Independent Review of Sea Cucumber Stock Assessments

Report to Fisheries Queensland, Department of Agriculture and Fisheries, FQ24013

Rik C Buckworth and Timothy D Skewes

Sea Sense Australia Pty Ltd and Tim Skewes Consulting

Citation

Buckworth, R.C. and Skewes, T.D. (2024). Independent Review of Sea Cucumber Stock Assessments Report to Fisheries Queensland, Department of Agriculture and Fisheries, FQ24013 Unpublished. 28p. Sea Sense Australia Pty Ltd, Mission Beach, Qld Australia.

Copyright and disclaimers

Contact Details

Sea Sense Australia Pty Ltd
PO Box 375 Mission Beach
Qld Australia 4852
rik.buckworth@gmail.com
+61 (0)435120107

Independent Review of Sea Cucumber Stock Assessments

Rik C Buckworth and Timothy D Skewes

Executive Summary

We reviewed stock assessments for four sea cucumber species in the Queensland Sea Cucumber Fishery (QSCF): Burrowing blackfish (*Actinopyga spinea*), Prickly redfish (*Thelenota ananas*), Herrmanni curryfish (*Stichopus herrmanni*) and Vastus curryfish (*S. vastus*), by the Queensland Department of Agriculture and Fisheries (DAF) (Smart et al., 2024a; 2024b). The assessments, and the review, were a condition for approval by the Department of Climate Change, Energy, the Environment and Water (DCCEEW, Australian Government), of a Wildlife Trade Operation (WTO) to export under the Environment Protection and Biodiversity Conservation Act 1999. The status of stocks in the QSCF has been poorly understood, and concerns have been expressed about their current status. There have not previously been numerical stock assessments of the four species in the QSCF.

The assessments indicate that the biomass of each of the species and stocks in 2023 was above the target levels of 60% of unfished exploitable biomass. There should be confidence in these results, which reflect positively on the suite of management measures in place to protect the sea cucumber species and support the fishery. The assessments are thorough, and great pains have been taken to utilise the available data, extract biological information and to capture most sources of uncertainty. We note, however, that in a recent Lizard Island area survey, there were low relative densities of Burrowing blackfish within the fished area relative to the adjacent MPA. This is a concern and is an inconsistency to be addressed.

Our review is based on the assessment reports (Smart et al., 2024a; 2024b) and presentations and discussions during a two-day workshop addressing the assessments. This effective process added detail and nuance about the fishery and the assessments, and prompted testing of suggestions in real time. Industry-commissioned scientists provided a session focused on recent population surveys, that were critical inputs into the stock assessments. We were guided by a set of specific questions from QDAF that supported careful review.

The assessments aimed to provide the best possible estimates of stock status and were conducted using two modelling approaches: an integrated age-structured model in Stock Synthesis (SS) software and a delay difference model (DDUST) developed within DAF. These make the best use of the data available. The outputs of these two model forms were very consistent. The SS model was more difficult to implement, requiring more detailed parameter inputs but was also preferred, capturing more detail including additional data (length frequency composition), explicitly incorporating the important management device of Minimum Legal Size, and providing more detailed dynamics.

Although the assessments were constrained by the limited data and information available from these small fisheries, they were largely in agreement with the best practices described by Punt (2023). The good convergence of the different model scenarios provides confidence in the assessment outputs and conclusions.

Stock structures chosen were appropriate to the purpose of the assessments. We note, however, that these structures do not include the areas that cannot be fished, including the GBRMP no-take zones and other fishery closures. These were not accounted for in the models, which adds a level of conservatism to the assessment, especially for the reef-associated Prickly redfish and Curryfish species. There was little alternative to this approach given the lack of knowledge about the spatial dynamics of recruitment for these species. We recommend research and exploratory modelling in this topic area, perhaps with the future development of spatially explicit models. Similarly, connectivity with stocks in the Coral Sea and Torres Strait might be explored in joint assessments or hierarchical models.

These assessments used catch and effort data from logbook and catch disposal records for the modern fishery. Records were often in different product forms and careful conversions were undertaken between them to produce consistent information. An abundance index was developed from standardised catch rates. This was likely to be hyperstable, but this problem was partly addressed by down weighting the index, relative to survey abundance estimates, in subsequent model fitting. A historical fishery (early 1800s to 1940) heavily targeted Prickly redfish. A scenario should be modelled to capture that impact and confirm that the stocks recovered by the beginning of the modern fishery in the 1980s. We also noted that there had been no consideration of fishing power changes in the fishery in the reports. This requires future attention.

Recent surveys provided abundance estimates, as well as length frequency data that was used in the SS models. We also suggested that data from surveys conducted in the mid-2000s should be examined to establish whether additional estimates of abundance as well as length frequency composition could be extracted. These would strengthen the assessments. Survey abundance estimates are likely to be much more informative about population status than the abundance indices based on standardised catch rates. Nevertheless, the abundance indices (from catch rates), abundance estimates (from surveys) and the survey LF data produced very consistent results in the models.

To address the paucity of information available on biological parameters, the assessment team used what information was available to generate feasible base values for growth, maturity and fecundity, natural mortality and stock-recruitment steepness. This was necessary for the assessments to actually proceed. Wide ranges of alternative values of the parameters were then used as scenarios in the subsequent assessment modelling, effectively capturing and making explicit the uncertainties in the values. We suggested that the reports should provide additional focussed discussion on the low natural mortality scenarios; in response to recent research that has indicated that, for the adult population at least, there is slow growth and potentially low natural mortality.

It was also suggested in the workshop that the topics of suppression of recruitment at high adult densities, depensatory recruitment and size-varying natural mortality rates, should be further discussed in the reports.

Thorough assessments by Smart et al. (2024a,b) were undertaken to establish the status of important species in the Queensland Sea Cucumber Fishery. We concur with the conclusion that stocks of Herrmanni curryfish (*Stichopus herrmanni*) and Vastus curryfish (*S. vastus*), (Smart et al., 2024b) are at high levels, substantially above the target level of 60% of unfished biomass, B60.

We also concur with their conclusion for the Prickly redfish stock, subject to recommended additional investigations to determine the recovery (or otherwise) of the stock from the impact of the historical fishery. The assessment authors have committed to the further analyses which are likely to confirm the status of this stock. We again note that the assessments do not account for the proportion of these stocks in protected areas. All three species' stocks reported by Smart et al. (2024b) are likely to be well above sustainable levels.

We concur with the conclusions from the assessments of Bunker and Gould Burrowing blackfish stocks, determined to be well above the B60 target, again substantially above sustainable levels.

The Lizard stock assessment weighs information from biology, catch rates, survey length frequency compositions, and survey abundance and concludes that this stock also is significantly above the B60 level. However, the assessment could not incorporate the recent observation of low relative survey densities of Burrowing blackfish within the fished area, relative to a transect in the adjacent protected area (Koopman and Knuckey, 2022). We note that the restricted scope of these observations was not sufficient to address in the survey abundance estimate nor in the assessments, so that their meaning is unclear. The assessment authors have agreed to incorporate the older survey abundance and length frequency composition data, as well as providing thorough investigation of catch rates from the area, and to expand discussion of the topic. We expect that these efforts will provide confidence in the assessment.

Acknowledgements

This project was undertaken with consultation with Fisheries Qld staff members. We thank Dr Jonathan Smart, Montana Wickens and Dr Joanne Wortmann for guidance on the assessment details and their strong efforts to increase the transparency and quality of assessments. Dr Michael O'Neill provided guidance during the development of the contract covering this work. Additionally, during the workshop, Dr Ian Knuckey and Matthew Koopman of Fishwell Consulting provided valuable discussion of recent abundance surveys.

Table of Contents

Figures

Shortened forms

AIMS	Australian Institute of Marine Science
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DDUST	Delay Difference model with User-specified Time Step
GBRMP	Great Barrier Reef Marine Park
h	The Steepness of the Stock Recruitment Relationship
LF	Length frequency
M	Instantaneous Natural Mortality Rate
MPA	Marine protected area
Qld	Queensland
QSCF	Queensland Sea Cucumber Fishery
RHA	Rotational Harvest Arrangement
S-RR	Stock-Recruitment relationship
SS	Stock Synthesis
WWII	World War II

Background

This report is a review of stock assessments for four sea cucumber species in the Queensland Sea Cucumber Fishery (QSCF): Burrowing blackfish (*Actinopyga spinea*), Prickly redfish (*Thelenota ananas*), Herrmanni curryfish (*Stichopus herrmanni*) and Vastus curryfish (*S. vastus*). Carried out by Queensland Department of Agriculture and Fisheries (DAF), the assessments were required as a condition for approval of a Wildlife Trade Operation (WTO) to export under the EPBC Act (Environment Protection and Biodiversity Conservation Act 1999) by the Department of Climate Change, Energy, the Environment and Water (DCCEEW, Australian Government), as was this independent review (DAWE, 2021).

