

Expert advice for the assessment of Australian teatfish (*Holothuria whitmaei* and *H. fuscogilva*) Fisheries: National report

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

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Acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
AFMA	Australian Fisheries Management Authority
B ₀	Virgin biomass
<i>Blim</i>	The biomass level beyond which the risk to the stock is regarded as unacceptably high (often related to the PRI - Point of Recruitment Impairment).
BMEY	Biomass which corresponds to maximum economic yield.
<i>Btarg</i>	The desired status of stocks (often at about BMEY)
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CSCMR	Coral Sea Commonwealth Marine Reserve
CSF	Coral Sea Fishery
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSMP	Coral Sea Marine Park
DAF	Queensland Department of Agriculture and Fisheries
DCCEEW	Commonwealth Department of Climate Change, Energy, the Environment and Water
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999, including any Act amending, repealing or replacing the Act.
ETS	east Torres Strait
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
GBRMPPA	Great Barrier Reef Marine Park Authority
GVP	Gross Values of Productions
HS	Harvest strategy
IPA	Indigenous Protected areas
IUCN	International Union for the Conservation of Nature.
IUU	Illegal, unreported and unregulated fishing
Landed Wt	Fishery catch and catch limits in all Australian fisheries are reported as landed weight. In the CSF and QSCF, this is in gutted and salted product form; in the TSCDMF, it is in fresh gutted form.
LRP	Limit Reference Point – a reference point that equates to the population at <i>Blim</i>
MSC	Marine Stewardship Council
MSL	Minimum Size Limit
MSY	Maximum Sustainable Yield
NDF	CITES Non-detriment finding
NNR	National Nature Reserves
PNG	Papua New Guinea
PRI	Point at recruitment impairment. The point at which biomass has been reduced through catch so that average recruitment levels are significantly reduced.
PSA	Productivity Susceptibility Analysis
PZJA	Torres Strait Protected Zone Joint Authority
QLD	Queensland (State of)
QSCF	Queensland Sea Cucumber Fishery (East Coast)

RHS	Rotational Harvest Strategy
RUSS	Reducing Uncertainty in Stock Status
SEC	Southern Equatorial Current
SICA	Scale Intensity Consequence Analysis
t	Tonnes
TAC	Total Allowable Catch
TACC	Total Allowable Combined Catch
TEP	Threatened, endangered and protected species
TIB	Traditional Inhabitant Boat (a type of fishing licence in Torres Strait)
TSBDMF	Torres Strait Beche-de-mer Fishery
TSPZ	Torres Strait Protected Zone
WA	Western Australia (State of)
WASCF	Western Australian Sea Cucumber Fishery
WPBDMF	Western Province Beche-de-mer Fishery, Papua New Guinea
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. These fisheries are typical of sea cucumber fisheries globally in that they are primarily focussed on exporting dried sea cucumber product (beche-de-mer) to meet demand from China. They are relatively small scale and multispecies in nature.

This report sets out to provide background information suitable for addressing the information requirements of NDFs for Black teatfish and White teatfish in Australian fisheries. It includes:

- Information about the species.
- An overall synthesis of Australian fisheries targeting teatfish species (Fishery specific information for the three fisheries primarily target teatfish: the Queensland Sea Cucumber Fishery (East Coast) (QSCF); Torres Strait Beche-de-mer Fishery (TSBDMF); and the Coral Sea Fishery (CSF), is contained in separate fishery specific reports).
- Regional fishery status.
- Recent trade information.
- A synopsis of Australian fishery product weight definitions and conversion ratios.
- Current gaps in available information relevant to the making of NDFs, including, but not limited to, population status, range, density, movement/migration, harvest and susceptibility to environmental matters such as climate events.

Most of the information was sourced from published scientific papers and reports, and on fishery assessment and synthesis reports by the state and federal fishery management agencies.

2 The species

Black teatfish (*Holothuria whitmaei*) and White teatfish (*H. fuscogilva*) both sit within the: Phylum Echinodermata, Class Holothuroidea, Order Holothuriida, Family Holothuriidae, Genus *Holothuria*, Subgenus *Microthele* (ADF, 2024).

The teatfishes have been subject to some taxonomic changes in recent history, and the group has still some uncertainties that require taxonomic attention. For example, a molecular study in 2004 using mtDNA split the former complex Black teatfish (*H. nobilis*) into two separate species: *H. whitmaei* occurring in the Pacific Ocean (and presumably in the east Indian Ocean as well as the study included specimens from the west Australian coastline), and *H. nobilis* in the west Indian Ocean (Uthicke et al. 2004b). Both that and subsequent studies have raised the possibility of cryptic species in the White teatfish clade, especially in the Indian Ocean (Purcell et al., 2017; Uthicke et al., 2009b; Oury et al., 2019; Karan et al., 2024).

However, there is strong support for Black teatfish (*H. whitmaei*) and White teatfish (*H. fuscogilva*) as valid species in Australia, and the current nomenclature is unlikely to change in the future (Uthicke et al. 2004b; Uthicke et al., 2009b).

2.1 Distribution

2.1.1 Black teatfish (Pacific)

The (Pacific) Black teatfish is found throughout the west Pacific and east Indian Ocean. It occurs from Indonesia, the west coast of Australia, north to Japan and China, and southeast to Palau, Guam, Tonga, Tuvalu, and the Cook Islands (Figure 1) (FAO, 2024; Purcell et al., 2023a).

In Australia, Black teatfish are distributed from Ningaloo Reef in Western Australia across most of northern Australia and down the east coast to Moreton Bay in Queensland (Figure 2). They are also found on the offshore islands and reefs from the Cocos (Keeling) Islands in the west to Elizabeth and Middleton Reefs in the east (Table 1, Figure 2).

Black teatfish are exclusively found associated with reef structures and commonly occur on reef flats, shallow reef slopes, the tops of lagoon pinnacles and sandy seagrass beds between 0 and 20 m. (Purcell et al., 2023a). In Australian fisheries, they are mostly commonly caught in waters shallower than 10 m, though they can be caught in deeper water in areas with large tidal ranges and extensive deep reef habitats such as those found on the southern GBR (Koopman and Knuckey, 2021a).

Table 1. Records of occurrence for Black teatfish and White teatfish (Additional to established records in FAO, 2024).

Location	Black teatfish	White teatfish
Cocos (Keeling) Islands	Yes (Bellchambers et al., 2011)	Yes (Bellchambers et al., 2011)
Christmas Island	No records	No records
Ashmore Reef	Yes (Skewes et al., 1999 ^a)	Yes (Skewes et al., 1999)
Scott Reefs	Yes (Prescott et al., 2016)	Yes (Prescott et al., 2016)
Rowley Shoals	Yes (Bryce and Marsh, 2009)	Yes (Rees et al., 2003)
Kimberley	No, only offshore (Sampey and Marsh, 2015)	No, only offshore (Sampey and Marsh, 2015)
Ningaloo Reef	Yes (Sheill, 2004 ^a)	No record
Moreton Bay	Yes (Qld Museum, 2011)	No record
Elizabeth and Middleton Reefs	Yes (Edgar et al., 2019)	No records

^a listed as *H. nobilis*

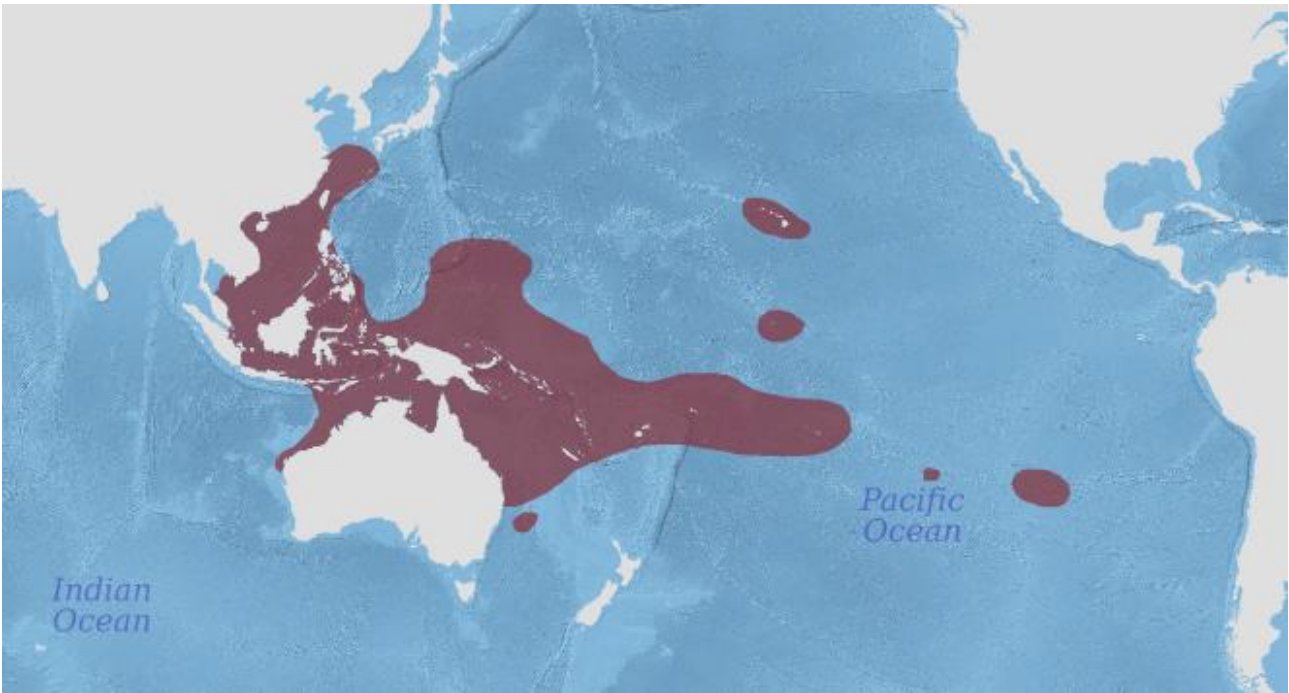


Figure 1. Distribution of (Pacific) Black teatfish (*H. whitmaei*). Source: FAO, 2024. Aquatic Species Distribution Map Viewer. <https://www.fao.org/figis/geoserver/factsheets/species.html>

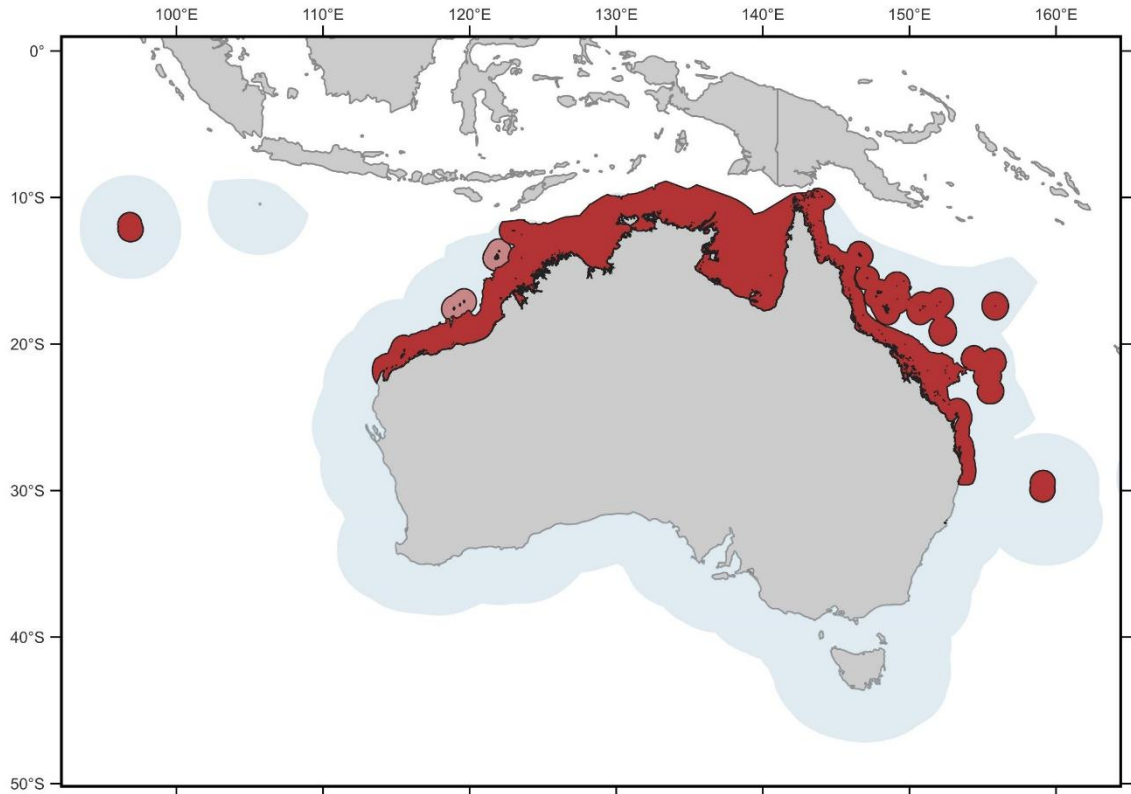


Figure 2. Distribution of Black teatfish (*H. whitmaei*) in Australia. Using existing distribution maps in Conand, et al., 2013a; FAO Aquatic Species Distribution Map Viewer and Purcell et al., 2023a. Additional occurrence records for Australian territories as per Table 1 - in pink.

2.1.2 White teatfish

This species is found throughout the tropical Indo-west Pacific, from East Africa, the Maldives, and southern India. It is present throughout much of Southeast Asia, including Indonesia, the Philippines and the South China Sea. In the tropical Pacific, the species is present from northwestern Australia to Enewetok, Guam and the Ryukyu Islands southwards to most of the islands of the Central Western Pacific and as far east as French Polynesia (Figure 3; FAO, 2022; Purcell et al., 2023a).

In Australia, White teatfish are distributed from about the Dampier in Western Australia across northern Australia and down the east coast to Northern, NSW (Figure 4). They are also found on the offshore reefs from the Rowley Shoals in the west to Mellish Reef in the Coral Sea (Table 1, Figure 4).

White teatfish are prevalent in ocean-influenced deep reef slopes, lagoons and passes in water depths 10 m to 50 m depth, though they have been reported in depths greater than 100 m (Purcell et al., 2023a). On the GBR, White teatfish commonly inhabit deep reef edges or features associated with reefs in the south, whereas in the north they are mostly taken in deeper waters on the landward side of outer barrier reefs (Koopman and Knuckey, 2021b). In the Coral Sea over 70 % of the White teatfish catch is taken at locations with a maximum depth over 30 m - they also have a high density associated with deep reef pinnacles (Skewes and Persson, 2017). Surveys in east Torres Strait have found that 72% of the White teatfish population was in deep (>20 m deep) reef associated habitats, though none were seen deeper than 37 m (Murphy et al., 2021a; Murphy et al., 2021b).

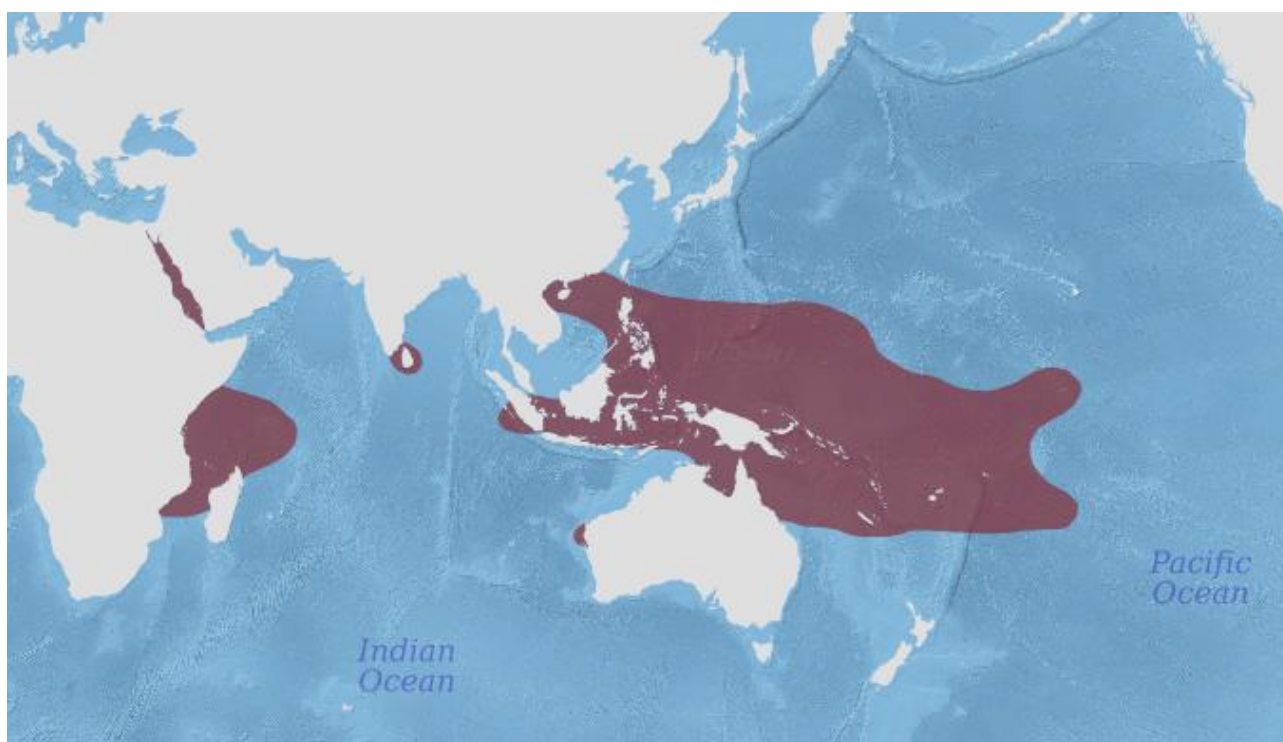


Figure 3. Distribution of White teatfish (*H. fuscogilva*). Source: FAO, 2024. Aquatic Species Distribution Map Viewer. <https://www.fao.org/figis/geoserver/factsheets/species.html>

