Expert advice for the assessment of Australian teatfish (*Holothuria whitmaei* and *H. fuscogilva*) Fisheries: Coral Sea Fishery

A report for Australia's Scientific Authority for the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES)

Timothy Skewes
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Important disclaimer

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Acronyms

AFMA	Australian Fisheries Management Authority
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
B_{LIM}	The biomass level beyond which the risk to the stock is regarded as unacceptably high (often related to PRI).
B_{MEY}	Biomass which corresponds to maximum economic yield.
B_{TARG}	The desired status of stocks (often at about B_{MEY})
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CSF	Coral Sea Fishery
CSMP	Coral Sea Marine Park
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EEZ	Exclusive Economic Zone
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999, including any Act amending, repealing or replacing the Act.
GBR	Great Barrier Reef
HS	Harvest strategy
IUCN	International Union for the Conservation of Nature.
Landed Wt	Fishery catch and catch limits are reported as landed weight. In the CSF, landed weight is in gutted and salted product form.
LRP	Limit Reference Point – a reference point that equates to the population at B_{LIM}
MSC	Marine Stewardship Council
MSL	Minimum Size Limit
MSY	Maximum Sustainable Yield
NDF	CITES Non-detriment finding
NNR	National Nature Reserves
PRI	Point at recruitment impairment
QSCF	Queensland Sea Cucumber Fishery (East Coast)
RZS	Rotational Zone Strategy
RUSS	Reducing Uncertainty in Stock Status
SEC	Southern Equatorial Current
SICA	Scale Intensity Consequence Analysis
t	Tonnes
TEP	Threatened, endangered and protected species
TSBDMF	Torres Strait Beche-de-mer Fishery
WTO	Wildlife Trade Operation

1 Background

Sea cucumbers have been harvested for centuries to supply the Chinese market (Yang and Bai, 2015). After a virtual hiatus of over three decades following the second world war, global sea cucumber fisheries rapidly re-emerged from about 1980 in response to increasing demand from a resurgent China (Anderson et al., 2011; Eriksson et al., 2015; Fabinyi et al., 2017). This early expansion phase was often poorly regulated and many sea cucumber fisheries were overexploited (Purcell et al., 2013), especially in developing countries (Barclay et al., 2019) and for high value species (Purcell et al., 2014).

High demand, rapid and largely unregulated expansion and easy access has resulted in 16 species being listed as globally threatened (Vulnerable or Endangered; IUCN, 2023), many of them being the larger, valuable and highly targeted species (Purcell et al., 2014), including the (Pacific) Black teatfish (*Holothuria whitmaei*) which is listed by the IUCN as Endangered (Conand et al., 2013a); and White teatfish (*Holothuria fuscogilva*) which is listed as Vulnerable (Conand et al., 2013b). Subsequently, three species belonging to the subgenus *Holothuria (Microthele)*: White teatfish (*Holothuria (Microthele) fuscogilva*), (Indian Ocean) Black teatfish (*Holothuria (Microthele) nobilis*); and (Pacific) Black teatfish (*Holothuria (Microthele) whitmaei*) were listed on Appendix II of CITES in June 2019 (CITES, 2019).

With the listing of species in Appendix II of CITES, member countries, of which Australia is one, must carry out a non-detriment finding (NDF) for any listed species before it can be exported. This is based on the principle that: "An export permit shall only be granted when… a Scientific Authority of the State of export has advised ***that such export will not be detrimental to the survival of that species"*** (CITES, 1973: Article IV, paragraph 2a). Furthermore, the Scientific Authority must monitor and "limit" the export… "***in order to maintain that species throughout its range at a level consistent with its role in the ecosystems in which it occurs and well above the level at which that species might become eligible for inclusion in Appendix I***" (CITES, 1973: Article IV, paragraph 3).

Australia has several sea cucumber fisheries in State and Commonwealth waters across northern Australia, including the Coral Sea Fishery (CSF) that includes most of the offshore reefs off northeast Australia. This fishery mirrors sea cucumber fisheries globally in that it is primarily focussed on exporting dried sea cucumber product (beche-de-mer) to meet demand from China. It is small scale and multispecies in nature.

This report sets out to provide information that may be suitable for addressing the information requirements of an NDF for Black teatfish and White teatfish in the CSF. Most of the information was sourced from published scientific papers and reports, from fishery assessment and synthesis reports by the fishery management agencies, and from fishery commercial vessel logbook and buyer logbook data for the period 23/02/1998 to 13/03/2023 which was supplied by the Australian Fisheries Management Authority (AFMA). The data were used to characterise fishing for teatfish species in the CSF, and to calculate total annual harvests and catch rates. The data contained daily entries for each boat for harvest in kilograms and the geographic location within the sea cucumber fishery. For a more detailed description of vessel logbook and buyer returns data, see Appendix A.

1.1 The fishery

Fishing for sea cucumbers on the reefs of the Coral Sea likely began in the mid-1800s, as part of a broader western Pacific maritime trade, exporting a range of products directly to China and nearby ports (Mullins, 1992; 1995; Ganter, 1994), with this phase of the fishery lasting up until about the second world war (Uthicke, 2004) (for a more detailed description of all early Australian fisheries, see CITES National report).

The (modern) CSF is a 907,000 km^2 area of the Australian exclusive economic zone (EEZ) that extends from Cape York in the north to Sandy Cape, Queensland in the south; and is bounded on the east by the Australian EEZ (and abutting the EEZ boundaries of Paua New Guinea, Solomon Islands and New Caledonia) and on the west by the Queensland Sea Cucumber Fishery (East Coast) (QSCF) (AFMA, 2021a) (Figure 1,

Figure 2). The Torres Strait Beche-de-mer Fishery (TSBDMF) is 70 km to the west of its northern tip (Figure 2).

It includes most of the reefs and shoals that sit within Australia's jurisdiction of the Coral Sea (i.e. reefs east of the Great Barrier Reef), apart from Marion, Saumarez, Ashmore and Boot Reefs, which are part of the QSCF.

The CSF is managed by AFMA and has four sectors: Lobster and Trochus; Line and Trap; Aquarium; and Sea Cucumber. Entry to the CSF is limited to 12 fishing permits, and two of those permit holders are authorised to take sea cucumbers (AFMA, 2021a) (see Management section below).

The entire CSF occurs within the Coral Sea Marine Park (CSMP) (see section below).

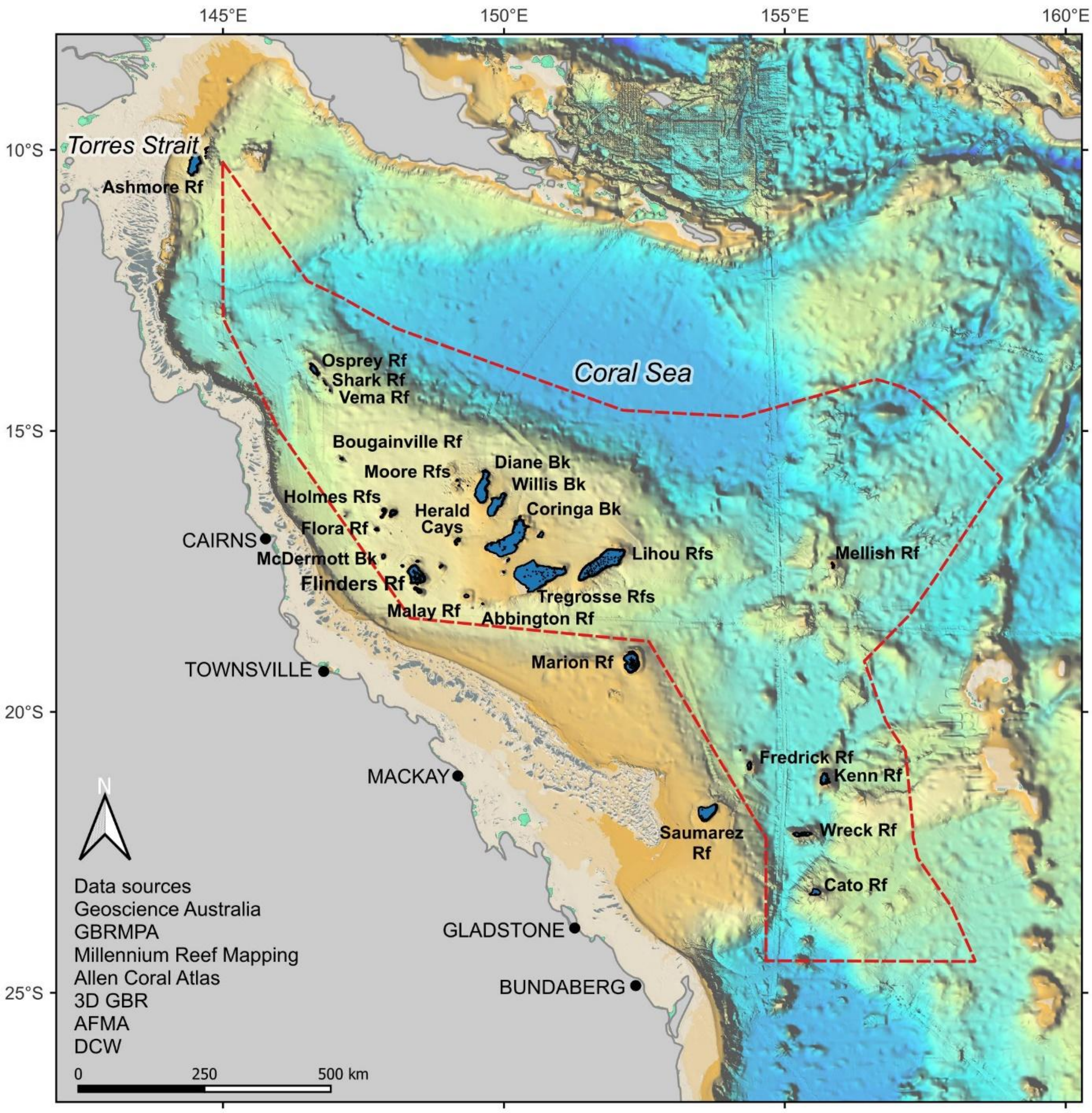


Figure 1. Area of the Coral Sea Fishery (red boundary).

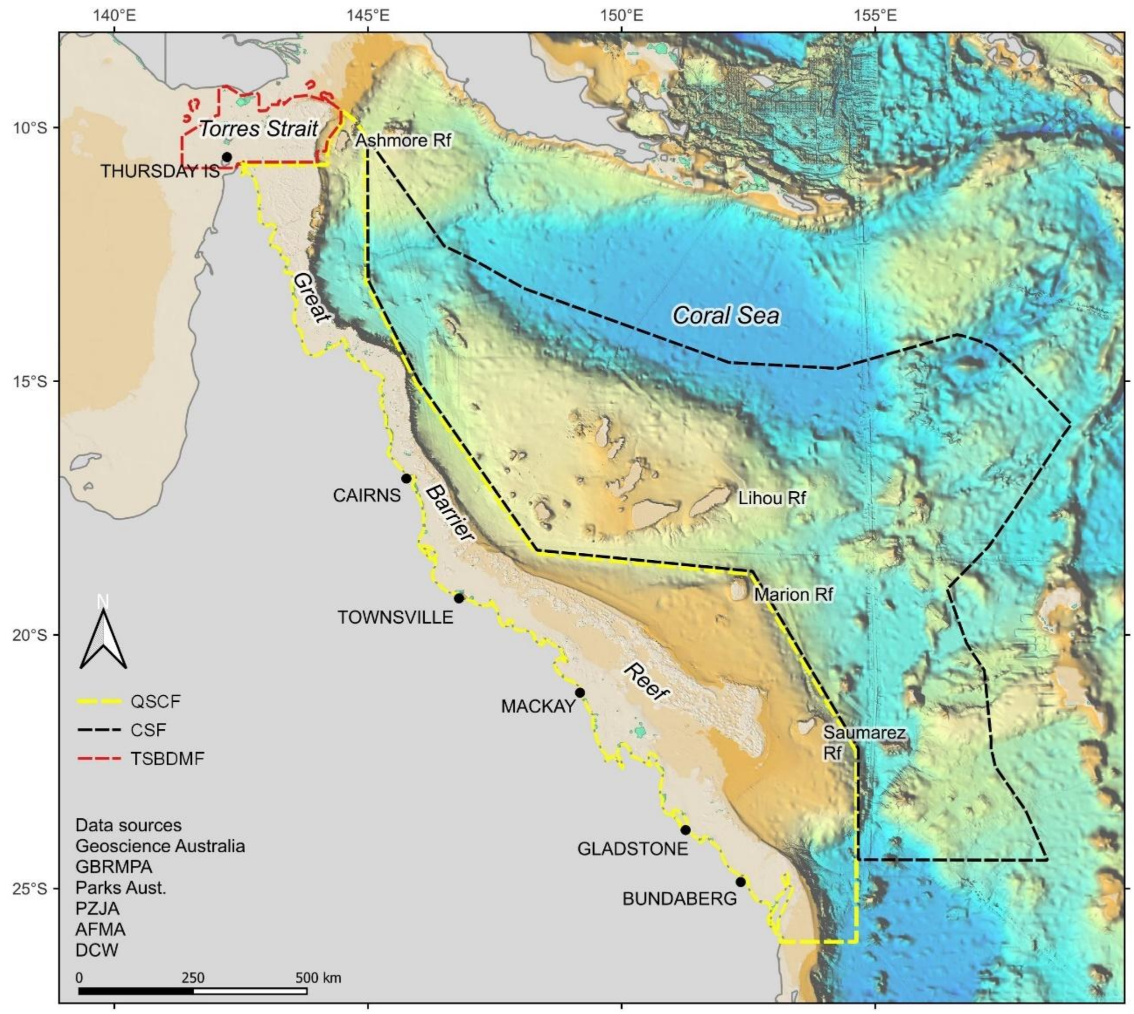


Figure 2. The three sea cucumber fisheries in north east Australia.

Currently, the fishery is fished by motherships with up to 4 (but usually 2) tender vessels carrying up to 6 (usually 2-4) divers, either free diving or using surface supply hookah equipment, on trips that usually last between 1 and 2 weeks (CSF vessel logbook data). Sea cucumbers are usually partially processed on board the motherships by gutting and salting or gutting, parboiling and freezing. Product is landed at Queensland regional ports and transhipped to mainland processing facilities, where they are processed into various products predominantly for export to Asian markets, with minimal supply to the domestic market (AFMA, 2020; 2021a).

1.1.1 Sea cucumber habitat mapping

A map of fishery habitats in the CSF relevant to sea cucumber distribution, based on: depth, slope, exposure to prevailing waves, and reef morphology (Woodhams et al., 2015; Purcell et al., 2023; Skewes and Persson, 2017; Murphy et al., 2021a) was formulated from three separate mapping products: Millennium Coral Reef Mapping Project (IMaRS-USF, IRD, 2005); Allen Coral Atlas (Allen Coral Atlas, 2022); and 3D GBR (Beaman, 2010) (for a full description of spatial analysis methods, see Appendix B).

The reef habitats defined for the CSF were:

1. Forereef (the ocean facing reef edge, <20 m deep, facing the predominant SE trade winds)
2. Backreef (the ocean facing reef edge, <20 m deep, facing the NW monsoon winds)
3. Inner slope (sloping reef edge, <20 m deep, facing an enclosed or partially enclosed lagoon)
4. Reef flat (emergent reef flat)
5. Sub-tidal reef flat (subtidal reef flat to approximately 20 m depth)
6. Pass (deep high flow areas between sub-reef units, 5-40 m deep)

7. Deep reef (20-70 m deep areas associated with reef complexes). Note: the deep reef habitat within the CSF area is not well mapped but was crossed checked with available nautical charts.
8. Lagoon pinnacles (small coral reef structures, <5 m deep, within enclosed deep lagoons)

There is approximately 1.28M ha of sea cucumber fishery habitat (including shallow reefs and deep reef associated habitat up to 70 m deep) on 31 reef features in the CSF area (Table 1, Figure 3, Appendix B). The three large reef systems, Coringa Bank, Lihou Reefs and Tregrosse Bank accounts for about 2/3 of all the shallow and deep reef combined habitat in the CSF (Figure 3, Appendix B).

Of that habitat area, 166,319 ha is shallow (< 20 m deep) reef habitat (Figure 3, Figure 4). This compares to 240,300 ha of shallow reef habitat in the TSBDMF, and 2.6M ha of shallow reef habitat in the QSCF (GBRMPA; Beaman et al., 2010; Skewes et al., 2014). Lihou reef alone had 23.6 % of all shallow reef habitat in the CSF (Figure 3, Figure 4).

The extensive area of deep reef (20-70 m) habitat in the CSF area, covering about 1.11M ha (Figure 3, Appendix B), compares roughly to 110,400 ha of “deep-reef” habitat in Torres Strait and 23.2M ha of “shelf” habitat for the QSCF (GBRMPA; Skewes et al., 2014). The three large banks, Tregrosse, Coringa, and Lihou, had over 70% of the deep reef habitat of the CSF (Figure 3).

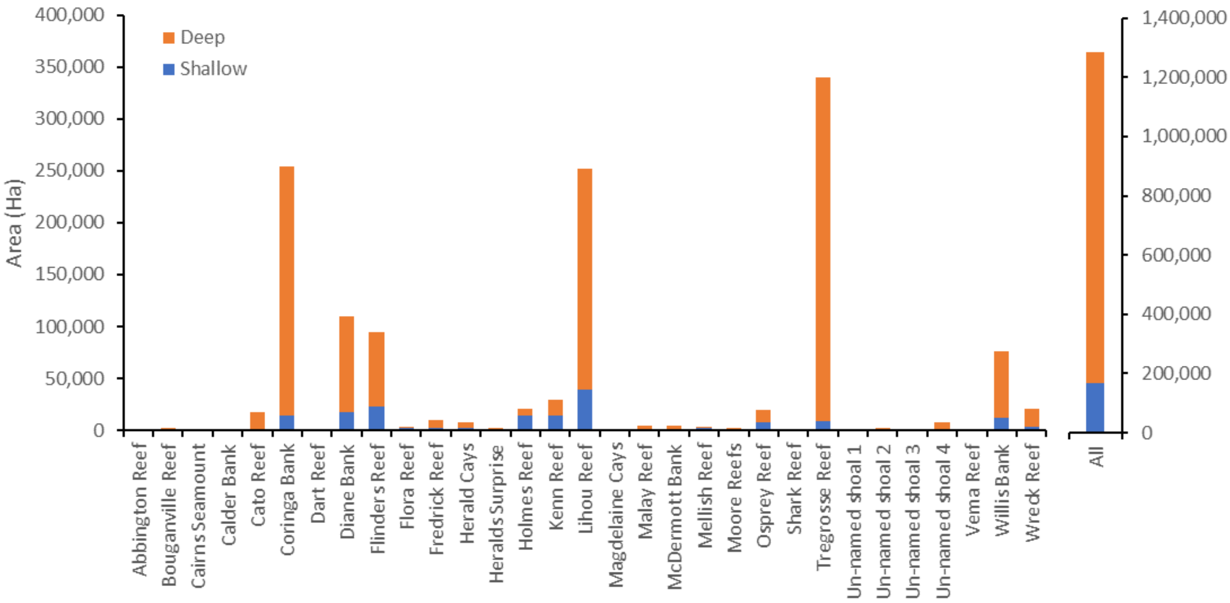


Figure 3. Reef features of the CSF and their shallow (<20 m) and deep reef (20-70 m) area.

Table 1. Area (km^2) for shallow (<20 m) and deep (20-60 m) reef associated habitat in the CSF area.

Habitat	Total area (km^2)	Closed to fishing (km^2)	Closed to fishing (%)
CSF area	989,836	238,400	24.1
Shallow habitats	1,663	739	44.4
Deep reef habitats	11,172	4,894	43.8
All reef habitats	12,835	5,633	43.9

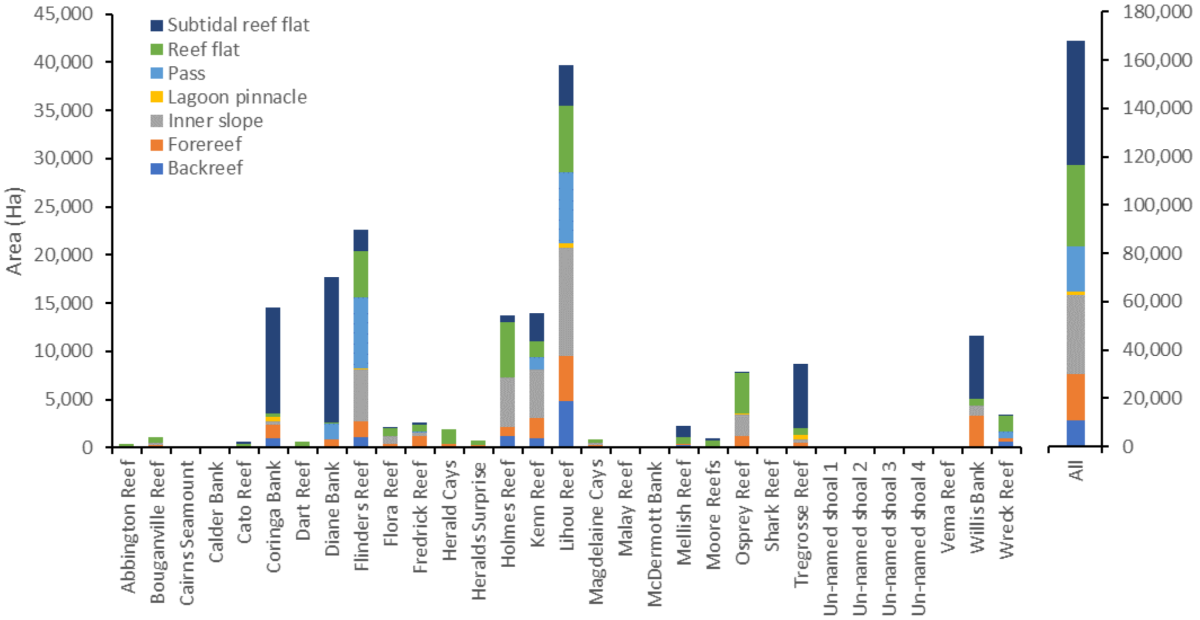


Figure 4. Reef features of the CSF and their shallow (<20 m) habitat areas.

1.1.2 Biophysical research

Of the 31 "reef" features identified in the CSF area shallower than 70 m (Appendix B, Figure 1, Figure 3), only about half have been subject to scientific surveys; though most of the larger and shallower ones have been the subject of some survey work (Ceccarelli et al., 2013; Hoey et al., 2021; 2023b), but very little of that in the deeper reef (20-70 m) habitats (Bongaerts et al., 2011; Galbraith et al., 2023).

These studies have shown that generally, coral cover and fish density is higher in the larger central reefs of the Queensland Plateau, with reef size, the degree of sheltered habitat available, and the isolation of each reef from other reef systems thought to be important drivers of the abundance and composition biota on the Coral Sea Reefs (Ceccarelli et al., 2013; Hoey et al., 2021; 2023b). The Coral Sea reefs are characterised as having a relatively low coral cover compared with coastal reef domains (e.g. GBR), with a general lack of sheltered habitat. Highly exposed reef crests are cemented with a ridge of crustose coralline algae, and wave-swept reef flats are dominated by low-lying algal turf (Ceccarelli et al., 2013).

Coral, fish and invertebrate populations show key differences from the Great Barrier Reef (Oxley et al., 2003; Hoey et al., 2021; 2023b), driven in part by the oligotrophic conditions in the Coral Sea dominated by picoplankton and microbial processes (Ceccarelli et al., 2013).

Reefs are subject to a high degree of exposure to tropical cyclones and coral bleaching events. Recovery of impacted reefs appears variable (Ceccarelli et al. 2008; Hoey et al., 2021; 2023b). Coral species that are naturally more resistant to bleaching dominated tracts of the recovering reefs. Recently discovered low-light (mesophotic) coral communities at depths of 30-150m on the Osprey Reef slope may provide larvae for the recovery of isolated reefs after major disturbance (Bongaerts et al. 2011). At Holmes and Flora Reef, deep reef habitat in 40–100 m depth were covered by extensive mesophotic coral ecosystems, which harboured diverse scleractinian coral communities.

1.2 Coral Sea Marine Park

The Coral Sea Marine Park (CSMP) fully encompasses the CSF area (Figure 5, Figure 7). All areas designated National Park Zone (IUCN II) within the CSMP prohibit fishing for sea cucumbers.

The Coringa-Herald and Lihou Reef National Nature Reserves that sit within the CSMP were originally proclaimed under the National Parks and Wildlife Conservation Act 1975 on 16 August 1982 and were closed to fishing (E.A., 2001). This amounted to 34% of shallow reefs (<20 m) and 42% of deep reef (20-70 m) habitat; overall 41% of fishery habitat, protected from fishing from before the start of the CSF sea cucumber sector fishery.

The CSMP was proclaimed under the EPBC Act on 14 December 2013 and renamed Coral Sea Marine Park on 9 October 2017. It covers 989,836 km² of the Coral Sea. The National Park Zone (IUCN II), which prohibits all commercial fishing, covers 238,400 km² (24%) of the Marine Park area (Coral Sea Marine Park Management Plan).

In 2018, Osprey and Mellish Reefs, and parts of Kenn (~50%) and Bougainville (~75%) Reefs were added as no fishing (National Park (IUCN II)) zones (Figure 5). Half of Marion Reef was also added but this is not in the area of the CSF (Figure 5, Figure 7).

As a result of the CSMP zoning, 44.4% of shallow reef (<20 m) and 43.8% of deep reef (20-70 m) are closed to fishing (National Park Zone (IUCN II)) (Table 1). This equates to a total of 43.9% of all potential sea cucumber habitat in the CSF area being closed to fishing.

Most of the "remote" or most isolated reefs in the CSF (e.g. Mellish, Osprey, Kenn (~50%) and Bougainville (~75%) Reefs) are protected as Marine Park Zones (Figure 5, Figure 7, Table 17).

All identified fishery habitat classes within the CSF area were well represented within the area closed to fishing (Table 17, Figure 6).

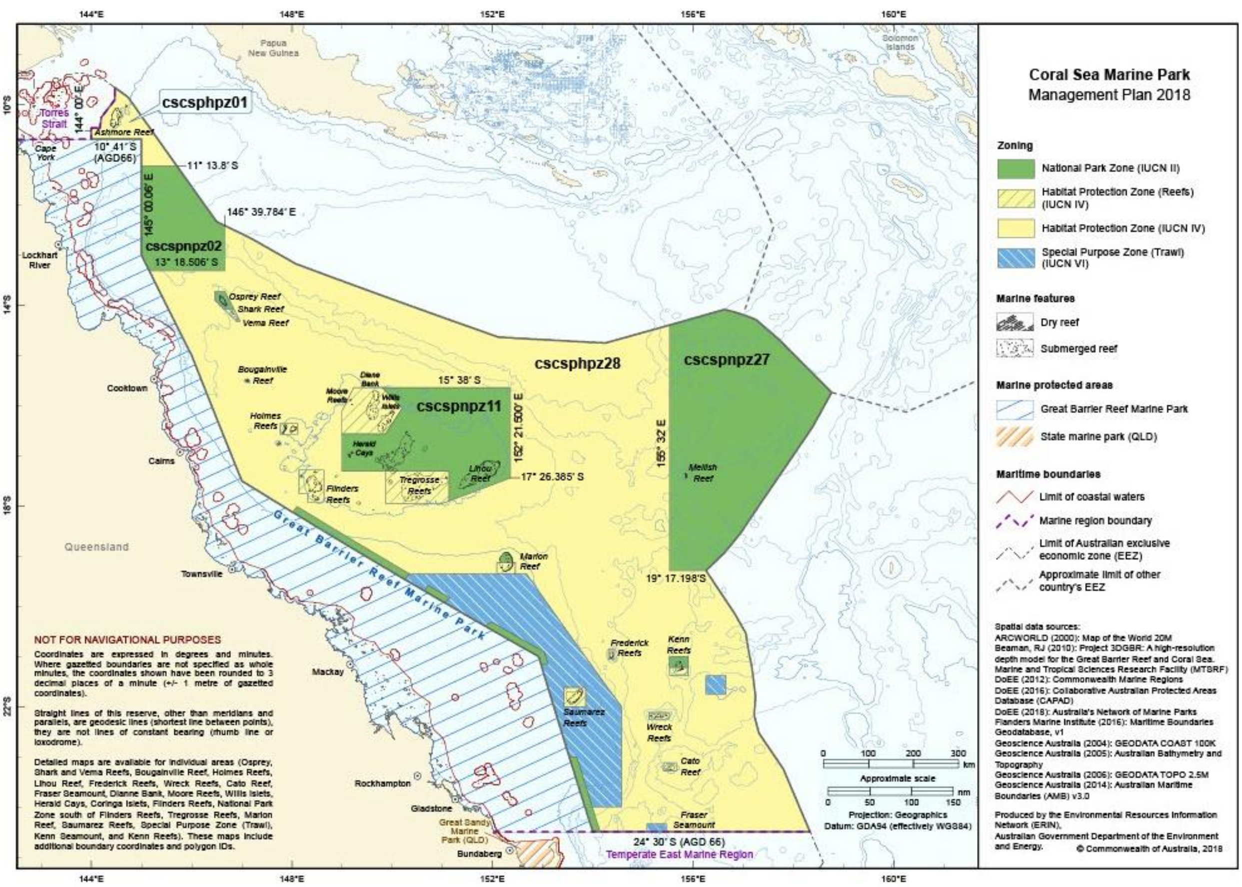


Figure 5. Coral Sea Marine Park management plan implemented in 2018. (Parks Australia: https://parksaustralia.gov.au/marine/parks/coral-sea/maps/)

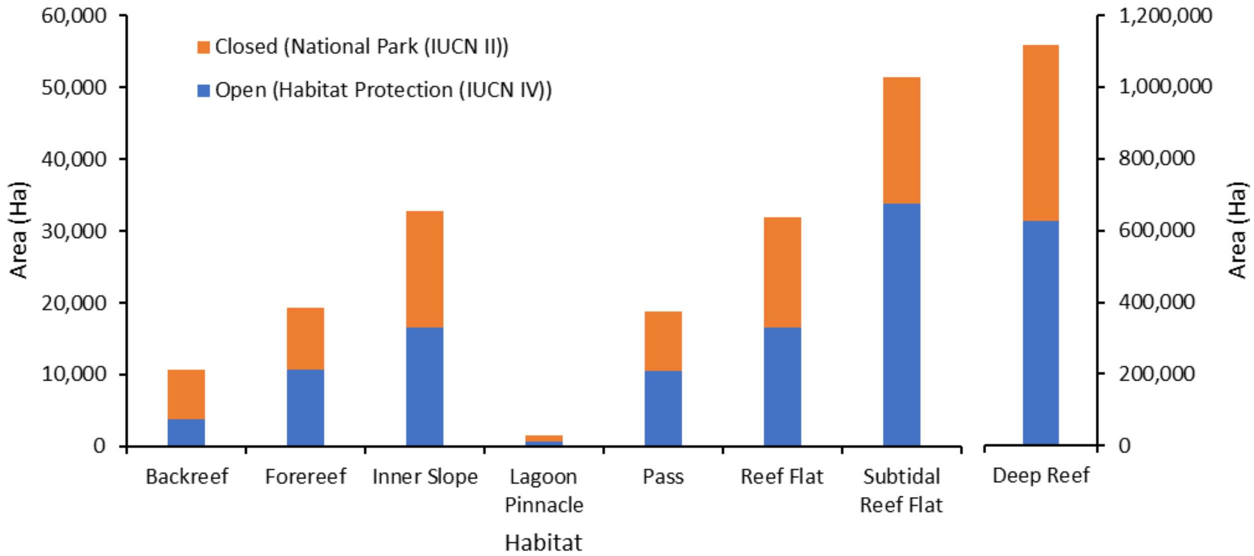


Figure 6. Area of reef associated habitats, shown as open to fishing (Habitat Protection Zone (IUCN IV)) and closed to fishing (National Park Zone (IUCN II)).