The status of stocks in the QSCF has been poorly understood. Of the four species addressed in this report, only Burrowing blackfish stock status has been included in routine reporting (e.g. Status of Australian Fish Stock Reports reported Burrowing blackfish status as "Sustainable" based primarily on catch and CPUE trends; SAFS, 2020). However, there have been concerns expressed about their current status, especially for Burrowing blackfish, and the lack of fishery independent data (e.g. surveys) to underpin stock status assessments (Eriksson and Byrne, 2015; Wolfe and Byrne, 2022; DAWE, 2021).

None of the four species assessed here has previously undergone a numerical stock assessment in the QSCF – but all of them have been the focus of at least one and, for Burrowing blackfish, two stock surveys (Leeworthy, 2007a; 2007b; 2010; Koopman et al., 2019; 2024; Koopman and Knuckey, 2022; 2023a). The current stock assessments aimed to provide the best possible estimates of stock status (biomass ratio and fishing pressure), from the available data. They were conducted using two modelling approaches: an integrated age-structured model in Stock Synthesis (SS) software and a delay difference model (DDUST) developed within DAF.

Our review is based on the assessment reports and associated information supplied by DAF, and also from presentations and discussions during a two-day workshop held on 4–5 March 2024, where stock assessment scientists from DAF presented the assessments. This process added detail and nuance about the fishery and the assessments that was additional to the assessment reports and prompted testing of suggestions in real time where feasible. Industry-commissioned scientists also attended, on-line, for a session focused on the recent population surveys that were considered as critical inputs into the stock assessments.

DAF provided a set of specific queries or requirements to include in the review:

1. Is the spatial structuring of analyses and the assessment suitable for the available data? Considerations include likely spatial scales of reproductive connectivity and fishing behaviour.

2. Are the key aspects of the catch rate modelling sound? Considerations include: the species are appropriately analysed in spatial and temporal scope, the data has been thoroughly explored and adequately characterised in identifying catchability and density covariates, the model selection and diagnostics are appropriate, and the final indices input to the population models have been appropriately assembled.

3. Are the historical annual catch reconstructions, including the assumed start year and product weight conversions, sufficient for consideration of plausible catch history scenarios? These harvest (annual dead catch) time-series are inputted to the population models.

4. Have the key biological uncertainties been modelled? For example, appropriate handling of the relevant biological settings of maturity, fecundity, longevity/natural-mortality, and steepness.
5. Assess the population models used, their configurations, parameters, results, and diagnostics. Were they adequate to achieve the assessment objectives for stock status?
6. Comment on the accuracy and reliability of key statements in the report summary and conclusion. How well were they supported by the data, analysis, and literature?
7. Review the suitability of the data sources and whether any other data sources would be useful. Are there any improvements for the methods applied?
8. Provide comment on any other important aspects you see or that the report should have completed, provided they relate to the estimation of stock status.

These and additional questions are addressed below. The Burrowing blackfish fishery assessment (Smart et al. 2024a) was reported separately to those for Prickly redfish, Herrmanni Curryfish and Vastus Curryfish (Smart et al. 2024b). This was due primarily to different population spatial structuring and fishing strategies for the two groups.

However, there are many commonalities between the assessments and this review steps through the questions above, identifying differences between the assessments where appropriate.

Review

1. Is the spatial structuring of analyses and the assessment suitable for the available data? Considerations include the likely spatial scales of reproductive connectivity and fishing behaviour.

Population structure

There is no information on the population structure of any of the focus species. However, it is likely that the Prickly redfish and Curryfish stocks, being widely distributed reef-associated species could be considered as "local populations with maximum connectivity within the meta-population" (or Type D stock structure according to the Marine Stewardship Council population structure classification system; MSC, 2022), with larval transport on the scale of 10s to 100 km and significant levels of reef level self-seeding, but with relatively well-mixed populations in the QSCF over the medium to long term (Skewes, 2023a). In this case, assessment as a single stock is appropriate, but with caveats that consideration of population dynamics on the scale of 50-100 km to maintain local density and for ecological considerations is still required.

Burrowing blackfish in the QSCF is often found in deep lagoon and inter-reefal seabed habitats, and is widely distributed throughout the QSCF (Figure 1; Pitcher et al., 2007). However, it has a relatively patchy distribution with high density populations in several locations throughout the GBR – most of which are fished as dedicated BBF zones (Koopman et al., 2019; Koopman and Knuckey, 2022; 2023a; Smart et al., 2024a). As such, with distances between local populations that would preclude significant "demographic level" recruitment (while still keeping populations genetically connected), the populations are likely "local populations with partial isolation" (or Type B stock structure according to the Marine Stewardship Council population structure classification system; MSC, 2022) where for assessment and management purposes, they are considered as self-sustaining populations. In this case the assessment approach of treating each population in isolation is appropriate.

Fishing effort spatial structure

Fishing effort for all species will be a function of density, proximity to port and other operational factors (e.g. fishability in bad weather). For most species, there are clear patterns of fishing effort throughout the fishery in response to these variables (e.g. Prickly redfish; Skewes, 2024a; Koopman et al., 2024), leading to concerns about localised depletion within the QSCF (DEH, 2004).

For reef associated species (Prickly redfish and Curryfish species), this issue is at least partially addressed by the implementation of the Rotational Harvest Arrangement (RHA) in 2004 which limits effort at the local (zone) scale (18 days once every three years) which has been shown to spread effort (Smith and Roelofs, 2011) and reduce local and overall depletion risk (Skewes et al., 2014; Plaganyi et al., 2015). Nevertheless, it may still not be spreading effort to the extent where it achieves its full benefit—even after the implementation of the RHS in 2004, 90% of the catch of Prickly redfish is still caught in about 35% of potential fishery grids (Skewes, 2024a). The concentration of harvest needs to be assessed as to the potential for localised depletion, especially for highly targeted grids/RHA zones. This may be the focus of future modelling that applies spatially explicit population models.