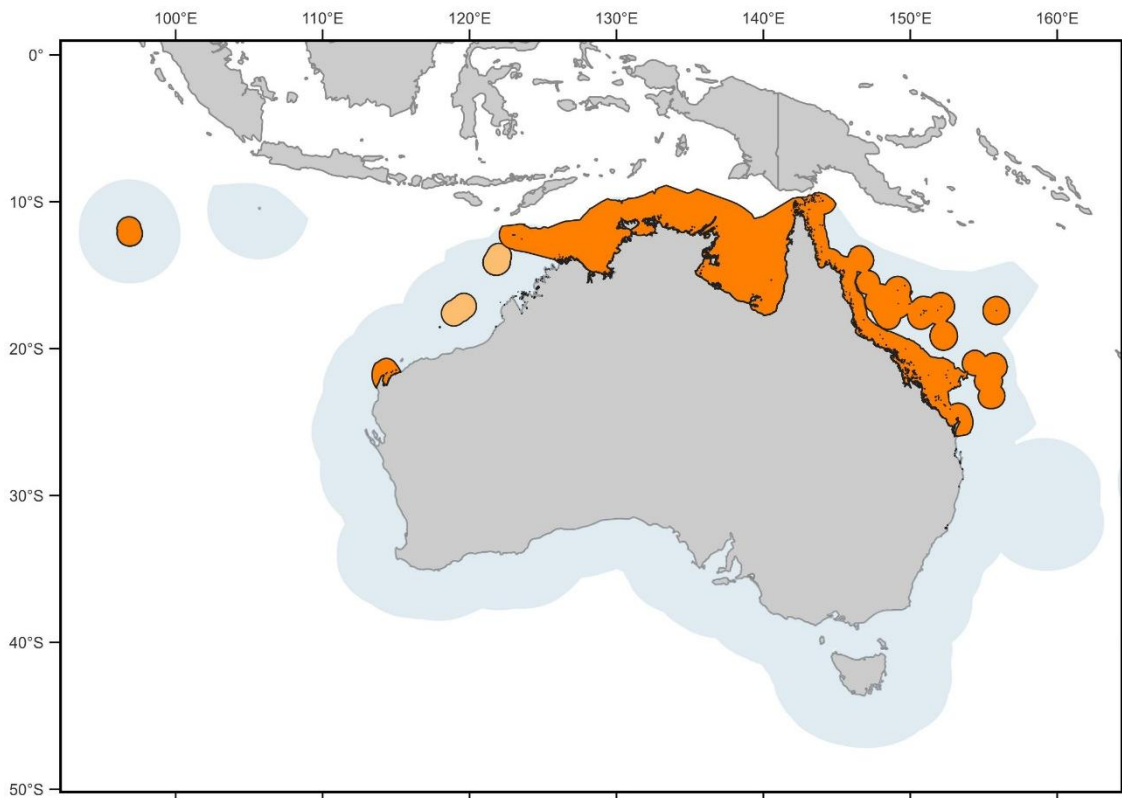


Figure 4. Distribution of Whites teatfish (*Holothuria fuscogilva*) in Australia. Using existing distribution maps in Conand, et al., 2013b; FAO Aquatic Species Distribution Map Viewer and Purcell et al., 2023a. Additional occurrence records for Australian territories as per Table 1 - in light orange.

2.2 Life history

For a comprehensive compilation of life history parameters for Black teatfish and White teatfish, see Wolfe and Byrne (2022).

2.2.1 Growth

Growth in holothurians generally is poorly understood. Traditional mark-recapture studies are challenging due to size plasticity (Ebert 1978, Uthicke & Benzie 2000; Purcell et al., 2016b), and poor tag retention (Conand, 1988; Purcell et al., 2006; Shiell and Uthicke, 2006; Rodríguez-Barreras et al., 2014). However, there has been some studies of growth using genetic “tag-recapture” techniques (Uthicke et al., 2004a) which indicated very slow growth for adult Black teatfish, with many animals actually showing shrinkage over the study period. In addition, aquaculture experiments have also found slow growth rates for newly settled White teatfish juveniles of 0.13 g/day, and taking about 2 years to reach 150 g (Burgy and Purcell, 2024). Black teatfish newly settled juveniles grew faster at 0.3 g/day (Burgy and Purcell, 2024).

Black teatfish in the Western Pacific typically grow to 34-37 cm (CITES, 2019; Purcell et al., 2023a), though can reach 54 cm (Purcell et al., 2023a). Maximum length reported in Torres Strait is 45 cm (Murphy et al., 2024), 42 cm on the GBR (Benzie and Uthicke, 2003) and 31 cm in Coral Sea (Skewes and Persson, 2017).

White teatfish in the Western Pacific typically grow to 42 cm (CITES, 2019), though it can reach 57 cm (Purcell et al., 2023a). Maximum length reported in Torres Strait is 37 cm (Murphy et al., 2021a) and 32 cm in Coral Sea (Skewes and Persson, 2017).

2.2.2 Mortality/longevity

Mortality rates and longevity, like growth, are not well established for sea cucumbers. However, genetic tag-recapture studies showing slow growth of adult sea cucumbers suggests that Black teatfish at least are long-lived “potentially in the range of several decades” (Uthicke et al., 2004a). It has been suggested that sea cucumbers may not experience senescence, or at least have a lower senescence with age (FAO, 2019).

Some potential issues with establishing average growth and mortality rates for sea cucumbers include: growth inhibition on younger animals by older cohorts (as occurs in sea urchins; Ebert, 2020); and negative senescence, which is characterised by a decline in mortality with age after reproductive maturity, generally accompanied by an increase in fecundity (Ebert, 2020; Romero-Gallardo et al., 2018). Also, the mark recapture experiments that have been carried out so far on tropical holothurians are likely hampered by them being focussed on the observable “adult” cohort that are gaining weight and shrinking in length in almost equal proportions (Uthicke et al., 2004a; Purcell et al., 2016b; Hammond and Purcell, 2023), confounding traditional mark-recapture growth models.

2.2.3 Reproduction

Both teatfish species are gonochoric (separate sexes) broadcast spawners (release sperms and eggs in mass events). Neither Black teatfish or White teatfish are known to be fissiparous species (breaks apart into multiple individuals), relying on sexual reproduction to maintain and grow populations (Conand, 1993).

Black teatfish has been 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 occurs 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 (Conand, 1993) or as a strategy to avoid cross fertilisation with closely related White teatfish (Shiell and Uthicke, 2006).

Not only are Black teatfish one of the few winter spawning aspidochirote holothurians, they likely also have an unusual model of gonad development, the so called Tubule Recruitment Model (TRM) where tubules mature progressively from the 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 cucumbers (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 slightly 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, there could be some variation in the timing of spawning over its broad latitudinal range.

As both species are sedentary and have limited ability to aggregate, lower densities will result in a dilution effect of adult gametes in the water column which will lead to decreased fertilisation success and reduced larval production – contributing to Allee effects (depensation) in the stock recruitment relationship. However, the characteristics of the “Allee effect threshold”, where reduced density begins to negatively affect population productivity and the “Allee threshold”, where populations will continue to decrease even when fishing ceases, are unknown for any sea cucumber population (Hutchings, 2015; González-Durán et

al., 2018). 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., 2011; Ramírez-González et al., 2020; Friedman *et al.*, 2010; Prescott et al., 2017; FAO, 2022).

Both teatfish species larval biology is relatively well studied, due in part to aquaculture focused research (Friedman and Tekanene, 2005; Burgy and Purcell, 2024). Their larvae are planktonic and planktotrophic (feeding on small, suspended material in the water column) and their larval duration is in the order of 2-4 weeks (Tanita et al., 2023; Burgy and Purcell, 2024).

The only reliable estimates of size at first sexual maturity for teatfish are for New Caledonia, with estimates of the length at which 50% are mature (TL50) of 26 cm for Black teatfish and 32 cm for White teatfish (Conand, 1993), though an earlier study by the same author listed TL50 as 22.7cm and 32.4cm for Black teatfish and White teatfish respectively (Conand, 1981). That study found, for Black teatfish at least, the onset of sexual maturity coincided with the change in colour pattern from the mottled white juvenile form to the uniformly black adult form.

2.2.4 Movement

Sea cucumbers are benthic, generally with a low mobility and annual displacements of 100 m or less (Purcell et al., 2016b; Hammond et al., 2020; Purcell et al., 2023b). However, the ability of adult sea cucumbers to move larger distances may also be underestimated (De la Rosa Castillo, 2023). In any case, Black teatfish and White teatfish populations are very likely restricted to the reef on which they settle.

2.3 Connectivity/metapopulation structure

For sustainable fisheries management and assessment, and for managing the risk of localised extirpation, understanding stock structure and matching biological processes and management action is critical. If population structure is not adequately considered, depletion and even extinction of subpopulations can occur before adequate information is available to initiate action (Perry et al., 1999).

Population structure is defined by population spatial distribution at multiple scales, usually driven by the distribution of suitable adult habitat, and the connectivity, in terms of recruitment, between populations (or subpopulations within a metapopulation). Population connectivity will depend on several factors, including (but not limited to): distance between populations/subpopulations; larval production (quantity and timing), duration, behaviour (vertical migration, active swimming and settlement cues) and mortality rates; and hydrodynamics and current patterns (speed and directionality at multiple scales driven by tides, local winds, large scale ocean circulation and continental shelf waves) (Leis, 2015; Trembl et al., 2015). Though active current patterns may promote connectivity, entrainment by embayments and reef systems will also be an important driver of relative recruitment potential to local populations.

Defining suitable population units is not straightforward, as functional (or demographic) connectivity can be variable in space and time and include source and sink considerations, all of which have different implications for meta population management.

Two types of connectivity have been defined (Sale et al., 2010; Johnson et al., 2018):

- 1) Evolutionary (genetic) connectivity: the amount of gene flow occurring among populations over a timescale of several generations. It determines the extent of genetic differences among populations.
- 2) Demographic (ecological) connectivity: an exchange of individuals among local populations that can influence population demographics and dynamics through the exchange of offspring between populations via larval dispersal, and recruitment of juveniles and survival of these juveniles to reproductive age.

Maintaining genetic connectivity is important for long-term conservation planning. But demographic connectivity is important for informing day-to-day fishery management (Johnson et al., 2018). It is therefore important that management is consistent in terms of how connectivity is considered in the its

objectives and approaches, and ideally these should be based on demographically independent populations (Wallace et al., 2010). In terms of population risk however, it is better to have multiple management and assessment units applied to a single population than having multiple populations within a single management unit (Reiss et al., 2009).

The following table shows the level of assessment expected and considerations for scoring the unit stock outcome and harvest strategy components of Marine Stewardship Council (MSC) fishery assessments for a single population stock (case A), and for 3 different forms of metapopulations (cases B, C, and D) (MSC, 2022).

Table 2. Stock structure characterisations, and implications for assessment for different forms of metapopulation for Marine Stewardship Council (MSC) outcome assessments (PRI is Point of Recruitment Impairment – analogous to BLim in most Harvest Strategies) (MSC, 2022; Table G2)

Stock structure	Description (degree of connectivity and self-recruitment)	Implications for management of the stock
<p>A. Single population</p>	<p>Completely isolated. Self-contained with no emigration or immigration of individuals from or to the stock. Occupies a well-defined spatial range and is independent of other stocks of the same species.</p>	<p>Whole population. Fishing on the population has no effect on the dynamics of neighbouring populations. Normal expectations may apply for reference points. The fishery must manage the stock above the point of recruitment impairment (PRI) to ensure recruitment is sustained.</p>
<p>B. Local population (LP) with partial isolation</p>	<p>Partially isolated and minimal connectivity. Self-sustaining. The degree of connectivity with other LPs in the metapopulation is so weak that, for management purposes, it can be considered a self-sustaining population. This may be true even if occasional larval exchanges between LPs are enough to maintain a certain degree of genetic flow and homogeneity.</p>	<p>Local population. Fishing on the local population appears to have no effect on the dynamics of neighbouring populations. Normal expectations may apply for reference points. The fishery must manage its own local unit stock above the PRI to ensure recruitment is sustained. Requires information on the biology of the species, larval dispersal, source-sink dynamics and oceanographic conditions supporting management at a local level.</p>
<p>C. Local population(s) with moderate connectivity within the meta-population</p>	<p>Moderate connectivity. The degree of connectivity between LPs is enough to maintain genetic flow and some degree of homogeneity. Source-sink dynamics with variable degree of self-recruitment. Sources of recruits act as core areas in the species range where the species occurs in all years and where the typical age composition exhibits regular recruitment patterns with multiple age classes present. There may be sinks where occasional individuals or low densities usually occur and</p>	<p>Local population(s). Fishing on local populations affects the dynamics of neighbouring populations. Fishing and the management decision affecting upstream populations will have impacts on the components downstream. Local populations are not entirely in control of their productivity. The fishery must manage its own local unit stock above the PRI to ensure recruitment is sustained. But reference points also need to take into account connections with and dependences on neighbouring local populations. Per recruit reference points (e.g. percentage spawners per recruit) may confirm that the good management of the fishery contributes to the wider surrounding populations.</p>

	where populations typically consist of only 1 or a few age groups, often of old individuals.	Separate monitoring of absolute reference points (either of incoming recruitment or of local population levels) may also be needed to confirm that the inputs of external recruitment are being sustained. Requires information on the biology of the species, larval dispersal, source-sink dynamics and oceanographic conditions to support management at a local level.
D. Local populations with maximum connectivity within the meta-population	Maximum connectivity. Metapopulation is panmictic (mating is random within the entire metapopulation). Subpopulations are arbitrary. Well-mixed larval pool.	Whole metapopulation. Fishing on local populations affects the dynamics of neighbouring populations. The fishery must manage the whole metapopulation (unit stock) above the PRI to ensure that recruitment is sustained. Special attention may be needed in setting reference points to ensure that the LP structure is not affected by fishing.

One tool used for defining population structure has been using genetic connectivity. However, this is not always useful. At one end of the scale, if a significant and reproducible genetic differentiation can be detected, the populations should be considered demographically independent. However, genetic connectivity can be maintained with a few recruits per generation, making it difficult to determine subpopulation independence (Underwood et al., 2012). Indeed, measuring genetic connectivity requires the comprehensive sampling of populations, and is very sensitive to the nature and type of genetic marker being used (DiBattista et al., 2017). Three factors appear to be essential to maximise the power of genetic studies to detect structure in marine fishes: temporal replication, a sufficient sample size and the use of adequate molecular markers. It is important to be aware that genetic data are only one component of defining biological units, and other phenotypic markers and criteria should ideally be incorporated in the assessment of biologically meaningful management units (Reiss et al., 2009).

2.3.1 Black teatfish

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 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).

2.3.2 White teatfish

The stock structure of White teatfish in Australian fisheries is unknown. We can, however, make inferences about population structure based on proxies, such as the genetic studies on Black teatfish (above) and other species (below), 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) (Tremblay et al., 2015; Choukroun et al., 2021).

Other species

While small scale (<100 km) population structuring has been identified for coastal species such as Sandfish (Uthicke and Benzie 2001; Uthicke and Purcell, 2004; Gardner et al., 2012), deep water archipelagic species (e.g. Lollyfish, *H. atra* (Skillings et al., 2011)) and offshore shelf species (e.g. *Cucumaria frondosa* (So et al., 2011), and *H. leucospilota* (Chieu et al., 2023)) have shown high population connectivity across large distances (1,000s of km), mirroring the finding for Black teatfish (see above).

Given the habitat preferences for White teatfish, it is likely to 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).

On the GBR, studies of coral dispersal and connectivity has shown (for coral species with comparable larval durations as sea cucumbers), that the formulation of “equivalent reef community configurations” that might serve as distinct operational management units, are of the order of 10’s to 100’s of km, with smaller units closer to the coast and along the inshore-offshore gradient (Thomas et al., 2014).

Linked physical-biological models

Potential connectivity of White teatfish in eastern Australian has been estimated using a passive 28-day model of particles released during the summer new moon (CONNIE3: www.csiro.au/connie3). Release locations included northern, central and southern GBR reef locations, and the Coral Sea reefs of Saumarez, Marion, Flinders and Lihou Reef (Figure 5). This indicated that the larval transport within the GBR reef area is likely to be relatively restricted, mirroring the results of other modelling outputs showing limited larval transport vectors in dense reef regions due to “sticky water” effects (Wolanski et al., 2013). The results also indicate that the adjacent reefs of the Coral Sea are capable of providing recruits to the GBR. This provides some indication that there is likely to be connectivity between all three east coast fisheries for White teatfish in Australia.