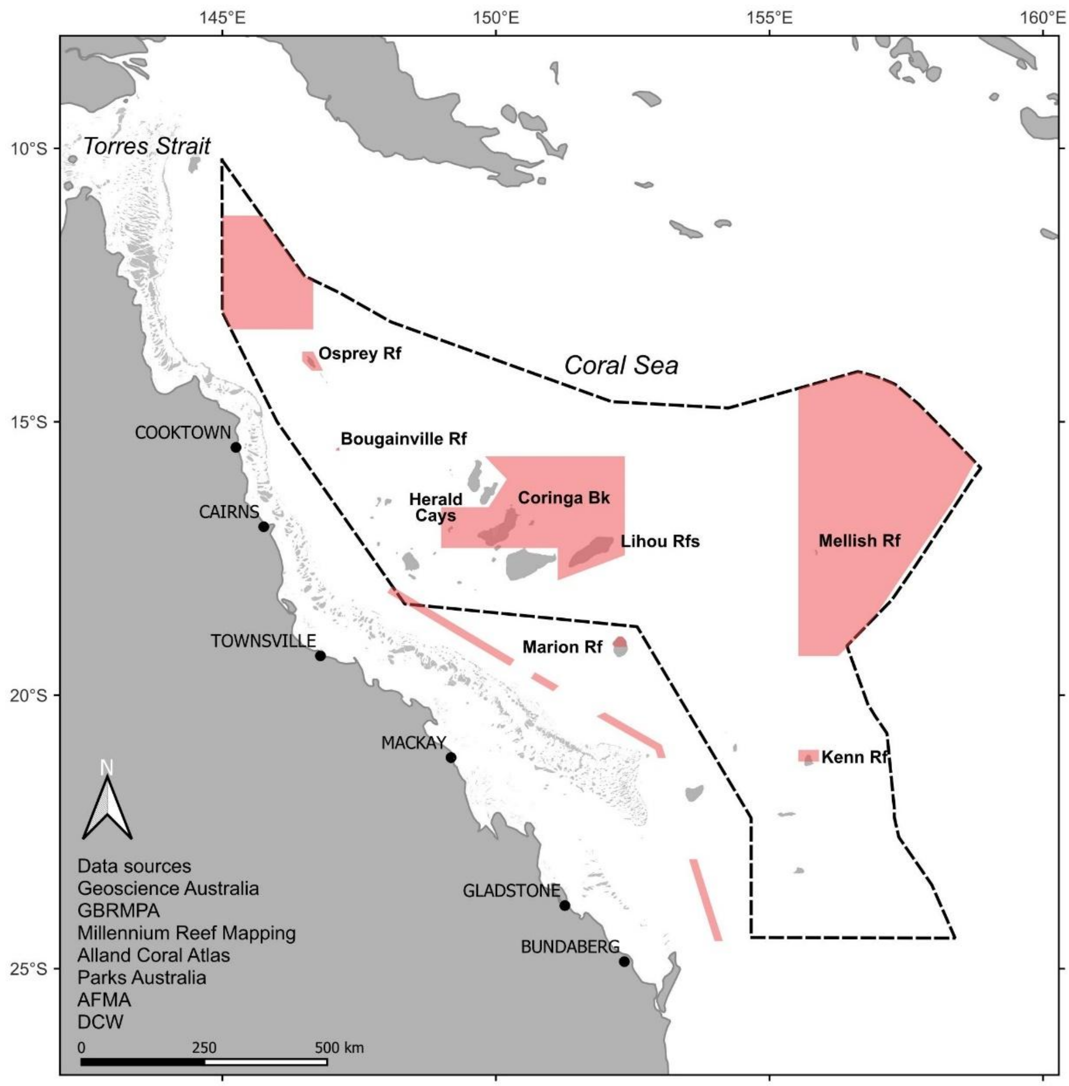


Figure 7. CSF area and areas closed to fishing (National Park Zones (IUCN II) (pink) of the Coral Sea Marine Park.

2 The species

2.1 Distribution within the CSF

2.1.1 Black teatfish

Black teatfish is widely distributed in the CSF. It has appeared in catches from every fished reef in the CSF, and in survey data from every protected reef (CSF vessel logbook data; Section 4, this report) though they appear to be more common on some reefs (using fishery catch per day as a rough proxy of density – e.g. Mellish, Wreck and Flora Reefs and McDermott Bank) (Figure 8). It is a commonly observed species found during reef health surveys in the Coral Sea MPAs (Ceccarelli et al., 2008; Hoey et al., 2021; 2023b).

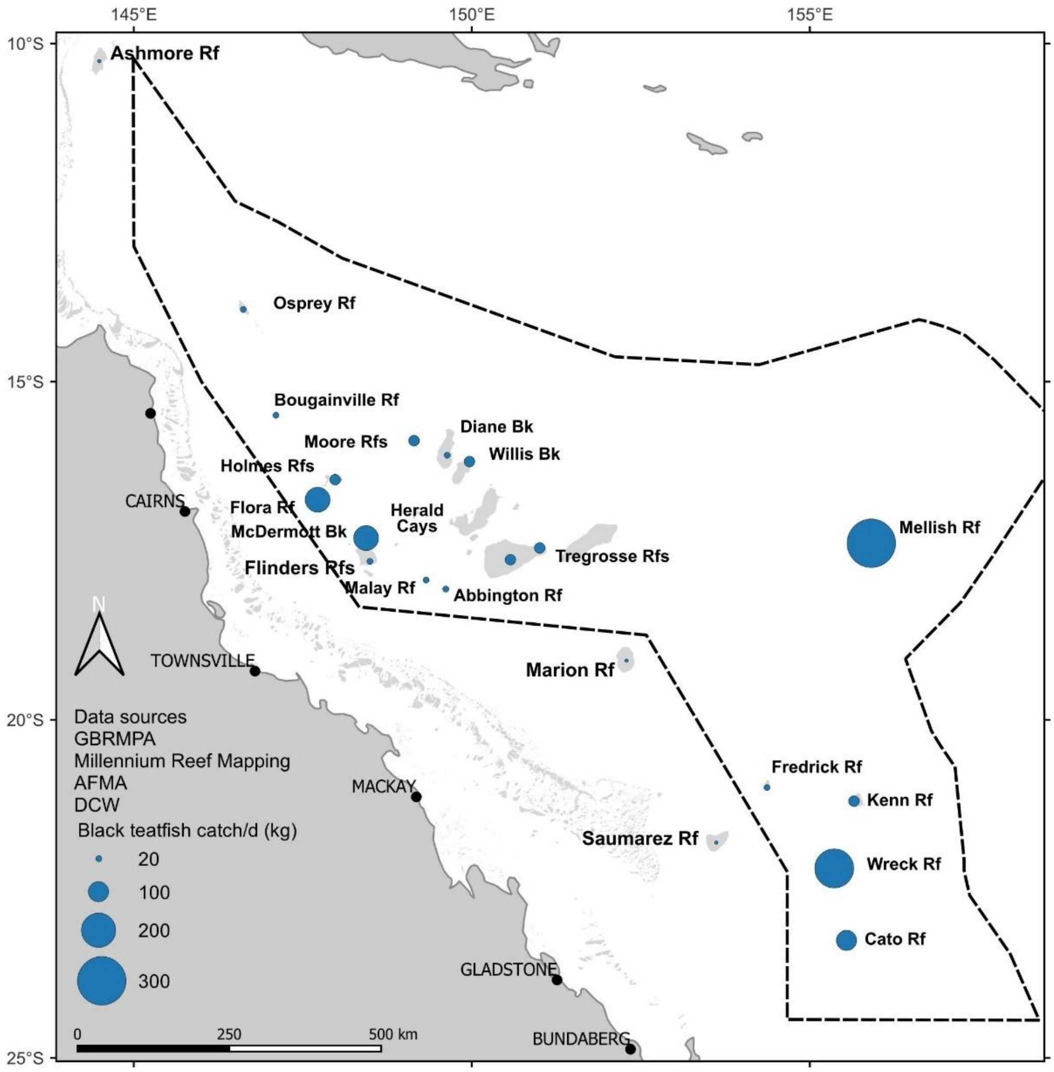


Figure 8. Average catch per day (kg landed wt) for Black teatfish by Reef for the period 1997-98 to 2022-23 (CSF vessel logbook data). Also shown are catch per day for Black teatfish for the offshore reefs of the QSCF (QSCF vessel logbook data).

Black teatfish documented habitat preference is for on reef flats, reef slopes and sandy seagrass beds between 0 and 20 m. (Purcell et al., 2023a), and in the CSF, they are most commonly caught in waters shallower than 10 m (Figure 10). During a survey in 2017 (Skewes and Persson, 2017) it had its highest density on deep lagoon pinnacles that reached to near the surface (Section 4).

2.1.2 White teatfish

White teatfish is widely distributed in the CSF and has appeared in catches from every fished reef except Bougainville and Malay reefs, and in survey data from every protected reef (CSF vessel logbook data; Section 4, this report). In the CSF, White teatfish has the highest catch rates on Osprey Reefs and Diane and Willis Banks (Figure 9), though catch rates may be a poor indictor of overall density due to low targeting in deep lagoon habitats. During the 2017 survey, it was found on 4 out of 6 surveyed reefs (highest density being on Lihou Reef) (Skewes and Persson, 2017; Section 4). Reef health surveys have also found White teatfish on Coringa Bank (Ceccarelli et al., 2007) and Lihou Reef (Ceccarelli et al., 2008).

Their documented habitat preference is for outer barrier reef slopes, reef passes and sandy areas in semi-sheltered reef habitats in 10 to 50 m water depth (Purcell et al., 2023a). In the CSF, they are most commonly caught in waters deeper than 30 m (Figure 10).

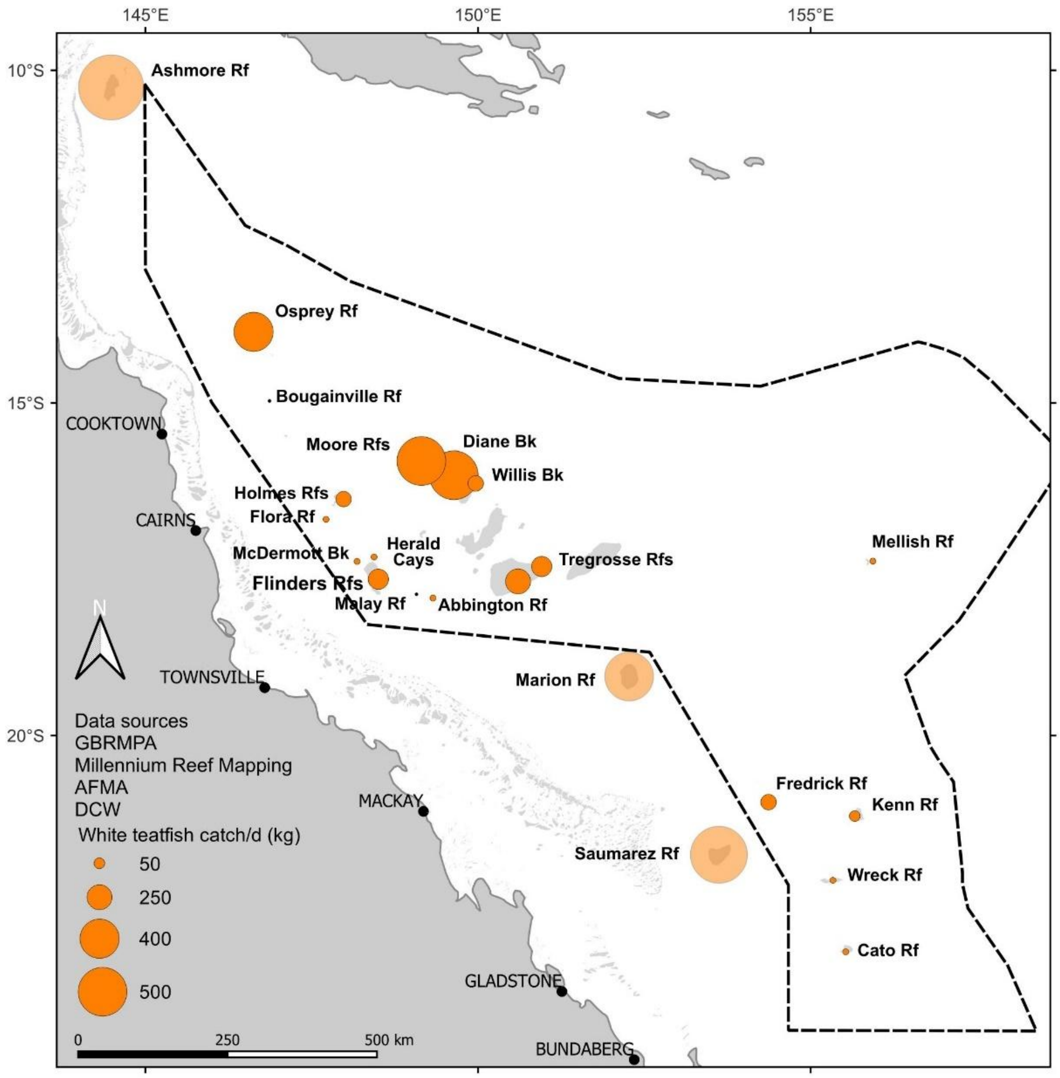


Figure 9. Average catch per day (kg landed wt) for White teatfish by Reef for the period 1997-98 to 2022-23 (CSF vessel logbook data). Also shown are catch per day for White teatfish for the offshore reefs of the QSCF (QSCF vessel logbook data).

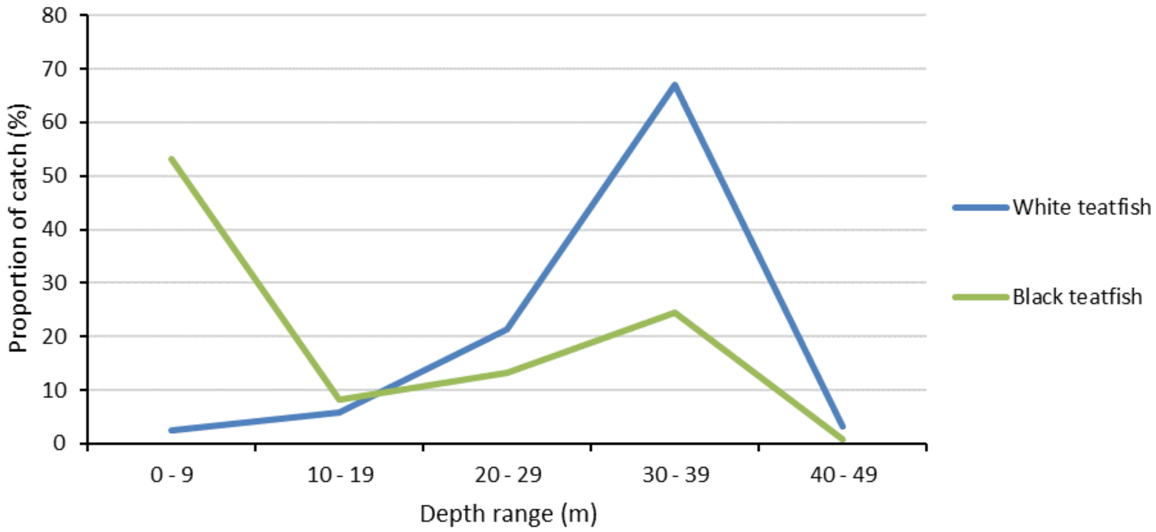


Figure 10. Proportion of the catch of key sea cucumber species in the CSF by depth range of maximum depth field recorded in logbooks (after Woodhams et al., 2015).

2.2 Population structure

The stock structure of Black teatfish and White teatfish in the CSF is unknown. There can, however, be inferences made inferences about population structure based on studies in other jurisdictions, studies on other species; and the biological and oceanographic drivers of population connectivity (e.g. adult population movements, distance between suitable benthic habitats, larval duration, survival, and propagule current delivery vectors) (Treml et al., 2015; Choukroun et al., 2021).

2.2.1 Other regions

The stock structure of Black teatfish in the GBR has been the focus of some study. Genetic studies using allozymes (Uthicke and Benzie, 2000) and mitochondrial DNA (Uthicke and Benzie, 2003) showed no significant genetic structure of Black teatfish populations within the GBR indicating high contemporary levels of gene flow. There was also a suggestion of high gene flow between populations in the GBR, the Coral Sea and Western Australia. However, it was postulated that the population genetic structures observed between eastern and western Australia at least were likely formed prior to the last ice age (Uthicke and Benzie, 2003). There were other factors that may have contributed to mask evidence of fragmentation in Australian Black teatfish populations, including slow mutation rates of genetic markers and high contemporary gene flow (Uthicke and Benzie, 2003).

2.2.2 Other species

Studies on offshore shelf species such as *Cucumaria frondosa* (So et al., 2011), and *H. leucospilota* (Chieu et al., 2023) and deep-water archipelagic species, e.g. *H. atra* (Skillings et al., 2011) has shown high population connectivity across large distances (1,000s of km).

This is in contrast to small scale (<100 km) population structuring observed in most inshore species, especially those inhabiting isolated habitats (e.g. Sandfish, *H. scabra* (Uthicke and Benzie, 2001; Uthicke and Purcell, 2004; Gardner et al., 2012)).

Given the offshore reef setting for Black teatfish and White teatfish in the CSF, they would likely be aligned with the offshore species in showing high population genetic connectivity across broad regions. However, high genetic connectivity does not infer high demographic connectivity, where populations are highly connected by significant levels of recruitment (Johnson et al., 2018).

2.2.3 Biological and oceanographic information

In the absence of appropriate genetic studies, population structure and connectivity can be inferred using biological and oceanographic information, and by the development of coupled biological-oceanographic models (e.g. CONNIE, http://www.csiro.au/connie) (Choukroun et al., 2021; Fontoura et al., 2022).

Adult biology

Sea cucumbers are benthic with a generally low mobility, with annual displacements of 100 m or less (Purcell et al., 2016b; Hammond et al., 2020). However, the ability of adult sea cucumbers to move larger distances is likely underestimated (De la Rosa Castillo, 2023). Therefore, the sea cucumber populations in the Coral Sea are very likely restricted to the reef on which they settle, with both teatfish species likely to be found throughout individual reef systems, including deeper lagoon areas of most reefs for White teatfish at least.

Spawning timing

Black teatfish has been reliably recorded as spawning during winter (April to June) on the GBR (Shiell and Uthicke, 2006) and in New Caledonia (Conand 1993) – although it has also been recorded as spawning during the northern hemisphere summer (April to August) in Guam (Richmond, 1996), and a single record of a Black teatfish male has been recorded as spawning soon after the full moon in December on the GBR (Babcock et al., 1992). Black teatfish are one of the few holothurians that spawn in winter, with this being a key driver for assessments of high vulnerability to climate change for this species (Welch and Johnson, 2013). It may be that some spawning outside the winter established period, with some mature gonads present throughout the year and limited field observations of summer spawning, though only by males (Babcock et al., 1992; Shiell and Uthicke, 2006). This inverse timing has been suggested as an adaptation to the competition with other species (Conad, 1993) or as a strategy to avoid cross fertilisation with closely related White teatfish (Sheill and Uthicke, 2006).

Not only are Black teatfish one of the few winter spawning aspidochirote holothurians, they may also have an unusual model of gonad development, the so called Tubule Recruitment Model (TRM) where tubules mature progressively from anterior to the posterior region of the gonad with at least four stages of gametogenesis present at any one time (Smiley, 1988; Shiell and Uthicke, 2006). This is in contrast to most other sea cucumber species (including White teatfish) where all gonad tubules are generally at a similar stage in development, even though the reinitiation of gametogenesis in spawned and unspawned tubules can occur, resulting in overlapping generations of immature and relict oocytes (Ramofafia et al., 2000; Ramofafia and Byrne, 2001). Other features of Black teatfish reproduction on the GBR include a high fecundity and a male skewed sex ratio (Uthicke and Benzie, 2000; Shiell and Uthicke, 2006).

White teatfish is documented as spawning during summer (November to January) in New Caledonia (Conand, 1993), and late winter to spring (August to October) in the Solomon Islands (Ramofafia et al., 2000). This may indicate some plasticity of breeding seasonality for White teatfish – therefore local studies are likely required. Additionally, the QSCF area covers a large latitudinal range, and it could be that there is variation in the timing of spawning within the fishery area.

Larval biology

Empirical estimates of larval dispersal are key to assessing metapopulation connectivity, especially within a demographic context (Carson et al., 2011). Teatfish species larval biology is reasonably well studied - their larvae are planktonic and planktotrophic (feeding on small, suspended material in the water column) (Tanita et al., 2023). Larval duration has been recorded as between 2 and 4 weeks for White teatfish (Friedman and Tekanene, 2005; Burgy and Purcell, 2024) and between 3 and 7 weeks for Black teatfish (though longer periods are from a study in Japan that may have lower temperatures) (Nguyen et al., 2021; Martinez & Richmond, 1998; Minami, 2011).

Ocean currents within the Coral Sea

The circulation within the Coral Sea is relatively well established. The surface currents are dominated by the broad westward flowing Southern Equatorial Current (SEC), which enters the Coral Sea mostly as two main jets, the North Caledonian Jet (NCJ) and the North Vanuatu Jet (NVJ), as it passes between the Solomon Islands, Vanuatu and New Caledonia (Gourdeau et al., 2008, Ganachaud et al., 2014; Rousselet et al., 2016). These jets then flow through the coral reef complexes forming smaller scale jets and eddies that move predominantly (but not always) westward toward the GBR (Ceccarelli et al., 2013, Johnson et al., 2018) (Figure 11).

Circulation in the northern Coral Sea is dominated by the clockwise Coral Sea gyre (Gulf of Papua Current - Figure 11), which can carry planktonic larvae back through the coral sea and to the GBR (Pitcher et al., 2005). However, during summer, the strength of this circulation is reduced and can even reverse as anti-clockwise eddies form in the Gulf of Papua (Johnson et al., 2018).

While these broad currents predominantly drive larval vectors, finer scale current patterns, especially adjacent to reefs, are more complex, with standing eddies and even reversals in the form of counter currents, which can vary significantly over a range of timescales (Rousselet et al., 2014; Hristova et al. 2014; Johnson et al., 2018; Choukroun et al., 2021). This promotes mixing and multi vectoral delivery mechanisms, and elevated larval retention and self-recruitment at the reef scale (Treml et al., 2012; Ceccarelli et al., 2013).

Having said this, circulation features in the Coral Sea vary on seasonal to multidecadal timescales, with the magnitude and the drivers of this variability not well understood (Brewer et al., 2007; Ceccarelli et al., 2013).

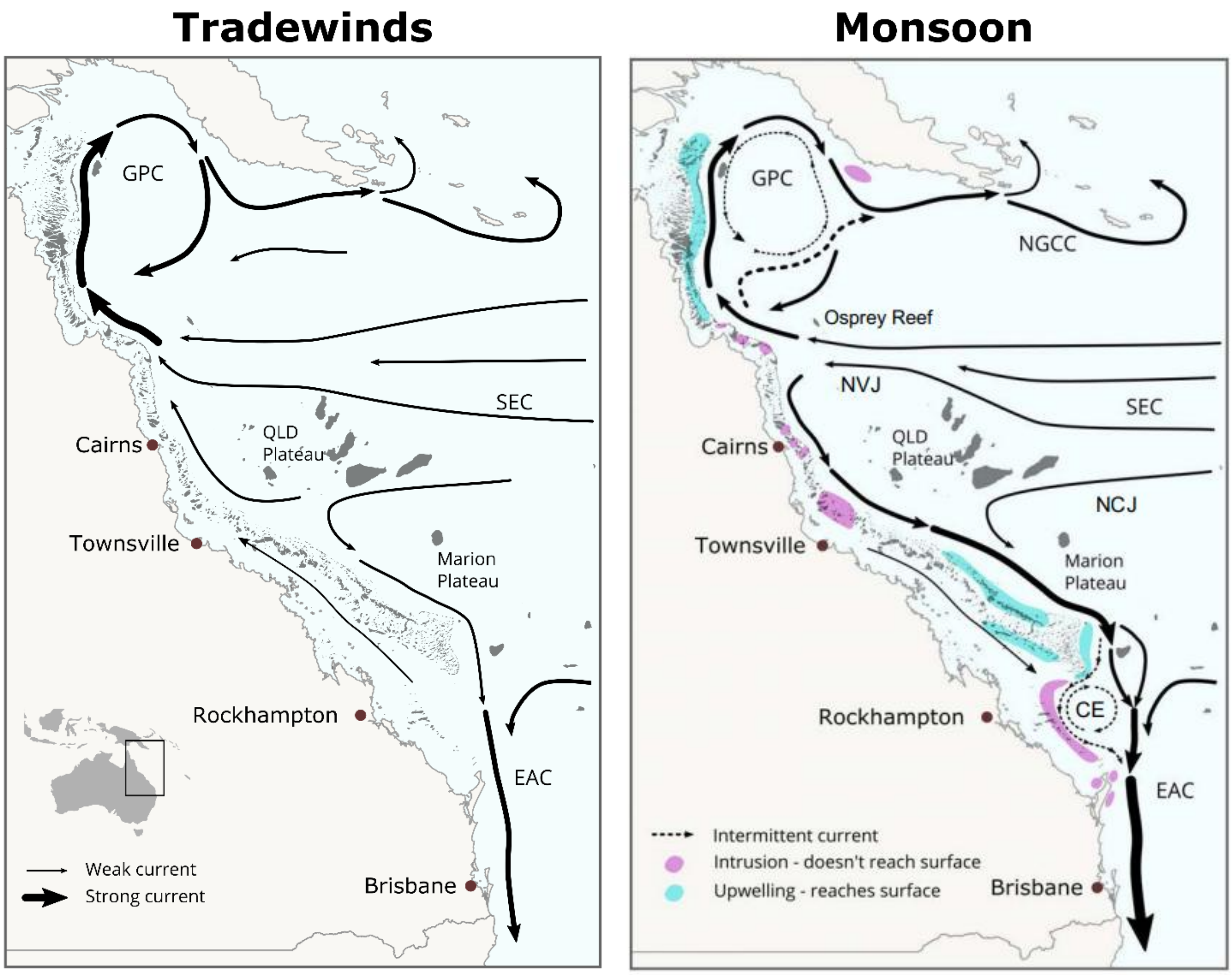


Figure 11. Prevailing surface currents in the Coral Sea and adjacent biogeographical provinces during the Tradewinds (winter) and monsoon (summer) seasons. GPC – Gulf of Papua current, NGCC – New Guinea Coastal Current, NVJ – North Vanuatu Jet, NCJ – New Caledonia Jet, SEC – South Equatorial Current, CE – Capricorn Eddy, EAC – East Australian Current. Sources: Choukroun et al., 2021; Craig Stienberg and Eric Lawrey (2018) eatlas.org.au

Connections with neighbouring regions

The generally westward flowing SEC passes several large reef domains in the southwest Pacific on its way to the Coral Sea, including the adjacent reefs of Vanuatu, New Caledonia, and the close proximity Chesterfields (Ceccarelli et al., 2013), providing the possibility of larval recruitment from these areas.