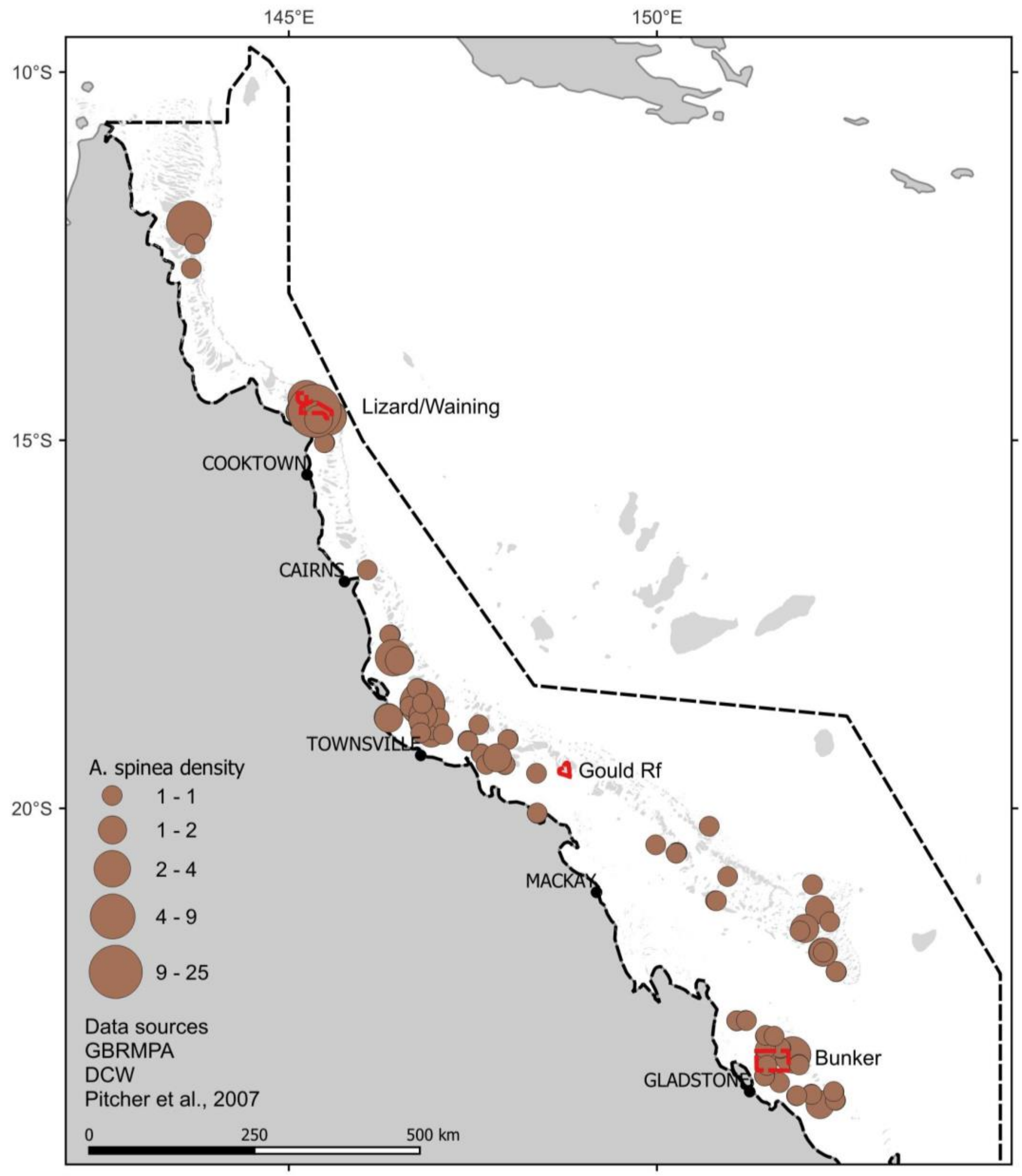

Figure 1. Distribution of Burrowing blackfish (A. spinea) observed at over 1500 sites during a seabed biodiversity survey in 2003-06 (Pitcher et al., 2007). Also shown (in red) are the locations of the three BBF Zones.

2. Are the key aspects of the catch rate modelling sound? Considerations include: the species are appropriately analysed in spatial and temporal scope, the data has been thoroughly explored and adequately characterised in identifying catchability and density covariates, the model selection and diagnostics are appropriate, and the final indices input to the population models have been appropriately assembled.

Spatial scope

The spatial scopes were appropriate, reflecting the stock structures as discussed above.

However, we note that the catch rate indices cannot capture information on the abundance of sea cucumbers in the areas of the GBRMP closed to fishing. For broadly distributed reef associated species, a significant proportion of their population will be contained within a system of no-take areas throughout the fishery (the GBRMP Zoning Plan). The closed areas were progressively implemented in the GBRMP—5.3% no-take reefs by 1989, 22% by 2001, and 33.1% by 2004 (GBRMPA, 2003; Breen, 2001; McCook et al., 2010; Skewes et al., 2014)—meaning that the three reef associated species assessed here (Prickly redfish and the Curryfish species) are unlikely to have been substantively fished in currently closed areas. Although the degree of connectivity between populations in the closures and the fished areas has not been established, the closed areas were constructed in such a way that 90% of fished reefs will be within 20 km of a no-take reef (McCook et al., 2010).

As there is not likely to be significant movement of sea cucumbers post-settlement, the abundance indices from catch rates reflect the density of sea cucumbers only within the defined open stock areas. The dynamics of the closed parts of the populations are not modelled explicitly in the current assessments; however, the benefit will be contained in the model outputs nonetheless, as donation of recruits from closed areas. This is acknowledged in the reports as adding a level of conservatism to the assessment, and we concur.

Fishing for Burrowing blackfish also postdates the implementation of the current system of no-take zones; however, the closed area benefit may not be as significant – the known distribution of Burrowing blackfish does not indicate that a significant proportion of the population is held in no-take zones (Pitcher et al., 2007), apart from perhaps the Lizard Island population (see below; Figure 2). Nor are the major populations of Burrowing blackfish included in any rotational harvesting approaches – therefore, they do not benefit from any temporal reprieve from fishing.

In addition, though QSCF populations are likely to be relatively well connected and the fishery self-seeding to a large extent, connectivity between the QSCF and the fisheries in the Coral Sea (CSF) and Torres Strait (TSBDMF) and (especially between the northern GBR and Torres Strait) is also likely to be significant (Skewes, 2024a). Joint assessments, perhaps based on the development of hierarchical models that make use of joint information among all three fisheries, would likely help improve overall understanding of status of species in the region.

Temporal scope

Burrowing blackfish and both Curryfish species are considered as recently targeted species in the modern fishery, with significant targeting beginning in about 2004 and 2008 respectively. Prickly redfish has been targeted for slightly longer, beginning in the "diversification phase" of the fishery (after the restrictions placed on Sandfish and the closure of Black teatfish) in about the year 2000 (Eriksson and Byrne, 2015). In this case, the temporal scope for all four species appears to be appropriate as pertains to the modern QSCF.

However, sea cucumbers have been fished in Queensland waters since the early 1800's, with the early fishery lasting until about the Second World War (WWII). Catch records of this early fishery are scant; however, it appears that Prickly redfish at least were targeted during this time (see section on Historical Catch below).

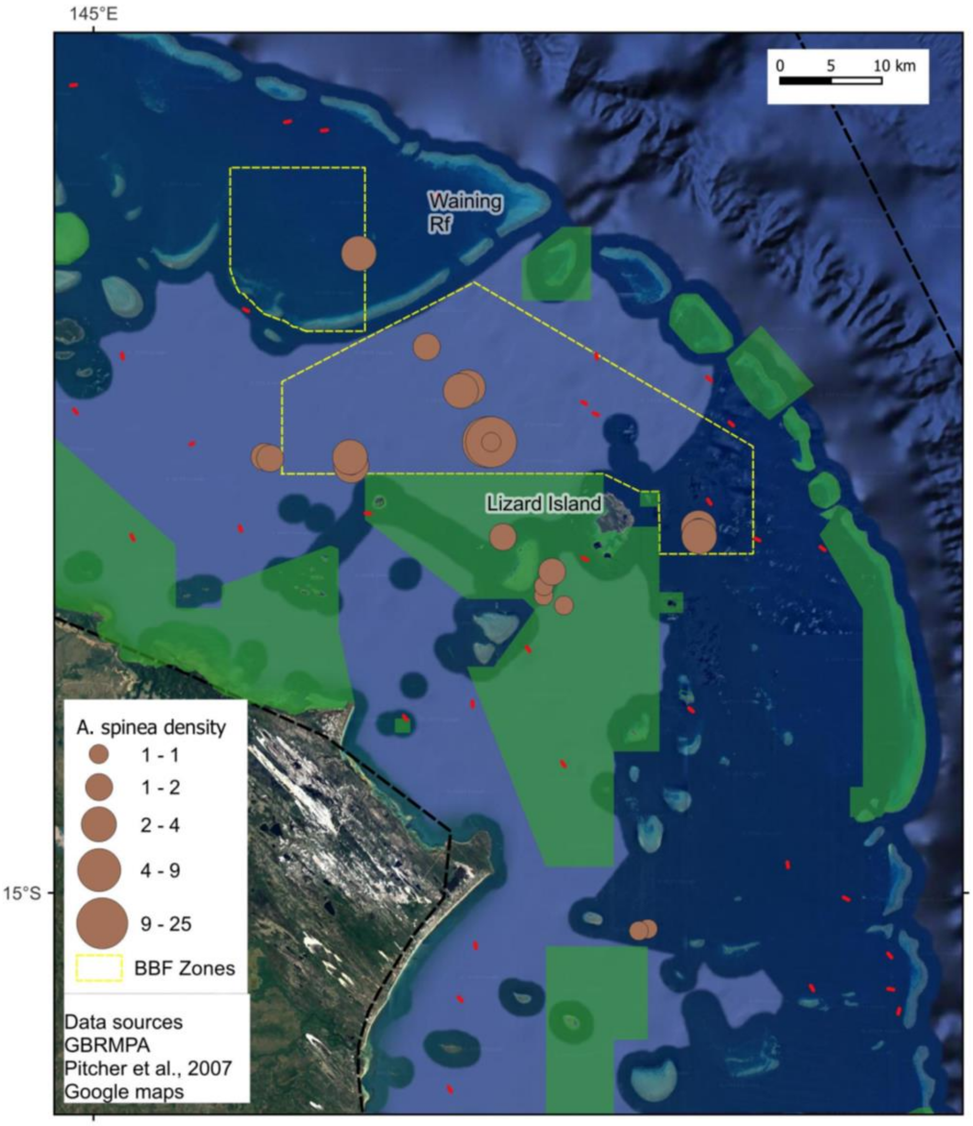

Figure 2. Lizard/Waining BBF Zone with location and density of Burrowing blackfish surveyed during the seabed biodiversity survey in 2003-06 (Pitcher et al., 2007) (Green areas are no-take for the QSCF).

