Department of
Primary Industries and Regional Development

GOVERNMENT OF WESTERN AUSTRALIA

Western Australian Marine Stewardship Council Report Series No. 12

Resource Assessment Report Western Australian Sea Cucumber Resource

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November 2018

Correct citation:

Hart, A.M., Murphy, D.M., Caputi, N., Hesp, S.A., Fisher, E.A. (2018). Western Australian Marine Stewardship Council Report Series No. 12: Resource Assessment Report Western Australian Sea Cucumber Resource. Department of Primary Industries and Regional Development, Western Australia. 89pp.

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ISSN: 2205-3670 (Print) ISBN: 978-1-921258-14-5 (Print)
ISSN: 2205-3689 (Online) ISBN: 978-1-921258-15-2 (Online)

Executive Summary

- The sea cucumber resource comprises eight species that inhabit the tropical shallow continental shelf waters of the North Coast Bioregion, and are taken in the Western Australian Sea Cucumber Fishery (WASCF). However >99% of the harvest in the WASCF is two main species, *Holothuria scabra* (sandfish) and *Actinopyga echinites* (redfish), which this assessment report is focused on.
- Sandfish and redfish are both widely distributed tropical Indo-Pacific species. Redfish is sometimes known as the deepwater redfish to distinguish it from a closely related species, the surf redfish (*Actinopyga mauritania*), however, the distinction has not been necessary thus far for Western Australia as only *A. echinites* is harvested. The resource is harvested from two main regional areas; the Kimberley and the Pilbara. Sandfish is harvested from both regions, with most of the catch coming from the Kimberley (84%). Redfish is currently only harvested in the Pilbara region.
- There is a dichotomy of opinion of the inherent vulnerability of sea cucumbers to fishing. Some studies suggest they are particularly vulnerable, unable to be sustained under exploitation rates of greater than 5% of unfished biomass. Other analyses suggest they are inherently robust due to early age-at-maturity, high fecundity, and relatively high natural mortality. It may be that unmanaged and unregulated fishing has been a major contributor to the poor track record for sea cucumber fisheries, and thus their vulnerability is not an indication of "management" *per se*, but rather a lack of management. Overall, the dichotomy of opinion on their inherent vulnerability suggests considerable uncertainty and a conservative approach is required where data or history is lacking.
- The resource is harvested by hand collection while diving or wading. Small quantities of sea cucumber species not targeted by the WASCF are collected by the Marine Aquarium Fish Managed Fishery (MAFMF) for aquarium display purposes and some are discarded in trawl fisheries. Recreational and customary take is negligible, although Indigenous communities can apply for a permit to fish independent of licensed commercial fisheries.
- Data on the life history of individual species that comprise the resource is sparse for Western Australia. Substantial information on age, growth, mortality, genetics and distribution of these species does exist, however, owing to their commercial and artisanal importance throughout communities within the Indo-Pacific region. This information in combination with accurate catch and effort logbooks, and biological surveys where necessary has been used to guide management of this resource.
- The sandfish and redfish stocks are assessed each year using annual indices of biomass derived from fine-scale catch, effort and fishery-independent abundance data. These are compared with specified reference points, namely biomass and standardised catch rate (SCPUE) targets, thresholds, and limits developed from historical fishing patterns and biomass models. If the threshold or limit reference points are breached the prescribed management action (involving fishery closures) is implemented. Accompanying any management action is a review involving exploration of additional data including fine-scale

fishing patterns and catch rates and trends in annual mean weights and size-frequency information.

- A weight-of-evidence assessment of the stocks in 2017 concluded that there was no evidence to suggest unacceptable stock depletion for either of the two main species. The lines of evidence included: catch, catch distribution, abundance indices (catch rates), population surveys, mean size of catch, PSA (Productivity Susceptibility Analysis), and model-based biomass estimates of depletions relative to unfished biomass (B_0). The assessment did, however, indicate that further work was needed on estimating key biological parameters such as age and/or size at maturity, and furthering the independent survey program to include the Kimberley stock for sandfish.

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List of Abbreviations

CAES	Catch and Effort Statistics
Department	Department of Primary Industries and Regional Development (formerly Department of Fisheries)
EBFM	Ecosystem-Based Fisheries Management
ENSO	El Niño Southern Oscillation
ESD	Ecologically Sustainable Development
EPBC	Environment Protection and Biodiversity Conservation (Act)
FRMA	Fish Resources Management Act
GLM	Generalised Linear Model
MAFMF	Marine Aquarium Fish Managed Fishery
MSC	Marine Stewardship Council
NCB	North Coast Bioregion
SCPUE	Standardised Catch per Unit Effort (catch rate)
WA	Western Australia
WASCF	Western Australian Sea Cucumber Fishery

1 Scope

This document provides a cumulative description and assessment of the Sea Cucumber Resource and all of the fishing activities (i.e. fisheries / fishing sectors) affecting this resource in Western Australia (WA). The overall resource comprises two main species (sandfish *Holothuria scabra* and redfish *Actinopyga echinites*), and few minor species that inhabit the tropical shallow continental shelf waters of the North Coast Bioregion. Based on the stock units considered for management, the resource is separated into two main regional areas; the Pilbara and the Kimberley.

The report is focused on the two main species that comprise this resource. Commercial harvest is permitted by license holders in the Western Australian Sea Cucumber Fishery (WASCF). Permitted harvest collection method is hand collection by diving and wading primarily in shallow waters of northern WA, from Exmouth Gulf to the Northern Territory border. Small quantities of sea cucumber species not targeted by the WASCF are collected by the marine aquarium managed fishery for aquarium display purposes and some are discarded in trawl fisheries.

The report contains information relevant to assist the assessment of the Sea Cucumber Resource against the Environment Protection and Biodiversity Conservation (EPBC) Act export approval requirements and the Marine Stewardship Council (MSC) Principles and Criteria for Sustainable Fishing.

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, the Department) Risk Register for fisheries and aquatic resources, 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 annual planning 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 (Department of Fisheries 2015) has been designed to ensure that the harvest strategies cover the broader scope of EBFM and thus consider 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).

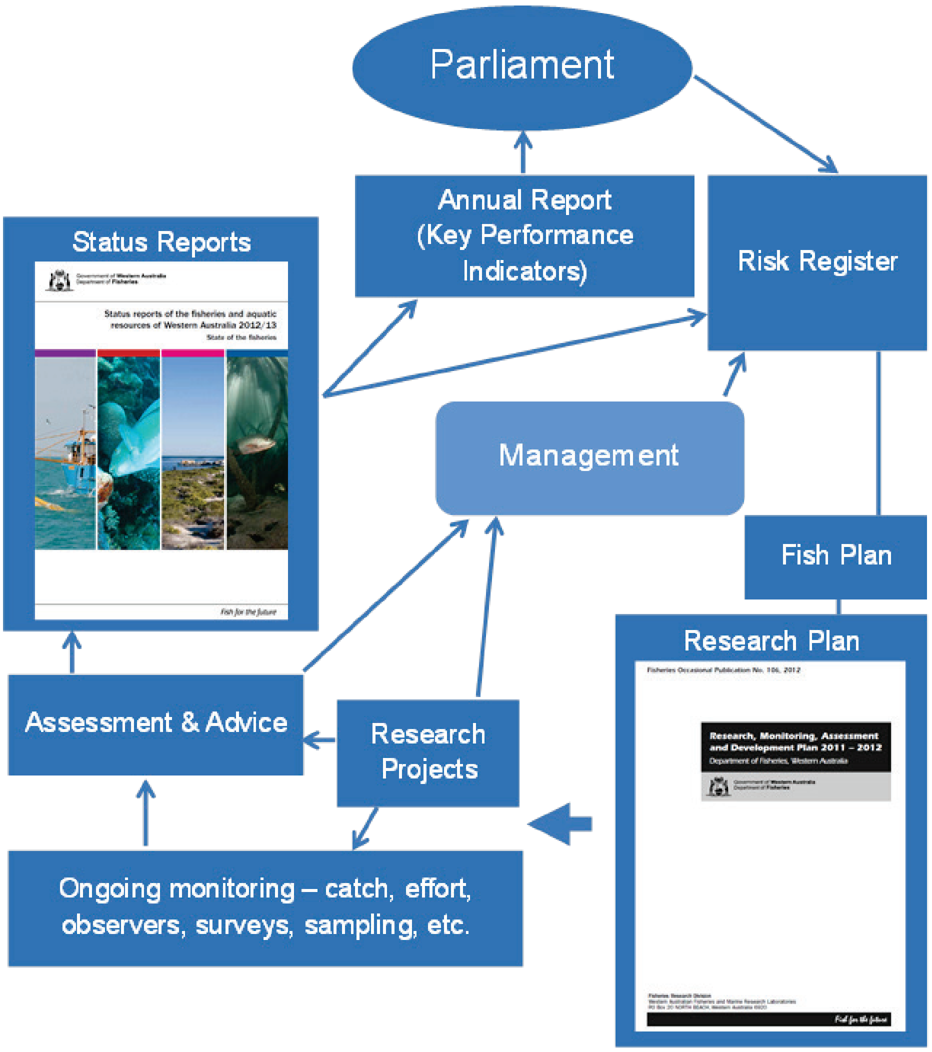

Figure 2.1. An outline of the risk-based planning cycle used for determining Departmental priorities and activities.

3 Aquatic Environment

The North Coast Bioregion (NCB) of WA (see Figure 3.1) has a unique combination of features that distinguish it from other marine regions around Australia; including the wide continental shelf, very high tidal regimes, high cyclone frequency, unique current systems, warm oligotrophic surface waters and unique geomorphological features (Brewer et al. 2007). The oceanography of the NCB includes waters of Pacific origin that enter through the Indonesian archipelago bringing warm, low-salinity water pole-wards via the Indonesian Through-flow and seasonal Holloway Current. Ocean temperatures range between 22°C and 33°C, with localised higher temperatures in coastal waters, particularly along the Pilbara coast. Fish stocks in the NCB are tropical, with most having an Indo-Pacific distribution extending eastward through Indonesia to the Indian subcontinent and Arabian Gulf regions.

Coastal waters are generally low-energy in terms of wave action, but are seasonally influenced by infrequent, but intense, tropical cyclones, storm surges and associated rainfall run-off. These cyclone events generate the bulk of the annual rainfall, although the Kimberley coast does receive limited monsoonal thunderstorm rainfall over summer. Significant river run-off and related coastal productivity can be associated with cyclone events, with run-off ceasing during winter. The entire north coastal region is subject to very high evaporation rates (three metres per year), although the Pilbara coast is more arid than the Kimberley coast, due to its lower annual rainfall. Another significant influence on coastal waters is the extreme tidal regime. Spring tides range from 11 metres along the Kimberley coast down to around two metres in the west Pilbara.

The Kimberley coast has a well-developed and highly indented shoreline, with bays and estuaries backed by a hinterland of high relief, a suite of local nearshore islands and a distinct suite of coastal sediments. Broad tidal mudflats and soft sediments with fringing mangroves are typical of this area. The eastern Pilbara coast is more exposed than the Kimberley, with few islands and extensive intertidal sand flats. Softer sediments and mangroves occur around river entrances in this region. The western Pilbara is characterised by a series of significant, but low-relief islands, including the Dampier Archipelago, Barrow Island and the Montebello Islands. Near-shore coastal waters include rocky and coral reef systems, creating significant areas of protected waters. West Pilbara shorelines also include areas of soft sediments, salt-marshes and mangrove communities.

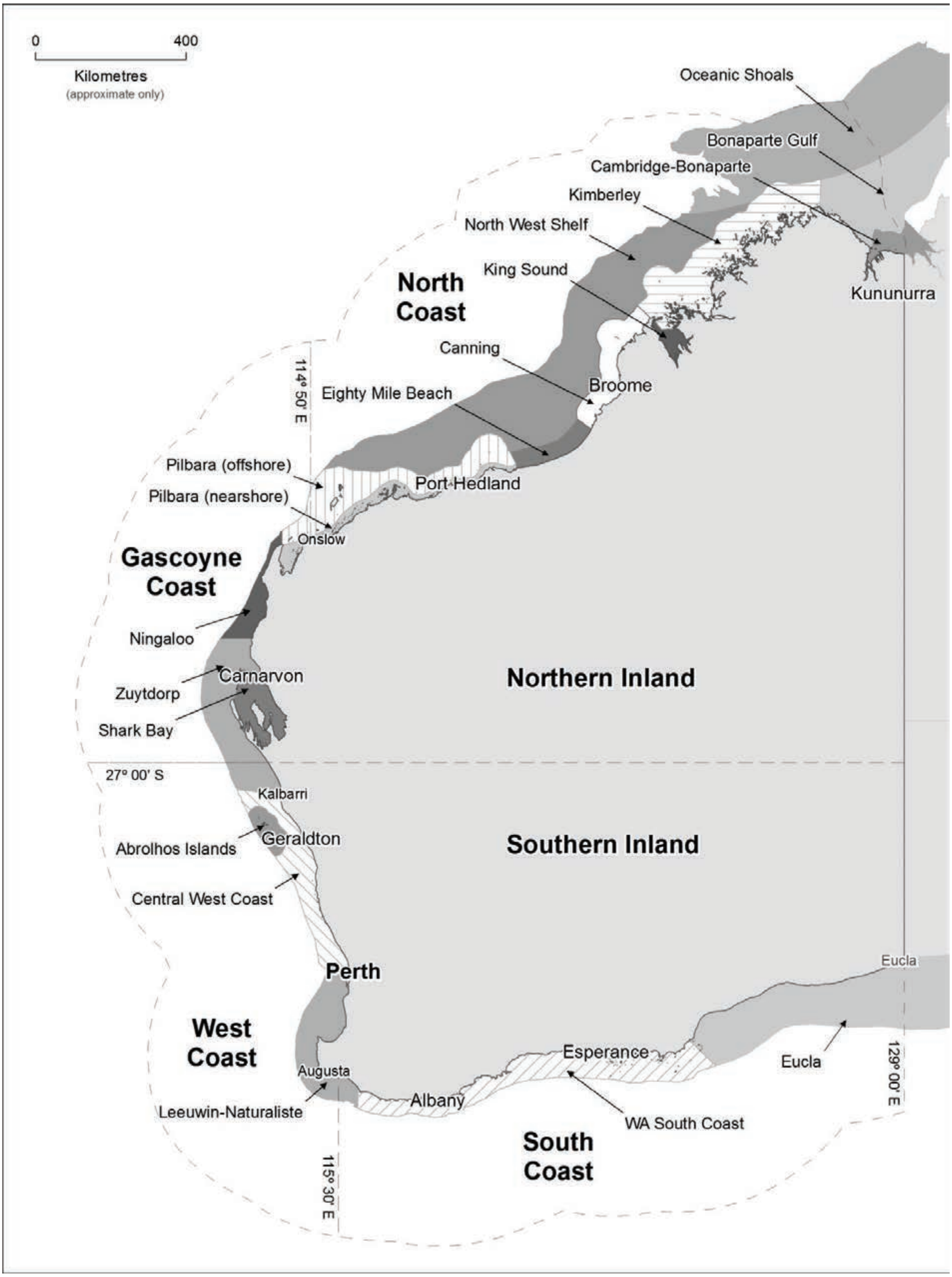

Figure 3.1. Locality of the North Coast Bioregion within WA and boundaries of the different IMCRA ecosystems identified along the coast.

4 Resource Description

4.1 Sea Cucumber Resource

Sea cucumbers or 'trepang', are in the Phylum Echinodermata, Class Holothuroidea. They are soft-bodied, elongated animals that usually live with their ventral surface in contact with the benthic substrate or buried in the substrate. The resource targeted by the fishery comprises two widely-distributed tropical Indo-Pacific species, sandfish (*Holothuria scabra*) and deepwater redfish (*Actinopyga echinites*). Redfish is sometimes known as the deepwater redfish to distinguish it from a closely-related species, the surf redfish (*A. mauritania*). In tropical WA, sandfish and redfish occur primarily within low energy environments behind fringing reefs or within protected bays.

There are six other commercial species that fishers in the WASCF may retain: Black teatfish (*Holothuria whitmaei*), white teatfish (*H. fuscogilva*), prickly redfish (*Thelenota ananas*), lollyfish (*H. atra*), brown curry fish (*Stichopus wastus*) and curry fish (*S. hermanni*). However, since 2001, only black teatfish have been retained in significant numbers, i.e. >1 t, in addition to the two main target species.

As data on local sea cucumber populations remain sparse, information on the life history, biological information required for management purposes in WA is predominantly sourced from other jurisdictions within the Indo-Pacific region where sea cucumber fisheries have high commercial and artisanal importance.

The stock structures of the sandfish and redfish in WA have not yet been established, however, genetic studies of sandfish populations in Northern Territory and Queensland state waters have indicated genetically distinct stocks occur within these regions (Uthicke and Benzie 2001; Gardner and Fitch 2012). This suggests there may be genetic differences in stocks along the WA coast, and particularly between the fished stocks of the Kimberley and the Pilbara.

Sandfish can produce up to 18 million viable eggs and spawning can occur year round, although the main spawning season occurs during September to November. The planktotrophic larvae feed on microalgae in the water column during the dispersive larval phase, metamorphose and settle to the sea floor (Mercier et al. 2000). In populations outside of WA, sexual maturity occurs at approximately 150 mm in length or two years of age. This species exhibits sexually dimorphic growth, with males maturing earlier than females. Redfish can produce up to 25 million viable eggs and the size at maturity is approximately 120 mm.

There is a dichotomy of opinion of the inherent vulnerability of sea cucumbers to fishing. Some studies suggest they are particularly vulnerable, unable to be sustained under exploitation rates of greater than 5% of unfished biomass (Purcell et al. 2013). Other analyses suggest they are inherently robust due to early age-at-maturity, high fecundity, and relatively high natural mortality. It may be that unmanaged and unregulated fishing has been a major contributor to the poor track record for sea cucumber fisheries, and thus their vulnerability is not an indication of "management" per se, but rather a lack of management. Overall, the dichotomy of opinion on their inherent vulnerability suggests considerable uncertainty and a conservative approach is required where data or history is lacking

5 Species Description

5.1 Sandfish (*Holothuria scabra*)

Figure 5.1. *Holothuria scabra* in its (a) natural sandy habitat, and (b) burrowed mud habitat).

5.1.1 Taxonomy and Distribution

Sandfish, *Holothuria scabra*, vary in shades of greyish-black on the upper side with dark-coloured wrinkles (Figure 5.1) but paler on the underside. In Australia it grows up to 40 cm long, is broader than it is high and has a tough pliable skin. It is generally recognised that a sub-species of *H. scabra*, known as *H. scabra versicolour* does exist (Hamel et al. 2001). The distinction however, has not been made for WA stocks, and all animals harvested are assumed to be *H. scabra*.

5.1.2 Stock Structure

Holothuria scabra is widely dispersed in shallow water on soft sediments throughout the Indo-Pacific region, bounded by the East Coast Africa, the tropics of Cancer and Capricorn and west of mid Pacific Ocean (Bell et al. 2008) (Figure 5.2).

In WA, the boundaries of commercially fished populations are Barrow Island in the south-west of its range, and Wyndham in the north, a distance of about 1800 km. Within these populations, areas fished are discrete and generally separated by large distances. Most fishing activity targets the densest populations of sandfish, occurring within the remote bays and estuaries of the Pilbara and Kimberley coasts.

Uthicke and Benzie (2001) investigated gene flow in *H. scabra* populations with a view to increasing knowledge on this commercially important species and assisting management along the north-east coast of Australia. Allozyme analyses identified and concluded that *H. scabra* populations along the north-east coast of Australia can be grouped into at least 3 genetically distinct stocks: (1) southern populations from the Hervey Bay area, (2) one population from the central coast, and (3) populations from Torres Strait. The latter region is closely related to samples from the Solomon Islands. A similar result was reported by Gardner and Fitch (2012) in relation to *H. scabra* populations within Northern Territory waters, suggesting the existence of genetically distinct stocks in the Gulf of Carpentaria (or eastern population) and the Arafura Sea (or western population).

In view of these studies, and noting the existence of morphological differences between Pilbara and Kimberley sandfish, these are considered to represent two separate stocks for management purposes.

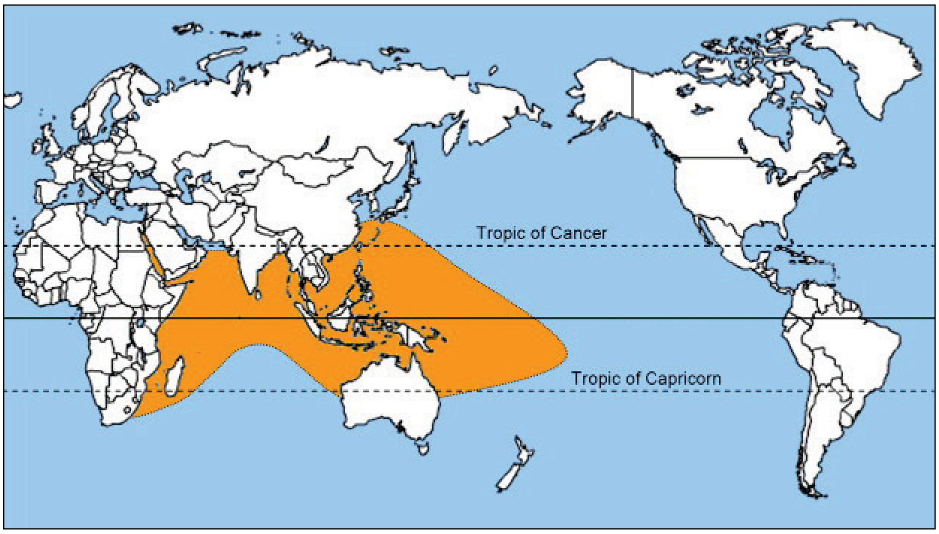

Figure 5.2. Global distribution of sandfish, *Holothuria scabra.*

5.1.3 Life History

Holothuria scabra are sexually dimorphic, although this is not apparent by their visual appearance and their sexual maturity will vary slightly depending on geographic location. Animals will generally mature at 150 mm in length after approximately two years, although the size can vary substantially between sexes and locations (Table 5.1). Animals can spawn year round but spawning can also be triggered by temperature, salinity and lunar changes. Spawning aggregations will occur in deeper water where broadcast fertilisation will follow (Figure 5.4). A fertilised egg will form into an auricularia larvae after 1 – 2 days, this is a feeding phase. The doliolaria stage (non-feeding) will follow after which 1 mm pentactula will settle in shallow water substrate, seagrass and mangroves. Juveniles will inhabit this zone up to 10 mm long.

5.1.3.1 Morphological Relationships

Adults generally measure between 150 and 400 mm in length (Figure 5.3). The body wall accounts for about 56 % of the total weight (Conand 1989). The reported body weight varies considerably, between 300 and 3000 g, over its geographical range. However, it has been noted that the weight depends on the amount of coelomic water and sediment in the alimentary canal (Conand 1989) and length-weight measurements can be highly variable. An illustration of the length-weight relationships in *H. scabra* is found in Figure 5.5, Figure 5.6, and Table 5.1. The relationship for WA is of a similar form to a Queensland population from the Torres Strait.

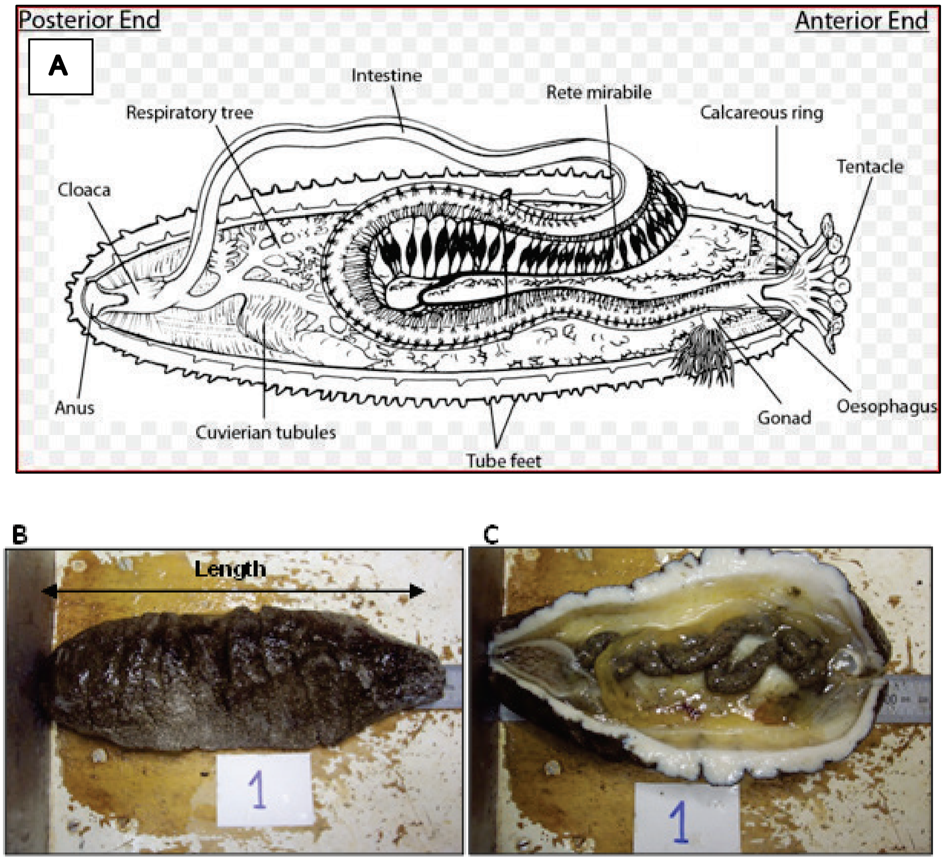

Figure 5.3. Anatomy and morphometric measurement commonly used to measure the morphology of *Holothuria scabra.*

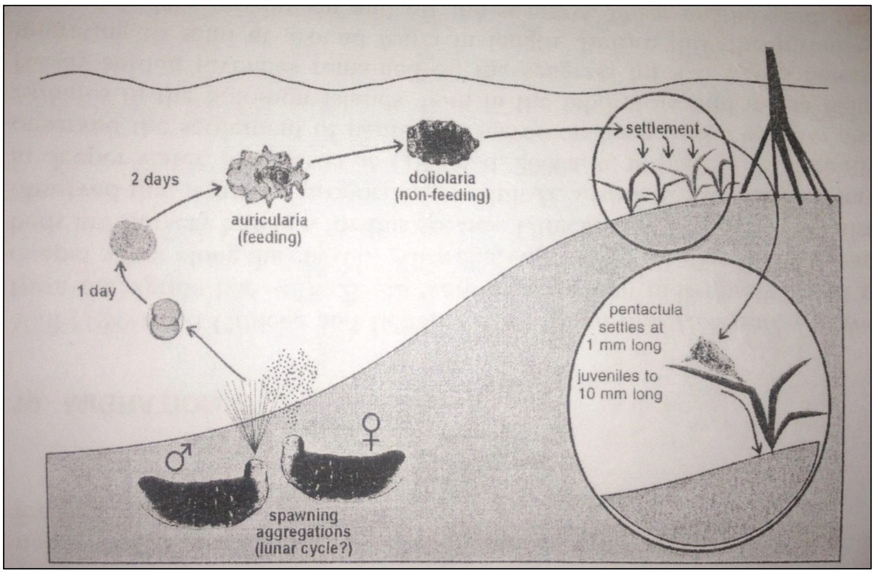

Figure 5.4. Life cycle of sandfish, *Holothuria scabra* (from Hamel et al. 2001).