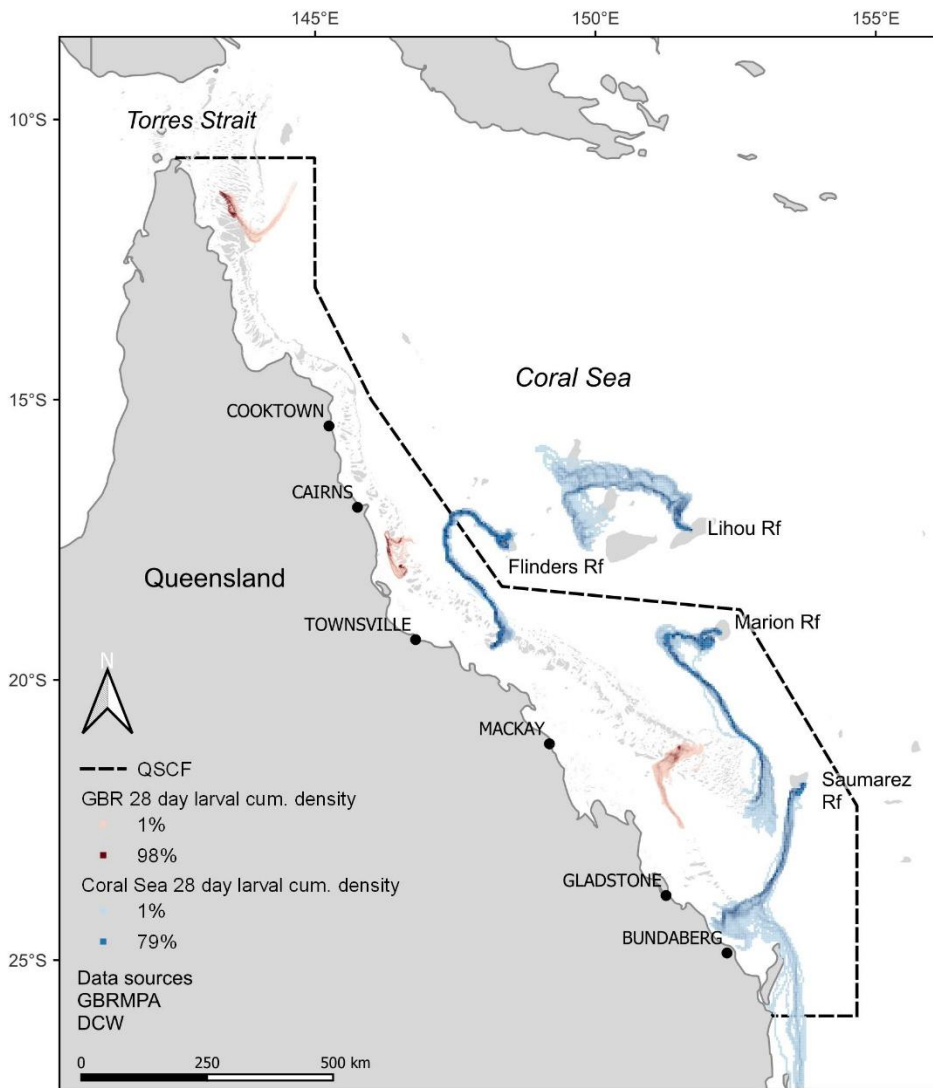


Figure 5. Larval particle model trajectories with 28-day period for summer new moon release (6/1/2019) for three GBR (red) and four Coral Sea (blue) point release locations. (Connie3: <https://connie.csiro.au/>)

Broader scale biophysical models also predicted strong connections from the Coral Sea reefs and GBR, which is consistent with the dominant westerly current flow in the Coral Sea (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 (Choukroun et al., 2021). The study did not test for connections from the GBR to the Coral Sea.

A recent study on broadscale connectivity of larval fishes in northeastern Australia (Fontoura et al., 2022) indicated that many reefs in the Coral Sea act as source reefs for recruitment of fish populations to the GBR; and that the Torres Strait reefs were largely considered as a sink population that rely on reefs of the northern GBR for recruitment. Internally the GBR is a complex mix of source and sink reefs (Figure 6). Connectivity for larvae with a 30-day pelagic larval duration showed strong connectivity between the northern GBR and Torres Strait.

Connectivity on broader scales, such as between the GBR and Indian Oceans through the Torres Strait, is not well understood (Ceccarelli, 2013). However, the low net flows through Torres Strait would indicate it is

a barrier to demographic scale recruitment between eastern and northern Australian benthic populations (Saint-Cast, 2008; Wolanski et al., 2013).

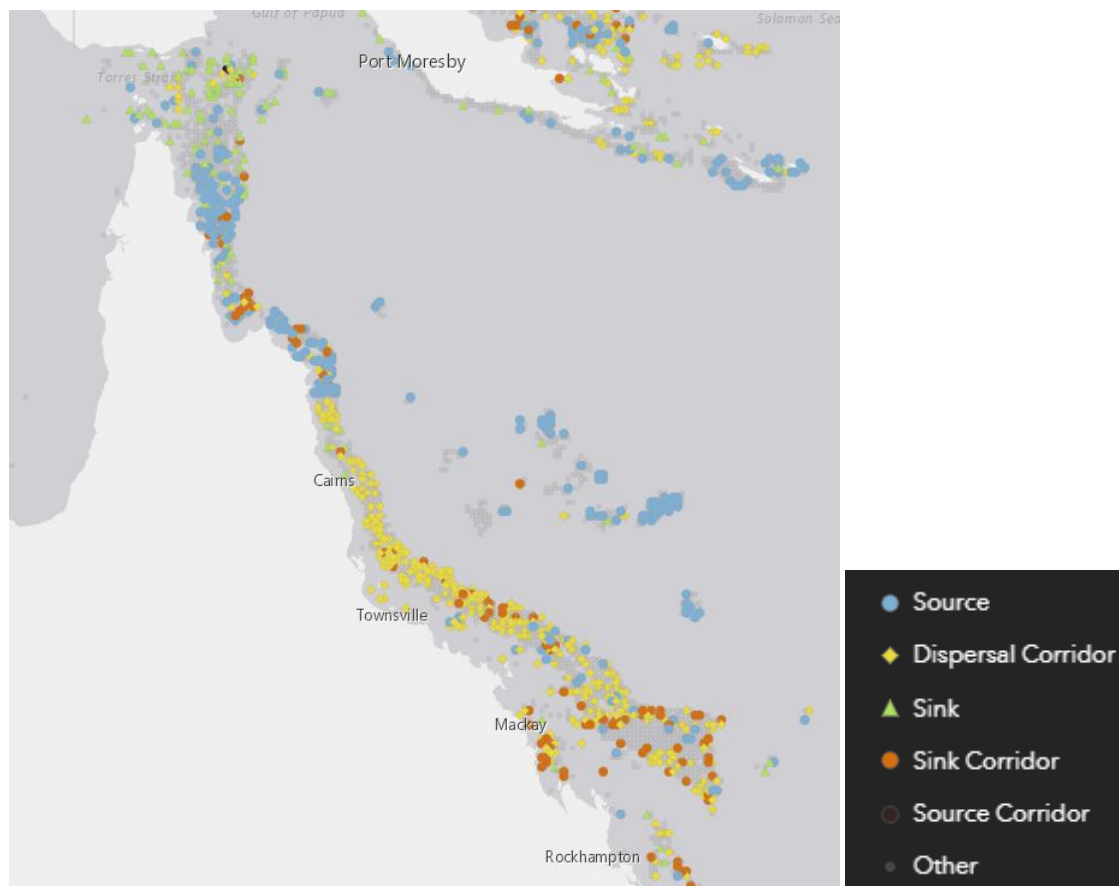


Figure 6. Fish Larval Connectivity on Coral Reefs: Spatial Distribution of Sinks, Sources & Corridors (Fontoura et al., 2022) (<https://www.arcgis.com/apps/dashboards/7d7167d11e4e4c4496ced8cafcb0fed>)

2.3.3 Population structure - conclusions

While there is likely to be relatively restricted larval transport and significant levels of self-seeding for reef based populations of tealfish in Australian fisheries, current-driven larval transport supports relatively well-mixed populations of both species in east Australian fisheries over the medium to long term. There is also likely to be some significant connectivity between the adjacent Coral Sea reefs and the GBR, and between the northern GBR and Torres Strait populations, with the northern GBR more likely to be source populations (Fontoura et al., 2022). There may also be some variability to this connectivity on annual and seasonal scales, due to the effect and timing and strength of the monsoon (Saint-Cast, 2008; Murphy et al., 2012) and other stochastic factors (Uthicke et al., 2009).

There is likely to be less demographic scale mixing between east and west Australian fisheries (due simply to distance), and between Australian and the Southwest Pacific. However, genetic connectivity is likely to be maintained through “stepping stone” mechanisms (Uthicke and Benzie, 2003; Ceccarelli et al., 2013).

Therefore, the population structure of both tealfish species within east Australian fisheries is likely to be considered as “local populations with maximum connectivity within the meta-population” (or Type D stock structure; MSC, 2022; Table 2) in Torres Strait and the GBR; and “local populations with partial isolation” (at least for isolated reefs) within the Coral Sea (or Type B stock structure; MSC, 2022; Table 2).

In this case, management of east Australian fisheries as a single stock is appropriate, but with consideration of population dynamics on the scale of 50-100 km (or isolated reefs in the case of the CSF) to maintain local density and for ecological considerations. For a stock that has well-connected metapopulations that

straddle management areas, this is not a risky situation if each fishery is managed on a sustainable basis. However, for isolated reefs such as in the CSF, there is a risk of local population/sub-population extirpation, often before any indication from monitoring.

For isolated reefs, such as occurs in the CSF, a precautionary approach would be to manage at the reef (or reef system) level. The large Qld east coast fisheries of the GBR and Torres Strait are likely to have at least moderately well connected metapopulations, and hence fishery or large-scale sub-fishery level management approaches should be sufficient.

2.4 Climate change

Climate change stressors in marine environments include increased sea temperature (and so-called marine heat waves), sea level rise, changes to ocean current patterns, increased storm intensity, and ocean acidification (IPCC 2019; Hobday et al. 2018). These physical changes in turn influence the abundance, distribution, phenology and physiological condition of marine species, affecting the productivity, location and composition of fisheries resources (Pecl et al., 2014; Hughes et al., 2018; Fulton et al., 2021). Natural climate variability in Australia's Tropical Pacific Ocean region is also 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).

2.4.1 Direct impacts of climate change

Temperature

Longer-term (> a few weeks) experiments on 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 to elevated temperature (*Holothuria atra*, *Stichopus chloronotus*, and *Holothuria edulis*), suggesting that species might respond differently to ocean warming. A study of the royal 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. Although 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 (Khalil et al., 2023). While they found that temperature regulated starfish physiology, the combination of high temperature and lower pH showed nonlinear and potentially synergistic effects on organismal physiology (e.g., metabolic rate). Furthermore, 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.

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. *Holothuria scabra*, *H. parva*, *H. forskali*, *Apostichopus japonicus*) (Collard et al., 2014; Yuan et al. 2015; 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. Sandfish, Black teatfish) (Plagányi et al., 2013) and is likely to be neutral for deeper water species such as White teatfish.

Changes in cyclone frequency and intensity

Shallow species such as Black teatfish may be negatively impacted by scouring and dislocation by severe storms. Impacts to deeper water species such as White teatfish are likely to be negligible.

2.4.2 Indirect impacts of climate change

Repeated exposure to damaging marine heatwaves has already resulted in coral bleaching events on the GBR in 1998, 2002, 2016, 2017, 2020 and 2022 (AIMS, 2023), likely resulting in at least short reductions in the cover of live coral, and changes in coral community structure. In the longer term, this is likely to lead to irreversible changes in coral reef assemblages depending on the intensity and timing between successive thermal stress events (Hughes et al., 2018; Johnson et al., 2018).

The impact of these changes to reefs and their benthic and fish communities on sea cucumbers is uncertain. Trophic effects are poorly understood but are likely to be impactful in the longer term (Fulton et al., 2018).

2.4.3 Vulnerability of teatfish species to climate change

A vulnerability assessment of 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). Hence, the vulnerability of White teatfish to climate change stressors 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 pCO₂ 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).

2.5 Ecological role

Effect on benthic habitats

Holothuroids (Class Holothuroidea) feed on the sea bed sediments, reducing the organic load and redistributing surface sediments. This form of bioremediation enhances the productivity of benthic communities) and the nutrient recycling is crucial in ecosystems with low nutrient levels, as in the Coral Sea (Ceccarelli et al., 2013). Feeding and excretion by sea cucumbers also increase seawater quality and alkalinity, which contributes to local buffering of ocean acidification (see below). 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). For a comprehensive review of sea cucumber ecological role, see Purcell et al. (2016a).

Sea cucumbers are known to be consumed by a diverse range of predators from at least seven phyla, including 19 species of sea stars, 17 crustaceans, several gastropods and around 30 species of fish (Purcell et al., 2016a). 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 such as teatfish species 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

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.

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 systems where 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 in preferred habitats of both species, and the preference for slope and deeper reef habitats by White teatfish (Purcell et al., 2023a; Murphy et al., 2021a), that any local ameliorating effects on water chemistry by both teatfish species would be modest at best.

2.6 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 teatfish and White teatfish.

Factors increasing inherent vulnerability

- Both species are large, easily seen (for the adults at least) sea cucumbers and are thus easily harvested.
- Both species are high value species that have been consistently targeted by fishers.
- Generation length for both species is unknown, but may be greater than several decades (Conand et al., 2013a; 2013b; Uthicke et al., 2004a).
- 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).
- Larvae of both species are planktotrophic (Tanita et al., 2023), 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 localised 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 because it is commercially exploited throughout its range, and is considered to have declined by more than 60-80% in at least 30% of its range, and was considered overexploited in at least 40% of its range (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).

Factors reducing inherent vulnerability

- Both species have a broad geographical range globally (Conand et al., 2013a; 2013b), and within Australian waters (see above).
- 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 (FAO, 2019; Knuckey and Koopman, 2016; Helidoniotis, 2021a; Murphy et al., 2024)
- Juveniles are very cryptic and rarely observed – offering protection from fishing for juvenile year classes (Uthicke, 2004a; Prescott et al., 2013; CITES, 2019; Burgy and Purcell, 2024).
- White teatfish inhabits deeper reef habitats so is less susceptible to fishing (Murphy et al, 2021b) though this protection will be reduced in fisheries that utilise underwater breathing apparatus (Purcell et al., 2014).
- There is unlikely to be ongoing significant illegal, unreported and unregulated (IUU) fishing for teatfish species in Australian fisheries (this report).

Black teatfish are very susceptible to overexploitation, inhabit the shallow reef that is most susceptible to exogenous impacts (including climate change) and can take some time to recover from heavy depletion, therefore an assessment of the Inherent Vulnerability of 'high' for Black teatfish in Australian waters is warranted.

White teatfish, likely has a lower inherent vulnerability than Black teatfish – being less susceptible to fishing pressure due to the potential for relatively high density of White teatfish in deep reef habitats (Murphy et al., 2021a; Koopman and Knuckey, 2021), and exogenous perturbations, therefore a precautionary assessment of the Inherent Vulnerability of 'medium-high' for White teatfish in Australian waters is recommended.

3 Trade

Sea cucumbers have been consumed in China for centuries, if not millennia, with records of sea cucumber consumption in the Three Kingdoms Period (220-280 AD), and the South Song Dynasty (1127-1279 AD), where they were served at banquets and special occasions in royal households (Choo, 2008; Yang and Bai, 2015).

The Chinese have long believed that sea cucumbers have medicinal properties that can help with a variety of ailments, including kidney and blood disorders, “yang strengthening” and male sexual vitality, “yin invigorating”, and are traditionally called ‘haishen’, meaning *sea ginseng* (Choo, 2008; Fu et al., 2016). The recognition of sea cucumbers as having medicinal qualities dates back to at least the Ming Dynasty (1368-1644), when sea cucumbers were documented in various texts including the "Compendium of Materia Medica" by Li Shizhen, written in 1578 (Liu et al., 2015).

Its consumption became more mainstream at the beginning of the Qing dynasty (1636-1912 AD) (Dai, 2002; Sutherland, 2000) and demand remained high until a virtual hiatus in the late 1930s as the Sino-Chinese war, the Second World War and Chinese civil war decreased consumption dramatically (Kinch et al., 2008; Anderson et al., 2011), though low level consumption still occurred through Hong Kong and Singapore (Sachithanathan, 1994). This hiatus in demand lasted until the 1970s, when a re-opening China and increased affluence saw consumption and imports increase dramatically (Choo, 2008; Anderson et al., 2011).

Historical records show that China was importing up to 60 t of dried sea cucumber per year from the mid-1700s, increasing to over 1,000 t per year by the mid-1800s, and peaking at 2,650 t in 1896, most of this originating from Southeast Asia (Dai, 2002). As for the modern sea cucumber trade, imports of dried sea cucumbers into Hong Kong peaked around 1990 at about 8,000 t and have been declining slightly since then (Choo, 2008; To et al. 2018; Figure 7). However, a clear understanding of trade volumes is significantly hampered by the lack of transparency in trade between exporting and importing countries, Hong Kong SAR, Vietnam and mainland China (FAO, 2019). Other significant trade destinations for sea cucumber include Taiwan, Malaysia, South Korea, and the United States (CITES, 2019, 2022; FAO, 2022). It is estimated that more than 90% of Australian sea cucumbers are annually exported to Hong Kong (AFMA, 2023). Other Australian export destinations include Canada, Malaysia, Singapore and the United States (AFMA, 2023).