Abundance indices

The key aspects of the development of an abundance index via catch per unit effort modelling were sound, conforming in general with the advice of Maunder and Punt (2004) and Hoyle et al. (2023).

The data were thoroughly explored and adequately characterised. The data filtering was straightforward. The temporal scopes of the indices were appropriate. These were dictated by the data available. Some issues are identified below where clarification is needed in the report.

The model selection was straightforward, with few variables given the small fleet, and diagnostics are appropriate. The final indices used in the population models have been appropriately assembled.

We noted the following issues with the standardised catch rates, where some clarification is needed:

Species targeting

Whether there were attempts at capturing the potential effects of targeting individual species was not explicitly reported in the analyses. For Burrowing blackfish modelling, data were restricted at the data filtering step, to those records where the catch was mostly (>75%) Burrowing blackfish, effectively (but arbitrarily) identifying fishing days where Burrowing blackfish were the target species.

For the Prickly redfish catch rate standardisation, *catch percent* was introduced as a variable. If this was an attempt at capturing targeting behaviour, it should be stated so. Presumably, the data could not support use of this variable for Curryfish species.

For the Curryfish species and Prickly redfish, Smart et al. (2024b) indicate in 2.3.1.1 Data Filtering that "The data were reduced to boats who fished a total of more than 100 kg". It needs to be clarified whether this amount was a daily total catch of all sea cucumber species, or of just Prickly redfish plus the Curryfish species, or individual species. Was this just to remove trivial records or was there an intent to capture target fishing for individual species?

Presumably there are differences in densities at different sites that experienced skippers and divers might exploit. We note, for example, that Prickly redfish have been declining in value relative to the other species over time (Purcell et al., 2018), so that there would be correspondingly, increasing incentive to target the Curryfish species over them. To address targeting of the Curryfish species and Prickly redfish may not have been feasible with the available data, but if that was the case, it should have been stated and perhaps warrants some discussion as to how this might be addressed.

Additional variables

The variables presented for the analyses were the basic set available from logbook data and catch disposal records, that would be expected in this work. We suspect they capture all the information available. If so, that should be stated explicitly. But if not, were additional variables considered? Given the QSCF is a hand-harvest fishery, it follows that individual skill levels might influence catch rates, and that skill might improve over time (learning). Were data available on catch rates by individuals or teams of divers, or skippers? We assumed that such data were not available, but the impacts of these variables might be a discussion point and an area identified for future work.

Hyperstability

The catch rates used to build the abundance index are likely to be hyperstable (i.e. catch rates stay high as the abundance drops; Hilborn and Walters, 1992). This is not dealt with in the catch rate modelling and recognition of this problem with some discussion of the implications is warranted. It is at least partly compensated for in the assessment by the use of an additional standard deviation for the abundance index (See below).

Fishing Power

There is no discussion in the reports of whether, over the course of the modern fishery, there has been an increase in fishing power, by which we mean changes in catchability induced by changes in technology or fishing techniques, or simply by increased skill of individual divers or skippers. It was discussed in the workshop that fishery has had a short lifespan, and techniques and equipment have not changed. However, the industry-commissioned scientists indicated that the dories used in the fishery now have plotters on board -exemplifying that new technology will be adopted and perhaps not captured in fishery data systems. It was felt during the workshop that these would have minimal impact. However, they could enhance position finding and locating suitable dive locations, and so may have had a small impact, that should be captured in future. Hoyle et al. (2024) recommended that stock assessments should consider a range of reasonable scenarios regarding long-term catchability trends, emphasising that a zero average annual rate of increase is rarely plausible. This is an issue that should be discussed briefly in the reports and identified as an area for future attention.

Environmental drivers

Environmental drivers were not considered in these reports. We note that work to address environmental drivers of sea cucumber abundance might be a substantial project but given the ecological importance of these species (Purcell et al., 2016a; Wolfe et al., 2020) it should be considered for future work.

3. Are the historical annual catch reconstructions, including the assumed start year and product weight conversions, sufficient for consideration of plausible catch history scenarios? These harvest (annual dead catch) time-series are inputted to the population models.

Historical catch

Commercial fishing for sea cucumbers on the Queensland east coast (including the current QSCF) began in the early 1800s (for a synopsis of the history of the Queensland east coast fishery, see Skewes, 2023b).

Species composition of the very early pre-1850 fishery is not known. Catch during the next pulse of the fishery during the 1880's included Black and White teatfish, various species of *Actinopyga* (red and black varieties), Lollyfish, Prickly redfish and Sandfish (in rough order of relative value), with several "supplementary species" bulking up the catch of about 20 species (Saville-Kent, 1893). Prickly redfish was, at one time (around 1880), the highest value species (Saville-Kent, 1893; Ryle, 2000). Of note is that most *Stichopus* (e.g. Curryfish species) species were generally not considered commercial due to easy disintegration. The catch after 1900 until WWII is unknown, but likely similar to the 1880s catch.

When the modern incarnation of the fishery began in the early 1980s, the initial focus species were Sandfish and Black teatfish. Although reliable catch data is only available from 1995, there were likely to be only small catches of Prickly redfish, and even less of Curryfish species and Burrowing blackfish.

Given market acceptance and accessibility to fishing by free divers, Prickly redfish were heavily targeted by the historical fishery. With the draft assessment for Prickly redfish beginning in 1995, It is implicit that this species had recovered to unexploited levels by inception of the contemporary fishery. However, we suggest that this assumption should be tested. This would be by including extra scenarios for the harvest history for Prickly redfish that include a potential significant depletion due to the early fishery, up until about 1940, or otherwise demonstrating the probable degree of recovery from heavily exploited to unexploited levels.

The two Curryfish species were essentially not acceptable to the fishery and so were not harvested until suitable handling and processing methods were developed for the species, in the mid-2000s. Beginning the assessment period from 1995 is acceptable for these species.

Conversion factors

Conversion factors were used to convert catch weight to live weight for the analysis, using established conversion factors (Murphy et al., 2021). For Burrowing blackfish, available gutted weight to live weight conversion factors were used (from New Caledonia; Purcell et al., 2009), even though the catch is reported (mostly) as "frozen and boiled" (in practice—gutted, par-boiled and then frozen). It is likely that there is some additional weight loss between "gutted" and "frozen and boiled" products for most species, as affirmed by the change in TAC in 2007, from 380 t to 361 t, due to the change in reporting from gutted weight to "landed" (salted or par boiled and frozen) based on agreed weight conversion ratios (DPIF, 2008; Skewes, 2023a).

Live weight to frozen and boiled weight conversion factors have been identified as a key information gap for the QSCF (Skewes, 2023a); in the meantime, it might be prudent to use the live weight to salted weight conversion factors for Burrowing blackfish as this will increase extractions in numbers for population modelling purposes. These are available for all species assessed in Murphy et al. (2023).

Management

The management framework for all assessed species has been relatively consistent over the period of the modelling, at least in terms of affecting catch (e.g. TACs) and effort (licences, gear and boat restrictions, rotational harvesting, closed areas). However, the current MLSs were implemented by authority condition for the 2004/2005 quota year (Roelofs, 2004)—before that it was a blanket 15cm MLS for the entire fishery. The only species this would potentially affect is Prickly redfish. The authors need to briefly discuss how this might or might not have affected the assessment for that species.

4. Have the key biological uncertainties been modelled? For example, appropriate handling of the relevant biological settings of maturity, fecundity, longevity/natural-mortality, and steepness.

There was little information available on biological parameters for all but Prickly redfish, including from other regions. The assessment team used what information was available to generate feasible base values for the parameters and visually evaluated these for consistency with other aspects of natural history and demography, using a set of plots. Alternative values of the parameters were then used as scenarios in the subsequent assessment modelling.

This approach allowed the assessments to proceed despite having limited information on some inputs. We recommend that the plots provided in the workshop, used to evaluate the biological inputs for consistency, should be provided as appendices to the reports. A fuller discussion of the scenarios and impact on model outputs would also be beneficial.