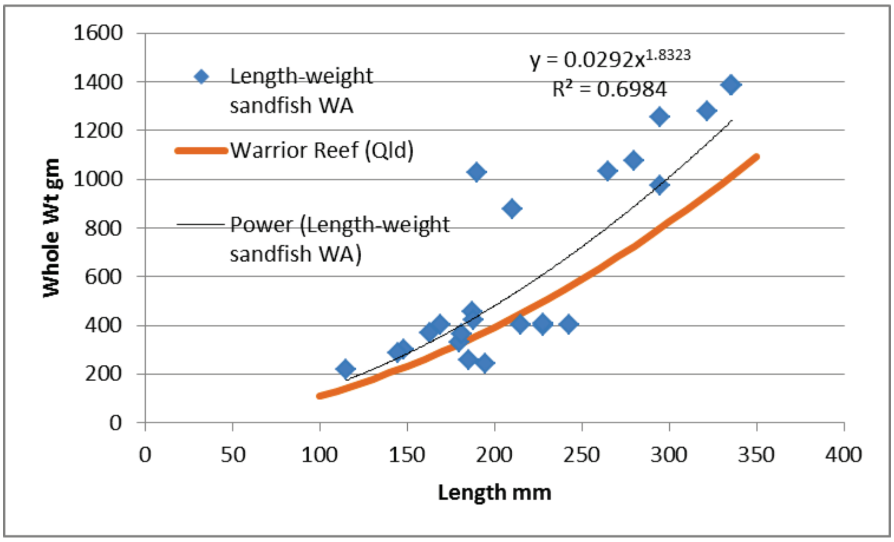

Figure 5.5. Length-weight relationship between WA sandfish (Kimberley region) and Queensland sandfish (Warrior reef - curve from Skewes et al. 2000).

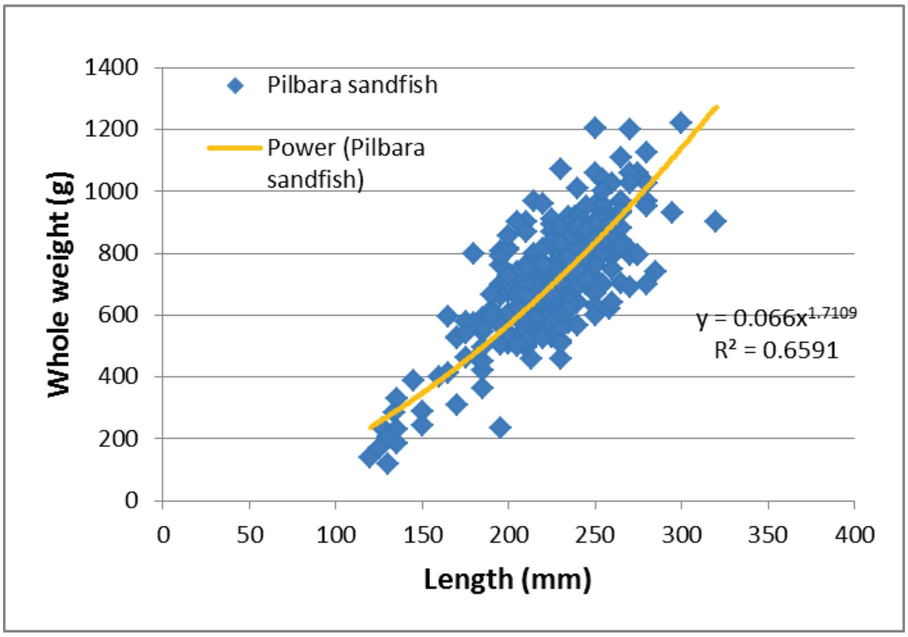

Figure 5.6. Length-weight relationship for sandfish in the Dampier Archipelago (Pilbara region – Karratha Bay).

Table 5.1. Summary of biological parameters for sandfish (*Holothuria scabra*)

Parameter	Value(s)	Comments / Source(s)
Growth parameters		
L_∞ (mm)	350	Dissanayake & Wijeyaratne (2007)
K (year^{-1})	0.8	Dissanayake & Wijeyaratne (2007)
Maximum age (years)	6 – 10 years	Skewes et al. (2014)
Maximum size (mm)	400	Skewes et al. (2014)
Natural mortality, M (year^{-1})	0.4, 1.16, 1.49	Skewes et al. (2014), Dissanayake & Wijeyaratne (2007)
Length-weight parameters		
a (Kimberley)	0.0292	$W = a\ TL^b$; *W in g, TL in mm*
b (Kimberley)	1.83	$W = a\ TL^b$; *W in g, TL in mm*
a (Pilbara)	0.066	$W = a\ TL^b$; *W in g, TL in mm*
b (Pilbara)	1.71	$W = a\ TL^b$; *W in g, TL in mm*
Reproduction		
Maturity parameters		
A_{50} (years)	2	
L_{50} (mm)	Females 200, Males 140-170	Hamel et al. (2001), Kithakeni and Ndara (2002)
Fecundity	9 – 17 x 10^6 oocytes per female	Hamel et al. (2001)
Size-fecundity parameters	Not Available	
Spawning frequency	Spawning occurs year round in some areas, but is likely seasonal in spring months in Australia	Hamel et al. (2001)

5.1.3.2 Habitats

Holothuria scabra are distributed within low energy environments behind fringing reefs or within protected bays. Original distributions are mostly the shallow sub-tidal areas but can occur in depths up to 40 m. Strong tidal currents appear to be the common habitat/environmental feature of both historical and presently important areas of wild stocks.

5.1.3.3 Age and Growth

Average growth of *H. scabra* under controlled conditions range from 7 to 15 mm per month and a corresponding weight gain, estimated between 6 to 27 grams per month (Battaglene et al. 1999). When *H. scabra* were stocked at a biomass > 225 g m-², growth ceased and some individuals even lost weight (Battaglene et al. 1999; Conand 1983).

In contrast, studies in the wild, although scarce indicate a growth rate of 10 to 15 mm per month (Mercier et al. 2000). Hatchery reared *H. scabra* juveniles of 15 mm cm have been known to attain 10 cm after six months spent in a closed lagoon.

Age and growth estimation is difficult in Holothurians due to their variable morphology, however sandfish have been estimated to live beyond six years of age and reach the age at maturity in two years (Conand 1989, 1998; Kinch et al. 2008).

5.1.3.4 Natural Mortality

Limited information is available on natural mortality (*M*) in these species due to the difficulty in measuring age and size, or conducting mark-recapture experiments. A recent review of harvest strategies for populations of sea cucumbers on East Coast Sea Cucumber fishery of Queensland assumed an *M* of 0.4 $year^{-1}$ was appropriate for most species, with 0.3 $year^{-1}$ being used in species considered especially vulnerable (Skewes et al. 2014). These estimates of *M* are considerably lower than several estimates reported in the literature for *H. scabra* (e.g. Dissanayake & Wijeyaratne 2007), and highlights the uncertainty surrounding knowledge of this important parameter.

5.1.3.5 Reproduction

In Australia, the main spawning season of *H. scabra* occurs in the spring months of September to November. Geographically, there is variability from month to month and season to season. Triggers for spawning include temperature, salinity and lunar changes, including chemical cues from males which initiate spawning. Numerous studies have concluded spawning continues year round (Hamel et al. 2001).

Size at-maturity (L_{50}) for male *H. scabra* various geographically, and has been reported in the range of 140 to 170 mm. Females were identified from 199 mm onwards and the sex ratio reached 45:55 female to male at maturity, other studies in different geographical locations indicate sex ratios are more even at 1:1 (Hamel et al. 2001; Table 5.1). No studies are available for size at maturity studies of WA populations of sandfish and voluntary size limits are based on Northern Territory data. Preliminary examination of 20 animals in the size-range of 115 to 330 mm from WA populations found only three animals with undefined gonads (Hart and Murphy, unpublished data).

Conand (1989, 1993) evaluated potential fecundity by dissecting mature whole gonads of *H. scabra* and proposed values of >2 – 18 million oocytes per female, with higher values for the larger females. Conand (1989, 1993) found that the absolute fecundity of *H. scabra versicolour* varied between nine and 17 x 10^6 oocytes per female and was correlated with body size (Hamel et al. 2001).

5.1.3.6 Factors Affecting Year Class Strength and Other Biological Parameters

Field studies in the Solomon Islands (Mercier et al. 2000) indicate the larvae of *H. scabra* actively select certain seagrasses, possibly through chemical selection. Mercier et al. (2000) hypothesised that larvae settling on suitable seagrass have an increased chance of growth and survival because they are provided with a suitable sub-stratum to grow, and a bridge to sandy sub-stratum.

James et al. (1994) indicated that the main predators of the larval forms of *H. scabra* were copepods and ciliates that attacked the larvae, causing injury and death. These organisms also indirectly harmed juveniles, especially those recently settled, by competing for food (Battaglene et al. 1999).

In relation to *H. scabra*, water temperature, salinity and tidal movements are likely to be the most important factors affecting settling recruits for this species as they generally inhabit protected bays and estuaries of the Kimberley.

5.1.3.7 Diet, Trophic Level and Ecosystem Function

Holothuria scabra are classified as deposit and detritus feeders, and diet descriptions are relatively uniform the literature. On soft bottoms they ingest large amounts of sediment using their retractile tentacles from which they extract food (Conand 1998). Gut contents are generally composed of bacteria, copepods, diatoms and other algae, molluscs, foraminiferans, sand and mud.

Sea cucumbers tend to be preyed upon by a relatively small group of predators, which can be attributed to the success of chemical defence mechanisms in preventing predation by generalists (Bakus 1968, 1973, see Francour 1997 for a review). However, a number of sea cucumber species are consistently targeted by specialist predatory species, indicating that some predators depend on sea cucumbers for part of their dietary intake (Francour 1997). It has also been suggested that juvenile sea cucumbers are an important prey item in food webs (Purcell et al. 2013). For example, Wiedemeyer (1994) showed that the main predators of the larval forms of *A. echinites* were gastropods, causing injury and death. These predators also adversely affected juveniles by competing for food. Fish species preying upon juvenile *A. echinites* include; scorpion fish, lion fish, groupers, lizard fish, trigger fish and puffer fishes.

Sea cucumbers play an important ecological role in the ecosystems in which they occur (Birkeland 1988; Uthicke 2001; Wolkenhauer et al. 2010). Burrowing species assist in oxygenating sediments through bioturbation (e.g. Bakus 1973; Birkeland 1988; Uthicke 1999). By consuming large quantities of sediments, organic detritus is converted into animal tissue and nitrogenous wastes, which can be taken up by algae and seagrasses and increase their productivity (e.g. Uthicke and Klump 1998; Wolkenhauer et al. 2010). In coral reef systems this nutrient-recycling function is likely to be significant (Birkeland 1988). It has also been suggested that the presence of sea cucumbers improves sediment quality and phytoplankton abundance through bioturbation and (incidental) 'grazing' of cyanobacteria (Purcell et al. 2013). For example, Uthicke (1999) showed that in aquaria without sea cucumbers sediments were eventually covered in a mat of cyanobacteria, while diatoms dominated the aquariums with sea cucumbers, while Moriarty (1982) – conducting cage experiments on the Great Barrier Reef – observed that mats of cyanobacteria established where holothurians were excluded. Purcell et al. (2013) therefore suggested that the removal of sea cucumbers may reduce primary production in some systems and affect sediment infauna by reducing the aerobic layer of sediments.

5.1.3.8 Parasites and Diseases

Juvenile *H. scabra* reared in the Aqua-Lab hatchery of Toliara, Madagascar, suffered a disease that caused death within three days. The first sign of the infection is a white spot that appears on the integument of individuals, close to the cloacal aperture. The spot extends quickly onto the whole integument leading to the death of individuals. The lesions consist in a zone where the epidermis is totally destroyed and where collagen fibres and ossicles are exposed to the external medium. This zone is surrounded by a border line where degrading epidermis is mixed with connective tissue. Lesions include three bacterial morphotypes: rod-shaped bacteria, rough ovoid bacteria, and smooth ovoid bacteria. Three species of bacteria have also been put in evidence in the white spot lesions thanks to biomolecular analyses (DGGE and sequencing): Vibrio sp., Bacteroides sp., and a Proteobacterium (Lovatelli et al. 2004).

5.1.4 Inherent Vulnerability

Plaganyi et al. (2013) examined climatic effects on managing sea cucumber fisheries and concluded that higher sea temperatures will have a positive effect i.e. higher production and yields given the expected faster growth rates leading to larger sizes and increased fecundity. This positive view on their vulnerability is supported by a productivity susceptibility analysis (PSA) which indicates that sea cucumbers are inherently robust to exploitation as a result of their life history parameters which suggest they are high productivity populations (Section 9.3.6).

However, sea cucumbers are also considered to have a high level of inherent vulnerability to fishing. Most species with tropical distributions inhabit shallow waters within the range of breath-hold or hookah-assisted divers (Kinch et al. 2008). They tend to have sluggish displacement rates (e.g. Purcell and Kirby 2006 with respect to *H. scabra*), indicating they are slow to move away from high density patches identified and targeted by fishers (Purcell et al. 2013).

As gonochoric broadcast spawners, sea cucumbers need to be in close proximity of mates to ensure fertilisation success (Purcell et al 2013). Fertilisation rates decline with decreasing density, due to reduced gamete densities and associated reduced probabilities of egg-sperm encounters (Levitan 1991; Babcock et al. 1994; Wahle and Peckham 1999). Such changes in fertilization success and resulting reduced gamete production are disproportional to changes in adult densities, a form of Allee effect (Uthicke 2004).

Allee effects and population density extremes have been suggested to be more pronounced in broadcast-spawning echinoderms with planktotrophic larval stages (such as sandfish) as opposed to species with lecithotrophic development. This is because larvae of the latter species are independent from the requirement to feed in the plankton and tend to settle quicker (presumably resulting in lower mortality rates in the plankton and enhanced local recruitment) (Uthicke et al. 2009).

For species vulnerable to Allee effects, the severity of a population decline and ultimate time for recovery depends on the geographic extent of the decline, and the connectivity of subpopulations (Uthicke et al. 2009). In the case of the *H. scabra*, population reduction in the

Torres Strait off northern Australia (which resulted in a population biomass of <10% of the original biomass determined from fishery surveys in 2002 and 2004, 4 and 6 years after the fishery was closed in 1998, showed that recovery was very slow (Skewes et al. 2000).

5.2 Redfish (*Actinopyga echinites*)

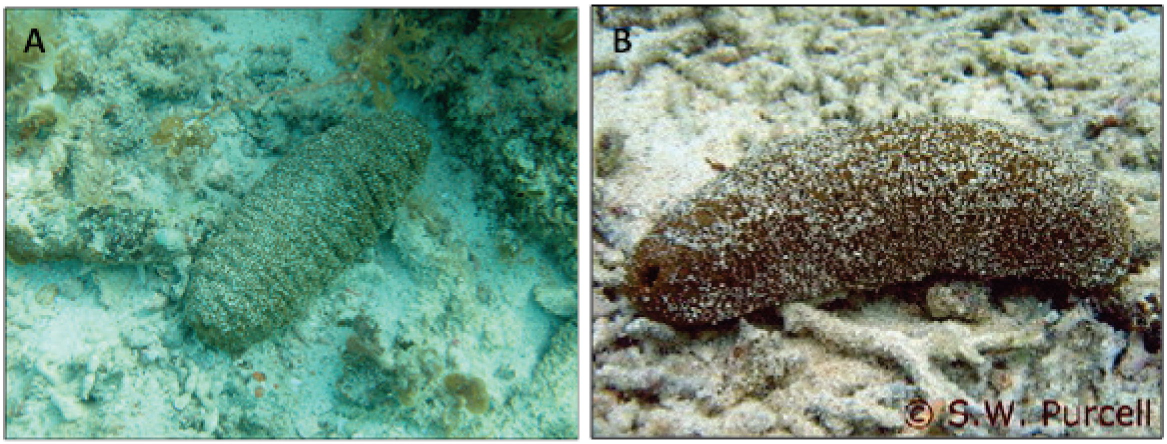

Figure 5.7. *Actinopyga echinites* in its (a) sandy, coral habitat, and (b) coralline habitat.

5.2.1 Taxonomy and Distribution

Deepwater redfish or redfish, *Actinopyga echinites*, is a sea cucumber which varies in colour from light brown to orange and has a rough outer skin covered in numerous papillae, the upper surface is often covered with sand (Figure 5.7). Distribution occurs throughout the Indo-Pacific region, bounded by the East Coast Africa, the tropics of Cancer and Capricorn and west of mid Pacific Ocean (Figure 5.8).

5.2.2 Stock Structure

Actinopyga echinites is a broadcast spawner that produces up to 25 million viable eggs. The egg and larval stages spend up to two weeks in the plankton. The animal is widely dispersed in northern WA, however, commercially fished populations are located on the southern Pilbara coast. Most fishing activity targets the densest populations of deepwater redfish, which occur within the north-eastern shallow water lagoons between Barrow and Montebello Islands. For management purposes, redfish in the Pilbara is considered to represent a single stock.

5.2.3 Life History

Actinopyga echinites are sexually dimorphic, although this is not apparent by their visual appearance and their sexual maturity will vary slightly depending on geographic location. Animals will generally mature at 120 mm in length after approximately two years (Table 5.2). Studies at Reunion Island in the Western Indian Ocean indicate animals have a major spawn in December and January and another minor spawn in May (Kohler et al. 2009). The southern Pilbara coast has similar latitude to Reunion Island.

Spawning aggregations will occur in deeper water where broadcast fertilisation will follow. A fertilised egg will form into an auricularia after 1 – 2 days, this is a feeding phase. The doliolaria stage (non-feeding) will follow after which 1 mm pentactula will settle in shallow water substrate, and have a stronger preference for limestone and dead coralline material. Juveniles will inhabit this zone up to 10 mm long and then start to forage.

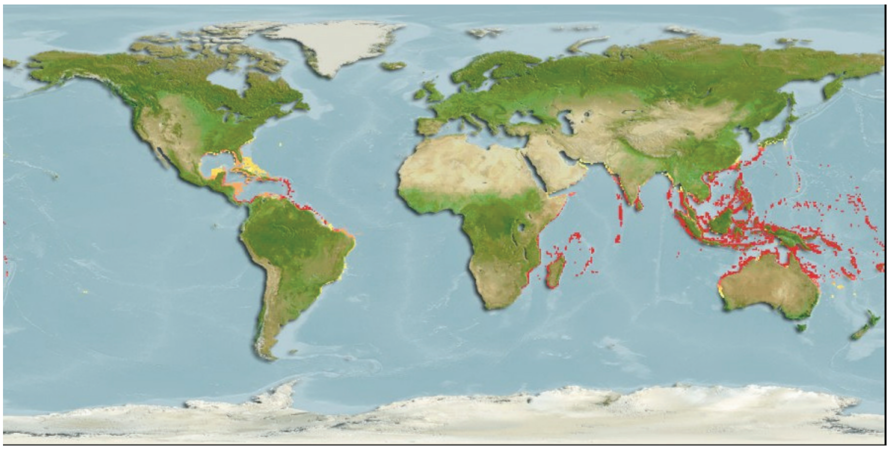

Figure 5.8. Worldwide distribution of redfish, *Actinopyga echinites* (computer generated native distribution map, source: www.aquamaps.org, version of Aug. 2013.

5.2.3.1 Movements

The movements of sea cucumber larvae prior to settlement on the benthos are dictated by physical oceanographic processes such as tidal movements, wave action, prevailing winds and currents. Once attached the animals have further ability to colonise new habitats or move to a more favourable position. *A. echinites* move with their tube feet densely distributed on their ventral surface of the body wall and also through muscular action of the body wall.

Table 5.2. Summary of biological parameters for redfish (*Actinopyga echinites*)

Parameter	Value(s)	Comments / Source(s)
Growth parameters		
L_∞ (mm)	320	Dissanayake & Wijeyaratne (2007)
K (year^{-1})	1.9	Dissanayake & Wijeyaratne (2007)
Maximum age (years)	12+ years	
Maximum size (mm)	320 - 350	Skewes et al. (2014), unpublished WA data
Natural mortality, M (year^{-1})	0.3 - 2.69	Dissanayake & Wijeyaratne (2007)
Length-weight parameters		
a	5.86 x 10^{-5}	$W = a\ TL^b$
b	3.02	$W = a\ TL^b$
Reproduction		
Maturity parameters		
A_{50} (years)	2	
L_{50} (mm)	120 mm	Kohler et al. (2009)
Fecundity	4 – 25 x 10^6 oocytes per female	Conand (1983, 1989, 1998)
Size-fecundity parameters	Not Available	
Spawning frequency	Major and minor spawning events in Spring and Autumn	Kohler et al. (2009)

5.2.3.2 Age and Growth

Actinopyga echinites generally grows to sizes of 300 – 350 mm. Growth of holothurians is the least established biological parameter of the taxon. Kohler et al. (2009) measured a maximum size of 650 g total weight for *A. echinites* in the Western Indian Ocean, but the age is unknown. In Okinawa, Japan, Wiedemeyer (1994) results show an exponential increase in weight of juvenile *A. echinites* from 0.87 to 12.82 g during a single year growth experiment, but this exponential growth trajectory is unlikely to be sustained over the entire life cycle, as it would mean that maximum size (200 g drained body weight- 600 g total weight) is attained around two years of age.

Preliminary morphometric relationships have been derived for *Actinopyga echnites* from the WASCF (Figure 5.9). However there is considerable variability in weight at length, highlighting the difficulty in establishing growth information for sea cucumbers. Experiments designed to standardise length measurements through the use of anaesthetic techniques did not reduce the weight-length variability in this species (unpublished data).

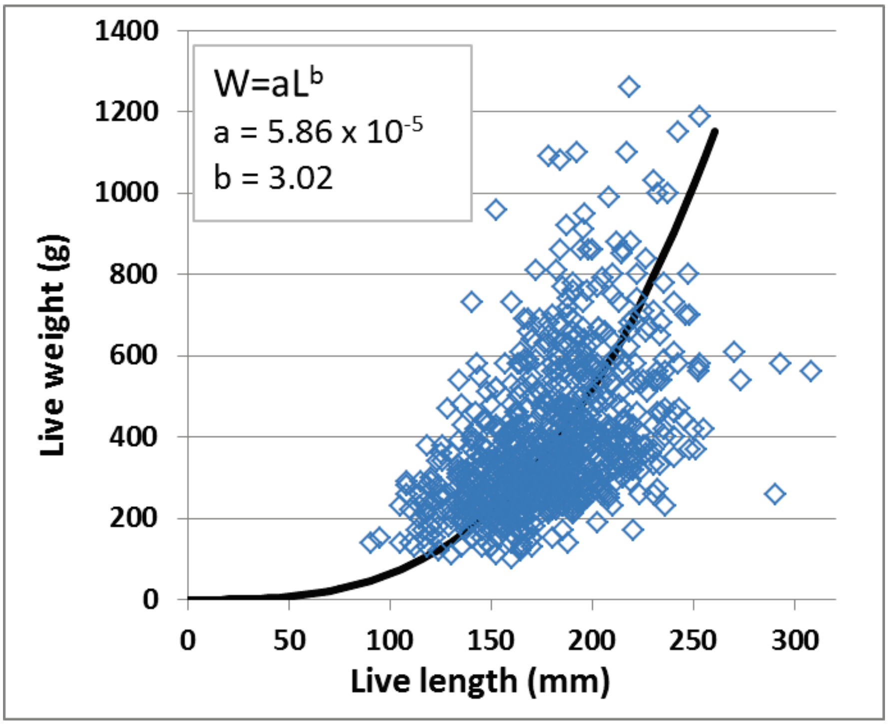

Figure 5.9. Length (mm) – weight (g) relationship for *Actinopyga echinites* from the Montebello Islands. Weight is live whole weight (no processing).

5.2.3.3 Natural Mortality

Limited information is available on natural mortality in these species due to the difficulty in measuring age and size, or conducting mark-recapture experiments. A recent review of harvest strategies for populations of sea cucumbers on East Coast Sea Cucumber Fishery of Queensland, assumed an *M* of 0.4 was appropriate for most species (Skewes et al. 2014). However a study using standard length-based methods in Sri Lanka estimated *M* to be 2.6 for this species (Dissanayake & Wijeyaratne 2007).

Natural mortality of juvenile *A. echinites* was comparatively low, even when predation effects were included. Never the less it should be kept in mind that dislodgement effects were not entirely excluded in experiments. Dislodgement effect may considerably increase the rate of natural mortality particularly in areas of strong wave action or similar effect. As predation makes up to 77 % of natural mortality of the juveniles, the survival rate in the field may decrease considerably while the individuals body weight increase because larger juveniles of *A. echinites* tend to inhabit more exposed substrate types (Wiedemeyer 1994).

5.2.3.4 Reproduction

Studies of *A. echinites* on Reunion Island indicate a major spawning event, deduced by a strong increase of gonad index (GI) from October to a maximum in December followed by a decline until February indicating that gametes were released during this two-month period (Kohler et al. 2009). GI was slightly peaking again in April, followed by a second decrease until June revealing a minor second spawning event within this month. Mean monthly GI increased and coincided with increasing temperature from October to December during gamete development, but there after no correlation remained. However, there was a stronger correlation between light illumination and GI. In the lead up to the major spawning event illumination was increasing, and GI decreased from January to May when illumination was falling. There was no correlation between rainfall and GI (Kohler et al. 2009)

Size at-maturity for *A. echinites* is approximately 120 mm. From 160 samples of *A. echinites* at Reunion Island, 94 were female, 47 male and 18 of undetermined sex, giving a sex ratio significantly different from 1:1 and closer to 1:2 ratio. Undetermined sex specimens, i.e. resting and immature stages, were encountered from June to October (Kohler et al. 2009).

