TIM SKEWES CONSULTING

Seychelles sea cucumber survey 2021/22 – sample design, analysis of survey data and management recommendations

Final report

October 2022

Seychelles Fishing Authority

Citation

Skewes TD and BG Long (2022) Seychelles sea cucumber survey 2021/22 — sample design, analysis of survey data and management recommendations. Final Report to the Seychelles Fishing Authority. Tim Skewes Consulting, Australia.

Acknowledgments:

This works is funded by SWIOFish3, which is financed primarily by the World Bank and the Global Environment Facility (GEF), in conjunction with the Seychelles Department of Blue Economy, and the Seychelles Fishing Authority.

Contents

Figures

Tables

Summary

This report contains information related to a stock survey and assessment of the Seychelles Sea Cucumber Fishery (SSCF) carried out in 2021-22. The field survey was carried out by the Seychelles Fishing Authority (SFA) with participants from the commercial fishing industry; and Tim Skewes Consulting provided sample design, data analysis and management advice.

The Seychelles sea cucumber fishery began in the late 1980s, and the fishery recorded its highest catch in 2012-13 (though early catch reporting is unreliable). The bulk of the catch since 2007-08 has been of Pentard (also called Flower teatfish). The current fishery is restricted to three species (Pentard, White teatfish and Prickly redfish) with separate catch quotas.

The first full-scale stock survey for the fishery was carried out in 2004 and included a survey of 246 sites throughout the Amirantes and Mahé Plateau. The 2021-22 survey was designed to revisit about 200 of these sites again to estimate the trends in density and population size since 2004. An additional survey on a restricted area of the Mahe Plateau was also carried out in 2011 (Koike, 2017), and data from this survey was also used to assess stock status.

Fishery logbook data has been collected since the early 2000s, and it was available up until 2016, and for the 2020-21 season. We reanalysed this data to produce CPUE (number of each species caught per minute diving) for the three main fishery species and Black teatfish (only up to 2016 for the later).

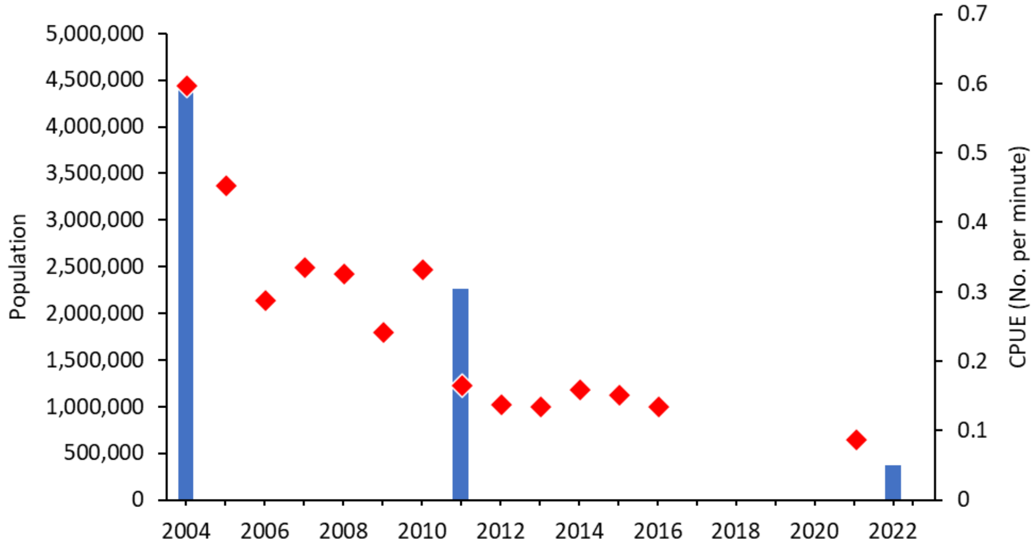
The 2021-22 survey used standard survey and stratified analysis techniques to gather and analyse the data. Uniquely, the survey included commercial divers who participated in dive transects and video observations. Scientific and commercial divers both saw about the same number of sea cucumbers during the diver surveys.

The 2021-22 survey team visited 206 sites (of the original 220 sites planed) with 14 sites abandoned due to poor visibility and/or high currents, outstanding achievement given the scope of work.

White teatfish (*Holothuria fuscogilva*)

The population estimate for White teatfish in 2021-22 was 378,378 (± 73.7%, 60% CI) or only 8.3% of the 2004 stock estimate. The decline in the population observed during the 2021-22 survey continued a trend observed in 2011 (Koike, 2017). CPUE also declined and matched the survey data closely – with the 2020-21 CPUE only 14.4 % of the 2004 estimate, the lowest CPUE value in the data series.

The decrease in average density at repeated sites, the decline in population estimates, and declining CPUE for White teatfish all point to a heavily depleted population, to approximately 10% of its 2004 level, and highly likely to be below the level of recruitment impairment. It requires immediate cessation of fishing to allow rebuilding and monitoring every three years to detect any recovery.



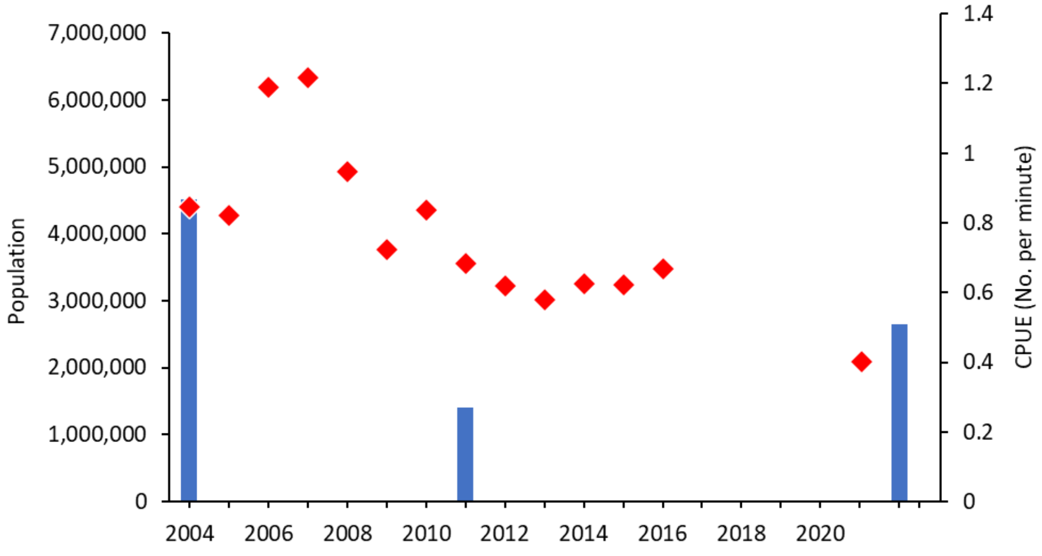
Survey population (blue bars) and logbook CPUE (red diamonds) data for White teatfish from 2004 to 2022.

Pentard/Flower teatfish (*Holothuria sp.* (type "Pentard"))

The population of Pentard in 2021-22 was 2,663,685 (± 38.1%, 60% CI), which was about 59% of the 2004 estimate. The CPUE data shows a variable but slow decline in CPUE that matches the survey data fairly closely – with the 2020-21 CPUE (number caught per minute of diving) declining to 47.4 % of the 2004 estimate.

The data indicates that the Pentard population may have been reduced by about half since 2004. This still represents a remarkably stable population status given the heavy fishery focus on this species, and particularly in comparison to the sharp decline in the White teatfish population.

While the stock level may not have reached a level where recruitment impairment is occurring, the downward trajectory of CPUE would indicate that current fishing levels are likely unsustainable. We would recommend an immediate reduction in the quota for this species by another 10% as an additional small buffer to overexploitation, and the urgent implementation of targeted stock assessment modelling, using the recent survey and fishery logbook data to establish stock status in relation to BMSY and sustainable levels of fishing mortality FMSY. Further management actions would be based on the outcomes of that assessment.

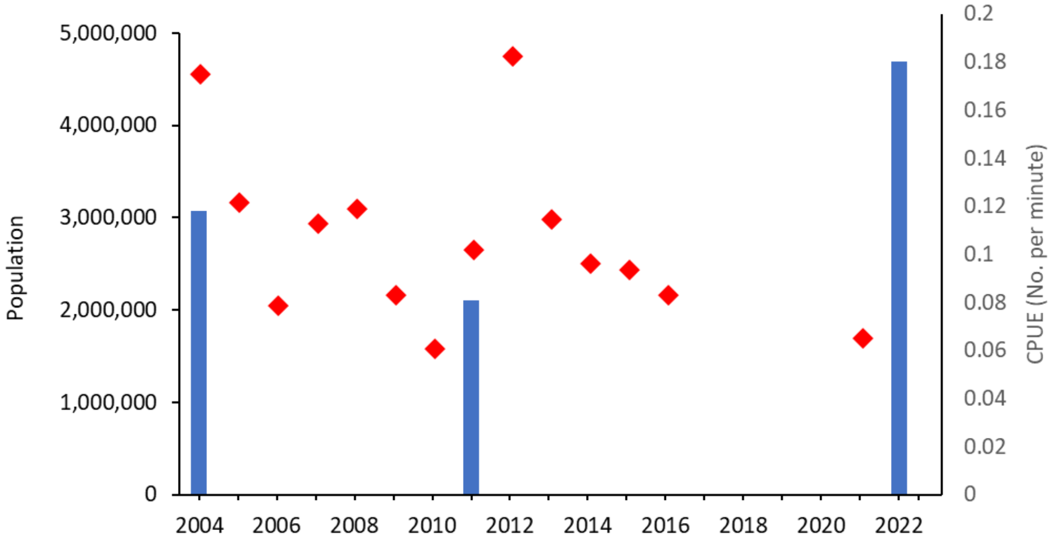


Survey population (blue bars) and logbook CPUE (red diamonds) data for Pentard from 2004 to 2022.

Prickly redfish (*Thelenota ananas*)

The population estimate for Prickly redfish in 2021-22 was 4,688,498, an increase of 52% on the 2004 estimate (Figure 21). CPUE was highly variable, with a very weak temporal trend (R^2 = 0.1704) – however with the 2020-21 CPUE was at the lower end of the scale.

In this case, there is not a strong signal in the that would indicate a decline in the Prickly redfish population or vice versa. However, given the survey results that have indicated a substantial increased since 2004, it would appear unlikely that this species has declined to levels that would warrant a change in fishing pressure sat this stage. On the other hand, additional analysis of fishery or other data may provide the basis for an increase in catch.

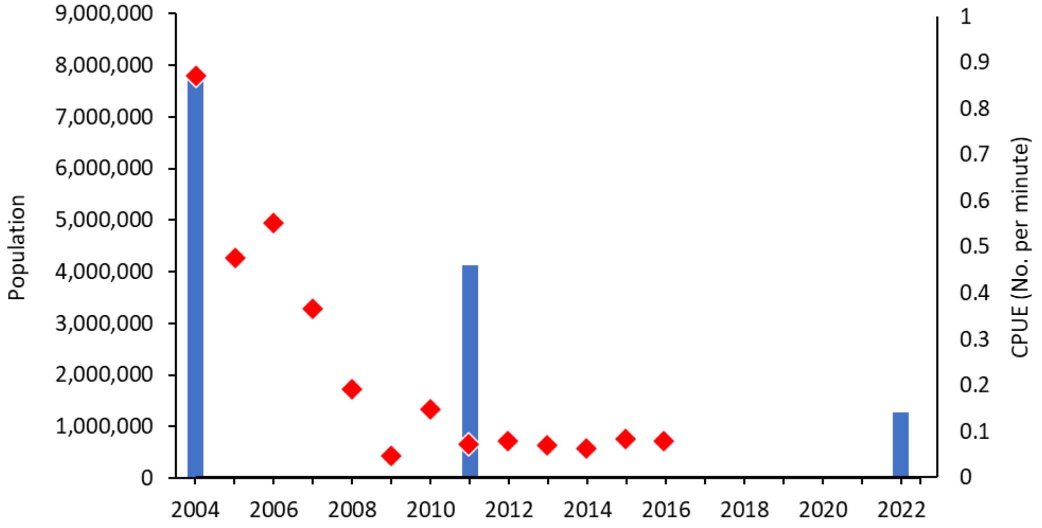


Survey population (blue bars) and logbook CPUE (red diamonds) data for Prickly redfish from 2004 to 2022.

Black teatfish (*Holothuria nobilis*)

The population estimate for Black teatfish in 2021-22 was 1,271,570 (± 40.4%, 60% CI), a decline of 84% from the 2004 estimate (Figure 26). The decline in the population observed during the 2021-22 survey continued a trend of a declining population also observed in 2011.

CPUE data was only available up to 2016 also showed a large decline in the population of Black teatfish, with the 2016 CPUE only 9% of the 2004 CPUE estimate. The data for Black teatfish indicates that this species is still in a depleted state, even though fishery effort ceased in 2018. However, there are indications that a recovery is occurring, with higher densities than when the population reached its lowest level in 2017. This population should be monitored with the view to a possible reopening once the stock reaches predetermined levels (at least to those levels consistent with BMSY – MRAG, 2017).



Survey population (blue bars) and logbook CPUE (red diamonds) data for Black teatfish from 2004 to 2022.

Other species

Due to identification issues, *Actinopyga miliaris*, *A. palauensis* and *A. echinites* are combined as "Spork"; and *Bohadschia vitiensis*, *B. atra* and *B. subrubra* are combined as "Lakol". Spork and Lakol species groups both showed decreases in density in 2021-22 compared to 2004, though only for Lakol was this decline statistically significant ($P<0.05$). Species that make up the Lakol group are known to burrow during the daylight hours and therefore are prone to under-counting.

Elephant trunkfish was at similar densities in 2021-22 to 2004. This is a large, easily identifiable species that has not been significantly targeted in the Seychelles sea cucumber fishery (due to its low value), therefore this result provides some validation to the accuracy of the survey comparisons for other species.

The highly abundant species, Lollyfish, was seen at lower densities in 2021-22 (-62%), however, Pinkfish were recorded at much higher densities in 2021-22 (+600%) – this result could be due to misidentification of Lollyfish as Pinkfish. However, there has been some targeting of Lollyfish by the Seychelles fishery in the past, therefore this could also indicate some depletion of this species.

Red/yellow surffish (*Actinopyga mauritiana* complex) showed a large increase in density (+300%) between 2004 and 2021-22, much of this on the Amirantes shallow reefs.

Flowerfish showed a large increase in density, largely due to an increase in shallow non-reef areas of the Mahe Plateau – this would be unusual for the reef obligate species such as this and it could be that some of these were misidentified as actually being Bohadschia species in the Lakol group.

Curryfish were lower overall, though the decrease was not statistically significant for this patchy species. Greenfish and Amberfish were found in low densities in 2021-22, similarly to 2004.

The overall sea cucumber population estimate in 2021-22 of 77.7M was about 30% lower that the estimate in 2004 of 115.4M ($P<0.05$).

There has been no exploitation of these species since 2017, and only red/yellow surf had previous sustainability concerns. Several of these species could be candidates for reintroduction to fishing quotas. However, before this occurs, there would likely be the need for additional targeted research and/or a controlled reopening with a small quota and additional catch reporting (e.g. high resolution catch location and effort data, and animal size etc). This information could then be used on a continuing basis to assess the sustainability of the catch for these reopened species.

Conclusions

The Seychelles sea cucumber fishery is at an important crossroads. It has fished down its natural capital and now finds itself sliding into fishery “dept”. It is fortunate that some species appear to be somewhat resilient to heavy fishing pressure; however, even some of those are now showing signs of over-exploitation (e.g. Pentard). This has been driven by the short-term economic imperative to maximise the catch and profits, an approach that is almost guaranteed to deprive future generations of economic opportunities that a healthy fishery would provide.

The reputation of the Seychelles sea cucumber fishery is at stake. There is increasing scrutiny on sea cucumber fisheries globally (e.g. through CITES listing), mostly in response to global overexploitation and stock collapses. If the Seychelles sea cucumber fishery can act and demonstrate sustainable fishing practices, then access to global markets will remain open, and possibly at a premium given the Seychelles growing reputation for environmental stewardship.

Recommendations

1. Cease fishing immediately on White teatfish and monitor again in 3 years.
2. Reduce the quota for Pentard by 10% and urgently implement targeted stock assessment using the recent survey and logbook data to establish stock status in relation to B_{MSY} and sustainable levels of fishing mortality F_{MSY}.
3. Carry out additional stock modelling on Prickly redfish, using the recent survey and fishery logbook data to investigate a possible increase in fishing pressure for this species.
4. Continue to monitor the recovery of Black teatfish.
5. Investigate the potential reintroduction of small experimental quotas (with TACs at <2% of population estimates) for underexploited or recovered species (e.g. red/yellow surffish) with additional catch reporting requirements.
6. Formulate and apply standardised species names for the fishery; and produce a comprehensive fishery species ID guide.
7. Implement a multispecies fishery harvest strategy for the Seychelles sea cucumber fishery which would include the following components:
    i. A shared vision and objectives (stock, environmental, economic, social and occupational) for the fishery for all fishery stakeholders
    ii. Indicators (how will the fishery performance be measured?)
    iii. Reference levels (what are the target and limit points for the indicators?)
    iv. Harvest Control Rules (what are the agreed actions that will be taken if a reference level is reached?)
8. Implement a comprehensive and representative system of closed areas in deeper non-reef areas throughout the fishery area (target 30% of each fishery area).
9. Investigate the utility of a rotational harvest scheme to reduce risk.
10. Investigate potential for stock enhancement approaches (reseeding, broodstock aggregation etc).