On the western side, as the generally westward SEC currents flow through the Coral Sea and impinge upon the Queensland continental shelf and the GBR, they are deflected to the north to contribute to the North Queensland Current and the Hiri current (also called the Gulf of Papua Current and New Guinea Coastal Current) and the Coral Sea gyre in the northern Coral Sea, to the south to form the East Australian Current (Figure 11) (Ceccarelli et al., 2013; Johnson et al., 2018). The location of the bifurcation point moves seasonally north and south (Ceccarelli et al., 2013).

Linked physical-biological models

The Coral Sea reefs are spatially arranged at two levels: very isolated reefs (e.g. Mellish, Osprey, Flinders, Wreck, Kenn and Fredrick Reefs) where they are separated from the nearest neighbour reef by 100 km or more; and reef clusters (e.g. reefs of the central Queensland Plateau: e.g. Lihou and Tregrosse Reefs; Coringa, Willis and Dianne Banks; Herald Cays) that are separated by only 10's of km.

Broadscale models of dispersal-driven connectivity suggest the reefs within the central Coral Sea are likely to be relatively well connected, though that connectivity may be highly variable between years (Choukroun et al., 2021). On the other hand, more isolated reefs may be largely reliant on self-seeding (Ceccarelli et al., 2013). For example, modelling of dispersal of fish and coral with similar larval durations as sea cucumbers indicate that the scale (average distance) of dispersal in the Pacific is on the order of 50–150 km (Treml et al., 2008), with high levels of self-recruitment (Treml et al., 2012).

Studies on reef fishes (Underwood et al., 2012) and corals (Gilmour, 2016) on the isolated reefs off NW Australia showed a low demographic connectivity between isolated reefs, particularly further offshore (Underwood et al., 2020), although genetic connections between systems are likely maintained by occasional long-distance dispersal. There was some evidence of restrictions to connectivity even at a local scale (tens of kilometres). This research suggested that the majority of recruits are retained close to their natal reef.

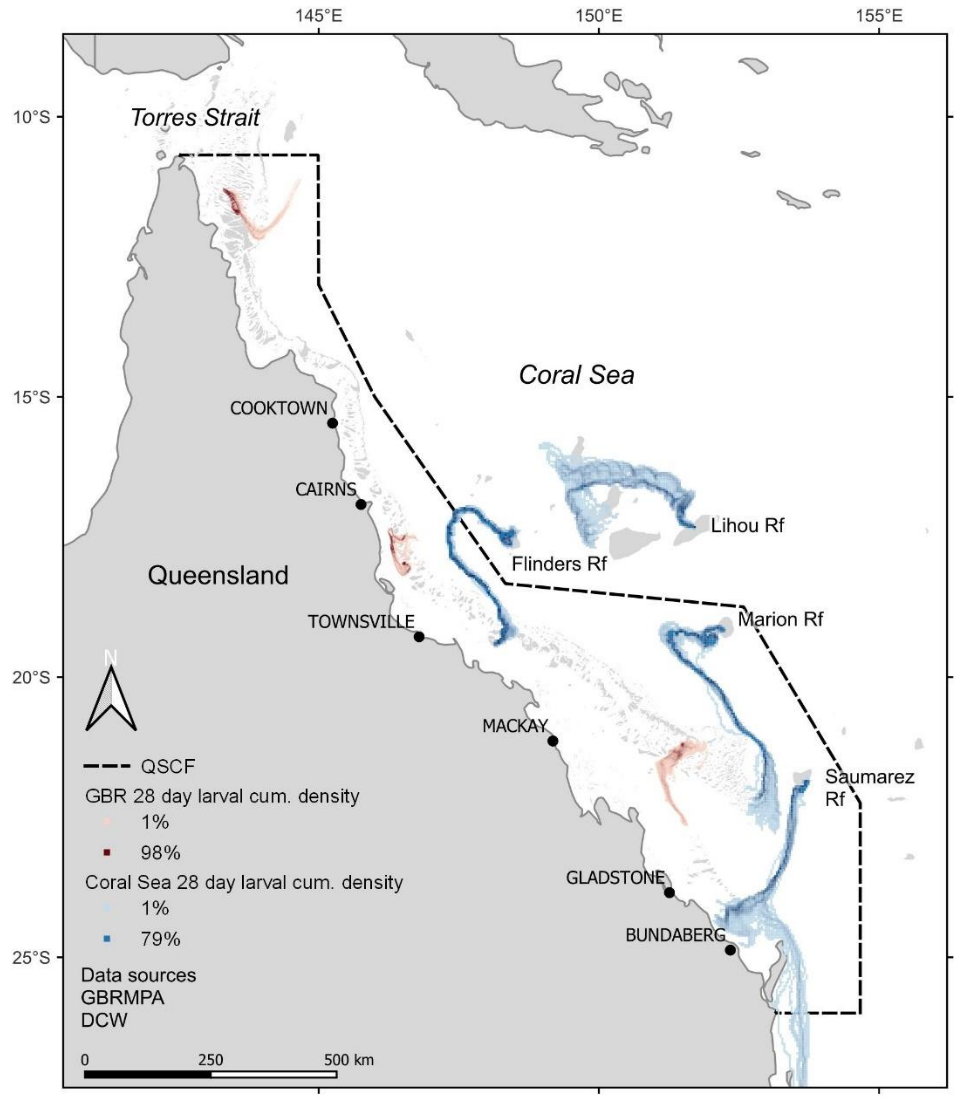


Figure 12. Larval particle model trajectories with 28-day period for summer new moon release (6/1/2019) for three GBR (red) and four Coral Sea (blue) point release locations. (Connie3: https://connie.csiro.au/)

Links with neighbouring regions

Biophysical models predicted strong connections from the Coral Sea reefs and GBR, which is consistent with the dominant westerly current flow in the Coral Sea (Figure 12; Choukroun et al., 2021). Connectivity for larvae with a 30-day pelagic larval duration showed strong connectivity between the Coral Sea and GBR, and between the northern GBR and Torres Strait, but the offshore reefs of the Coral Sea (e.g. Mellish Reef) were less connected. Connectivity from northern Coral Sea reefs (Osprey and Bougainville Reefs) to the northern GBR was among the strongest connections observed in the model (the study did not test for connections from the GBR to the Coral Sea) (Choukroun et al., 2021). A recent study on broadscale connectivity of larval fishes also indicated that many reefs in the Coral Sea act as source reefs for recruitment of fish populations to the GBR (Figure 13) (Fontoura et al., 2022).

Connectivity on broader scales, such as between the Coral Sea and western Pacific and Indian Oceans through northern Australia is not well understood (Ceccarelli, 2013).

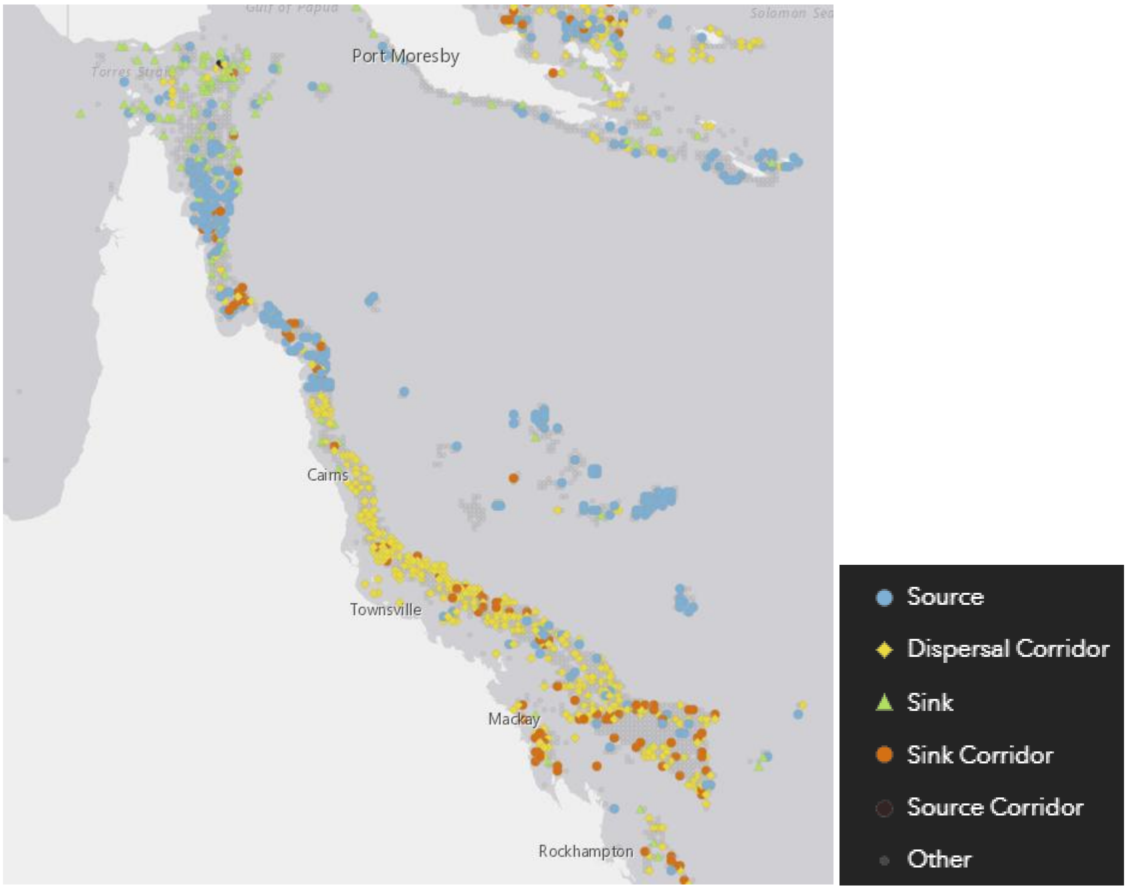


Figure 13. Fish Larval Connectivity on Coral Reefs: Spatial Distribution of Sinks, Sources & Corridors (Fontoura et al., 2022) (https://www.arcgis.com/apps/dashboards/7d7167d11e4e4c4496ced8cafacb0fed

2.2.4 Conclusions

While there is likely to be at least some level of connectivity between most reef subpopulations in the Coral Sea for both species, it is also likely to be low for isolated reefs, and probably variable on annual scales, due to current variability and other stochastic factors, including recruitment variability associated with the planktotrophic feeding mode of teatfish larvae – a high risk, high gain or boom-bust strategy (Uthicke et al., 2009). Population genetics studies have already shown that connectivity patterns among marine populations are more complex than expected and that larvae do not always disperse over large distances (Pirog et al., 2019).

Therefore, the population structure of both teatfish species in the Coral Sea is likely to be considered as “local populations with partial isolation”, at least for isolated reefs (or Type B stock structure according to the Marine Stewardship Council population structure classification system; MSC, 2022). In this case, management of the Coral Sea populations as one stock is not a precautionary approach. Stocks should be managed at a level that takes into account stock structure – such that the smallest “functional” stock level should be acknowledged and managed. A precautionary approach would be to manage stocks carefully at least for isolated reef systems. The reefs of the Queensland Plateau are probably relatively well connected in a demographic sense to manage as a sub-population in its own right.

It is useful that the most easterly reefs, including Mellish Reef and Lihou Reefs, are protected from fishing, as they are likely source reefs for recruitment to other areas of the CSF and beyond. It is also pertinent to remember however, that for many marine species, metapopulation growth and persistence is most sensitive to factors such as adult fecundity and the survival and growth of juvenile stages, and less so to population connectivity (Carson et al., 2011; Lopez-Duarte et al., 2012).

2.3 Climate change

2.3.1 Climate change in the Coral Sea

Climate change stressors in marine environments include increased sea temperature (and so-called marine heat waves), sea level rise, ocean acidification, changes to ocean current patterns, and increased storm intensity. Natural climate variability in Australia's Tropical Pacific Ocean region is associated with El Niño and La Niña events, which now occurs on top of the warming trend with the potential to modify climate-ocean interactions with flow-on effects on Australia's climate (McInnes et al., 2015; IPCC, 2019).

The number and intensity of marine heatwaves in the CSMP has increased 1.5 to 3.5-fold in the last 35 years (Figure 14), with a concomitant decrease in the return time between events (where DHW> 3) to less than 2 years (Hoey et al., 2021). Marine heatwaves in the Coral Sea will continue to increase in intensity and duration (Johnson et al., 2018).

Sea levels have risen on average 2.1 mm/yr over 1966–2009 and 3.1 mm/yr over 1993–2009 around Australia, after accounting for the influence of the El Niño and the effects of vertical land movements due to glacial rebound, the effects of natural climate variability and changes in atmospheric pressure (McInnes et al., 2015). Sea levels are expected to rise by 0.47 m (0.30-0.64) under RCP4.5 and 0.64 m (0.44-0.87) under RCP8.5 by 2090 (projections for Mackay; McInnes et al., 2015)

Uptake of anthropogenic CO_2 into the oceans has led to a 0.1 unit change in the ocean's surface water pH (to pH 8.1), which represents a 26 % increase in the concentration of hydrogen ions in seawater (IPCC, 2019). By 2030, pH change is projected to be another 0.08 units lower (to pH 8). By 2090, it is projected to be up to 0.15 units lower (to pH 7.95) for RCP4.5 and up to 0.32 units lower (to pH 7.8) for RCP8.5, representing an additional increase in hydrogen ion concentration of 40 and 100 % respectively (McInnes et al., 2015; IPCC, 2019).

Modelling of climate change impacts on the currents of the Coral Sea showed very little change in the strength or direction of the SEC current jets that flow through the Coral Sea. However, there may be a strengthening of the Gulf of Papua Gyre, and the EAC may slightly weaken in the top 50 m (Johnson et al., 2018).

Projected changes in tropical cyclones predict that they will become less frequent but increase in intensity (McInnes et al., 2015).

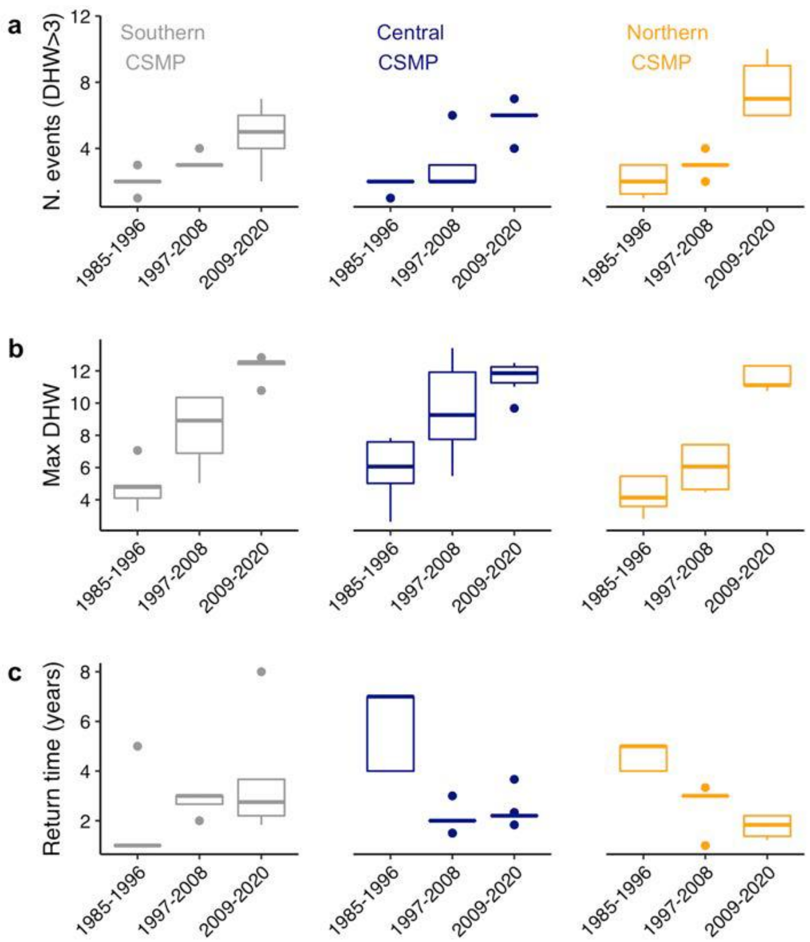


Figure 14. The (a) number, (b) intensity and (c) return time of marine heatwaves that are likely to induce coral bleaching (Degree Heating Weeks; DHW > 3) in the Coral Sea Marine Park between 1985 and 2020 (Hoey et al., 2021).

2.3.2 Direct impacts of climate change

Temperature

Longer-term (> a few weeks) experiments of the effect of raised temperature on sea cucumbers are sparse. Buccheri et al. (2019) found variability in the stress tolerance of three common tropical reef holothurians, *Holothuria atra, Stichopus chloronotus,* and *Holothuria edulis*, to elevated temperate, suggesting that species might respond differently to ocean warming. A study of a sea cucumber (*Parastichopus regalis*) in the central Mediterranean Sea indicated a range reduction and density decrease, possibly related to climate change temperature and pH changes – though this finding was not conclusive due to other potentially detrimental factors (e.g. bottom trawling) (Scannella et al., 2022).

Longer term experiments on starfish showed that adult mortality was not altered by increased temperature. However, they found that temperature regulated starfish physiology, but that the combination of high temperature and lower pH showed nonlinear and potentially synergistic effects on organismal physiology (e.g., metabolic rate), where the elevated temperature allowed starfish to better cope with the adverse effect of lower pH on calcification and reduced skeletal dissolution (antagonistic interactive effects) interpreted as a result of energetic trade-offs (Khalil, 2023).

Ocean acidification

Studies on several species have shown that adult sea cucumbers are largely resilient to projected future changes in pH (pH 7.8 by 2100; IPCC, 2019), but that larger changes can have negative impacts on the acid-base balance, energy consumption, grazing and growth rates of sea cucumbers (e.g. *H. scabra*, *H. parva*, *H.*

forskali, *Apostichopus japonicus*) (Collard et al., 2014; Yuan et al. 2016; Yuan et al., 2018). Less-calcified sea cucumbers may be more tolerant to seawater acidification than other heavily calcified echinoderms (Yuan et al., 2018).

There has been some experimentation on the effect of changes in pH on holothurian larvae. For *H. spinifera*, larvae developed faster, grew better and had better survival rates at pH 7.8 (Asha and Muthiah, 2005). For *A. japonicus* a 0.62 unit decrease in pH had relatively small effects on early life-history compared to other echinoderms, leading to a maximum of 6% decrease in post-fertilization success (Yuan et al. 2015). This indicates that predicted changes in pH in the Coral Sea may not greatly impact larval survival, though more extreme changes may have a larger impact on larval survival (González-Durán et al., 2021).

Sea level rise

Sea level rise has been assessed as being mostly positive for shallow water species (e.g. *H. scabra*, *H. whitmaei*) (Plaganyi et al. 2013) and is likely to be neutral for deeper water species such as prickly redfish and Amberfish.

Changes in cyclone frequency and intensity

Shallow species may be negatively impacted by scouring and dislocation by severe storms. Impacts to deeper water species such as Prickly redfish and Amberfish are likely to be negligible.

2.3.3 Indirect impacts of climate change

The CSF habitats will be impacted by climate change. Repeated exposure to damaging marine heatwaves can lead to irreversible changes in coral reef assemblages depending on the intensity (maxDHW) and time between successive thermal stress events (Hughes et al., 2018).

In the Coral Sea, climate change related coral bleaching and mortality reduced coral cover in the CSMP from 27% in 2020 to 13% in 2022, a mean decline of 52% (Hoey et al., 2021; 2022). The declines in coral cover varied among regions, and reefs ranging from 17% in the northern CSMP (13-29% among reefs), 39% in the southern CSMP (24-73% among reefs), to 43% in the central CSMP (13-59% among reefs). There was also considerable variation in the relative coral loss among sites within individual reefs (e.g., 19% vs 59% at two sites on Holmes Reef). The 2020 bleaching event occurred against a longer-term decline following bleaching events in 2016 and 2017 (Hoey et al., 2021). There have now been three consecutive bleaching events (2020, 2021, and 2022) that have had a significant impact on coral and reef fish communities in the CSF area (Hoey et al., 2023b).

While the coral cover has been impacted, the remaining coral cover on CSMP reefs (17%) is comparable to recent estimates for the GBR (19%), and considerably higher than that of some central CSMP reefs (i.e., Herald Cays, Chilcott Islet and Lihou Reef) from the early 2000’s (Hoey et al., 2021).

There were also associated declines in the species richness, abundance, and biomass of reef fishes within the central Coral Sea (Hoey et al., 2021). Even so, the total biomass of reef fishes across all reefs in the CSMP (500 - 3,000 kg per hectare) is high relative to coral reefs globally (Hoey et al., 2021).

The impact of these changes to coral cover and fish communities on sea cucumbers is uncertain. Trophic effects are poorly understood.

2.3.4 Vulnerability of *Holothuria* species in the Coral Sea to climate change

Black teatfish in Torres Strait was assessed as having a high vulnerability to climate change, mainly due to a low adaptive capacity related to winter spawning, low productivity and limited mobility (Johnson and Welch, 2016). However, White teatfish are summer spawners and inhabit deeper water habitats, which may reduce climate change risks (Dutra et al., 2020). The vulnerability of White teatfish to climate change stressors in the CSF in the short to medium term would appear to be moderate, but with considerable uncertainty, especially for long term temperature changes and indirect impacts.

There could also be synergistic effects to consider. Experiments on starfish showed that the combination of high temperature and high pCO_2 showed nonlinear and potentially synergistic effects on organismal physiology (e.g., metabolic rate) (Khalil et al., 2023). In addition, shifts in ecosystem state can potentially go unnoticed and eventually undermine the sustainability of seemingly sustainable fisheries (Fulton et al., 2021).

It is increasingly important to develop models to link climatic effects over a range of life history components and critical habitats for fisheries (e.g. seagrasses, coral reefs) and quantify the resultant impact on fisheries productivity using alternative emission scenarios (Dutra et al., 2020). An integrated risk assessment of sea cucumbers in Torres Strait, based on a Management Strategy Evaluation (MSE) (Plagányi et al., 2013), found that status quo management would result in half the species falling below target levels, moderate risks of overall and local depletion, and significant changes in species composition. Three simple strategies (spatial rotation, closed areas, multi-species composition) were all successful in reducing these risks (Plagányi et al., 2013), all strategies that are applied in the CSF.

2.4 Inherent vulnerability

In the CITES context (CITES, 2011), "Inherent Vulnerability" can be defined as the susceptibility to intrinsic or external effects that increase the risk of extinction, even when mitigating factors are taken into account. There are a number of taxon or case-specific biological and other factors that may affect the extinction risk associated with a given percentage decline, small population size or restricted area of distribution (CITES, 2011). Many of these factors are poorly understood for Black and White teatfish, in particular.

Factors increasing inherent vulnerability

- Both species are large, easily seen sea cucumbers and are thus easily harvested.
- Both species are high value species that have been consistently targeted by CSF fishers (Woodhams et al., 2015; this report) and likely previously targeted/fished by IUU fishers (Skewes, 2017).
- Generation length for both species is unknown, but may be greater than several decades (Conand et al., 2013a; 2013b; Uthicke et al., 2004).
- Both species have been considered as being of low productivity (FAO, 2019).
- There are likely to be depensation (Allee) effects on population productivity at low population density, primarily driven by low fertilisation success for widely distributed spawning pairs (a dilution effect) (Uthicke, 2004). However, the characteristics of the "Allee effect threshold" (e.g. proportion of virgin biomass where low density begins to negatively affect population productivity) and "Allee threshold" (where populations continue to decrease even when fishing ceases) are unknown for any sea cucumber population (Hutchings, 2015; González-Durán et al., 2018). Also, the persistence and recovery (albeit often slow) of heavily depleted sea cucumber populations would suggest the Allee threshold is likely <0.1 of virgin biomass (B_0) (Murphy et al., 2011a; Ramírez-González et al., 2020; Friedman *et al*., 2010; Prescott et al., 2017; FAO, 2022).
- Larvae of both species are likely planktotrophic, which has been described as a "high risk, high reward" strategy which may lead to high variability in recruitment (Uthicke et al., 2009).
- Subpopulations on isolated reefs are likely to be primarily self-seeding, and particularly vulnerable to overexploitation.
- Black teatfish is listed as Endangered under IUCN criteria because it is commercially exploited throughout its range, the population trend is declining, and IUCN estimates that populations have declined by 80-90% in at least 50% of the species' range, and populations are overexploited in at least 30% of its range (Conand et al., 2013a).
- White teatfish are listed under IUCN criteria as Vulnerable (Conand et al., 2013b).
- Both species are reef-associated (Purcell et al., 2023a) and will be impacted by declining reef health associated with a range of pressures, including climate change (Hughes et al. 2018; see above).
- Sea cucumbers on more isolated fished reefs will be subject to higher risk of localised depletion and be less resilient due to low recruitment connectivity.

Factors reducing inherent vulnerability

- Both species have a broad geographical range regionally (Conand et al., 2013a; 2013b), and within the CSF and adjacent fisheries.
- Both species appear to be resilient to local extirpation, even in heavily exploited fisheries (Prescott et al., 2017; FAO, 2019).
- There are some examples of recovery of overfished teatfish stocks (Skewes et al., 2009; Knuckey and Koopman, 2016; Helidoniotis, 2021a)
- Juveniles are very cryptic and rarely observed – offering protection from fishing for juvenile year classes (Prescott et al., 2013; CITES, 2019).
- White teatfish inhabits deeper reef habitats so is less susceptible to fishing, though this effect will be reduced with the use of underwater breathing apparatus utilised in the CSF (Purcell et al., 2014; Koopman and Knuckey, 2021b).
- Both species are likely to have a significant proportion of their population protected within a comprehensive system of closed MPAs throughout the CSF area.

From the above, it can be implied that both species have features that would support a range of possible "inherent vulnerability" findings, with White teatfish having the most uncertainties. Black teatfish certainly are very susceptible to overexploitation, inhabit the shallow reef that is most susceptible to impacts (including climate change) and can take some time to recover, therefore a precautionary assessment of the Inherent Vulnerability of 'high' is likely warranted. White teatfish, on the other hand, probably has a lower inherent vulnerability than Black teatfish – being less susceptible to fishing pressure (Skewes et al., 2014; FAO, 2019) the potential for relatively high density of White teatfish in deep reef habitats (Murphy et al., 2021a; Koopman and Knuckey, 2021b), and extensive closed areas throughout the fishery area, a precautionary assessment of the Inherent Vulnerability of 'medium-high' for White teatfish in the CSF is recommended.

2.5 Ecological role

Effect on benthic habitats

Holothuroids (i.e., class Holothuroidea) feed on the sea bottom, reducing the organic load and redistributing surface sediments (Uthicke, 1999; Hammond et al., 2020; Williamson et al., 2021), making them bioremediators by enhancing the productivity of sea bottom life (for a comprehensive review of sea cucumber ecological role, see Purcell et al., 2016a). This form of nutrient recycling is crucial in ecosystems with low nutrient levels, as in the Coral Sea (Ceccarelli et al., 2013). The depletion of holothuroids has also resulted in the hardening of the sea floor, thereby eliminating potential habitat for other benthic organisms (Bruckner et al., 2003).

Sea cucumbers are known to be consumed by diverse predators from at least seven phyla, including 19 species of seastars, 17 crustaceans, several gastropods and around 30 species of fish (Purcell et al., 2016a). Although there is little information regarding predators of teatfish. For predators that rely heavily on sea cucumbers as a food source, depletion of sea cucumber populations is likely to have a negative impact (Purcell et al., 2016a). Thus, overexploitation of sea cucumbers may result in a loss of biodiversity or abundance of these predator species or cause them to switch to other prey species, with potential cascading effects in the ecosystem (Purcell et al., 2016a).

Effect on local water chemistry

Feeding and excretion by sea cucumbers also increase seawater quality and alkalinity, which contributes to local buffering of ocean acidification. Studies on several sea cucumber species (Curryfish - *Stichopus herrmanni,* Lollyfish - *Holothuria atra,* Snakefish - *H. leucospilota*) has shown they can affect local seawater alkalinity through their digestive processes and release of ammonia (Uthicke, 2001; Schneider et al., 2011; 2013; Wolfe et al., 2017; Vidal-Ramirez and Dove, 2016), potentially moderating ocean acidification and benefiting calcifying organisms such as corals, though the size and even direction of the net impact is dependent on water flushing rates and time of day.