The weight at first sexual maturity in which 50 % of *A. echinites* were in stages 3, 4 and 5 was found to have a mode of 46 – 55g of eviscerated weight, equal to a total weight of 65 g (Kohler et al. 2009).

Fecundity of *A. echinites* is rather high, cited in the literature for New Caledonia (Conand 1983, 1989, 1998) with values of absolute fecundity from four to 25 million oocytes compared to the weight of ripe ovaries from the different sites. Concerning the influence of environmental factors on the reproductive cycle of *A. echinites* in La Réunion, the onset of gametogenesis seems to be triggered by the increase of solar illumination in July. However, for *A. echinites* both temperature and rainfall factors did not seem to control the reproduction.

5.2.3.5 Factors Affecting Year Class Strength and Other Biological Parameters

Field studies in Japan (Wiedemeyer 1994) indicate the larvae of *A. echinites* displayed a strong preference for plate substrate consisting of limestone and dead coralline material and coarse sand. Wiedemeyer (1994) hypothesised that larvae settling on suitable hard substrate have an increased chance of growth and survival because they are provided with a suitable sub stratum to forage and grow.

5.2.3.6 Diet, trophic level, and ecosystem function

Sea cucumbers tend to be preyed upon by a relatively small group of predators, which can be attributed to the success of chemical defence mechanisms in preventing predation by generalists (Bakus 1968, 1973, see Francour 1997 for a review). Further discussion of their trophic level and ecosystem function is found in section 5.1.3.7.

5.2.3.7 Parasites and Diseases

Amongst echinoderms, the Holothuroidea represents the class that is the most infested by parasites. Parasites of holothuroids are Bacteria, Protozoa and Metazoa. There are about 150 species of metazoans which parasite holothuroids. Most of them are turbellarians, gastropods, copepods, crabs or fishes. The main body compartments suffering of the infestations are the digestive system and the coelom. The diseases induced by metazoan parasites are mostly structural: they create galls at the surface of the epidermis, pierce the respiratory tree or dig into the body wall down to the coelom. Most metazoans that live in the digestive system do not induce obvious diseases and their relationship with their hosts is probably close to commensalism. Most Protozoa that parasite holothuroids are sporozoans. They occur mainly in the coelom and/or the haemal system, one species having been reported infesting the gonads. Even in heavily infested hosts, the signs of disease induced by sporozoans are low: at most, host haemal lacuna is occluded by trophozoites or cysts are formed into the coelomic epithelium. The most pathogen agents reported from cultured sea cucumbers are Bacteria. Cultivated holothuroids may suffer from a bacterial disease, called skin ulceration disease that affects their body wall.

5.2.4 Inherent Vulnerability

Plaganyi et al. (2013) examined climatic effects on managing sea cucumber fisheries and concluded that higher sea temperatures will have a positive effect i.e. higher production and yields given the expected faster growth rates leading to larger sizes and increased fecundity. This positive view is supported by a productivity susceptibility analysis (PSA) which indicates that sea cucumbers are inherent robust to exploitation as a result of their life history parameters which suggest they are high productivity populations (Section 9.3.6).

However, sea cucumbers are also considered to have a high level of inherent vulnerability to fishing. Further discussion of this is found in section 5.1.4.

It may also be that unmanaged and unregulated fishing has been a major contributor to the poor track record for sea cucumber fisheries, and thus their vulnerability is not an indication of "management" *per se*, but more likely no management at all. In any case the dichotomy of opinion on their inherent vulnerability suggests considerable uncertainty and a conservative approach is required.

6 Fishery Information

6.1 Fisheries / Sectors Capturing Resource

A commercial fishery for the Western Australian Sea Cucumber Resource first developed in 1995, originally known as the Bêche-de-Mer Fishery. It is a small, low value fishery with a GVP in 2014 of less than $300,000 (Hart et al. 2015). Management has been primarily through input controls including limited entry, maximum number of divers, species-specific minimum target sizes (until 2017), and gear restrictions. Originally six licences were issued, however consolidation of these licenses occurred with their purchase by one company (Tasmanian Seafoods Pty Ltd) in 2000. This was followed by a substantial reduction in effort due to the use of smaller boats (resulting in a holding capacity reduction from 30 t to 10 t), fewer crew (reduction from 7-10 to 3-4 crew) and shorter fishing trips.

Other commercial sectors that harvest sea cucumbers include the Marine Aquarium Fish Managed Fishery (MAFMF), which is permitted to collect sea cucumber species not targeted by the WASCF for marine aquarium display purposes only, and inshore trawl fisheries, which capture sea cucumbers in very low numbers as bycatch but discard them.

Recreational harvest of sea cucumbers is allowed under a daily bag limit, however the actual recreational catch is negligible. Similarly, customary take is allowed, but also negligible.

The section(s) below provide more detailed information about the main fisheries / sectors that target the sea cucumber resource

6.2 Western Australian Sea Cucumber Fishery

6.2.1 History of Development

Commercial fishing for sea cucumbers began in 1995, and until 2007 it was primarily a single species fishery with 99% of the catch being sandfish (*Holothuria scabra*). Redfish (*Actinopyga echinites*) has been targeted since 2007 (Figure 6.1). Apart from sandfish and redfish, only black teatfish is caught with some consistency, although still in very low numbers.

Initially high catches of sandfish were taken (a total of 1360 t in the first 6 years), however, total catch of sea cucumbers has averaged 95 tonnes per year in the subsequent 16 years (Figure 6.1). Total catch has varied between 0 t (2013) and 380 t (1997). Between 2007 and 2014, redfish was typically the dominant species caught, however, sandfish remains the primary species in the fishery due to its wider distribution.

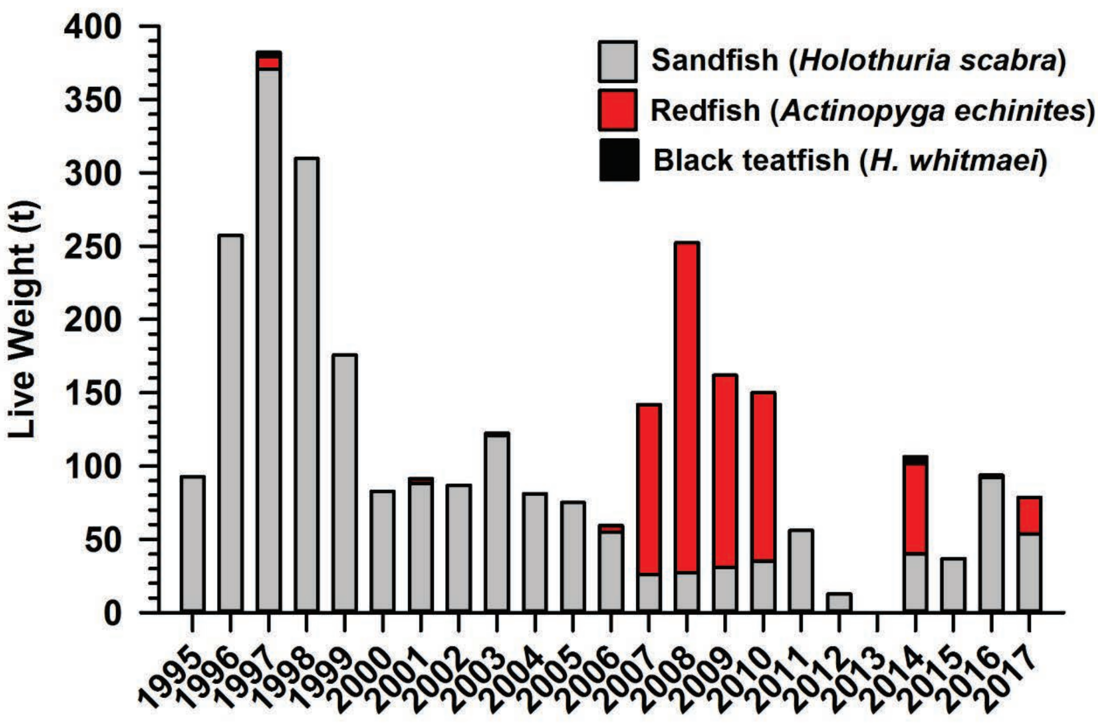

Figure 6.1. Annual total retained catches (tonnes) in the WASCF between 1995 and 2017.

6.2.2 Current Fishing Activities

A summary of key attributes of the WASCF and the fishing fleet is provided in Table 6.1.

The WASCF is currently managed under Fisheries Notice No. 366 (Prohibition for Commercial Fishers Unless Otherwise Endorsed- Shellfish, Coral, Fish of class Echinoidea and Bêche-de-Mer). Fishers in the WASCF operate under an exemption to this Notice under Section (7)(3)(c) of the *Fish Resources Management Act* (FRMA).

The WASCF is permitted to operate throughout WA waters with the exception of marine parks, reserves and sanctuaries and a number of specific closures around Cape Keraudren, Cape Preston and Cape Lambert, the Rowley Shoals and the Abrolhos Islands (Figure 6.2). To date however fishing has only occurred on tropical species in the northern half of the state.

Table 6.1. Summary of key attributes of the commercial sea cucumber fishery (WASCF)

Attribute	
Fishing methods	Hand collection (95% diving, 5% wading)
Fishing capacity	Maximum of 6 vessels
Number of permits	6
Number of vessels	1-2 operating in any given year
Size of vessels	10-12 m
Number of people employed	<10
Value of fishery	$<1 million (Level 1)

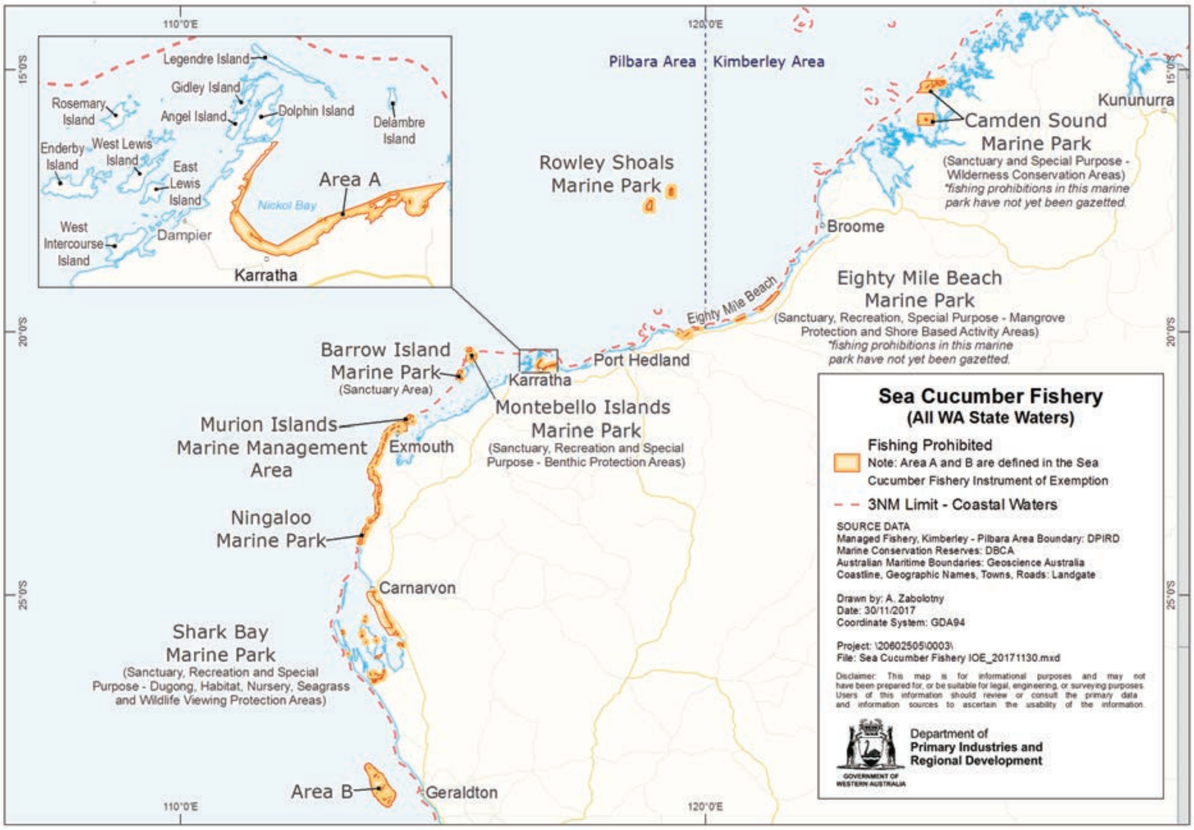

Figure 6.2. Fishing area (out to 3 nm) with closures (shaded areas) for the WASCF.

The WASCF targets remote and largely inaccessible stocks in a very large region with challenging conditions (e.g. extreme tidal movements, strong currents, poor visibility and the presence of saltwater crocodiles). Both the Kimberley region for sandfish (*H. scabra*) and Barrow Island/the Montebello Islands for redfish (*A. echinites*) are isolated, making these populations difficult and expensive to access and requiring immediate processing of the catch (gutting, boiling, freezing) to maintain the quality of the product for market.

The environmental conditions under which fishing in these regions takes place result in limited 'windows of opportunity'. To maintain high catch rates, current practice for sandfish is a 'pulse' fishing operation that targets sandfish aggregations throughout a number of specific locations in the Kimberley on average for two to three trips of 14-20 days each per year. Sandfish in the Pilbara region have been targeted less frequently. Redfish has historically been targeted sporadically, although this may change now that a local operator (based in the Pilbara) has leased one of the boat licences. These conditions have resulted in natural refuges for sea cucumbers and significant periods during which aggregations that are targeted by the fishery are left undisturbed.

6.2.3 Fishing Methods and Gear

The method of fishing involves drift diving using hookah in small vessels <3 m long known as dorys. Fishers operate using the one up one down method, one diver is in the water collecting sea cucumbers and the other remaining in the vessel steering its course. Diving is typically in water <5 m deep. The divers and dorys return to the main vessel at the end of a day where the sea cucumbers undergo initial processing. This involves gutting, boiling and a short drying period before being frozen in blocks. Secondary processing occurs in Melbourne where sea cucumbers are dried and packaged before being exported as 'beche-de-mer' to Asian markets.

6.2.4 Susceptibility

The species are both widely distributed in the shallow near-shore habitat, however, fishing mostly occurs in shallow-water mangrove lagoons and estuaries during neap tides, as the strong currents and poor visibility in the Pilbara and Kimberley regions due to the extreme tidal ranges renders fishing impractical at other times. Collection is limited to specific sites characterised by easily accessible, open water areas where impediments to fishing operations from crocodiles are less likely to occur and visibility is sufficient to allow collection by hand. These limitations, coupled with the burrowing nature of sea cucumbers (for example, Skewes et al. (2000) found that the population abundance of the sandfish can be underestimated by up to 60 % due to its burrowing habit in seagrass beds at high tide), means that individuals less than the size at maturity are rarely caught, as evidenced also by observed trends in size structure (Section 9.3.5).

6.3 Recreational and Customary Fishery

Recreational harvest of sea cucumbers is allowed under a capped daily bag limit of 10 individuals of other "non-listed" molluscs and invertebrate species. However, the actual recreational catch is negligible. Similarly, customary take is allowed, but also negligible. Currently management arrangements for Aboriginal and customary fishing are being reviewed and licenses for commercial fishing could be issued to relevant institutions in the future.

7 Fishery Management

7.1 Management System

The harvest strategy for the sea cucumber resource of WA is a *constant exploitation approach* where the catch varies in proportion to variation in stock abundance.

In line with the harvest strategy, the WASCF is managed primarily using input controls, including limited entry, species restrictions and minimum legal sizes, gear/method restrictions, and spatial closures. The sandfish fishery in the Kimberley is based on a large number of smaller populations that have been harvested over a longer time period, whereas the sandfish and redfish fisheries in the Pilbara primarily target dense but localised populations found in the Montebello Islands and the Dampier Archipelago. Consequently, it is possible to conduct cost-effective fishery-independent biomass surveys of the sandfish and redfish stocks in the Pilbara region. Whether these approaches or a modified version of them, are applicable to the Kimberley area requires further investigation.

Recreational harvest of sea cucumbers is allowed under a capped daily bag limit of 10 individuals of other [non-listed] molluscs and invertebrate species. However, the actual recreational catch is negligible. Similarly, customary take is allowed, but also negligible.

7.2 Harvest Strategy

A harvest strategy for the sea cucumber resource outlines the long- and short-term objectives for management (Department of Primary Industries and Regional Development 2018). 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 main objectives, performance indicators, reference levels and control rules are defined in Table 7.1 for each of the three key stocks currently fished, i.e. Kimberley sandfish and Pilbara sandfish and redfish. A graphical representation of the performance of the stocks against each biological reference point is shown in Figure 7.1.

The key considerations informing the harvest strategy for the sea cucumber resource in WA are its geographical isolation, the spatially discrete nature of the resource, and the intrinsic vulnerability of sea cucumber stocks when effort is difficult to constrain.

The principal performance indicators for the sea cucumber resource are spawning biomass indices. These are the annual standardised catch rate for Kimberly sandfish, or a biomass estimate derived from a biomass dynamics model for Pilbara sandfish and redfish (Table 7.1, Figure 7.1). The model incorporates catch data from the beginning of the fishery, catch rate data from the inception of the daily logbook program, and a fishery-independent survey biomass estimate undertaken in 2015 for redfish, and 2017 for sandfish. Associated reference points have been set using the estimate of unfished biomass (B_0) at the beginning of the fishery. Reference levels defined as: Target (40% B_0), threshold (30% B_0) and limit (20% B_0) (Table Table 7.1).

If catch data show that new (previously unfished) areas of high sea cucumber densities have been discovered, a review of the harvest strategy and stock-based reference points and will be undertaken. It will also consider what level of future monitoring of that area is required. For example, the rediscovery of a lightly exploited area of sandfish in the Pilbara region in 2016, with an initial catch of 70 t (Figure 9.1) at high catch rates (Figure 9.10), led to the completion of a fishery-independent survey to determine biomass-based reference points and performance indicators for this stock in 2017. However, there are still productive areas of sandfish habitat in the Pilbara outside of the current survey boundaries and these have been historically fished.

Table 7.1. Summary of the key performance indicator, reference levels and control rules for the two species of the WA Sea Cucumber Resource.

Management Objective	Resource/ Asset	Performance Indicator(s)	Reference Levels	Control Rules
To maintain spawning stock biomass of each retained species above B_{MSY} to maintain high productivity and ensure the main factor affecting recruitment is the environment.	Sandfish (Kimberley stock)	Annual standardised catch rate (numbers per hour)	**Target:** 11.67	1. If the PI is ≥ Target, no specific management action required. 2. If the PI is < Target and ≥ Threshold, review all available information to decide if further management action is required.
			Threshold: 8.75	3. If there is <80% probability that the PI is > Threshold, implement a 2 year spatial closure for the stock.
			Limit: 5.84	4. If there is <80% probability that the PI is > Limit, implement a 3 year spatial closure for the stock.
	Sandfish (Pilbara stock	Annual biomass estimate (tonnes whole weight)	**Target:** 81	1. If the PI is ≥ Target, no specific management action required 2. If the PI is < Target and ≥ Threshold, review all available information to decide if further management action is required.
			Threshold: 61	3. If there is <80% probability that the PI is > Threshold, implement a 2 year spatial closure for the stock.
			Limit: 41	4. If there is <80% probability that the PI is > Limit, implement a 3 year spatial closure for the stock.
	Redfish (Pilbara stock)	Annual biomass estimate (tonnes whole weight)	**Target:** 821	1. If the PI is ≤ the Target, no specific management action required 2. If the PI is < Target and ≥ Threshold, review all available information to decide if further management action is required.
			Threshold: 615	3. If there is <80% probability that the PI is > Threshold, implement a 2 year spatial closure for the stock.
			Limit: 410	4. If there is <80% probability that the PI is > Limit, implement a 3 year spatial closure for the stock.

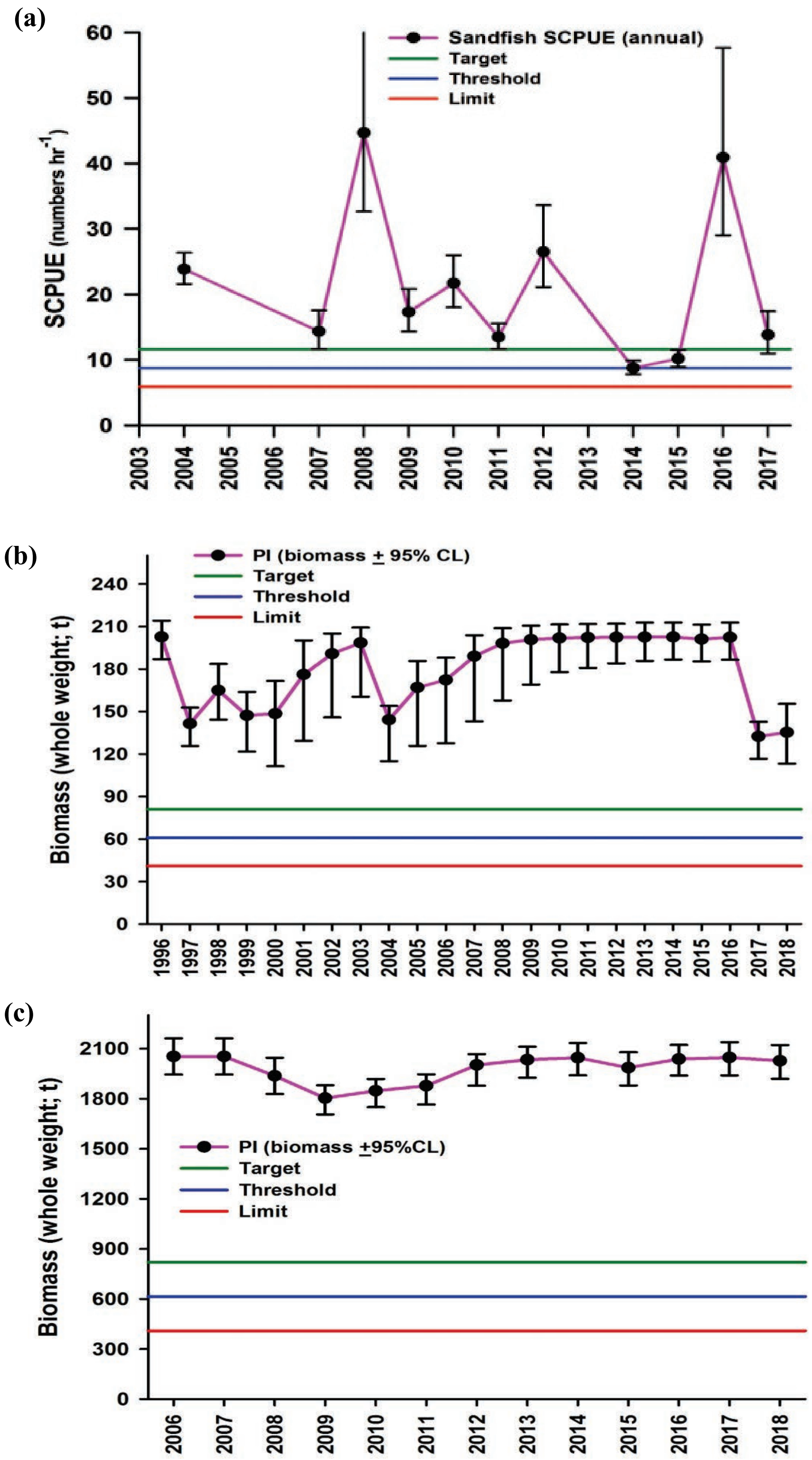

Figure 7.1. Summary of the key performance indicator and reference levels for the WA Sea Cucumber Resource. (a) Kimberley sandfish, (b) Pilbara sandfish, (c) Pilbara redfish.

7.3 External Influences

External influences include other activities and factors that occur within the aquatic environment that may or may not impact on the productivity and sustainability of fisheries resources and their ecosystems. The main external influences included here are environmental factors.

7.3.1 Environmental Factors

The species harvested in the sea cucumber resource are distributed through shallow water lagoons in remote regions throughout the Kimberley and Pilbara ecosystems. Consequently, they are impacted from time to time by tropical deluges and adverse swell conditions associated with cyclones. These have the potential to create localised stock depletion or even extinctions. Anthropogenic influences, such as run-off from polluted waterways are largely considered negligible due the low or negligible human population densities within the fished regions.

Other studies (see Holbrook and Johnson 2014 for a review) on the observed and/or anticipated impacts of global climate change on fisheries count: (i) distributional shifts, (ii) expansion of 'locally invasive' species, (iii) range contraction of thermally sensitive species, (iv) earlier age at maturity/mortality and (v) habitat loss/degradation, among the potential outcomes of climate change.

There is currently little data from which the likely impacts on sea cucumbers and preferred shallow water habitats in WA can be estimated, but there is some evidence to support the idea that sea cucumbers are not among the most susceptible of organisms to ocean acidification (e.g. Dupont et al. 2010) and increased water temperatures. With respect to the latter, Plaganyi et al. (2013) assessed the potential impacts of projected climate changes to physical variables and critical habitats for a range of life history variables and for each of three sea cucumber life history stages. The results suggested that higher sea temperatures may have a positive effect on growth rates and fecundity although these benefits may be (partially) offset by increased larval and juvenile mortality and potential declines in seagrass habitats, which are nurseries for sandfish juveniles.

7.3.1.1 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 Leeuwin Current, 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 Leeuwin Current resulted in unusually warm ocean temperatures in coastal waters of south-western WA (Pearce et al. 2011). This "marine heatwave" altered the distribution and behaviour (e.g. spawning activity and migration) of some species and caused widespread mortalities of others.

8 Information and Monitoring

8.1 Range of Information

A summary of the research and monitoring activities for the WA Sea Cucumber Resource is provided in Table 8.1. Data types range from fishery dependent catch and effort records, VMS spatial tracking, exploratory fishing trials, and fishery-independent survey information.