1 Background

The modern Seychelles fishery began in the late 1980's when there was a rapid increase in catch (Aumeeruddy and Conand, 2008). Historically targeted species were: Black teatfish (*Holothuria nobilis*); White teatfish (*H. fuscogilva*); Sandfish (*H. scabra*); Prickly redfish (*Thelenota ananas*); Pentard (*H.* sp. type "Pentard"), also called Flower teatfish; and Surf redfish (*Actinopyga mauritiana* complex), also called Red surffish, Yellow surf and White belly (Aumeeruddy and Payet, 2004; MRAG, 2017; SFA unpublished data). (For a full list of commercial species in the fishery, see Table 5).

Although catch records before the year 2000 are incomplete, available data indicates that the sea cucumber fishery recorded its highest catch in 2012-13 (Figure 1). The bulk of the catch since 2007-08 has been of Pentard, reaching its peak in 2012-13 with a total of 377,000 pieces. After 2012-13, there was a decline in the catch to 2018-19, with a rebound in 2019-20, and reduction thereafter (Figure 1).

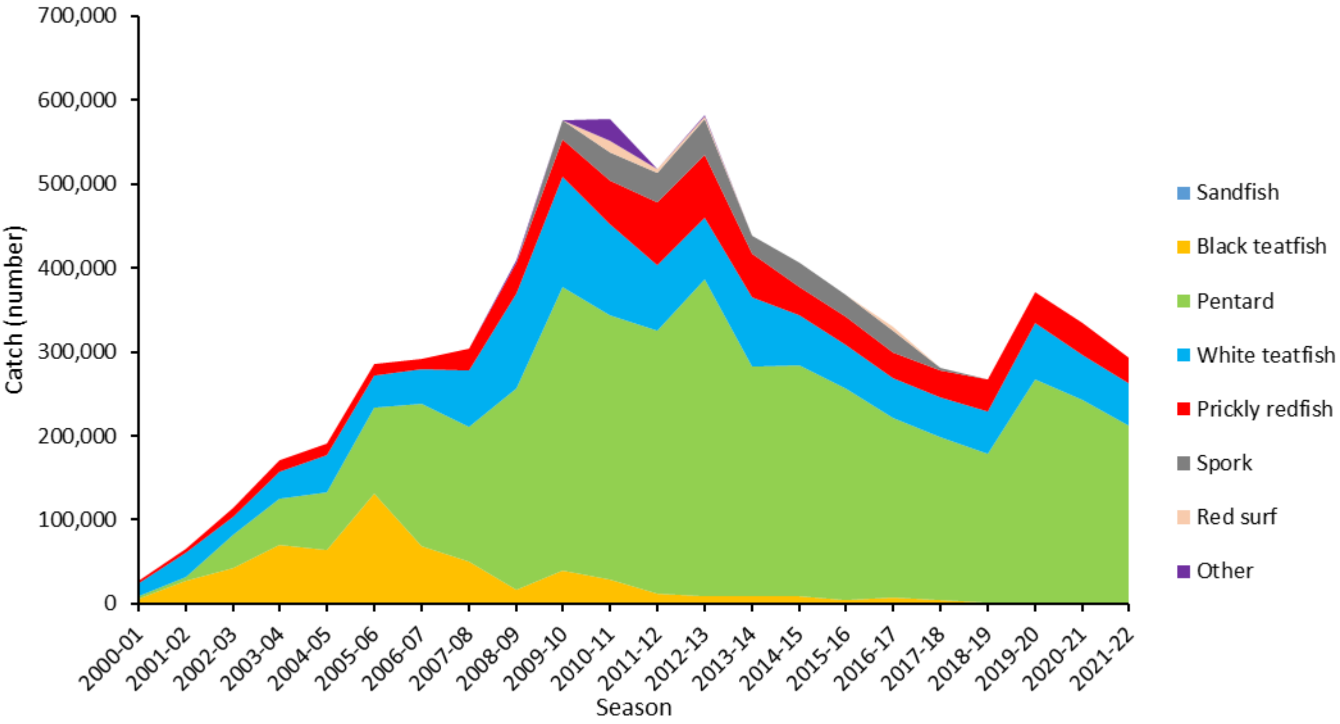


Figure 1. Catch data for the period 2000-2022 (SFA logbook data 2000-01 to 2008-09, landings data 2009-10 to 2021-22) (For species names of fishery species, see Table 11).

Spatial patterns in fishing intensity can be gathered from logbook data (Figure 2), although the grids are to large to be useful for spatial management and there is some evidence of fishing zone misreporting (MRAG, 2017). VMS data can also provide some finer scale fishing intensity maps (Figure 3, Figure 4), but there are also some limitations using this data for stock assessment – such as the fact that fishing catch is not included with the VMS locations.

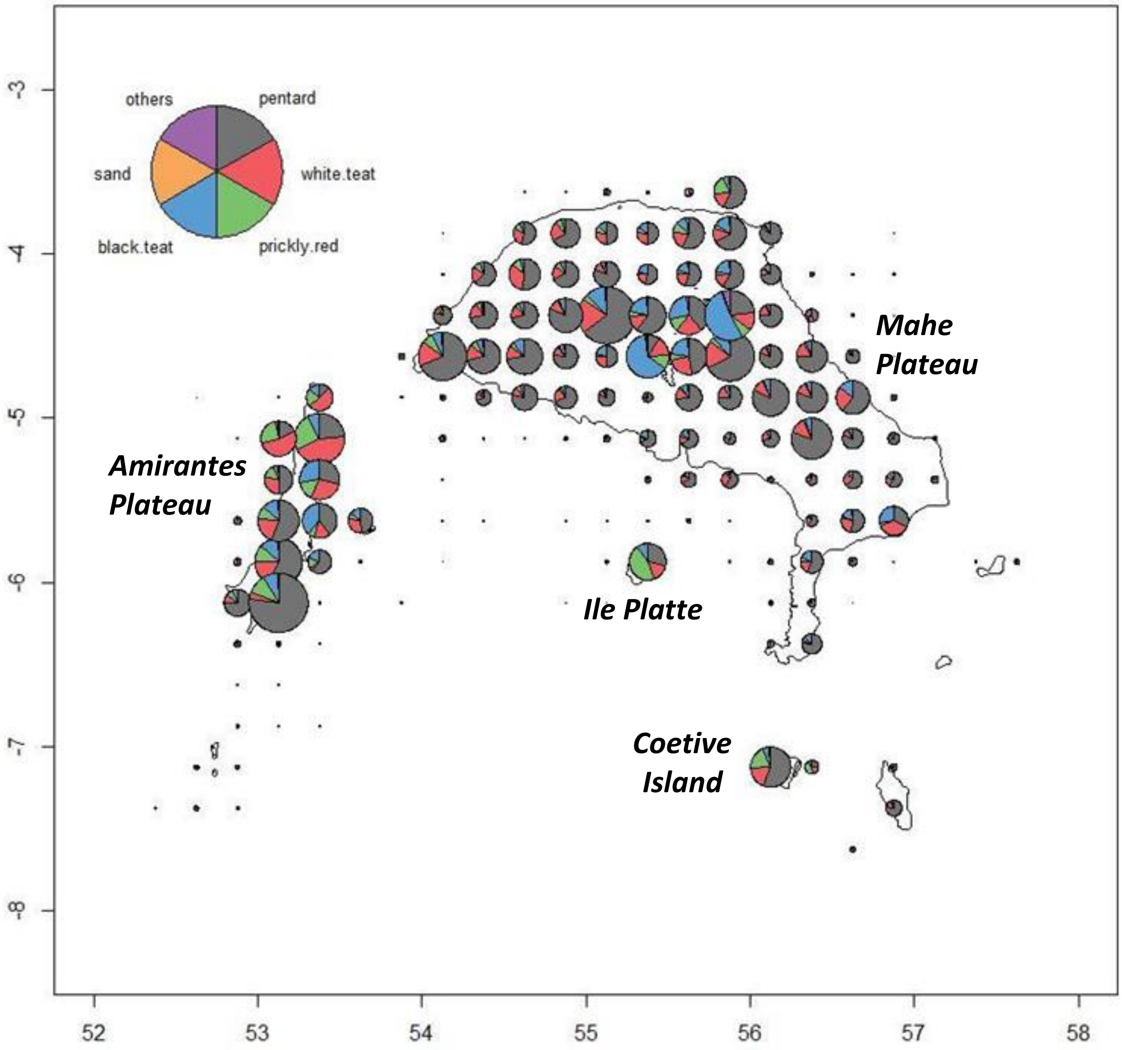


Figure 2. Species composition of total catches between 2001 and 2016 by grid with catch graduated pie charts. The 200m contour is shown as a solid black line. (MRAG, 2017)

In any case, this spatial data show that fishing is concentrated in a central Mahe Plateau and its western banks and shoals (Owen Bank, Seagull shoals). Almost the entirety of the Amirantes Plateau, apart from some constrained deeper areas in the south-west, is also heavily targeted, as are the small reefs of Ile Platte and Coetive Island (Figure 2, Figure 3, Figure 4).

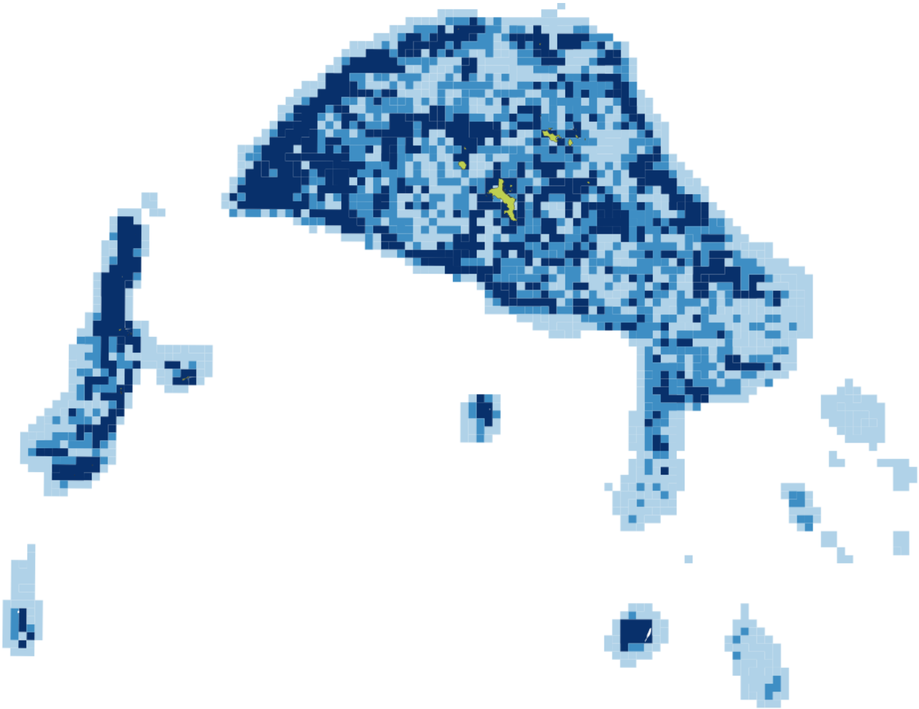


Figure 3. Fishing intensity (Light (<2 boat hrs), Moderate (2-7 boat hors), and Intense (>7 boat-hrs)) as cumulative daytime VMS tracks below 1 knots from 2004 to 2011 (Koike, 2017)

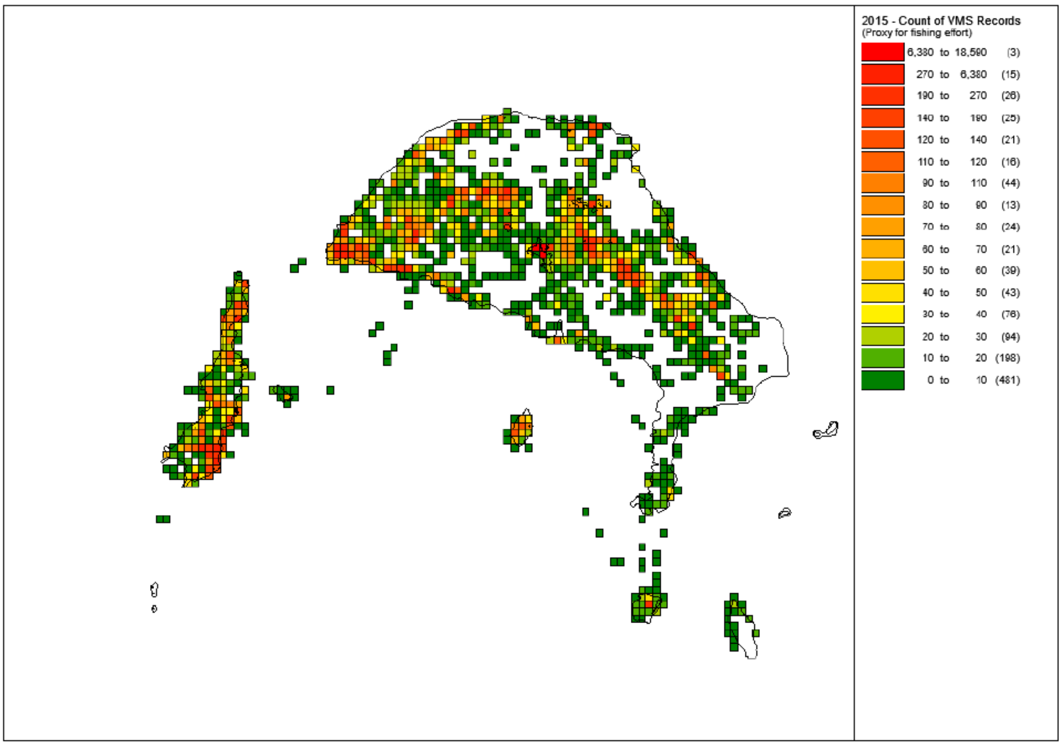


Figure 4. Fishery VMS data for 2015 (MRAG, 2017)

1.1 Management

In 1999, in response to declining catch rates and a lack of baseline information on the status of the stock, the Seychelles Fishing Authority (SFA) introduced management measures for the fishery, including issuing a limited number of non-transferable fishing licenses (25), and limiting the number of divers per license (4), and mandating logbook and receipt books that had to be submitted to the SFA on a monthly basis (Aumeeruddy and Payet, 2002).

A closed season for the months of July to September was introduced in 2008.

Further measures were introduced in 2018, including species TACs and quota allocations (Table 1). Fishers could only target three species of sea cucumber: Pentard (Flower teatfish), White teatfish and Prickly redfish. In 2021, the TAC was reviewed and the overall quota for Pentard was reduced by 10% for the 2021-22 season.

Table 1. Quota per species for the Seychelles sea cucumber fishery for 2021-22 season.

(Number)	Pentard (Flower teat)	White teat	Prickly red	Total
Total Quota	253,125	56,250	37,500	375,000
Quota per vessel	11250	2250	1500	

1.2 Previous stock assessments

The first full-scale stock survey was carried out in 2004 (Aumeeruddy et al., 2005) and included a survey of sea cucumber density at 246 sites throughout the Amirantes and Mahé Plateau. The survey produced stock estimates for 24 commercial (or potentially commercial) species.

The assessment indicated that Sandfish and Surf redfish were overexploited, and White teatfish and Pentard were fully exploited. Recommendations for management included total allowable catch (TAC) for all target species, controls in fishing effort for high value species close to the main islands, minimum size limits and the implementation of continuous periodic surveys (Aumeeruddy et al., 2005). The project also recommended that a comprehensive species identification guide be produced to improve fishery data accuracy. None of the recommendations were subsequently implemented.

A second stock survey of a restricted area of the Mahe Plateau was carried out from 2011 - 2013 (Koike, 2017). It found that the abundance of Lollyfish (*Holothuria atra*) and Black teatfish declined significantly compared to the 2004 survey. However, Blackfish (*Actinopyga miliaris*) had increased. It also did some spatial fishery modelling of White teatfish which indicated that there had been very little recruitment of that species between 2002 to 2011.

The next stock assessment was carried out in 2012 (MRAG, 2012) and 2017 (MRAG, 2017) based on fishery dependant (logbook) data from 2002 to 2016. It was based on a spatially disaggregated standardized catch per unit effort (CPUE) time series, and surplus production models to estimate biomass and maximum sustainable yield. Evidence of significant population decline was observed for White teatfish and Black teatfish, especially in high effort areas, though Pentard appeared to be relatively stable. Prickly redfish had on average a low CPUE, but highly variable between operations, and showing no real trend. This would appear to indicate that Prickly redfish were more opportunistically taken than Black teatfish, White teatfish and Pentard. Sandfish had a very low CPUE from the beginning of the dataset in 2000 – sandfish were probably fished out before then.

They also found that the average depth of fishing operations had increased at about 2013, from around 15 m to 30 m. Most of their attempt to carry out species level population modelling was unsuccessful due to data uncertainty and limited temporal span. They were able to use the catch data to model the population of Black teatfish for the Amirantes only and this showed a steep decline in the population, however, with some estimates of recovery trajectories under a no fishing scenario. Another significant finding was that the logbook and VMS data only matched about half the time – highlighting the need for better logbook position recording. (as well as species and effort data). They also noted that logbook species identification was uncertain for some species.

Based on the outputs of these studies, in 2018 further measures were introduced including reduction in fishing season from 9 months to 8 months, species TACs and quota allocations (Table 1). Fishers could only target three species of sea cucumber: Pentard (Flower teatfish), White teatfish and Prickly redfish.

The 2017 fishery assessment also recommended a new fishery independent survey to increase the confidence in stock status. Considering that the last comprehensive sea cucumber resource survey was in 2005, SFA recognized the need to carry out a new assessment to obtain a better understanding of the current status of the stock.

1.3 Project objectives

The 2020/21 survey was focused on all commercial sea cucumbers and their habitats on the Mahé and Amirantes Plateaus. The survey consisted of underwater visual census carried out by scientific and commercial divers in shallow areas(<20m) and a remotely operated vehicle (ROV) in deeper areas.