Wolfe et al. (2017) found that Curryfish (*S. herrmanni*) had significant impacts on seawater chemistry through respiration, dissolution of $CaCo_3$ in the gut and by down grazing effects on algae and infauna. These actions contributed to increased reef dissolution during the day, but decreased dissolution at night when reef systems are most vulnerable to dissolution. However, the effect was only measurable in closed mesocosm systems – Curryfish had little effect on seawater chemistry under flowing conditions. Another study on the effect of Lollyfish (*H. atra*) on seawater carbonate chemistry found that the feeding and excretion of that species may even exacerbate the impacts of acidification due to the dissolution of $CaCO_3$ resulting from their production of respiratory CO_2 (Vidal-Ramirez and Dove, 2016).

It is likely then, given the dynamic nature of water currents on reef systems in the Coral Sea (Choukroun et al., 2021), and primarily slope and deeper water habitats favoured by White teatfish (Purcell et al., 2023a; Murphy et al., 2021a; Skewes and Persson, 2017), that local ameliorating effects on water chemistry would be modest at best.

Ecological role in the Coral Sea

The Coral Sea fishery habitats are well offshore and classified as oligotrophic (apart from reefs surrounding small islands with high density bird populations; Ceccarelli et al., 2013). Nutrient recycling by larger sea cucumbers such as teatfish will therefore play an important role in reef functioning in this area.

3 Harvest levels and trends

3.1 Fishery extractions

A note on fishery catch weight. Sea cucumbers will change their weight depending on the time out of the water and processed state (Murphy et al., 2021b). Typically, sea cucumber fisheries collect catch weight information at the first opportunity for operators to reliably weigh the catch. In the case of the CSF, this is when the product is partially processed (and stabilised) onboard the mother vessels as gutted and salted (AFMA, 2021a), but also as gutted, parboiled and frozen (*pers obs.*; industry *pers. comm.*) – hereafter referred to as “landed weight”.

In this case, all survey data will need to be expressed as fishery landed weight (or vice versa) for application to fishery assessments and to TACs. Live to salted weight conversion factors are available for teatfish (Murphy et al., 2021b) but par-boiled and frozen weight conversion factors are not.

Fishing for sea cucumbers on the reefs of the Coral Sea has a long history. It likely began in the mid-1800s, as part of a broader western Pacific maritime trade, exporting a range of products directly to China and nearby ports (Mullins, 1992; 1995; Ganter, 1994), with this phase of the fishery lasting up until about the second world war (Uthicke, 2004). There is very little detail about the catch, or the level of depletion of the CSF stocks during this period.

The modern CSF began in the early 1990’s, initially focussed on Black teatfish, Prickly redfish and Surf redfish (R. Lowden, pers comm.). The catch for the period 1993 to 1995 has been reported as 8.0 t – with about half being Black teatfish (3.1 t) and Prickly redfish (0.8 t) and the rest being unidentified (Damschke, 1997). The information presented in this report is based on fishery data collected from the 1997-1998 fishing year.

Sea cucumbers have been fished from most reefs in the CSF apart from the long established National Nature Reserves (NNRs) of Lihou and Coringa Herald Reefs (Hunter et al., 2002; Woodhams et al., 2015). In 2018, Osprey and Mellish Reefs, and parts of Kenn (~50%) and Bougainville (~75%) Reefs were also declared as no fishing (National Park IUCN II) zones under the Coral Sea Marine Park.

The fishery was more active in its early years (Figure 15, Figure 16, Table 2), with the average annual catch for the period 1997-1998 to 2004-2005 averaging 15.8 t per year compared to 3.7 t per year after 2005-2006 (Table 2, Figure 16). The reasons for the lower catches since the early 2000’s are primarily related to the high costs associated with operating in this remote fishery and management changes (e.g. TAC reductions for White and Black teatfish in 2003). It is also possible that the catches taken in the peak of the fishery in 2000-01 reduced catch rates to less profitable levels. Both CSF permit holders also operate in the QSCF, therefore is may be that the sporadic catch and effort applied in the CSF is due to the greater focus on the QSCF (Woodhams et al., 2015; Noriega, 2022).

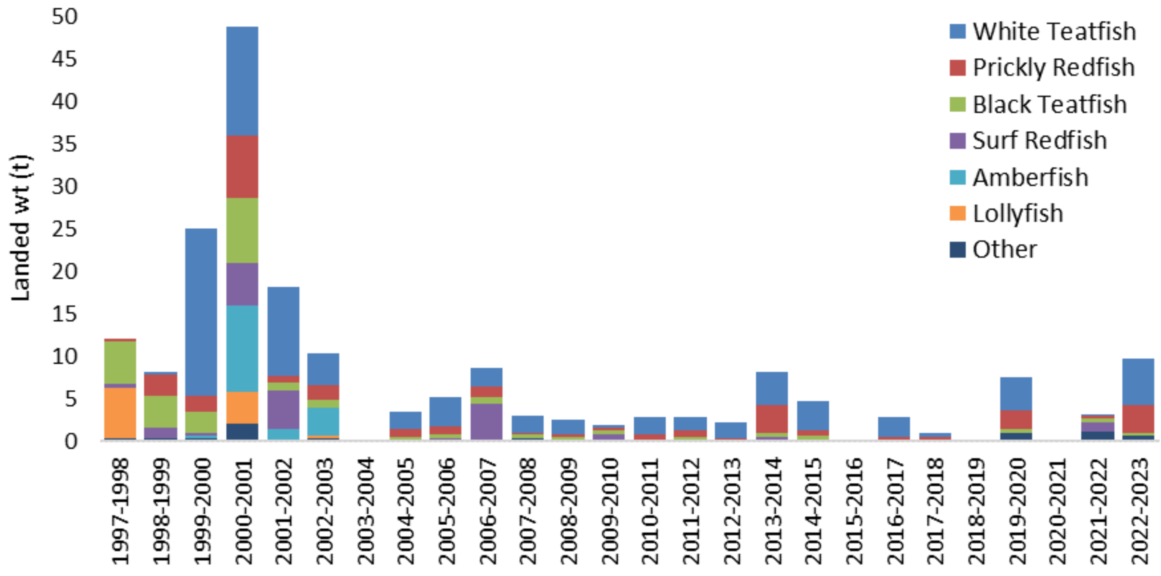


Figure 15. Catch (tonnes landed wt) of the CSF for 1997-98 to 2022-23 (top 6 species by catch weight only shown as individual species, equating to 96% of total catch) (CSF vessel logbook data).

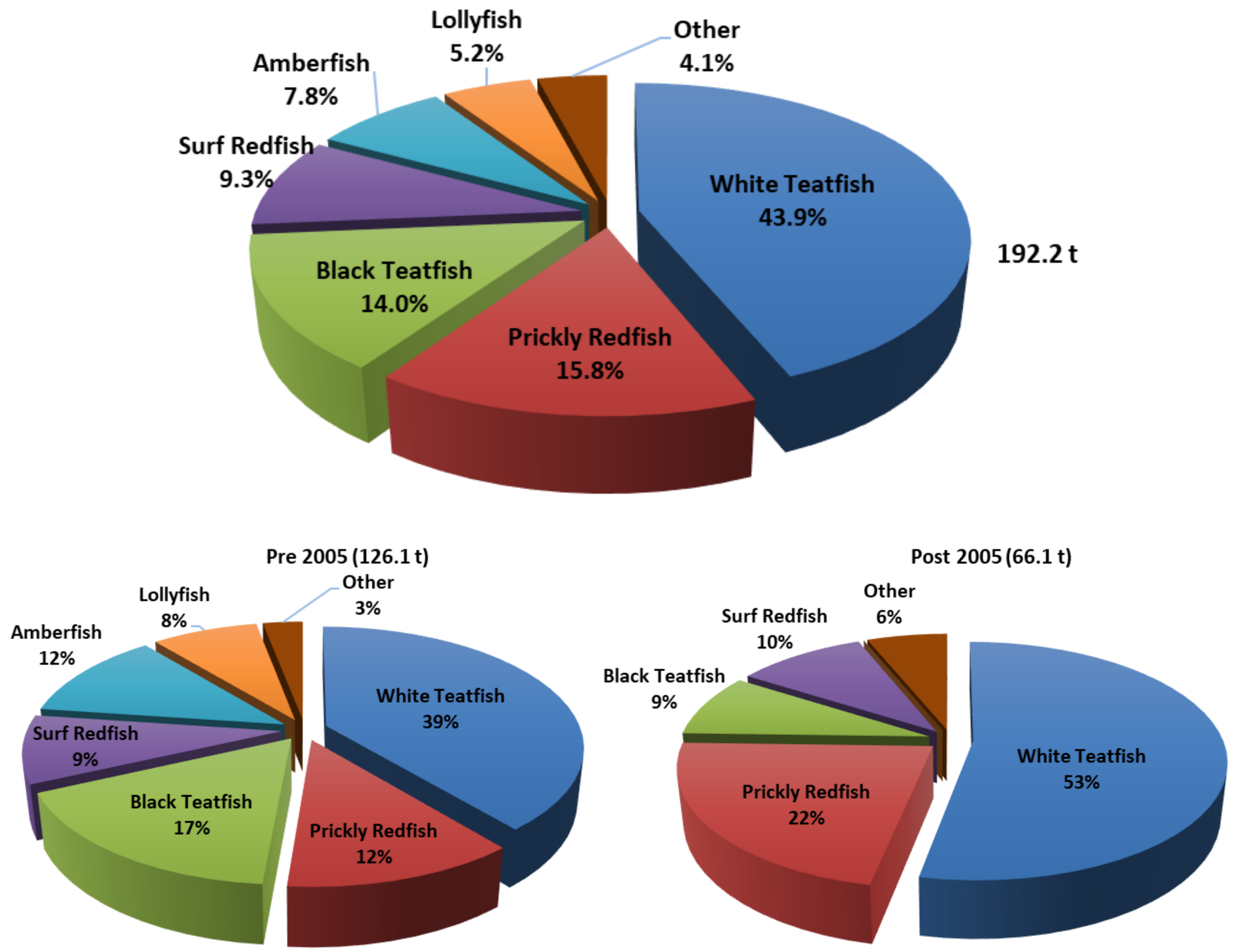


Figure 16. Breakdown of CSF catch for 1997-98 to 2022-23, and for pre-2005 and post-2005 (Top 6 species in catch weight only shown as individual species, making up 96% of the overall catch).

Table 2. Catch of Black teatfish and White teatfish in the CSF for the period 1997-98 to 2022-23 (t landed wt), catch per year (t/yr) and number caught for each species recorded in fishery logbooks. Also showing for pre-2004 and post 2004 data (CSF Logbook data).

					Pre-2005		Post 2005	
Common name	**Species name**	**Total (t)**	**Av. t/yr**	**Total (n)[4]**	**Total (t)**	**Av. t/yr**	**Total (t)**	**Av. t/yr**
Black Teatfish	*H. whitmaei*	26.8	1.03	28,702	21.2	2.64	6.0	0.32
White Teatfish	*Holothuria fuscogilva*	84.3	3.24	72,532	49.2	6.15	37.1	1.95

3.1.1 Black teatfish

Total catch of Black teatfish in the CSF since 1997-98 is 26.8 t (Table 2), and it is the third most important species in the fishery (after White teatfish and Prickly redfish; Figure 16).

The peak season for Black teatfish was in 2000-01 at 7.7 t (Figure 17), which was also peak catches for the CSF total catch (Woodhams et al., 2015; Noriega et al., 2022) (Figure 15). Since 2000–01, the annual commercial catch of Black teatfish has fluctuated between 0 t (several years) and 1 t (2002–03). A 1 t TAC was introduced in 2003 – before that the average annual catch was 3.5 t; after that it was 0.3 t per year.

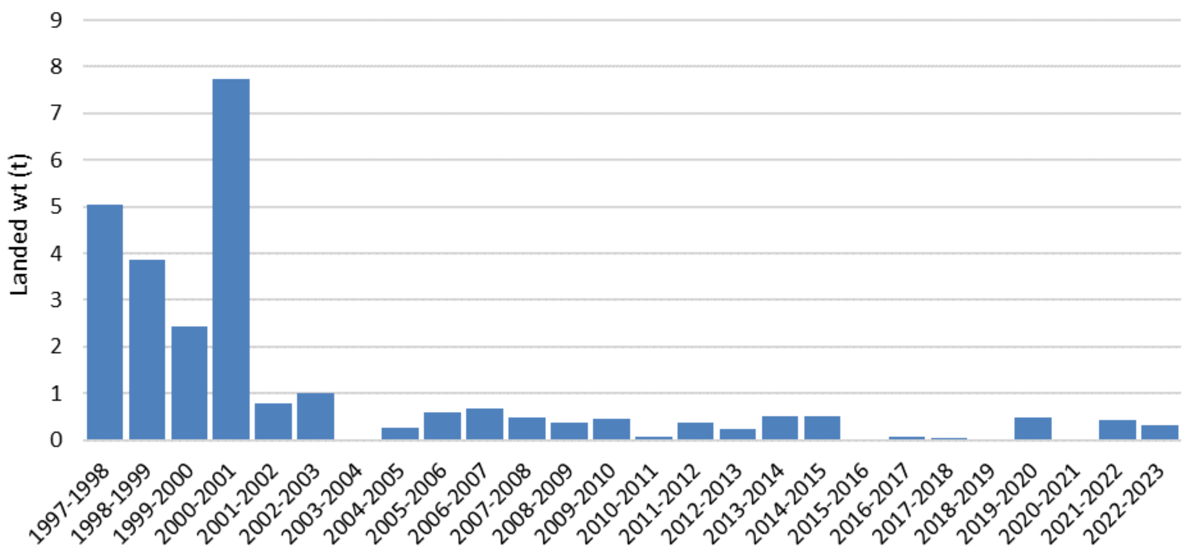


Figure 17. Catch (tonnes landed wt) of Black teatfish in the CSF for the period 1997-98 to 2021-22 (CSF vessel logbook data).

The highest Black teatfish catches have been taken from Wreck, Flinders Mellish and Homes Reefs, but the catch was spread over several reefs throughout the CSF area (Figure 18).

With respect to spatial fishing patterns, the logbook effort is reported in zones (roughly equivalent to reefs) for application of a rotational zone strategy (RZS). About 70% of the catch of Black teatfish came from 5 zones (Figure 19), and those plus an additional 5 zones accounted for more than 90% of the catch (Figure 19) – which was about 56% of all zones that had some Black teatfish catch in the CSF.

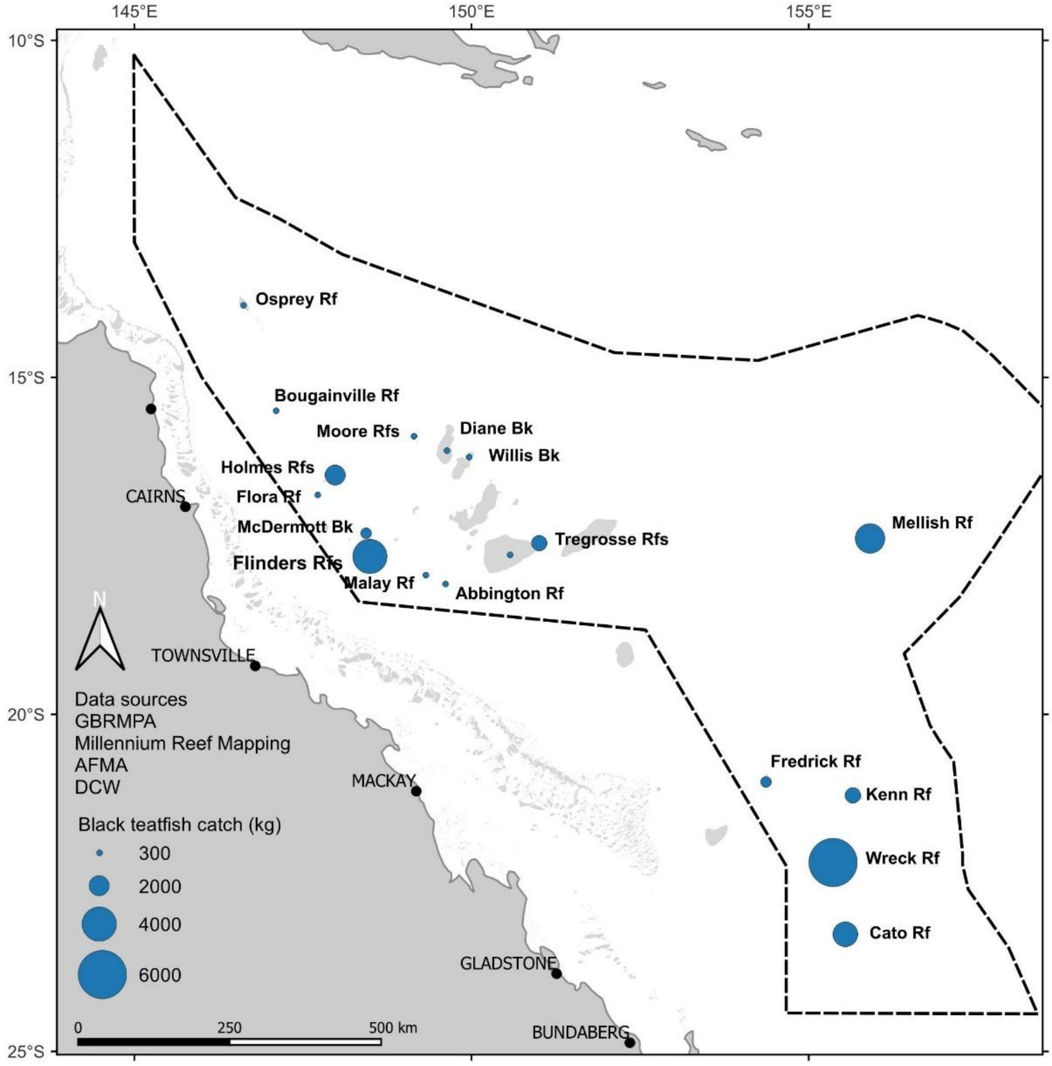


Figure 18. Catch (kg landed wt) of Black teatfish in the CSF by reef for the period 1997-98 to 2022-23 (CSF vessel logbook data)

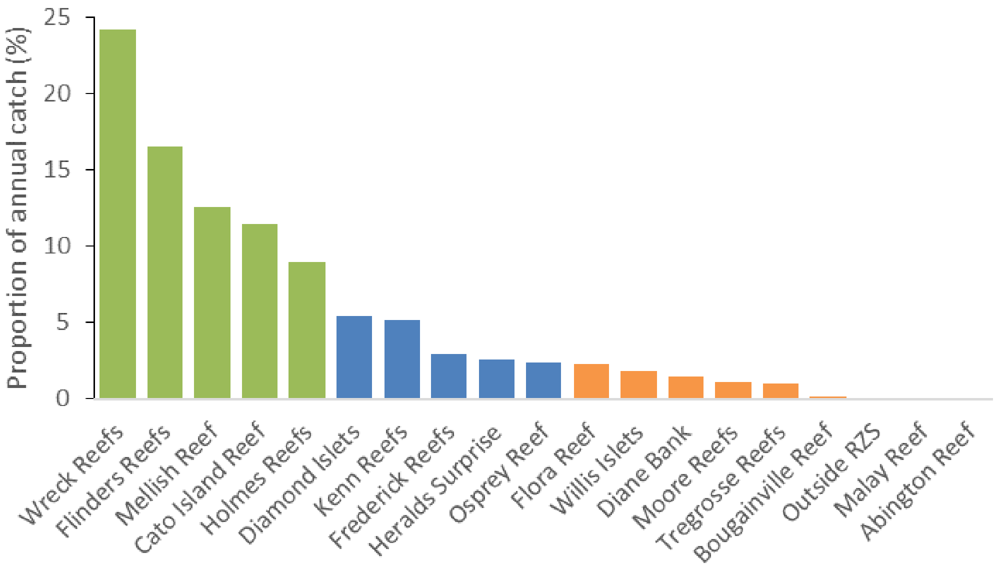
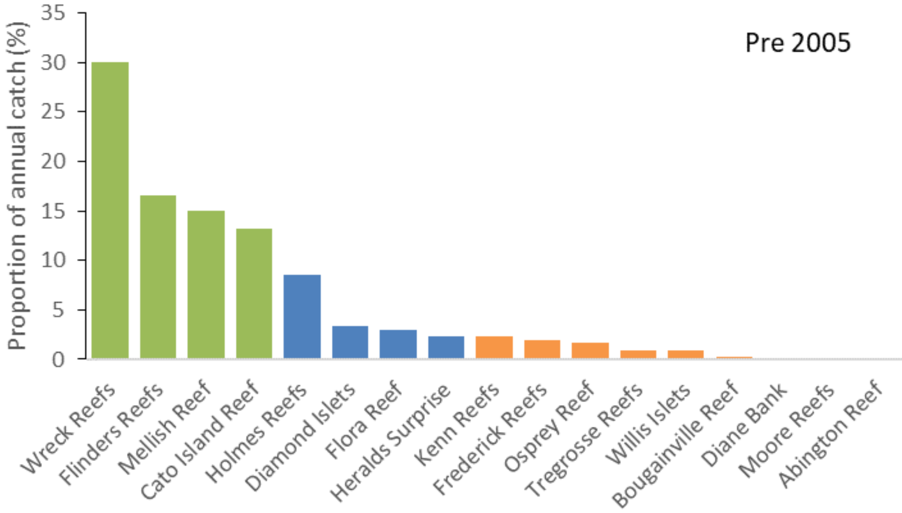


Figure 19. Catch (Proportion %) of Black teatfish in the CSF for the period 1997-98 to 2022-23 in RZS zones that comprise 70% (green) and 90% (green and blue) of the catch and the remainder in all other zones (brown) (CSF vessel logbook data).

About 79% (21.2 t) of the Black teatfish catch recorded in fishery logbooks was caught before the implementation of the rotational harvest arrangement in 2005 (RZS – Section 5.1.1.) compared to 21% (5.7 t) after (Figure 16). Even though the catch was lower after 2005, the catch was taken over more zones after 2005 than before – with 90% of the catch taken in 8 zones before 2005 compared to 11 zones after 2005 (Figure 20).



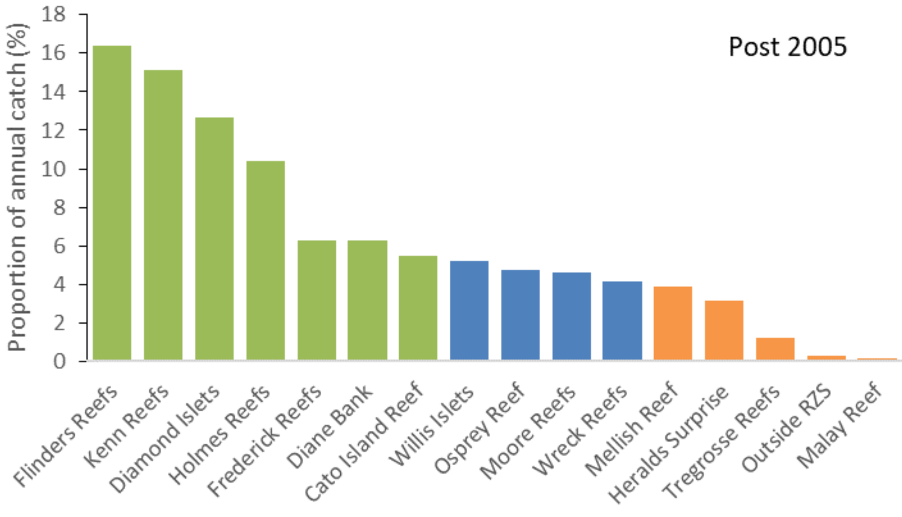


Figure 20. Catch (Proportion %) of Black teatfish in the CSF for the period 1997-98 to 2022-23 in RZS zones that comprise 70% (green) and 90% (green and blue) of the catch and the remainder in all other zones (brown) Top: before the implementation of the RZS in 2005, and Bottom: after (CSF vessel logbook data).

3.1.2 White teatfish

Total catch of White teatfish in the CSF since 1997-98 is 84.3 t (Table 2), and it is the most important species in the fishery (Figure 16).

The peak season for White teatfish was in 1999-2000 at 19.8 t (Figure 21), which was the second highest annual total catch for the CSF (Woodhams et al., 2015; Noriega et al., 2022) (Figure 15). Since 1999-2000, the annual commercial catch of White teatfish has reduced and fluctuated between 0 t (several years) and 12.3 t (2000–01). A 4 t TAC was introduced in 2003 – before that the average annual catch was 7.9 t; after that it was 1.9 t per year.

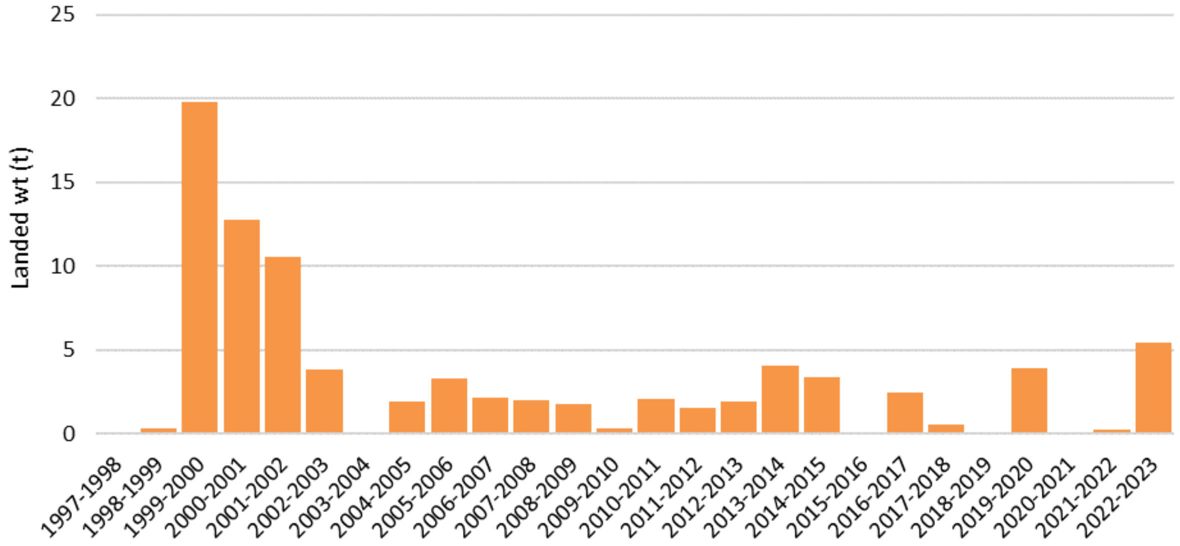


Figure 21. Catch (tonnes landed wt) of White teatfish in the CSF for the period 1997-98 to 2021-22 (CSF vessel logbook data).

The highest White teatfish catches have been taken from Flinders and Osprey Reefs (accounting for about 66% of the overall catch), with low levels of catch spread over most other fished reefs throughout the CSF area (Figure 23).

With respect to spatial fishing patterns, about 70% of the catch of White teatfish came from 3 zones (Figure 22), and those plus an additional 3 zones accounted for more than 90% of the catch – which was about 33% of all zones that had some White teatfish catch in the CSF.

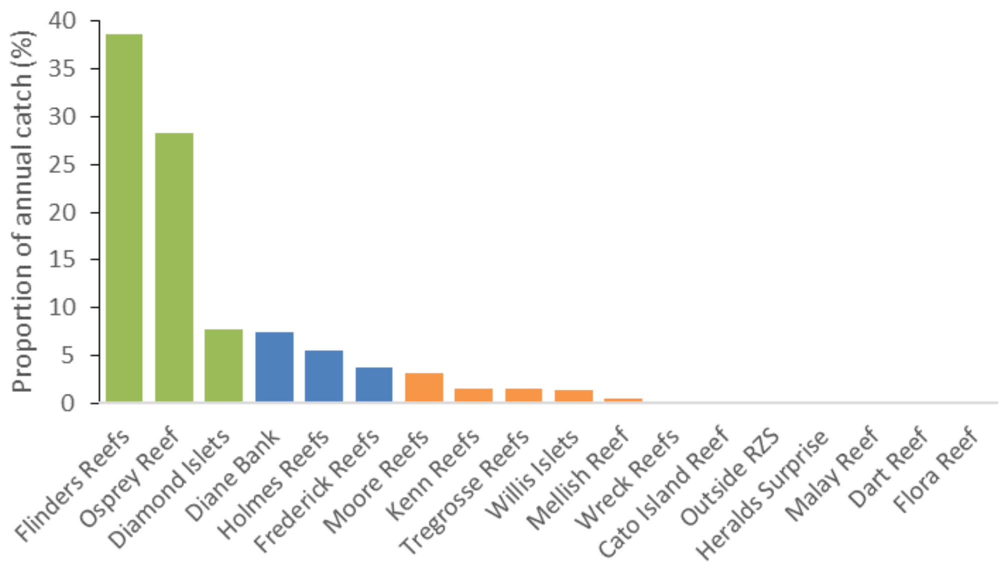


Figure 22. Catch (Proportion %) of White teatfish for the period 1997-98 to 2022-23 in RZS zones that comprise 70% (green) and 90% (green and blue) of the catch and the remainder in all other zones (brown) (CSF vessel logbook data).