Maturity and Fecundity

Information on maturity and fecundity is required in the SS models but not for DDUST.

Length-at-50%-maturity for Prickly redfish and Herrmanni curryfish were derived from the literature and approximated for Vastus curryfish by using the values for Herrmanni curryfish. Maturity for Burrowing blackfish was pre-specified to occur approximate to the MLS of 20 cm.

Sensitivity of the assessment models to these values was evaluated by using scenarios using alternate values.

There is no information on fecundity for these species. A simple approach adopted was that fecundity was pre-specified to occur linearly with length.

Growth

Note that contrary to the reports, DDUST requires growth information in the form of rho from the Ford-Walford plot (Hilborn and Walters, 1992). How the rho parameter was derived for the DDUST models needs to be made explicit.

SS required fully specified growth models (data were not sufficient to estimate growth within the models).

Prickly redfish growth parameters were available from the literature. For Curryfish species and Burrowing blackfish growth, the assessments used or were derived from the values based on expert elicitation from stakeholder workshops (Skewes et al. 2014). Again, the sensitivity of the SS model to these assumed parameters was tested through alternate values.

Plus group ages were derived from literature and again sensitivity a tested, as for other parameters.

Longevity/natural mortality

Literature values were acquired for Natural mortality, with sensitivity testing applied using alternate parameter values, as for the other uncertain parameters.

Recent research has indicated that, for the adult population at least, there is slow growth and potentially low mortality (e.g. Prickly redfish; Purcell et al., 2016). Though the low mortality scenario for all species shows a poor fit to the data (discussed at the Workshop but not addressed in the assessment reports), given that generally the low mortality scenario shows a lower biomass relative to unfished biomass, this scenario should be a focus of some discussion about its appropriateness for indicating possible stock status for all four species.

Steepness

The steepness of the S-RR (*h*) was not estimated but was again provided as a range of values. A low but feasible value was chosen for the base case, (0.3 for all species and stocks), given the knowledge that sea cucumber species often have low biological productivity, and the recovery of overfished populations is often slow (Uthicke et al., 2004). Alternate medium and high values of *h* were included in the sensitivity testing.

5. Assess the population models used, their configurations, parameters, results, and diagnostics. Were they adequate to achieve the assessment objectives for stock status?

General points

Although the assessments (Smart et al. 2024a; 2024b) were subject to the limited data and information available from these small fisheries, they were largely in agreement with the best practices described by Punt (2023).

The integrated age-structured model (Stock Synthesis, SS) and delay difference model (with user specified time step, DDUST) make best use of the data available.

Smart et al. (2024a; 2024b), describe the relative merits and requirements of the two model types. The use of the two models forms firstly established whether the SS model could be applied consistently compared with the DDUST– SS is the more demanding, requiring more detailed growth and maturity information. As well as giving the confidence in performance that comes with a widely-used off the shelf package, SS outputs a broad set of diagnostics and provides the opportunity to utilise a wider range of data input types, including in these assessments, LF and the MLS specified explicitly.

Both model forms used available biological parameters. In some cases, as mentioned above, these needed to be inferred from those of other sea cucumber species or expert information and were chosen to be consistent with other parameter inputs. More such inference was required for SS. Both model forms used catch and effort data from logbooks and the catch disposal records systems, and the abundance estimates from recent surveys (Koopman et al., 2019; Koopman and Knuckey 2022; 2023a). The SS model additionally used length frequency (LF) data from those recent surveys.

Comparing SS outputs with those of DDUST tested whether the more closely specified growth and maturity parameters required by SS were appropriately chosen, and then whether the survey LF data were consistent with the catch rate abundance indices and the survey abundance estimates. There was a high degree of consistency between the outputs of the two model forms, and in the SS models with and without the inclusion of the LF data.

Given the lower demands of DDUST (in terms of parameters and assumptions), its performance in this assessment was very efficient. Nevertheless, the assessment team rightly considered that the Stock Synthesis models the more informative, as they consistently provided the best fit to surveyed biomass, incorporated the LF data and moreover explicitly considered the MLS.

As discussed above, we believe that the spatial structures chosen for the assessments were appropriate. These structures do not include the part of the populations that is protected by the GBRMP no-take zones and other areas closed to fishing. These would almost certainly represent some spawning biomass that is not accounted for in the assessment models. The spatial dynamics of these species are basically unknown, so the magnitude of this component of the populations and its contribution to the fished stocks might only be guessed at. Smart et al. (2024a; 2024b) recognise this limitation and note that the likely consequence of this in terms of model outputs is that they are probably conservative i.e. underestimate spawning biomass and stock status.

The models could not use sex information (there is no data on sex composition of catches) and all parameters relating to the biology are essentially an average over the sexes. There is no information on this topic, but hopefully, this creates no bias.

Compared to many fisheries, the modern QSCF has had a short life span. The models begin with the inception of this contemporary fishery, assuming an unfished equilibrium prior to that. This assumption is reasonable for all species and all sectors. However, there is some potential for the effects of historical fishing on Prickly redfish to have had an effect, even five decades since that historical fishery ceased. We recommended during the workshop that this question be investigated.

The models have used both catch and effort information from the fishery, as well as absolute biomass estimated from the recent surveys. In the workshop, it was agreed that the abundance estimates from the surveys were much more informative and more reliable than the abundance indices from standardised catch rates. We suggested that a post survey stratification of the Leeworthy (Leeworthy 2007a; 2007b) survey data could be feasible, and that inclusion of abundance estimates from them would potentially provide substantial enhancement to the assessments. If the results are largely unchanged when the models are updated with that survey data, then credibility of the assessments will be enhanced.

Annual time steps for the models are reasonable, in keeping with the longevity of the animals as well as the availability of data. Potential seasonal variability in abundance in the standardised catch rate series was picked up, for most species, by using a *Month* term in the standardisation (for some, data shortcomings prevented this).

A paucity of biological information means that biological parameters for sea cucumbers can be problematic. However, for the DDUST models, only limited growth information is required. The SS models require detailed growth and maturity parameterisation. This was reasonably achieved as described for Question Four, above. The small differences between the DDUST, and SS implementations of the analysis suggest that this approach to growth and maturity in the models was consistent.

The authors made no attempt to estimate natural mortality rates (*M*) within the models. Given the short history of exploitation and lack of contrast in population sizes, it is very unlikely that much information on *M* could be extracted other than via the scenario modelling presented. Rather, Smart et al. (2024a; 2024b) presented alternative scenarios for a range of *M* values, centred on a feasible value calculated using the approach of Cope and Hamel (2022). This approach is appropriate given the short time span of these fisheries and the apparent lack of contrast in the impact of fishing and captures the uncertainty that the lack of knowledge about *M* puts into the assessments. Also discussed in the workshop, was the conjecture that *M* may decrease with size in mature adults. It was discussed in the workshop that *M* could be modelled as a function of age (or size), rather than constant, and apply the Lorenzen (1996) approach, for example. We were concerned that this might currently be based on little data, but the models would be better informed in the future as more size data becomes available form surveys.

The models used the Beverton-Holt stock-recruitment relationship (S-RR), with the recruitment at unfished equilibrium, R0, being a leading parameter of the models. The steepness of the S-RR (*h*) was not estimated but was again provided as a range of values based on a reasonable value. The scenario ranges tested the influence and attempted to capture uncertainty in that parameter.

Given the probable narrow range of populations sizes over the fishery history, there would be a lack of contrast in the data to support an estimation of *h* within the models. The input of a range of *h* values avoided confounding with the other parameters of the model. A wide range of values were included as scenarios for all species.

There was discussion in the workshop whether there could be an opportunity to test whether a high density of adults would suppress recruitment. It was suggested that a Ricker S-RR, in which recruitment rates are suppressed at high adult densities, could be included as a scenario, Additionally, we asked that the potential for depensatory recruitment (such as an Allee effect) might be discussed further than the brief mention in the current reports. Given the high abundance levels indicated in the assessments, depensation is not likely to be important at this stage of the fishery.

Recruitment deviations were estimated as parameters rather than as random effects, reflecting the simple lack of information available to these assessments. Recruitment variability was also tested by a range of scenarios, with low and high values tested against a base case value that was first tuned to minimise over-fitting to catch rates. For all species, there were no apparent strong patterns nor extreme recruitment events observed.

Selectivity was described by a length-based logistic curve and largely determined by the MLS. There was good agreement between fishery and survey selectivity. There was no apparent reason to adopt a dome-shaped curve given the nature of fishing sea cucumbers in a hand-harvest fishery.