The results from the fishery independent survey will be used to inform the next steps in the development of new management measures for the fishery. This will include reviewing the TAC for exploited species in use which is currently based on the 2017 stock assessment so that it reflects the current status of the stock.

The objectives of the project were:

1. To conduct a fisheries independent survey to assess the abundance of all sea cucumber resources,
2. To provide information on the stock status of the main commercial species,
3. To collect biological and ecological information on sea cucumber species,
4. To understand the effect of exploitation on sea cucumber population and distribution,
5. Provide management advice to guide the future management of the sea cucumber fishery.

The primary focus species (stock size and trends) were:

- White teatfish
- Pentard (Flower teatfish)
- Prickly redfish

Secondary focus species were:

- Black teatfish (trends - recovery)

- Sandfish (trends - recovery)
- Other commercial species (trends)
- Other species (trends)

1.3.1 Study outputs

- Stock size estimates
    - The survey will produce population estimates of the three primary species, as well as other secondary species encountered in the surveyed habitats.
    - Expected survey precision was 60% CI < +/- 25%. This will allow the application of a sufficient precaution by using the lower 80th percentile of the population estimate for setting TACs.
    - The target precision will be dependent on surveying at least 200 sites.
- Stock trends
    - Trends in species density over time (i.e. comparison to 2004 and 2011 survey density) to provide an indication of the effect of exploitation on the target sea cucumber stocks.
    - Trends in annual average logbook CPUE data.

2 Methods

2.1 Sample design

It was recommended that the 2021-22 survey be based on a repeated measures design, using sites from the 2004 survey. The benefits of this approach were:

- Prior field knowledge: information about the depth and substratum assists with sampling safety and efficiency.
- More statistical power: repeated measures designs are usually more powerful than random designs for detecting change, particularly over time from multiple sampling occasions, because they control for factors that cause variability between new sites.
- Fewer sites: due to the greater statistical power, a repeated measures design can use fewer sites to detect a desired effect size.
- Further sample size reductions are even possible in future monitoring because each site is involved with multiple surveys.
- Lower probability of site loss: as sites characteristics are largely known, the potential for site loss due to depth or other issues is greatly reduced.
- More efficient logistics: sampling approaches (e.g., ability to utilise divers) can be largely predetermined from previous site sampling data

Potential disadvantages are:

- Order effects: if repeated sampling affects the site in any way, then this can bias outputs (e.g., if sea cucumbers are removed during sampling and this impact the subsequent survey). This is unlikely to be a problem in this case as the previous sampling was in 2004 (and potentially 2011) and sea cucumbers will, in most cases, be returned to the same general area as the sample site. GPS accuracy – even with high accuracy it is unlikely that the same area will be resampled. For diving, wind and sea conditions will affect the direction of the current and for drift-video-recording these effects can be even more pronounced.
- Spatial scale of habitat heterogeneity can also affect repeated sampling. If changes in habitat occur at a spatial scale less than the length of the transect this can affect how repeated samples match up in terms of habitat. Note, fishing of survey sites does NOT bias the outputs – this effect is incorporated as part of the overall fishery density change.
- Detecting changes in species distribution: changes in the distribution of surveyed populations can result in repeated measures trends being biased downwards, if site selection is based on density to any extent. This is unlikely when population density and habitat are correlated, and habitat is correlated with depth (i.e., depth will not change markedly over time). Regardless, this bias can be addressed by including “exploratory” sites during monitoring surveys.

2.1.1 Fishery area stratification

Depth is an important factor in determining the distribution and abundance of holothurians and for imposing constraints on sampling, especially diving. The data from the 2004 survey shows that sea cucumbers generally have higher densities in shallow waters, and have a low density below about

50 m (Figure 5). As for the three target species, they are generally found in all habitats down to about 50 m (Figure 6) (though there are very low densities in the 55-60 m range). This accords with the information for these species globally (Purcell et al., 2012).

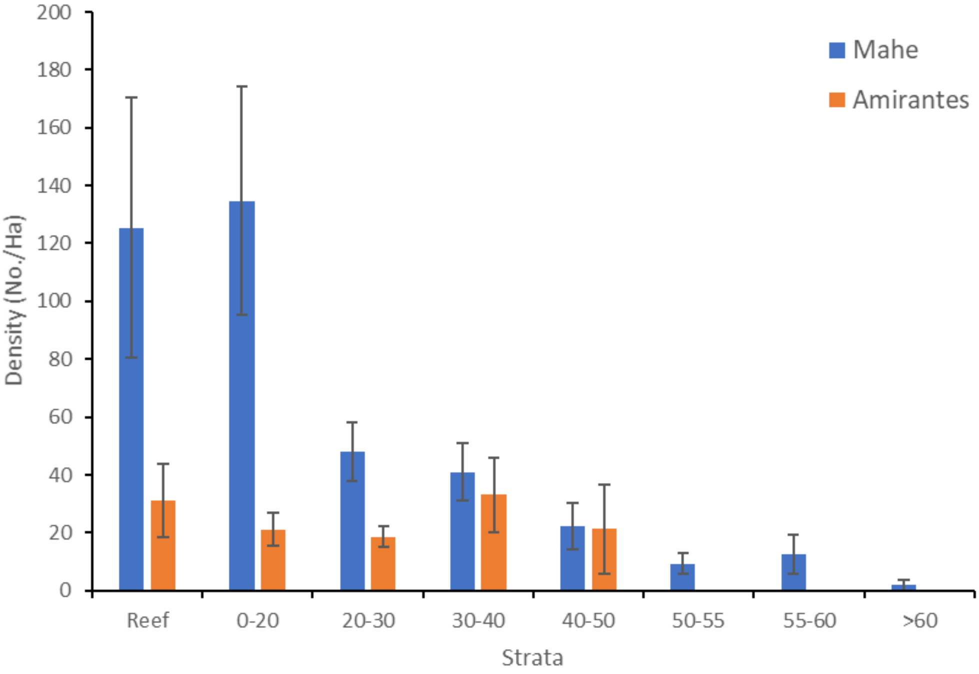


Figure 5. Depth-density relationships – all commercial species.

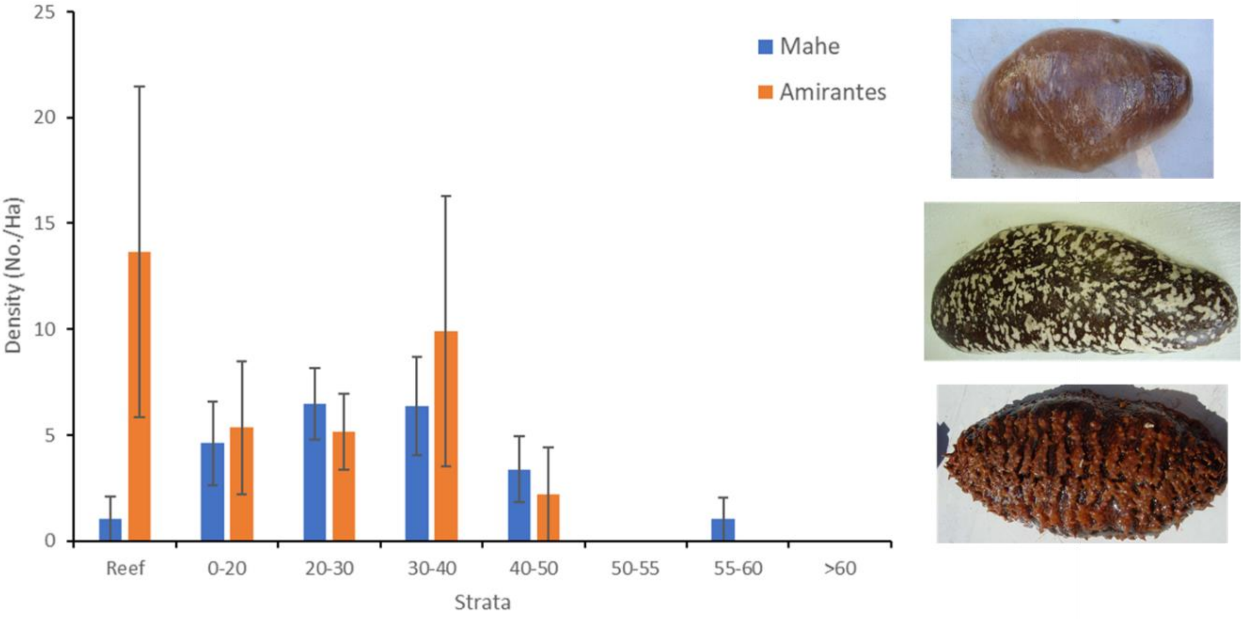


Figure 6. Depth-density relationships – fishery target species.

Bathymetry used to stratify the fishery habitats in 2004 included some available bathymetry and digited charts (Aumeeruddy et al., 2004). This proved to be a poor match to the final survey depth classes and, while this did not bias the resulting outputs due to the random placement of sites within strata, it did not provide the higher accuracy stratified variance benefits that accurate habitat classification could. We therefore investigated other sources of information to re-stratify the Seychelles fishery habitats, particularly for the Mahe Plateau.

Bathymetry for Seychelles is publicly available as GEBCO 2021 and Global Multi-Resolution Topography Data Synthesis (GMRT) (Appendix B). The GEBCO 2021 has obvious artifacts that are visually apparent in a deep-water section in the north-east of Mahe plateau. This artifact has been somewhat addressed in the GMRT. To further explore the relationship between field depth data and publicly available data, an analysis was done regressing field depth data against GMRT and GEBCO 2021 data layers (Appendix B). This showed, however, that all bathymetry mapping available is not very accurate.

We also had a series of ship track data from the 2004 survey that we considered suitable for classifying the plateau areas of Mahe and Amirantes (Appendix C). In addition, the latest global reef mapping, the Alan Coral Atlas (Allen Coral Atlas, 2020), matched the previous survey sites and satellite data precisely. We therefore stratified the study area into a new stratification schema: Reef (emergent or near emergent coral reefs including reef edges down to approx. 20 m deep); and 3 “plateau” strata: 0-30 m; 30-60 m; and >60 m. The strata area for the three “plateau” strata was estimated using recorded bathymetry tracking information gathered during the 2004/05 survey (Table 2).

Table 2. Strata (depth and plateau based) statistics for 2004 sample sites.

Strata name	Area (ha)	% of fishery area	Hol density (No./Ha)	% of pop	Fishery species density (No./Ha)	% of pop	2004 Sites (%)
Amirantes reef	11,639	0.2	32.7	0.3	5.00	0.9	8.0
Amirantes 0-30m non-reef	148,065	3.1	13.6	1.8	1.32	2.6	8.4
Amirantes 30-60m	286,712	5.9	26.6	6.9	3.95	13.8	5.6
Mahe reef	10,184	0.2	138.9	1.3	4.69	0.3	13.2
Mahe 0-30m non-reef	476,815	9.8	39.5	17.0	6.16	14.7	24.8
Mahe 30-60m	3,194,050	65.8	24.0	69.2	2.41	67.6	34.4
Mahe >60m	710,935	14.7	5.3	3.4	0.00	0.0	5.6
All	**4,838,398**	**100**	**23.85**	**100**	**2.49**	**100**	**100**

2.1.2 Site selection

We then reassigned the 2004 survey sites based this new stratification schema, based on their spatial alignment to the reef strata and depth. Note that the original site stratification from 2004 included several sites that were classified as plateau 0-30 m strata that were actually shallow-reef sites. These have been corrected by reassignment in the new strata schema. When we reanalysed the 2004 data based on the new stratification, we found that there was a significant improvement in the precision of the biomass estimates. It also resulted in an increase in the average density and stock estimate due to the increase in the area of 30-60 m habitat, which is a primary fishery habitat, and was a known shortcoming of the previous stratification scheme.

We selected 200 priority sites from the existing site list, that will be surveyed in November 2021 and March 2022, i.e., 100 sites per field trip. We also included some additional sites in areas that have not been surveyed in the past, such as the area north of Mahe, and in response to the guidance from the optimal allocation process. Sample sites >60 m deep were included for continued assurance that the deep stratum does not contain significant quantities of commercial sea cucumbers.

We also optimally allocated sites to the new strata, and then compared the confidence intervals to the actual sites placement – this was to test the “inefficiency” of using the repeated sites rather than reallocated new sites. We found that there was not a significant increase in confidence intervals that would outweigh the benefit of using repeated sites as noted above (Table 3). Additional sites were added haphazardly within the designated sample area. However, it is not certain that the selected site locations will be consistent with the strata designations (i.e. sites designated as plateau 30-60m may be shallower). In this case, the suggested protocol was to travel to the site location, and if the depth is not consistent with the site designation, then travel in a straight line towards the next site until the depth is consistent with the site designation, and sample the site.

A full list of sample sites is included in Appendix D .

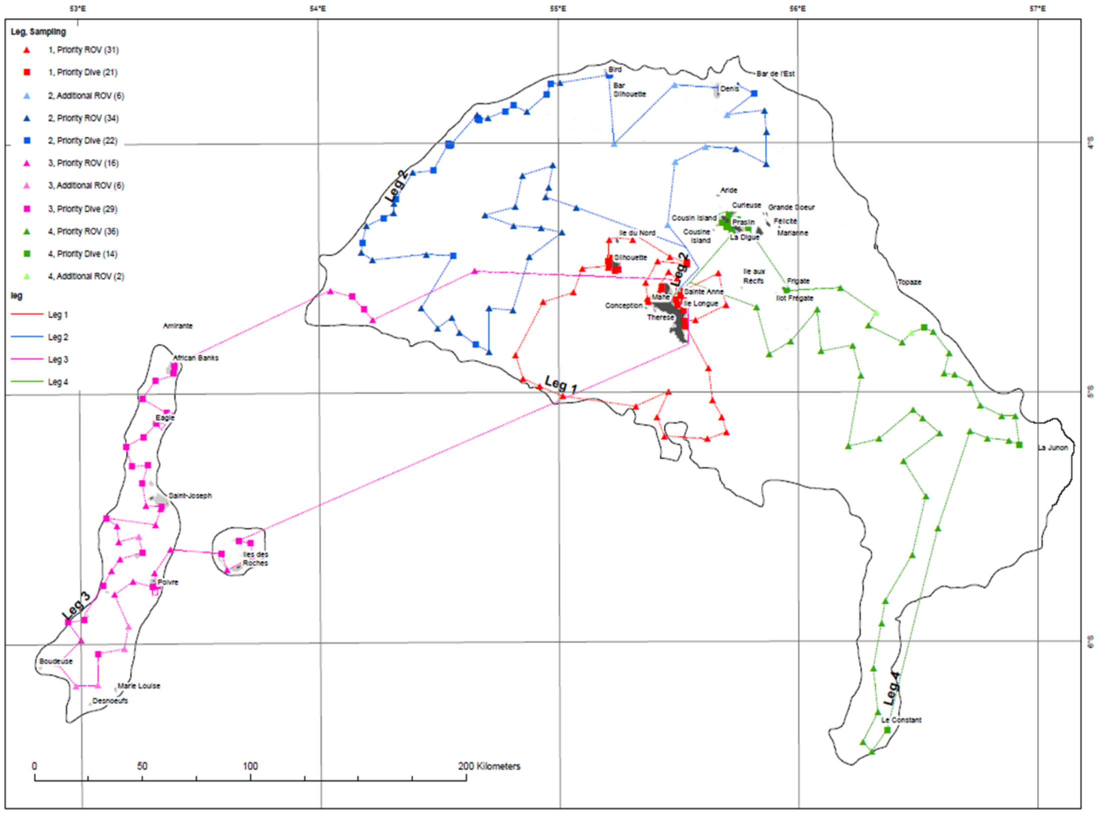


Figure 7. Sample design for 2021-22 survey.

Table 3. Number of sites to be sampled in 2021-22

Strata name	Opt. All spp.	Opt fishery spp.	2004 sites	2021-22 resample	2021-22 addition	2021-22 total
Amirantes reef	0	1	20	10	0	10
Amirantes 0-30m non-reef	2	4	21	15	0	15
Amirantes 30-60m	10	21	14	14	6	20
Mahe reef	2	1	33	15	0	15
Mahe 0-30m non-reef	32	39	62	50	0	50
Mahe 30-60m	159	152	86	86	10	96
Mahe >60m	10	0	14	10	0	10
TOTAL	216	216	250	200	16	216
Predicted precision (80% CI)	9.16	16.68	-	-	-	11.44/19.37

2.2 Survey timing and duration

It was recommended that the survey timing be based on logistical, safety (e.g., weather) and personnel issues, not based on aligning with fishery opening. As for survey length, it was recommended that the proposed 4-week cruises be split into at least four legs, with a short furlough in home port between legs (Appendix A).

2.3 Industry involvement

Industry involvement in surveys was considered desirable for several reasons:

- Access to trained divers
- Higher degree of industry acceptance of survey results
- Transfer of knowledge on sea cucumber biology and distribution

However, it also has some risk and issues:

- Involvement of non-scientific observers will require specific training and calibration procedures to avoid survey bias
- Training, health and safety issues
- Chain of command issues

It was recommended that industry divers data be paired with scientific divers on transects, for later validation and potential adjustment.

2.4 Cruise logistics and path analysis

The survey was carried out over two surveys, each with two legs. Approximately 50 sites per leg were sampled, as a mix of dives and video. As previously mentioned, each leg began and ended at Mahe Island.

Site positions and proposed ships track were provided. Ships tracks were not prescriptive, it was strongly recommended that they were followed unless there are compelling reasons to do otherwise.

2.5 Field sampling

Field approaches were similar to previous surveys. For a full description of the field sampling approach, refer to Appendix H .