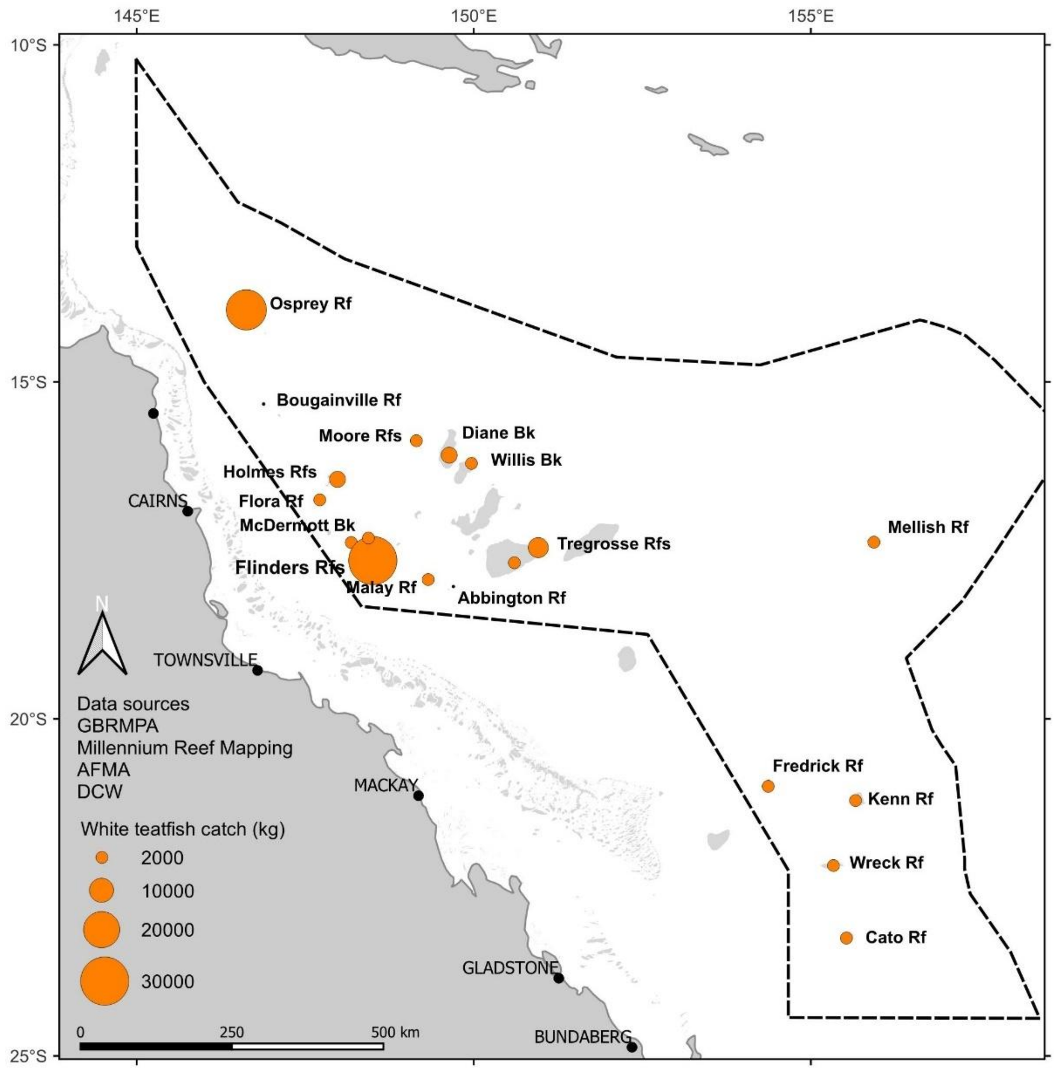


Figure 23. Catch (kg landed wt) of White teatfish in the CSF by reef for the period 1997-98 to 2022-23 (CSF vessel logbook data).

About 58% (49.2 t) of the Black teatfish catch recorded in fishery logbooks was caught before the implementation of the rotational harvest arrangement in 2005 (RZS – Section 5.1.1.) compared to 42% (35.1 t) after (Figure 16). Even though the catch was lower after 2005, the catch was taken over more zones after 2005 than before – with 90% of the catch taken in 3 zones before 2005 compared to 8 zones after 2005 (Figure 24).

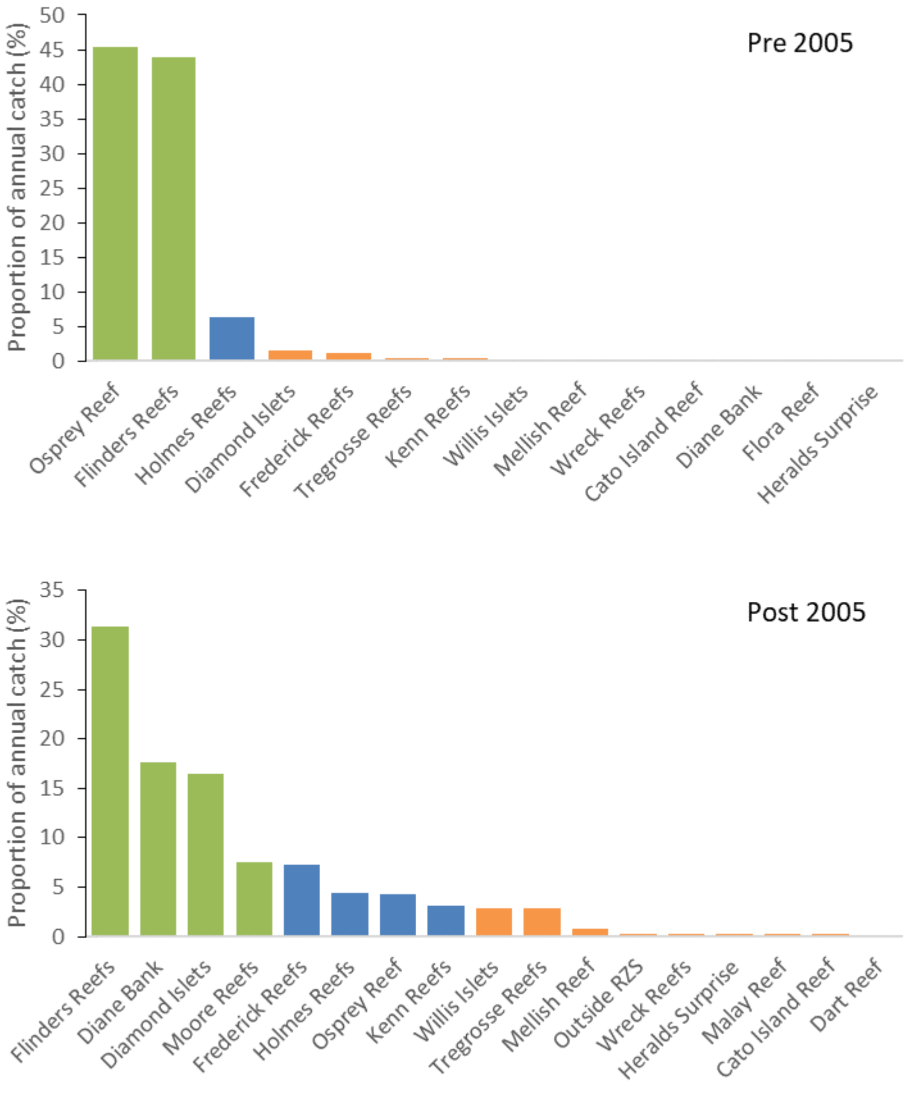


Figure 24. Catch (Proportion %) of White teatfish in the CSF for the period 1997-98 to 2022-23 in RZS zones that comprise 70% (green) and 90% (green and blue) of the catch and the remainder in all other zones (brown) Top: before the implementation of the RZS in 2005, and Bottom: after (CSF vessel logbook data).

3.1.3 Discards

Discard rates in the fishery are unknown but likely to be low (Furlani et al., 2007). Sea cucumbers are harvested by hand and fishers are likely to be selective. Undersize animals are likely returned to source habitats, though this is not reliably documented.

There is significant recreational fishing activity in the area of the CSF, however, this effort is mostly by charter operators targeting pelagic and reef fish (DEWHA, 2009). Recreational catch of sea cucumbers is not known but is likely to be negligible.

3.2 Illegal, unreported and unregulated (IUU) fishing

The reefs of the CSF have been subject to illegal fishing by foreign owned and crewed fishing vessels, predominantly by Vietnamese based fishing vessels (blue boats) focused on sea cucumber. This activity resulted in the sighting of 34 vessels in the CSF area, of which 6 were apprehended with illegal sea cucumber product in 2016 and 2017 (AFMA, unpublished data; Skewes, 2017). Over half (18) of the vessel sighting in the CFS were on Lihou Reef, with the remainder split equally at Dianne Bank, Willis Bank, Kenn Reef and Wreck Reef (AFMA, unpublished data). A further 15 vessel sightings and 7 apprehensions were carried out in the QSCF area (including Saumarez Reef) over the same period (AFMA, unpublished data; Skewes, 2017).

Of the vessels apprehended in the CSF area, the estimated catch on board was 18.8 t (gutted and salted weight), and an average of 3.1 t per vessel. This compares to 36.8 t of sea cucumber estimated on vessels apprehended in the QSCF area, at an average of 5.3 t per vessel (AFMA, unpublished data).

The species composition of the catch of IUU vessels in the CSF is not known. However, the catch of two vessels apprehended at Saumarez Reef (within the QSCF) indicated that they were mainly targeting White teatfish (86%), with smaller quantities of Black teatfish (10%) and only limited Prickly redfish (2%) (Skewes, 2017). It is likely that the catch was sourced from reef passes and deeper lagoon habitats of the Coral Sea reefs, as indicated by ship logs and plotter information found on board (AFMA, unpublished data; Skewes, 2017).

As of 2023, there had been no confirmed sightings of FFVs in the Coral Sea since 2016–17 (AFMA, 2023, pers. comm., reported in Noriega and Curotti, 2023).

Table 3. Catch estimate of a FFV apprehended at Saumarez Reef in February 2017, in t salted and live weight (Skewes, 2017).

CATCH (T)	WHITE TEATFISH	BLACK TEATFISH	PRICKLY REDFISH	LEOPARD FISH	REDFISH	STONE FISH	TOTAL
Salted weight	5.32	0.61	0.12	0.05	0.05	0.05	6.19
Live weight	12.26	1.15	0.24	0.11	0.11	0.11	13.98

4 Stock trends and stock assessments

4.1 Fishery independent data (surveys)

There has not been a comprehensive survey of sea cucumber populations in the CSF. However, there has been one dedicated commercial sea cucumber survey that visited six reefs of the CSF in 2017 (Skewes and Persson, 2017) and several other “reef health” surveys that included sea cucumber that have visited many of the shallow reef systems in the CSF area over the years, but heavily focussed on the long term NNR of Lihou and Coringa Herald reef systems (Ceccarelli et al., 2013; Hoey et al., 2023b).

Reef health surveys 2003-2008.

Four previous surveys of reefs in the two Coral Sea NNR (Coringa Herald and Lihou) were carried out between 2003 and 2009 primarily for ecological and reef health purposes. These surveys used several visual census sampling techniques to estimate the cover of coral, fin fishes and benthic invertebrates, including sea cucumbers. The surveys included (from a summary in Woodhams et al., 2016):

- Coringa-Herald NNR, March-April 2003 (Oxley et al., 2003)
- Lihou NNR, March 2004 (Oxley et al., 2004)
- Coringa-Herald NNR, May and October 2007 (Ceccarelli et al., 2008)
- Lihou NNR, December 2008 (Ceccarelli et al., 2009).

The surveys produced density estimates for several sea cucumbers in several locations within the NNRs, with dive locations on the reef flat and slopes down to 20 m deep in some years. The survey found that sea cucumber populations were generally lower in species diversity and density than the GBR. This research also indicated that the Coral Sea reefs are subject to a high degree of disturbance, with exposure to a high frequency of tropical cyclones and coral bleaching events (Ceccarelli et al., 2013).

The density estimates from the 2003-2008 reef health surveys (Oxley et al., 2003; 2004; Ceccarelli et al., 2008; 2009) were compiled to produce a CSF-wide density estimates that were then applied to estimates of fishery habitat (except for Cato and Mellish Reefs) to derive “plausible potential biomass scenarios” of population size for several species including Black teatfish in the CSF in 1997 (Woodhams, 2015) (Table 4). They used simulations based on several assumptions to estimate biomass for the CSF (Table 5), using a mean animal weight from logbook data (average weight of Black teatfish = 0.98 kg (s.e. 0.2)).

Data for White teatfish were insufficient for the analysis.

Table 4. Raw survey density and modelled density used to estimate population size for Black teatfish in the CSF in 1997 (Woodhams et al., 2015).

Habitat	N	Raw density (Ha^{-1})	Overall mean population density (Ha^{-1})	Lower confidence interval (95%) (Ha^{-1})	Upper confidence interval (95%) (Ha^{-1})	Reef density variance
Fore reef	14	3.93	3.39	1.38	9.5	34.61
Inner slope	10	8.00	7.34	3.61	16.18	67.65
Reef flat	15	4.33	4.14	2.25	7.98	20.62
Subtidal reef flat	3	2.33	–	–	–	–

Table 5. Estimates of Black teatfish population (numbers) biomass (landed weight) for the CSF (Woodhams et al, 2015)

	N (median)	N (20th percentile)	Biomass (t) median	Biomass (t) 20th percentile
Total open	338,154	163,190	331.4	159.9
Total reserves	222,183	180,014	217.7	176.4
Total	560,337	343,204	549.1	336.3

According to their estimate, Black teatfish was the most abundant commercial species in the CSF, with the second highest biomass (after Prickly redfish), with a median biomass (landed weight) of 549 t, and a lower 20th percentile of 336 t (Table 5).

The highest population biomass was for Lihou Reefs with 214 t (a closed reef), followed by Flinders Reefs with 113 t (Woodhams et al., 2015). Overall, they found that 40% of the population was in closed reefs (the NNR at that time - closed areas have increased since then) using the median biomass estimate, and 52% of the population using the lower 20th percentile estimate. They would go on to apply a surplus production model to this data to assess stock status and calculate MSY (Table 5, next section).

They indicated that the model was likely to underestimate the true population size (for example Cato and Mellish Reefs were not included), and they did not include any contribution from "deep reef" (>20 m) habitat due to poor data representation. However, a major uncertainty was the application of density estimates from the 2 NNRs to the entire CSF.

Sea cucumber survey – Coral Sea, 2017.

The first dedicated fishery independent sea cucumber survey occurred in 2017, on 6 reefs of the CSF (and also included Marion and Saumarez Reefs which are in the QSCF) (Skewes and Persson, 2017). The surveyed reefs and habitats that included an estimated 36% of the shallow (<20 m) reef and 1.5% of the deep (20-70 m deep) reef habitats of the CSF (Table 6). (For all species in the CSF reanalysis, see Appendix C).

Table 6. Proportion (%) of shallow (<20 m deep) and deep reef (20-70 m deep) surveyed habitats in the CSF, and proportion of overall area sampled during the 2017 survey (Skewes and Persson, 2017).

Habitat	Surveyed habitat proportion (%)	Proportion sampled (%)
Shallow	13.1	35.8
Deep reef	86.9	1.5
Overall	100.0	6.0

Black teatfish had an overall density of 1.4 per ha on the sampled CSF reefs, and was found on half the reefs sampled. It had its highest observed density on Lihou Reef and Herald Cays at about 2.6 per ha (Figure 25). It was found on most habitats but had its highest density on the lagoon pinnacles (27.8 per ha) and the inner reef slope and reef passes (Figure 26).

White teatfish had an overall density of 1.0 per ha on the sampled reefs, and was found on 4 out of 6 reefs sampled. It had its highest observed density on Lihou Reef at about 1.6 per ha (Figure 25). It was found on most habitats but had its highest density on the lagoon pinnacles (20.8 per ha) and reef passes (Figure 26).

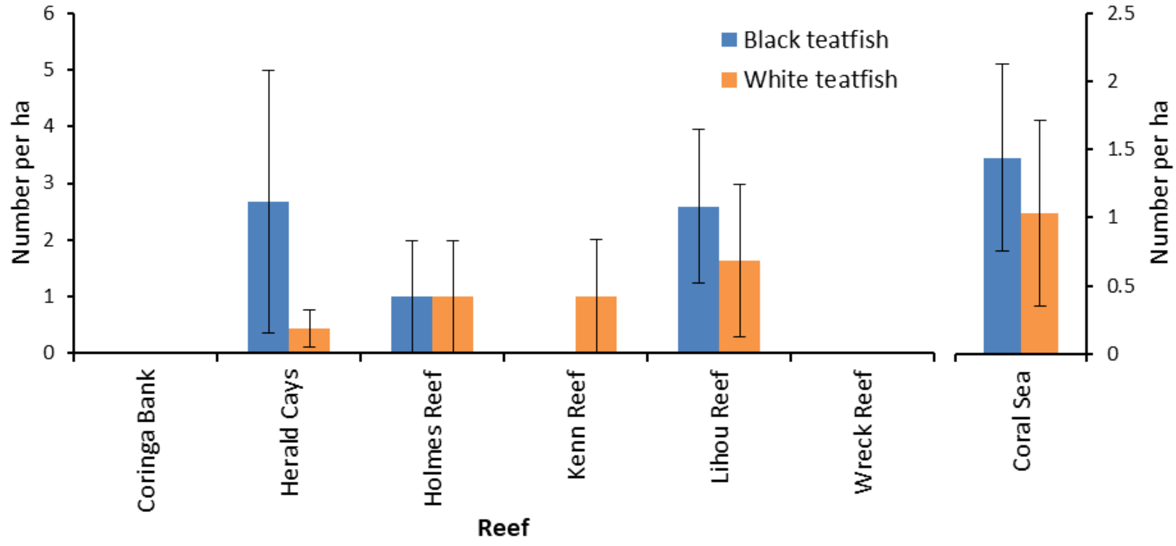


Figure 25. Density estimates of Black teatfish and White teatfish for each reef and for all reefs sampled during the 2017 in the CSF (Skewes and Persson, 2017).

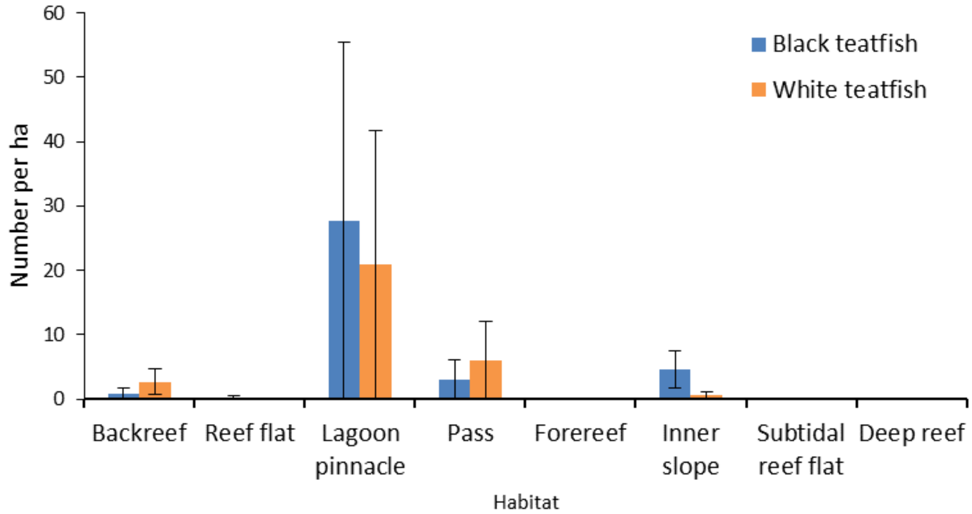


Figure 26. Density estimates of Black teatfish and White teatfish for each habitat surveyed in the 2017 survey of CSF reefs (Skewes and Persson, 2017).

The population biomass estimate for Black teatfish for the sampled reef-habitat combinations in the CSF (approx. 36% of shallow reef and 1.5% of deep reef habitat in the CSF) was 150 t landed weight (± 92 t; 80% CI) (Table 7). Lihou Reef had about 90% of the Black teatfish on the sampled reef-habitat combinations (Figure 27).

The population biomass estimate for White teatfish for the sampled reef-habitat combinations in the CSF was 116 t landed weight (± 99 t; 80% CI) (Table 7). Lihou Reef had about 79% of the White teatfish on the sampled reef-habitat combinations (Figure 27).

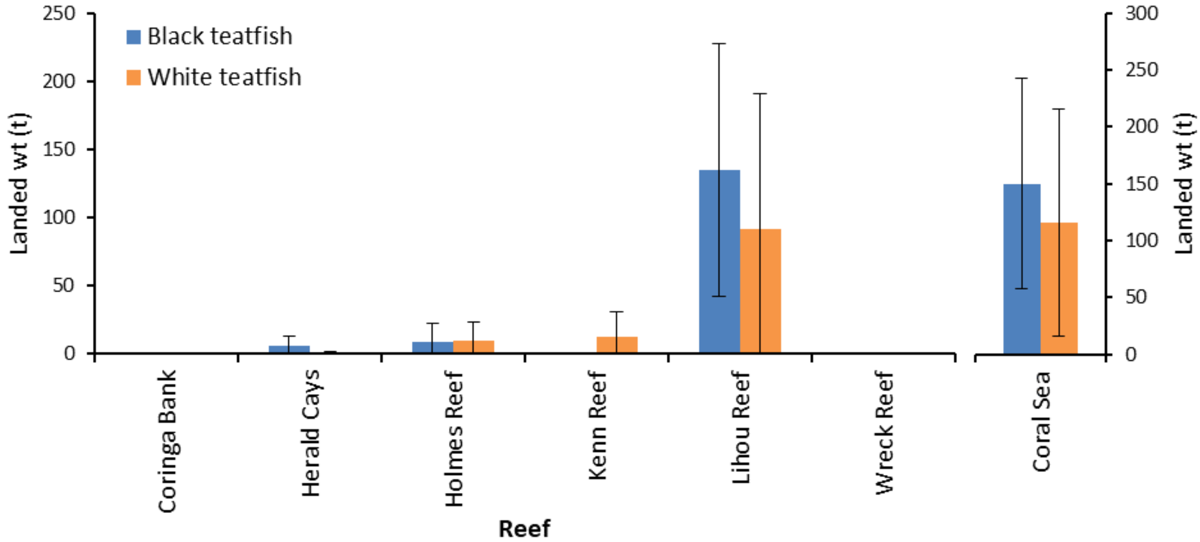


Figure 27. Biomass of Black teatfish and White teatfish on six reefs surveyed in 2017 in the CSF (Error bars are 80% CI).

Table 7. For Black teatfish and White teatfish, the average density, s.e., population stock estimate and landed (wet gutted) weight (N = 74) for sampled reef-habitat combinations (36% of shallow reef habitat and 1.5% of the deep reef habitats) in the CSF in 2017 (data from Skewes and Persson, 2017).

	Density	Density s.e.	Live weight (t)	Conversion factor	Landed weight (t)
Black teatfish	1.44	0.68	221.5	0.677	150.0
White teatfish	1.03	0.68	185.0	0.627	116.0

Coral reef health surveys, 2017-2023.

The density estimates for all species from those surveys (for up to 15 Coral Sea Reefs, including Marion, Saumarez and Ashmore Reefs) averaged 38 per ha in 2020, 56 per ha in 2021 and 38 per ha in 2022 and 24 per ha in 2023 (Hoey et al., 2020; 2021; 2023a; 2023b). All average densities were substantially lower than the 2017 sea cucumber survey densities of 133 per ha for all species combined (Skewes and Persson, 2017). However, these surveys were designed to provide robust estimates of coral and associated reef fish assemblages, and as such are not ideally suited to assess the population status of sea cucumbers, therefore they likely underestimate actual density (Hoey et al., 2023b).

Even so, the survey consistently observed Black teatfish each year surveyed (Hoey et al., 2023b) where they averaged about 3 per ha (Surf redfish and Prickly redfish generally having the highest density overall) (Hoey et al., 2021; 2022; 2023a; 2023b). White teatfish are generally not observed, probably due to the restricted depth and habitat preference for the shallow reef health surveys.

The surveys again showed that the density of sea cucumbers on Coral Sea reefs was generally lower than similar surveys on GBR reefs (though highly variable among reefs within each region) and were consistent with estimates of the density and richness of sea cucumbers from several previous studies (e.g. Oxley et al. 2003, 2004; Ceccarelli et al. 2008, 2009; Hoey et al., 2023a).

Uniquely, the recent reef health surveys have also included a deep reef survey using ROVs (Galbraith et al., 2023; Hoey et al., 2023b). Sea cucumbers observed during these deeper surveys have not yet been analysed (Galbraith et al., 2023; M. Hoey, 2023 pers comm.).

Comparing surveys

It is difficult to compare density and biomass estimates from the various surveys. While the 2017 survey was the only one to specifically target sea cucumbers, it suffered from a relatively small footprint and sample size. The Woodhams et al. (2015) analysis, while aimed at a fishery wide analysis, has some considerable uncertainty due to limited survey density data. Even so, the biomass estimates from that study and the 2017 survey are similar, due in part to the fact that the Woodhams study seed densities were considerably lower than the 2017 densities but was applied to a broader fishery area.

As for the reef health surveys, if they should continue, they may provide some useful information on the dynamics of sea cucumbers in the CSF, though the information would need to be provided in a more disaggregated way and with the caveat that it is from a limited habitat range.

All surveys indicated that, generally, sea cucumber densities were lower on Coral Sea reefs than on the GBR (Benzie and Uthicke, 2003; Skewes et al., 2014) and Torres Strait (Murphy et al., 2021a); apart from isolated high-density populations of Lollyfish (*H. atra*) and Greenfish (*S. chloronotus*) that are occasionally found on Coringa Bank, Herald Reefs and Lihou Reefs (Oxley et al., 2003, 2004; Ceccaralli 2007, 2009, Skewes and Persson, 2017) and probably reflects a lower overall carrying capacity on Coral Sea reefs to some extent at least.

4.2 Stock assessments

Logbook data analysis – 2002

The first attempt to assess stock status in the CSF was in 2002, which used logbook data and catch rates (CPUE) from 2000 and 2001 for a number of target species in the CSF (Hunter et al., 2002). Fishing records were spatially attributed to reefs and analysis undertaken comprised:

- daily and yearly total catch for each species, at each reef
- average dive time for both free-dive and hookah dive methods for vessels targeting sea cucumber
- CPUE (in kilograms per hour) for each species at each reef, daily and monthly.

Catch rates were standardised using linear models with trip and year as explanatory variables. Separate standardisations were undertaken for free-dive and surface supply (hookah) diving across five reefs and six sea cucumber species. In undertaking this work, they identified difficulties in separating catch according to the type of method applied (hookah or free-dive). There were also issues with the applicability of CPUE as an indicator of abundance for a highly targeted, spatially discrete, hand collection fishery.

CPUE of Black teatfish declined at Flinders, Cato and Wreck Reefs; White teatfish declined at Holmes and Flinders reefs, and prickly redfish declined at Osprey, Wreck and Flinders Reefs, although not to the same extent as Black teatfish.

The authors recommended considering further restrictions on the TAC of highly targeted species and modifying logbook design to incorporate recommended changes (to allow the separation of catches according to fishing method).

Following the assessment results and recommendations, AFMA reduced the existing TACs for White teatfish and Black teatfish to 4 t and 1 t respectively (AFMA, 2010).

RUSS project

The next attempt to assess the status of sea cucumber stock in the CSF was the RUSS (Reducing Uncertainty in Stock Status) project carried out by ABARES using data up to the 2009-10 fishing season (Woodhams et al., 2015). The RUSS project assessed the 4 primary target species, including Black teatfish and White teatfish (Woodhams et al., 2015).

The density estimates from the 2003-2008 reef health surveys (Oxley et al., 2003; 2004; Ceccarelli et al., 2008; 2009) were compiled to derive “plausible potential biomass scenarios” of population size in the CSF in 1997 (Table 9). Note: the biomass estimates from the RUSS study for Black teatfish were comparable to biomass estimates from the subsequent population survey carried out in 2017 (Skewes and Persson, 2017: see above) especially when extrapolated to the entire CSF, providing some support for the analysis outputs for Black teatfish at least.

They did investigate other potential assessment methods including catch per unit effort, size (weight) trends over time and stock depletion analysis. However, these methods were found to be inappropriate because of data quality/quantity issues or violation of assumptions that underlie the method (Woodhams et al., 2015). CPUE analysis was not considered to provide a reasonable index of abundance for several reasons related to: uneven distribution, patch targeting, variation in species targeting, variation in fishing methods, hyperstability, rotational harvesting arrangements, and a scarcity of data.

