</td>
<td>b) Individual &lt; half the size can escape or avoid gear</td>
<td>b) Individual &lt; half the size are retained by gear</td>
</tr>
<tr>
<td>Post-capture mortality</td>
<td>Evidence of majority released post-capture and survival</td>
<td>Evidence of some released post-capture and survival</td>
<td>Retained species or majority dead when released</td>
</tr>
</tbody>
</table>