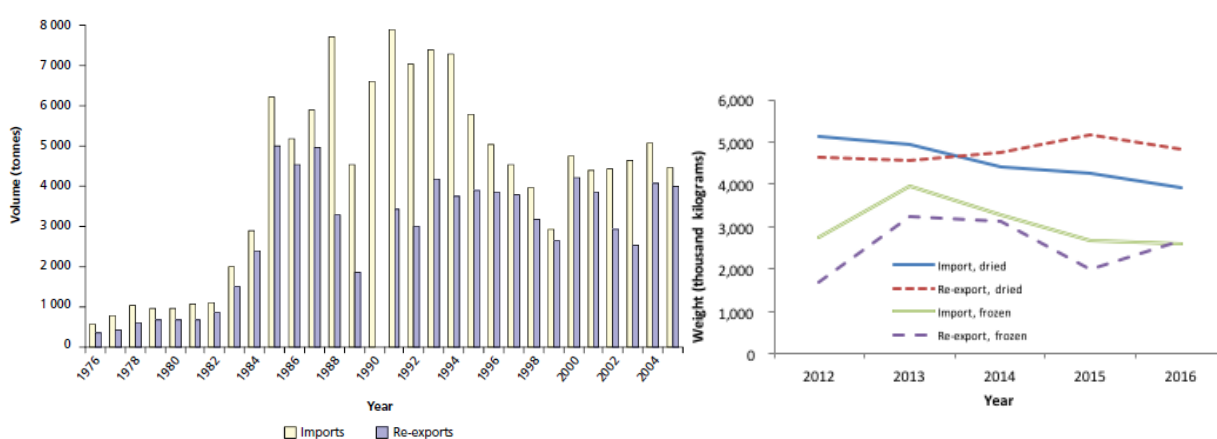


Figure 7. Sea cucumber (dried, salted and in brine) imports and re-exports from Hong Kong for 1976 to 2004 (left, Choo, 2008), and 2012 to 2016 (right, To, 2018).

Black teatfish is common in the sea cucumber international trade, and is considered a high value product (Purcell et al., 2018; FAO, 2019). Prices in the premium Hong Kong wholesale market averaged US\$180 per kg (and max US\$ 230) in 2011 (Purcell, 2014), and had increased to US\$208 per kg (and max US\$294) in 2016 (Purcell et al., 2018). This 15.6% increase compares to an average increase of 16.6% across all species

surveyed during that period (Purcell et al., 2018). There is a particularly strong size-value correlation for Black teatfish (Purcell et al., 2018).

White teatfish are also common in the sea cucumber international trade, though perhaps not historically as important as Black teatfish (Conand, 2013b; see historical fishing section below) and is currently considered a high value product (Purcell et al., 2018; FAO, 2019). Prices in the premium Hong Kong wholesale market averaged US\$192 per kg (and max US\$274) in 2011 (Purcell, 2014), and had increased to US\$219 per kg (and max 401) in 2016 (Purcell et al., 2018). This 14.1% increase compares to an average increase of 16.6% across all species surveyed during that period (Purcell et al., 2018).

Strong market demand is likely to continue for both species into the future, but with some uncertainty related to consumption trends, and economic and geopolitical trade considerations.

4 Sea cucumber fisheries

4.1 History of fishing

Sea cucumbers have been harvested to supply the Chinese market, where they were traditionally called 'haishen' (meaning *sea ginseng*) since at least the Three Kingdoms Period (220-280 AD) (Choo, 2008; Yang and Bai, 2015). Initially, the demand was met by local Chinese coastal fisheries, particularly Hainan in southern China (mostly tropical species), and Liaodong Peninsula in the north (primarily for the temperate *Apostichopus japonicus*) (Akamine, 2024). As the coastal fisheries came under pressure in the late fifteenth century, *A. japonicus* was sourced from further afield, including Japan, the Koreana Peninsula and current day eastern Russia (Akamine 2001; 2024; Kalashnikov, 2024).

Fisheries for tropical species were established along the Malay Peninsular by the late 1600s, where the name *trepang* was likely derived (Sumner, 1981), with the Philippines and east Indonesia, including modern day West Papua Province, being well established by the early 1700s (Dai, 2002; Adhuri, 2013). Around this time, Makassar in South Sulawesi became established as somewhat the centre for the sea cucumber trade for much of the southeast Asian region (Akamine, 2001; Sutherland, 2020), with fishing fleets ranging throughout the region, usually under the direction of, and financed by, local ethnic Chinese traders (Dai, 2002; Schwerdtner Máñez and Ferse, 2010). Macassan based fishers eventually roved as far south as the northern Australian coastline and were regular visitors by the mid-1700s (Macknight 1976; Schwerdtner Máñez and Ferse, 2010) (see section below).

Exploitation of sea cucumbers in the western Pacific began in the late 1700s through to the mid-1800s, generally supplying directly to the Chinese market (Kinch et al., 2008). This began in Polynesia (e.g. French Polynesia – 1810); Micronesia (e.g. Northern Mariana Islands – 1830s) and then Melanesia (e.g. Milne Bay PNG, GBR - early to mid 1800s), often following European and Japanese colonial expansion (Kinch et al., 2008; and citations therein). Apart from this export industry, there was, and still is, some local subsistence fishing for sea cucumbers in the region that probably dates back hundreds if not thousands of years, including in (modern day) Palau, Wallis Futura and French Polynesia (Kinch et al., 2008). The western Pacific trade conferred the name *bêche-de-mer* originally as the French derivation of the Portuguese *bicho do mar* (literally "sea animal" or "sea worm") (Saville-Kent, 1893; Merriam-Webster, 2024) - while also being French for "spade of the sea".

The east Australian sea cucumber fishery began in the early 1800s by Sydney based fishers, initially trading through east Indonesia (mostly Batavia), but by the 1870s exporting directly to China as an extension of the west Pacific maritime trade (see section below).

Sea cucumber fisheries in the subcontinent (e.g. India and Sri Lanka) and the Seychelles were active by the late 1800s, with other east African countries reported fisheries soon after (Conand, 2008; and citations therein). There is no evidence of any substantive fishing in the Americas or Atlantic Ocean during this early global fishery phase, apart from some nascent efforts in the Northeast Pacific (Toral-Granda, 2008; Hamel and Mercier, 2008; Frierson et al., 2024).

Sea cucumber fisheries throughout the Asia-Pacific region generally increased rapidly during the early 1800s and production remained at high levels throughout the 1800s (Dai, 2002; Schwerdtner Máñez and Ferse, 2010) even though some regions, particularly in the Western Pacific, had started to decline, partly at least due to over-harvesting (Kinch et al., 2008; Mitchell, 1994). Production declined to low levels for much of the early part of the twentieth century (Conand, 1990), before the outbreak of the Sino-Japanese War, World War II and the Chinese Civil War saw a dramatic decline in demand and thereafter production (Kinch et al., 2008; Anderson et al., 2011).

4.1.1 Catches

Records of target species in the early global fisheries are relatively scant. However, the Japanese sea cucumber (*Apostichopus japonicus*) was an early favoured species, and remains so to this day (Purcell et al., 2018), especially in northern China (Akamine, 2024). The earliest recorded tropical species (pre-1800) included Black teatfish and black *Actinopyga* species (Schwerdtner Máñez and Ferse, 2010). But by the early 1800s up to 15 species were being traded out of Makassar in south Sulawesi, including White teatfish, Sandfish and Prickly redfish (Crawford 1820 – cited in Akamine, 2001; Schwerdtner Máñez and Ferse, 2010). By the early 1900s, 112 different local names were applied to traded sea cucumbers (Koningsberger, 1904 – cited in Schwerdtner Máñez and Ferse, 2010), although identical species were named differently according to the product length and place of harvest, making the interpretation of historical references frustratingly difficult (Sutherland, 2000; Akamine, 2001). Even in early records, the size of the animal and the skills used in processing were recognised and important determinants of value (Schwerdtner Máñez and Ferse, 2010).

Black teatfish was an early favoured species exported from Makassar in the early 1700's, whereas White teatfish were not positively identified in the catch until the early 1800's (though it is possible that some White teatfish were mixed in with Black teatfish before then) (Schwerdtner Máñez and Ferse, 2010; and citations therein).

4.2 The modern global fishery

After a hiatus in global demand and supply following the Second World War (with the exception of Japanese sea cucumber fisheries in Japan and Korea which resumed soon after WWII (FAO, 2023), and low level consumption in Hong Kong and Singapore throughout the 1950s (Sachithanathan, 1994), global sea cucumber fisheries rapidly re-emerged after about 1980 in response to increasing demand from a resurgent China (Anderson et al., 2011; Eriksson et al., 2015; Fabinyi et al., 2017). Many central west Pacific nations (e.g. Tonga, New Caledonia, Fiji, PNG, Solomon Islands) had established sea cucumber fisheries by the mid-1980s (Figure 8), though some were intermittently active even in the late 1960's (Shelley, 1985; Preston, 1993). The Western Indian Ocean region and Indonesia were also early fishery development areas during the mid-1980s (Figure 8). While production waned in the central west Pacific and west Indian Ocean, fisheries in the Atlantic and Pacific northwest (primary for temperate species such as *Cucumaria frondosa*, *C. japonica* and *Apostichopus californicus*) increased production (Figure 8; Hamel and Mercier, 2008).

4.2.1 Catches

Early in this expansion phase, the higher value and easily accessible species were targeted, including Black teatfish, Sandfish, and Prickly redfish (Kinch et al., 2008), but other species followed as the initial target species were depleted. The fisheries during this time were often poorly regulated and many sea cucumber populations were rapidly overexploited (Purcell et al., 2013), especially in developing countries (Barclay et al., 2019) and for high value species (Purcell et al., 2014).

As mentioned above, recent fishery production for lower value but high volume temperate species such as *Cucumaria frondosa*, *C. japonica* and *Apostichopus californicus* have increased market share significantly (Figure 8; Akamine, 2024).

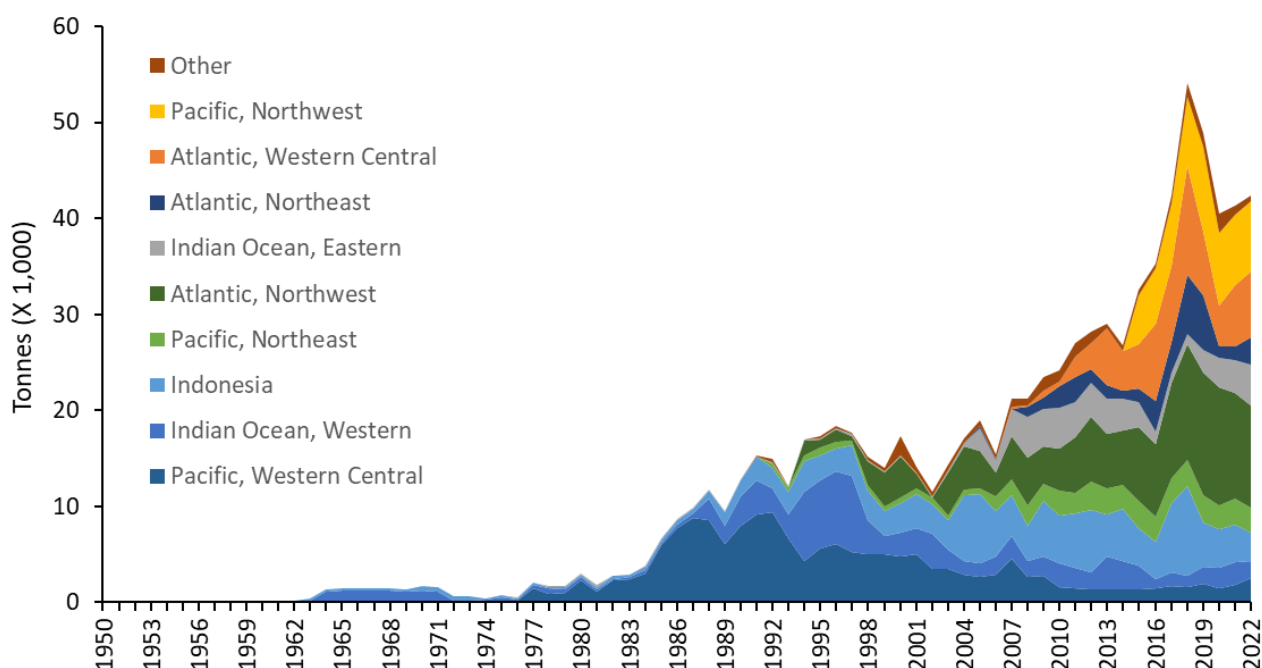


Figure 8. Global wild capture production in metric tonnes (t) of dried sea cucumbers between 1950 and 2022*. Individual regions producing 97% of production are shown, with the remainder in “Other” (FAO, 2023). Note that production figures are likely to be significant underestimates for various reasons, including poor fishery surveillance and IUU (Tuwo, 2004; Phelps Bondaroff and Morrow, 2024). *Excludes Japanese sea cucumber production in China, Japan, and Korea.

4.3 History of Australian fisheries

4.3.1 The Maccasans

Sea cucumber fishers associated with Macassar on the island of Sulawesi (in modern day Indonesia) likely began visiting the northern Australian coastline in the early 1700’s (Blair and Hall, 2013; Macknight, 2013), (though Indonesian mariners likely visited even earlier; Wesley et al., 2016), firstly in the Kimberley in Western Australia then expanding to the Arnhem Land coast and into the Gulf of Carpentaria (Macknight, 2011). The earliest reference to trepang being collected in Australia dates from 1754 when the Dutch authorities in Batavia reported that, as far as they knew, the ‘Southland’ southeast of Timor produced nothing but trepang (sea cucumbers) and wax (Macknight, 2013). Trepang processing along the north Australian coast intensified during the late 1700’s (Wesley et al., 2016) consistent with the expansion of the Macassan trepang trade (Schwerdtner Máñez and Ferse, 2010) peaking in the early 1800’s with sometimes over 100 praus and between 1000 to 2000 fishers visiting annually (Mitchell, 1994; Blair and Hall, 2013). The northern Australian Macassan fishery slowly declined during mid to late 1800’s, ceasing entirely by 1908 (Macknight 1976; Sumner, 1981; Mitchell, 1994).

Well documented encounters with Macassan trepang fishers in northern Australia include Matthew Flinders who encountered a fleet of about 60 Malay (Indonesian) ‘praus’ (perahu) and about 1000 men near Cape Wilberforce in NE Arnhem land in February 1803 (Flinders, 1814; Macknight 1976). Then in April 1803, the French naturalists Peron and Freycinet, on board the vessels *Geographe* and *Naturaliste* under the command of Nicholas Baudin, described meeting a fleet of 24–26 large “Malay” perahus also fishing for trepang off the Northwest Kimberley coast (Peron, 1816).

The two main areas fished by this industry was the Arnhem Land coast and adjacent areas in the NT and extending to Groote Eylandt and down into the bottom of the Gulf of Carpentaria— an area they called ‘*Marege*’ — and the Kimberley in Western Australia which they called ‘*Kayu Jawa*’ (Macknight, 2013; Adhuri, 2013; Blair and Hall, 2013). They also fished the offshore Timor Sea reefs and islands (e.g. Ashmore

Reef, Scott Reef, Seringapatam Reef, Cartier Island) probably well before the northern Australian mainland fisheries (Fox and Sen, 2002).

Northern Australia most likely became the southernmost limit of the Macassan trade (Blair and Hall, 2013). Despite their activities being reasonably well documented, there are no accounts of the Macassans visiting the Torres Strait or east Australian coast, and it is doubtful they did in any substantial way, as sailing through the Torres Strait would have been full of dangers from currents and reefs, to hostile Cape York and Torres Strait indigenous communities (Bolton, 1970).

The emergence of an Australian-based trepang industry in the northern Australian region in the 1870s led to pressure to restrict the Macassans; and in 1882, Macassan vessels were required to pay for an annual licence and customs duties were levied on the exported catch (Adhuri, 2013). This led to a decline in the numbers of visiting Macassan boats until it was finally closed by the South Australian Government after the 1906–07 season (Macknight 1976; Sumner, 1981). Still, sporadic visits to parts of the north Australian coast, particularly to the north-west or Kimberley coast, continued (Sumner, 1981), as well as regular visits to the offshore reefs that now form the Timor Sea MOU Box fishery, now fished by traditional Indonesian fishers (Fox and Sen, 2002).

Catches

There is some uncertainty regarding the main species in the catch of the northern Australian Macassan fishery. Flinders, in his encounter with the Macassan fleet in NE Arnhem land, recorded two sea cucumber vernacular names: *koro*¹ and *baatoo* (Flinders, 1814), which most closely translate to White teatfish and Black teatfish respectively (Akamine, 2001; Schwerdtner Máñez and Ferse, 2010). Some historical descriptions of catches from *Marege* indicate that they were mainly catching “grey trepang” (also described as chalk fish or white trepang) (Schwerdtner Máñez and Ferse, 2010) which most likely relate to Sandfish. Other indications that Sandfish also occurred in the catch include reports that the product was not of the highest quality, was very abundant and required skilful processing, including being buried in sand to remove the calcareous deposits in the skin (Schwerdtner Máñez and Ferse, 2010; Blair and Hall, 2013) – all consistent with the characteristics of Sandfish.

While it is tempting to try and characterise the Macassan fishery as being based on one or just a few species, it is more likely that it was a multi-species fishery reflecting the multispecies demand from China, the variation in habitats and populations available across northern Australia, the considerable cost to travel to Australia to fish, and the entrepreneurial nature of fishers. Fishers were described as using a range of fishing methods in depths ranging from intertidal to 8-10 fathoms (15-18 m) deep (Flinders, 1814). The Macassar market names for product from northern Australia, *Trepang Marege*, and *Trepang Kayu Jawa* (Schwerdtner Máñez and Ferse, 2010) likely reflects a multispecies catch from the corresponding region rather than a single species. Regional traders were notorious for their inventive and fluid naming conventions for sea cucumber products, making reconstruction of species lists from market records difficult (Sutherland, 2020).

What is clear is that the Macassan fishery harvested a lot of sea cucumbers over an extended period of time, with catches of 350 tonnes of dried trepang per season (equivalent to several thousand tonnes of landed (gutted) sea cucumbers), estimated for the first half of the nineteenth century (Macknight, 1976; Schwerdtner Máñez and Ferse, 2010), only decreasing in the late 1800s (Mitchell, 1994). Indeed, at its peak, *Trepang Marege* made up the largest part of Macassan exports and of the total imports into China (Macknight, 1976; Blair and Hall, 2013).