They applied two surplus production models: a Schaefer model and a Pella–Tomlinson production curve (where maximum production was set to occur at 75 per cent of the pre-fished biomass in 1997, B_0), with the later intended to reflect the Allee effect, where there is a reduced relative productivity with decreasing density, even to the extent that productivity is zero, which results in population extirpation. Median biomass for Black teatfish in both models was greater than 99% B_0 and no individual reef was found to drop below 70% B_0, even for the 20th percentile starting biomass scenarios (Table 8).

Sustainable yield was estimated using a formula adapted from Gulland (1983) by Perry et al. (1999) and used by Skewes et al. (2004) in assessing Torres Strait sea cucumber stocks: MSY=0.2*M*B, where *M*=natural mortality and B = biomass. For Black teatfish, *M* = 0.3 was applied, and the resulting MSY median estimate was 19.9 t per year for open reefs, but with a 20th percentile value of 9.6 t (Table 9).

Due to data deficiencies, White teatfish were not able to be reliably modelled.

Table 8. Proportion of starting (1997–98) biomass remaining in 2010 (%), and number of individual reefs below 70% biomass level, for the Schaefer and Pella–Tomlinson model, median starting biomass and lower 20th percentile biomass, for Black teatfish in the CSF in 2010 (Woodhams et al., 2015).

	Schaefer		Schaefer 20th perc.		Pella–Tomlinson		Pella–Tomlinson 20th perc.	
	%	No. <70%	%	No. <70%	%	No. <70%	*	No. <70%
Black teatfish	99	0	99	0	100	0	100	0

Table 9. Estimates of population biomass (landed weight) and maximum sustainable yield (landed weight) for Black teatfish in the CSF (Woodhams et al., 2015)

Species	Biomass (t) mean	Biomass (t) 20th perc.	Closed median (%)	MSY (t) Total (median)	MSY (t) Total (20th perc.)	MSY (t) Open (median)	MSY (t) Open (20th perc.)
Black teatfish	549.1	336.3	40%	32.9	20.2	19.9	9.6

The study outputs meant that they classified Black teatfish “not overfished” and “not subject to overfishing”. For White teatfish, the stock status remained uncertain with respect to being overfished and overfishing.

They also recommended that the RZS be revised based on the reef level outputs from the analysis, based primarily on potential habitat areas, estimates of population size and sustainable yield and the regularity with which reefs are open to fishing. The authors also recommended against the strict application of median MSY estimates as TACs for future application (Woodhams et al., 2015).

Coral Sea MSE

An additional component of the RUSS project was the implementation of an MSE to the CSF sea cucumber sector (Plaganyi et al., 2011), using the outputs described above, with the focus on testing the utility and robustness of the HS to meet the fishery objectives. Although it found that there were large uncertainties in assessing the status and trends of the CSF sea cucumber populations, it was still able to discriminate between the performance of different harvest strategies. It found that there is a substantial decrease in risk to the resource (in terms of local and overall depletion) due to the implemented rotational zone strategy coupled with move-on provisions.

It found that the Black teatfish and White teatfish TACs are low enough to pose minimal risk to the resource. It also concluded that reef choice models based on profitability resulted in much heavier depletion of reefs close to the major ports because of the large travel distances to some reefs in the CSF, with a large associated risk of depletion to the resource. Its outputs indicated that under a fully implemented RZS, it may not be possible to achieve the full TAC for all species in all years.

The risks to the resource are substantially reduced because of the relatively large area of reef protected by the Lihou and Coringa-Herald National Nature Reserves. The biomass in these closed areas was explicitly included in the model.

The starting biomass for species assessed in the MSE (Black teatfish, 1036 t; White teatfish, 321 t) are greater than those reported by available survey data (Woodhams et al., 2015; Skewes and Persson, 2017) therefore the conclusions as to the risk associated with those species should be used with caution.

2017 stock survey

Although the results of the 2017 population survey (Skewes and Persson, 2017) have not been used in a numeric stock assessment, the outputs have been used to infer stock status using a number of inferences and a “weight of evidence” approach:

Black teatfish

Black teatfish density was relatively low overall (1.44 per ha), and lower than previous surveys (4.5 per ha; Ceccarelli et al., 2008; 2009) and lower than comparable reefs in the Torres Strait (9.4 per ha; Skewes et al., 2010) and the GBR (21 per ha for closed and 5 per ha for open reefs; Uthicke and Benzie, 2000). The low population density and downward trend of Black teatfish would appear to indicate some fishery related depletion of this species. Even so, the estimated landed weight biomass, 150 t, was large in relation to the known annual catch of the CSF of about 1 t per year; and the estimated catch for one apprehended FFV of 0.6 t (Skewes, 2017).

White teatfish

White teatfish was found in very low densities throughout the study area, but was particularly scarce on the southern reefs, and was not seen at all on Wreck Reef. It was thought at the time that this low density could be due to heavy fishing pressure by the Australian CSF catch and recent illegal fishing by FFV. However, it may also be that this species is rare in the southern reefs in any case (see above).

It was also acknowledged that the estimated population size for White teatfish from this survey was likely underestimated due to limitations on survey depth (generally <20 m) and sea cucumber visibility, especially of juvenile White teatfish (Skewes and Persson, 2017). Isolated reef pinnacle and deep reef structures are likely to hold White teatfish populations that would be largely protected from fishing (Murphy et al., 2021a; Koopman, M., Knuckey, I., 2021).

Fishery Catch per unit effort (CPUE)

There are several limitations with respect to using catch per unit effort (CPUE) as a proxy for density/abundance for sea cucumber fisheries, including (but not limited to) hyperstability, differential targeting, spatial and habitat variations, and changes in fisher effort efficiency. However, it is still likely that reduced fishery density/abundance is reflected as a reduction in CPUE, especially over the long term.

Catch per day for Black teatfish is greatly reduced from about 1999-2000 (Figure 28) averaging 408 kg per for the first two years and 45 kg per day after that. The cause of this decline could be related to local fishery depletion (Hunter et al., 2002) or shifting fishery focus (Skewes et al., 2014; Eriksson and Byrne, 2015).

Average annual catch per day of White teatfish was variable, averaging 235 kg per day (Figure 29). The cause of this variability in catch rates is not known, however, this could be related to variability in fished areas and/or species targeting by fishers. In any case, there is no indication that catch per day had declined over the period of the fishery.

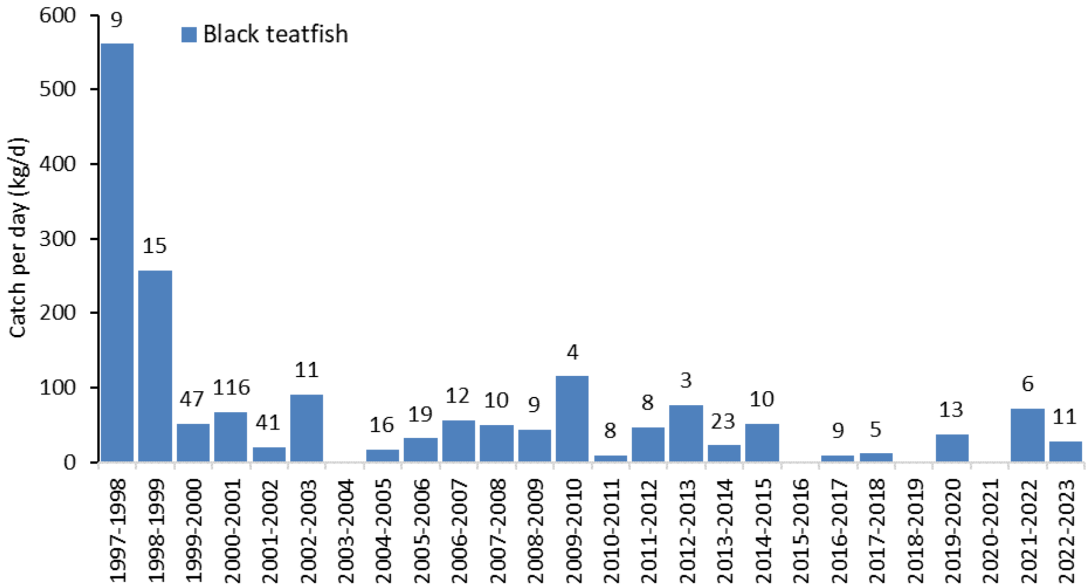


Figure 28. Annualised average catch per day (kg/d) of Black teatfish for the period 1997-98 to 2021-22 for vessels fishing in the CSF on days when Black teatfish occurred in the catch (Numbers are number of days) (CSF vessel logbook data).

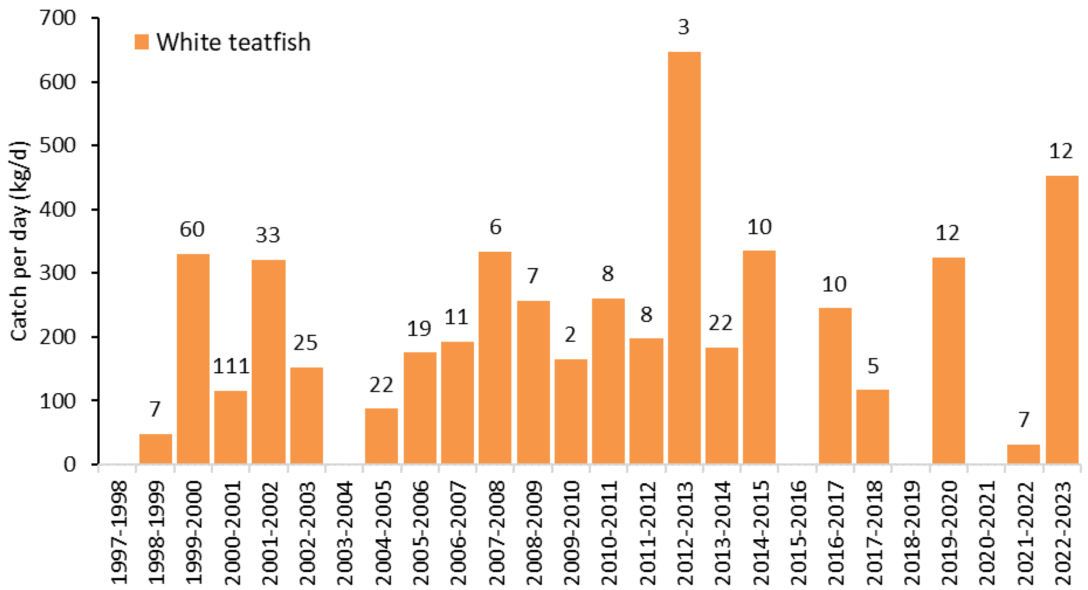


Figure 29. Annualised average catch per day (kg/d) of White teatfish for the period 1997-98 to 2021-22 for vessels fishing in the CSF on days when White teatfish occurred in the catch (Numbers are number of days) (CSF vessel logbook data).

ABARES Fishery Status Reports

Annually, ABARES reviews the available information and assesses the status of Commonwealth fisheries. They make a determination on the fishing mortality status (is it being overfished or not); and population biomass status (is it overfished to be the limit reference point (LRP) or not). As for the definition of LRP, ABARES equates this to a biomass limit (B*lim*) "where the risk to the stock is regarded as unacceptable" as defined in the Commonwealth Fisheries Harvest Strategy Policy (HSP; DAWE, 2018). The Harvest Strategy Policy (HSP) specifies default LRP as half the biomass required for MSY ($0.5B_{MSY}$) or 20 per cent of the unfished biomass ($0.2B_0$). The HSP requires that fish stocks remain above a biomass level reference point, where the risk to the stock is regarded as unacceptable (B*lim*), at least 90 per cent of the time (DAWE, 2018).

In assessing biomass status, ABARES considers whether the biomass of a stock is above or below the limit reference point (B*lim*). If biomass is below this level, a stock is considered to be overfished. ABARES uses a weight-of-evidence approach to determine status (ABARES, 2022; Stobutzki et al., 2015).

Note that the level of risk (10% chance of depleting a fishery below B*lim*) is likely too high for a CITES listed species, given that the consequence of such an occurrence may lead to at least localised extinction. Also, there have been no specific B*lim* determined for sea cucumber species, and the default HSP B*lim* of $0.2B_0$ is likely to be too low for sea cucumbers (being based on generic indices for finfish) due to the likelihood of significant depensatory (Allee) effects on population productivity at low population densities (Hutchings, 2015; González-Durán et al., 2018), and sea cucumbers important ecological role in maintaining the health of coral reef systems (Purcell et al., 2016a).

In the most recent assessment (for the 2021-22 fishing year; Noriega and Curtotti, 2023), Black teatfish and White teatfish were assessed as uncertain for biomass status and fishing mortality – a change from more positive assessments (for Black teatfish at least) that occurred up to 2021 (Table 10).

This assessment was mostly based on the outputs of the 2017 survey (Skewes and Persson, 2017) where Black teatfish survey densities were assessed as being well below comparable fishery areas (see above), and there was considerable uncertainty regarding the White teatfish population size. As it was uncertain whether both stocks were above or below the B*lim*, it was not possible to determine whether even the low recent catches would allow biomass to remain above the LRP or prevent biomass from rebuilding to the B*lim*, therefore fishing mortality status was classified as uncertain (Noriega and Curtotti, 2023).

Table 10. Biological stock status of sea cucumber stocks in the CSF, as Fishing mortality status (is it being overfished or not); and Biomass status (is it overfished or not). For the target species: Black teatfish and White teatfish for the period 2017 to 2022. Source: ABARES Fishery status reports 2018-2022 (see Noriega and Curtotti, 2023 and previous).

	2017		2018		2019		2020		2021		2022	
Stock	Fishing mortality	Biomass	Fishing mortality	Biomass	Fishing mortality	Biomass	Fishing mortality	Biomass	Fishing mortality	Biomass	Fishing mortality	Biomass
Black teatfish (*Holothuria whitmaei*)	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Yellow
White teatfish (*Holothuria fuscogilva*)	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow

Green	Not subject to overfishing/Not overfished
Yellow	Uncertain

4.3 Ecological Risk Assessment (ERA)

An Ecological Risk Assessment for Effects of Fishing (ERA) for the CSF sea cucumber sector was carried out in 2007 (Furlani et al., 2007). An expert judgement-based Level 1 analysis (SICA – Scale Intensity Consequence Analysis) resulted in a Moderate Risk for Black teatfish (the only species assessed as it was considered the most at risk species) resulting from fishing pressure, requiring either direct management of identified risks or further risk assessment.

Habitats and communities were also assessed in 2007. Results indicated that the translocation of species from inshore areas via hull and anchor fouling to offshore areas, impacting species, habitats and communities, remained as a moderate or higher risk from the direct impact of fishing. The assessment did not include management actions that occurred during the ERA implementation, such as catch reductions on BTF, harvest strategy, rotational zone strategy.

There have been no further ecological risk assessments of the CSF sea cucumber sector (Noriega, 2022). The ERA was scheduled to be updated with the latest stock, environmental and management information in 2022-23, although this has not yet been completed.

5 Management

5.1 Current management

The CSF sea cucumber sector is one of four sectors in the CSF and is managed by AFMA under the *Fisheries Management Act 1991* (the Act) (AFMA, 2021a). Commercial fishers are allowed to fish in in the fishery area under permit with conditions. A decision to re-grant permits is made each year under the Act. Policies such as harvest strategies, bycatch and discard workplans and voluntary industry codes also contribute to the management of the fishery. Fishers are also subject to spatial management under the Coral Sea Marine Park (CSMP) Management Plan.

The following conditions (equivalent to input and output controls) relate to the sea cucumber sector of the CSF (AFMA, 2020; 2021a; Director of National Parks, 2018):

- Limited entry - 2 permit holders.
- Catch limits – Individual (per permit) TACS for 5 priority species and trigger limits for remaining species, and an overall fishery TAC of 150 t (75 t TAC per permit) (Table 11):
  - Black teatfish – 1 t TAC (500 kg per permit)
  - White teatfish – 4 t TAC (2 t per permit)
  - Prickly redfish – 20 t TAC (10 t per permit)
  - Surf redfish – 10 t TAC (5 t per permit)
  - Sandfish – 1 t TAC (500 kg per permit) (Note: sandfish are unlikely to be found in the CSF)
  - Greenfish (*Stichopus chloronotus*) and lollyfish (*H. atra*) - 10 tonne combined trigger limit.
  - All other species are subject to a 5 t trigger limit
- Move-on provisions - Once 5 t of any mixture of sea cucumber species has been taken from any location within the fishery, no further fishing may be undertaken within a 15 nautical mile anchorage during the fishing year.
- Gear restrictions (hand collection with or without underwater breathing apparatus).
- Effort restrictions (maximum of seven divers and two tender boats per permit).
- Rotational zone strategy (RZS) - 19 zones (reefs) with a total of 129 fishing days allocated roughly proportional to size and a 3-year cycle (each zone fished only once per 3-year cycle). The days allotted are fished on a competitive basis. It is the permit holder's responsibility to ensure that they do not exceed the number of days allotted (AFMA, 2021a). Note that Saumarez and Marion Reefs, as part of the Queensland East Coast Sea Cucumber Fishery (QSCF), is also part of a similar RZS that is implemented in that fishery. Ashmore and Boot reefs, which are fished under permit by fishers from the QSCF, has its own 3-year rotation implemented by agreement between industry and Queensland Fisheries. Research on both the Coral Sea (Plaganyi et al., 2011) and GBR fisheries (Skewes et al., 2014; Plaganyi et al., 2015) have indicated that risk of overexploitation was reduced under a RZS for sea cucumbers.
- Spatial closures - The CSMP National Park zone (IUCN II) prohibited commercial fishing activities (both fishing and processing) including hand collection (See below for estimate of fishery habitat in that zone).
- Fishing activity limitations – Permit holders must not fish outside the CSF if fishing activity has been undertaken in the CSF, unless prior approval has been granted by AFMA (also known as dual jurisdiction trips); and they must not transfer fish from one vessel to another while at sea, unless explicitly authorised (also known as transhipping).

The following conditions relate to the operation of the fishery in relation to compliance and interactions with protected species:

- Fish Receiver Permits - Operators in the CSF are required to unload their catch to a licensed Commonwealth fish receiver permit holder

- Fishery Observers - A fishing operator must carry an AFMA observer upon request by AFMA (this has never occurred for the sea cucumber sector permit)
- Protected species interactions - interactions with protected species must be entered in a Listed Marine and Threatened Species (TEP) Form (located at the back of your logbook). (For a definition of “interaction” see AFMA, (2021)).

There are also minimum size limit (MSL) “guidelines” for sea cucumber (see Table 11 below) which are implemented through a voluntary agreement with industry. They are intended to allow individuals to breed once before being fished. (Note: as these are voluntary, the MSL have not been listed in the Management Booklets published by AFMA since about 2019).

It is also governed by a harvest strategy that outlines actions based on catch triggers that mostly take the form of initiating further analysis and assessment (see section below).

Table 11. Species TAC/trigger limits and minimum size limits (voluntary) for the sea cucumber sector of the CSF (AFMA, 2021a, 2021b).

Common name	Species	Total Allowable Catch/Trigger limits	Minimum size limit (voluntary)
Black teatfish	*Holothuria whitmaei*	1 tonne	25 cm
White teatfish	*Holothuria fuscogilva*	4 t	32 cm
Prickly redfish	*Thelenota ananas*	20 t	30 cm
Surf red fish	*Actinopyga mauritiana*	10 t	15 cm
Sandfish	*Holothuria scabra*	1 tonne	16 cm
Greenfish and Lollyfish	*Stichopus chloronotus and Holothuria atra*	10 t	15 cm
Other species		10 t	15 cm
All species of the Order Aspidochirotida		150 t (including the take of the above species)	15 cm

Table 12. Sea cucumber sector rotational zone strategy (AFMA, 2021a)

2021-22		2022-23		2023-24	
Days permitted	Zone	Days permitted	Zone	Days permitted	Zone
15	Wreck Reefs	15	Flinders Reefs	15	Holmes Reefs
5	Tregrosse Reefs	15	Willis Islets	15	Diamond Islets
5	Moore Reefs	5	Dianne Bank	10	Kenn Reefs
5	Cato Island Reef	2	Malay Reef	5	Frederick Reefs
5	McDermott Bank	2	Abington Reef	2	Bougainville
2	Dart Reef			2	Flora Reef
2	Heralds Surprise				
2	Shark Reef				

5.1.1 Rotational Zone Strategy

Rotational zone strategy (RZS) was first implemented in 2005 and modified in 2018 (due to the new closed areas implementation at Osprey, Mellish, Kenn (~50%) and Bougainville Reefs (~75%)). The CSF area is divided into 19 zones (roughly equivalent to reefs; Appendix D; Table 19, Figure 36) with a total of 129 fishing days allocated roughly proportional to size and a 3-year cycle (each zone fished only once per 3-year cycle) (Table 13; Appendix D) (before 2018 it was 21 zones with a total of 144 fishing days). The days allotted are fished on a competitive basis, and it is the permit holder's responsibility to ensure that they do not exceed the number of days allotted (AFMA, 2021a). Note that Saumarez, Marion, Ashmore and Boot Reefs, as part of the QSCF, are also part of a similar RZS that is implemented in that fishery. Research on both the Coral Sea (Plaganyi et al., 2011) and GBR fisheries (Skewes et al., 2014; Plaganyi et al., 2015) have indicated that risk of overexploitation was reduced under a RZS.

Note: not all fishing is associated with a RZS zone – e.g. "Unnamed shoal 2" was fished on two occasions, resulting in a catch of 0.63 t, mostly Prickly redfish, and Cairns Seamount was fished on one occasion, resulting in a catch of 0.08 t.

The implementation of the RZS appears to have spread the effort in the fishery. Before the implementation, 89.1% of the average annual catch came from just 5 reefs, whereas after the implementation, the 5 top reefs only contributed 65.9% of the catch (Figure 37). Flinders reef was still the most important reef before and after the RZS implementation, but Osprey and Wreck reefs were targeted much less so (even before the closure of the former in 2018).

Compliance with RZS allocations appears to be high. Apart from 2 reefs fished out of sequence in 2006-2007 for a total of 5 days, and one reef that was fished for 1 day over its allocation in 2022-2023, fishers complied with the RZS during 161 fishing days fished in RZS zones between 2005-2006 and 2022-2023 (Appendix D).

There is a wide range in the proportion of allocated fishing days that are fished for each zone from a high of 53.3% for Flinders Reefs to zero for 5 zones since the implementation of the RZS (Table 13). So although not a breach of the RZS allocations, it still illustrates the preferential targeting of some reefs – potentially due to proximity and high catch rates.

Table 13. Zone allocations and fishing days for period 2005-2006 to 2022-2023, and proportion of total fishing days used over that period.

Zone	Allocated	Fished	%
Abington Reef	12		0
Bougainville Reef	12		0
Cato Island Reef	30	10	33.3
Dart Reef	12	1	8
Diamond Islets	90	22	24.4
Diane Bank	30	11	36.7
Flinders Reefs	90	48	53.3
Flora Reef	12		0
Frederick Reefs	30	14	46.7
Heralds Surprise	12	2	16.7
Holmes Reefs	90	7	7.8
Kenn Reefs	60	13	21.7
Malay Reef	12	2	16.7
McDermott Bank	30		0
Mellish Reefs	25	2	8
Moore Reefs	30	5	17
Osprey Reef	150	10	6.7

Shark Reef	12		0
Tregrosse Reefs	30	3	10
Willis Islets	90	6	6.7
Wreck Reefs	90	5	5.6
Outside RZS		2	
Grand Total	**949**	**163**	

5.1.2 Harvest strategy

In 2008, a formal Harvest Strategy (HS) was implemented in all sectors of the CSF as part of a rollout of HS in Commonwealth Fisheries in response to the Commonwealth Fisheries Harvest Strategy Policy 2007 (HSP) (DAFF, 2007) which directed that Commonwealth fisheries should be managed to pursue 'the sustainable and profitable utilisation of Australia's Commonwealth fisheries in perpetuity through the implementation of harvest strategies that maintain key commercial stocks at ecologically sustainable levels and within this context, maximise the economic returns to the Australian community'. The Australian Commonwealth Harvest Strategy Policy (HSP) requires that fish stocks remain above a biomass level reference point at least 90 per cent of the time.

The CSF sea cucumber sector was regarded as a "low data" fishery in that there was a lack of local survey and assessment information available at the time of the HS formulation (Dowling et al., 2008; 2015; AFMA, 2007). The HS has no formal objectives, and comprises conservative TACs and trigger limits (based on catches), and includes a SESSF Tier 4 rule to adjust the TACs for all species CPUE and current catch. The basis of the HS was therefore predicated on an assumption that existing fishing effort was sustainable, and that any changes in catch and/or catch composition would result in further action (management and/or assessment). Most of the trigger levels that either control catch or initiate additional analysis and/or assessment are contained in the harvest strategies.

Catch limits are set in accordance with the Sea Cucumber HS that adopts a risk-based approach and reflects the low effort, low catch and low GVP of the fishery. Catch levels were considered conservative enough, within which fishing can continue without significant new information or management arrangements (AFMA, 2021a).

In relation to the current HS, the most recent strategic assessment of the fishery (DCCEEW, 2024; see below) raised the following condition for the fishery:

Condition 7: By 30 January 2025 the sea cucumber harvest strategy must be reviewed. In particular this review must consider:

- whether the current biomass limit reference point is appropriate for the target species;
- the effectiveness of the rotational zone strategy;
- the effectiveness of voluntary minimum size limits.

5.1.3 Fishery approval under the EPBC Act

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) requires the Australian Government to assess the environmental performance of fisheries and promote ecologically sustainable fisheries management (DAWE, 2021; DCCEEW, 2024). The department's primary role is to evaluate the environmental performance of fisheries, including:

- the strategic assessment of fisheries under Part 10 of the EPBC Act
- assessments relating to impacts on protected marine species under Part 13 and
- assessments for the purpose of export approval under Part 13A.

An independent assessment of all export and all Australian Government managed fisheries is required. These assessments ensure that, over time, fisheries are managed in an ecologically sustainable way. The assessments are conducted against the 2nd edition of the Guidelines for the Ecologically Sustainable

Management of Fisheries (the Guidelines) and in doing so, also consider all public comments received on the application. The Guidelines outline specific principles and objectives designed to ensure a strategic and transparent way of evaluating the ecological sustainability of fishery management arrangements.

The Department's assessment forms the basis for approvals granted under Parts 13 and 13A of the EPBC Act, and also forms the basis for the Australian CITES Scientific Authority's Non-Detriment Finding for CITES species harvested in this fishery.

A positive finding under this process results in the granting of a Wildlife trade operations certificate for each species exported. In order to export Australian native animal or plant specimens and/or CITES listed specimens for commercial purposes, the specimens must come from an approved program such as a Wildlife trade operation.

The most recent assessment of the CSF by the Department was published in 2024 (DCCEEW, 2024). Both the public submissions and AFMA's response were considered in the Department's assessment.

The Department recommended that the fishery be declared an approved WTO for a period of three years until 16 February 2027 subject to conditions. These conditions (relevant to the sea cucumber sector) include:

- implement updated catch limits for Prickly redfish (*Thelenota ananas*), Amberfish (*T. anax*) and surf redfish (*Actinopyga varians*)
- review the CSF sea cucumber harvest strategy (see above)

As for the two CITES listed teatfish species, the department had previously concluded (DAWE, 2021) that there was not sufficient information to support a non-detriment finding to be made in relation to the harvesting of White Teatfish from the Coral Sea Fishery, but that it had approved a total allowable take of 1 tonne for export of Black Teatfish.

5.1.4 Consultation

The Coral Sea Fishery Stakeholder Group is the key body providing advice to AFMA on management and research issues in the Coral Sea Fishery. The stakeholder group is composed of fishery scientists, fishery industry members, AFMA representatives, state government representatives, environmental non-government organisation representatives and recreational representatives.

There have been no recent meetings of this group pending announcement of the fishing methods and areas permitted in the Coral Sea Commonwealth Marine Reserve.

5.2 History of management

1979: Offshore constitutional settlement arrangements finalised which provides frameworks for allocating fisheries jurisdiction to Commonwealth in formerly Queensland waters.

1982: The Coringa-Herald and Lihou Reef National Nature Reserves proclaimed under the National Parks and Wildlife Conservation Act 1975 on 16 August 1982. These areas were closed to commercial fishing (E.A., 2001).

1990s: (Modern) Australian fishers begin fishing in the Coral Sea under Commonwealth fishing licences.

1995: Offshore Constitutional Settlement (OCS) agreement between the Queensland and Australian Governments gives AFMA jurisdiction over most reefs in the Coral Sea, and defines the western boundary for the modern-day CSF (leaving Marion, Saumarez, Ashmore and Boot Reefs in Queensland fisheries jurisdiction). AFMA consolidates a number of small-scale Commonwealth demersal line, trawl and hand collection fisheries that had existed prior to the agreement into the CSF (DEH, 2004). Permits were granted with a 20-day performance criteria (fishers are obligated to spend at least 20 days fishing in the CSF per year), a catch limit of 75,000 pieces and size limits. Up to

3 permits are granted to take sea cucumber (Stutterd and Williams, 2003) (but no more than 2 are granted from 1997 (DEH, 2004)).