2.6 Data entry and storage files

The suggested data entry and storage approach was based on a MS Excel data entry and validation workbook linked to an MS Access database. This is because Access, while good for securely storing and summarising data using SQL is difficult to enter data into, and Excel, while excellent for data entry and validation, is vulnerable to formula corruption. Also, most scientist are familiar with Excel.

This setup will also allow almost real time data checking and problem solving by the consultant and potentially other SFA staff back on Mahe – depending on being able to link to the internet if only periodically to upload synced files. This would entail nothing to be done by field staff other than to maintain the folder integrity on the vessel computer. Once the field program is complete, the data files can be uploaded to SFA servers for safe storage.

Another advantage of linked data workflow is there will only ever be a single master data. Changes and edits are made to the master and the effects are propagated throughout the entire data workflow system.

For this project, we will implement data entry, analysis, spatial visualization and storage using the following data model:

- MS Excel for data entry and verification
- MS Access for data storage as tables and queries suitable for export as flat tables for analysis and reporting using Excel and other statistical packages
- ArcGIS/QGIS for survey design, routeing, spatial analysis, and visualization

2.7 Data analyses

The following analysis were carried out.

1. Density estimates
    a. Stratified approach
    b. Repeated sites only
    c. Paired t test to test for statistical difference between two surveys.
2. Population estimates
    a. Stratified approach
    b. All data
    c. Report 60% CI (such that we are 80% certain that the true estimate is lower than the upper CI)

3. Comparison of scientific and commercial divers.
    a. Paired average density comparisons
    b. Paired t test

2.7.1 Density

Density (number per hectare) of sea cucumber species for each site were calculated by dividing the species count by transect area. The whole of fishery average density was then calculated using a stratified analysis approach that takes into account the heterogeneity of variance between fishery habitats their total area within in the fishery area (Cochran, 1977). This is a common and well proven approach that has been used for many fisheries population studies over the past 30 years or more, including for sea cucumbers in Torres Strait (Long et al., 1995, Skewes et al., 2002), the Australian Coral Sea fishery (Skewes and Perrson, 2017), the Cook Islands (Drumm, 2005), PNG (Skewes et al.,2002) and the Seychelles (Aumeeruddy et al., 2004).

Detail of the analytical approach is contained in Appendix J Stratified analysis approach.

Only those repeated sites that were sampled in 2004 and 2021-22 were used in the calculation of density.

2.7.2 Stock size

Estimates of standing stock were calculated as the product of estimates of density and stratum area. For stock size, we report the 60% Confidence Interval (60% CI), such that we can report the lower 20th and upper 80th percentile. This is an approach to risk and certainty that takes into account i) the highly variable nature of the survey counts, ii) the level of risk suitable for a small-scale commercial fishery of this nature.

Note that all data available for each survey was used in the calculation of stratified stock size estimates.

2.7.3 Repeated measures paired comparisons

For comparison between sample years, and between commercial and scientific divers, we used a repeated measures analysis approach where the difference in density was calculated at the site level first for all repeated sites. This increases the precision and reduces potential bias between comparisons due to habitat and other considerations. Statistical significance of differences can then be carried out by examining confidence intervals ($1-\alpha$) of the paired differences for each parameter – particularly their zero coverage - to assessed whether significant changes in density had occurred between years and diver types (with test size α). This type of test is preferable to standard parametric tests due to the zero-inflation of counts and the skew and nonconformity of the distribution of observed densities.

In this case, the principals of stratified design were extended to difference test be weighting the differences from sites within each stratum by the stratum weight.

3 Survey report

The 2021-22 survey was carried out over two four weeks cruises, with each cruise divided into two legs beginning and ending at Mahe Island. The 1st and 2nd legs were carried out between the 3rd to 30th November 2021, and the 3rd and 4th legs between 1st to 29th March 2022. The primary vessel was the R/V L'Amitie, with commercial vessel F/V Etelis participating in legs 1 and 2, and F/V Escapade in legs 3 and 4.

The survey team visited 206 sites (Figure 8) with 14 sites abandoned due to poor visibility and/or high currents – resulting in 192 survey sites completed (Table 4). Of the 200 priority sites in the sample design, the team collected data from 182 sites (repeated sites from 2004), an outstanding achievement given the scope of work.

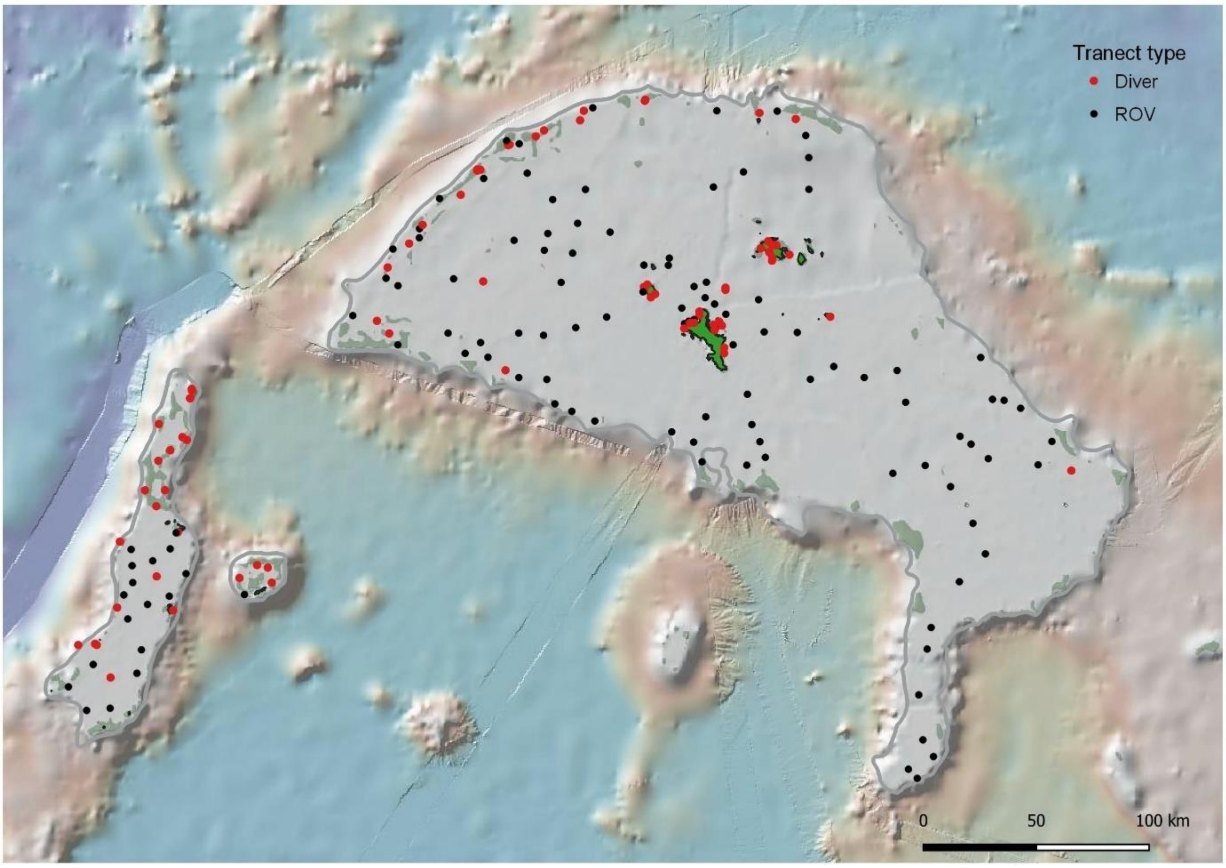


Figure 8. Sites sampled in 2021-22 survey, by transect type.

Table 4. Site counts for 2021-22 survey.

Strata	Reef (0-20 m)	Shallow non-reef (0-30 m)	Intermediate (30-60 m)	Deep (>60 m)	All
Amirantes	10	14	19		43
Mahe	26	32	87	4	149
All	36	46	106	4	192

3.1 Data Validation

The survey data was entered into the dedicated survey database, and included the same fields as the 2004 survey data. Extensive data validation was carried out to correct and validate the data, including a comparison of data sheets, database, size frequency datasheets and size frequency database. A full list of data validation issues and rectifications are contained in Appendix I .

Although there is a high degree of certainty regarding the identification of the high priority species, (Pentard, White teatfish, Prickly redfish and Black teatfish), some lower value species are difficult to distinguish as the common names used during the survey refer to species groups (Table 5; Skewes and Aumeeruddy, 2006), and therefore some results will be combined (see Results).

Table 5. Species observed during surveys in 2004 and 2021-22.

Scientific Name	Common Name	Local name
Holothuria nobilis	Black teatfish	Kokosye Nwanr
Holothuria fuscogilva	White teatfish	Kokosye Blan
Holothuria sp. (type "Pentard")	Pentard, Flower teatfish	Pentard
Holothuria fuscopunctata	Elephant trunkfish	Safran
Holothuria atra	Lollyfish	Spork, Spork koray, Disan
Holothuria edulis	Pink Fish	
Holothuria scabra	Sandfish	Kokonm
Holothuria lessoni	Golden sandfish	Kokonm
Actinopyga mauritiana	Surf redfish, Yellow surf	Brisan
Actinopyga miliaris	Hairy blackfish	Spork
Actinopyga echinites	Deepwater redfish	Spork
Actinopyga palauensis	Deepwater blackfish	Spork
Bohadschia vitiensis	Brown sandfish	Lakol
Bohadschia atra	Tiger fish	Lakol
Bohadschia subrubra	Bohadschia white belly	Lakol
Pearsonothuria graeffei	Flowerfish	
Thelenota ananas	Prickly redfish	Sanpye
Thelenota anax	Amberfish	
Stichopus herrmanni	Curryfish	
Stichopus chloronotus	Greenfish	

3.2 Comparing diver types

The 2021-22 survey was unique in that scientific and commercial divers carried out the dive transects as a pair, each sampling one side of a fixed transect line. The average density of all sea cucumbers and current fishery species (White teatfish, Pentard and Prickly redfish) for both diver types were very similar, and were not statistically significantly different ($P>0.05$) between the two diver types (Table 6, Figure 9).

This result provides confidence that there is unlikely to be any sample bias associated with the scientific divers. Overall, it was a useful approach to include commercial divers in the survey, particularly for the learning and extension opportunities for both sides.

Table 6. Sea cucumber density statistics for commercial and scientific divers on paired transects during the 2021-22 survey (n=79).

Diver type	All species	Current fishery species
Commercial (s.e.)	62.66 (12.27)	10.76 (2.80)
Scientific (s.e.)	71.52 (17.53)	8.23 (2.62)

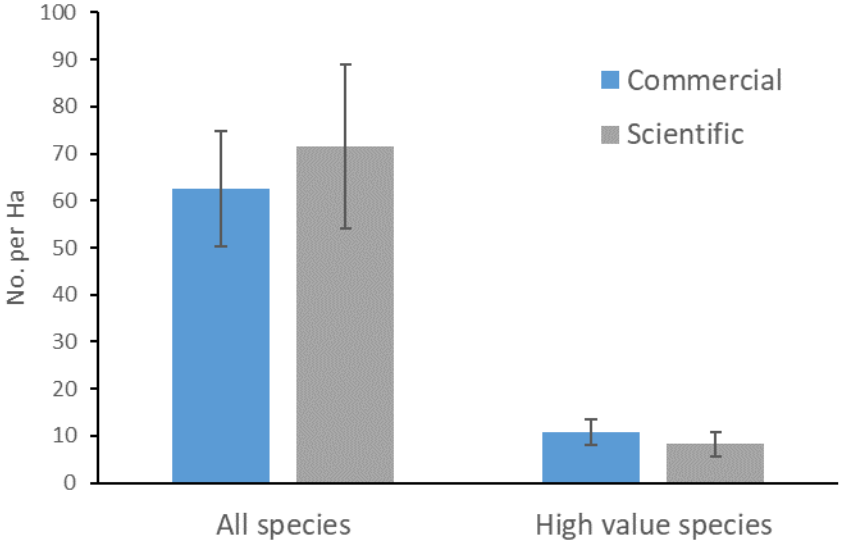


Figure 9. Sea cucumber density for commercial and scientific divers on paired transects during the 2021-22 survey for all species and high value species (error bars are 1 s.e.) (n=79).

4 Results

4.1 White teatfish (*Holothuria fuscogilva*)

4.1.1 Density

Overall density of White teatfish at repeated sites declined by 91.3% between 2004 and 2021-22 (Figure 10), a statistically significant decline (P<0.05, Figure 36). The greatest decline was for the Mahe Plateau; there was a small increase on the Amirantes plateau, but from a very low estimate in 2004.

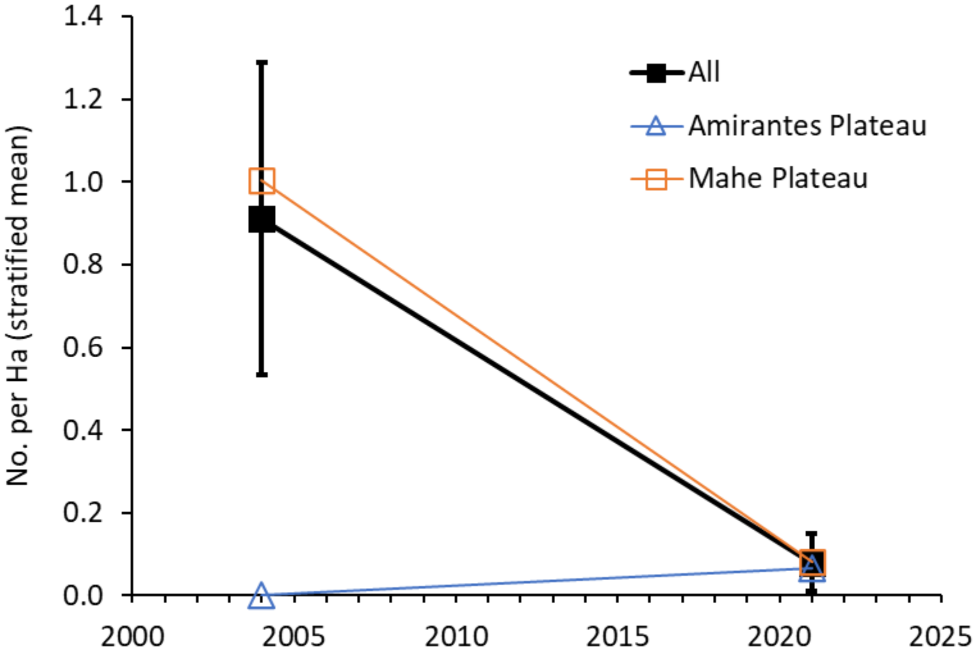


Figure 10. Overall and plateau average (stratified) density (No. per Ha) for White teatfish (*H. fuscogilva*) at repeated sites in 2004 and 2021-22 (error bars = 1 s.e.) (n=182).

The shallow reef habitats on both the Mahe and Amirantes Plateaus had the highest densities of White teatfish - however, they were still depauperate at only ~2 per ha, and being relatively small in area, did not hold large numbers of White teatfish (14% of the Seychelles population combined) (Table 7). Densities in all other strata were very low in the 2021-22 survey. White teatfish have never been observed at any site in the very deep (>60m) strata. This mirrors the results of other deep habitat surveys in Australia (Murphy et al., 2021) and globally (Purcell et al., 2012) where White teatfish are rarely found deeper than 50m.

4.1.2 Stock estimate

The population estimate for White teatfish in 2021-22 was 378,378 (± 73.7%, 60% CI) (Table 7, Figure 11). The bulk of the population was found in the Mahe 30-60m strata (87%). The stock estimate mirrored the decline in the density data, with the 2021-22 mean stock estimate only 8.3% of the 2004 mean stock estimate. Even taking the upper 60% CI (so that we are 80% certain it is less than that) the 2021-22 estimate was only 14.6% of the 2004 mean stock estimate.

Table 7. Stock estimate for White teatfish (*H. fuscogilva*) in 2004 and 2021-22. For each stratum and year surveyed, the density (No. per Ha) and population stock estimate in numbers and the 60% CI (as a % of the population estimate) (n=192).

Strata	Density (No. per Ha) 2004	Number 2004	60% CI (%)	Density (No. per Ha) 2021	Number 2021	60% CI (%)
Mahe reef	1.69	17,238	63.8	1.92	19,584	59.3
Mahe 0-30m non-reef	2.45	1,166,123	44.0	0.00	0	0.0
Mahe 30-60m	1.03	3,288,423	40.2	0.10	325,951	84.6
Mahe >60m	0.00	0	0.0	0.00	0	0.0
Amirantes reef	0.00	0	0.0	2.50	29,096	87.9
Amirantes 0-30m non-reef	0.00	0	0.0	0.00	0	0.0
Amirantes 30-60m	0.00	0	0.0	0.00	0	0.0
All	**0.92**	**4,471,783**	**31.6**	**0.08**	**374,631**	**73.7**

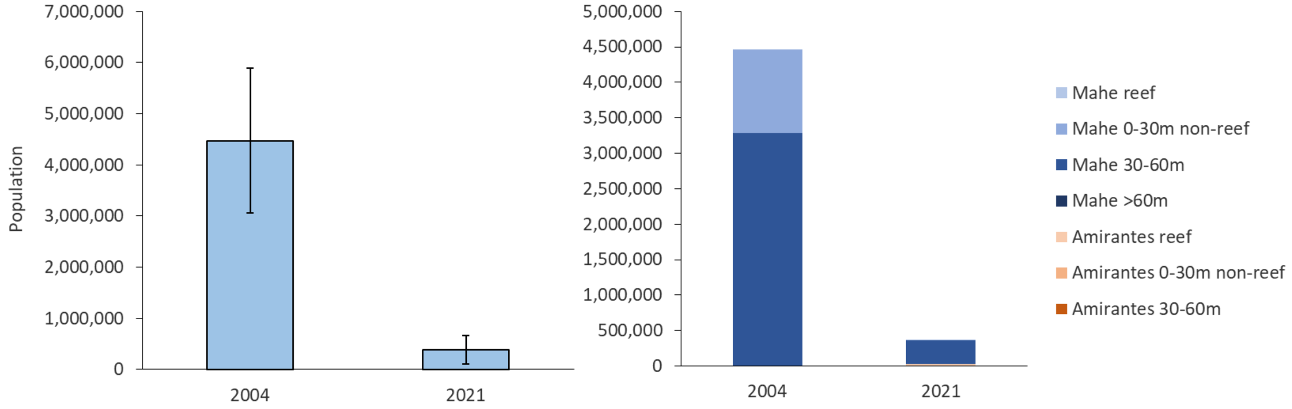


Figure 11. Stock estimate (in numbers of individuals) for White teatfish (*H. fuscogilva*) for the entire fishery (left) and for each stratum (right), for each year surveyed (error bars are 60% CI).