¹ Adding to the confusion, the term ‘koro batu’ and ‘koro susu’ are common contemporary Indonesian names Black teatfish and White teatfish respectively, whereas ‘koro’ is an old Macassan word meaning “wrinkled” or “shrunk”.

4.3.2 The early east coast “Queensland” fishery – GBR, Coral Sea and Torres Strait

Sea cucumbers have been fished on the Australian east coast since the early 1800’s when the first Sydney-based beche-de-mer fishers began catching and processing sea cucumbers on island-based processing stations on the GBR, but also the inner Coral Sea reefs (Sumner, 1981; Ganter, 1990; Mullins, 1995). The product initially supplied the local Chinese miners but was subsequently exported to Indonesian ports including Batavia (modern day Jakarta), Surabaya and Kupang (in Timor) (Sumner, 1981; Ganter, 1990; Mullins, 1995). During this time, direct access to China was thwarted by the tight control of the British East India Company’s monopoly on trade to China (Mullins, 1995).

The earliest record of fishing was in 1804 when James Aicken collected several barrels of beche-de-mer from Wreck Reef in the Coral Sea (Mullins, 1995), and in 1908, James Austen briefly operated a beche-de-mer station on Lady Elliott Island (Sumner, 1981). A few vessels are known to have been employed in the industry on Queensland’s east coast in the 1820s, with 10 tons of bêche-de-mer shipped from the Cooktown area to Kupang in 1827 (Ganter, 1990), and by the 1840s a regular Sydney-based fishery had developed (Mullins 1992; 1995). In 1845 there was a beche-de-mer station in the Holme islands group off Cape Grenville, run by Martin McKenzie, who had a reputation as one of the most experienced beche-de-mer fishermen at this time (Mullins, 1992; 1995). He recruited Indonesian fishers and landed them at various islands in the vicinity of Cape Grenville where they collected and processed beche-de-mer for later transport to Kupang or Surabaya (Mullins, 1995). But by 1850, this industry appears to have all but died out, due mostly to the closure of northern Australian outposts such as Port Essington, and the emergence of the profitable sandalwood industry in the South Pacific (Mullins, 1992).

The east coast fishery became active again in the early 1860s, this time as part of a broader western Pacific maritime trade, exporting a range of products directly to China and nearby ports (Mullins, 1992; 1995; Ganter, 1990). In the 1850’s the western Pacific maritime trade had developed, mostly based on harvesting and transporting sandalwood to China, but also increasingly supplemented by beche-de-mer and turtle shell (Mullins, 1995). The crews were composed of many different ethnic groups, but the majority were Pacific Islanders (Mullins, 1995).

At this time, a Sydney based maritime trader with experience in the west Pacific, Robert Towns, quit the declining western Pacific sandalwood trade to concentrate on the east coast beche-de-mer fishery (as well as shipping and pastoral investments). His vessels sailed regularly along the east coast picking up beche-de-mer and dropping off supplies, not only for his own stations, but for others in the region (Mullins, 1995). He and another Pacific trader, James Paddon, were instrumental in expanding the fishery into Torres Strait (see section below).

After languishing almost entirely around 1870, the fishery revived with a rise in prices, resulting in a flourishing export trade with Hong Kong and China, including a fleet of over 40 boats operating from ports north of Townsville (Bolton, 1970, Sumner, 1981). By the end of the decade beche-de-mer worth over £13,000 was shipped each year to this market (Bolton, 1970). Cooktown, where thirteen boats were estimated to employ 450 men (mainly non-European), was the headquarters of the industry (Bolton, 1970).

Though records are patchy, exports during this period reached a peak between 1880 and 1890, operating mostly on the northern GBR and Torres Strait (Saville-Kent, 1893; Ryle, 2000; Sumner, 1981). By 1890 there was a substantial industry, mostly working out of Thursday Island and Cooktown (Saville-Kent, 1893), and crewed mainly by Indigenous Australians. Over 100 boats were engaged in the fishery in 1889 (Saville-Kent, 1893).

Assessments of the health of the fishery at the time were optimistic, with government officials stating that there did not appear to be any signs of depletion of the fishery even up to 1890, and that the main fishery had reached no further south than Mackay (Saville-Kent, 1893). It was thought that depleted reefs were being restocked by populations in deeper water, usually after a one-year duration (Saville-Kent, 1893).

However, this optimistic viewpoint was soon proved incorrect, with fishers asserting the need to venture further afield toward PNG by as early as 1882 (Lloyd, 2016), and by the early 1890s the inner reefs were fished out and fishers were forced farther out into the Coral Sea, New Guinea, the Solomon Islands and the

New Hebrides (present day Vanuatu) (Saville-Kent, 1893; Lloyd, 2016). These regions were worked by larger ships staying out to sea for 6 months (Bolton, 1970; Sumner, 1981). Catches fluctuated greatly after 1890 (Ryle, 2000). The *bêche-de-mer* fishery during this time, while known for some wealth, was largely associated with terror and drudgery (Lloyd, 2016).

By 1901 the fishery was in somewhat of a revival, with 11 licensed vessels working out of Cooktown, and based on the reemergence of sea cucumbers on the GBR and also near Erub (Darnley I.) and Mer (Murray I.) in the Torres Strait (Lloyd, 2016). By then, the *beche-de-mer* trade was almost entirely under the control of Japanese or Thursday Islanders (Sumner, 1981), and by 1908, it was rumoured that over fifty Japanese vessels operated in the area south of Cooktown (Ryle, 2000).

Claims that the industry had been taken over by the Japanese, and that prices paid in Cooktown were being manipulated, led to a Royal Commission into the fishery in 1908 (Ryle, 2000). John Mackay, the chairman of the Queensland Marine Board, chaired the Royal Commission into the working of the fisheries with specific instructions to investigate these issues (Lloyd, 2016). The Commission concluded that the industry had reached its 'zenith' in 1907 and grounds had been fished bare from New Guinea to Lady Elliot Island. They recommended a two-year closure. However, strong fishing interests and a government focused on economic development saw this recommendation remain unimplemented (Lloyd, 2016).

While there are reports that the Queensland fishery ceased during the First World War (Sumner, 1981), this is not supported by available catch data - exports were still 300-700 t per year throughout the war (Anon, 1946), though much of this may have originated in Torres Strait, where fishing continued under a government subsidised company boat system (Mullins, 2012).

The *beche-de-mer* industry in Queensland limped on until the 1930s, but had ceased by the start of the Second World War (Sumner, 1981). There was a brief attempt at revival in 1946-7, but by the 1950s fishing activity had ceased altogether (Sumner, 1981).

Torres Strait – the pivotal role of the *beche-de-mer* fishery

There are some reports of very early Chinese and/or Malay contact in Torres Strait that predate colonial times, (e.g. reports that suggest the Chinese may have passed through the Torres Strait area in the 1400s (Menziess, 2002)). Kinch et al. (2008; citing Laade, 1966) also claims that the oral history of Torres Strait Islanders indicate that Chinese and Malays regularly visited the islands to harvest sea cucumbers long before European explorers arrived. However, this would appear unlikely as there is no firm evidence of a sea cucumber industry in Torres Strait before 1860, and reports of Chinese sea farers reaching Australia on a regular basis have been somewhat discredited (Finlay, 2004; Anderson, 2000).

Even so, for decades before colonial occupation in the 1860s Torres Strait Islanders had traded with the crews of passing ships (Mullins, 1995). Sydney-based fishing boats were reported trading in Torres Strait as early as 1846 at Badu Island (MacGillivray 1852, as reported in Beckett, 1977 and Sumner, 1981). However, they were likely procuring turtle shell and artifacts (Mullins, 1995) rather than *beche-de-mer* (as reported in MacGillivray, 1852), as the accounts were for Badu Island, which does not have substantive stocks of *beche-de-mer* in its vicinity (Long et al., 1996), and there was no evidence of a *beche-de-mer* industry in Torres Strait at that time (Mullins, 1992).

By the late 1850s, two principal traders operating mostly in the central west Pacific, James Paddon and Robert Towns, had begun supplementing a shrinking sandalwood industry with *beche-de-mer* and exporting directly to China (Mullins, 1995). In July 1860 Paddon sent one of his most experienced masters, William Banner, to Torres Strait aboard the 100 ton brig, *Julia Percy* to exploit whatever resources he could find (Mullins, 1995). This vessel was crewed mostly with south sea islanders from Eromanga in the New Hebrides (modern day Vanuatu).

After landing on Lizard Island and setting up a *beche-de-mer* station there, Banner visited the islands of Torres Strait in November 1860 (Mullins, 1992; 1995). He visited most of the inhabited islands in the main shipping channel on his way to and from Erub (Darnley Is.) and found that the Islanders were very experienced in dealing with Europeans. He procured more than 100 pounds of turtle shell as well as some rare and valuable artifacts (Mullins, 1995). Presumably, Banner would also have been taking stock of *beche-de-mer* resources on his visit. The Lizard Island station was abandoned in January 1861 due to poor garden

production (though beche-de-mer were reportedly plentiful) and Banner returned to Sydney. While the voyage to Erub had been a success, Paddon had died while the *Julia Percy* was at sea, and with that the project collapsed (Mullins, 1995).

Based largely on Banner's reports, in 1862, Charles Edwards, who had links with Robert Towns, set sail from Sydney on the *Blue Bell*; again with a mostly south sea islander crew. They set up a bêche-de-mer station on Albany Island just off the mainland at Cape York, before moving on to Erub in 1864 (Mullins, 1992; 1995). At that stage, Torres Strait was outside the control of the colonial government (designated essentially as "high seas"), and Erub was fertile, relatively friendly and had a ready workforce (Ganter, 1990). By 1866 Towns had invested heavily in what he called his 'Torres Strait venture', and three large vessels connected with himself and Edwards, the *Blue Bell*, *Melanie* and *Woodlark*, were at work in northeastern Torres Strait (Mullins, 1995).

In July 1865 William Banner returned, with the financial backing of the Sydney firm James Merriman and son, and with the *Telegraph* and *Metaris* set off for the beche-de-mer fishery in the northern GBR and Torres Strait. In 1869, he established a beche-de-mer station on the northwest side of Tudu (Warrior Is.) (Chester, 1870; Mullins, 1995). There are conflicting reports as to the circumstances of Banner's arrival at Tudu – by some accounts Banner and his labour force of Pacific Islanders arrived with guns and occupied the Tudu site by force (Thomassin, 2019; Shnukal, 2004), and by other accounts he developed cordial business relations with the Tudulgal chief, Kebisu (Mullins 1992; 1995). The truth is probably somewhere between the two, and the operations were soon employing local labour alongside South-Sea Islanders (Ganter, 1994; Mullins, 1995; Shnukal, 2004). Banners' operation was pivotal to the development of Torres Strait, as his was the first to "discover" the goldlip pearlshell at Warrior Reef adjacent to Tudu. This became a prized resource that would do more to transform colonial era Torres Strait than any other industry or event (apart perhaps, from the arrival of missionaries on Erub in 1871 – the "Coming of the Light").

By 1872 there were beche-de-mer (and sometimes pearling) stations at Tutu, Gabba (Two Brothers Is.), Erub, Mer (Murray Is.), Tappoear (Campbell Is.) and Dalrymple Is. (Mullins, 1995), and semipermanent floating stations at Poruma (Coconut Is.) (Mullins, 1995). Erub had several beche-de-mer stations and was considered the centre of the bêche-de-mer industry in Torres Strait (Ganter, 1990), and the deforestation caused by harvesting the timbers required to boil the beche-de-mer pots is a feature of the island to this day (K. Bedford, *pers comm.*). The establishment of the beche-de-mer (and pearlshell) stations in the eastern islands of Torres Strait and the establishment of a small British settlement at Somerset on Cape York marked the beginning of sustained outsider presence in Torres Strait (Shnukal, 2004).

The development of the Torres Strait maritime industry also fomented actions by the colonial government to control (and presumably tax) these activities. In 1872, the colony of Queensland annexed all Torres Strait islands within a 60 nautical mile radius of the coast of Queensland, and in 1879, annexed the remaining islands including Erub and Mer, and the islands adjacent to the PNG coastline of Boigu, Saibai and Dauan (Ganter, 1990), though its influence on these far flung island was limited for a time (Mullins, 1995).

In 1881, fisheries activities in Torres Strait became subjected to *The Pearl-Shell and Bêche-de-mer Fishery Act of 1881* authorising the Queensland government to regulate the industry and get some revenue from it through licensing of boats and divers (Ganter, 1990; Thomassin, 2019). *The Native Labourers' Protection Act 1884* was passed exclusively for the purpose of protecting indigenous Australia and New Guinea employed in the marine industries. It required native labourers to be signed on and paid off before the shipping master, and to be returned home after a maximum term of twelve months (Ganter, 1990).

The influx of south sea islanders was also a feature of the early Torres Strait maritime industries. When William Banner arrived at Tutu in the *Blue Bell* early in 1869, he had about 70 Pacific Islanders aboard (Mullins, 1995). Some well know examples include Banners' foreman, Tongatapu-Joe, who married into the local tribe and was pivotal in purloining local islander knowledge of pearlshell in 1869 (Mullins, 1995).

The fishery bought immigrants such as Edward (Yankee Ned) Mosby, who set up a beche-de-mer station on Masig (Yorke Is.) in 1874, with the blessing of the then island's chief (or mamoose) Mandi (Thomassin, 2019; Shnukal, 2004; Ganter, 1990). In mid-1880s, Mosby had 'about fifty Islanders fishing for him' on his bêche-de-mer station' (Thomassin, 2019; Shnukal, 2000). Another notable immigrant was Douglas Pitt, a black West Indian from Jamaica who arrived in Torres Strait in 1871, and subsequently set up a bech-de-

mer station on Mer (Murray Is.) with a crew of Pacific and Torres Strait Islanders (Ganter, 1990; Mullins, 1995).

Being a maritime people, Torres Strait Islanders were well qualified to do the work asked of them, and there is no doubt that many young Islanders were keen to work in the boats (Mullins, 1995). When the local police magistrate, Henry Chester, visited Banner's station in September 1870 he commented that the 'utmost harmony' prevailed between the Pacific and Tutu Islanders. And by 1886, John Douglas, Chester's successor, estimated that 500 men and boys were employed in the beche-de-mer fishery, "of whom probably a third, though possibly a half" had come from the Australian mainland (Shnukal, 2004). The police magistrates, such as Chester and Douglas, had limited control over the outer Torres Strait Islands, but could exercise it mainly through the maritime industry fleet (pearlshell and beche-de-mer) and the missionaries (Mullins, 1995).

The early beche-de-mer and pearlshell fisheries in Torres Strait had a strong influence on Torres Strait governance and culture. Not only did its commercial presence transform the economy and political oversight of the region, the infusion of south sea islanders and Christian missionaries that had close connections with the industry transformed islander communities from traditional communities to hybrid communities in short very short order (Mullins, 1992). The islanders gathered in fewer more central villages rather than smaller scattered communities, and the semi-nomadic lifestyle of the central islands, at Tudu in particular, ceased (Mullins, 1995). However, many of the old traditions remained, particularly regarding land tenure, and intermarriage strengthened the social cohesion of a Torres Strait wide identity (Mullins, 1995, Haddon et al., 1901). This extended to the usage of a common language, beach-la-mar, the forerunner of later Torres Strait creole, or Yumplatok (Snukul, 2016).

This period was not without hardship or drama. It was the unwillingness or inability of ship masters to control their Pacific Islander crewmen which caused the Torres Strait Islanders the greatest physical and psychological trauma (Mullins, 1995). However, Torres Strait Islanders showed a remarkable plasticity and resilience to absorb and adapt to the new ways, such that their society was transformed, but still retained its essential character without the widespread bloodshed and dispossession that occurred on the mainland (with the exception of the inner islands of the Karaureg which were decimated by early colonial "retaliatory" attacks; Smith, 2018). The establishment of a quasi-local government, with a *mamoose* or head man (replaced by island councils in 1899) and local courts, meant that European influence over their affairs was somewhat limited, though the passing of the "Aboriginals Protection and Restriction of the Sale of Opium Act" in 1897, did herald a period of more regulation and less self-determination (Mullins, 1992; 1995).

Slowly the maritime industries shifted from being run by outsiders to being a truly "local" industry. Much of the beche-de-mer caught in Torres Strait after 1904 came from the subsidised "company boat" system (Mullins, 2012). These were based on a semi-government supported philanthropic company called Papuan Industries Limited (PIL) – the forerunner of the current Islanders Board of Industry & Service (IBIS) – which encouraged islander communities to co-operatively rent or purchase their own luggers.

The industry in the Strait had peaked from the late 1890s to 1910 and declined rapidly after about 1922. There was a total cessation of activity during World War II, in part as a result of evacuation of islands after bombing raids and the compulsory acquisition of fishing vessels in wartime operations. Despite proposals to re-establish the fishery in Torres Strait as part of post-war reconstruction of northern Australia, there were only sporadic commercial catches over the next 40 years (DEH, 2005).

Catches of the early east coast "Queensland" fishery

Records of the early "Queensland" fishery catch are only available from 1878 and for about the next decade (Saville-Kent, 1893). They start again when the Commonwealth Year Books began recording exports after federation in 1901 (Anon, 1946). Uthicke (2004) reconstructed historical catches for the early "Queensland" fishery (Figure 9) with data given in Saville-Kent (1893), Sumner (1981) and Anon (1946). As the early export data were recorded as dry weight or value, several assumptions and conversions had to be made, and the author cautions that the data presented can only be taken as a rough estimate (Uthicke, 2004). Weight data was converted from dry-weight (beche-de-mer product) to landed (wet gutted) weight, using a conversion factor of 7.6 (supposedly using conversion data for *Holothuria nobilis*). While this conversion rate is

dissimilar to established conversion rates for Black teatfish (e.g. 5.64 in Murphy et al., 2021c), this is probably a realistic conversion factor for a mixed species catch (Murphy et al., 2021c).