Table 8.1. Summary of information available for assessing the WA Sea Cucumber Resource

Data type	Fishery-dependent or independent	Purpose / Use	Area of collection	Frequency of collection	History of collection
Monthly commercial catch and effort statistics	Dependent	Monitoring of commercial catch and effort trends and calculation of catch rates	Whole fishery	By month and statistical block (60 x 60 miles)	1995 to 2007
Daily catch and effort statistics	Dependent	Fine spatial scale analyses Calculation of performance indicators	Whole fishery	By individual fishing event (diving or wading)	2007 to present
VMS data	Dependent	Verification of boat locations for logbook analysis	Whole fishery	Opportunistic	Sporadic, VMS exists on vessels, but no requirement to use it exists
2004 Fishing trials	Dependent	Exploration of indices for developing performance indicators; benchmark data for different fishing grounds and exploratory fishing	Previously fished and unfished areas throughout the fishery	One-off trial in 2004	2004
Biomass and population surveys	Independent	Calculate biomass for redfish and sandfish	Pilbara	Every 5 years	2015 (redfish), 2017 (sandfish)
Biological information	Independent	Morphometry, determining conversion factors	Whole fishery	Opportunistic	2004, 2015

8.2 Monitoring

8.2.1 Commercial Catch and Effort

Historically, sea cucumber fishers provided monthly returns under the statutory catch and effort statistics (CAES) system. These returns contain data on catch (processed weight and/or live weight), days and hours fished by month and year, and number of crew on each vessel. Catch and effort are spatially allocated to 60 x 60 nm statistical blocks. Fishers also note method fished and condition of catch (whole or "gilled and gutted"). Most catch is recorded as gutted and boiled therefore whole weight (live weight) is calculated using a conversion factor of 3.0 for sandfish and 4.0 for redfish. These conversion factors have been established by experiments

Since 2007, there has been a statutory obligation to provide a daily catch and effort logbook. Information recorded on this logbook includes detail on the vessel; name and registration numbers, crew names/numbers and vessel anchorage. The effort component includes number of dives (air supply or snorkel) and wades, catch by method in both biomass (kg) and numbers, GPS starting positions, duration of effort, depth fished and distances covered. See Appendix 4 for an example of the daily logbook.

8.2.2 Customary Catch

Cultural take is uncapped and included under allowances (as opposed to allocations) factored in when setting commercial and recreational allocations. The cultural take of sea cucumbers in WA is negligible. The total annual harvest for non-fish – other (which includes sea cucumbers) in WA was estimated at 49 animals (Henry and Lyle 2003). While there is a provision under Section 251 of the FRMA for the Department of Fisheries WA to grant Aboriginal communities non-transferable licences authorising the commercial take of potential culturally-significant species, there has been negligible catch to date with respect to sea cucumbers.

8.2.3 Illegal, Unreported or Unregulated Catch

This is likely to be negligible, with both overt and covert surveillance undertaken both Commonwealth and State agencies, primarily for border protection (preventing entry of illegal foreign vessels). Surveillance is also undertaken to prevent illegal fishing. Also, the remoteness and patchy nature of the stocks affords extra protection due to the cost involved in access.

8.2.4 Fishery-Dependent Monitoring

In addition to catch and effort data, daily logbook returns provide information on numbers of animals caught as well as weight (Appendix 4). Consequently an average weight index for each species is also obtained and used in assessments.

8.2.5 Fishery-Independent Monitoring

Fishery-independent surveys have been undertaken in the WASCF in 2015 and 2017. In 2015 a major survey was undertaken near Barrow and Montebello Islands in the Pilbara region with the objectives to estimate biomass to inform the harvest strategy for the redfish stock. In 2017, a similar survey was undertaken in the Dampier Archipelago of the Pilbara region with the objectives to estimate biomass to inform the harvest strategy for the sandfish stock. The intention is to repeat these surveys every five years to update the harvest strategy. Where appropriate, and resources permit, surveys of other areas/species will be undertaken in the future as the need arises.

With regard to the redfish surveys, commercially fished habitat of this species in the Barrow and Montebello Islands areas of the Pilbara region were mapped, and fishery-independent surveys targeted on nine strata divided across two main areas, north and south of Parakeelya

Island (Figure 8.1). During the survey, population density and size-structure information (numbers, length, and weight) were collected by hookah dive survey from a total of 122 survey sites, each consisting of a transect of 100 m^2 (Figure 8.1). Data collected were used to estimate current biomass (Section 9.3.8), and virgin biomass as part of the input information to a biomass dynamics model (Section 9.3.9).

With regard to the sandfish surveys, a more exploratory design was implemented. Based on information of commercially fished habitat of this species in the Dampier Archipelago, a number of potential areas were mapped, and surveys targeted on fifteen strata made up principally of island bays from the Dampier Archipelago and the Burrup peninsula (Figure 8.2). During the sandfish survey, population density information was collected by hookah dive survey from a total of 183 survey sites, each consisting of a transect of 50 m^2 (Figure 8.1). Additionally, size-structure information (length, and weight) were obtained by sampling 300 animals from 10 sites (30 per site) within Karratha Bay, which was the area of the main population. Data collected were used to estimate current biomass (Section 9.3.8), and virgin biomass as part of the input information to a biomass dynamics model (Section 9.3.9).

8.2.6 Environmental Monitoring

Databases with environmental variables (e.g. water temperature, wind and sea level) are continuously updated and extended as new data becomes available from collections by the Department, internet sources and from other agencies (see Caputi et al. 2015). 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.

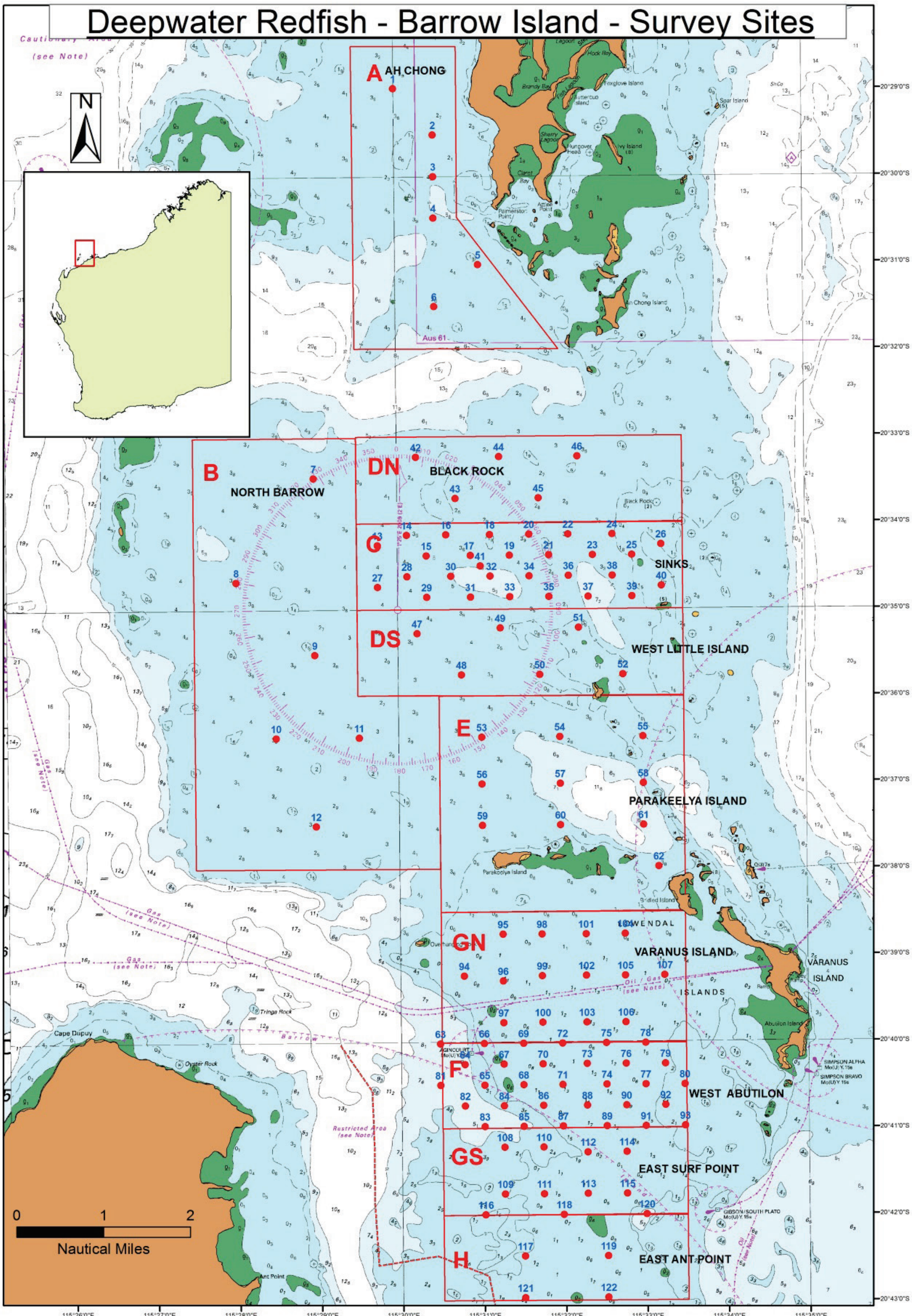

Figure 8.1. Biomass survey design for redfish (*Actinopyga echinites*) at Barrow and Montebello Islands. Survey strata divided into North (A, B, DN, G, DS, E) and South (GN, F, GS, H) of Parakeelya Island. Red dots indicate each survey site (100 x 1 m^2 transect), and blue numbers above red dots are the site numbers. Strata A and B were excluded from estimation procedures, as no *A. echinites* were found in and these areas.

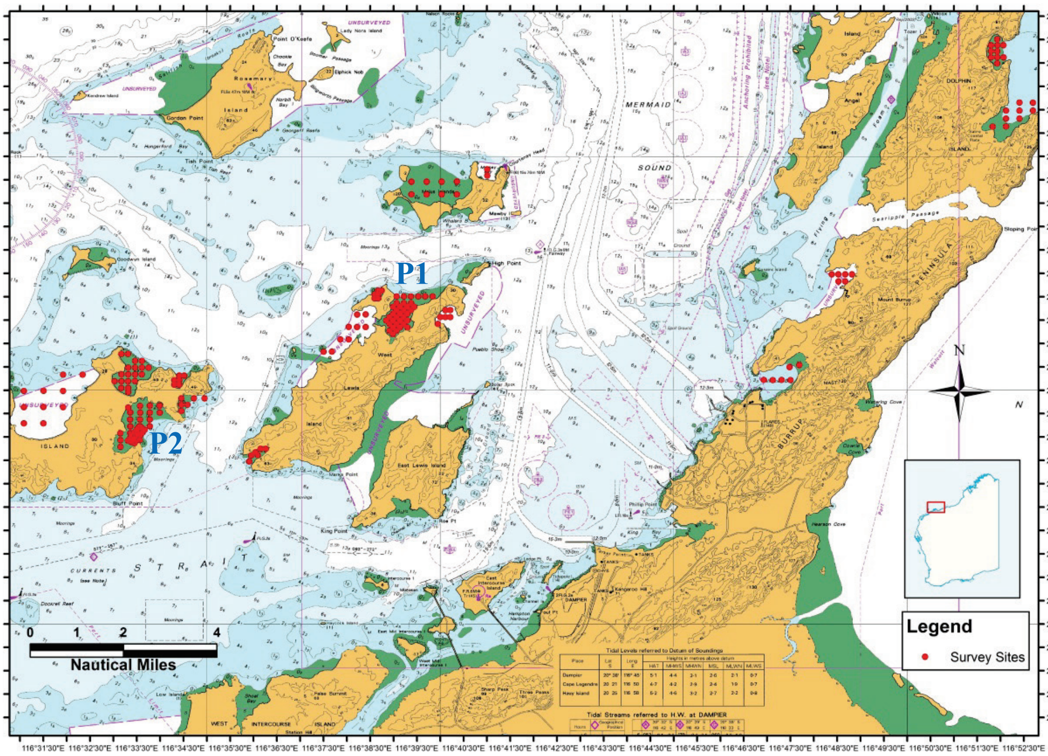

Figure 8.2. Biomass survey design for sandfish (*Holothuria scabra*) within the Dampier Archipelago of the Pilbara region. Survey strata divided into 15 bays and inlets across the Archipelago. Red dots indicate each survey site (50 x 1 m^2 transect). A total of 183 sites were surveyed across the 15 strata. P1 (Karratha Bay) and P2 (Enderby South) indicate the strata that contained significant populations of sandfish (see Section 9.3.8.1).

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 annual catches and 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 requires specifically the 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; Appendix 2) to determine the most appropriate combinations of consequence and likelihood to determine the overall current risk status.

9.2 Assessment Overview

The stock status of the sea cucumber resource in WA is assessed using a weight-of-evidence approach that considers all of the available (fishery-dependent and fishery-independent) information for this resource. This annual assessment is primarily based on monitoring of catch, effort, catch distribution, trends in size-structure, fishery-dependent standardised catch rates (catch per unit effort, SCPUE) for Kimberley sandfish, and biomass surveys for redfish and sandfish in the Pilbara. Appropriate statistical approaches such as the use of generalised linear models (GLM) to estimate abundance indices from catch rates or stratified random sampling techniques for deriving estimates of population size or biomass are applied where necessary. An additional important aspect of assessments for sea cucumbers in the Pilbara region is the use of fishery-independent biomass surveys coupled with fishery catch and catch rate data to estimate virgin biomass of stocks. These estimates were then use to derive target, threshold and limit reference points to support the harvest strategy for these two stocks (Pilbara sandfish and redfish, further details are found in Section 9.3.8 and 9.3.9).

Previously, a discrete version of the surplus production model (or biomass dynamics model) with an annual time step (applying the Schaefer production equation) have been used to estimate the current level of biomass of sandfish, relative to estimated unfished levels in those areas (Hart et al. 2015). When applying this model to obtain reliable estimates of annual biomass, it is necessary to have both a reliable abundance index and a level of "signal" in the abundance index (SCPUE) reflecting changes in stock abundance over time. The initial modelling was based on a single catch rate index, which appeared to have a strong signal reflecting changes in stock abundance over time. However, a change in the method of collection of catch rate data from monthly catch and effort returns (CAES data) to daily catch and effort data (i.e. from fishery logbooks) in 2007 resulted in an abrupt change in the scaling of the SCPUE index. Consequently, for this assessment, it was considered no longer appropriate to analyse all of the catch rate data as a single time series. On re-analysis of the data, that considered the data to constitute two-time series (i.e. CAES vs logbook period), it was evident that the catch rate indices now lacked a strong signal and thus, in turn, it was not possible to fit a biomass dynamics model of the form used in the previous assessment. This therefore meant that, without additional information, it was no longer possible to produce estimates of biomass for sandfish by applying this model-based approach.

9.2.1 Peer Review of Assessment

Stock assessments of key target species are internally reviewed as part of the Department's process for providing scientific advice to management and the Minister on the status of fish stocks. Assessment summaries (see weight-of-evidence risk assessment presented in Section 9.3.9) are signed off by the relevant Supervising Scientists and the Director of Research before being provided to the fishery managers to inform decision-making. Assessments and annual catch information are also presented by the Department and discussed with commercial licence holders at Annual Management Meetings (AMMs).

In recent years, the Department has had a schedule for peer review of assessments for all fisheries; this "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. The sea cucumber fishery has also been assessed by the Federal government as part of an export approval process to ensure the fishery is sustainable under the provisions of the EPBC Act 1999. This fishery is currently accredited for export until 2025.

The sea cucumber fishery is currently pursuing third party certification against the Marine Stewardship Council (MSC) standard for sustainable fishing (V2.0).

9.3 Analyses and Assessments

9.3.1 Data Used in Assessment

CAES / Logbook / Processor returns / VMS data Fishery-dependent data Fishery-independent survey data

9.3.2 Catch and Effort Trends

9.3.2.1 Commercial Catches

Based on the last 11 years of fishing, catches of sea cucumber in the WASCF are approximately 38% sandfish, 62% redfish, and 0.4% black teatfish, with other species making up a very minor contribution (Table 9.1). Although there has been a substantial fluctuation in catch composition over the history of the fishery, catch between 1995 and 2006 was >99% sandfish (see Figure 6.1).

Table 9.1. Current catches of sea cucumbers (tonnes, whole weight) retained by the WASCF targeting the resource, calculated as a total, and average, for 2007-2017.

Common name	Species name	Retained catch (2007 to 2017)		% of total
		Total	11 year average	
Sandfish	*Holothuria scabra*	411	41.1	37.6
Redfish	*Actinopyga echinites*	676	67.5	61.9
Black teatfish	*Holothuria whitmaei*	4.7	0.47	0.4
Other species		0.36	0.036	<0.1
Total		**1012**	**109.1**	

9.3.2.1.1 Sandfish

Catches of sandfish peaked at 370 t in 1997 in the third year of the fishery (Figure 9.1). By 2000 it had declined to less than 100 t and has remained below this figure since, with the exception of 2003. A contributing reason for the reduced catch has been a consolidation of industry effort and the implementation of more precautionary and economical fishing practices, such as use of smaller boats requiring less crew, shorter fishing trips and a voluntary rotational fishing strategy.

The majority of the catch has come from the Kimberley region, but in recent years the Pilbara has been more important (Figure 9.1). Catch increased significantly in 2016 to 90 t, which was primarily due to the rediscovery of a population within the Dampier Archipelago of the Pilbara region that had not been fished since 2003.

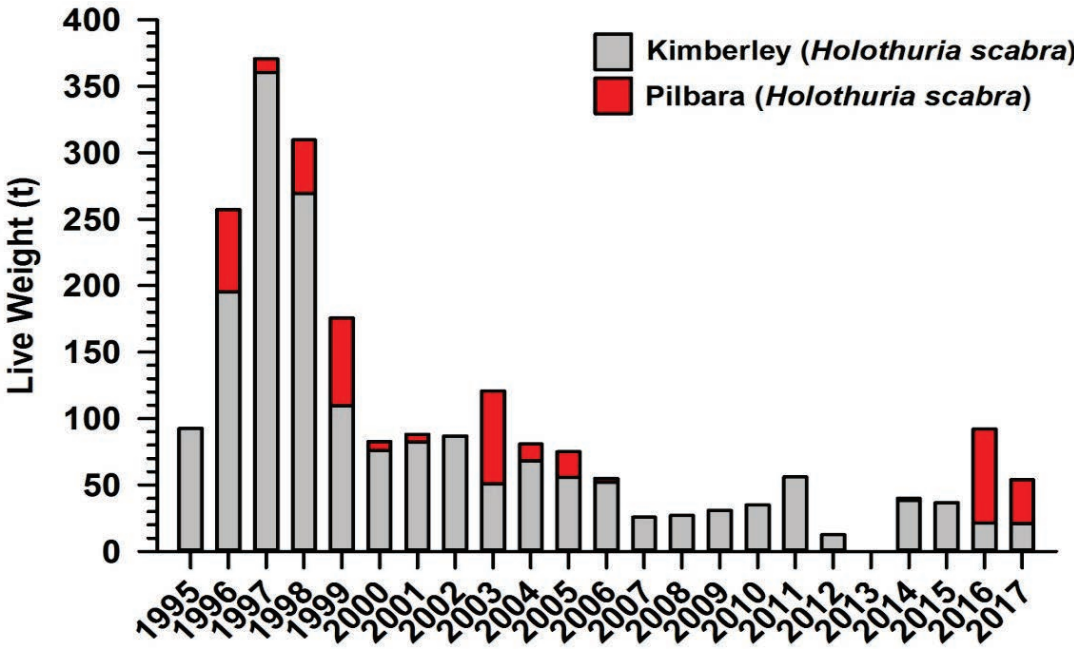

Figure 9.1. Annual total retained catches (tonnes) of sandfish (*Holothuria scabra*) in the Kimberley (grey bars) and Pilbara (red bars) regions of the WASCF from 1995 to 2017.

9.3.2.1.2 Redfish

Catches of redfish were only minor in the first 10 years of the WASCF (1995 to 2006; see Figure 6.1) but increased sharply to 116 t in 2007 (Figure 9.2). The catch peaked the in 2008 at 225 t before declining to around 120 t in 2009 and 2010 (Figure 9.2). Since 2010, redfish has only been targeted in two years (61 t in 2014; 25 t in 2017), and a minor catch of < 2 t landed in 2016. This is the result of a rotational fishing strategy, enforced by contractual arrangements between the license owners and the lease fishers. Redfish has been the most significant component of the WASCF over the most recent decade, comprising 67% of the total catch (Table 9.1). All of it is taken from the Pilbara region.

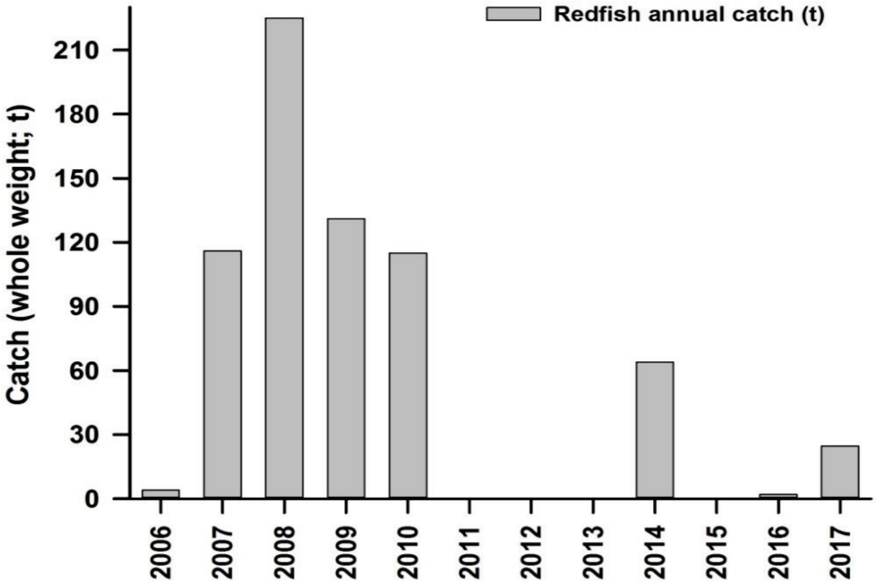

Figure 9.2. Pilbara redfish annual catch between 2006 and 2017.

9.3.2.2 Commercial Effort

Fishers initially provided monthly and daily returns under the statutory catch and effort system, either by statistical block or by fishing event (Table 8.1). These contained data on catch, days fished, hours fished, and spatial location as well as crew numbers. Effort is calculated in the metric of "crew days", with the following equation.

$$\text{Crew days} = \text{Days fished} \times \text{number of crew}$$

The other metric for effort is hours fished. This information has been available since 2007, from the daily logbook data, which requires fishers to accurately record the time spent fishing at a finer spatial scale.

Effort rose dramatically from 700 to 4000 crew days in the first four years of the fishery, then declined markedly over the next two years to 1200 days and has slowly decreased since then to an average of around 300 days in the last decade (Figure 9.3). In the first ten years, the majority of effort was expended in the Kimberley region, with occasional forays into the Pilbara stocks (Figure 9.3). The highest levels of effort in the Pilbara occurred during the early exploration phase of the fishery in 1998 and 1999. In the second decade of the fishery (2007 to 2016), approximately equal effort was allocated between the Kimberley and Pilbara stocks.

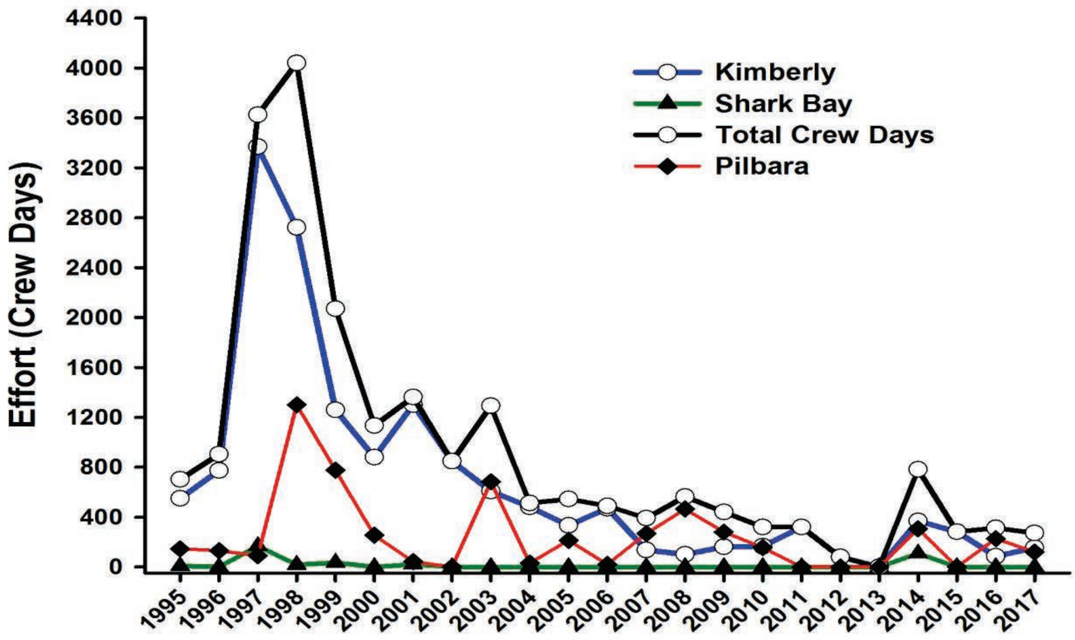

Figure 9.3. Effort in crew days by area and total for the WASCF between 1995 and 2017.

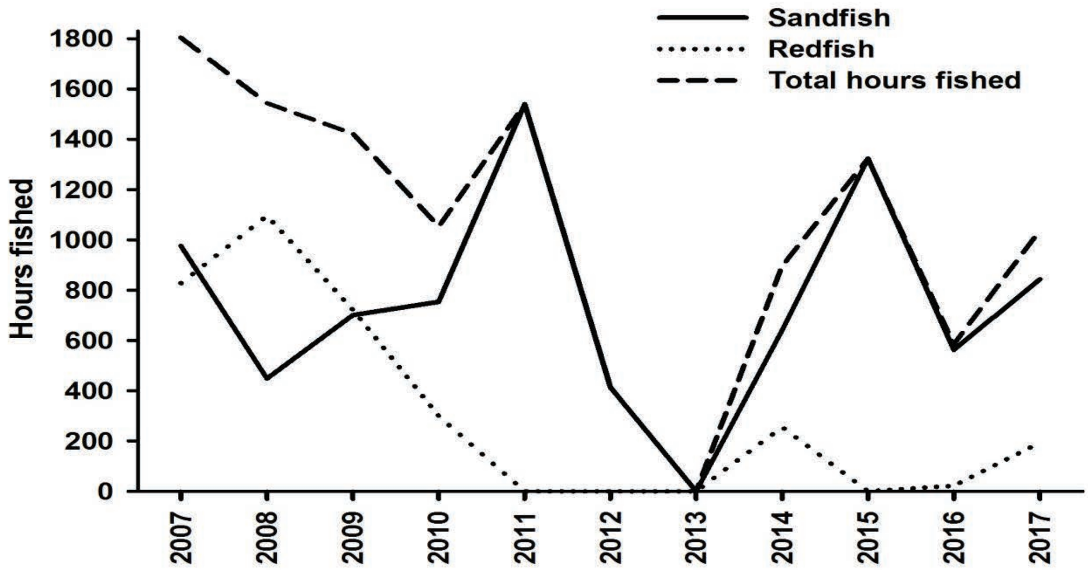

Figure 9.4. Effort in hours fished by species and total for the WASCF between 2007 and 2017.