The decline in the population observed during the 2021-22 survey continued a trend observed in 2011 (Figure 12) (Koike, 2017) – although the 2011 survey uses a different data frame and fishery area to the 2004 and 2021-22 survey, therefore the comparison should be treated with some caution.

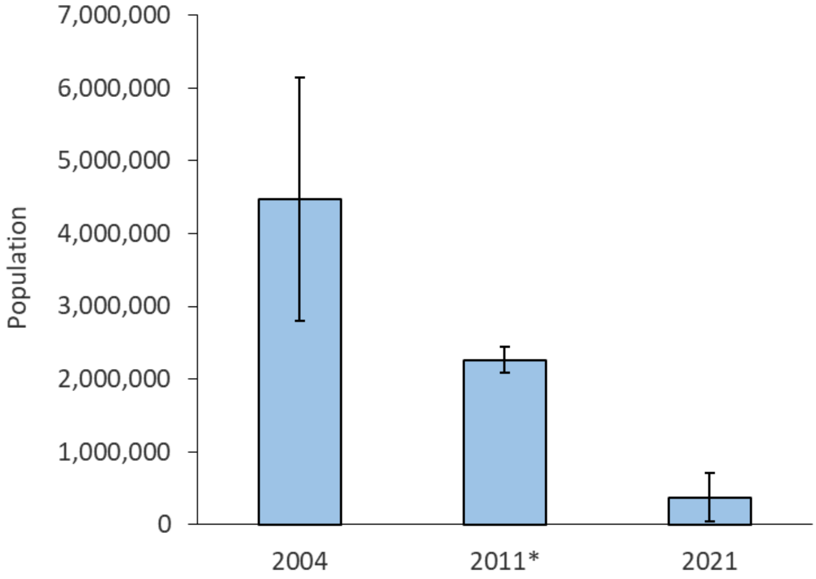


Figure 12. Comparison of 2004 and 2021-22 fishery population estimates of White teatfish with that of 2011 (Koike, 2017) (error bars are 1 s.e.) *2011 survey utilises a different survey dataset and fishery area.

4.1.3 CPUE

An analysis of catch and effort data from fishery logbooks for the period 2004 to 2016 (MRAG, 2017) and the 2020/21 season shows a declining trend in CPUE that matches the survey data closely – with the 2020-21 CPUE (number caught per minute of diving) declining to only 14.4 % of the 2004 estimate (Figure 13), the lowest CPUE value in the data series.

The linear regression r^2 (coefficient of determination) of CPUE over time was relatively high (0.74), indicating that the change over time was a relatively stable trend — that is, it was not highly variable over the years, giving us some confidence that the CPUE trend represents actual abundance.

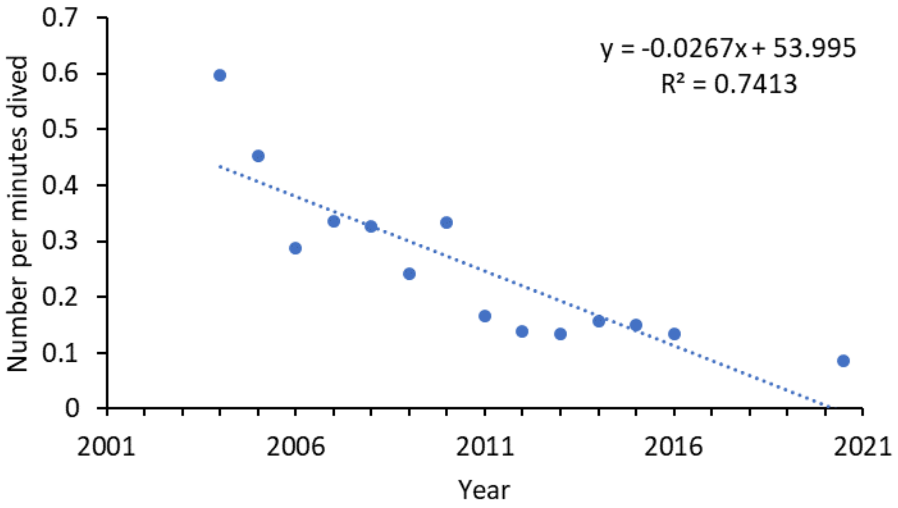


Figure 13. CPUE (number caught per minute dived) of white teatfish for 2004 to 2016 (MRAG, 2017) and for 2020/21 season from available fishery logbook data. Linear regression line also shown.

These multiple lines of evidence strongly point to a severely depleted population of White teatfish in the Seychelles fishery, with a decline in the order of 90% since 2004. A significant decline in white teatfish has also been acknowledged by some fishers during limited interviews carried out in early 2022.

4.1.4 Stock status

Stock status is usually assessed as the populations size or density relative to its virgin (before fishing) size/density (usually referred to as B_0), which is related to the ecological carrying capacity for that species. This can be a difficult parameter to estimate if there is no “before fishery” survey data, and when dealing with species that may have variable recruitment and/or population density over time or have a patchy distribution between or even within fishery habitat areas.

The next source of uncertainty is the stock level reference points – that is, the stock level where yield is maximised (B_{MSY}), and the stock level at the point of recruitment impairment (B_{PRI}). These have not been well established for sea cucumber fisheries, however, they are likely to be greater than the “rule of thumb” reference levels set for finfish fisheries of 40% and 20% of B_0 for MSY and PRI respectively (MSC, 2018).

In this case, the decrease in average density at repeated sites, the decline in population estimates, and declining CPUE for White teatfish all point to a heavily depleted population, to approximately 10% of its 2004 level (Figure 14). Given that the fishery had been operating for several years before the 2004 survey, and that there were already indications of depletion even at that stage (Aumeeruddy et al., 2005), it is a very strong likelihood that the population has been reduced to below even the default the level or PRI (20% of B_0)– even given the uncertainty around the population estimates.

The current catch quota of 56,250 per annum, while only about 13% of the mean 2021-22 stock estimate, has resulted in continued depletion of the white teatfish population – reinforcing findings from other teatfish fisheries in Australia and elsewhere that sustainable yields for teatfish may be of the order of 5% or less (Uthicke et al., 2004). Previous stock modelling using CPUE data up to 2011 has also suggested that this stock has been consistently overfished throughout the years, which has likely resulted in recruitment overfishing (Koike 2017).

In any case, this population has been severely depleted and requires immediate cessation of fishing to allow rebuilding. While there is still a significant population of white teatfish in the Seychelles fishery, the main concern will now be that dilution effects (low fertilisation rate of gametes in the water column) due to low densities will hamper recovery. Reseeding, aggregating or other enhancement activities may assist, but will require dedicated research effort to determine the correct approach.

The population could be monitored every three years until an agreed density is attained that would indicate a population recovery to a level that would allow some fishery take. This “reopen” stock level will require some additional stock modelling and agreement, preferably as part of a broad fishery wide sea cucumber harvest strategy.

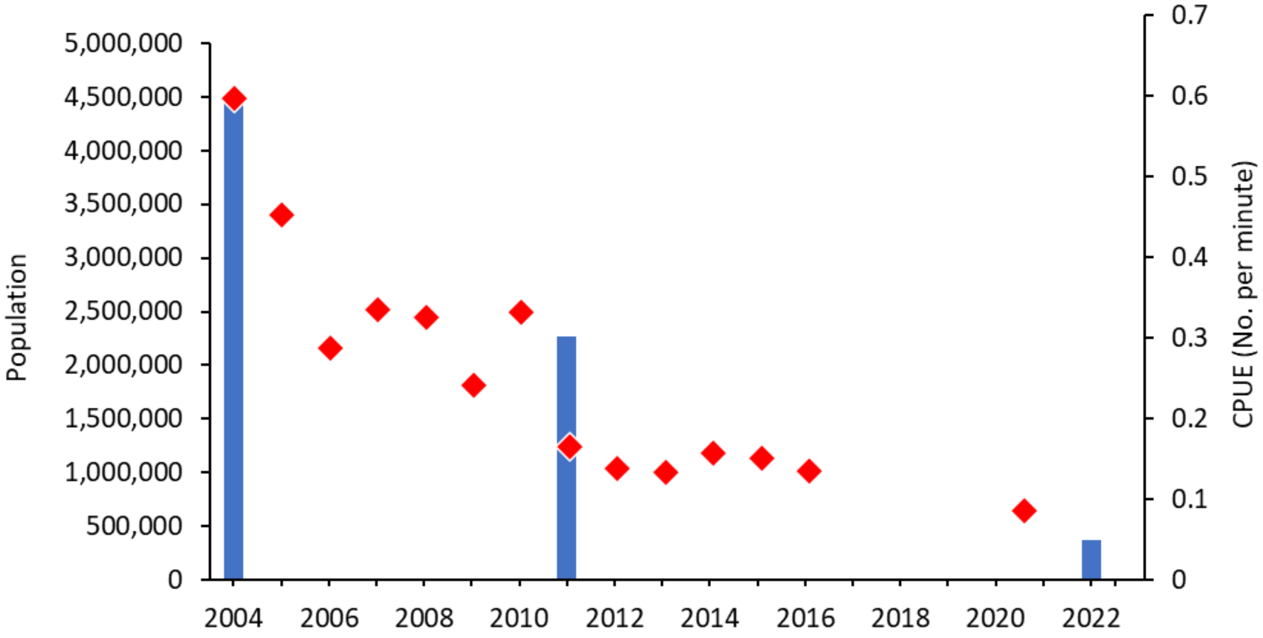


Figure 14. Survey population (blue bars) and logbook CPUE (red diamonds) data for White teatfish from 2004 to 2022.

4.2 Pentard/Flower teatfish (*Holothuria spp.* (type “Pentard”))

4.2.1 Density

Overall density of Pentard dropped by about 35% between 2004 and 2021-22 at repeated sites (Figure 15), though this decrease was not statistically significant (Figure 36). While the average density on Mahe Plateau declined, Amirantes plateau increased.

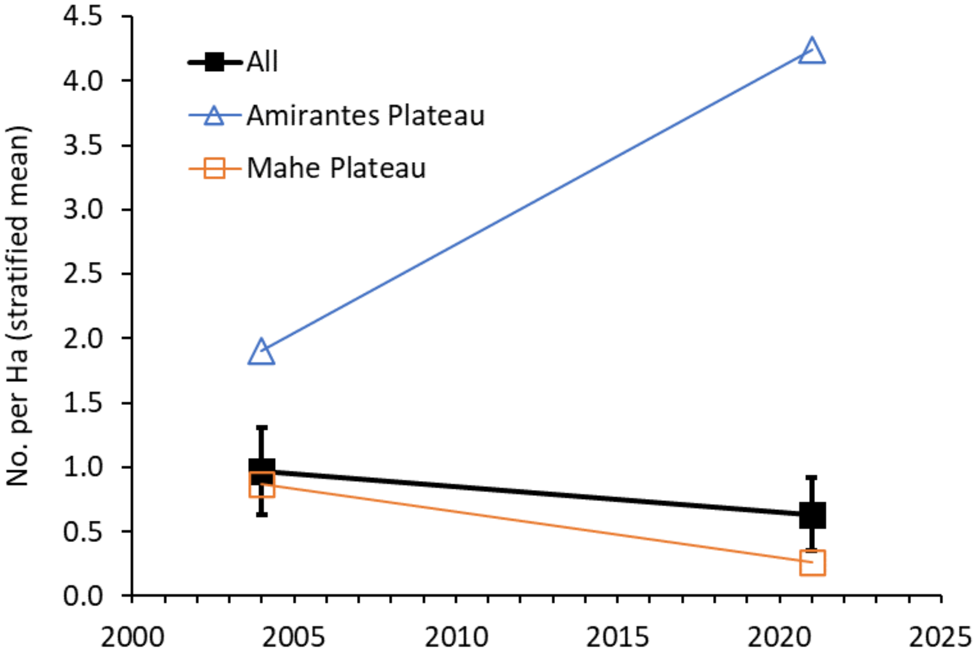


Figure 15. Overall and plateau average (stratified) density (No. per Ha) for Pentard/Flower teatfish (*H. spp.* (type “Pentard”)) at repeated sites in 2004 and 2021-22 (error bars = 1 s.e.) (n=182).

While the two non-reef shallow and intermediate depth strata on the Amirantes increased in density, there was a general decline in all other strata. The reef strata for both plateaus had very low densities of this species (Table 8).

4.2.2 Stock estimate

The population estimate for Pentard in 2021-22 was 2,663,685 (± 38.1%, 60% CI), which was about 59% of the 2004 estimate (Table 8, Figure 16). The population was spread relatively evenly throughout all shallow and intermediate non-reef strata on both plateaus.

Table 8. Stock estimate for Pentard/Flower teatfish (*H. spp.* (type 'Pentard")). For each strata and year surveyed, the density (No. per Ha) and population stock estimate in numbers and the 60% CI (as a % of the population estimate) (n=192).

Strata	Density (No. per Ha) 2004	Number 2004	60% CI (%)	Density (No. per Ha) 2021	Number 2021	60% CI (%)
Mahe reef	0.39	3,978	85.3	0.00	0	0.0
Mahe 0-30m non-reef	1.90	906,985	34.6	0.78	372,512	85.3
Mahe 30-60m	0.88	2,810,682	36.1	0.23	744,292	84.6
Mahe >60m	0.00	0	0.0	0.00	0	0.0
Amirantes reef	0.00	0	0.0	0.00	0	0.0
Amirantes 0-30m non-reef	0.00	0	0.0	3.57	528,802	59.0
Amirantes 30-60m	2.78	795,878	86.5	3.52	1,009,524	66.8
All	**0.93**	**4,517,523**	**27.8**	**0.55**	**2,655,130**	**38.1**

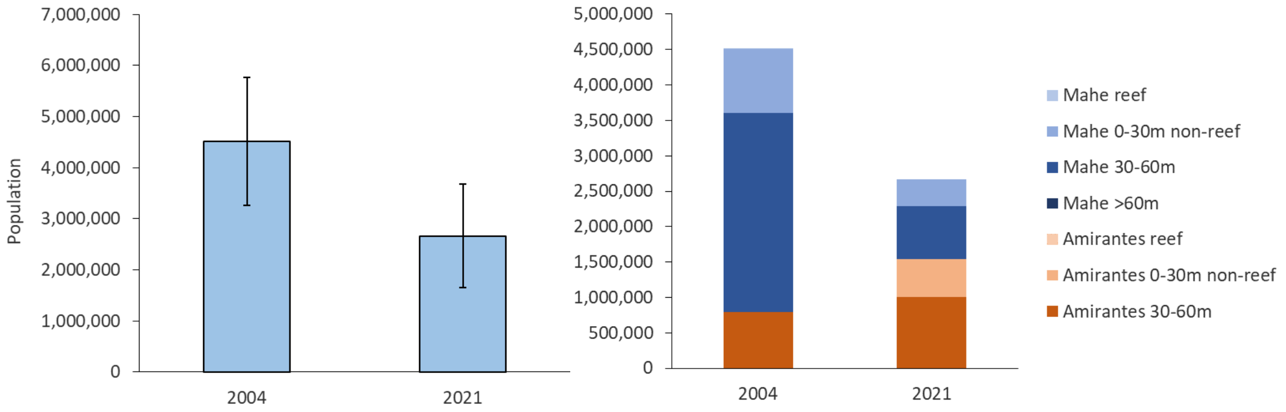


Figure 16. Stock estimate (in numbers of individuals) for Pentard/Flower teatfish (*H. spp.* (type 'Pentard")) for the entire fishery (left) and for each strata (right), for each year surveyed (error bars are 60% CI).

4.2.3 CPUE

An analysis of catch and effort data from fishery logbooks for the period 2004 to 2016 (MRAG, 2017) and the 2020/21 season shows a decline in CPUE that matches the survey data closely – with the 2020-21 CPUE (number caught per minute of diving) declining to 47.4 % of the 2004 estimate (Figure 17).

The linear regression r^2 (coefficient of determination) of CPUE over time was 0.61, indicating that the change over time reflected a relatively stable trend — that is, it was not highly variable over the years, giving us some confidence that the CPUE trend represents actual abundance.