Given the short time span of the fisheries and that a MLS has been in place for most of the modern fishery period, a constant rather than time varying selectivity relationship is a reasonable assumption. The MLS engenders size-specific fishing mortality, but given the low fishing mortality in these fisheries, this is unlikely to affect the size-at-age distributions in the population in ways that distort the model.

For the base case, abundance indices and LF plots were in reasonable agreement with the model predictions (although the LF plots tended not to achieve the peaks shown by the data). Standard residual diagnostics for the base cases showed no particular patterns nor issues with magnitude. The sensitivity tests of the different scenarios were largely in agreement, although the low *M* scenarios tended to be divergent. The suite of MCMC diagnostics were consistent with reasonable model fit for most scenarios. The authors noted the poor support for the low *M* scenarios.

There was little difference between MCMC and the MLE results. The reports illustrated that there were no issues with convergence (several diagnostics were provided by the authors in Smart et al. 2024a; 2024b) although the plots for low *M* tended to be quite divergent from the mass of MCMC scenario plots.

Given the general consistency of outputs, the median of the parameter posteriors for the sets of scenarios is a reasonable presentation of an average outcome of the various scenarios.

There was no formal weighting between the catch rate indices, the abundance estimates, and the LF data sets. However, applying an extra standard deviation parameter to the standardised catch rate series, effectively reduced the weighting of that input. The outputs of the models were little-changed. The addition of the LF data provided some precision but also had little impact on the model outputs. This indicates the consistency of the abundance indices (from catch rates) and abundance estimates (from surveys) and the survey LF data.

6. Comment on the accuracy and reliability of key statements in the report summary and conclusion. How well were they supported by the data, analysis, and literature?

The key finding from the Smart et al. (2024a; 2024b) reports is that all species and stocks assessed were, in 2023, at biomass levels well above the target level of 60% of unfished exploitable biomass, B60. This finding is supported by the biomass estimates from recent surveys. The results affirm the effectiveness of the wide range of management measures designed to manage fishing of these species to keep population levels of B60 and above.

Given the good convergence of the different model scenarios, there should be confidence in the outputs and their interpretation might be considered straightforward. However, the initial finding of the assessment that the Burrowing blackfish spawning population in the Lizard Island zone is at 78% of B0 (Smart et al., 2024a) appears to be inconsistent with the conclusion from the industry survey report for that zone that “the low densities of BBF recorded in the current survey of commercially fished areas of the Primary Waining Reef stratum and Primary Lizard Island stratum are of concern” (Koopman and Knuckey, 2022). Industry has implemented a voluntary closure subject to an additional survey, to be carried out in 2024. The assessment authors need to discuss this inconsistency.

Also, the 2022 survey area within the neighbouring MPA (Koopman and Knuckey, 2022) was a small number of transects, and the results might simply represent local high density. But is there a way in which the assessments might be optimistic? This problem also highlights the value of quantitative surveys, even in the protected areas.

The stock status results for the other two Burrowing blackfish zones, and for Prickly redfish and Curryfish species are not inconsistent with the survey report findings.

Prickly redfish and the Curryfish species were found to be at relatively high biomass levels with results supported by survey biomass estimates. With a rotating harvest and MLS of all three species that are large relative to their maximum sizes, there is substantial protection from fishing for the majority of the populations. Such measures should support healthy biomass levels and consistent with this, the stock assessments estimated low levels of fishing mortality (*F*) and high levels of relative biomass in 2023.

Delay difference models (DDUST) and integrated age-structured models (Stock Synthesis, SS) were both used in the assessments. Smart et al. (2024a; 2024b), describe the relative merits and requirements of the two model types, with a Stock Synthesis implementation being the more desirable as it provides greater detail in its outputs, including extensive diagnostic support. It also provided the best fit to surveyed biomass, explicitly considers an MLS and could make use of the LF information from surveys. The length frequency data used in the SS model was consistent with the abundance indices and the survey abundance estimates, providing some confidence in the model outputs.

The consistency in outputs between the DDUST and SS models demonstrates that they have both been implemented successfully. The assessments here were the first for these species in this fishery. The advantages of implementing SS models will grow as future assessments incorporate more data forms.

7. Review the suitability of the data sources and whether any other data sources would be useful. Are there any improvements for the methods applied?

The assessments relied on logbook catch and effort data, and catch disposal and sales records. These provide the only source of information on removals from the stocks (as harvest), and this is a necessary set of information.

They also provide the raw data for the standardised catch rates. It is acknowledged that these indices are likely to be hyperstable. The issue was dealt with in the Smart et al. (2024a; 2024b) analyses only by downweighting the input of the indices into the models.

The model might not have been reliable had the only indices of abundance been those from standardised catch rates. Fortunately, the estimates of absolute abundance were available from the surveys. In the long run, as further surveys are undertaken, it might be feasible to rely less on the standardised catch rate series.

The surveys are also a good source of length frequency data and could provide the platform for various projects designed to collect biological and demographic data. Their continuation would support strong assessments into the future.

The assessments for Burrowing blackfish would be strengthened by using the survey data from the early fishery population surveys carried out for the Lizard/Waining and Gould Reef BBF zones (Leeworthy 2007a; 2007b). Though the earlier surveys used a grid-based design, rather than a random stratified design (as was done for Koopman et al., 2019 and Koopman and Knuckey, 2022) we believe that post-survey stratification of the data sets from the Leeworthy (2007a; 2007b) would be feasible, potentially providing additional biomass estimates that could be included in the assessments. The post-stratification would need to be undertaken with significant care as these would likely be informative and influential in the assessments.

A preliminary perusal of the Bunker survey design indicates that there is little scope of including the early survey data in the current assessment – as there is little overlap between the early (Leewothy, 2010) and recent (Koopman and Knuckey, 2023a) survey.

There were clearly data quality issues with the various conversions between product forms. Collection of data to support reliable conversion factors would be highly valuable.

8. Provide comment on any other important aspects you see or that the report should have completed, provided they relate to the estimation of stock status.

The fisheries and stocks of sea cucumbers are subject to a suite of input and output controls. Qualitatively, these should provide substantial protection to the stocks but that protection is difficult to quantify other than in total, in assessments such as those reported by Smart et al. (2024a; 2024b).

Current management

The QSCF is managed under relevant Queensland fisheries legislation. Fishers must also comply with state marine park and Great Barrier Reef Marine Park zoning rules. The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) applies to export product from the fishery.

Since September 2021, the sea cucumber fishery has been managed under the Queensland sea cucumber fishery harvest strategy (HS) (DAF, 2021), which implements objectives consistent with the Queensland Sustainable Fisheries Strategy 2017–2027 (DAF, 2017), most notably a target exploitable biomass level (B*targ*) of 60% of that aims to maximise economic yield (MEY) for the fishery and a limit reference point (B*lim*) of 20% of the exploitable biomass being the biomass level that the harvest strategy aims to avoid.

The primary management strategies include:

- Limited entry. Commercial fishery access can only occur under a primary commercial fishing licence with a B1 fishery symbol. From January 1995 entry into the fishery was limited to 18 licences. (Currently, all licences are controlled by 2 operators in the fishery)
- The fishery has been quota-managed since 1991 with a total allowable commercial catch (TACC). The TACC is allocated amongst individual transferable quota (ITQ) units for black teatfish, white teatfish and other sea cucumbers. The TACC is adjusted according to the decision rules in the HS each year. The current TACC can be found in the Fisheries Quota Declaration 2019.
- Gear restrictions – collection by hand only, commercial collectors allowed to use underwater breathing apparatus.
- Species specific minimum size limits (MSL) are in place as a condition of authority
- Vessel restrictions – One main vessel that is allocated on each authority, with up to 4 dories less than 7m in length for each authority holder.
- Up to 6 persons (fishers) per authority working at any one time.
- The fishery is managed under a rotational harvest arrangement. Reefs within the Great Barrier Reef Marine Park and the Coral Sea in the fishery area are divided into 158 zones –

apart from an annual harvest of Burrowing black fish for defined Zones with the following catch levels – Lizard = 120 tonnes, Gould = 45 tonnes and Bunker = 60 tonnes.
- An approved vessel tracking unit must be installed as per the department's Vessel tracking installation and maintenance standard.
- Compliance with Queensland State fisheries reporting requirements.