Total hours fished has declined since 2007, from around 1800 hours to 1000 hours in 2017 (Figure 9.4). The majority of effort has been focused on sandfish, with the exception of 2008 and 2009, which were the peak years for the redfish fishery (Figure 9.4). A key reason for the reduced effort has been a consolidation of industry ownership, which led to changes in fishing practices, such as use of smaller boats (i.e. reduction in holding capacity), smaller crews, shorter trips and a voluntary rotational fishing strategy.

9.3.2.3 Recreational / Charter Catches

The recreational catch of sea cucumber in WA is negligible – the most recent estimate of the recreational annual harvest of 'other taxa' in WA (including sea cucumbers, sea urchins, cunjuvoi and 'other non-fish') was <1,000 individuals (Henry and Lyle 2003).

9.3.2.4 Recreational / Charter Effort

There are no estimates of recreational effort for sea cucumbers, however, it is assumed to be negligible.

9.3.2.5 Conclusion

Sandfish (Kimberley)	Catch and effort in this fishery has followed a typical fishery developmental path, with initial large catch and effort and reductions thereafter, instigated largely by conditions from assessments (e.g. under the EPBC Act), which required the development of fine-scale catch and effort records, and changes in industry practices, such as use of smaller boats (i.e. a reduction in holding capacity), smaller crews, shorter trips and rotational fishing strategies. There is no indication within the catch data of unacceptable stock depletion.
Sandfish (Pilbara)	Catch and effort in this fishery has followed a similar pattern to the Kimberley stock, although effort has been more intermittent, with minimal effort on sandfish over the past ten years. Much of the area remains only lightly exploited and the rediscovery of an area that has not been fished since 2003 suggest there are expanses of areas unfished each year due to relatively low levels of effort. There is no indication within the catch data of unacceptable stock depletion.
Redfish (Pilbara)	Catches from this stock were initially large (587 t in first 4 years), however, minimal catch in the past 6 years (63 t). Stock is exploited on a rotational basis by commercial contractual agreements within Industry. There is no indication within the catch data of unacceptable stock depletion.

9.3.3 Catch Distribution Trends

9.3.3.1 Sandfish

In WA, the extent of commercially fished populations of sandfish is Barrow Island in the south-west of its range, and Wyndham in the north, a distance of about 1800 km. Within these populations, areas fished are discrete and separated by large distances. Most fishing activity targets the densest populations, which occur in nearshore waters, mainly within bays and estuaries, of the Kimberley and Pilbara coasts (Figure 9.5; Figure 9.6).

In terms of the catch distribution between the Kimberley and Pilbara stocks over the history of the fishery, the overall proportions are 84% Kimberley and 16% Pilbara (Figure 9.8). However that has varied significantly from year to year. In 2004, 2016 and 2017, the majority of catch has been taken in the Pilbara region (Figure 9.8).

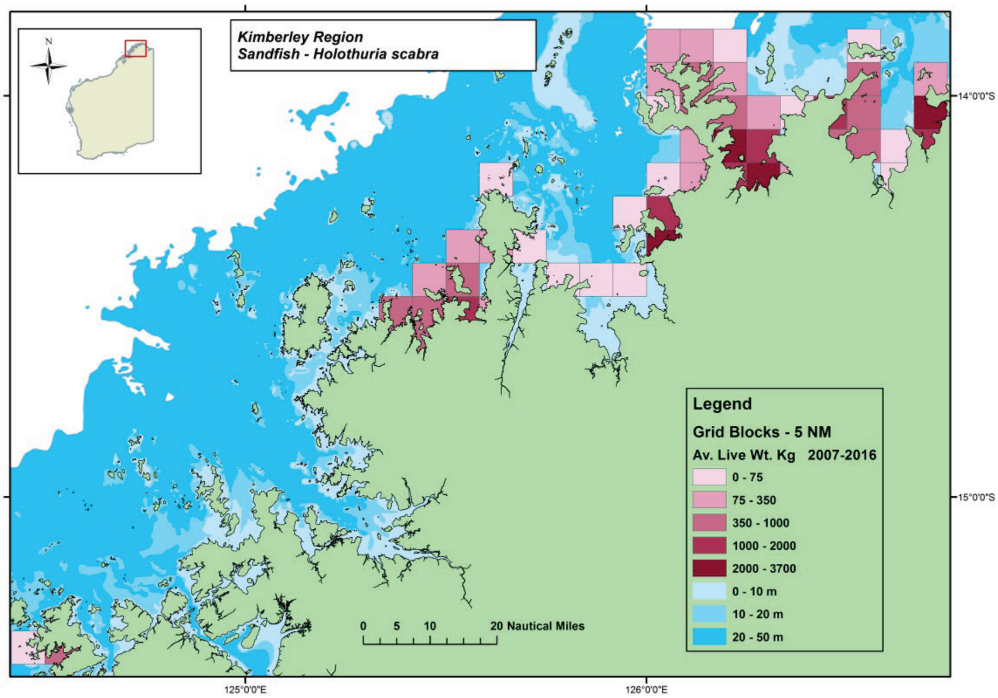

Figure 9.5. Catch distribution map (5 x 5 nm blocks) for the Kimberley stock of sandfish (*Holothuria scabra*). Data is mean annual catch for the period (2007-2016) when fine-scale fishing data has been available

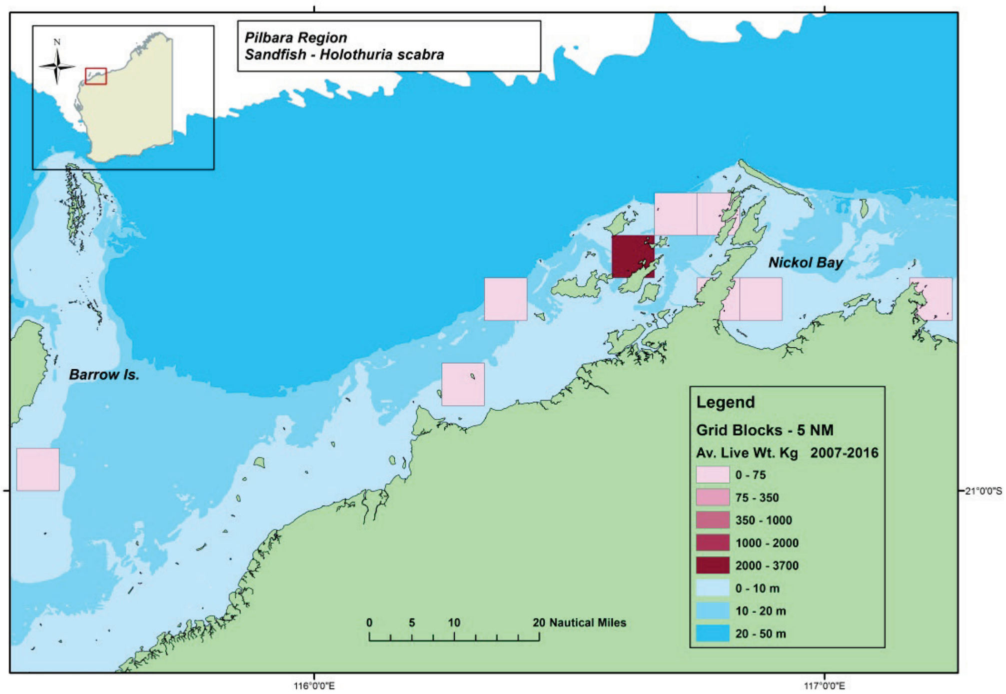

Figure 9.6. Catch distribution map (5 x 5 nm blocks) for the Pilbara stock of sandfish (*Holothuria scabra*). Data is mean annual catch for the period (2007-2016) when fine-scale fishing data has been available.

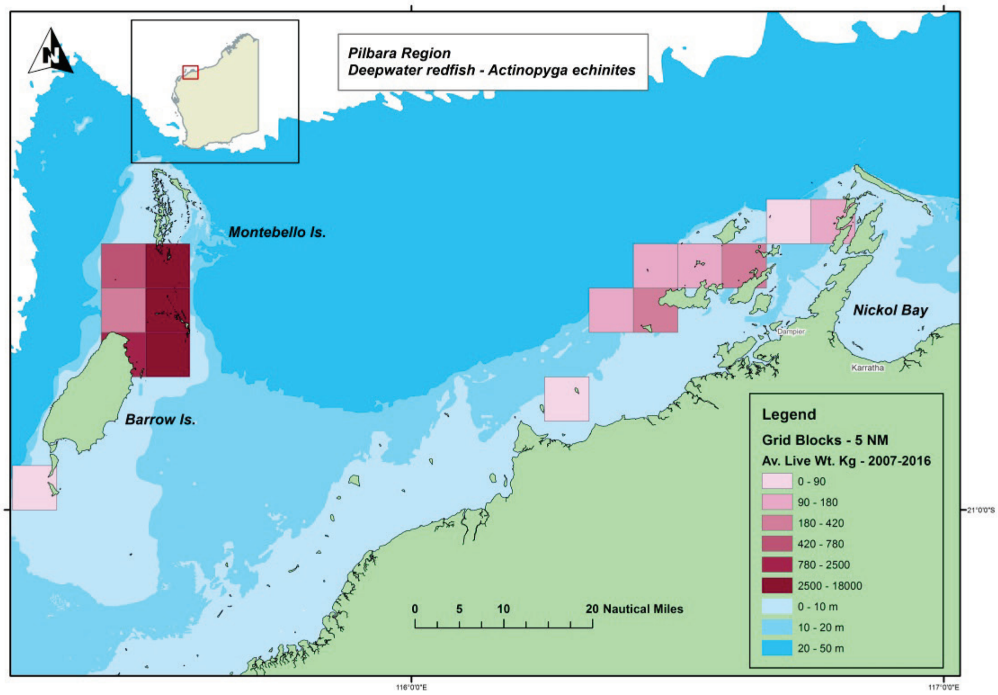

Figure 9.7. Catch distribution map (5 x 5 nm blocks) for the Pilbara stock of redfish (*Actinopyga echinites*). Data is mean annual catch for the period (2007-2016) when fine-scale fishing data has been available.

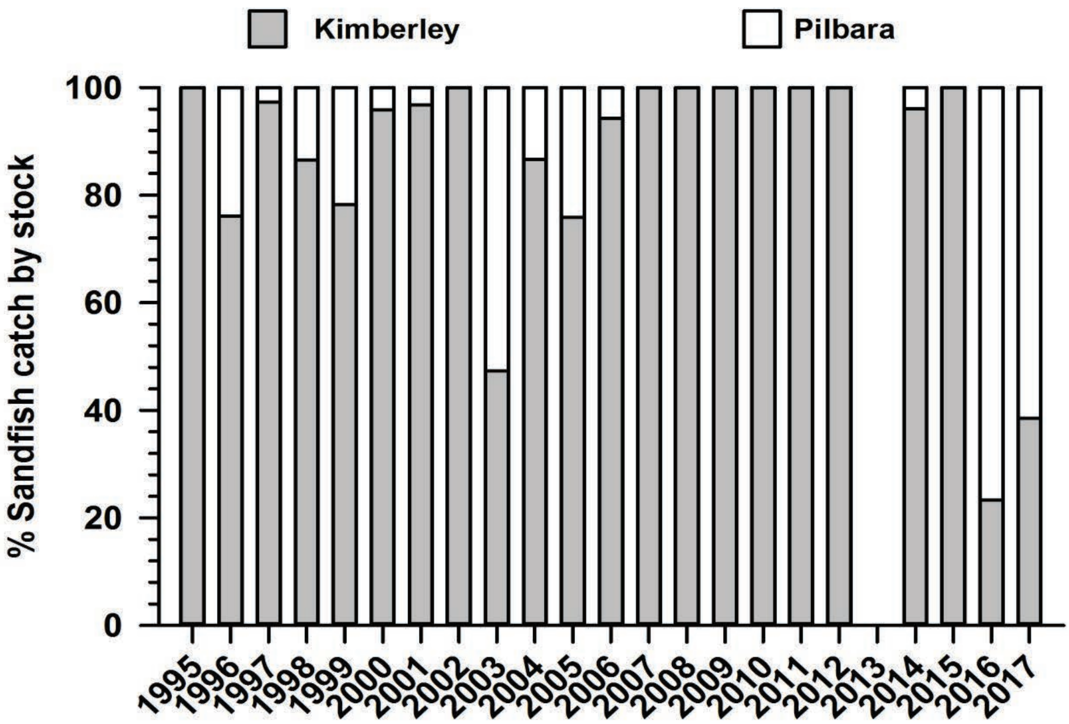

Figure 9.8. Percent distribution of sandfish catch between the two main stocks over the history of the fishery

9.3.3.2 Redfish

Redfish is widely distributed, but only very small catches were taken prior to 2007. The Montebello Islands redfish fishery (Pilbara region) began in 2007, which was the first year of the daily catch and effort logbook. Consequently it was possible to obtain a detailed analysis of the spatial scale of the fishery from its inception. Spatial distribution of catch in the redfish fishery is summarised in Figure 9.7. The vast majority comes from a shallow water lagoonal area between Barrow Islands and the Montebello Islands.

9.3.3.3 Conclusion

Sandfish (Kimberley)	The spatial distribution of catch has remained largely consistent over the history of the fishery. The fishery is widespread, with catch coming from a few high productivity areas, and a variable number of lower productivity areas. Catch distribution is also managed by rotational harvest strategies. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Sandfish (Pilbara)	Effort in the Pilbara has historically been focused on redfish and has involved fishing in places where sandfish are not abundant. The rediscovery of lightly exploited high-density populations of sandfish (such as those fished in the Dampier Archipelago in 2016 and 2017) may influence effort distribution in the Pilbara in the future. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Redfish (Pilbara)	The fishery is primarily based on the discovery of an unexploited stock in 2007 at Montebello Islands. Effort has been re-focused on the same spatial areas, although there is considerable fine-scale variation in the harvested areas. Stocks have been targeted 5 times in the 10 year history of the fishery, but only once since 2010. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.

9.3.4 Fishery-Dependent Catch Rate Analyses

Standardisation of catch rates is an integral part of the stock assessment and is used to inform the annual review and harvest strategy. The current standardised catch rate (SCPUE) models applied to data for each species and stock are summarised below.

Since the introduction of the daily logbook in 2007, it has been possible to accurately measure effort in hours fished, which takes into account the actual time fishing and the number of fishers in the water. Prior to 2007, data was only returned on monthly logsheets with a coarse level of spatial resolution (60 x 60 nautical mile blocks) and could not account for the finer-scale spatial distribution of the fishery. This earlier dataset (1996 to 2006) is excluded from the standardised CPUE analysis.

The SCPUE model applied to catch rates is numbers per hour, for each stock, is defined as follows:

$$\ln(CPUE + 1) = \mu + \beta_1 (Year) + \beta_2 (Sub - area) + \varepsilon$$

Where ln is the base$_e$ logarithm, CPUE is the catch rate data (numbers/hour) from each fishing event recorded per day (1 – 6 events per day); β_2 (Sub-area) is the effect of spatial differences in abundance between targeted stocks. The "Sub-areas" are geographical regions within the fishery. For example, in the Kimberley sandfish stock, the Sub-areas defined for the purposes of generating the SCPUE abundance index include Admiralty Gulf, Augustus Island, Napier Broome Bay and Vansitart Bay. There are three defined sub-areas from which sandfish are occasionally harvested within the Pilbara region (Montebello, Karratha Bay, and Nickol Bay). The least squares mean of the Year factor is used to produce an annual index of the relative abundance (SCPUE) of sea cucumbers.

In the case of the Pilbara redfish fishery, the numbers per hour index is the most suitable due to the availability of effort information in 'hours fished' since the inception of the fishery. Currently there is only one sub-area (Montebello) harvested commercially, so the GLM reduces to one factor, namely year. The effect of vessel is considered an important feature of variability in CPUE in this fishery; however, insufficient data is available to adequately account for this factor at present. Consequently the SCPUE time series for redfish is not used as the performance indicator in the harvest control rule, but as an additional line of evidence in the biomass dynamics model (Section 9.3.9), and in the overall weight of evidence assessment (Section 9.4.3.1).

9.3.4.1 Sandfish

Overall trends in Kimberley sandfish abundance, as indexed by SCPUE, have varied between 10 and 45 animals per hour (Figure 9.9). There is, however, no long-term-trend upwards or downwards, indicating that abundance is variable. The annual SCPUE (i.e. the primary performance indicator for the harvest strategy of this stock) is currently above the target reference point (see Section 7.2).

The Pilbara stock of sandfish is a minor contributor to catch in the WASCF, about 16% over the history of the fishery, although in 2016 and 2017 it produced 65% of the total harvest (Figure 9.8) after being unfished for over ten years. There are only three years of data with accurate catch rates in the Kimberley; 2004, 2016, and 2017. Catch rates were around 100 animals per hour in 2004 and 2016, and declined to around 80 animals per hour in 2017 (Figure 9.10).

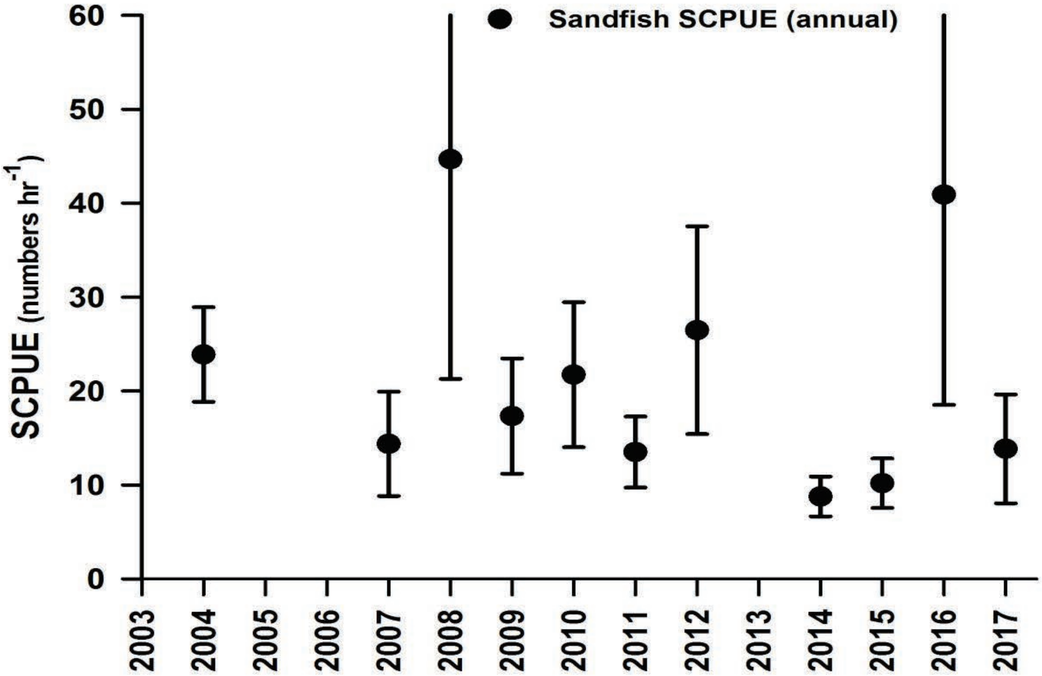

Figure 9.9. Abundance trends in the Kimberley sandfish stock (*Holothuria scabra*), as measured by a standardised catch rate index (SCPUE; ±95% CL).

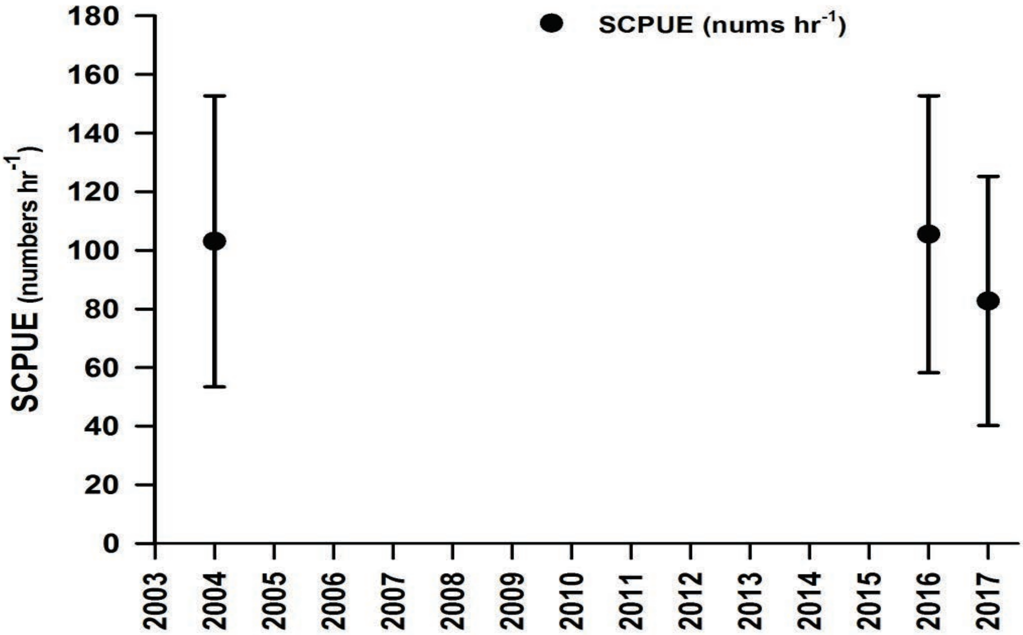

Figure 9.10. Abundance trends in the Pilbara sandfish stock (*Holothuria scabra*), as measured by a standardised catch rate index (SCPUE; ±95% CL).

9.3.4.2 Redfish

Redfish standardised CPUE was stable for the first three years of the fishery, and then increased in the fourth year (Figure 9.11). Over 500 tonnes was harvested in this period. Catch rates declined in 2014, then increased again in 2016 and 2017. Only 2 tonnes was harvested in 2016, compared to 64 tonnes and 25 tonnes in 2014 and 2017 (Figure 9.2). Overall the abundance signals arising from the SCPUE need more years to be confident in their interpretation, however, no declines are evident from them. They are also relatively high (mean = 190 animals per hour), compared to sandfish catch rates.

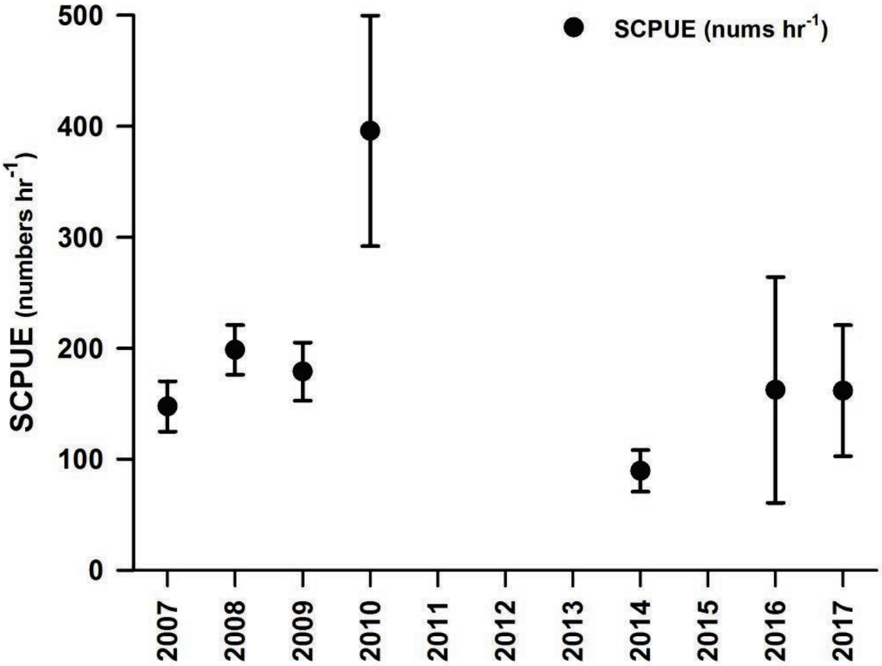

Figure 9.11. Abundance trends in the Pilbara redfish stock (*Actinopyga echinites*), as measured by a standardised catch rate index (SCPUE). The units of the index are number per hour (±95% CL).

9.3.4.3 Conclusion

Sandfish (Kimberley)	The SCPUE in the Kimberley sandfish fishery is currently oscillating up and down, with no obvious trend. In 2017, the SCPUE was just above the target reference level. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery.
Sandfish (Pilbara)	The SCPUE in the Pilbara sandfish fishery is currently high with only a small reduction seen in 2017. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery.
Redfish (Pilbara)	Catch rates in the Pilbara redfish fishery have oscillated over time, with no clear overall trend upwards or downwards. Despite the low catch rates observed in 2014, the 2016 and 2017 catch rates were similar to those at the beginning of the fishery in 2007, when the stock was unexploited. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery.

9.3.5 Trends in Size Structure

Since the introduction of the daily logbook in 2007, it has been possible to measure average size harvested, as information on both numbers caught and weight of catch is provided. The average size at harvest, particular in relation to size-at-maturity, provides another line of evidence to assess stock status. The analysis model of average size harvested takes into account differences in size between regions in determining the overall size of sea cucumbers caught. The GLM is as follows

$$W = \mu + \beta_1(Year) + \beta_2(Sub - area) + \varepsilon$$

where W is the average weight of sea cucumbers (numbers / weight) from each fishing event recorded per day (1 – 6 events per day); β_2 (Sub-area) is the effect of spatial differences in abundance between targeted stocks. The "Sub-areas" are geographical regions within the fishery; there are currently 8 defined geographical regions; five from the Kimberley area and three from the Pilbara area.

9.3.5.1 Sandfish

Average annual weight of sandfish harvested in WA is compared against the mean size and weight-at-maturity to establish what protection is being afforded by the size-at-maturity (Figure 9.12).

Size at-maturity for sandfish has been estimated to be 150 mm for Queensland populations of this species (Table 3 of Skewes et al. 2014), with other populations exhibiting variability between 140 and 200 mm, depending on location and sex (Table 5.1). No studies are available for size at maturity estimates of WA populations of sandfish, and voluntary size limits are based on Queensland and Northern Territory data. A 150 mm sandfish in WA is approximately 0.3 kg, based on length-weight relationships provided in Figure 5.5 and Figure 5.6.