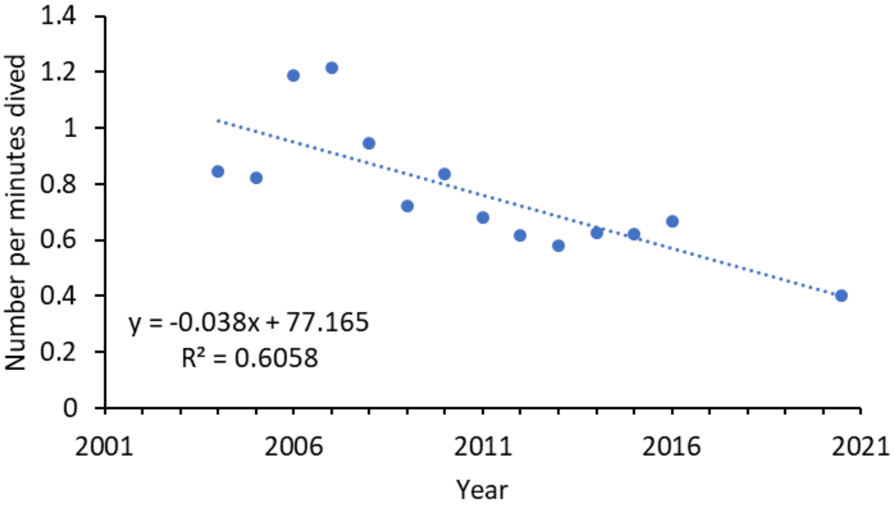


Figure 17. CPUE (number per minutes dived) of Pentard/Flower teatfish for 2004 to 2016 (MRAG, 2017) and for 2020/21 season from available fishery logbook data. Linear regression line also shown.

4.2.4 Stock status

The average density at repeated sites, population size estimate and CPUE data for Pentard indicates that the Pentard population may have been reduced by about half since 2004 (Figure 18). It does appear though that the very high catches in the 2009 to 2014 did take a toll on the population with the decline in CPUE being most marked between 2008 and 2013 (Figure 19).

This still represents a remarkably stable population status given the heavy fishery focus on this species, and particularly in comparison to the sharp decline in the White teatfish population.

While the stock level may not have reached a level where recruitment impairment is occurring, the downward trajectory of CPUE would indicate that current fishing levels are likely unsustainable. We would recommend an immediate reduction in the quota for this species by another 10% as an additional small buffer to overexploitation, and the urgent implementation of targeted stock assessment modelling, using the recent survey and fishery logbook data to establish stock status in relation to B_{MSY} and sustainable levels of fishing mortality F_{MSY}. Further management actions would be based on the outcomes of that assessment.

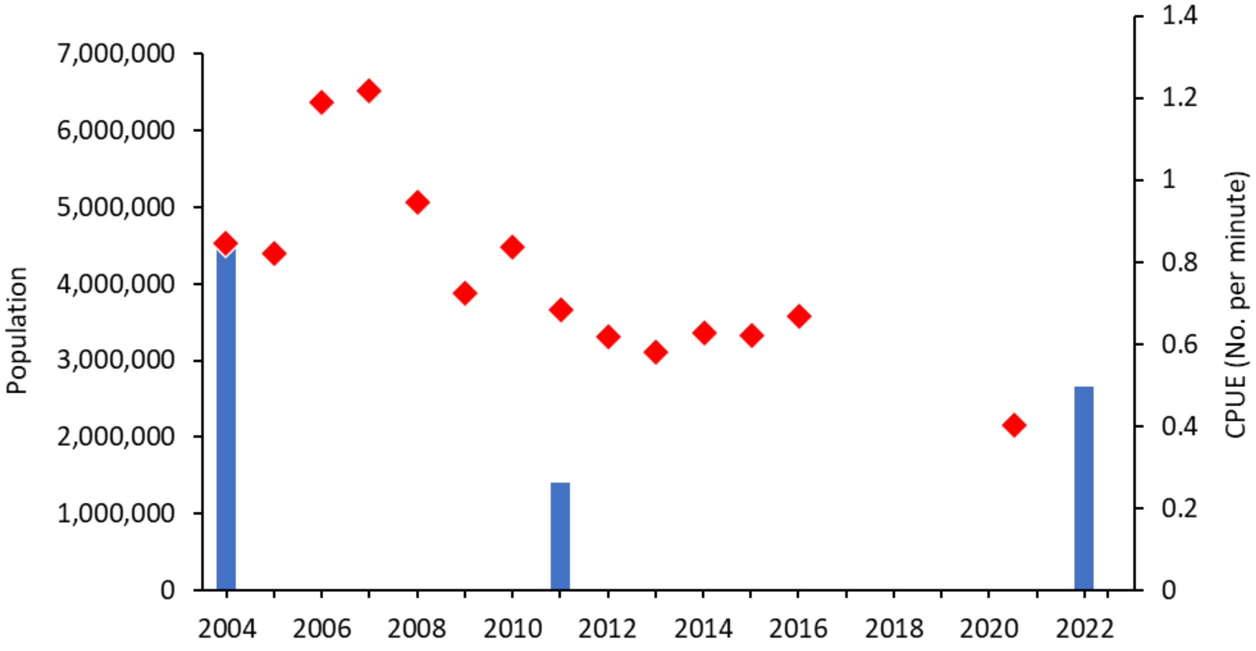


Figure 18. Survey population (blue bars) and logbook CPUE (red diamonds) data for Pentard from 2004 to 2022.

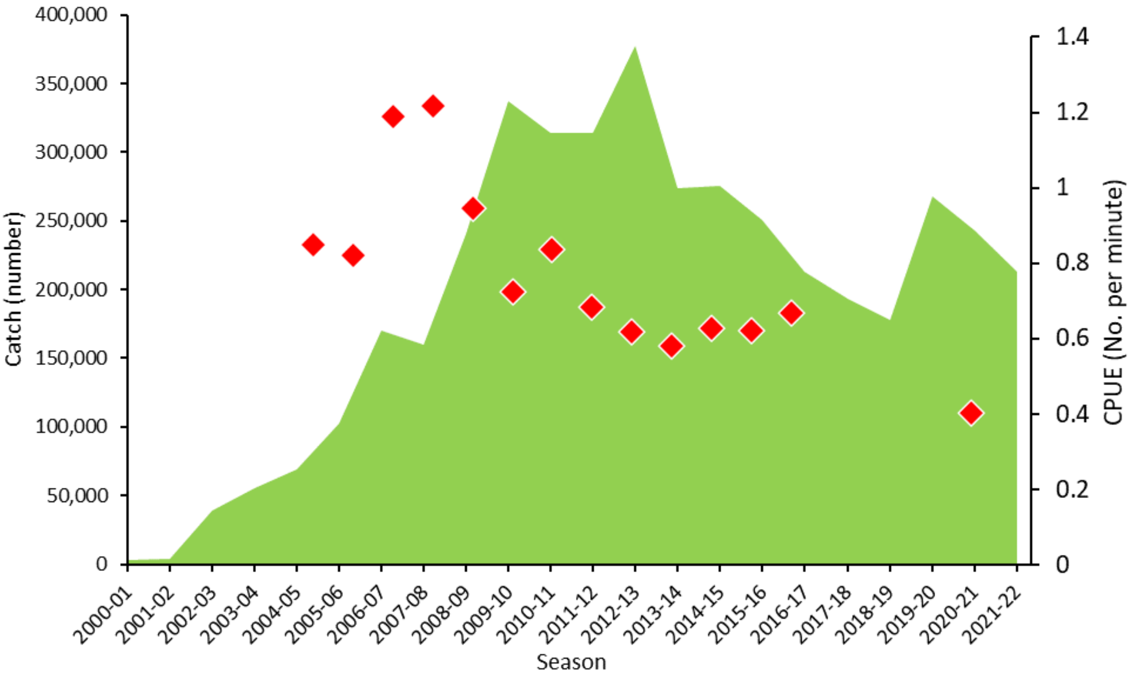


Figure 19. Catch and logbook CPUE (red diamonds) data for Pentard from 2004 to 2022.

4.3 Prickly redfish (*Thelenota ananas*)

4.3.1 Density

Overall density of Prickly redfish increased by about 45% between 2004 and 2021-22, though this increase was not statistically significant (Figure 20, Figure 36). While the Mahe Plateau was relatively stable, there was a large increase in the Amirantes Plateau.

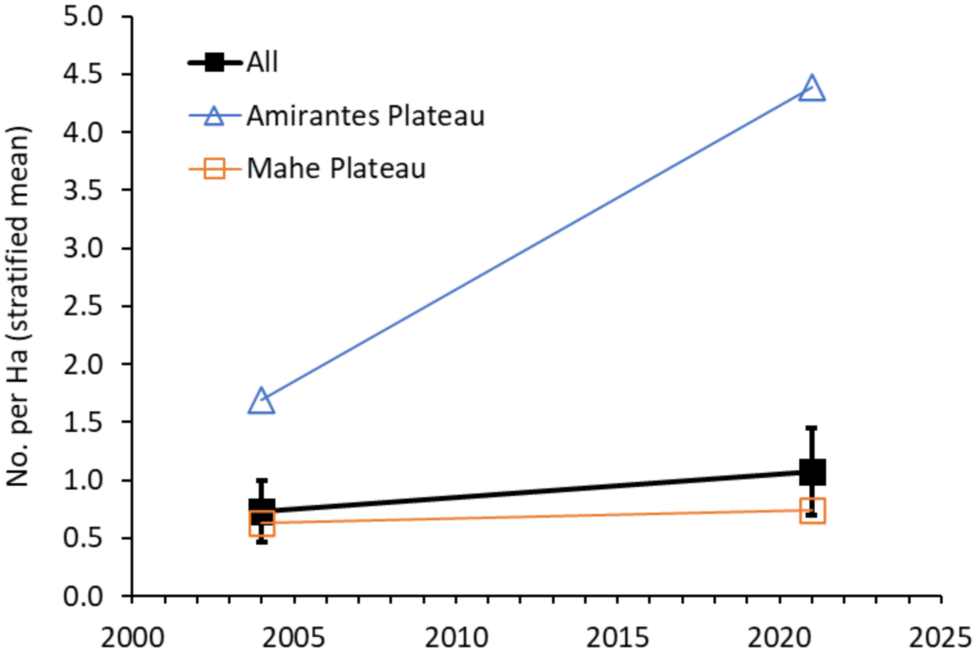


Figure 20. Overall (top) and stratum (bottom) average (stratified) density (No. per Ha) for Prickly redfish (*T. ananas*) at repeated sites in 2004 and 2021-22 (n=182) (error bars = 1 s.e.).

The increase was observed in all strata, apart from Amirantes reef (stable) and Mahe 30-60m (decline from a low base). There have never been any Prickly redfish observed in very deep (>60m) habitats (Table 9).

4.3.2 Stock estimate

The population estimate for Prickly redfish in 2021-22 was 4,688,498, an increase of 52% on the 2004 estimate (Table 9). The Prickly redfish population was found in nearly every stratum but was particularly abundant in the shallow non-reef strata on both plateaus (Figure 21).

Table 9. Stock estimate for Prickly redfish (*T. ananas*). For each strata and year surveyed, the density (No. per Ha) and population stock estimate in numbers and the 60% CI (as a % of the population estimate) (n=192).

Strata	Density (No. per Ha) 2004	Number 2004	60% CI (%)	Density (No. per Ha) 2021	Number 2021	60% CI (%)
Mahe reef	2.60	26,520	37.7	5.77	58,751	37.4
Mahe 0-30m non-reef	1.81	863,564	30.2	6.25	2,980,092	43.3
Mahe 30-60m	0.50	1,595,265	52.5	0.00	0	0.0
Mahe >60m	0.00	0	0.0	0.00	0	0.0
Amirantes reef	5.00	58,193	54.9	7.50	87,289	62.5
Amirantes 0-30m non-reef	1.32	194,822	59.2	7.14	1,057,604	49.6
Amirantes 30-60m	1.18	337,342	86.5	1.76	504,762	66.8
All	**0.64**	**3,075,705**	**30.2**	**0.97**	**4,688,498**	**30.2**

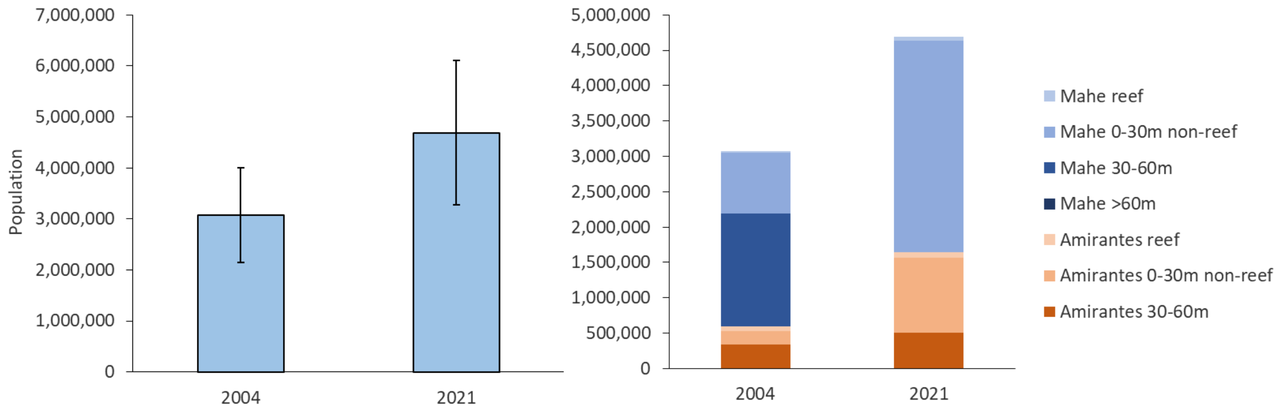


Figure 21. Stock estimate (in numbers of individuals) for Prickly redfish (*T. ananas*) for the entire fishery (left) and for each stratum (right), for each year surveyed (error bars are 60% CI).

Comparison of the survey population estimates with data collected in 2011 (Koike, 2017) shows that the 2011 estimate was also lower than 2021-22 – however the 2011 survey was only from a restricted area of the Mahe Plateau and an area that likely had some depletion of Prickly redfish compared to other more remote areas of the fishery.

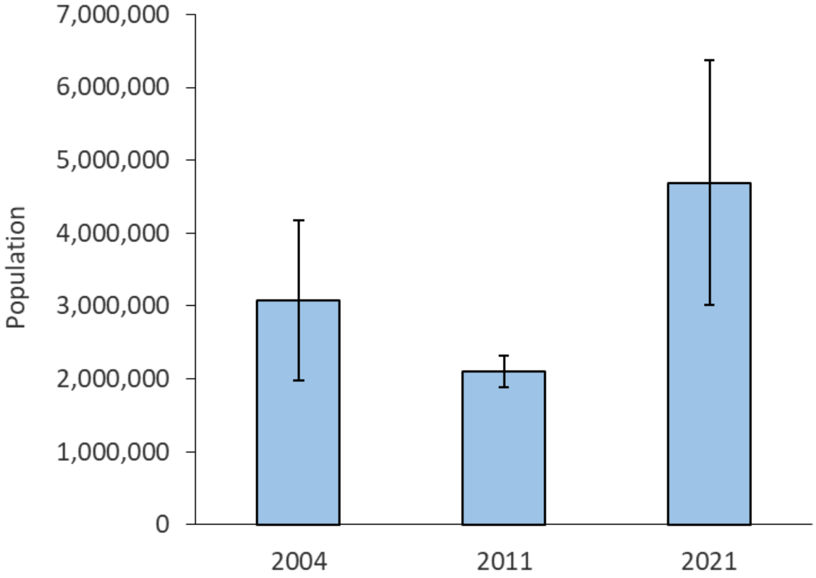


Figure 22. Comparison of 2004 and 2021-22 population estimates or Prickly redfish with that of 2011 (Koike, 2017) *2011 survey refers to a different survey dataset and fishery area.

4.3.3 CPUE

An analysis of catch and effort data from fishery logbooks for the period 2004 to 2016 (MRAG, 2017) and the 2020/21 season shows a highly variable CPUE, with a very weak temporal trend (R^2 = 0.17) – however with the 2020-21 CPUE (number caught per minute of diving) being at the lower end of the scale (Figure 23). In any case, there is not a strong signal in the CPUE data that would indicate a decline in the Prickly redfish population or vice versa.

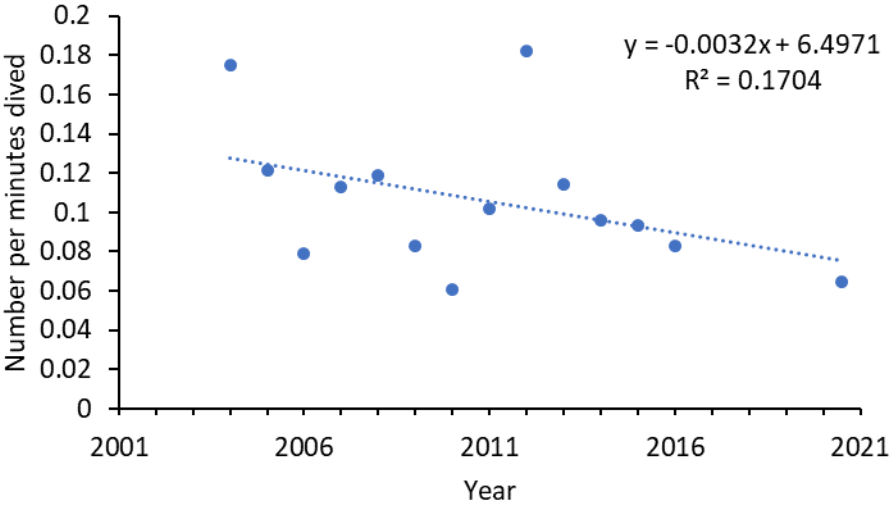


Figure 23. CPUE (number per minutes dived) of Prickly redfish for 2004 to 2016 (MRAG, 2017) and for 2020/21 season from available fishery logbook data.

4.3.4 Stock status

The density, population size and CPUE data for Prickly redfish shows a high variability and considerable uncertainty regarding stock status (Figure 24). However, given the survey results that have indicated a substantial increased since 2004 – and this species generally has a high observability therefore the survey result has a relatively high confidence – it would appear unlikely that this species has declined to levels that would warrant a change in fishing pressure sat this stage. On the other hand, additional analysis of fishery or other data may provide the basis for an increase in catch.