Also, for the years from 1901 to 1940, only the value of the catch is reported. These values were converted to weight by assuming an average value of £4.4 (Australian Pounds) per cwt (hundredweight = 50.8 kg); this figure being the average value of exported sea cucumber for the period 1925 to 1940 derived from Australian Commonwealth export data (Anon., 1946). However, this value may be too low as the average price paid for sea cucumbers in Queensland in the years 1923 and 1928 was £9.36 per cwt (Sumner, 1981). Applying this alternative valuation factor would reduce the 1900-1940 estimated catch in Uthicke (2004) by over 50% - illustrating the uncertainty in the final output. It is also important to acknowledge that the reported catches are likely to be an underestimate of actual fishery extractions, due to discarding and non-reporting.

In any case, the sea cucumber catch during the historical east coast fishery was very likely several times greater than its modern-day successors – the historical fishery was described as being fished in “vast quantities” over an extended period – with over 100 boats active in the fishery in the early 1880s, the majority based in Thursday Island and Cooktown (Saville-Kent, 1893). In the 1860’s a whaler could catch up to 1300 teatfish on one trip (MacGillivray, 1862; cited in Mullins, 1992), and a good average catch rate for a fishing station on the northern GBR fishing grounds during the 1880s was 1 ton of dried beche-de-mer (approximately 7.6 t gutted) per month, working with four boats, carrying twenty to twenty-four men (Saville-Kent, 1893). The curing process was labour intensive – between 8,000 and 8,700 teatfish and 18,500 'red fish' were needed to make one ton, and a whaler could catch up to 1300 teatfish on one trip (MacGillivray, 1862; cited in Mullins, 1992).

Most of the catch was picked up by walking the reef at the spring low tide, but the higher value species, including Black teatfish and Prickly redfish, was also obtained by free diving to a depth of 2 or 3 fathoms (6-9 m) (Saville-Kent, 1893). Generally, 9 fathoms (16.5 m) was the maximum depth worked (Sumner, 1881).

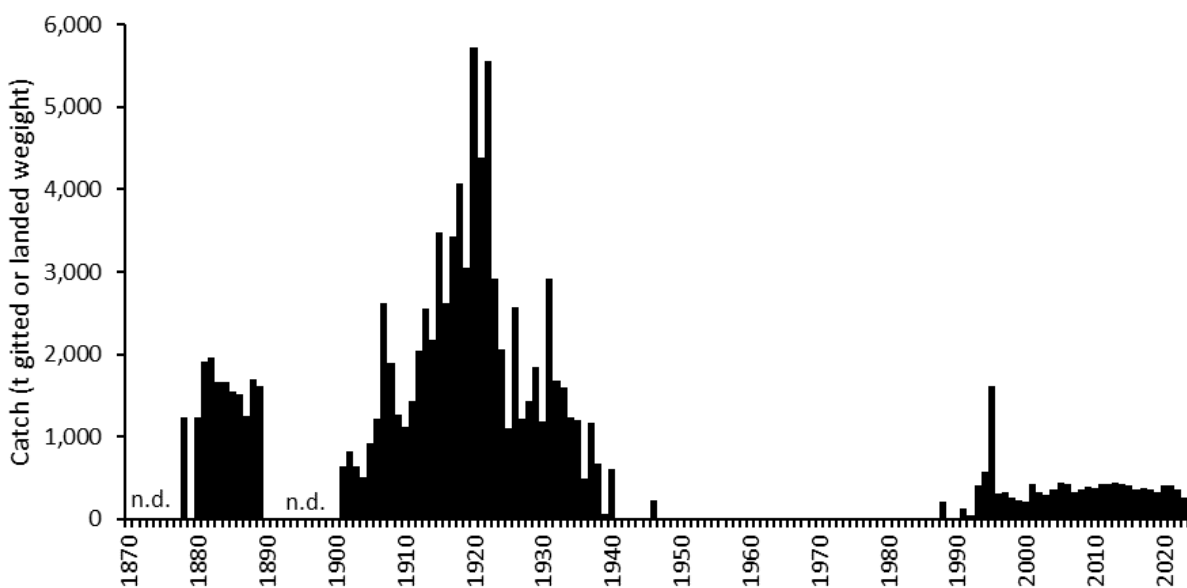


Figure 9. Catch of the historic (pre-1950) Queensland sea cucumber fishery (including the GBR, Torres Strait and the Coral Sea) in tonnes gutted weight; and the modern (after 1987) fishery catch for the QSCF, TSBDMF and CSF combined. Early data are from Saville-Kent (1893), Sumner (1981) and Anon (1946). Values for the period after 1987 are from QSCF, TSBDMF and CSF logbook data (after Uthicke, 2004). n.d. = no data.

Species composition of the catch of the initial phase of the Queensland fishery (1820-1850) is not known. Catch during the next fishing pulse during the 1880’s included Black teatfish, various species of *Actinopyga* (“black and “red” varieties), White teatfish, Prickly redfish and Sandfish (in rough order of relative value) (Saville-Kent, 1893). In 1890 values ranged from £150 per ton for Black teatfish, and £80 to £110 per ton for the black and red *Actinopygas*; to £20 per ton for the less well-regarded Sandfish (Saville-Kent, 1893). Several “supplementary species” bulked up the catch, including other *Actinopyga* (e.g. Stonefish) and some

Bohadschia (e.g. Leopardfish). However, most *Bohadschia* (due to the expelling of cuverian tubules) and *Stichopus* (due to easy disintegration) were generally not considered commercial. The total edible species count during the 1880's was about 20 (Saville-Kent, 1893).

Black teatfish was the highest value species at the time, and White teatfish was of only small commercial value (presumably due to moderate value and “low abundance”) (Saville-Kent, 1893). Prickly redfish was, at one time (around 1880), the highest value species, but a poisoning accident in 1881 (caused by processing the sea cucumber in a copper pot) reduced its value, and it never really regained its preeminent position (Saville-Kent, 1893; Ryle, 2000). Sandfish was then considered a low value species, primarily due to the abundance of calcareous spicules on its integument (Saville-Kent, 1893). Species composition during the third phase of the early fishery from 1900 to WWII is unknown.

As for the catch proportions, there is no data. However, all indications are that it was a broad multispecies catch (Saville Kent, 1893, Sumner, 1981). While the value of Black teatfish was £150 per ton in 1890, the average value of the catch for the period 1881-1889 was £90 per ton (Saville Kent, 1893), and the average value of the top 8 listed species was £79 per ton, indicating a well-mixed catch (Saville Kent, 1893). In any case, there is sufficient evidence to overturn the lingering paradigm of historical fisheries being focused on a single or even a small number of target species – more likely that fishers targeted a wide range of species, probably fishing down the value and accessibility chain over time to some extent – but certainly not leaving accessible commercial species unexploited over the period of the fishery.

All three current east coast fisheries in the Torres Strait, Queensland east coast and Coral Sea will have been included in the above compilation, and catch from PNG, the Solomons and Vanuatu may also be included to some extent at least (Saville Kent, 1893, Sumner, 1981). It is not known if there were differences in the catch of these regions, though it is reasonable to expect that Torres Strait would have had the highest proportion of Sandfish (having the large Warrior Reef Sandfish population, but also an abundance of other species in east Torres Strait), followed by the Queensland east coast, and with the Coral Sea having no Sandfish.

There is no evidence that any early beche-de-mer fishing operations used underwater diving equipment, and harvesting was generally restricted to 9 fathoms (16.5 m) (Saville-Kent, 1893; Sumner, 1981), though there is mention of weighted spears that could potentially increase the fishing depth. It is likely then that deeper water populations, particularly White teatfish and Prickly redfish would have been protected somewhat from heavy depletion during the historical fishery. Areas with extensive deep habitat, such as the Swains Reefs in the southern GBR may also have been relatively lightly fished – this area would have been very difficult for small sail powered vessels and even larger processing vessels to navigate and work, being exposed to the prevailing winds, waves and currents.

4.3.3 Early fishery management

The early fisheries were characterised by maintaining a consistent strategy of “resource-raiding” (Ganter, 1990), supported by early assessments of the fishery that leaned towards an attitude of unlimited resources and unrealised development potential (Saville-Kent, 1893; Lloyd, 2016). Regulation was usually about jurisdictional control, taxation and labour (especially in the use of indigenous and south sea islander labour in the industry) (Ganter, 1990; Mullins, 2012).

The annexation of all Torres Strait islands by the colony of Queensland between 1872 and 1879 and the implementation of *The Pearl-Shell and Bêche-de-mer Fishery Act of 1881* was largely driven by a desire to exert control over and regulate the rapidly emerging beche-de-mer and pearlshell fisheries, however it was primarily aimed at regulating the recruitment activities of boat masters and obtaining revenue through licensing of boats and divers (Gantor, 1990; Thomassin, 2019).

While the closely aligned pearlshell fishery did see some regulation aimed at fishery sustainability (e.g. a minimum shell size limit and closure of some areas in 1889 (Lloyd, 2016)), no limits were applied to the early beche-de-mer fisheries.

4.4 The modern Australian fishery

Fishing for sea cucumbers in Australian waters resumed in the mid-1980s, mirroring the global resurgence of sea cucumber fisheries driven by resurgent China (see section above). There are currently seven sea cucumber fisheries in the Australian EEZ, six being active (Table 5) – the Moreton Bay sea cucumber fishery was last fished in 2007. The Timor MOU Box fishery is fished by Indonesian fishers under an MOU between Australia and Indonesia that came into effect in 1975 (Fox and Sen, 2002; Prescott et al., 2017).

Fisheries were re-established firstly in the QSCF on the GBR, then in the TSBDMF and subsequently in the WASCF, NTTF and the CSF (Figure 10). The QSCF is Australia’s largest sea cucumber fishery, with over 60% of the total recorded catch since records of the modern fishery began in 1988. The TSBDMF is the second largest (15%), followed by the NTTF (12.6%), and the WASCF (9.8%). The CSF and MBSCF are both minor fisheries with about 1% of total recorded Australian catch (Figure 10).

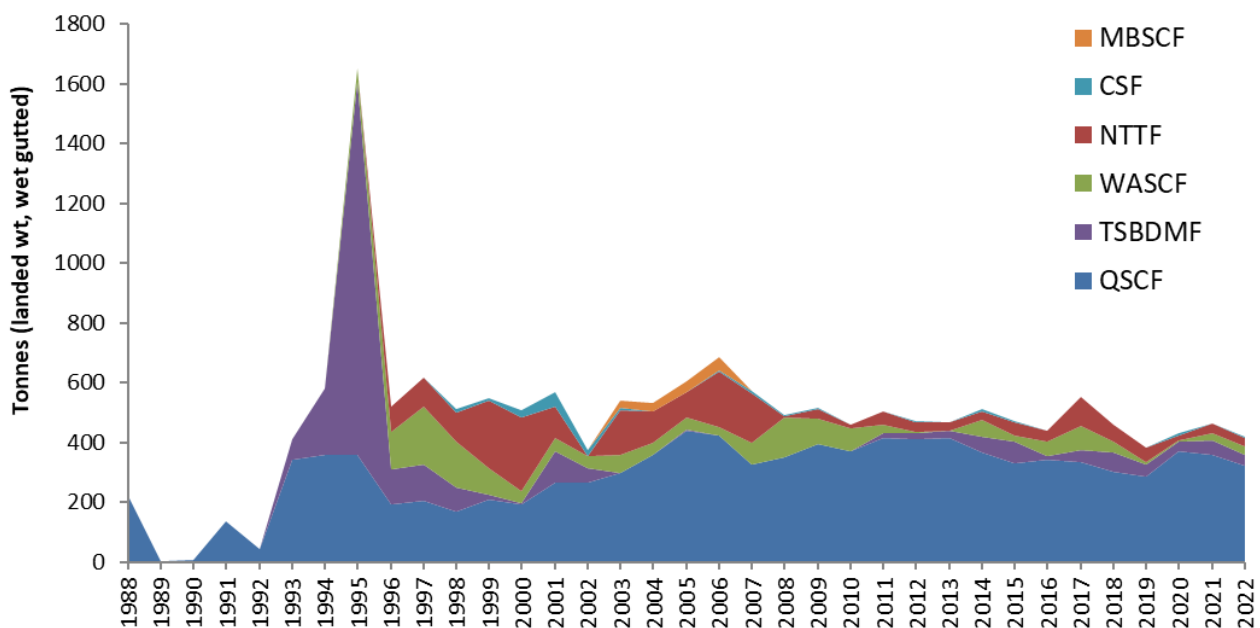


Figure 10. Catches of all sea cucumber species in Australian fisheries for the period 1988 to 2022 (in wet gutted weight given caveats mentioned in text) (not including Timor Sea MOU Box fishery). (MBSCF: Moreton Bay Sea Cucumber Fishery, CSF: Coral Sea Fishery, NTTF: Northern Territory Trepang Fishery, WASCF: Western Australian Sea Cucumber Fishery (converted from live weight using established conversion ratios), TSBDMF: Torres Strait Beche-de-mer Fishery, QSCF: Queensland Sea Cucumber Fishery (East Coast). Data sources: Fishery logbook data (AFMA, Qld DAF), Fishery Status Reports (ABARES, WA DPIRD, NT DITT)

Of the three eastern fisheries, the CSF has the greatest area, but the QSCF has the most shallow reef habitat (87% of total) (Table 3). For all three fisheries combined, over 30% of the shallow reef habitat is closed to fishing (Table 3, Figure 11).

Table 3. Area (km²) of each of the three east coast fisheries that target teatfish species, including the area of shallow (<20 m deep) and deep (>20 m deep) reef habitat, and closed areas in each fishery.

Fishery	Fishery area	Closed	%	Shallow reef	Closed	%	Deep reef	Closed	%
QSCF	545,982	132,252	24.2	26,792	8,655	32.3	232,323 ¹	67,285	29.0
CSF	989,836	238,400	24.1	1,663	739	44.4	11,172	4,894	43.8
TSBDMF	42,160	0 ²	0.0	2,403	0 ²	0.0	1,104	0 ²	0.0
TOTAL	1,577,978	370,652	23.5	30,858	9,394	30.4	244,600	72,179	29.5

¹ This is the shelf area of the GBR which is a zone adjacent to a continent (or around an island) extending from the low water line to a depth at which there is usually a marked shelf edge (GBRMPA). An estimate of the area of “submerged banks” on the GBR is 41,000 km² (Harris et al., 2013).

² There are three Indigenous Protected Areas (IPA) in Torres Strait, however the fishery protection status of those IPAs for sea cucumbers is not known.

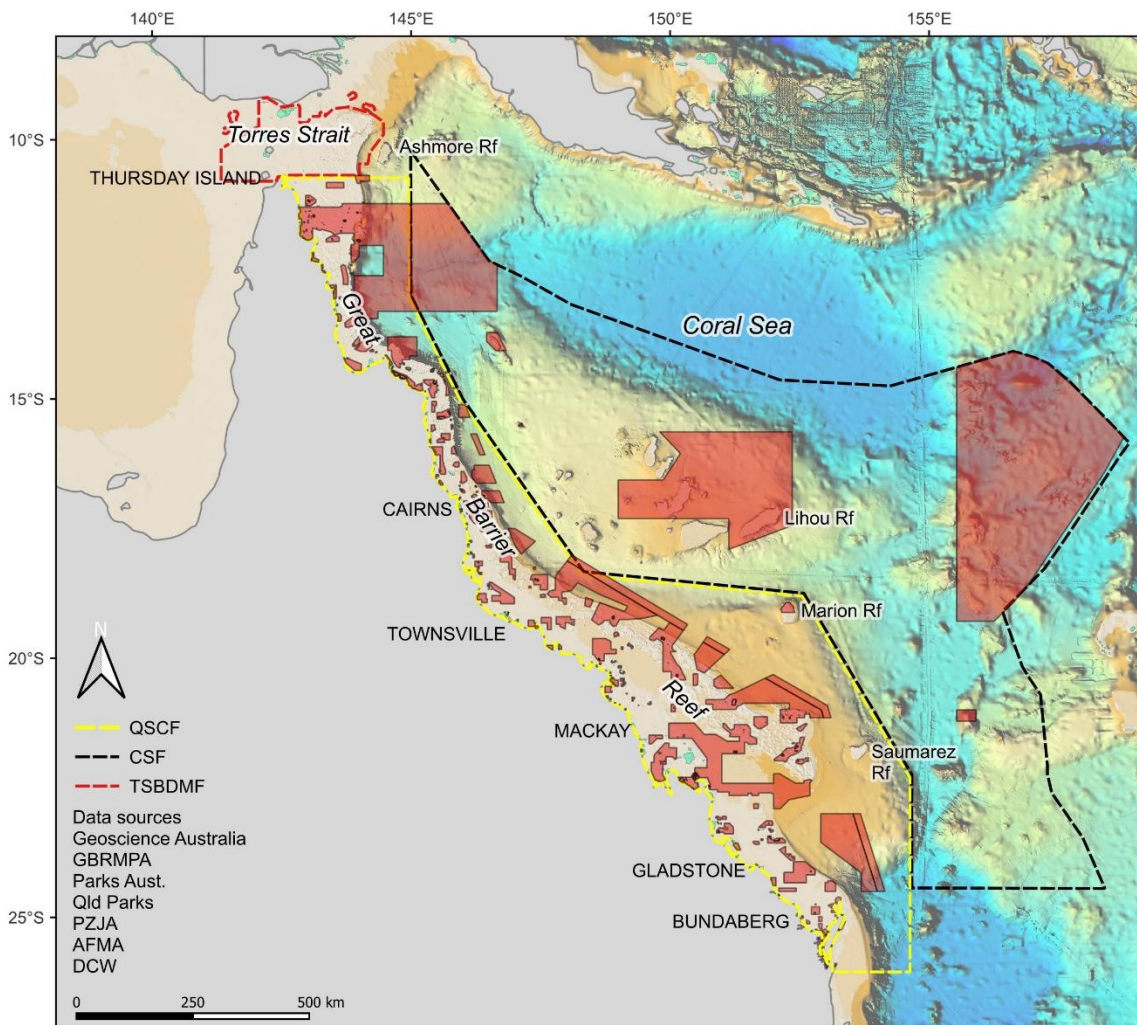


Figure 11. The three east coast sea cucumber fisheries and areas closed to fishing (IUCN IA and II) (in red)

4.4.1 Catch

A note on fishery catch reporting. Sea cucumbers, like other marine resources, can be assessed, reported and managed as individual numbers or by weight. In Australian sea cucumber fisheries, catch is usually reported and managed by weight, typically using the product form (processed state) at the first opportunity for operators to reliably weigh the catch (Table 4) – often referred to as “landed” weight. These range from: whole live (e.g. WASCF); gutted (TSBDMF); gutted and salted (CSF, QSCF); and gutted, parboiled and frozen (QSCF, NTTF). In the case of the QSCF, two product forms are included in the calculation of fishery catch weight: gutted and salted; and gutted, parboiled and frozen. Export data is mostly as reported as dried product, though some will be exported in a “wet” product form (e.g. individually quick frozen Burrowing blackfish).