1998: A logbook designed specifically for recording catch and effort from vessels fishing in the sea cucumber sector of the CSF is implemented.

2000: AFMA implemented precautionary management arrangements for the sea cucumber including (Stutterd and Williams, 2003):

- Limit of two permits for sea cucumber (transferable)
- Individual species TACs for the five high value species and a catch limit of 75 t landed weight per permit (an overall fishery TAC of 150 t).
  - Black teatfish – 5 t per permit (10 t total TAC)
  - White teatfish – 10 t per permit (20 t total TAC)
  - Prickly redfish – 10 t per permit (20 t total TAC)
  - Surf redfish – 5 t per permit (10 t total TAC)
  - Sandfish – 5 t per permit (10 t total TAC)
- Implementation of Vessel Monitoring System (VMS)
- Note: minimum size limits are not included in the new management arrangements but are implemented as a “voluntary agreement with industry”.

2002: Removal of the 20-day performance criteria (CSF MAC paper).

2002: Implementation of the 5 tonne move on provision (CSF MAC paper).

2003: Reduction in TACs for some species following research that showed a marked decline in catch and catch rate (Hunter et al., 2001; Stutterd and Williams, 2003):

- Black teatfish – 500 kg per permit (1 t total TAC)
- White teatfish – 2 t per permit (4 t total TAC).

2005: Implementation of MOU stipulating a rotational zone strategy. The CSF area was divided into 21 zones (roughly based on reefs) each with allocated fishing days roughly proportional to size (totalling 164 fishing days) allocated on a 3-year rotation.

2007: Reduction in TAC for Sandfish – 500 kg per permit (1 t total TAC)

2007: Harvest Strategy implemented for the sea cucumber sector of the CSF that includes established TACs for five species and new Trigger limits for remaining species in the catch:

- Greenfish (*Stichopus chloronotus*) and Lollyfish (*H. atra*) - 10 t combined trigger limit.
- All other species are subject to a 5 t combined trigger limit.

2018: the Coral Sea Marine Park (CSMP) Management Plan Implemented. In addition to the Coringa-Herald and Lihou Reef National Nature Reserves, Osprey and Mellish Reefs, and parts of Kenn (~50%) and Bougainville Reefs (~75%) Reefs are declared as National Park Zones (IUCN II) (no commercial fishing).

2018: Rotational zone strategy modified to accommodate new marine park implementations: reduced to 19 zones and a total 129 fishing days allocated on a 3-year rotation.

2020: Black teatfish and White teatfish listed as CITES species.

2022: Prickly redfish and Amberfish listed as CITES species with full implementation in May 2024.

5.3 Coral Sea Marine Park

Fishing for sea cucumbers is not permitted in the National Park Zone (IUCN II) of the Coral Sea Marine Park (see section above). Class approvals attached to fishing permits outline the areas where commercial fishing can occur, the fishing methods that can be used, and the conditions that need to be followed while operating or transiting through Australian Marine Parks. Hard or electronic copy of the class approval must be carried on board fishing vessels. Class approval also requires a navigational chart showing the boundaries of the approved zones in which the approved actions are being conducted to be kept aboard or otherwise accessible (AFMA, 2021a).

5.4 Illegal, unreported and unregulated fishing (IUU)

IUU fishing within the Australian EEZ is addressed through a National Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (NPOA-IUU). It involves several government agencies that cooperate to carry out aerial surveillance, sea patrols and real-time monitoring of fishing vessels.

Australia is also active at an international level promoting stronger measures to combat IUU fishing through The International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (IPOA-IUU) which calls on all states to take effective measures globally, regionally and nationally to combat IUU fishing.

AFMA's approach to combating IUU fishing is outlined in its International Compliance and Engagement Program 2022-24 and includes five components:

- Communication: Improving public understanding and awareness of AFMA's activities to combat IUU fishing, including working with Australia's neighbouring countries in sharing information and planning regional fisheries operations.
- Enforcement operations: Leading and supporting enforcement operations to support monitoring, control and surveillance (MCS) activities in Australian waters and in areas of Australia's interest.
- Strategic engagement: Working closely with other Australian Government departments and agencies in engaging with other countries, particularly Australia's neighbours, to develop and promote regional strategies to address IUU fishing.
- Capability development and supplementation: Developing national and regional capacity to undertake risk-responsive MCS operations to combat IUU fishing, delivered through the provision of theoretical training, on-the-job mentoring and participation in regional fisheries surveillance operations.
- Targeted threat program: Implementation of a risk-based compliance approach to facilitate the effective and efficient deployment of AFMA's resources to high-risk areas.

Despite a pulse of IUU fishing in 2016 and 2017, the sustained and coordinated efforts of Australian Government agencies, including apprehensions and convictions of several vessel and diplomatic efforts with source countries to curtail IUU vessels in their home ports, appears to have been successful in eliminating IUU activities within the CSF area (Noriega, 2022).

5.5 Effectiveness (monitoring and compliance)

AFMA takes a risk-based approach to monitoring and compliance in accordance with its National Compliance and Enforcement Policy 2012 (the Policy), which aims to target compliance and enforcement in the areas where it is most needed, "thereby using AFMA's resources most effectively" (AFMA, 2017). In addition to the risk treatment model, AFMA maintains a general deterrence program by maintaining a presence at fishing ports (and at sea).

The risk assessment process involves stakeholders (e.g. AFMA managers and industry) and AFMA intelligence ranking the risks of non-compliance with management arrangements to provide an overall picture of where non-compliance may occur across Commonwealth fisheries. The highest risks ratings are often related to failure to have a VMS operating at all times and quota evasion.

Primary compliance tools used by AFMA to monitor fishing activity and more generally deter non-compliant activity include: Vessel Monitoring System (VMS) on all vessels, catch disposal records and fish receiver records, at-sea and in-port inspections of vessels and in-port fish receiver inspections. AFMA also uses an observer program to monitor fishing activity. Fishers must report catch by species, weight and location in logbooks. Catch is assessed annually against triggers outlined in the Sea Cucumber Harvest Strategy and this information is published annually on AFMAs website in the Trigger Report for the CSF (AFMA, 2021a).

Penalties for infringements are set out in the FMA 1991 and are based on two tiers: low-level ‘on the spot’ fines (i.e. infringement notices) and larger fines, which require successful criminal prosecution. Under Section 106 and following a conviction of certain offences (Section 13 or Section 95(5)), a court may order forfeitures – including boats, gear, catches or the proceeds of the sale of catches. AFMA or a court may, in certain circumstances, also cancel fishing concessions.

There is evidence the Commonwealth MCS program is working effectively with VMS compliance rates of 98.2% in 2021/22 (AFMA, 2022). Non-compliance in the CSF sea cucumber sector appears to be low, with no infringements evident for failure to complete logbooks or fishing in restricted zones.

6 Conclusions and recommendations

The CSF sea cucumber sector is a remote poorly understood fishery, but with a long history. It is currently lightly utilised given its size, but has also been subject to significant IUU fishing in 2016 and 2017. The fishery habitats are diverse and include isolated reefs. A significant proportion of the CSF is protected from fishing.

There have been few broad scale sea cucumber surveys, and the assessments carried out to date have relied on limited survey and proxy data. Some key uncertainties are:

- Population biomass of both species, but particularly of White teatfish in deep reef habitats of the CSF.
- Species biology of both species, especially with respect to early growth of juveniles to breeding age, fecundity and breeding seasonality, and mortality rates of juveniles and adults.
- Climate change impacts and their effect on future extinction risk for teatfish species.

This report has attempted to address the key information fields for an NDF for Black teatfish and White Teatfish in the CSF. Some of the key findings related to each species are:

Black teatfish

- Inherent vulnerability for Black teatfish in the CSF is assessed as high.
- Black teatfish are widely distributed within the CSF, however their overall density and biomass are low relative to neighbouring fisheries (QSCF and TSBDMF).
- Black teatfish are a high value species and were targeted early in the fishery, however, catches have been low since about 2001.
- Maximum annual catch is 7.7 t and average annual catch is 1.0 t.
- Catch rates in the CSF have reduced greatly since the early 2000's.
- A significant proportion of the population (likely >40%) is protected within a comprehensive and representative system of no-take zones (much of it dating from before the modern fishery began operations), including most of the isolated reefs within the CSF.
- The current catch (0.3 t per year since 2005) and TAC (1 t per year) are very modest in relation to likely biomass.
- Modelling up to 2011 indicated that the Median biomass was greater than 99% of 1997 biomass, and the current take is much lower than modelled MSY (Woodhams et al., 2015).
- An MSE (Plaganyi et al., 2011) found that the Black teatfish TAC was low enough to pose minimal risk to the resource, however the model inputs may be too optimistic.
- A voluntary minimum size limit of 25 cm in place but is below the size at first maturity (26 cm).
- Overall fishery operation monitoring is adequate, and compliance is likely to be high.

White teatfish

- Inherent vulnerability for White teatfish in the QSCF is assessed as medium-high.
- Population size and status is uncertain.
- It is likely that White teatfish occurs in deep reef habitats throughout the CSF. Most larger reef systems in the Coral Sea have extensive areas of deep lagoon habitat in the 20 to 40 m depth range that likely provide suitable habitat for White teatfish (Murphy et al., 2021b; Purcell et al., 2023; Koopman and Knuckey, 2021).
- White teatfish are the most important fishery species, being the highest caught by weight and number.
- Maximum annual catch is 19.8 t and average annual catch is 3.2 t.
- The White teatfish catch (2 t per year since 2005) and TAC (4 t per year) are modest compared to the habitat area and catch per ha in neighbouring fisheries.

- Despite being the primary target species in the CSF, there are no indications of depletion in fishery average annual catch per day.
- White teatfish were a primary target of IUU fishing in 2016 and 2017.
- A significant proportion of the population (likely >35% but uncertain) is protected within a comprehensive and representative system of no-take zones (much of it dating from before the modern fishery began operations), including most of the isolated reefs within the CSF.
- An MSE (Plaganyi et al., 2011) found that the White teatfish TAC was low enough to pose minimal risk to the resource, however the model inputs may be too optimistic.
- A voluntary minimum size limit of 32 cm is in place which is likely about the size at first maturity.
- Overall fishery operation monitoring is adequate, and compliance is likely to be high.

6.1 Recommendations

1. Apply reef-based catch limits for White teatfish

   Though its status is uncertain, the White teatfish TAC of 4 t is modest relative to the likely (but currently unknown) population of this species in the CSF. It has been a primary target species for over 20 years and there are no indications of depletion. In addition, while the MSE carried out in 2010 showed a low risk to this species, the starting population parameters are likely unjustified until more is known about the deep reef population. The level of uncertainty is not appropriate for a CITES listed species, and this species requires additional research inputs to underpin its management. While the size of the deep reef population is a key uncertainty for this species, the application of an updated CSF MSE with up-to-date input parameters could also provide some confidence in the application of management strategies with an appropriate level of risk. In the meantime, conservative management arrangements are recommended, including annual reef-based catch limits (suggest 2 t) and the strict application of overall TAC and size limits.

2. Maintain current management arrangements for Black teatfish

   The Black teatfish TAC of 1 t is very modest for the areal extent of the fishery. Even considering the substantial uncertainty about the status of Black teatfish stock in the CSF, available information indicates a very low risk to population sustainability under current management arrangements.

3. Gain an understanding of potential populations of commercial species in deep reef habitats.

   A central question to the status and fisheries sustainability of White Teatfish in the CSF is the potential for a significant proportion of the population to inhabit the deep reef (20-70 m) habitat, of which there is a vast area. There has recently been some information gathered on this deep reef habitat that may provide some density estimates for sea cucumbers (Galbraith et al., 2023; M Hoey, pers comm.) which could be informative in this regard. Other opportunities to gather density information of the deep (and shallow reef) sea cucumber populations should be investigated.

4. Update the CSF sea cucumber sector HS

   The HS was formulated in 2007 (and was one of the first for Commonwealth fisheries in Australia). It is dated, does not use the most up to date information about the fishery and is probably not precautionary enough. Note that this is at the second highest (riskiest) tier in the HS tier system developed by Dichmont et al., (2017), and that "the more data-limited a fishery is, the poorer the performance of a stock assessment and harvest strategy in terms of risk" (Dichmont et al., 2017). It requires updating with the most recent information on the fishery, and improved efficacy for reducing risk of unacceptable depletion for all target species (including localised depletion), and extinction risk for CITES listed species.

5. Consider a higher default B*lim* for the CSF.

   The default HS biomass limit reference point, B*lim*, is at 20% of the unfished biomass level. This is likely too low for sea cucumber species due to potential “Allee” affects where there is low fertilisation success for sea cucumbers at low densities, but also due to their high susceptibility to overexploitation, slow recovery from overexploitation, and important ecological role sea cucumber play in reef ecosystems. (For example, in the Torres Strait, the beche-de-mer HS biomass limit reference point is 40% of unfished biomass.)

6. Re-assess the effectiveness of the RHS for reducing risk to fishery species.

   While the RZS has had some demonstrated benefit in spreading fishery effort, some reefs (generally those closer to fishing ports) continue to have higher levels of fishing effort proportional to their fishery habitat – and this will likely be exacerbated by the closure of Osprey Reef. There have been changes to zones (reduced from 21 to 19) and there are indications that for some species at least, the day limits are not restrictive enough (e.g. Surf redfish at Cato Reef). This should be the focus of a review and updating of the RZS to meet its primary objective of spreading effort and reducing the risk of local and overall depletion. An updated MSE (Plagányi et al., 2011) updated with the latest information would be useful to underpin this. In the meantime, it would be prudent to halve the day allocations in the RZS for reefs that have higher proportional levels of fishing effort, such as Cato and Flinders Reefs.

7. Implement compulsory appropriate minimum size limits (MSL).

   The MSL currently applied to the fishery are voluntary and no assessment of compliance has been reported. The efficacy of the RZS for reducing risk relies on the implementation and compliance of MSL for the fishery, both in the Coral Sea (Plaganyi et al., 2011) and GBR fisheries (Skewes et al., 2014; Plaganyi et al., 2015; Wickens et al., 2024). Recent guidance is for a MSL 125% the size at maturity (Wicken et al., 2024), which is a basic principle for increasing resilience and reducing risk (Purcell, 2010; Prince and Hordyk, 2019).

8. Assess and account for climate change risks.

   The vulnerability of Black teatfish in particular to climate change stressors may be significant, but with considerable uncertainty, including for indirect impacts. An MSE (Plagányi et al., 2013) in CSF sea cucumbers indicated that status quo management (under the current HS) may result in half the species falling below target levels, moderate risks of overall and local depletion, and significant changes in species composition. Three simple strategies (spatial rotation, closed areas, multi-species composition) were all successful in reducing these risks (Plagányi et al., 2013). It would be useful to reapply this MSE under current fishery conditions to re-assess current risks.

9. Support research on important life history parameters

   Life history parameters (growth, natural mortality, reproductive biology) are all critical inputs into stock assessments and the application of effective management strategies. The fisheries biology of both teatfish species, especially with respect to local size at maturity and breeding seasonality, early growth of juveniles to breeding age, and mortality rates of juveniles and adults are uncertain or unknown. This knowledge gap applies to many commercial sea cucumber populations and requires more research.

10. Establish accurate conversion ratios for live to processed forms used in the fishery.

    Catches are reported as gutted and salted weight – however it is likely that some of the catch is also landed as gutted, parboiled and frozen product. This information should be entered into the fishery catch reporting mechanisms and conversion factors established (this can be done in collaboration with the QSCF which has the same issue).

    On a related issue, there needs to be a better reconciliation of logbook and catch disposal records data which appears to have a wide discrepancy in some years.

11. Monitoring

    To account for potential impacts and uncertainty in the vulnerability of teatfish in the CSF, species level and environmental monitoring is required to reduce sources of uncertainty (such as how climate affects recruitment), and to detect changes that affect the status and/or vulnerability of teatfish species. A monitoring program of the population and related environmental parameters should be formulated and incorporated into the HS.

There is some significant monitoring of species and habitats that provide useful information for the status and trends of teatfish species and their fishery habitats (e.g. reef health surveys, Hoey et al., 2021; 2023b). However, the information collected on sea cucumber density is not always presented in a useful format for stock assessment purposes. Some cooperation and coordination between Parks Australia and AFMA, and formulation of suitable guidelines for information collection, could be useful in this regard.

12. Co-ordinate management of straddling stocks in the TSSCF and QSCF.

CSF reefs are likely to be seed populations for the other two east Australian fisheries. Coordinated management (e.g. HS frameworks and fishery reference points, temporal and spatial closures, size limits, rotational zone size, timing and move-on provisions) and research (life history parameters, MSE, conversion ratios) among all three fisheries will help reduce risk to species in the region.

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Appendix A: Catch logbook data for the CSF

The following changes were made to the supplied logbook database:

- Sandfish (*Holothuria scabra*) changed to Golden sandfish (*H. lessoni*) based on likely distribution information for these species and fisher advice (R. Lowden, *pers comm.*)
- Changed longitude for fishing day 5/11/2010 from 147.58333 to 148.58333 due to obvious data entry error.
- 10 records (out of 1913, ~0.5%) had no locational data, equating to 1.25 t (out of 191.8 t, ~0.65%).
- 12 records had the number caught but not the weight. Replaced weight with the product of the average weight of that species from CDR data (Table 14) and the number caught.

Table 14. Average weight applied to records with missing weight values for logbook data. Values estimated form CDR data except where data not available and then average weight from the QSCF was used*.

Species	Av. wt (kg)
Amberfish	2.11
Black teatfish	0.93
Blackfish	0.76
Elephant's trunkfish	1.09
Deepwater redfish	0.65*
Greenfish	0.16*
Leopardfish	0.75
Lollyfish	0.30
Prickly redfish	1.47
Golden sandfish	0.65*
Selenka's sea cucumber	0.16*[1]
Stonefish	0.43*
Surf redfish	0.42
White teatfish	1.16

[1] Use Greenfish as proxy

There was generally good agreement between the Logbook and CDR data (Figure 30), though often the CDR was lower than the logbook totals and there were some years where there were logbook records but no CDR data was recorded.

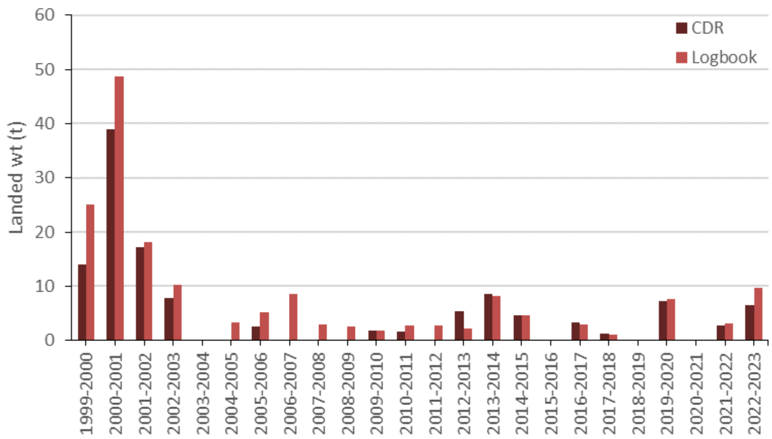

Figure 30. Landed weight for the CSF for Catch Disposal Records (CDR; Buyer data) and Logbook data for each year.

Figure 31. Annual catch (t) of the CSF for the period 23/2/1998 to 13/3/2023.

Common name	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023	TOTAL
White Teatfish	0.0	0.3	19.8	12.8	10.6	3.8	0.0	1.9	3.3	2.1	2.0	1.8	0.3	2.1	1.6	1.9	4.0	3.3	0.0	2.4	0.6	0.0	3.9	0.0	0.2	5.4	84.3
Prickly Redfish	0.3	2.5	1.9	7.4	0.8	1.6	0.0	1.1	0.9	1.3	0.2	0.4	0.3	0.6	0.8	0.1	3.2	0.6	0.0	0.3	0.3	0.0	2.2	0.0	0.3	3.2	30.3
Black Teatfish	5.1	3.9	2.4	7.7	0.8	1.0	0.0	0.3	0.6	0.7	0.5	0.4	0.5	0.1	0.4	0.2	0.5	0.5	0.0	0.1	0.1	0.0	0.5	0.0	0.4	0.3	26.8
Surf Redfish	0.4	1.2	0.4	4.9	4.6	0.0	0.0	0.0	0.1	4.2	0.0	0.0	0.7	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	17.9
Amberfish	0.0	0.0	0.3	10.2	1.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
Lollyfish	6.0	0.0	0.0	3.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
Blackfish	0.2	0.3	0.2	0.9	0.1	0.2	0.0	0.1	0.1	0.2	0.3	0.0	0.1	0.1	0.1	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.5	0.0	0.2	0.5	4.7
Elephant's Trunkfish	0.0	0.0	0.0	0.9	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.4
Leopardfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.9	0.1	1.1
Selenka's Sea Cucumber	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Golden Sandfish	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Green Fish	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Stonefish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Deepwater Redfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grand Total	12.1	8.2	25.1	48.8	18.2	10.3	0.0	3.4	5.1	8.6	2.9	2.6	1.9	2.9	2.8	2.3	8.2	4.6	0.0	2.9	1.0	0.0	7.6	0.0	3.2	9.6	192.2

Table 15. Catch (kg) by reef feature for species in the CSF logbook catch.

Reef	Amberfish	Black Teatfish	Blackfish	Deepwater Redfish	Elephant's Trunkfish	Green Fish	Leopardfish	Lollyfish	Prickly Redfish	Golden sandfish	Selenka's Sea Cucumber	Stonefish	Surf Redfish	White Teatfish	Grand Total	% Total
Abington Reef	0	1	0	0	0	0	0	0	0	0	0	0	15	0	16	<0.1
Bouganville Reef	0	50	1	0	0	0	0	0	28	0	0	0	103	0	182	0.1
Cairns Seamount[2]	0	2	8	0	0	0	0	0	15	0	0	0	0	50	75	<0.1
Cato Reef	0	3044	286	0	29	106	790	48	867	18	111	0	11637	139	17075	8.9
Dart Reef	0	0	8	0	0	0	0	0	10	0	0	0	45	25	88	<0.1
Diane Bank	13	385	600	0	0	0	42	0	1852	0	0	0	0	6242	9134	4.8
Flinders Reef	9941	4384	1082	0	780	0	141	1311	6662	151	0	3	739	32544	57738	30.0
Flora Reef	13	602	7	0	1	19	0	0	252	0	0	0	62	22	978	0.5
Fredrick Reef	0	778	86	2	25	0	0	45	1396	0	0	0	102	3110	5544	2.9
Heralds Surprise	0	669	155	0	0	20	18	0	304	0	0	0	223	101	1490	0.8
Holmes Reef	1255	2389	287	0	49	0	0	134	2929	0	0	0	30	4655	11728	6.1
Kenn Reef	0	1372	89	0	155	0	0	11	773	0	0	0	1670	1276	5346	2.8
Lihou Reef[2,4]	0	660	0	0	0	0	0	0	250	0	0	0	0	0	910	0.5
Malay Reef	0	9	64	0	0	0	9	0	1050	0	0	0	0	92	1224	0.6
Mellish Reef	0	3336	106	0	3	0	0	0	1623	0	0	0	113	377	5558	2.9
Moore Reefs	0	283	19	0	0	0	0	0	475	0	0	0	76	2630	3483	1.8
Osprey Reef	3179	637	449	0	2	0	0	1731	5796	6	138	1	74	23769	35782	18.6
Tregrosse Reef[3]	566	1043	474	0	32	0	0	13	2112	0	0	0	2	7725	11967	6.2
Unknown[1]	0	249	5	0	0	0	0	0	534	0	0	0	312	150	1250	0.7
Un-named shoal 2[2]	0	13	37	0	0	0	15	0	512	0	0	0	0	53	630	0.3
Willis Bank	10	483	300	0	77	0	27	1	1055	0	0	0	231	1174	3358	1.7
Wreck Reef	0	6447	632	0	229	21	106	6732	1784	0	0	0	2500	199	18650	9.7
Grand Total	**14977**	**26836**	**4695**	**2**	**1382**	**166**	**1148**	**10026**	**30279**	**175**	**249**	**4**	**17934**	**84332**	**192206**	

[1] No location reported
[2] Not included in a RZS Zone
[3] Includes 2 RSZ Zones
[4] This catch from 1998 may be a location recording error

Appendix B: CSF reef mapping

A map of the extent of reef and shoal habitat classes relevant to sea cucumber distribution in the CSF, based on: depth, slope, exposure to prevailing waves, and reef morphology (Woodhams et al., 2015; Purcell et al., 2023; Skewes and Persson, 2017; Murphy et al., 2021a) was formulated from three separate mapping products:

Millennium Coral Reef Mapping Project: (IMaRS-USF, IRD, 2005). The mapping was done using high-resolution (30 metres) multispectral satellite imagery (Landsat 7 images acquired between 1999 and 2002) that was subjected to a supervised classification (by IMaRS/USF) to generate geomorphological classes. Features are mapped at less fine scale than the Allen Coral Reef Atlas product, and shallow reef features have a slightly larger extent. This product has been shown to be suitable for mapping shallow (<20 m) reef habitats in the CSF area (Woodhams et al., 2015; Skewes and Persson, 2017).

Allen Coral Reef Atlas: Fine scale (<5 m pixels) mapping using PlanetScope (Dove) imagery with derivation of several shallow reef geomorphological types. Does not map reef habitats deeper than about 10 m in the Coral Sea (including deeper reef slopes, reef passes, reef pinnacles and deep reef habitats) therefore underestimates shallow (<20 m) habitat considerably compared to the Millennium Coral Reef Mapping product.

3D GBR: (Beaman, R. 2010) Defines two geomorphologies – reef and dry reef. The boundaries of reef areas were mapped to show the outer-most extent of each coral reef that could be observed in Landsat imagery, thus identifying the greatest area of each reef observed in the Coral Sea. The extent of "reef" matched quite well the Millennium Coral Reef Mapping deeper reef habitats (Deep lagoon, Deep terrace and Deep bank), and even extends out further in same cases (e.g. the dee p habitat associated with Tregrosse Reefs and Queensland Plateau shoals). However, when applied to isolated steep sided reefs (e.g. Mellish Reef) the reef outline may overestimate deep reef (<70 m) habitat considerably.

The reef habitats defined for the CSF were:

1. Forereef (the ocean facing reef edge, <20 m deep, facing the predominant SE trade winds)
2. Backreef (the ocean facing reef edge, <20 m deep, facing the NW monsoon winds)
3. Inner slope (sloping reef edge, <20 m deep, on the inside of the reef crest facing an enclosed or partially enclosed lagoon)
4. Reef flat (emergent reef flat)
5. Sub-tidal reef flat (subtidal reef flat to approximately 20 m depth)
6. Pass (deep high flow areas between sub-reef units, 5-40 m deep)
7. Deep reef (deep habitat, 20 -70 m deep, associated with reef complexes). Note: the deep reef habitat within the CSF area includes reef associated flat habitat up to about 60 m deep as crossed checked with available nautical charts (e.g. gpsnauticalcharts.com).
8. Lagoon pinnacles (small coral reef structures, <5 m deep, within enclosed deep reef habitat (deep lagoons))

The Millennium Coral Reef Mapping classifications was assigned to the above habitat schema based on classifier descriptions and available field data (Table 16). The following modifications were also made to the Millennium Coral Reef Mapping product based on field data, depth, slope exposure to prevailing waves and reef morphology (Oxley et al., 2003; 2004; Ceccarelli et al. 2008; 2008; Skewes and Persson, 2017):

- Holmes Reefs, added reef pass between the north and south reefs;
- Holmes Reef, defined a backreef habitat adjacent to the reef flat;
- Herald Cays, added 7 reef pinnacle habitats using information from Google earth image;
- Wreck Reef, added a reef pass habitat to the east of Porpoise Cay.

However, the Millennium Coral Reef Mapping product did not cover all the reef features in the CSF area, with the following reef features included from the 3dGBR and/or Allan reef mapping products: Mellish Reef, Cato Reef, Shark Reef, Vema Reef, Malay Reef, Moore Reefs, McDermott Bank, Calder Bank and

Cairns Seamount (with the last two not as even recognised as CSMP or CSF feature names). Note: Suamarez, Marion, Ashmore and Boot Reefs are also included in the Coral Sea data layer, but are not included here as they are not in the CSF.

For these features, layers from the Allen Coral Reef Atlas and 3DGBR were reclassified and combined (Table 16). This was then merged to the Millennium Coral Reef Mapping product to produce a map of all reef and shoal (<70 m deep) features in the CSF area.

Table 16. Classification schema for available reef mapping products to produce generic habitat classes for the CSF.