The framework of management for each of the species described in the assessments needs to be described in more detail to provide context. Perhaps in the Discussion sections, qualitatively describe the extent to which these measures support the sustainability of the fisheries (or not).

Conclusions and Recommendations

Overall, the assessments are thorough and great pains have been taken to utilise the available data, extract biological information where there was little available, and to capture most sources of uncertainty. The assessments indicate that the status of the species is above target levels. While we agree that there should be some confidence in these results, we reiterate that the issues with relative densities of Burrowing blackfish within the fished area relative to the adjacent MPA, in the 2023 Lizard Island area survey, is a concern and is an inconsistency to be addressed.

The review found that, for all four species, the spatial scale of assessment was appropriate, but with the caveat that, for Prickly redfish and Curryfish species stocks, consideration of population dynamics on the scale of 50-100 km to maintain local density and for ecological considerations is still required. It is recommended that spatially explicit population models be developed in the future to account for this uncertainty.

Though the implementation of RHA will spread effort and reduce local and overall depletion risk, there is still some evidence that fishing effort is unevenly spread throughout the fishery. This may be the focus of future modelling that applies spatially explicit population models.

The closed areas are not included in the population models. We agree that this adds a level of conservatism to the assessment, especially for the reef-associated species; Prickly redfish and Curryfish species. This creates a real challenge for assessments, given the lack of knowledge about the spatial dynamics of recruitment for these species. Nevertheless, unbiassed assessments are desirable and we recommend research and exploratory modelling in this topic area. We also caution that interpreting the status of sea cucumbers in the unfished, protected areas, based on the results of catch rates and survey results in the fished areas, would not be appropriate.

Stocks in the QSCF are likely connected to stocks in the Coral Sea and Torres Strait. Though strong source-sink dynamics that would nullify the application of stock assessments at the fishery scale are unlikely, joint assessments perhaps based on the development of hierarchical models would likely help reduce the fishery level and overall risk to species in the region.

The temporal scope for all four species appears to be appropriate as pertains to the modern QSCF. However, it is likely that Prickly redfish at least was heavily targeted in the historical fishery (early 1800s-1940), and consideration in the assessments is needed of a potential significant depletion due to the early fishery, up until about 1940, or otherwise demonstrating the probable degree of recovery from heavily exploited to unexploited levels.

Live weight to frozen and boiled weight conversion factors have been identified as a key information gap for the QSCF; in the meantime, it would be prudent to use the live weight to salted weight conversion factors for Burrowing blackfish as this will increase extractions in numbers for population modelling purposes.

The management framework for all assessed species has been relatively consistent over the period of the modelling, apart from the change in MLS from a blanket 15 cm to species-based MSL in 2004. The only species this would potentially affect are Prickly redfish. The authors need to briefly discuss how this might or might not have affected the assessment for that species.

The assessment report acknowledges the dearth of information on population parameters available for the focus species, especially for Vastus curryfish and Burrowing blackfish. The approach was to generate feasible base values and then apply alternative values of the parameters as scenarios. We recommend that plots of biological inputs should be provided as appendices to the reports. A fuller discussion of the scenarios and impact on model outputs would also be beneficial.

In particular, given recent research indicating slow growth and potentially low mortality for some sea cucumbers, low natural mortality scenarios should be a focus of some discussion about its appropriateness for indicating possible stock status for all four species. Also, there was some conjecture that *M* may decrease with size in mature adults. We encourage the assessment team investigate whether there is evidence for reduced M as size increases in future assessments.

Additionally, how the rho parameter was derived for the DDUST models also needs to be made explicit in the report.

The lack of biological information for these species is problematic in that it reduces confidence in assessments such as these. Concerted effort needs to be applied to address the shortcomings in biological data for the species examined here.

All the assessments utilise recent population surveys which adds great strength to the modelling outputs. In addition, there are early fishery surveys for the three Burrowing blackfish zones that have not been utilised due to concerns about the sampling approach. Smart et al. (2024a) noted the potential value of these older surveys but they were not utilised in the assessments. We suggested that a post survey stratification of the early surveys for Lizard/Waining and Gould Reef (Leeworthy 2007a; 2007b) could be feasible, and that their inclusion would potentially enhance the assessments.

There was discussion in the workshop whether there could be an opportunity to test whether a high density of adults would suppress recruitment. It was suggested that a Ricker S-RR, in which recruitment rates are suppressed as adult densities increase, could be included as a scenario. We appreciate that there might be insufficient contrast in available data to define this.

Additionally, we asked that the discussion in the reports of the potential for depensatory recruitment (such as an Allee effect) should be expanded to how it might be detected and investigated. We conceded that this would be hard to detect in fishery models where there is little contrast in historical abundance but also note that the problem might be manifested on very small spatial scales.

In addition to the issues with relative densities of Burrowing blackfish within the fished area relative to the adjacent no-take zone, another challenge for modelling Burrowing blackfish populations is that they could be somewhat ephemeral, much like scallop populations such as in Bass Strait (Haddon et al., 2006). In this case, what the management of these fisheries relies on is a suite of broader fishery objectives (rather than fixed reference levels) (AFMA, 2015), regular surveys (Koopman and Knuckey, 2023b) and adaptive management. The implication is that abundance at the scale of the zones could fluctuate substantially irrespective of the impact of fishing. Surveys, and probably catch rates, would both detect such abrupt abundance changes but it would perhaps be difficult to ascertain whether fishing or other factors were the drivers. Do or could the current population surveys provide sufficient information to evaluate an hypothesis that populations of Burrowing blackfish (and other sea cucumber species) are ephemeral ("dynamic")?

Recommendations

Current modelling

1. Test the assumption, for Prickly redfish at least, that the population had recovered from depletion caused by the early (1800s – 1940) east coast fishery to near virgin densities and quasi-equilibrium by the start of the modern fishery.
2. Use salted weight conversion factors to convert to live weight for Burrowing blackfish rather than gutted weight – as the par-boiled and frozen product weights are likely to be closer to salted weight than gutted weight.
3. The plots of biological parameters provided in the workshop, used to evaluate the biological inputs for consistency, should be provided as appendices to the reports.
4. Advise whether variables other than those included were considered for the catch rate standardisation modelling. Were data available on catch rates by individuals or teams of divers, or skippers?
5. Potential changes in fishing power should be discussed briefly in the reports and identified as an area for future attention.
6. Clarify the data filtering applied for Prickly redfish and the Curryfish species indicating whether targeting of each species was dealt with, discuss whether target fishing for these species might be significant and whether it can be evaluated in this assessment or in the future.
7. Provide some focussed discussion on the low mortality scenario for each species – in response to recent research that has indicated that, for the adult population at least, there is slow growth and potentially low mortality for some sea cucumbers (e.g. Prickly redfish; Purcell et al., 2016).
8. Investigate potential to include the survey data from the early fishery population surveys for Burrowing blackfish, for Lizard/Waining and Gould Reef as this would strengthen the assessments.
9. Address the inconsistency between the relatively optimistic finding in the stock assessment modelling that the current population is at 78% of B0 (Smart et al., 2024a) and the industry survey report that concludes that "the low densities of BBF recorded in the current survey of commercially fished areas of the Primary Waining Reef stratum and Primary Lizard Island stratum are of concern" (Koopman and Knuckey, 2022) and the implementation of a voluntary closure by industry.

Future stock assessments

1. Develop spatial explicit population models to address possible localised depletion.
2. Address possible size-dependent mortality.
3. Investigate potential assessment and management approaches for "dynamic" population patches (for BBF only).
4. Consider investigating environmental drivers of these sea cucumber populations and potentially incorporating the drivers into stock assessments.
5. Consider joint assessments among all three east coast fisheries to help reduce risk to species in the region.

References

AFMA, 2015. Harvest Strategy for the Bass Strait Central Zone Scallop Fishery (BSCZSF).

Cope, J.M., and Hamel, O.S., 2022. Upgrading from M version 0.2: an application based method for practical estimation, evaluation and uncertainty characterization of natural mortality. Fish. Res. https://doi.org/10.1016/j.fishres.2022.106493

DAF, 2021. Sea Cucumber Harvest Strategy: 2021-2026. Available at https://www.publications.qld.gov.au/dataset/queensland-fisheries-harvest-strategies/resource/f9ec2eab-9f61-4d49-930f-6f9446102b85

DAWE, 2021. Assessment of the Queensland Sea Cucumber Fishery (East Coast). Department of Agriculture, Water and the Environment.

DEH, 2004. Assessment of the Queensland East Coast Beche-de-mer Fishery.