To calculate Australian catch statistics, all catch data has been converted to gutted weight using available conversion ratios (see section on conversion ratios below). Gutted weight was chosen as the product type to report sea cucumber fishery extractions - whole live weight is a highly variable due to various amounts of water and sediment in the gut, whereas the gutted weight provides a more accurate representation of animal somatic weight and of the usable final product.

Table 4. Fishery product forms for fishery catch reporting in Australian sea cucumbers fisheries.

Fishery	Fishery catch reporting
QSCF	Landed weight, as gutted and salted; or gutted, par-boiled and frozen weight (catch form is recorded in logbooks and buyer returns) (DPIF, 2008; DAF, 2020).
CSF	Landed weight, as gutted and salted weight (AFMA, 2021).
TSBDMF	Wet gutted weight. Catch is recorded in logbooks in several processed states, from whole live to dry weight. Weights are then converted to wet gutted weight using available conversion ratios (AFMA, 2023; Plaganyi et al., 2019).
WASCF	Live weight. Most catch is recorded in fishery logbooks as gutted and boiled, therefore whole live weight is calculated using locally derived conversion factors (3.0 for Sandfish and 4.0 for Redfish; unknown for teatfish) (Hart et al., 2022).
NTTF	Gutted, blanched weight (DITT, 2021).

In the initial phase of the modern fishery, the catch was primarily made up of Black teatfish and Sandfish (Figure 12) – two easily accessible high value species. By the late 1990s, most Sandfish and Black teatfish fisheries were considered depleted and closed in the eastern fisheries, and the catch diversified. Current primary fishery species include Burrowing blackfish (33% by landed weight) Sandfish (14%, mostly from the WASCF and NTTF), White teatfish (12%), Prickly redfish (11%), and Curryfish (11%) (Figure 12). These five species made up over 80% of the catch in 2016 to 2022. Black teatfish made up about 3.6% of the catch over the same period.

Only four Australian fisheries (excluding the Timor Sea MOU Box fishery fished by Indonesian fishers) have targeted Black teatfish to any significant degree (Table 5). Catch data shows that Black teatfish was an early fishery target species but was either closed or reduced to very low levels by 2001 (Figure 13). Note that catches before 1996 are uncertain and not shown, however, were likely to be substantial in both the QSCF and TSBDMF. After a 15 to 20 year closure, Black teatfish fisheries are once again established in the QSCF and TSBDMF, albeit at modest levels (~40 t per year) compared to the earlier phase of the fishery (Figure 13).

Only three Australian fisheries (again excluding the MOU Box fishery) have targeted White teatfish – these being the three fisheries in north-eastern Australia (Table 5). Catches of White teatfish show that they increased rapidly from about 1998, peaking at 166 t landed weight in 2001 (Figure 14), most of that being

caught in the QSCF. Catches then reduced in the mid 2000's to a relatively stable 50-70 t per year (Figure 14).

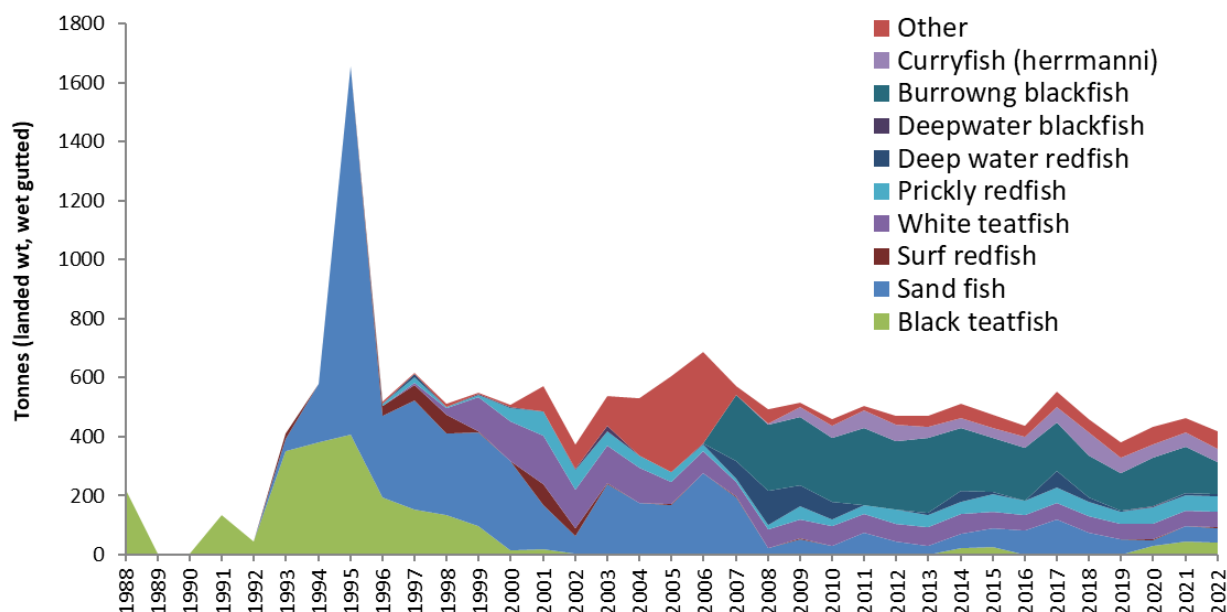


Figure 12. Catches of sea cucumber species in Australian fisheries for the period 1988 to 2022 (in landed weight, wet gutted weight given caveats mentioned in text) (not including Timor Sea MOU Box fishery). Only the most important species making up to 95% of catch are shown. Up to 12 species are included in the “Other” category. Data sources: Fishery logbook data (AFMA, Qld DAF), Fishery Status Reports (ABARES, WA DPIRD, NT DITT)

Table 5. Australian fisheries with recorded teatfish species catch.

Fishery	Black teatfish	White teatfish
Queensland Sea Cucumber Fishery (East coast) (QSCF)	Yes. An early target species. Closed in 1999, reopened 2019 with a 30 t TAC.	Yes. A primary target species of the QSCF. Currently a 53 t TAC.
Coral Sea Fishery (Sea cucumber) CSF	Yes. A primary target species, though catches restricted since 2003 to a 1 t TAC.	Yes. A primary target species, though catches restricted since 2003 to a 4 t TAC.
Torres Strait Beche-de-mer Fishery (TSBDMF)	Yes. An early target species. Closed in 2003, trial reopening beginning in 2014.	Yes (but generally low catches apart from a 3 year developmental licence in 2013-14).
Northern Territory Trepang Fishery (NTPF)	Yes. Listed as a fishery species, but have not been caught since at least 2011 (DITT, 2021)	Yes. Listed as a fishery species, but have not been caught since at least 2011 (DITT, 2021)
Western Australian Sea Cucumber Fishery (WASCF)	Yes. But long-term catches <1% overall catch (Hart et al., 2022)	Yes. Listed as a fishery species, but catches negligible (Hart et al., 2022)
Moreton Bay beche-de mer fishery ¹	No. Does not occur in fishery area (Skewes and Brewer, 2019)	No. Does not occur in fishery area (Skewes and Brewer, 2019)
Timor Sea MOU Box fishery ²	Yes. Currently makes up a minor but significant portion of the catch (Prescott et al., 2015).	Yes. Currently makes up only a small proportion of the catch (Prescott et al., 2016).

¹ This fishery has not been active since 2007.

² This fishery is fished by Indonesian nationals under an international MOU.

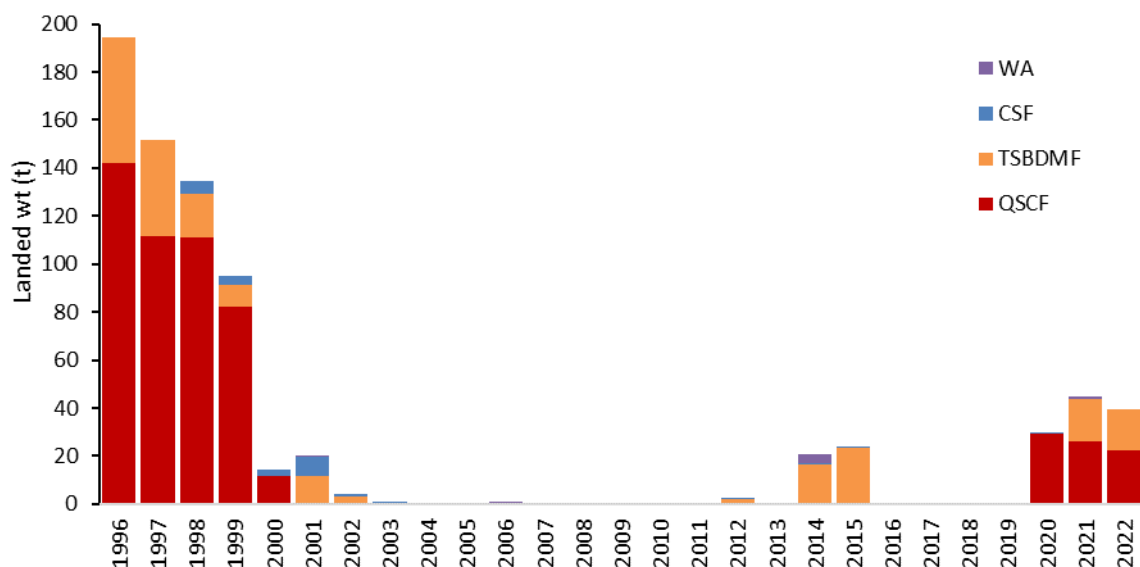


Figure 13. Annual catch (tonnes landed wt) of Black teatfish in the four Australian fisheries that have reported catch since 1996. QSCF and CSF data is in financial years, with reported year being end year.

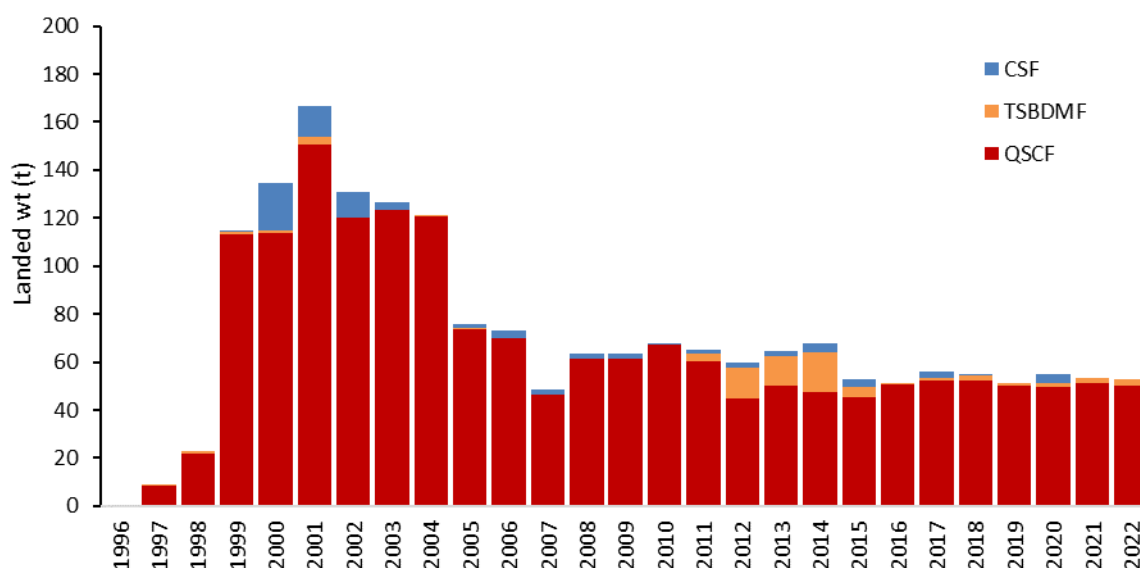


Figure 14. Annual catch (tonnes landed wt) of White teatfish in the three Australian fisheries that have reported catch since 1996. CSF and QSCF data is in financial years, with reported year being end year.

4.4.2 IUU and any other extractions

There has been documented illegal take of sea cucumbers in several jurisdictions around Australia. Sea cucumbers within the QSCF and CSF fishery areas have been subject to illegal fishing by foreign fishing vessels (FFV), predominantly Vietnamese based fishing vessels (blue boats) (Skewes and Persson, 2017). This activity resulted in 49 FFV sightings within the area (15 in the QSCF and 34 in the CSF) between March 2016 and February 2017, of which 13 (7 in the QSCF and 6 in the CSF) were apprehended (Figure 15) (AFMA, unpublished data; Skewes, 2017). Eighteen (36.7%) of the sightings were at Lihou Reef in the Coral Sea. 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).

Of the 13 Vietnamese vessels apprehended, the estimated catch on board was 55.6 t (gutted and salted weight) (18.8 t in the CSF area, and 36.8 t in the QSCF area (AFMA, unpublished data). 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).

There has also been substantial IUU reported in Torres Strait, including apprehensions dating back to the mid-1990s, primarily by PNG nationals fishing on Warrior Reef, and primarily targeting Sandfish, Tropical rock lobsters, and finfish (AFMA, unpublished reports; ABC, 2023b). This IUU fishing effort by PNG nationals in Torres Strait is ongoing, centred on Warrior Reef and primarily targeting a range of species including Sandfish.

IUU fishing has also occurred along a wide area of the western and northern Australian coastlines and offshore reefs by Indonesian nationals, including on the Rowley shoals, which most likely included catch of teatfish species (ABC, 2021). Encroachments by Indonesian vessels into Australian waters fishing for sea cucumber is likely to be an ongoing challenge for managing fishery populations in the WASCf and NTTf, as well as for protected reefs in the Timor Sea MOU Box (Ashmore and Cartier Reefs; ABC, 2023a).

As for domestic IUU, all indications are that it is negligible and most likely focussed on high value coastal species such as Sandfish. In all Australian fisheries there has only been one documented incidence of domestic IUU. This related to an unlicensed fish receiver in the TSBDMF who was apprehended in 2020 (AFMA, 2020).

4.4.3 Discards

While there have been some reports of discarding in Australian sea cucumber fisheries, it is likely to be minimal for teatfish species due to the highly selective nature of hand collection fisheries, and their high recognition high value species and established processing procedures (Dutra et al., 2021). Discarding occurred mainly during the early development phase when processing techniques were being established (various QSCF and TSBDMF fishers and processor – pers comm.), and, for example, in the TSBDMF due to the spoiling of Curryfish species soon after the capture and initial processing stages (HCWG papers – reports from fishers, pers comm).