Habitat class	Allan	Millennium	3DGBR
Forereef	Reef slope	Forereef (SE facing)	
Backreef	Back Reef Slope	Forereef (NW facing)	
Inner slope	Sheltered Reef Slope	Inner slope, Shallow terrace, Shallow lagoon terrace	
Reef flat	Inner Reef Flat, Outer Reef Flat, Reef Crest, Patch Reefs	Reef flat	
Subtidal reef flat	Shallow Lagoon	Subtidal reef flat	
Pass		Pass, Pass reef flat	
Deep reef	Deep lagoon, Plateau	Shallow lagoon, Deep lagoon, Deep terrace, Drowned bank, Enclosed lagoon	Reef (outline)
Lagoon pinnacles	Inner Reef Flat, Outer Reef Flat, Reef Crest, Patch Reefs within enclosed and partially enclosed lagoons	Lagoon pinnacle, Reef flat and Subtidal reef flat within enclosed and partially enclosed lagoons.	

The resulting CSF habitat areas were then calculated in the GIS (Table 17). It was also overlain with the current spatial management zones for the CSMP, Figure 7) to quantify the amount of identified habitat that was within the no-take (National Park Zone (IUCN II)) zones (Table 17).

Table 17. Reef (feature) name, marine park zonation (Open = Habitat Protection Zone (IUCN IV), Closed = National Park Zone (IUCN II)), habitat area (Ha), and shallowest depth (referring to nautical charts in the main, and Geoscience Australia multibeam sonar in bracket, where available).

Reef name	Zone	Backreef	Deep reef	Forereef	Inner slope	Lagoon pinnacle	Pass	Reef flat	Subtidal reef flat	TOTAL	Shallowest depth (m)
Abington Reef	Open	43		86	11			272		412	Emergent
Bouganville Reef	Open	58	101	4	44	1		134		343	Emergent
Bouganville Reef	Closed	6	184	175	259			448		1,072	Emergent
Cairns Seamount	Open		6							6	40 (36.7)
Calder Bank	Open		99							99	43
Cato Reef	Open	26	16,755	79				329	154	17,343	Emergent
Coringa Bank	Closed	906	240,001	1,406	370	476		432	10,890	254,481	Emergent
Dart Reef	Open	64	437	136				417		1,054	Emergent
Dianne Bank	Open		92,482	837			1,685	45	15,164	110,213	Emergent
Flinders Reef	Open	1,026	72,243	1,655	5,400	114	7,416	4,796	2,252	94,902	Emergent
Flora Reef	Open	129	284	285	752			839	166	2,455	Emergent
Fredrick Reef	Open	104	6,766	1,067	329		136	676	315	9,393	Emergent
Herald Cays	Closed	117	5,338	289		23		1,487		7,253	Emergent
Heralds Surprise	Open	86	379	201		10		439		1,115	Emergent
Holmes Reef	Open	1,149	7,388	992	5,132		60	5,671	732	21,123	Emergent
Kenn Reef	Open	290	4,603	1,435	3,250	5	569	845	1,658	12,656	Emergent
Kenn Reef	Closed	663	10,529	715	1,734	3	668	885	1,239	16,435	Emergent
Lihou Reef	Closed	4,815	211,958	4,680	11,244	424	7,447	6,859	4,242	251,670	Emergent
Magdelaine Cays	Closed			235	297			356		889	Emergent
Malay Reef	Open		4,426							4,426	200? (not well charted) (71.9)
McDermott Bank	Open		4,104							4,104	21.3
Mellish Reef	Closed	217	1,546	130				787	1,117	3,797	Emergent
Moore Reefs	Open		23		183			555	235	995	Emergent
Osprey Reef	Closed	147	11,782	1,003	2,326	4	94	4,228	48	19,633	Emergent
Shark Reef	Open		702							702	8.0
Tregrosse Reef	Open	119	331,610	369	353	513		720	6,575	340,258	Emergent
Un-named shoal 1	Open		290							290	17.9
Un-named shoal 1	Closed		845							845	Emergent

Un-named shoal 2	Open		2,324							2,324	OBSTRN [Obstruction]
Un-named shoal 3	Open		527							527	21.9
Un-named shoal 4	Closed		7,228							7,228	16.8
Vema Reef	Open		316							316	11.5
Willis Bank	Open		64,982	3,248	1,054			736	6,590	76,609	Emergent
Wreck Reef	Open	627	16,969	302			681	1,658	5	20,242	Emergent
TOTAL	Open	3,721	627,814	10,694	16,507	644	10,546	18,132	33,846	721,906	
TOTAL	Closed	6,871	489,412	8,634	16,230	929	8,208	15,482	17,536	563,302	
TOTAL	CSF	10,593	1,117,226	19,328	32,737	1,573	18,755	33,614	51,383	1,285,208	

Appendix C: 2017 CSF survey outputs

The following outputs are from a reanalysis of the 2017 SCF survey for all species (data from Skewes and Persson et al., 2017).

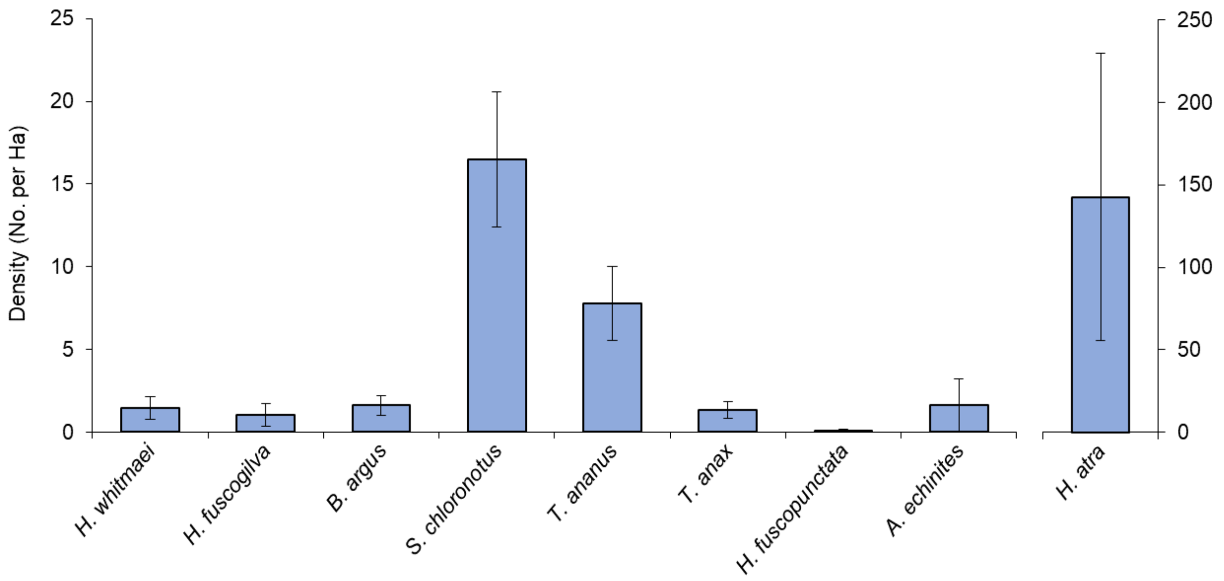

Figure 32. Density (stratified) of sea cucumbers in all reefs and habitats surveyed in 2017 in the CSF. (Error bars are 1 s.e.) (Note that H. atra is on a different scale)

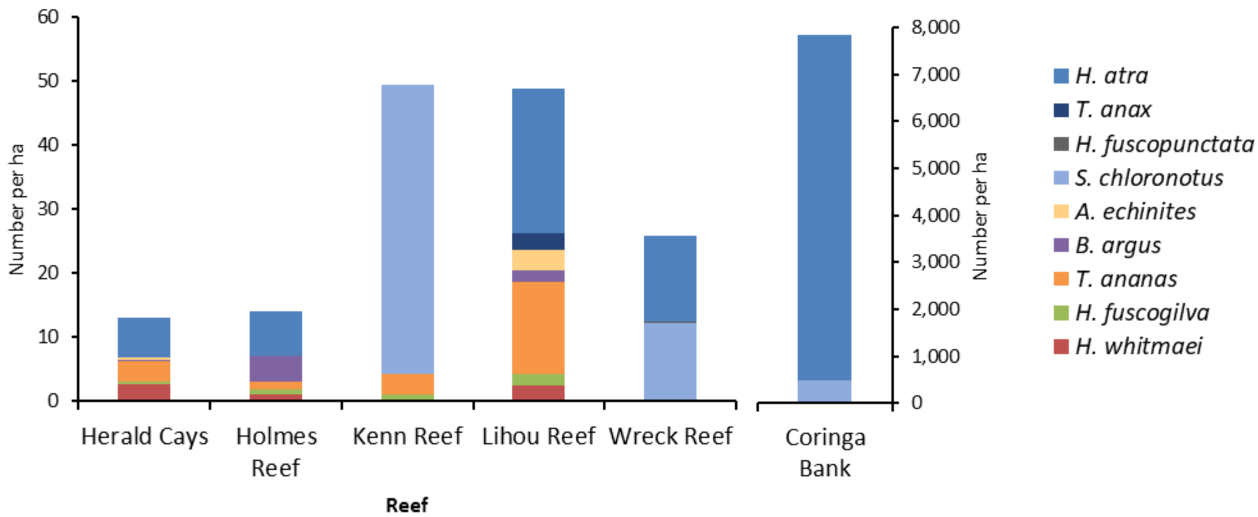

Figure 33. Density (stratified) estimates for each reef sampled during 2017 in the CSF (Note – Coringa back different scale in B)).

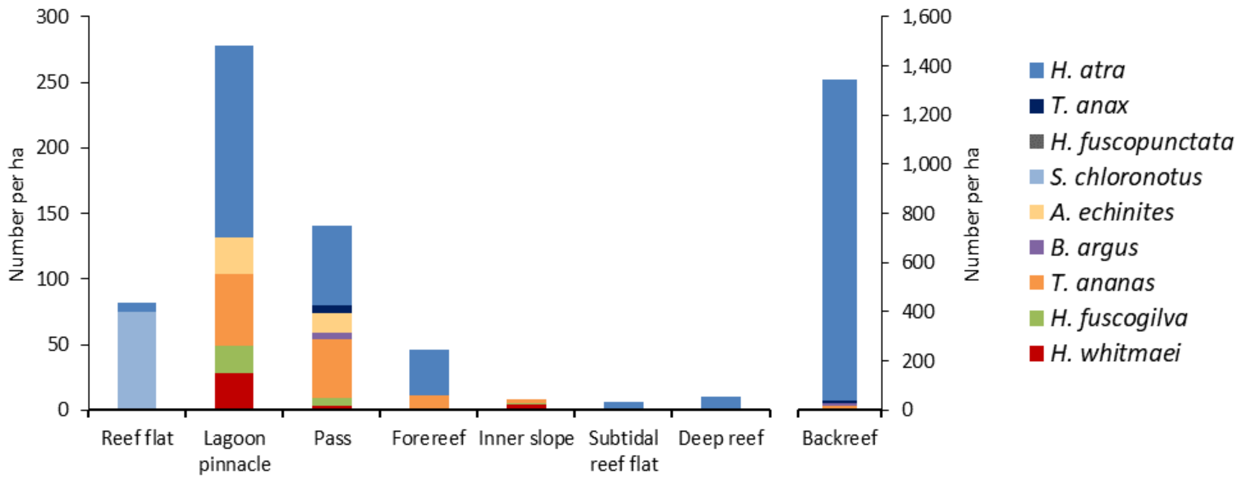

Figure 34. Density (stratified) estimates for each habitat and species for the 2017 survey of CSF reefs. (Note, backreef habitat on a different scale).

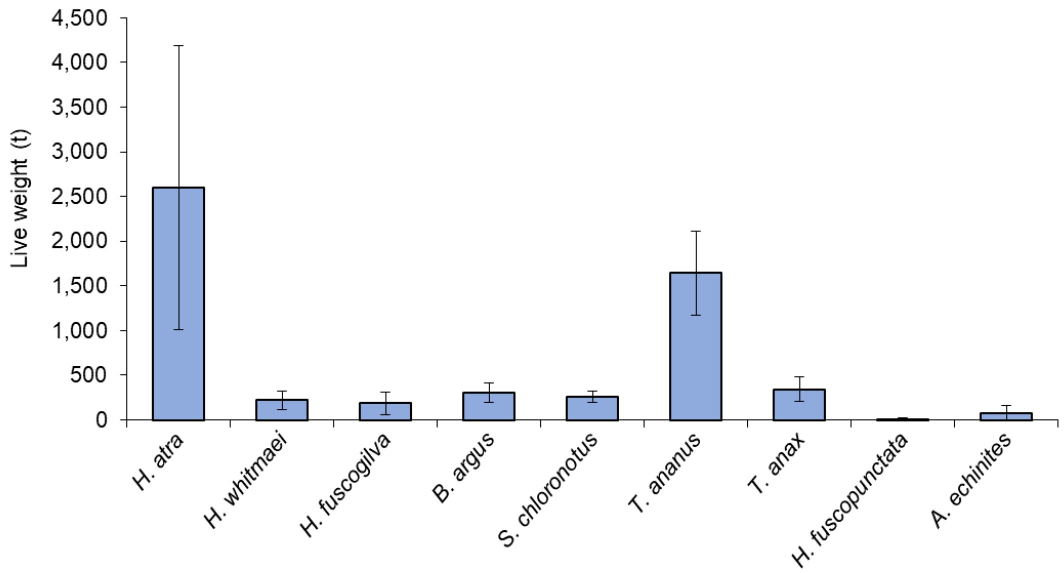

Figure 35. Live weight of sea cucumbers on each reef surveyed in 2017 in the CSF. (Error bars are 1 s.e.)

Table 18. For each species, the average density, s.e., population stock estimate and landed (wet gutted) weight (N = 74) in the CSF in 2017 (data from Skewes and Persson, 2017).

	Density	Density s.e.	Live weight (t)	Conversion factor	Landed weight (t)
All commercial	174.03	87.85	5,639.7	-	3,152.4
H. atra	142.65	87.29	2,597.3	0.436	1,132.4
H. whitmaei	1.44	0.68	221.5	0.677	150.0
H. fuscogilva	1.03	0.68	185.0	0.627	116.0
B. argus	1.61	0.59	302.3	0.665	201.0
S. chloronotus	16.48	4.10	259.7	0.651[a]	169.1
T. ananus	7.79	2.24	1,642.7	0.667	1,095.7
T. anax	1.34	0.52	343.6	0.667[b]	229.2
H. fuscopunctata	0.08	0.08	8.9	0.519	4.6
A. echinites	1.62	1.61	78.6	0.692	54.4

[a] No conversion data available – used data for *S. herrmanni*

[b] No conversion data available – used data for *T. ananas*

Appendix D: RZS

Detailed information in the current Rotational Zone Strategy (RZS) applied in the CSF sea cucumber sector.

Table 19. Sea Cucumber Sector rotational zone co-ordinates. Column A is the northern boundary, Column B is the southern boundary, Column C is the western boundary and Column D is the eastern boundary.

Zone name	Days	A (north)			B (south)			C (west)			D (east)		
		Lat min			Lat max			Long min			Long max		
		dd	mm	ss	dd	mm	ss	dd	mm	ss	dd	mm	ss
Abington Reef	2	18	2	0	18	7	30	149	34	30	149	39	0
Bougainville Reef	2	15	28	30	15	31	30	147	5	0	147	8	30
Cato Island Reef	5	23	14	30	23	15	30	155	31	30	155	34	30
Dart Reef	2	17	23	0	17	25	30	148	10	0	148	13	0
Diamond Islets	15	17	24	0	17	41	0	150	47	0	151	7	0
Diane Bank	5	15	42	0	16	18	0	149	28	0	149	45	0
Flinders Reefs	15	17	22	30	17	53	30	148	16	0	148	36	0
Flora Reef	2	16	43	30	16	46	30	147	41	30	147	46	30
Frederick Reefs	5	20	55	0	21	2	0	154	20	30	154	24	30
Heralds Surprise	2	17	18	30	17	20	0	148	26	0	148	29	30
Holmes Reefs	15	16	22	30	16	33	0	147	47	30	148	6	0
Kenn Reefs	10	21	5	30	21	17	0	155	42	0	155	48	0
Malay Reef	2	17	54	0	18	0	0	149	17	0	149	23	30
McDermott Bank	5	17	10	30	17	18	0	147	47	0	147	55	30
Mellish Reef	5	17	20	30	17	26	30	155	50	0	155	53	0
Moore Reefs	5	16	0	0	16	3	30	149	7	30	149	11	0
Osprey Reef	30	13	47	30	14	1	30	146	32	30	146	43	0
Shark Reef	2	14	4	0	14	12	0	146	45	30	146	52	30
Tregrosse Reefs	5	17	41	0	17	48	0	150	29	30	150	47	0
Willis Islets	15	16	6	0	16	19	0	149	56	0	150	3	0
Wreck Reefs	15	22	9	30	22	13	30	155	9	0	155	29	30

Note: The Moore Reef RZS coordinates are in the wrong place. It should be further north.

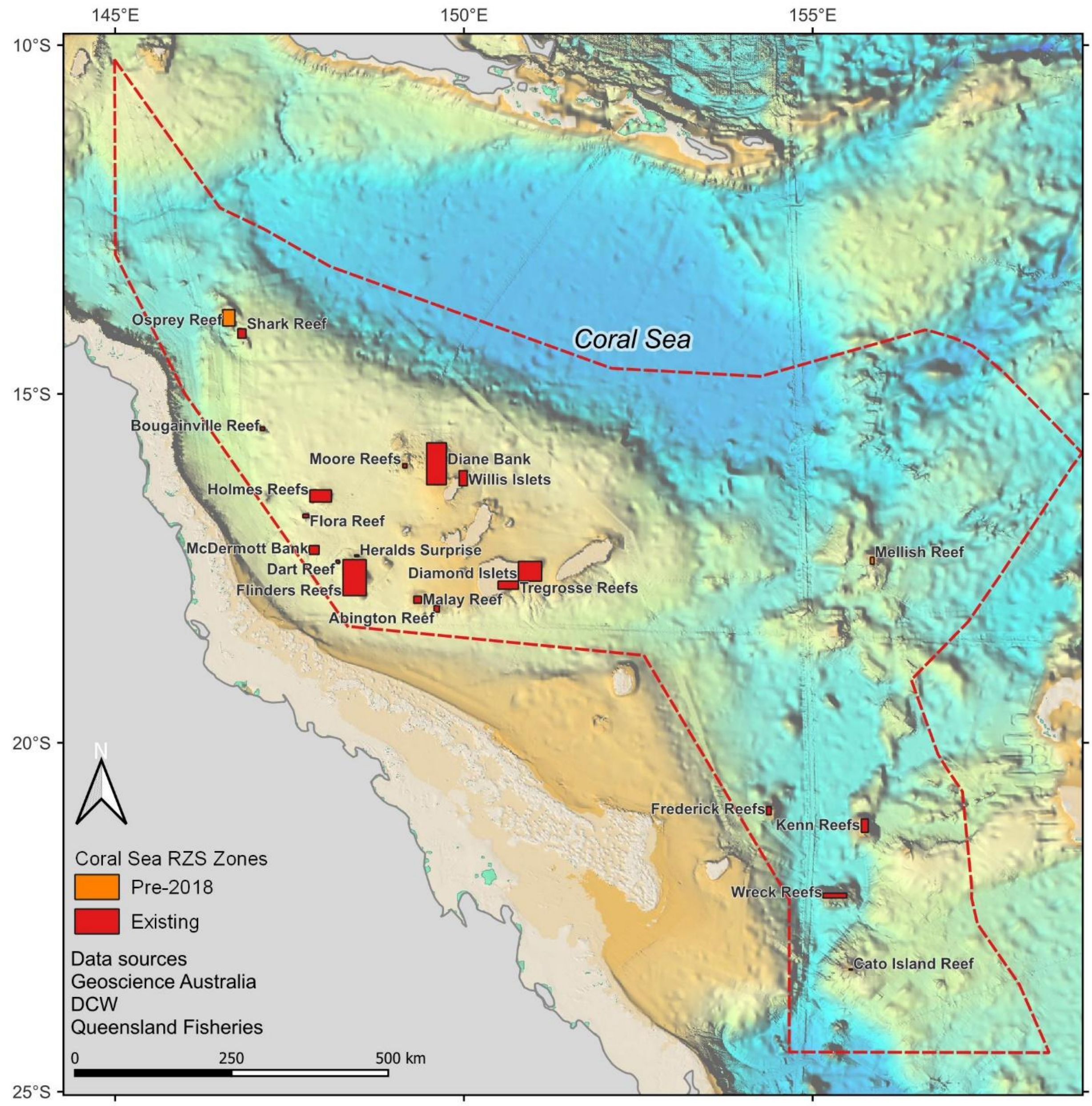

Figure 36. RZS zones for the CSF, including current zones and those that were also in operation before the implementation of the CSMP in 2018 (Osprey and Mellish Reefs).

Table 20. RZS zone allocations and days fished by year for period 2005-2006 to 2022-2023. *Days fished out of RZS sequence or over allocated fishing days.

Yr	Zone	Allocated	Fished
2005-2006	Bougainville Reef	2	
2005-2006	Diamond Islets	15	11
2005-2006	Flora Reef	2	
2005-2006	Frederick Reefs	5	5
2005-2006	Holmes Reefs	15	
2005-2006	Kenn Reefs	10	4
2006-2007	Cato Island Reef	5	5
2006-2007	Dart Reef	2	1
2006-2007	Diamond Islets		1*
2006-2007	Heralds Surprise	2	1
2006-2007	Kenn Reefs		4*
2006-2007	McDermott Bank	5	
2006-2007	Mellish Reefs	5	
2006-2007	Moore Reefs	5	2
2006-2007	Shark Reef	2	
2006-2007	Tregrosse Reefs	5	2
2006-2007	Wreck Reefs	15	
2007-2008	Abington Reef	2	
2007-2008	Diane Bank	5	
2007-2008	Flinders Reefs	15	10
2007-2008	Malay Reef	2	
2007-2008	Osprey Reef	30	
2007-2008	Willis Islets	15	
2008-2009	Bougainville Reef	2	
2008-2009	Diamond Islets	15	
2008-2009	Flora Reef	2	
2008-2009	Frederick Reefs	5	5
2008-2009	Holmes Reefs	15	
2008-2009	Kenn Reefs	10	4
2009-2010	Cato Island Reef	5	3
2009-2010	Dart Reef	2	
2009-2010	Heralds Surprise	2	
2009-2010	McDermott Bank	5	
2009-2010	Mellish Reefs	5	2
2009-2010	Moore Reefs	5	
2009-2010	Shark Reef	2	
2009-2010	Tregrosse Reefs	5	
2009-2010	Wreck Reefs	15	2
2010-2011	Abington Reef	2	
2010-2011	Diane Bank	5	
2010-2011	Flinders Reefs	15	8
2010-2011	Malay Reef	2	
2010-2011	Osprey Reef	30	

2010-2011	Willis Islets	15	
2011-2012	Bougainville Reef	2	
2011-2012	Diamond Islets	15	
2011-2012	Flora Reef	2	
2011-2012	Frederick Reefs	5	
2011-2012	Holmes Reefs	15	7
2011-2012	Kenn Reefs	10	
2011-2012	Outside RZS		1
2012-2013	Cato Island Reef	5	
2012-2013	Dart Reef	2	
2012-2013	Heralds Surprise	2	
2012-2013	McDermott Bank	5	
2012-2013	Mellish Reefs	5	
2012-2013	Moore Reef	5	
2012-2013	Moore Reefs		3
2012-2013	Shark Reef	2	
2012-2013	Tregrosse Reefs	5	
2012-2013	Wreck Reefs	15	
2013-2014	Abington Reef	2	
2013-2014	Diane Bank	5	
2013-2014	Flinders Reefs	15	11
2013-2014	Malay Reef	2	
2013-2014	Osprey Reef	30	10
2013-2014	Willis Islets	15	3
2014-2015	Bougainville Reef	2	
2014-2015	Diamond Islets	15	10
2014-2015	Flora Reef	2	
2014-2015	Frederick Reefs	5	
2014-2015	Holmes Reefs	15	
2014-2015	Kenn Reefs	10	
2015-2016	Cato Island Reef	5	
2015-2016	Dart Reef	2	
2015-2016	Heralds Surprise	2	
2015-2016	McDermott Bank	5	
2015-2016	Mellish Reefs	5	
2015-2016	Moore Reefs	5	
2015-2016	Shark Reef	2	
2015-2016	Tregrosse Reefs	5	
2015-2016	Wreck Reefs	15	
2016-2017	Abington Reef	2	
2016-2017	Diane Bank	5	
2016-2017	Flinders Reefs	15	10
2016-2017	Malay Reef	2	
2016-2017	Osprey Reef	30	
2016-2017	Willis Islets	15	
2017-2018	Bougainville Reef	2	

2017-2018	Diamond Islets	15	
2017-2018	Flora Reef	2	
2017-2018	Frederick Reefs	5	4
2017-2018	Holmes Reefs	15	
2017-2018	Kenn Reefs	10	1
2018-2019	Cato Island Reef	5	
2018-2019	Dart Reef	2	
2018-2019	Heralds Surprise	2	
2018-2019	McDermott Bank	5	
2018-2019	Mellish Reefs	5	
2018-2019	Moore Reefs	5	
2018-2019	Shark Reef	2	
2018-2019	Tregrosse Reefs	5	
2018-2019	Wreck Reefs	15	
2019-2020	Abington Reef	2	
2019-2020	Diane Bank	5	5
2019-2020	Flinders Reefs	15	5
2019-2020	Malay Reef	2	1
2019-2020	Osprey Reef	30	
2019-2020	Willis Islets	15	3
2020-2021	Bougainville Reef	2	
2020-2021	Diamond Islets	15	
2020-2021	Flora Reef	2	
2020-2021	Frederick Reefs	5	
2020-2021	Holmes Reefs	15	
2020-2021	Kenn Reefs	10	
2021-2022	Cato Island Reef	5	2
2021-2022	Dart Reef	2	
2021-2022	Heralds Surprise	2	1
2021-2022	McDermott Bank	5	
2021-2022	Moore Reefs	5	
2021-2022	Shark Reef	2	
2021-2022	Tregrosse Reefs	5	1
2021-2022	Wreck Reefs	15	3
2022-2023	Abington Reef	2	
2022-2023	Diane Bank	5	6*
2022-2023	Flinders Reefs	15	4
2022-2023	Malay Reef	2	1
2022-2023	Outside RZS		1
2022-2023	Willis Islets	15	
2023-2024	Bougainville Reef	2	
2023-2024	Diamond Islets	15	
2023-2024	Flora Reef	2	
2023-2024	Frederick Reefs	5	
2023-2024	Holmes Reefs	15	
2023-2024	Kenn Reefs	10	

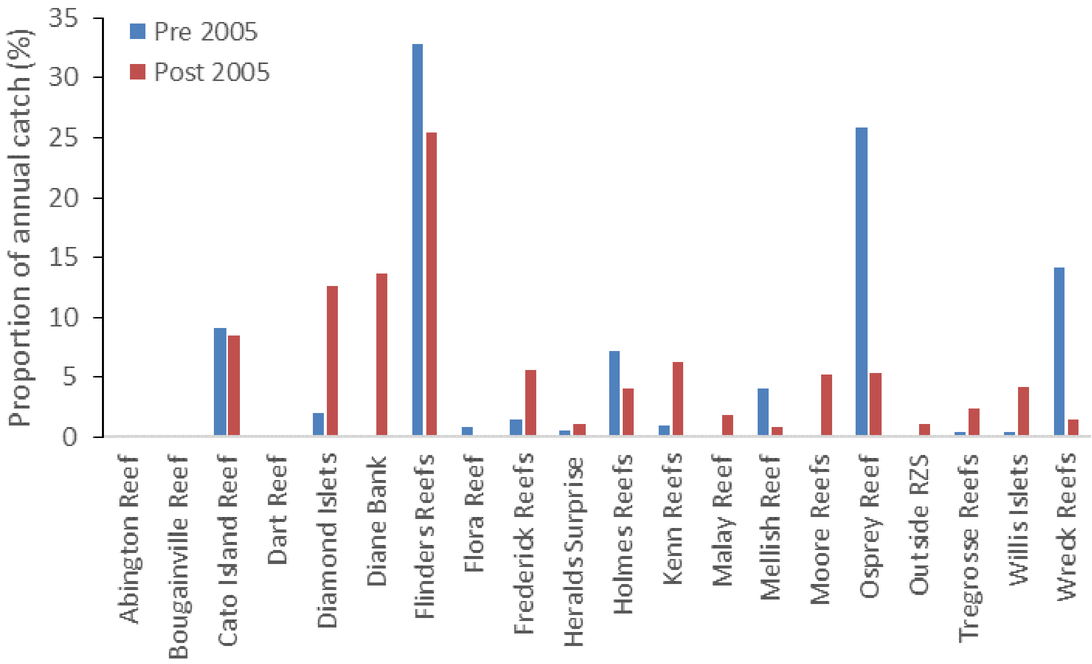

Figure 37. Proportion of annual average catch in each fishery zone for the CSF before (Pre 2005) and after (Post 2005) the implementation of the RZS in the CSF for period 2005-2006 to 2022-2023.

CONTACT
Tim Skewes Consulting
m +61 0419 382 697
e timskewes@outlook.com