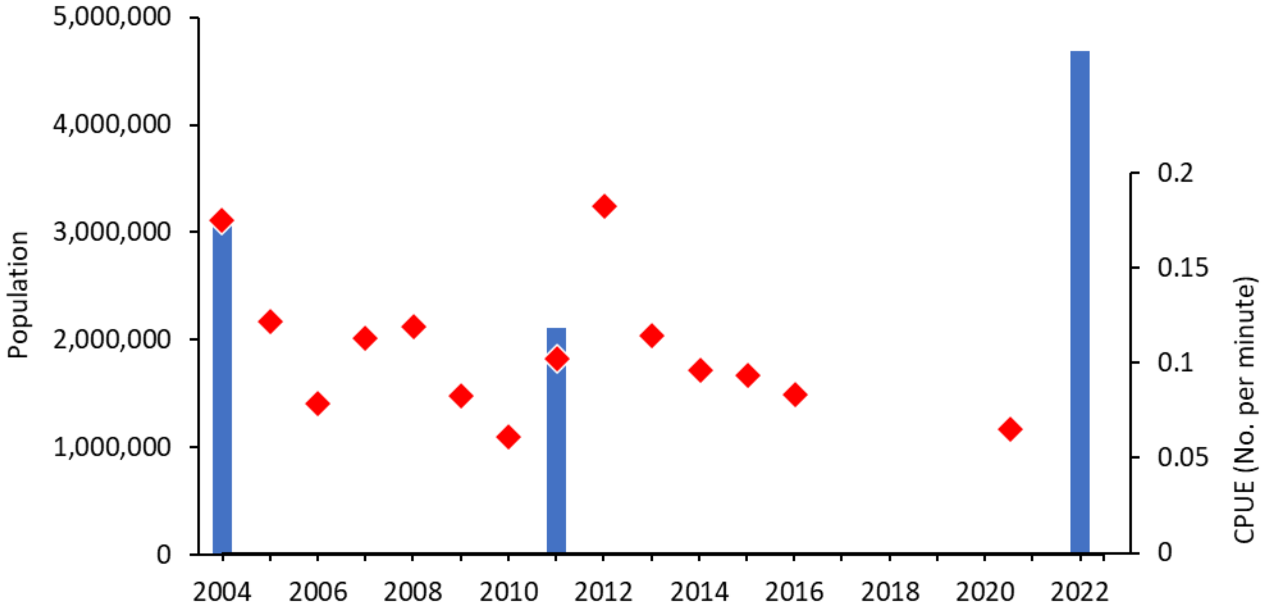


Figure 24. Survey population (blue bars) and logbook CPUE (red diamonds) data for Prickly redfish from 2004 to 2022.

4.4 Black teatfish (*Holothuria nobilis*)

4.4.1 Density

Overall density of Black teatfish had decreased by about 84% between 2004 and 2021-22 (Figure 25) a statistically significant decline (P<0.05, Figure 36). Both the Mahe Plateau and Amirantes Plateau declined in density.

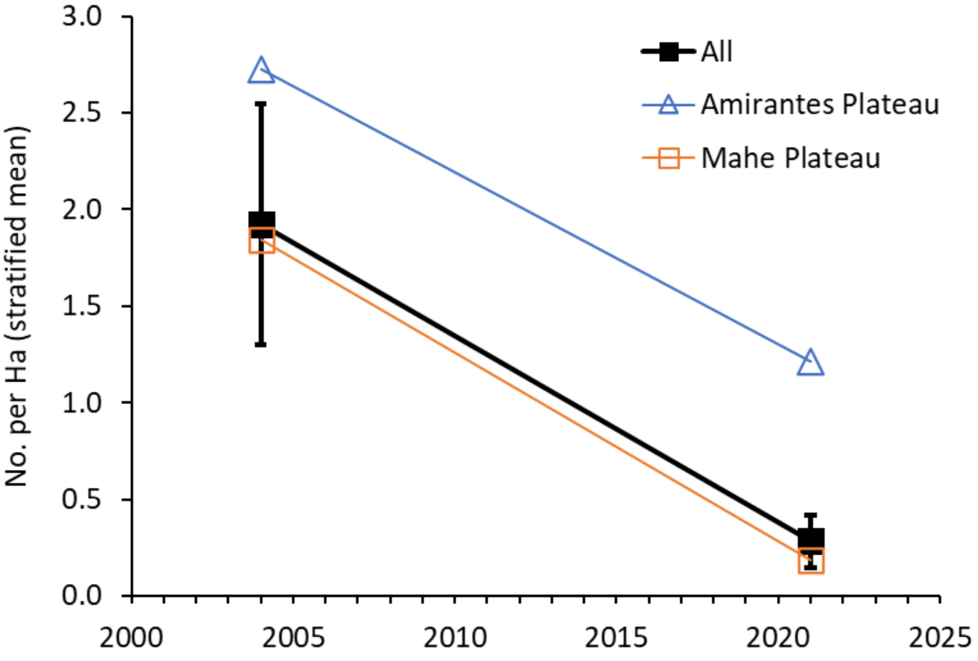


Figure 25. Overall (top) and stratum (bottom) average (stratified) density (No. per Ha) for Black teatfish (*H. nobilis*) at repeated sites in 2004 and 2021-22 (n=182) (error bars = 1 s.e.) (n=182).

The two strata that drove this decrease was the Mahe and Amirantes 30-60m strata – all other strata were stable and Amirantes reef actually increased in density (Table 10).

4.4.2 Stock estimate

The population estimate for Black teatfish in 2021-22 was 1,271,570 (± 40.4%, 60% CI) (Table 10), a decline of 84% from the 2004 estimate. The population was restricted to the shallow reef and non-reef strata of both plateaus (Figure 26). The estimated population size in 2004 was very high, and it was second most abundant species in the fishery area (after Lollyfish, *H. atra*) at that time – mostly found in the Mahe intermediate depth strata, therefore the 2021-22 estimate represents a serious decline.

Table 10. Stock estimate for Black teatfish (*H. nobilis*) in 2004 and 2021-22. For each strata and year surveyed, the density (No. per Ha) and population stock estimate in numbers and the 60% CI (as a % of the population estimate) (n=192).

Strata	Density (No. per Ha) 2004	Number 2004	60% CI (%)	Density (No. per Ha) 2021	Number 2021	60% CI (%)
Mahe reef	1.17	11,934	62.8	2.88	29,376	47.4
Mahe 0-30m non-reef	1.38	656,192	43.5	1.56	745,023	59.3
Mahe 30-60m	1.92	6,141,903	35.3	0.00	0	0.0
Mahe >60m	0.00	0	0.0	0.00	0	0.0
Amirantes reef	6.88	80,015	38.4	20.00	232,771	67.1
Amirantes 0-30m non-reef	1.65	244,412	60.5	1.79	264,401	86.8
Amirantes 30-60m	2.38	681,160	53.2	0.00	0	0.0
All	**1.62**	**7,815,615**	**28.3**	**0.26**	**1,271,570**	**40.4**

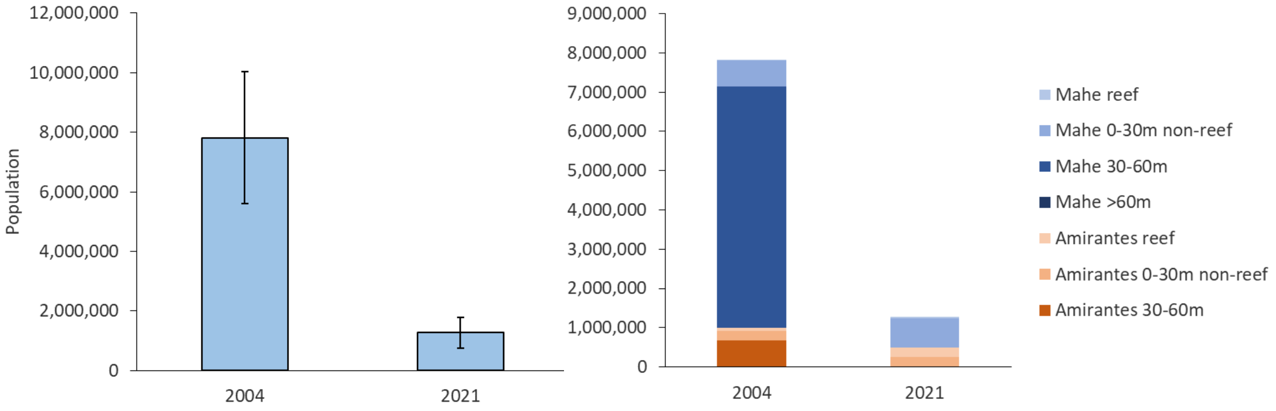


Figure 26. Stock estimate (in numbers of individuals) for Black teatfish (*H. nobilis*) for the entire fishery (left) and for each strata (right), for each year surveyed (error bars are 60% CI).

The decline in the population observed during the 2021-22 survey continued a trend of a declining population also observed in 2011 (Figure 27) (Koike, 2017) – although the 2011 survey uses a different data frame and fishery area to the 2004 and 2021-22 survey, therefore the comparison should be treated with caution.

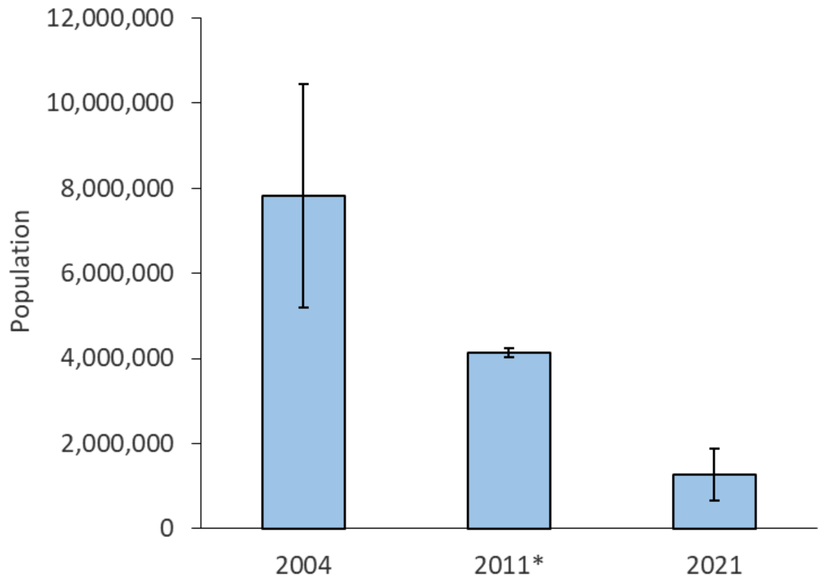


Figure 27. Comparison of 2004 and 2021-22 population estimates or Black teatfish with that of 2011 (Koike, 2017) *2011 survey refers to a different survey dataset and fishery area.

4.4.3 CPUE

An analysis of catch and effort data from fishery logbooks for the period 2004 to 2016 (MRAG, 2017) showed a large decline in the population of Black teatfish, with a consistently low CPUE after 2009 to the final fishing year in 2016 (MRAG, 2017) (Figure 23) – no new fishery logbook data is available for Black teatfish after this time.

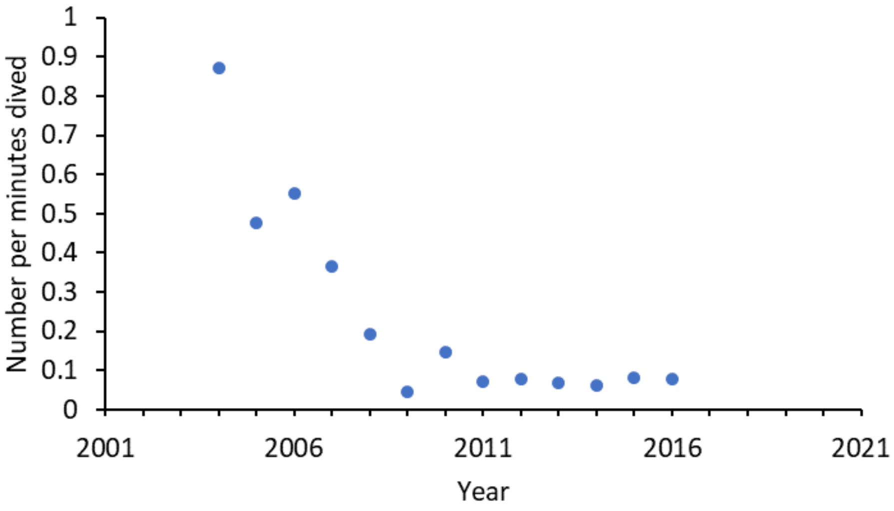


Figure 28. CPUE (number per minutes dived) of Black teatfish for 2004 to 2016 (MRAG, 2017).

4.4.4 Stock status

The density and population size data for Black teatfish indicates that this species is still in a depleted state, even though fishery effort on this species ceased in 2018 (Figure 29). However, there are indications that a recovery is occurring, with higher densities than when the population reached its lowest level in 2017.

In fact, the modelling of CPUE closely matches the trajectory of the 2004 and 2021-22 survey results for the fishery very closely, including a potential recovery since fishing ceased in 2018 (Figure 30). When plotted for the Amirantes only, the CPUE modelling and survey data is less matching, but still indicates the decline and recovery trajectory modelled using the CPUE data (Figure 31).

This population should be monitored with the view to a possible reopening once the stock reaches predetermined levels (at least to those levels consistent with B_{MSY} – MRAG, 2017).

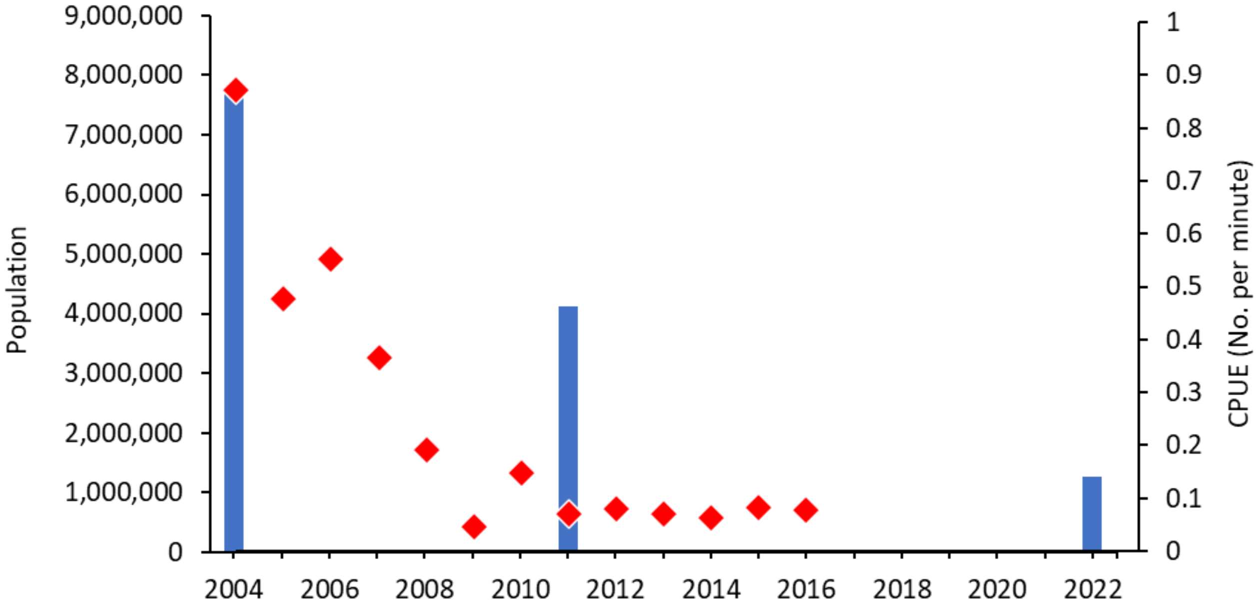


Figure 29. Survey population (blue bars) and logbook CPUE (red diamonds) data for Black teatfish from 2004 to 2022.

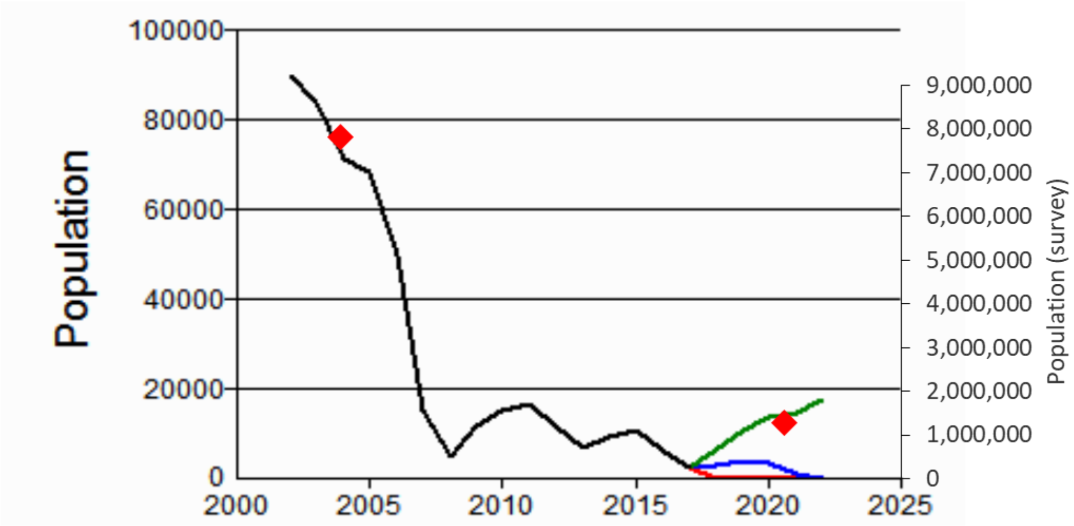


Figure 30. Comparison of a stock reduction model for Black teatfish for statistical area 4 based on logbook data to 2017, and projections of stock recovery under 3 scenarios for future catches (green line represents catch reduction (MRAG, 2017); with the results of the 2004 and 2021-22 survey for the entire study area (axis different scales).