Average weight of sandfish harvested in Kimberley region varied between 0.8 kg and 1.9 kg in the period 2004 to 2017 (Figure 9.12). This was much greater than the estimated size-at-maturity (0.3 kg; Figure 5.5), which implies a substantial component of the spawning stock is not vulnerable to being fished. Average weight of sandfish harvested in the Pilbara region was smaller than the Kimberley and varied between 0.7 and 1.3 kg (Figure 9.12). This was greater than the estimated size-at-maturity (0.3 kg; Figure 5.5), which provides protection of the spawning stock.

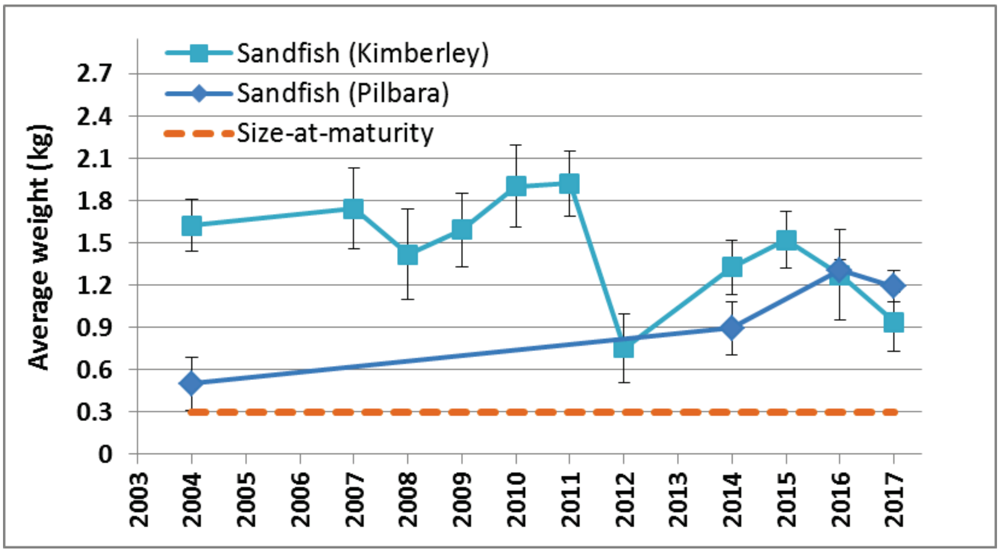

Figure 9.12. Standardised average weight of sandfish (*Holothuria scabra*) caught in the Kimberley and Pilbara regions of the WASCF between 2004 and 2017. Orange dotted line is estimated weight of animals with a 150 mm size-at-maturity (see Figure 5.5 for weight-length relationship).

9.3.5.2 Redfish

Average weight of redfish harvested in the fishery is compared against the size-at-maturity to establish if current size limits are protecting the spawning stock (Figure 9.13).

Size at-maturity for redfish has been estimated to be 120 mm for Queensland populations of this species (Table 3 of Skewes et al. 2014). A similar size-at-maturity was detected by Kohler et al. (2009) for Western Indian Ocean populations of redfish. No studies are available for size at maturity estimates of WA populations of sandfish, and voluntary size limits are based on Queensland and Northern Territory data. A 120 mm redfish in WA is approximately 0.13 kg, based on length-weight relationships provided in Figure 5.9.

Average weight of redfish harvested in the WASCF has been consistent at around 0.8 to 1.0 kg in the period 2007 to 2017 (Figure 9.13). This is significantly greater than the estimated size-at-maturity (0.13 kg; Figure 5.9), which provides protection of the spawning stock.

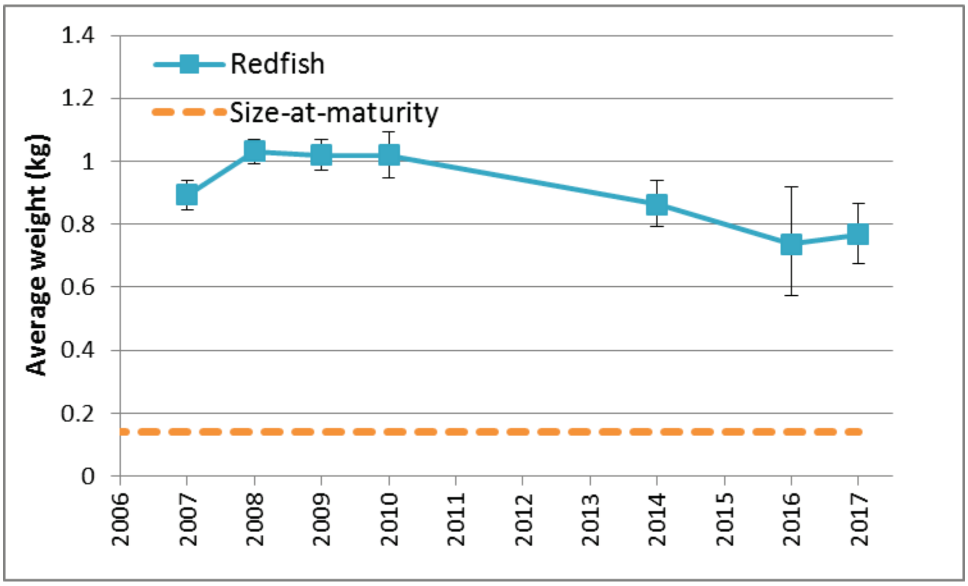

Figure 9.13. Standardised average weight of redfish (*Actinopyga echinites*) caught in the WASCF between 2004 and 2017. Orange dotted line is estimated weight of animals with a 120 mm size-at-maturity.

9.3.5.3 Conclusion

Sandfish (Kimberley)	Average weight of sandfish harvested in the Kimberley in the period 2004 to 2017 was > 3 times than the estimated size-at-maturity and stable over time. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery
Sandfish (Pilbara)	Average weight of sandfish harvested in the Pilbara has been increasing since 2004 and is > 3 times than the estimated size-at-maturity. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.
Redfish	Average weight of redfish harvested in the WASCF in the period 2007 to 2016 was > 3 times greater than the estimated size-at-maturity. This provides protection of the spawning stock, and fishing mortality is likely to be low. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.

9.3.6 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 3).

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. 2016). 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.

The sections below outline the PSA scores for each indicator species of the WA Sea Cucumber Resource.

9.3.6.1 Productivity

An assessment of the biological characteristics of the two WASCF target species in accordance with MSC scoring guidance (as set out under section PF4.3 in the MSC Fisheries Certification Requirements Version 2.0) results in low risk productivity scores of 1.33 for sandfish and 1.5 for redfish (Table 9.2). They are relatively fast-growing broadcast spawners with high estimates of natural mortality and thus score 1 in most attributes. The only productivity attribute in which they scored 3 was for density dependence (Table 9.2), due to their vulnerability to Allee effects. Allee effects and population density extremes have been suggested to be more pronounced in broadcast-spawning echinoderms with planktotrophic larval stages (such as sandfish and redfish) as opposed to species with lecithotrophic development. This is because larvae of the latter species are independent from the requirement to feed in the plankton and tend to settle quicker (presumably resulting in lower mortality rates in the plankton and enhanced local recruitment) (Uthicke et al. 2009).

Table 9.2. PSA productivity scores for sandfish and redfish

Productivity attribute	Sandfish	Redfish
Average maximum age	1	2
Average age at maturity	1	1
Reproductive strategy	1	1
Fecundity	1	1
Trophic level	1	1
Density Dependence	3	3
Total productivity (average)	1.33	1.50

9.3.6.2 Susceptibility

An examination of the susceptibility to fishing characteristics of sandfish and redfish results in similar scores. Both are widely distributed throughout WA within low energy environments behind fringing reefs or within protected bays, but populations of commercial density are less numerous. Also, given the current fishing operations (i.e. a single vessel spending 2 to 3 trips of 14-20 days each in the region), the areal overlap is likely to be <10%, but is conservatively estimated here as being in the range of 10-30%.

In the criteria of vertical overlap or encounterability, the method of fishing (by hand collection in shallow waters) means that sea cucumbers are susceptible to being encountered in the areas where fishing occurs. Although poor visibility prevents fishing to be as viable in neighbouring deeper waters, a conservative maximum score of 3 is applied.

In terms of selectivity, the analysis of average size caught indicates that animals harvested are well above size-at-maturity (Figure 9.12; Figure 9.13), indicating that fishing mortality is likely to be low. In the case of redfish, further evidence for a high size at selectivity is provided by the fishery-independent survey (Figure 9.19). Average size of animals in the stock was 0.4 kg (Figure 9.19), compared to average size of animals in the fishery (0.8 kg; Figure 9.13). However, given the difficulties of extracting reliable morphometric measurements from sea cucumbers, and the likelihood of considerable variability in size-at-maturity between different regions, a conservative score of 2 was applied (Table 9.3).

Finally, in the criteria of post-capture mortality, all catch is retained, therefore the maximum score of 3 is applied (Table 9.3).

Table 9.3. PSA susceptibility scores for sandfish and redfish

Susceptibility attribute	Sandfish	Redfish
Areal overlap	2	2
Vertical overlap	3	3
Selectivity	2	2
Post-capture mortality	3	3
Total susceptibility (multiplicative)	1.88	1.88

9.3.6.3 Conclusion

Based on the productivity and susceptibility scores, the overall weighted PSA scores were 2.3 for the sandfish resource and 2.4 for the redfish resource. These scores translate to associated MSC scores of 89 and 87 (out of 100), respectively, which indicates low inherent risks to the stocks.

Sandfish (Kimberley and Pilbara)	Sandfish are assumed to have a relatively short life span (maximum age around 10-14 years), and mature at 2 years of age. With a productivity score of 1.33 and susceptibility score of 1.88, the overall derived PSA score is 2.3 (MSC score > 80). This level of vulnerability indicates there is a relatively low chance of overfishing occurring at current levels of effort. However the significant risk of sea cucumber stocks to localised depletion cannot be discounted, despite this low vulnerability score.
Redfish (Pilbara)	Redfish assumed to have a relatively short life span (maximum age around 12 years), and mature at 2 years of age. With a productivity score of 1.5 and susceptibility score of 1.88, the overall derived PSA score is 2.4 (MSC score > 80)

9.3.7 Within-Season Depletion Model (Pilbara sandfish)

The recommencement of sandfish harvest in the Pilbara region in 2016 was primarily focused on Karratha Bay on West Lewis Island. Karratha Bay was one of 15 strata surveyed for sandfish stocks in the Pilbara region, and one of only two strata that contained significant populations of sandfish (Figure 8.2). The Bay was fished during a discreet period in October and November 2016, providing data that could be fitted by a within-season Leslie depletion model. This model was used to estimate initial biomass, harvest rate and the catchability co-efficient of the fishing gear. Estimates were then compared with values estimated by the fishery-independent biomass survey (FIS), carried in September 2017, 9 months after fishing had ceased, and prior to the 2017 fishing season.

A total of 58 tonnes whole weight (19 t landed weight) of sandfish was harvested from Karratha Bay in 2016 (Figure 9.14). The Leslie depletion model (Hilborn and Walters 1992) estimated harvest size biomass prior to fishing as 103 t ±26 t (Figure 9.15). This leads to a harvest rate in

2016 of 0.56 (F = 0.55) on the exploitable component of the population. In comparison, total estimated population biomass of Karratha Bay from the FIS method was 122 t ±26 t (Figure 9.15). The smaller median estimate from the depletion model is expected when it is noted that the commercial fishery did not target the entire population spectrum. Mean weight of sandfish harvested in 2016 was 1.2 kg (Figure 9.12), compared to 0.71 kg from the fishery-independent survey (Figure 9.16).

The agreement in biomass estimates between two independent methods strengthens the confidence in the overall estimates obtained from the fishery independent surveys described in Section 9.3.8.1.

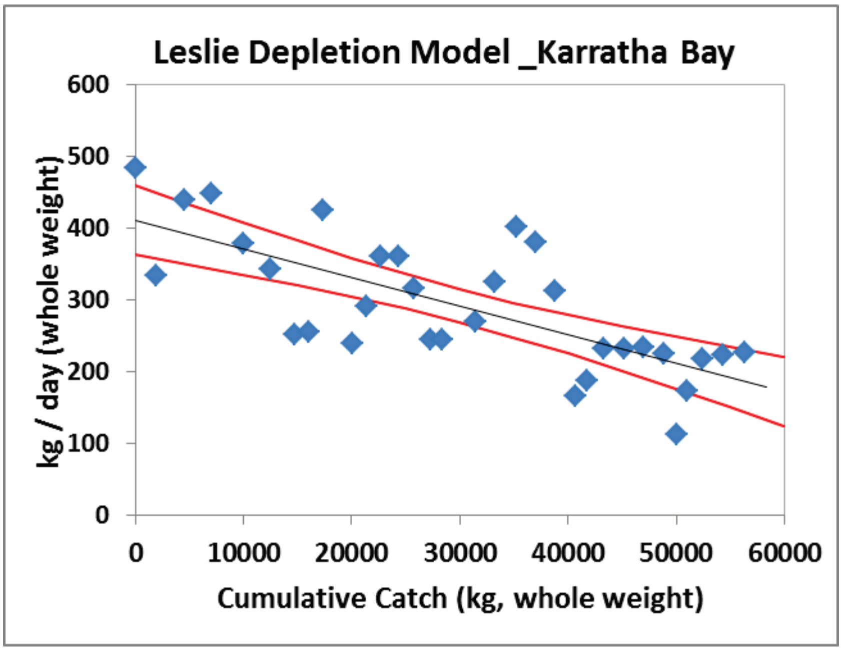

Figure 9.14. Within-season Leslie depletion model for Sandfish stock (*Holothuria scabra*) of Karratha Bay, Dampier Archipelago, from 2016. Catch rates are in kg whole weight per day, and cumulative catch weight is in kg, whole weight. Red lines are 95% confidence limits

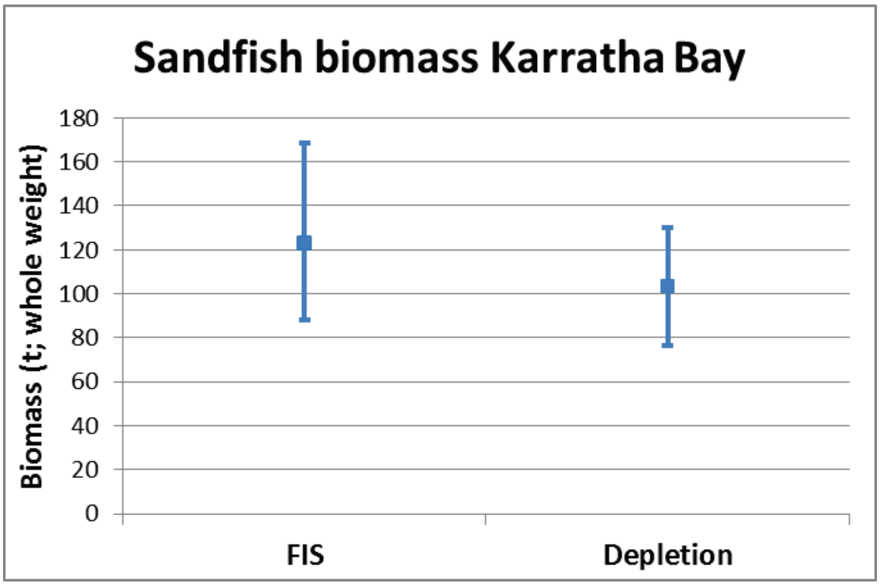

Figure 9.15. Comparison of estimates of population biomass from a within-season depletion model, based on fishery data ('Depletion'), and a fishery independent survey ('FIS') in Karratha Bay, Dampier Archipelago, Pilbara. Karratha Bay is 1 of 15 strata assessed by the FIS. Error bars are 95% CL. See section 9.3.8.1 for more detail.

9.3.8 Fishery-Independent Data Analyses

9.3.8.1 Sandfish (Pilbara)

For sandfish, a parametric resampling analysis (n = 10,000 resamples; Manly 1997) was undertaken to provide an estimate of biomass with associated uncertainty, based on data collected during fishery independent surveys in 2017, and given the area of the stock encompassed by the strata. The analysis assumed the data conformed to delta-lognormal distribution given knowledge of the area of the stock (Section 8.2.5). The abundance data were collected at 183 survey sites (Section 8.2.5; Figure 8.1). This type of analysis was similar to that used to estimate biomass of sedentary invertebrates and generate estimates of catch foregone as a result of the imposition of a marine sanctuary (Hesp et al. 2008). A biomass dynamics model, which assumed a distribution for the intrinsic rate of increase (r), was then simultaneously fitted to the biomass estimate derived from the FIS (Figure 9.18) and the catch rate data, to provide estimates of annual biomass and the initial, unfished biomass (Section 9.3.9).

The original survey design involved a total of 183 sites spread across 15 strata (Figure 8.2). At completion of the survey it was established that 13 of the 15 strata had negligible populations of sandfish. The two strata that did contain significant populations of sandfish were Karratha Bay on West Lewis Island, and Enderby South Bay on Enderby Island. A third high density stratum was established within Enderby South, resulting in a total of three strata used for population assessment. The total area of habitat of these strata was 3.53 km^2 or 3,535,684 m^2. Note that this area is substantially less than the total area surveyed for redfish populations, which was 59.35 km^2.

Mean length of sandfish in the Pilbara region in 2017 was 225 (±32 SD) mm, with a range between 90 and 300 mm (Figure 9.16a). Mean weight was 712 (± 182 SD) grams, with a range between 100 and 1200 g (Figure 9.16b).

In 2017, the estimated population abundance of sandfish in the Dampier Archipelago varied between 132,000 and 247,000 animals (95% CL), with a median estimate of 182,000 (Figure 9.17). The estimated population biomass of sandfish in the Dampier Archipelago varied between 98 and 181 tonnes whole weight (95% CL), with a median estimate of 134 t (Figure 9.18). This biomass estimate was used as input data in a biomass dynamics model to provide an estimate of unfished biomass (K), which was then applied in the harvest strategy.

Looking closely at the individual strata, the currently surveyed population of sandfish in the Pilbara is largely confined to Karratha Bay (Table 9.4). Median population biomass estimates were 10 tonnes in Enderby South Bay, and 122 tonnes in Karratha Bay (Table 9.4). Median biomass density ranged from 2 to 92 tonnes per km^2. Over 50% of the Enderby South Bay population is contained within a high density strata (22 t per km^2) of low area (0.27 km^2), and the rest spread across the bay at lower densities (2.09 t per km^2). See Table 9.4.

(b)

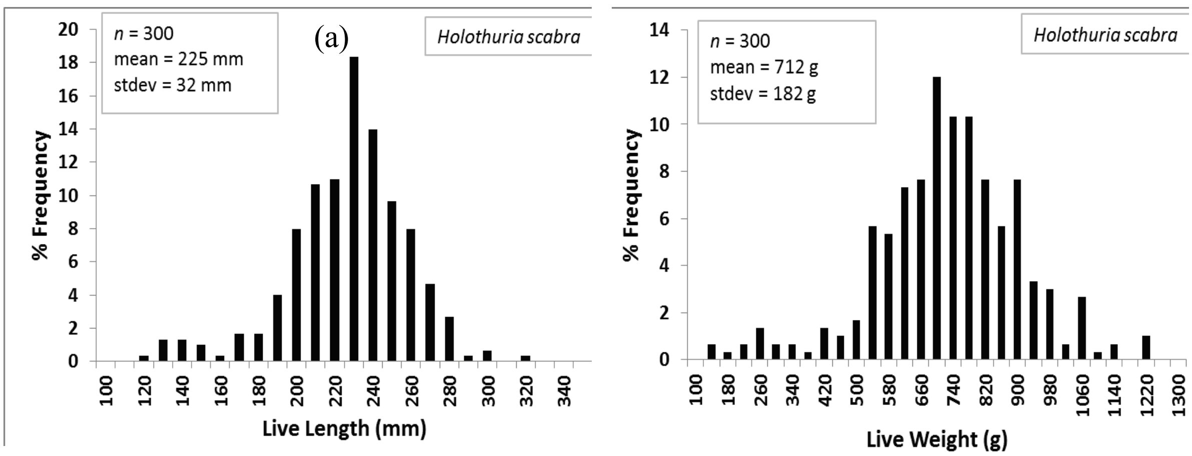

Figure 9.16. (a) Length (mm) and (b) whole weight (g) frequency distribution of sandfish at the Dampier Archipelago (Karratha Bay on West Lewis Island).

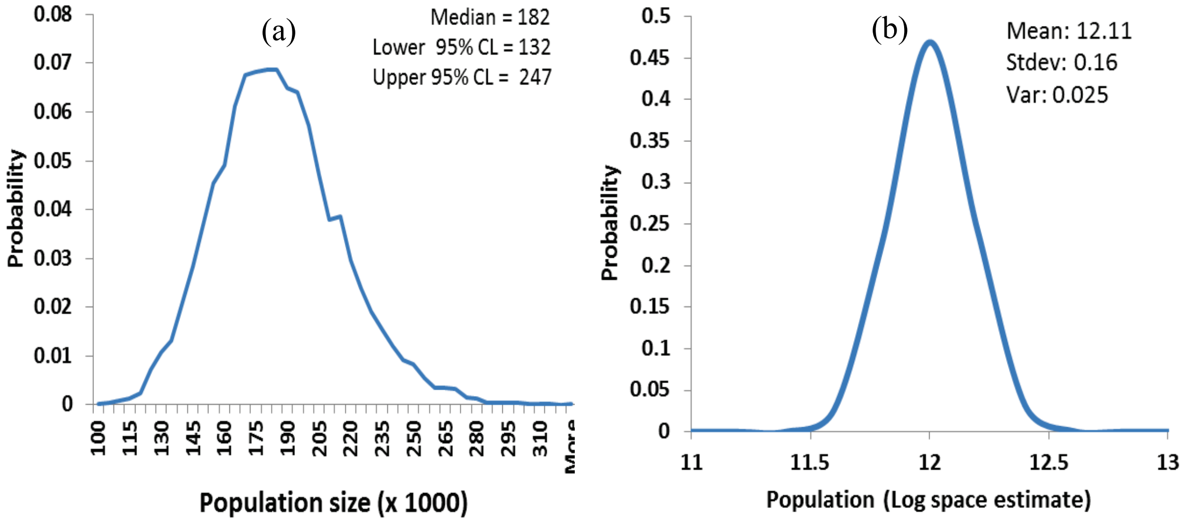

Figure 9.17. Probability estimates of population size for the sandfish stock in the Pilbara region (92% from Karratha Bay on West Lewis Island). (a) Distribution in normal units (numbers x 1000) with statistical parameters; (b) Distribution in log-transformed space with statistical parameters.

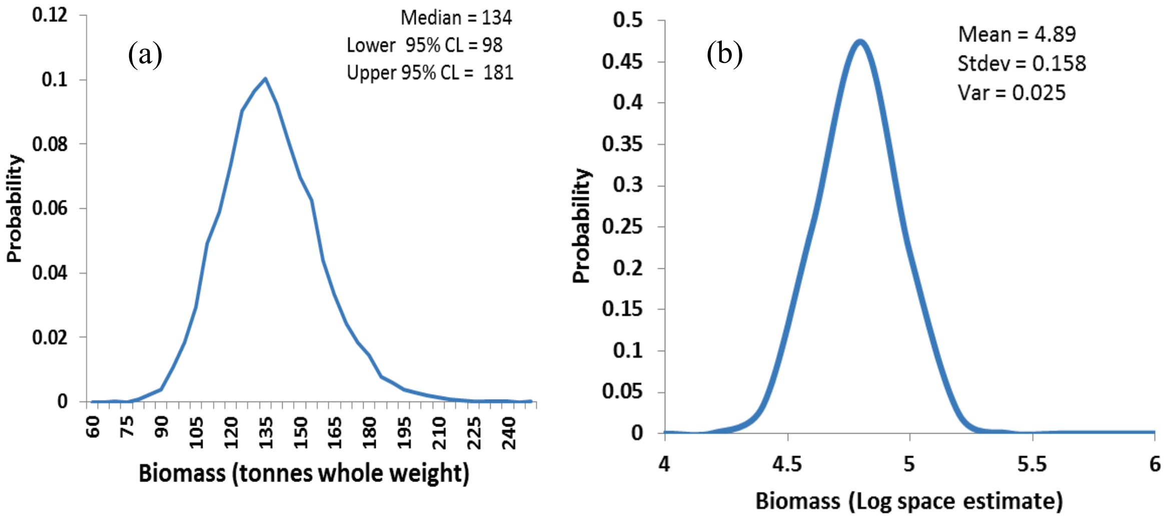

Figure 9.18. Probability estimates of biomass for the sandfish stock in the Pilbara region (primarily Karratha Bay on West Lewis Island). (a) Distribution in normal units (tonnes) with statistical parameters; (b) Distribution in log-transformed space with statistical parameters. Parameters from (b) were used in the biomass dynamics model (see section 9.3.9.7).

Table 9.4. Population biomass (t; whole weight) median estimates and 60% CL limits for individual strata within the *Holothuria scabra* fishery in the Pilbara region in 2017. See Figure 8.2 for a spatial map of strata.

Strata	Area (km^2)	Population biomass (t; whole weight)			Median biomass density (tonnes per km^2)
		Median	Lower 60% CL	Upper 60% CL	
Enderby South	1.962	4.11	2.23	6.48	2.09
Enderby South High Density	0.27	5.6	3.82	7.99	20.7
Karratha Bay	1.303	122.7	106.8	140.8	94.2

9.3.8.2 Redfish (Pilbara)

For redfish, a parametric resampling analysis (n = 10,000 resamples; Manly 1997) was undertaken to provide an estimate of biomass with associated uncertainty, based on data collected during fishery independent surveys in 2017, and given the area of the stock encompassed by the strata. The analysis assumed the data conformed to delta-lognormal distribution given knowledge of the area of the stock (Section 8.2.5). The abundance data were collected at 183 survey sites (Section 8.2.5; Figure 8.1). This type of analysis was similar to that used to estimate biomass of sedentary invertebrates and generate estimates of catch foregone as a result of the imposition of a marine sanctuary (Hesp et al. 2008). A biomass dynamics model, which assumed a distribution for the intrinsic rate of increase (r), was then simultaneously fitted to the biomass estimate derived from the FIS (Figure 9.18) and the catch rate data, to provide estimates of annual biomass and the initial, unfished biomass (Section 9.3.9).

The original survey design involved a total of 122 sites spread across 10 strata, with two strata receiving a higher intensity of sampling (Strata G and F), and the others receiving a lower intensity of sampling (Figure 8.1). At completion of the survey it was established that six of the low intensity strata had negligible populations of redfish. These were A, B, DS, E, and H. These strata were excluded from the population assessment. The final assessment was based on 4 strata; 2 × high density (G and F), and 2 x low density (DN; GN + GS). The total area of habitat of these strata was 59.35 km^2 (or 59,351,939 m^2).