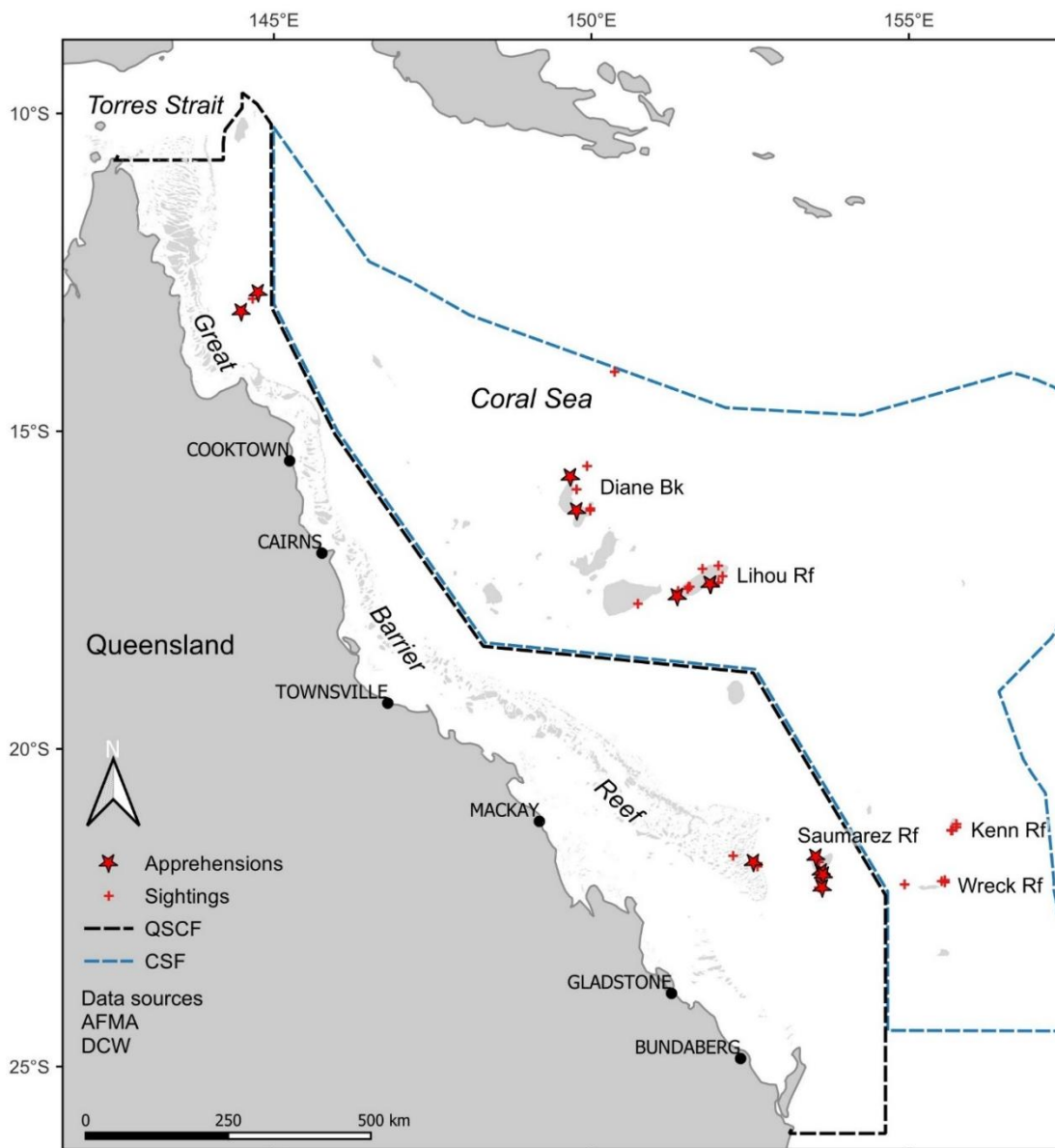


Figure 15. Location of sightings and apprehensions of Vietnamese based illegal fishing vessels (blue boats) for the period March 2016 to February 2017 (data supplied by AFMA).

4.5 Conversion ratios

Sea cucumbers will change their weight depending on the time out of the water and processed state (Skewes et al., 2004; Murphy et al., 2021c). As fisheries are managed using the weight of animals in several processed states, including : live whole, wet gutted; gutted and salted; and gutted, parboiled and frozen – (Table 4)), combining catches from various fisheries will require conversion ratios to a standard catch reporting state (usually gutted weight). In addition, fishery catch reporting in logbooks and catch disposal records can also be recorded in several processed forms (e.g. TSBDMF - Table 4), from live to dried product, requiring management agencies to convert this catch data to their own fishery reporting standard. Survey biomass is also mostly collected as whole live weight but is often converted to gutted weight or “landed” weight for application to fishery stock assessments and analysis outputs. Exports will mostly be recorded as dry weight, therefore applying appropriate conversion ratios will be critical for comparing catch and export data for compliance.

Conversion ratios have been formulated for many species between several processed states (for a recent compilation, see Murphy et al., 2021c). These conversion ratios are from studies in various locations in

Australia and the South Pacific. Conversion ratios for the same species from different locations do show some variation, no doubt due to differences in processing techniques but also likely due to regional variation in morphometrics related to body condition (Hammond and Purcell, 2024), therefore locally derived conversion ratios should be formulated and applied where possible.

Whole live, wet gutted, gutted and salted, and dried weight conversion ratios are available for Black teatfish and White teatfish (Table 6; Figure 7; Murphy et al., 2021c), however, gutted par-boiled and frozen conversion ratios are not.

Table 6. Conversion ratios for Black teatfish (all values are referenced from Murphy et al., 2021c and references contained within; except for notated values)

From \ To	To				
	Live whole	Wet gutted	Gutted and salted	Gutted, parboiled and frozen	Dried
Live whole		0.677	0.529	n/a	0.108
Wet gutted	1.477 ¹		0.824	n/a	0.177
Gutted and salted	1.89 ¹	1.213		n/a	0.220
Gutted, parboiled and frozen	n/a	n/a	n/a		n/a
Dried	9.259 ¹	5.649	4.545 ¹	n/a	

¹ These values calculated as the inverse or mirror value.

Table 7. Conversion ratios for White teatfish (all values are referenced from Murphy et al., 2021c and references contained within; except for notated values)

From \ To	To				
	Live whole	Wet gutted	Gutted and salted	Gutted, parboiled and frozen	Dried
Live whole		0.627	0.593	n/a	0.137
Wet gutted	1.595 ¹		0.775	n/a	0.237
Gutted and salted	1.686 ¹	1.290		n/a	0.309
Gutted, parboiled and frozen	n/a	n/a	n/a		n/a
Dried	7.299 ¹	4.219	3.236 ¹	n/a	

¹ These values calculated as the inverse or mirror value.

Table 8. Average weight of White teatfish from QSCF Buyer Return logbook (where weight and number recorded)

Product form	Average weight (kg)	Records
Gutted, parboiled and frozen	1.614	75
Gutted and salted	1.217	516

5 Stock trends and assessments

5.1 Australian EEZ population levels

Surveys for sea cucumbers, and especially for Black teatfish, have been carried out in the three east coast fisheries and other areas within the Australian EEZ (Table 9). Surveys of White teatfish have only been carried out in the TSBDMF and part of the CSF (Table 9). Survey biomass in most cases, and particularly in the QSCF, are considered an underestimate for various reasons (for details see jurisdictional reports).

Table 9. Stock estimates from surveys carried out in Australian waters for Black teatfish and White teatfish species (tonnes gutted weight)

Fishery/Area	Black teatfish	White teatfish	Year/Source
QSCF (Restricted habitat in Zone 1 and excluding offshore reefs)	4,384	-	2016/2021 (Knuckey and Koopman, 2016; Koopman and Knuckey, 2021)
QSCF (Marion and Saumarez Reefs only)	57	-	2017 (Skewes et al., 2017)
TSBDMF	1,233	1,493	2019/20 (Murphy et al, 2021a)
CSF (36% of shallow and 1.5% of deep reef habitat)	150	116	2017 (Skewes et al., 2017)
Cocos Island	-	6.5	2006 (Bellchambers et al., 2011)
Timor Sea MOU Box	162 ²	5.3 ²	1998 (Skewes et al., 1999)

¹ Only number reported – estimated using average weight of animals from Torres Strait

² Includes reefs and shoals

5.2 Stock assessments

Generally, fishery stock status is reported as the proportion of the stock in relation to unfished or “virgin” biomass. However, other factors may require consideration, such as stocks with high natural variability (so called “boom and bust” populations), differences in the regeneration potential spatially (e.g. source and sink populations) and reporting by size/age (size/age related fecundity).

In fisheries, assessment and management, population status may also be reported against two reference levels with respect to their status; a limit reference level (*Blim*), which is nominally equivalent to the point at recruitment impairment (PRI); and a target reference point (*Btarg*), or the population level at maximum sustainable yield (*BMSY*) or higher (*Btarg* may also be at the level of maximum economic yield (*BMEY*) or even higher to account for environmental considerations).

Global fishery status

Globally, sea cucumber populations have generally been overexploited, especially for easily accessible high and medium value species, including Black teatfish and White teatfish (Purcell et al., 2013). Of 77 sea cucumber fisheries assessed in 2013, 20 percent were considered depleted and 38 percent were over-exploited (Purcell et al., 2013), including most in the central west Pacific (Purcell et al., 2013). Many fisheries have closed or produce only low value species, and some have even moved to harvesting mostly nocturnal species (Prescott et al., 2013).

Australian fishery status

Available information on Black teatfish and White teatfish species stocks in Australian waters were synthesised to estimate stock status in relation to nominal *Blim* and *Btarg* biomass reference levels (Table

10). The QSCF and TSBDMF Black teatfish and White teatfish populations are assessed as likely to be greater than nominal *Blim* (see jurisdictional reports for justification and sources in Table 10), whereas for the CSF this is uncertain (see jurisdictional reports for justification and sources in Table 10).

Table 10. Status of Prickly redfish and Amberfish in Australian sea cucumber fisheries inferred from available information. As “likely” “uncertain” or “unlikely” to be greater than *Blim* and *Btarg*.

Fishery	Black teatfish		White teatfish		Sources
	> <i>Blim</i>	> <i>Btarg</i>	> <i>Blim</i>	> <i>Btarg</i>	
QSCF	Likely	Uncertain	Likely	Uncertain	QSCF jurisdictional report
CSF	Uncertain	Uncertain	Uncertain	Uncertain	CSF jurisdictional report
TSBDMF	Likely	Likely	Likely	Likely	TSBDMF jurisdictional report
WASCF	Uncertain	Uncertain	Uncertain	Uncertain	No information available
NTTF	Uncertain	Uncertain	Uncertain	Uncertain	No information available
Timor Sea MOU Box	Unlikely	Unlikely	Uncertain	Uncertain	Skewes et al., 1999; Prescott et al, 2013

5.2.1 Conservation status

The IUCN estimates there are approximately 1,711 described extant sea cucumber species. They have assessed about 22% (371) of the species in the IUCN Red List, mostly commercially important species. Of the species assessed so far, 7 are assessed as Endangered (EN), 9 as Vulnerable (VU), 111 as Least Concern (LC or LR/lc), and 244 as Data Deficient (DD). The main threats are overfishing (Conand et al., 2013a, 2013b). Most of those species listed are 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).

Black teatfish was listed as Endangered primarily due to its widespread targeting throughout its range as a high value species. It was considered to have declined by more than 60-90% in the majority of its range (at least 70%), and it was considered overexploited in other parts of its range (Conand et al., 2013b).

White teatfish were listed as Vulnerable due to its widespread targeting throughout its range as a high value species. It was considered to have declined by more than 60-80% in at least 30% of its range, and was considered overexploited in at least 40% of its range although exact declines were difficult to estimate. Global declines were estimated to be between 30%-50% based on estimates of depletion and overexploitation across its range. It was acknowledged that there is some refuge in deeper waters for this species, and that there was considerable uncertainty regarding the impact of fishing (Conand et al., 2013b).

6 Management

In the early stages the modern fisheries were characterised by a general lack of fishery knowledge and limited management oversight and control, with most of the emphasis on developmental fishery provisions to encourage fishery participation and development; for example in the QSCF, permits were granted to any applicant depending on their capacity to process product, and their business plans (Breen, 2001), and in the CSF there were minimum fishing day provisions to maintain licences (AFMA, 2004).

As reports of overexploitation of Sandfish and Black teatfish occurred in the early 1990s, fisheries agencies and scientists needed to “play catchup”. Effort was capped, controls imposed, and, by the late 1990s, most of the eastern Sandfish and Black teatfish fisheries were closed. Subsequently, most of the current input and output controls in Australian fisheries were implemented by the early 2000s. Fisheries access consolidated from multiple entitlement holders to fewer ‘main operators’ in all Australian jurisdictions except the Torres Strait and Timor MOU Box. As species controls tightened, the catch diversified and focused on quality and value adding products.

6.1 Current management

Catch limits are the primary harvest control rule, as well as size limits and spatial closures for most Australian teatfish fisheries. The three east coast fisheries that primarily target Black teatfish and White teatfish all have individual species based TACs (Table 11). In the NTTF the species are managed within a Total Allowable Combined Catch (TACC) (i.e. species basket), and in WA there are no catch limits (effort limits only), however catch is negligible.

Table 11. TACs (annual catch in tonnes per year) applied to Black teatfish and White teatfish in Australian fisheries. Weights are generally applied as wet gutted weight (see discussion in text about fishery weights).

Fishery	Black teatfish	White teatfish
QSCF	30 t TAC	53 t TAC
TSBDMF	20 t TAC	15 t TAC
CSF	1 t TAC	4 t TAC
NTTF	Part of a 246 t TACC (no trigger) ¹	Part of a 246 t TACC (no trigger) ¹
WASCF	Effort limits only	Effort limits only

¹ In these cases, the species are managed within a Total Allowable Combined Catch (TACC) (i.e. species basket), sometimes with trigger levels (in brackets).

6.1.1 Size limits

Size limits in Australian fisheries for Black and White teatfish are shown in Table 12. Size limits have generally been set so that animals can mature and breed before they are fished (Prince and Hordyk, 2019). The only reliable estimates of size at first sexual maturity for teatfish are for New Caledonia, with estimates of the length at which 50% are mature (TL50) of 26 cm for Black teatfish and 32 cm for White teatfish (Conand, 1993). Though an earlier work by the same author listed TL50 as 22.7cm and 32.4cm for Black teatfish and White teatfish respectively (Conand, 1981). That study found, for Black teatfish at least, that the onset of sexual maturity coincided with the change in colour pattern from the mottled white juvenile form. Juveniles are not often observed during scientific surveys, and presumably this is true for fishers as well. There are sometimes juvenile teatfish observed in the catch, but only in a fishery where the exploitation rate is extremely high, and fishers search among coral crevices for sea cucumbers (Prescott et al., 2013).

Table 12. Minimum size limits (MSL: in cm total length) applied to Black teatfish and White teatfish in Australian sea cucumber fisheries. MSL are generally applied to live animals.

Fishery	Black teatfish	White teatfish
QSCF	30	40
TSBDMF	25	32
CSF ^a	25	32
NTTF	26	32
WASCF ^b	26	32

^a Voluntary via memorandum of understanding

^b Voluntary via harvest strategy

6.1.2 Harvest strategies

Currently nearly all Australian sea cucumber fisheries have Harvest strategies (HS) implemented (except for the NTTF and Timor Sea MOU Box fishery), though with varying levels of complexity. The oldest is the CSF HS which was implemented in 2008. It has no formal objectives, and comprises conservative TACs and trigger limits (based on catches), and a SESSF Tier 4 rule to adjust the TACs for all species CPUE and current catch (AFMA, 2008). It is likely that this HS will be reviewed in the next few years.

The TSBDMF and QSCF HS were implemented in 2019 and 2021, respectively. Both have a tiered structure with higher level harvest control rules for primary target species (including Black teatfish and White teatfish), and “default” BLIMs of 0.4B₀ and 0.2B₀ respectively (AFMA, 2019; DAF, 2021).

6.2 EPBC/WTO

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, 2021b; DCCEEW, 2023a). DCCEEW’s (the Department) 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.

These assessments aim to 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 Departments’ 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 (WTO) certificate for each species exported.

The assessments are conducted against the 2nd edition of the Guidelines for the Ecologically Sustainable Management of Fisheries (the Guidelines). This is an assessment against 2 **Principles** with underlying **Objectives**. Each Objective has **Information requirements**, **Assessment**, and **Management responses** criteria.

PRINCIPLE 1. A fishery must be conducted in a manner that does not lead to over-fishing, or for those stocks that are over-fished, the fishery must be conducted such that there is a high degree of probability the stock(s) will recover.

Objective 1. The fishery shall be conducted at catch levels that maintain ecologically viable stock levels at an agreed point or range, with acceptable levels of probability.

Objective 2. Where the fished stock(s) are below a defined reference point, the fishery will be managed to promote recovery to ecologically viable stock levels within nominated timeframes.

PRINCIPLE 2. Fishing operations should be managed to minimise their impact on the structure, productivity, function and biological diversity of the ecosystem.

Objective 1. The fishery is conducted in a manner that does not threaten bycatch species.

Objective 2. The fishery is conducted in a manner that avoids mortality of, or injuries to, endangered, threatened or protected species and avoids or minimises impacts on threatened ecological communities.

Objective 3. The fishery is conducted, in a manner that minimises the impact of fishing operations on the ecosystem generally.

The agency submissions and resulting strategic assessments have an established history of improvement to fishery sustainability and management, and has been pivotal to promoting sustainable fishing in Australian export fisheries.

7 Conclusions and recommendations

7.1 Information gaps

Information gaps and research priorities for the three east coast fisheries that target Black teatfish and White teatfish are contained in separate jurisdictional reports, however some common themes are discussed below.

Given the above assessment framework, the most pressing information gaps for teatfish species in Australian fisheries is the assessment of the status of fishery populations in relation to virgin biomass, B_0 and against nominal estimates of *Blim* for each fishery, especially for the CSF and to a lesser extent the QSCF. These uncertainties can be addressed through population surveys, and/or ongoing stock assessment modelling using available fishery dependent and independent data.

Related to this is an understanding of appropriate levels of *Blim* and *Btarg* for application in sea cucumber fishery HS – currently there are multiple levels designated in various jurisdictions (e.g. *Blim* is designated as 20%B₀, 30%B₀ and 40%B₀ in the QSCF, WASCF and TSBDMF HS, respectively). This will be better developed through the stock assessment modelling and by applying MSE to assess the efficacy of current HS.

Size/age at maturity, growth and natural mortality of targeted sea cucumber species are all important inputs into population models – and these are poorly understood for local teatfish populations, and sea cucumbers in general.

The impact of climate change will remain an important information need for sustainable fisheries. However, in terms of maintaining populations at low risk levels, it is not essential for the proper operation of a reactive HS – more so for an understanding of ecosystems and the potential for adaptation of human systems to address threat and opportunities.

Accurate conversion ratios for different processed forms is critical for the application of fishery dependent and independent (surveys) data to the assessment and management of sea cucumber fisheries, and for traceability to export data. Some conversion factors are available for both species, however, live to par-boiled and frozen for both species should be verified.

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