DPIF, 2008. Annual status report 2008 - East Coast Beche-de-mer Fishery.

Eriksson, H., Byrne, M., 2015. The sea cucumber fishery in Australia's Great Barrier Reef Marine Park follows global patterns of serial exploitation. Fish and Fisheries 16, 329–341. https://doi.org/10.1111/faf.12059

Haddon, M., Harrington, J., Semmens, J., 2006. Juvenile Scallop Discard Rates and Bed Dynamics: Testing the Management Rules for Scallops in Bass Strait.

Hilborn, R. and Walters C.J., 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. (Chapman and Hall: New York, London). 570 p.

Hoyle, S.D., R.A. Campbell, N.D. Ducharme-Barth, A. Grüss, B.R. Moore, J.T. Thorson, L. Tremblay-Boyer, H. Winker, S. Zhou, and M.N. Maunder 2024. Catch per unit effort modelling for stock assessment: A summary of good practices. In: Fisheries Research 269, p. 106860.

Koopman, M., Knuckey, I. and A. Flynn. 2019. Survey to estimate the biomass and recovery of Burrowing Blackfish (*Actinopyga spinea*) at Gould Reef. Fishwell Consulting, 43pp. 2019. CC BY 3.0]

Koopman, M. and Knuckey, I. 2022. Survey to estimate the biomass of Burrowing Blackfish (*Actinopyga spinea*) at Lizard Island and Waining Reef. Fishwell Consulting, 36pp. 2022. CC BY 3.0]

Koopman, M. and Knuckey, I. 2023a. Survey to estimate the biomass and density of Burrowing Blackfish (*Actinopyga spinea*) at the Bunker Group. Fishwell Consulting, 34pp. 2022. CC BY 3.0]

Koopman, M., and Knuckey, I., 2023b. Bass Strait and Central Zone Scallop Fishery - 2023 Survey. (AFMA Project 2021-0802.). Fishwell Consulting.

Koopman, M., Knuckey, I., and K. McSpadden. (2024). 2023 survey to estimate the biomass and density of Prickly Redfish (Thelenota ananas) and Curryfish (*Stichopus hermanni* and *S. vastus*) in the Queensland Sea Cucumber Fishery (East Coast). Fishwell Pty Ltd, 48pp. 2024. CC BY 3.0]

Leeworthy, G., 2007a. Survey of the Burrowing Blackfish (*Actinopyga spinea*) stocks on the Great Barrier Reef, Queensland, using the hip-chain transect method for underwater visual census. Gould Reef, September 2004. Research report for the Queensland Sea Cucumber Association.

Leeworthy, G., 2007b. Survey of the Burrowing Blackfish (*Actinopyga spinea*) stocks on the Great Barrier Reef, Queensland, using the hip-chain transect method for underwater visual census. Lizard

Island/Waining Reef, January 2005. Research report for the Queensland Sea Cucumber Association. 26 pp.

Leeworthy, G., 2010. Report on the exploratory survey of the Burrowing Blackfish populations in areas of the southern Great Barrier Reef, Queensland. Zone M37, Bunker-Kent Group and Swains Reefs. Research report for the Queensland Sea Cucumber Association. 15 pp

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: A comparison of natural ecosystems and aquaculture. J. Fish Biol. 49: 627–642

McCook, L.J., Ayling, T., Cappo, M., Choat, J.H., Evans, R.D., De Freitas, D.M., Heupel, M., Hughes, T.P., Jones, G.P., Mapstone, B., Marsh, H., Mills, M., Molloy, F.J., Pitcher, C.R., Pressey, R.L., Russ, G.R., Sutton, S., Sweatman, H., Tobin, R., Wachenfeld, D.R., Williamson, D.H., 2010. Adaptive management of the Great Barrier Reef: A globally significant demonstration of the benefits of networks of marine reserves. Proceedings of the National Academy of Sciences 107, 18278–18285. https://doi.org/10.1073/pnas.0909335107

Maunder, M.N. and Punt, A.E., 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research. 70:141-159; 2004. 10.1016/j.fishres.2004.08.002

MSC, 2022. MSC Fisheries Certification Process and Guidance v3.0. Marine Stewardship Council.

Pitcher, C.R., Doherty, P., Arnold, P., Hooper, J., Gribble, N., et al., 2007. Seabed biodiversity on the continental shelf of the Great Barrier Reef World Heritage Area (AIMS/CSIRO/QM/QDPI CRC Reef Research Task Final Report). CSIRO Marine and Atmospheric Research, Cleveland, Qld.

Plagányi, É.E., Skewes, T., Murphy, N., Pascual, R., Fischer, M., 2015. Crop rotations in the sea: Increasing returns and reducing risk of collapse in sea cucumber fisheries. Proceedings of the National Academy of Sciences 112, 6760–6765. https://doi.org/10.1073/pnas.1406689112

Punt, A.E., 2023. Those who fail to learn from history are condemned to repeat it: A perspective on current stock assessment good practices and the consequences of not following them. Fisheries Research 261, https://doi.org/10.1016/j.fishres.2023.106642

Purcell, S., Conand, C., Uthicke, S., Byrne, M., 2016a. Ecological roles of exploited sea cucumbers. Oceanography and Marine Biology: An Annual Review 367–386.

Purcell, S., Piddocke, T., Dalton, S., Wang, Y., 2016b. Movement and growth of the coral reef holothuroids *Bohadschia argus* and *Thelenota ananas*. Mar. Ecol. Prog. Ser. 551, 201–214. https://doi.org/10.3354/meps11720

Purcell, S.W., Williamson, D.H., Ngaluafe, P., 2018. Chinese market prices of beche-de-mer: Implications for fisheries and aquaculture. Marine Policy 91, 58–65. https://doi.org/10.1016/j.marpol.2018.02.005

SAFS, 2020. www.fish.gov.au Accessed March, 2023

Skewes, T., Plaganyi, E., Murphy, N., Pascual, R., Fischer, M., 2014. Evaluating rotational harvest strategies for sea cucumber fisheries. Fisheries Research and Development Corporation, Brisbane.

Skewes T.D. 2023a. Expert Advice for the Assessment of Australian Sea Cucumber (Thelenota) Fisheries: Queensland Sea Cucumber Fishery (East Coast). A Report for The Department of Climate Change, Energy, the Environment and Water. Tim Skewes Consulting, Australia.

Skewes TD 2023b. Expert Advice for the Assessment of Australian Sea Cucumber (Thelenota) Fisheries: National Report. A Report for The Department of Climate Change, Energy, the Environment and Water. Tim Skewes Consulting, Australia.

Smart, J.J., Wortmann J., and Wickens M.E., 2024a. Stock assessment of Queensland east coast burrowing blackfish (*Actinopyga spinea*), with data to June 2023. Fisheries Queensland, Department of Agriculture and Fisheries.

Smart, J.J., Wortmann J., and Wickens M.E., 2024b. Stock assessment of Queensland east coast prickly redfish (*Thelenota ananas*), herrmanni curryfish (*Stichopus herrmanni*) and vastus curryfish (*Stichopus vastus*) with data to December 2023. Fisheries Queensland, Department of Agriculture and Fisheries.

Smith, T., Roelofs, A., 2011. Evaluating the effectiveness of the Rotational Zoning Scheme for the Queensland East Coast Bêche-de-mer Fishery. Fisheries Queensland, the Department of Employment, Economic Development and Innovation (DEEDI).

Uthicke, S., Welch, D. and Benzie, J.A.H., 2004. Slow Growth and Lack of Recovery in Overfished Holothurians on the Great Barrier Reef: Evidence from DNA Fingerprints and Repeated Large-Scale Surveys. Conservation Biology 18.5. 1395‑1404.

Wolfe, K., Byrne, M., 2022. Overview of the Great Barrier Reef sea cucumber fishery with focus on vulnerable and endangered species. Biological Conservation 266, 109451. https://doi.org/10.1016/j.biocon.2022.109451

Wolfe, K., Anthony, K., Babcock, R.C., Bay, L., Bourne, D.G., Burrows, D., Byrne, M., et al., 2020. Priority species to support the functional integrity of coral reefs, in: Hawkins, S.J., Allcock, A.L., Bates, A.E., Evans, A.J., Firth, L.B., McQuaid, C.D., Russell, B.D., Smith, I.P., Swearer, S.E., Todd, P.A. (Eds.), Oceanography and Marine Biology. CRC Press, pp. 179–318. https://doi.org/10.1201/9780429351495-5