Mean length of redfish in the Pilbara region was 178 (±32 SD) mm, with a range between 90 and 300 mm (Figure 9.19a). Mean weight was 395 (±201 SD) grams, with a range between 100 and 1200 g (Figure 9.19b).

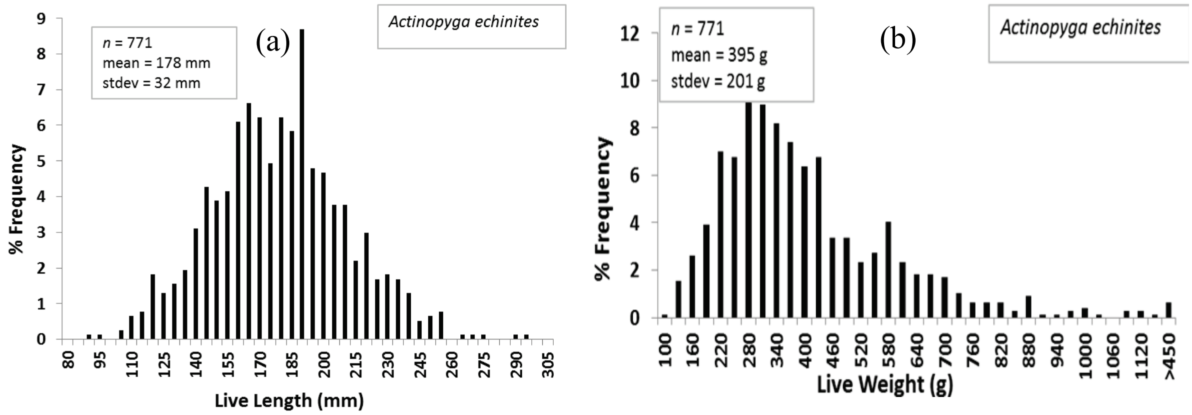

Figure 9.19. (a) Length (mm) and (b) whole weight (g) frequency distribution of redfish at the Montebello Islands.

In 2015, the estimated population biomass of redfish at the Montebello Islands varied between 1000 and 7400 tonnes whole weight (95% CL), with a median estimate of 2221 t (Figure 9.20). This biomass estimate was used as input data in a biomass dynamics model to provide an estimate of unfished biomass (K), which was then applied in the harvest strategy.

Looking closely at the individual strata, it is clear that the population is spread across the four main strata (Table 9.5). Median population biomass ranged from 311 tonnes in Strata C to 623 tonnes in Strata F (Table 9.5). Median biomass density ranged from 22 to 48 tonnes per km^2.

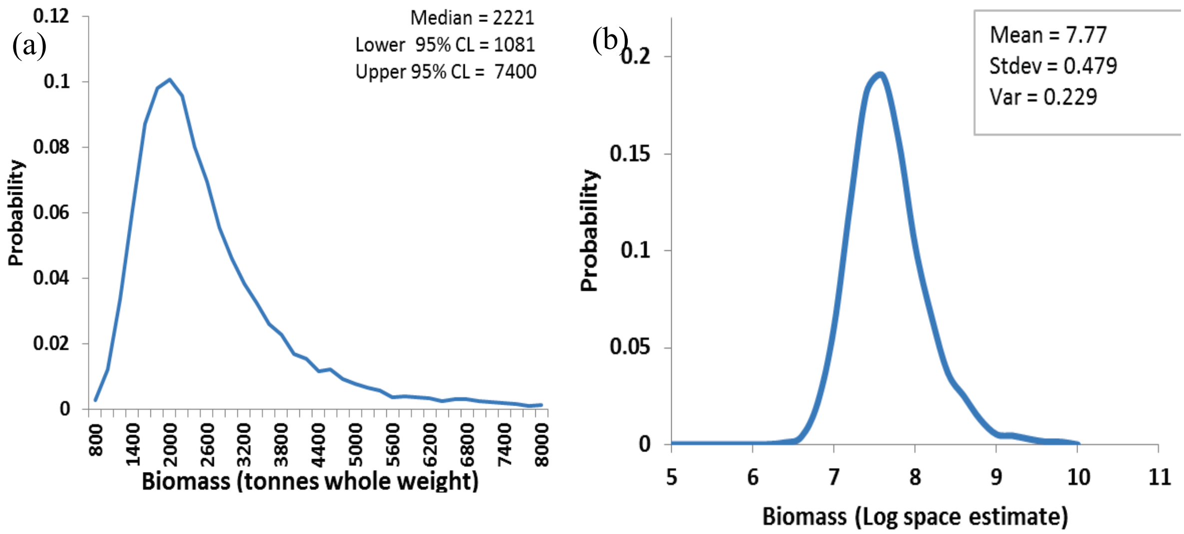

Figure 9.20. Probability estimates of biomass for the redfish stock in the Pilbara region (Barrow and Montebello Islands). (a) Distribution in normal units (tonnes) with statistical parameters; (b) Distribution in log-transformed space with statistical parameters. Parameters from (b) were applied in the biomass dynamics model (see Section 9.3.9.7).

Table 9.5. Population biomass (t; whole weight) median estimates and 60% CL limits for individual strata within the *Actinopyga echinites* fishery in the Pilbara region in 2015. See Figure 8.1 for a spatial map of strata.

Strata	Area (km^2)	Population biomass (t; whole weight)			Median biomass density (tonnes per km^2)
		Median	Lower 60% CL	Upper 60% CL	
C	12.87	311	207	462	24.2
F	14.53	623	389	1004	42.9
DN+DS	12.81	615	233	1564	48.0
GN+GS	19.15	422	268	656	22.0

9.3.9 Biomass Dynamics Model

9.3.9.1 Overview

A discrete version of the surplus production model with an annual time step (or biomass-dynamics model), applying the Schaefer (1954) production equation, was fitted to the catch, catch rate and fishery-independent survey biomass data for sandfish and redfish in the Pilbara region.

9.3.9.2 Model Description

B_{t+1}, the biomass in year $t+1$, is:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t$$

where B_t is the biomass in year t, C_t is the catch in year t, r is the intrinsic rate of in increase and K is the carrying capacity. $\widehat{U}_t$, the estimated catch rate in year t, is calculated as

$$\widehat{U}_t = qB_t,$$

where q is the catchability coefficient.

The model was fitted by maximising the sum of two log-likelihood components. λ_1, the log-likelihood associated with the catch rate data, was calculated as

$$\lambda_1 = -\frac{n}{2}[\ln(2\pi) + 2\log_e(\hat{\sigma}) + 1]$$

where the maximum likelihood estimate of the variance was derived from the sum of squared residuals between the natural logarithms of the observed (U_t) and expected annual catch ($\widehat{U}_t$) rates.

λ_2, the log-likelihood associated with the fishery independent survey estimate of biomass (see section 9.3.8.1 for sandfish and section 9.3.8.2 for redfish), was calculated from the probability density function for the lognormal distribution, i.e.

$$\lambda_2 = \ln\left\{\frac{1}{\hat{B}_{2015\ (or\ 2017)}\sigma\sqrt{2\pi}}\exp\left[-\frac{\ln\left(\hat{B}_{2015\ (or\ 2017)} - \mu\right)^2}{2\sigma^2}\right]\right\}$$

where $\hat{B}_{2015\ (or\ 2017)}$ is the model estimate of biomass for the year 2015 for redfish, or 2017 for sandfish, μ is the mean of the lognormal distribution for the fishery independent survey biomass estimate, and σ is the standard deviation for that estimate. Surveys were carried out in 2015 for redfish and 2017 for sandfish. Note that the values for μ and σ had been estimated by fitting a lognormal distribution to the resampled estimates of biomass, determined from the resampling analysis of the independent survey data, as summarised in Figure 9.18b for sandfish, and Figure 9.20b for redfish.

The overall log-likelihood associated with the biomass model fit to both data sets , λ, is thus

$$\lambda = \lambda_1 + \lambda_2$$

A parametric resampling approach was employed to account for uncertainty in the observed annual catch rate values. This involved generating 1000 random values for each mean annual catch rate, based on the value of that mean and its associated standard error. These values were employed to generate 1000 random catch rate time series, to each of which the model was fitted, and for which the estimated parameters and biomass values (and ratios of current / unfished biomass) were recorded. The 95% confidence limits associated for each parameter or biomass measure were taken as the upper 97.5 and lower 2.5 percentiles of the 1000 estimates for that respective parameter or biomass measure.

9.3.9.3 Scenarios for sandfish

Two modelling scenarios were investigated for sandfish stocks in the Pilbara. The first scenario assumes that the fishery-independent survey of biomass in 2017 had a total coverage of all stocks in the Pilbara region. This was known to be overly-conservative as most of the catch of sandfish in the Pilbara region was harvested before the introduction of the fine scale catch and effort logbook in 2007 (Figure 9.1), and knowledge of the exact locations of catch is scant. Of the total catch of sandfish removed from the Pilbara region, at least 35% was recorded from areas that were not surveyed in 2017. Thus the second modelling scenario for sandfish assumed that the FIS surveys in 2017 covered only 65% of the total population. For this scenario, the FIS biomass estimate was multiplied by 1.54 (i.e. 1/0.65) (Table 9.6).

9.3.9.4 Input Data and Parameters

The input data and parameters are summarised in Table 9.6 for sandfish and Table 9.7 for redfish. As demographic data were very minimal, r was not estimated, but specified using the proxy $r = 2M$ (Zhou et al. 2016, see also Quinn and Deriso 1999), where M is the instantaneous rate of natural mortality. Noting that M is difficult to estimate for sea cucumber species, Skewes et al. (2014) recently applied 0.4 as a conservative value for several species. This value was chosen as opposed to some of the higher estimates in the literature (see Table 5.2), which have been derived from length-based analyses. Other input data include observed catch rates, and observed biomass in 2017 for sandfish (Table 9.6), or 2015 for redfish (Table 9.7).

9.3.9.5 Results and Diagnostics – Sandfish (Pilbara)

Model outputs for Scenario 1 are summarised in Figure 9.21. Unfished biomass in 1996 was estimated at 203 t, with a range from 186 to 215 t. Biomass was reduced by around 30% in the first 5 years of fishing, but recovered to virgin levels in 2008 following the cessation of fishing (Figure 9.21d). The model estimated that it was highly unlikely that biomass was reduced below 0.6K at any time during the 21 year history of the fishery. Only three years of useful catch rate data were available, but showed a signal between 2016 and 2017, when it declined by around 10% (Figure 9.21e).

Model outputs for Scenario 2 are summarised in Figure 9.22. Unfished biomass in 1996 was estimated at 271 t, with a range from 253 to 287 t. Biomass was reduced by around 20% in the first 5 years of fishing, but recovered to virgin levels in 2008 following the cessation of fishing (Figure 9.22d). The model estimated that it was highly unlikely that biomass was reduced below 0.7K at any time during the 21 year history of the fishery. Only three years of useful catch rate data were available, but showed a signal between 2016 and 2017, when it declined by around 10% (Figure 9.21e). The catchability coefficient was lower in scenario 2, compared to scenario 1, due to the assumption of a larger stock conveyed by the scaling factor of 1.54 (=1/0.65) (Table 9.6).

Table 9.6. Input data and estimated parameters for the sandfish (*Holothuria scabra*) biomass dynamics model for the Pilbara region. Two scenarios were investigated, where the scaling factor (SF) was 1 (Scenario 1) or 0.65 (Scenario 2). Descriptions of scenarios are found in section 9.3.9.3

Parameter/ Data	Description	Values/Estimation
SF	Scaling factor	1 (Scenario 1) or 1.54 (Scenario 2). See section 9.3.9.3 for more detail
K	Carrying Capacity/ Virgin Biomass	Estimated in model
r	Intrinsic rate of population increase	From equation $r = 2M$. M assumed to be normally distributed, with a mean of 0.4 and SD of 0.1.
q	Catchability coefficient	Estimated in model
$\hat{\boldsymbol{U}}_{\boldsymbol{t}}$	Estimated catch rate	Estimated in model
U_t	Observed catch rate	Output from fishery dependent CPUE analysis (see Section 9.3.4.1).
C_t	Catch (tonnes) in year *t*	Catch records from fishery (1996 to 2017)
B_t	Biomass (tonnes) in year t	Estimated in model
$\hat{\boldsymbol{B}}_{\boldsymbol{2017}}$	Biomass (tonnes) in 2017	Estimated in model
$\boldsymbol{\mu}$	Mean of the lognormal distribution for the observed biomass in 2017	Output from fishery independent population surveys (see Figure 9.20)
$\boldsymbol{\sigma}$	Standard deviation of the lognormal distribution for the observed biomass in 2019	Output from fishery independent population surveys (see Figure 9.20)

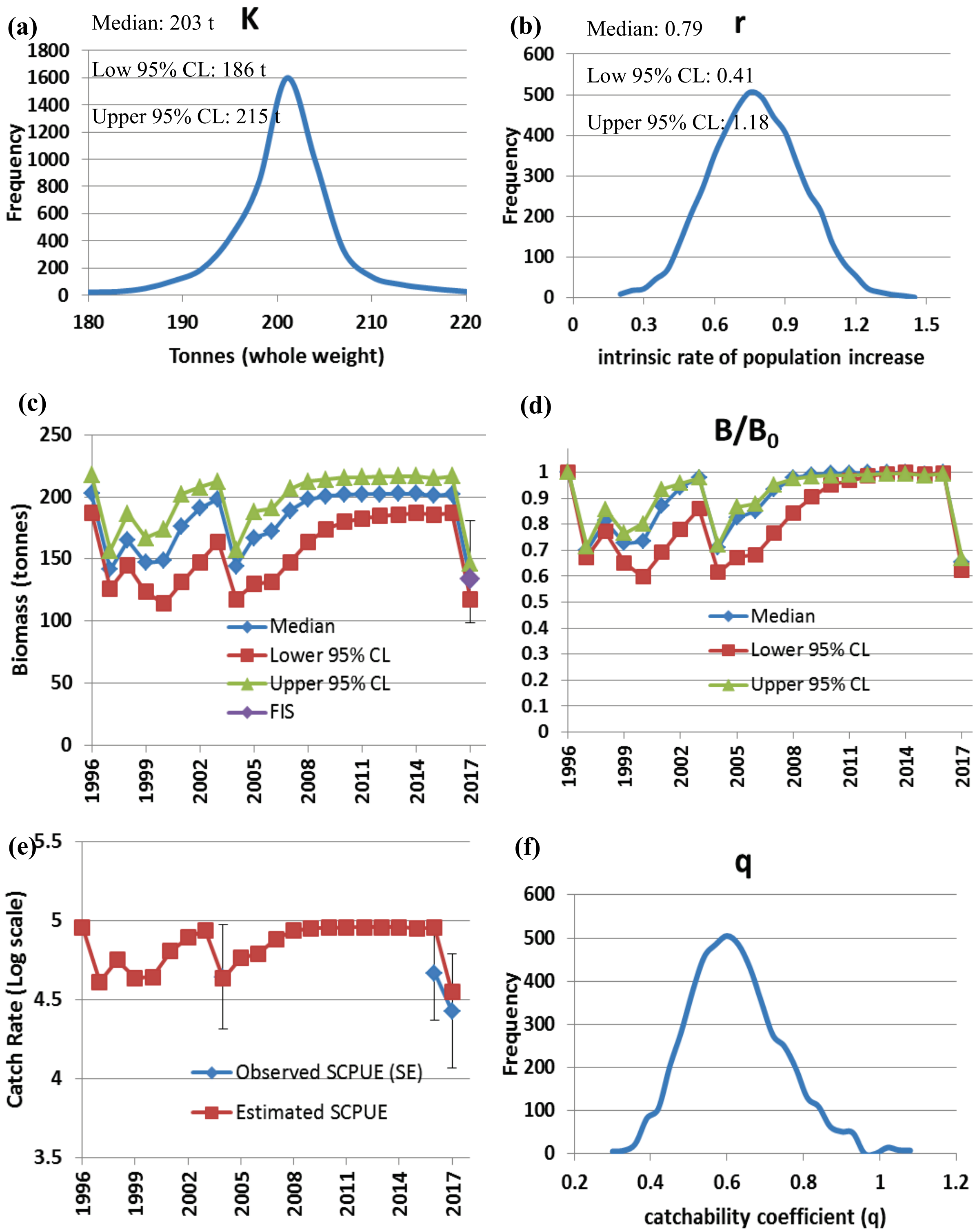

Figure 9.21. **Scenario 1 (*Holothuria scabra*). Estimates of key model parameters and outputs for sandfish stocks in the Pilbara region. (a) Unfished Biomass (K or B_0), (b) Intrinsic rate of population increase (*r*), (c) Biomass over the history of the fishery (2007 to 2017) with FIS (Fishery Independent Survey) estimate in 2017, (d) Annual biomass as a proportion of the unfished level (B/B_0), (e) estimated and observed SCPUE, (f) catchability coefficient (*q*). Outputs from *n* = 5000 model runs.**

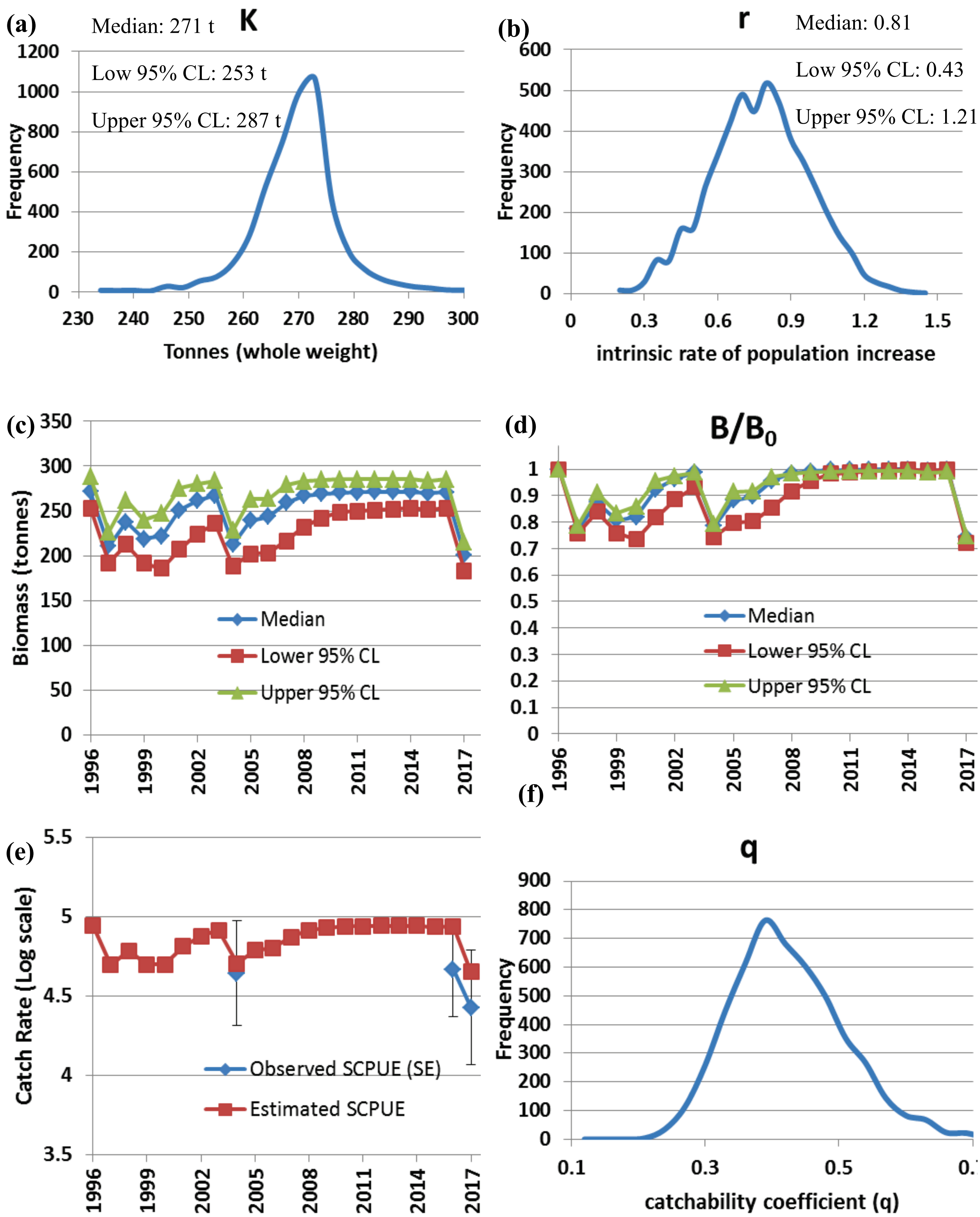

Figure 9.22. Scenario 2 (*Holothuria scabra*). Estimates of key model parameters and outputs for sandfish stocks in the Pilbara region. (a) Unfished Biomass (K or B_0), (b) Intrinsic rate of population increase (*r*), (c) Biomass over the history of the fishery (2007 to 2017), (d) Annual biomass as a proportion of the unfished level (B/B_0), (e) estimated and observed SCPUE, (f) catchability coefficient (*q*). Outputs from *n* = 5000 model runs.

Table 9.7. Input data and estimated parameters for the redfish (*Actinopyga echinites*) biomass dynamics model

Parameter/ Data	Description	Values/Estimation
K	Carrying Capacity/ Virgin Biomass	Estimated in model
r	Intrinsic rate of population increase	From equation $r = 2M$. M assumed to be normally distributed, with a mean of 0.4 and SD of 0.1.
q	Catchability coefficient	Estimated in model
$\hat{U}_t$	Estimated catch rate	Estimated in model
U_t	Observed catch rate	Output from fishery dependent CPUE analysis (see section 9.3.4).
C_t	Catch (tonnes) in year t	Catch records from fishery
B_t	Biomass (tonnes) in year t	Estimated in model
$\hat{B}_{2015}$	Biomass (tonnes) in 2015	Estimated in model
μ	Mean of the lognormal distribution for the observed biomass in 2015	Output from fishery independent population surveys (see Figure 9.20)
σ	Standard deviation of the lognormal distribution for the observed biomass in 2015	Output from fishery independent population surveys (see Figure 9.20)

9.3.9.6 Results and Diagnostics – Redfish (Pilbara)

Model outputs are summarised in Figure 9.23. Unfished biomass in 2006 was estimated at 2053 t, with a range from 1900 to 2200 t (Figure 9.23a). Biomass was reduced between 2007 and 2010 by approximately 20%. Total catch during this period was 587 tonnes. Biomass recovered to near virgin levels between 2010 and 2016, during which time only 62 tonnes was removed. The model estimated that it was highly unlikely that biomass was reduced below 0.8K at any time during the 10 year history of the fishery (Figure 9.23d). Minimal signal was found in the catch rates, with SCPUE in 2016 and 2017 being very similar to catch rates at the inception of the fishery (Figure 9.23e). MSY was estimated at a median of 415 tonnes (Figure 9.23f).

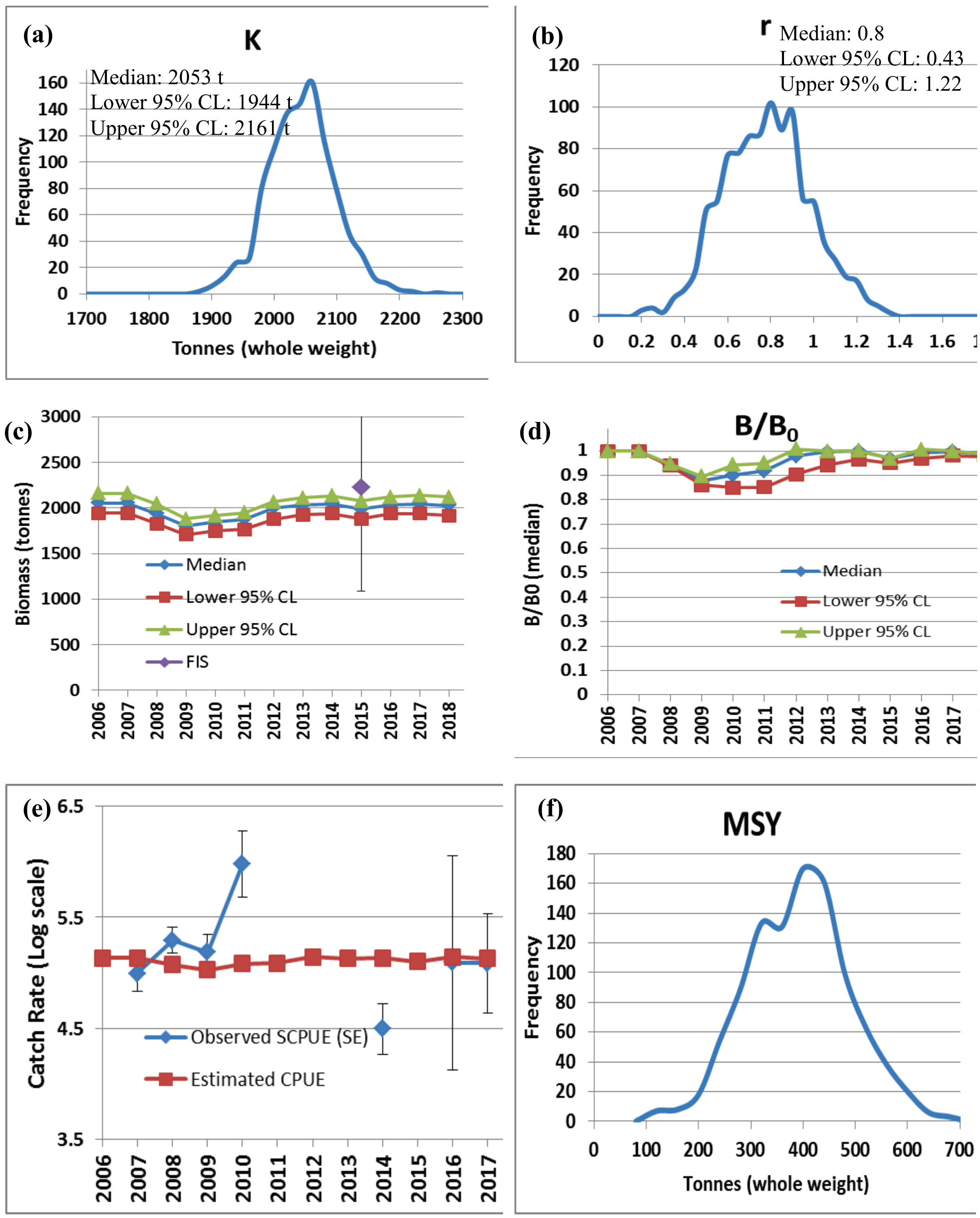

Figure 9.23. ***Actinopyga echinities*****. Estimates of key model parameters and outputs for the redfish stocks in the Pilbara region (Barrow and Montebello Islands). (a) Unfished Biomass (K or B_0), (b) Intrinsic rate of population increase (*r*), (c) Biomass over the history of the fishery (2007 to 2016), with FIS estimate in 2015, (d) Annual biomass as a proportion of the unfished level (B/B_0), (e) estimated and observed SCPUE, (f) maximum sustainable yield (MSY). Outputs from *n* = 1000 model runs.**

9.3.9.7 Accounting for Uncertainty

Resampling approaches were employed to account for uncertainty in key data/parameter inputs associated with generating biomass estimates. These data include:

Natural Mortality (M) and intrinsic rate of population increase (r): M was assumed to be normally distributed with a mean of 0.4 and standard deviation of 0.1. This figure has been previously used to model sea cucumber population dynamics (Skewes et al. 2014). Parametric resampling was employed to generate 1000 values for M, which in turn were used to estimate r using the formula $r = 2M$ (Zhou et al. 2016).

Observed catch rate (U_t): Parametric resampling was used to generate 1000 random values for each observed annual catch rate, given the estimated mean and standard errors for each year (for the estimates in log space). The model was fitted to each of the 1000 random values for r, and mean annual catch rate, to produce estimates of uncertainty for each estimated parameter and annual biomass value.

Observed Biomass in 2015 or 2017 (B_t): Parametric resampling was used to generate 1000 random values for the sandfish (2017) and redfish (2015) fishery independent survey biomass estimates. The uncertainty associated with the survey biomass estimated was incorporated into the model likelihood function. The nominal and log space estimated means and standard error are found in Figure 9.18 for sandfish and Figure 9.20 for redfish. In the case of sandfish, an additional source of uncertainty was the proportion of total stock enumerated by the fishery independent surveys. This uncertainty was modelled using two scenarios with different assumptions about the ratio of current known area to historically fished areas of stock (section 9.3.9.3).

9.3.9.8 Conclusion

Sandfish (Pilbara)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.6 K (unfished biomass) at any time during the 20 year history of the fishery. It must be noted that the model is based on limited data, and had to assume a distribution for r (as there was insufficient data to estimate this). There is thus some uncertainty, but the FIS biomass estimate helps reduce this.
Redfish (Pilbara)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.8 K (carrying capacity) at any time during the 10 year history of the fishery. It must be noted that the model is based on limited data, and had to assume a distribution for r (as there was insufficient data to estimate this). There is thus some uncertainty, but the FIS biomass estimate helps reduce this.

9.4 Stock Status Summary

Presented below is a summary of the available lines of evidence considered in the overall weight of evidence assessment of the indicator species' stocks for the WA Sea Cucumber Resource, followed by the management advice and recommendations for future monitoring of these species.

9.4.1 Sandfish (Kimberley)

9.4.1.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence / Status)
Catch (Section 9.3.2)	Catch and effort in this fishery has followed a typical fishery developmental path, with initial large catch and effort and reductions thereafter, instigated largely by conditions from assessments (e.g. under the EPBC Act), which required the development of fine-scale catch and effort records, and changes in industry practices, such as use of smaller boats (i.e. a reduction in holding capacity), smaller crews, shorter trips and rotational fishing strategies. There is no indication within the catch data of unacceptable stock depletion.
Catch distribution (Section 9.3.3)	The spatial distribution of catch has remained largely consistent over the history of the Kimberley sandfish fishery. The fishery is widespread, with catch coming from a few high productivity areas, and a variable number of lower productivity areas. Catch distribution is also managed by rotational harvest strategies. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Catch rates (Section 9.3.4)	The SCPUE in the Kimberley sandfish fishery is currently oscillating up and down, with no obvious trend. In 2017, the SCPUE was just above the target reference level. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery
Trends in size structure (Section 9.3.5)	Average weight of sandfish harvested in the Kimberleyin the period 2004 to 2016 was > 3 times than the estimated size-at-maturity and stable over time. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.
Vulnerability (PSA) (Section 9.3.6)	Sandfish are assumed to have a relatively short life span (maximum age around 10-14 years), and mature at 2 years of age. With a productivity score of 1.33 and susceptibility score of 1.88, the overall derived PSA score is 2.3 (MSC score > 80). This level of vulnerability indicates there is a relatively low chance of overfishing occurring at current levels of effort. However the significant risk of sea cucumber stocks to localised depletion cannot be discounted, despite this low vulnerability score.

Kimberley sandfish risk matrix					
Consequence (stock depletion) Level	Likelihood				
	L1 Remote (<5%)	L2 Unlikely (5-<20%)	L3 Possible (20-<50%)	L4 Likely (≥50%)	**Risk Score**
C1 Minor			X		3
C2 Moderate			MEDIUM		6
C3 High		X			6
C4 Major	NA				-

C1 (Minor Depletion): **Possible L3** – The primary performance indicator for this stock (SCPUE) was above the target reference level in 2017, however, the lower 60% confidence limit was between the target and threshold levels. Based on the lines of evidence, it is possible that the spawning biomass of sandfish in the Kimberley is greater than Target levels (i.e. > 40% of unfished levels).

C2 (Moderate Depletion): **Possible L3 –** Catches and catch rates have been fluctuating since 2001, with the lower 60% confidence limit around the SCPUE currently between the target and threshold levels. Average size fished is significantly higher than size-at-maturity and is currently increasing. This suggests fishing mortality is considerably less than natural mortality. Based on the lines of evidence, it is possible that the fishery is operating at maximum acceptable level of depletion, but not likely, i.e. spawning biomass < Target level but > Threshold level (B_{MSY}).

C3 (High Depletion): **Unlikely L2** – High average size fished, low catches, and wide distribution of catches (number of Grids of 5 x 5 nm targeted > 50) mean that it is unlikely that the level of depletion is unacceptable but still not affecting recruitment levels of stock.

C4 (Major Depletion): **NA** – Not plausible based on current evidence.

9.4.1.2 Current Risk Status

Based on the information and analyses available, the current risk level for Kimberley sandfish was estimated to be MEDIUM (C2 × L3). The MEDIUM risk (see Appendix 2) is consistent with previous assessments of the fishery. Therefore the overall Weight of Evidence assessment indicates the status of the Kimberley sandfish stock is adequate and that current management settings are maintaining risk at acceptable (medium) levels.

9.4.1.3 Future Monitoring

Information on size-at-maturity for the Kimberley sandfish would be desirable from the point of view of understanding more of the biology. However, the plasticity of morphological metrics in sea cucumbers reduces the efficacy of minimum legal lengths in protecting the breeding stock. More viable strategies will be those that maintain low levels of catch and effort, such as harvest strategies based on fishery-independent estimates of biomass.

9.4.2 Sandfish (Pilbara)

9.4.2.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence / Status)
Catch (Section 9.3.2)	Catch and effort in this fishery has followed a similar pattern to the Kimberley stock, although effort has been more intermittent, with minimal effort on sandfish over the past ten years. Much of the area remains only lightly exploited and the discovery of previously unfished high-density assemblages in 2016 suggest there are expanses of areas unfished each year due to relatively low levels of effort. There is no indication within the catch data of unacceptable stock depletion.
Catch distribution (Section 9.3.3)	Catch and effort in this fishery has followed a similar pattern to the Kimberley stock, although effort has been more intermittent, with minimal effort on sandfish over the past ten years. Much of the area remains only lightly exploited and the rediscovery of an area that has not been fished since 2003 suggest there are expanses of areas unfished each year due to relatively low levels of effort. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Catch rates (Section 9.3.4)	The SCPUE in the Pilbara sandfish fishery is currently high with only a small reduction seen in 2017. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery.
Trends in size structure (Section 9.3.5)	Average weight of sandfish harvested in the Pilbara has been increasing since 2004 and is > 3 times than the estimated size-at-maturity. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.
Vulnerability (PSA) (Section 9.3.6)	Sandfish are assumed to have a relatively short life span (maximum age around 10-14 years), and mature at 2 years of age. With a productivity score of 1.33 and susceptibility score of 1.88, the overall derived PSA score is 2.3 (MSC score > 80). This level of vulnerability indicates there is a relatively low chance of overfishing occurring at current levels of effort. However the significant risk of sea cucumber stocks to localised depletion cannot be discounted, despite this low vulnerability score.
Population biomass survey (Section 9.3.8)	The median biomass estimate for sandfish in 2017 was 134 t (95% CL range: 98 to 181 t). Highest density population is in Karratha Bay at 94 t per km^2.
Biomass dynamics model (Section 9.3.9)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.6 K (unfished biomass) at any time during the 20 year history of the fishery. It must be noted that the model is based on limited data, and had to assume a distribution for r (as there was insufficient data to estimate this). There is thus some uncertainty, but the FIS biomass estimate helps reduce this.

Pilbara sandfish risk matrix					
Consequence (stock depletion) Level	Likelihood				
	L1 Remote (<5%)	L2 Unlikely (5-<20%)	L3 Possible (20-<50%)	L4 Likely (≥50%)	**Risk Score**
C1 Minor				LOW	4
C2 Moderate		X			4
C3 High	X				3
C4 Major	NA				-

C1 (Minor Depletion): **Likely L4** – After more than a decade of low catches taken from the stock, the very high catch rates observed in 2016 and 2017, and with 2017 biomass estimates (and 60% CLs) being well above the Target level (i.e. > 40% virgin), it is likely that the Pilbara sandfish stock has only experienced minor depletion to date.

C2 (Moderate Depletion): **Unlikely L2 –** As biomass estimates (and 60% CLs) are well above the Target level, it is unlikely that the fishery is operating at maximum acceptable level of depletion, i.e. spawning biomass < Target level but > Threshold level (B_{MSY}).

C3 (High Depletion): **Remote L1** – High average size fished and very high catch rates mean that it is unlikely that the level of depletion is unacceptable but still not affecting recruitment levels of stock.

C4 (Major Depletion): **NA** – Not plausible based on current evidence.

9.4.2.2 Current Risk Status

Based on the information and analyses available, the current risk level for Pilbara sandfish was estimated to be LOW (C1 × L4). Therefore the overall Weight of Evidence assessment indicates the status of the Pilbara sandfish stock is adequate and that current management settings are maintaining risk at low levels.

9.4.2.3 Future Monitoring

Information on size-at-maturity for the Pilbara sandfish would be desirable from the point of view of understanding more of the biology. However, the plasticity of morphological metrics in sea cucumbers reduces the efficacy of minimum legal lengths in protecting the breeding stock. More viable strategies will be those that maintain low levels of catch and effort, such as catch-based harvest strategies based on fishery-independent estimates of biomass.

9.4.3 Redfish (Pilbara)

9.4.3.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence / Status)
Catch (Section 9.3.2)	Catches from this stock were initially large (587 t in first 4 years), however, minimal catch in the past 6 years (63 t). Stock is exploited on a rotational basis by commercial contractual agreements within Industry. There is no indication within the catch data of unacceptable stock depletion.
Catch distribution (Section 9.3.3)	The fishery is primarily based on the discovery of an unexploited stock in 2007 at Montebello Islands. Effort has been re-focused on the same spatial areas, although there is considerable fine-scale variation in the fishing areas. Stocks have been targeted 5 times in the 10 year history of the fishery, but only once since 2010. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Catch rates (Section 9.3.4)	Catch rates in the Pilbara redfish fishery have oscillated over time, with no clear overall trend upwards or downwards. Despite the low catch rates observed in 2014, the 2016 and 2017 catch rates were similar to those at the beginning of the fishery in 2007, when the stock was unexploited. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery.
Trends in size structure (Section 9.3.5)	Average weight of redfish harvested in the WASCF in the period 2007 to 2016 was > 3 times greater than the estimated size-at-maturity. This provides protection of the spawning stock, and fishing mortality is likely to be low. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.
Vulnerability (PSA) (Section 9.3.6)	Redfish assumed to have a relatively short life span (maximum age around 12 years), and mature at 2 years of age. With a productivity score of 1.5 and susceptibility score of 1.88, the overall derived PSA score is 2.4 (MSC score > 80). This level of vulnerability indicates there is a relatively low chance of overfishing occurring at current levels of effort. However the significant risk of sea cucumber stocks to localised depletion cannot be discounted, despite this low vulnerability score.
Population biomass survey (Section 9.3.8)	The median biomass estimate for redfish in 2015 was 2200 t (95% CL range: 1081 to 7400 t). Population density varied between 24 and 48 t per km^2
Biomass dynamics model (Section 9.3.9)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.8 K (carrying capacity) at any time during the 10 year history of the fishery. It must be noted that the model is based on limited data, and had to assume a distribution for r (as there was insufficient data to estimate this). There is thus some uncertainty, but the FIS biomass estimate helps reduce this.

Pilbara redfish risk matrix					
Consequence (stock depletion) Level	Likelihood				
	L1 Remote (<5%)	L2 Unlikely (5-<20%)	L3 Possible (20-<50%)	L4 Likely (≥50%)	**Risk Score**
C1 Minor				LOW	4
C2 Moderate		X			4
C3 High	X				3
C4 Major	NA				-

C1 (Minor Depletion): **Likely L4** – Based on the lines of evidence, with biomass estimates (and 60% CLs) being well above the Target level (i.e. > 40% unfished levels), it is highly likely that the Pilbara redfish stock has only experienced minor depletion to date.

C2 (Moderate Depletion): **Unlikely L2 –** Catches and catch rates increased during the first four years of exploitation, when most of the catch was taken. Average size fished is significantly higher than size-at-maturity. As biomass estimates (and 60% CLs) are well above the Target level, it is unlikely that the fishery is operating at maximum acceptable level of depletion, i.e. spawning biomass < Target level but > Threshold level (B_{MSY}).

C3 (High Depletion): **Remote L1** – High average size fished, low catches, relatively high biomass, and considerable rest periods imposed a by a rotational fishing strategy mean that there is only a remote likelihood that the level of depletion is unacceptable and is affecting recruitment levels of stock.

C4 (Major Depletion): **NA** – Not plausible based on current evidence.

9.4.3.2 Current Risk Status

Based on the information and analyses available, the current risk level for Pilbara redfish was estimated to be LOW (C1 × L4). Therefore the overall Weight of Evidence assessment indicates the status of the Pilbara redfish stock is adequate and that current management settings are maintaining risk at low levels.

9.4.3.3 Future Monitoring

Information on size-at-maturity for the Pilbara redfish would be desirable from the point of view of understanding more of the biology. However, the plasticity of morphological metrics in sea cucumbers reduces the efficacy of minimum legal lengths in protecting the breeding stock.

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Appendix 1

Justification for Harvest Strategy Reference Levels

The harvest strategy for the sea cucumber resource has been based around the behaviour of various metrics during a particular period of the fishery, defined here as the reference period. This can be a range of years, or a single year, depending on the nature of the indicator. Not all performance indicators require a reference period (see Table A1.1).

Various fishery-dependent and fishery-independent information and monitoring data were used to establish performance indicators and reference levels for the assessment of the sea cucumber resource. For a detailed description of the overall harvest strategy, see Department of Primary Industries and Regional Development (2018).

Sandfish

The principal performance indicator for the Kimberley sandfish resource is a spawning biomass index based on standardised catch rates. The index accounts for spatial variability and changes in fishing efficiency over the history of the fishery (Table A1.1). Associated catch rate-based (target, threshold and limit) reference points have been set for the stock based on a relevant reference period (Table A1.1).

The principal performance indicator for the Pilbara sandfish resource is a spawning biomass estimate derived from a biomass dynamics model. The model incorporates catch data from the beginning of the fishery (1996 to 2017), catch rate data from the inception of the daily logbook program, and a fishery-independent survey biomass estimate undertaken in 2017. The performance indicator is compared annually against reference levels that been set using the estimate of unfished biomass (B_0) in 1996. Reference levels defined as: Target (40% B_0), threshold (30% B_0) and limit (20% B_0) (Table 1). These levels are intended to be consistent with current internationally accepted benchmarks (Mace 1994; Caddy and Mahon 1995; Gabriel and Mace 1999; Wise et al. 2007).

Redfish

The principal performance indicator for the Pilbara redfish resource is a spawning biomass estimate derived from a biomass dynamics model. The model incorporates catch data from the beginning of the fishery (2006 to 2017), catch rate data from the inception of the daily logbook programme, and a fishery independent survey biomass estimate undertaken in 2015. The performance indicator is compared annually against reference levels that been set using the estimate of unfished biomass (B_0) in 1996. Reference levels defined as: Target (40% B_0), threshold (30% B_0) and limit (20% B_0) (Table 1). These levels are intended to be consistent with current internationally accepted benchmarks (Mace 1994; Caddy and Mahon 1995; Gabriel and Mace 1999; Wise et al. 2007).

Table A1.1. Performance indicators (PIs) and, where applicable, reference periods used for setting reference levels for each PI in the Sea Cucumber Resource

Species (Area)	Performance indicator (PI)	Reference Period	Justification
Sandfish (Kimberley)	Catch rate	2004 – 2017	Includes all available years of data which the fine-scale catch and effort data has been available. Reference levels define on year of lowest cpue, which is 2015. This set as the threshold level
Sandfish (Pilbara)	Biomass	1996	Unfished biomass (B_0) estimated for 1996. Reference levels defined as: Target (40% B_0), threshold (30% B_0) and limit (20% B_0) in relation to this.
Redfish (Pilbara)	Biomass	2006	Unfished biomass (B_0) estimated for 2006. Reference levels defined as: Target (40% B_0), threshold (30% B_0) and limit (20% B_0) in relation to this

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Appendix 2

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 × Likelihood Risk Matrix		Likelihood			
		Remote (1)	Unlikely (2)	Possible (3)	Likely (4)
Consequence	Minor (1)	Negligible	Negligible	Low	Low
	Moderate (2)	Negligible	Low	Medium	Medium
	High (3)	Low	Medium	High	High
	Major (4)	Low	Medium	Severe	Severe

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

<u>References</u>

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Appendix 3

Productivity Susceptibility Analysis (PSA) Scoring Tables

Productivity attribute	**High productivity Low risk Score = 1**	**Medium productivity Medium risk Score = 2**	**Low productivity High risk Score = 3)**
Average maximum age	<10 years	10-25 years	>25 years
Average age at maturity	<5 years	5-15 years	>15 years
Average maximum size (not to be used when scoring invertebrates)	<1000 mm	1000-3000 mm	>3000 mm
Average size at maturity (not to be used when scoring invertebrates)	<400 mm	400-2000 mm	>2000 mm
Reproductive strategy	Broadcast spawner	Demersal egg layer	Live bearer
Fecundity	>20,000 eggs per year	100-20,000 eggs per year	<100 eggs per year
Trophic level	<2.75	2.75-3.25	>3.25
Density dependence (only to be used when scoring invertebrates)	Compensatory dynamics at low population size demonstrated or likely	No depensatory or compensatory dynamics demonstrated or likely	Depensatory dynamics at low population sizes (Allele effects) demonstrated or likely

Susceptibility attribute	**Low susceptibility Low risk Score = 1**	**Medium susceptibility Medium risk Score = 2**	**High susceptibility High risk Score = 3)**
Areal overlap (availability) i.e. overlap of fishing effort with stock distribution	<10% overlap	10-30% overlap	>30% overlap
Encounterability i.e. the position of the species / stock within the water column / habitat relative to the position of the fishing gear	Low encounterability / overlap with fishing gear	Medium overlap with fishing gear	High encounterability / overlap with fishing gear (Default score for target species in a fishery)
Selectivity of gear type i.e. potential of gear to retain species	a) Individual < size at maturity are rarely caught	a) Individual < size at maturity are regularly caught	a) Individual < size at maturity are frequently caught
	b) Individual < size can escape or avoid gear	b) Individual < half the size can escape or avoid gear	b) Individual < half the size are retained by gear
Post-capture mortality i.e. the chance that, if captures, a species would be released and that it would be in a condition permitting subsequent survival	Evidence of majority released post-capture and survival	Evidence of some released post-capture and survival	Retained species or majority dead when released

Appendix 4

Western Australian Sea cucumber Daily Catch and Effort Log Book
HOW TO FILL IN YOUR DAILY CATCH AND EFFORT LOG SHEETS

The form is divided into two main sections. The top is for recording information from individual effort units (e.g. diving, wading or snorkeling) within a day's fishing for Sea cucumber, the bottom is for the information at the end of a day's catch. All relevant sections must be completed. Species codes for Sea cucumber are on the flip side of every log book page. If any aspects of the forms are unclear please contact the catch and effort returns officer (Dave Murphy 08 9203 0111).

Administration details Record all details on a minimum of one record per month. Record date and LFB for every days fishing.

Vessel name The name of the vessel from which you fished. If the name of your vessel changed during the month please make a comment on the bottom of the form.

Date The day to which the catch return relates, e.g. 12/10/2006.

Anchorage Location where vessel was on anchor for the previous night(s).

No. days fished Only record when filling out the unload record (see below).

Fishing Boat Licence (FBL) this 4 digit number is found on the licence issued by the Department of Fisheries if you operate a Licenced Fishing Boat. Example: FBL1234 please enter 1234. A return is required even if you do not have a vessel attached to your FBL - in this case the Boat Rego and Boat Name field is left blank.

Boat registration Also referred to as Licenced Fishing Boat or LFB. Enter the registration number of your vessel. If your vessel has licenced dinghies, as part of its fishing unit, **and** these dinghies always fish alongside the main vessel, please record all information on one catch return for the main vessel. Example: A96, A96A, A96B record all catch as A96 on one return.

Sea cucumber (MFL) When the Sea cucumber fishery becomes an official managed fishery, each operator will be required to indicate their Managed Fishery Licence (MFL). Presently this field is inactive.

Crew numbers Record total number involved in fishing for Sea cucumber, including the skipper.

Unload Port or Anchorage Location where vessel unloads catch.

Unload Record Only fill out this information on the day in which the vessel is unloaded. In days fished record the total number of days fished, and the total kg, which is the total catch being unloaded.

Catch and Effort For each unit of effort (up to 6 maximum in one day), circle whether it is a Dive (D), Wade (W), or Snorkel (S).

GPS Latitude Enter the start GPS latitude of each dive/wade/ snorkel. Decimal points for minutes are optional, but information down to individual minutes is required.

GPS Longitude Enter the start GPS longitude of each dive/wade/ snorkel. Decimal points for minutes are optional, but information down to individual minutes is required.

Start time Enter the start time of each dive/wade/ snorkel (e.g. 0800, 1450).

Number of Ds/Ws/Sn Enter the number of people that are diving, wading, or snorkeling for Sea cucumber.

Depth (m) Enter the depth (in metres) of each dive.

Duration of D/W/S Enter the time spent fishing for Sea cucumber (in minutes).

Distance waded Enter the average distance waded by individual harvesters. E.g. If 2 people are wading, the first wades approx 500 m, and the other 200 m, the average distance waded is 350 m.

Catch Select the main species caught (S – Sandfish, WT – White teatfish, BT – Black teatfish, R – Deepwater Redfish) and record the approximate number caught.

Other species catch Select the other species (of Sea cucumber) caught and record the approximate Number caught for each species after each dive/wade/snorkel. Species codes are found on the log sheet.

Daily weight estimates (kg) Enter the measured weight of the day's catch (after processing) for each of the main species.

Daily weight estimates (other species) Enter the measured weight (kg) of the day's catch (after processing) for each of the other species caught. If more than 3 different species have been caught, enter the information in the Comments section.

Processing Record processing details for boiling time (in minutes) and circle the processing method, e.g. GB for gutted and boiled, WW for whole wet weight. Specify if processing method differs from common types.

Protected species interactions The implementation of the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)* means that fishers need to record interactions with all listed marine and migratory species and threatened species in Commonwealth waters (whales, dolphins, dugongs, sea turtles, seals, pipefishes, seasnakes and many species of seabird – see website http://www.deh.gov.au). Consequently, we have included a special section to record interactions with protected species. For example, if you ran over or bumped a sea turtle with a dory, circle Yes to the first question (i.e. did you have an interaction?), and if it swam away alive, circle Yes to the second question (i.e. was the animal released?). An officer from the Department of Fisheries will contact you if any further details are required regarding the interaction.

Western Australian Sea cucumber Daily Catch and Effort Log Sheet

Vessel Name	Daze Off	Fishing Boat License (FBL)	5423	UNLOAD RECORD (record only when unloading vessel)		
Date (dd/mm/yyyy)	12 / 10 / 2007	Boat Registration (LFB)	F101	Unload Port	Darwin	Weight (kg) 4010.5
Anchorage	Admiralty Gulf	Sea Cucumber (MFL) (if known)		Master Name	James Brown	
No. days fished		Crew numbers (inc. master)	5	Crew names (specify)	John Strickland, Matt Dodge, Bill Letter, Rod Budge	

OFFICE USE

EFFORT	1	2	3	4	5	6
Dive/Wade/Snorkel (please circle)	(D) W S	D (W) S	(D) W S	D W S	D W S	D W S
GPS Latitude (eg 13°47')	13° 47. 86	13° 48. 00	13° 47. 9			
Start Longitude (eg 127°30')	128° 30. 20	128° 29. 5	128° 30. 8			
Start Time (eg 1350)	0800	1100	1400			
Number of Divers/Waders	3	3	3			
Depth (m)	5	—	7			
Duration of D/W/S (mins)	150	90	180			
Distance waded (m)		900				

CATCH																								
Main species (circle type)	(S)	WT	BT	R	S	WT	BT	(R)	(S)	WT	(BT)	R	S	WT	BT	R	S	WT	BT	R	S	WT	BT	R
Number caught (approx.)	600							200	200		10													
Other species (write down)									CU															
Number caught (approx.)									100															

DAILY WEIGHT ESTIMATES	S	WT	BT	R	OTHER SPECIES*
Estimated weight (kg)	350		10		30

PROCESSING	
Boiling time (mins)	20
Condition: (please circle)	(GB) WW Other (specify) Curryfish

PROTECTED SPECIES INTERACTION (please circle)		
Have you had an interaction with a protected species?	(YES)	NO
If yes, was the animal released alive?	(YES)	NO

COMMENTS (Include general and species interaction)

Dory 4 (Sticko) struck a green turtle but it swam away okay.
Good fishing day.
All Blackteat were salted only (no boiling).

I certify that the information on this form is correct. (Master, authorisation holder or agent)

Signature: James Brown

Date Signed: 12/10/2007

* If multiple other species, separate daily wts.

Note: TEAR OUT and RETURN the ORIGINAL and keep the DUPLICATE in the book for your personal use. Please submit returns to Fisheries Research, PO Box 20, North Beach, WA 6920.