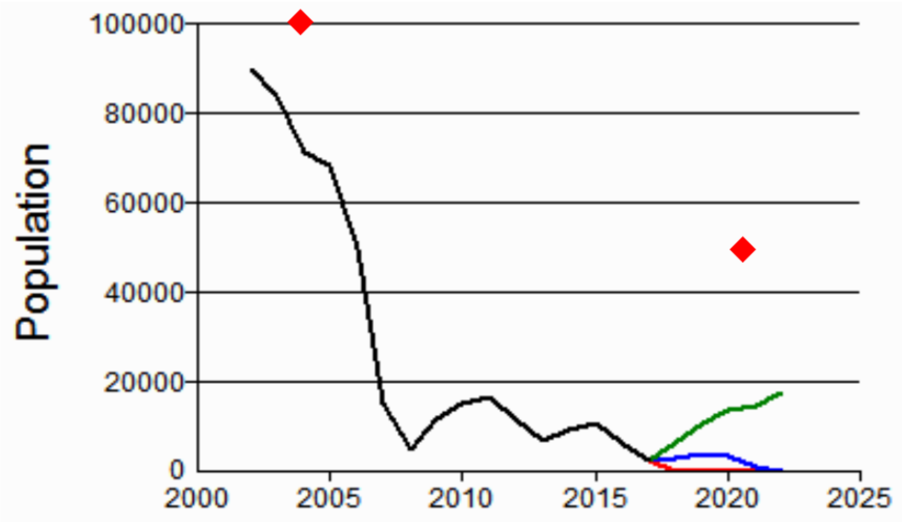


Figure 31. Comparison of a stock reduction model for Black teatfish for statistical area 4 based on logbook data to 2017, and projections of stock recovery under 3 scenarios for future catches (green line represents catch reduction (MRAG, 2017); with the results of the 2004 and 2021-22 survey for the Amirantes only (axis same scale).

4.5 Other species

4.5.1 Density

Density for remaining species at repeated sites in the survey are shown in Figure 32. Due to identification issues, *Actinopyga miliaris*, *A. palauensis* and *A. echinites* are combined as “Spork”; and *Bohadschia vitiensis*, *B. atra* and *B. subrubra* are combined as “Lakol” (Table 5).

Notably, Elephant trunkfish was at similar densities in 2021-22 to 2004. This is a large, easily identifiable species that has not been significantly targeted in the Seychelles sea cucumber fishery (due to its low value), therefore this result provides some validation to the accuracy of the survey comparisons for other species.

The highly abundant species, Lollyfish, was seen at lower densities in 2021-22 (-62%), however, Pinkfish were recorded at much higher densities in 2021-22 (+600%) – this result could be due to misidentification of Lollyfish as Pinkfish. However, there has been some targeting of Lollyfish by the Seychelles fishery in the past, therefore this could also indicate some depletion of this species.

Red/yellow surffish (*Actinopyga mauritiana* complex) showed a large increase in density (+300%) between 2004 and 2021-22, much of this on the Amirantes shallow reefs.

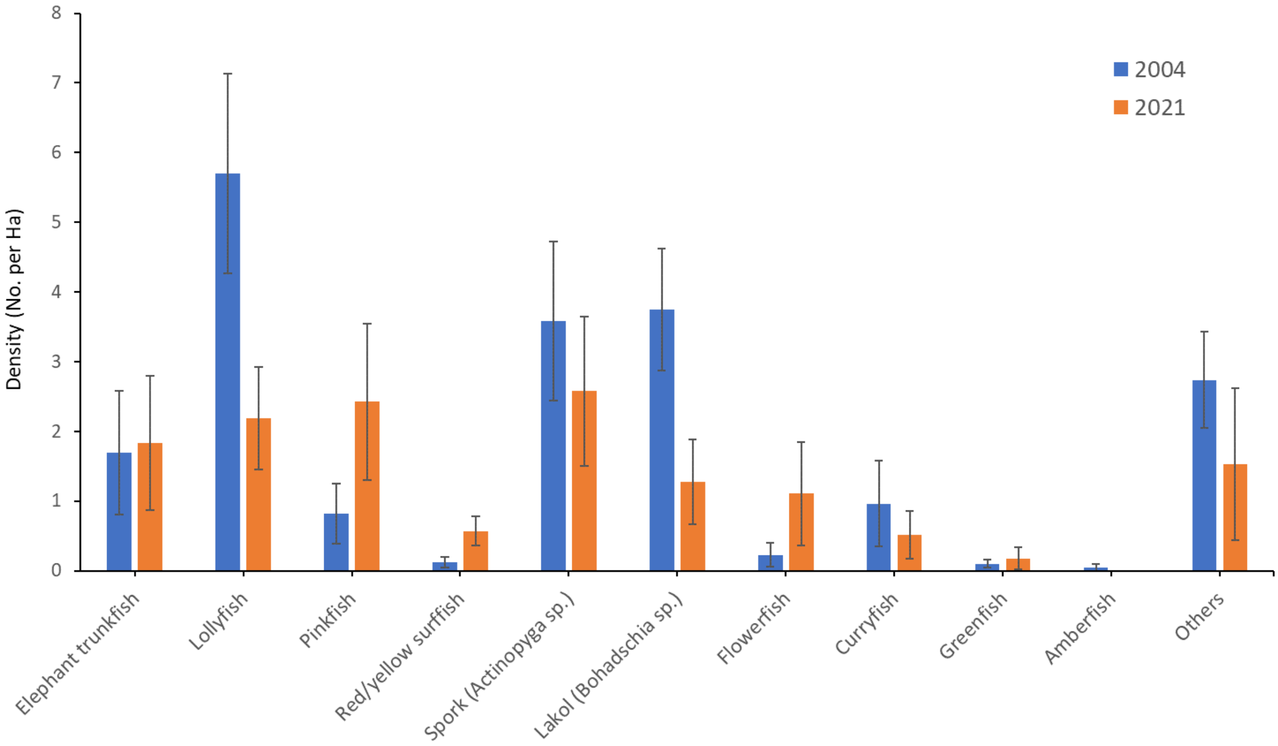


Figure 32. Overall average (stratified) density (No. per Ha) for non-priority species at repeated sites in 2004 and 2021-22 (n=182) (error bars = 1 s.e.).

Spork and Lakol species groups both showed decreases in density, though only for Lakol was this decline statistically significant (*P*<0.05). Species that make up the Lakol group (*Bohadschia spp.*) are known to burrow during the daylight hours and therefore are prone to under-counting.

Flowerfish showed a large increase in density, largely due to an increase in shallow non-reef areas of the Mahe Plateau – this would be unusual for the reef obligate species such as this and it could be that some of these were misidentified as actually being Bohadschia species in the Lakol group.

Curryfish were lower overall, though the decrease was not statistically significant for this patchy species. Greenfish and Amberfish were found in low densities in 2021-22, similarly to 2004.

Other (mostly unidentified) sea cucumbers were mostly made up of small dark individuals in deep water.

4.5.2 Stock estimate

The population estimates for species observed during the 2021-22 survey reflected the density trends discussed above (Figure 33). The overall sea cucumber population estimate in 2021-22 of 77.7M was about 30% lower that the estimate in 2004 of 115.4M ($P<0.05$, Figure 34). Much of this decline was for the Mahe Plateau (Figure 35).

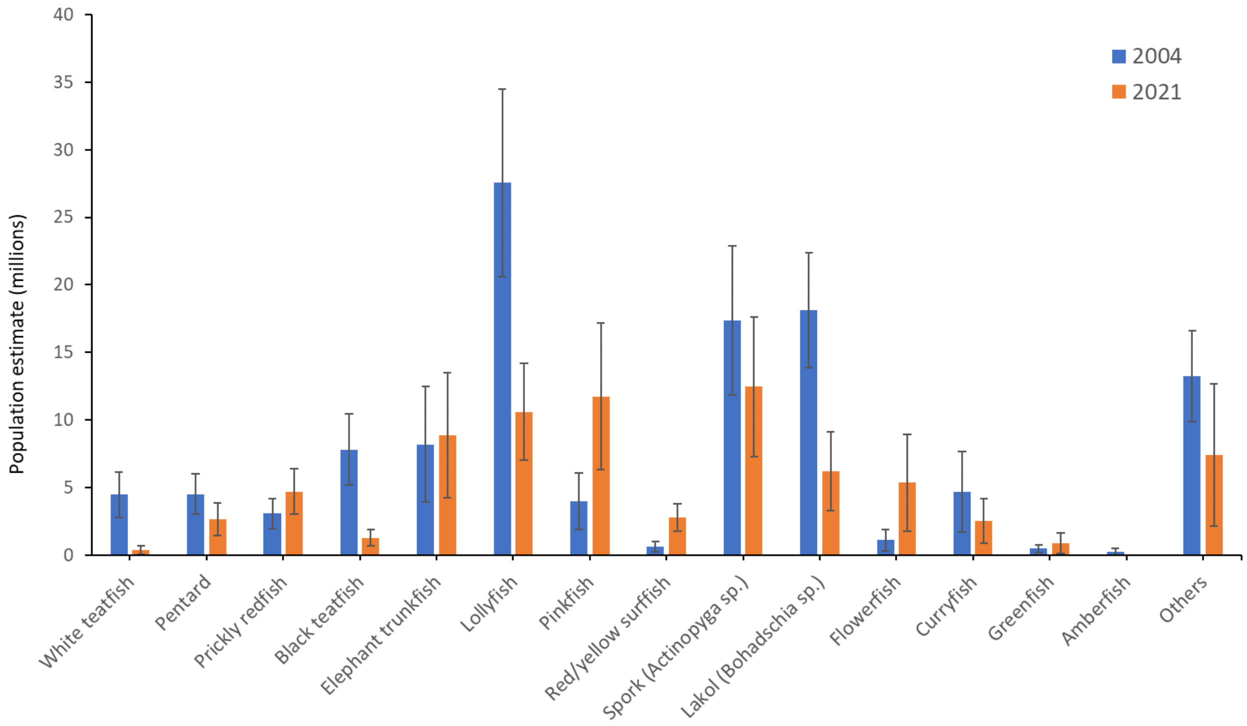


Figure 33. Stock estimates (in numbers of individuals) for all species for the entire fishery.

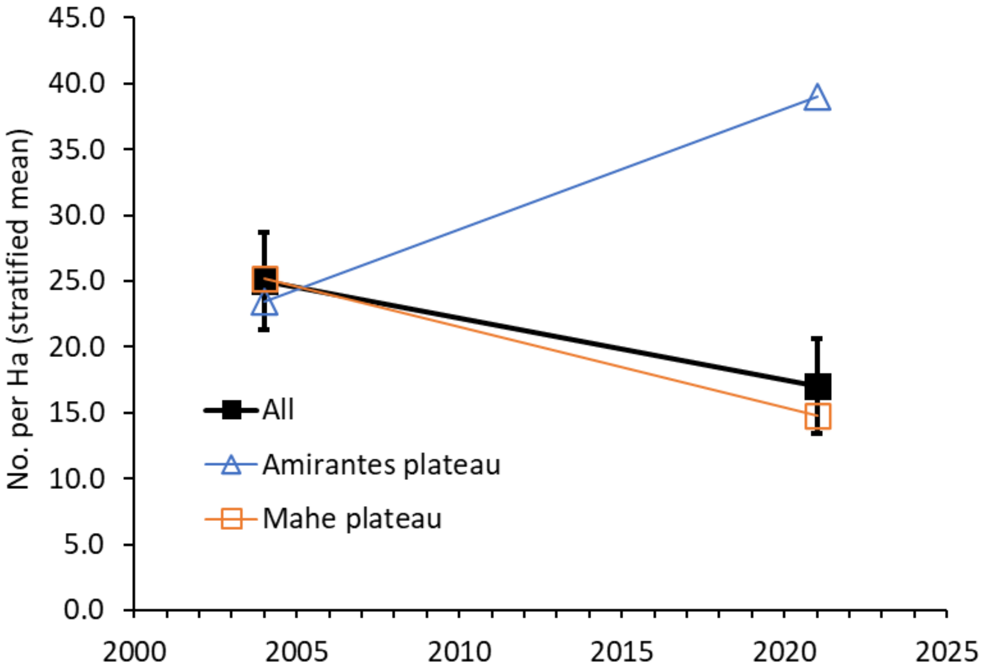


Figure 34. Overall (top) and stratum (bottom) average (stratified) density (No. per Ha) for all sea cucumbers at repeated sites in 2004 and 2021-22 (n=182) (error bars = 1 s.e.) (n=182).

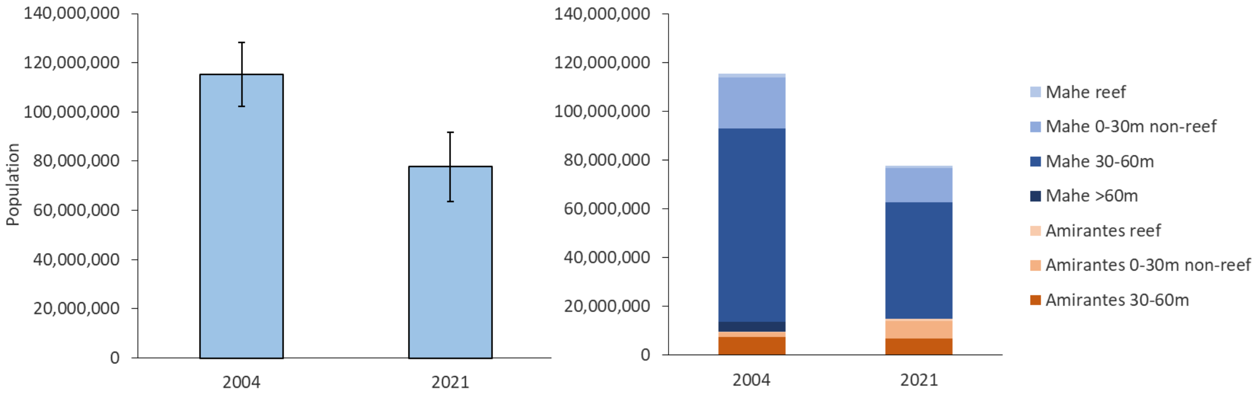


Figure 35. Stock estimate (in numbers of individuals) for all sea cucumbers for the entire fishery (left) and for each strata (right), for each year surveyed (error bars are 1 s.e.).

4.5.3 Stock status

There has been no exploitation of any of these species since 2017, and only red/yellow surf (*A. mauritiana* complex) had previous sustainability concerns (Aumeeruddy et al., 2005). Several could be candidates for reintroduction to fishing quotas. However, before this occurs, there would likely be the need for additional targeted information e.g. targeted surveys, and/or a controlled reopening with a small quota and additional catch reporting requirements (e.g. high resolution catch location and effort data, and animal size etc). This information could then be used on a continuing basis to assess the sustainability of the catch for these reopened species.

5 Discussion

We have used survey and fishery dependent (logbook) data to estimate the size and stock status for each species in the Seychelles sea cucumber fishery (Table 11). Several potentially commercial species are still uncertain with regard to their stock status, due in part to uncertainties in their identification and/or patchy distribution, and lack of historic fishery data. In addition, sea cucumber counts were highly variable, and probably more variable in 2021-22 than in 2004, and very few repeat sites had similar numbers of sea cucumbers, making statistically significant inferences about density trends difficult, with change statistics having wide confidence intervals (Figure 36).

Table 11. For each species surveyed, the likely population status and management recommendations.

Scientific Name	Common Name	Local name	Status	Management recommendation
Holothuria fuscogilva	White teatfish	Kokosye blan	Heavily depleted	No take and monitor recovery
Holothuria sp. Type "Pentard"	Flower teatfish	Pentard	Overexploited	Reduce TAC and carry out further stock assessment modelling
Thelenota ananas	Prickly redfish	Sanpye	Uncertain but possibly under-exploited	Maintain current TAC, monitor and carry out further stock assessment modelling
Holothuria nobilis	Black teatfish	Kokosye nwanr	Depleted but possibly recovering	No take and monitor recovery
Holothuria fuscopunctata	Elephant trunkfish	Safran	Near virgin biomass	Allow TAC <2% pop estimate
Holothuria atra	Lollyfish	Spork, Spork koray, Disan	Uncertain but likely under-exploited	Allow TAC <2% pop estimate
Holothuria edulis	Pinkfish		Uncertain but likely under-exploited	Allow TAC <2% pop estimate
Holothuria scabra	Sandfish	Kokonm	Uncertain	Carry out targeted surveys
Holothuria lessoni	Golden sandfish	Kokonm	Uncertain	Unlikely to be commercially viable in Seychelles
Actinopyga mauritiana (complex)	Surf redfish	Red surf, Yellow surf, Brisan	Uncertain but may have recovered	Allow small experimental quota, collect detailed fishery data and carry out further stock assessment modelling
Actinopyga miliaris	Hairy blackfish	Spork	Uncertain but likely under-exploited	As above
Actinopyga echinites	Deepwater redfish	Spork	Uncertain but likely under-exploited	As above

Scientific Name	Common Name	Local name	Status	Management recommendation
Actinopyga palauensis	Deepwater blackfish	Spork	Uncertain but likely under-exploited	As above
Bohadschia vitiensis	Brown sandfish	Lakol	Uncertain. Likely underestimated due to burrowing	As above
Bohadschia atra	Tigerfish	Lakol	Uncertain. Likely underestimated due to burrowing	As above
Bohadschia subrubra	White belly	Lakol	Uncertain. Likely underestimated due to burrowing	As above
Pearsonothuria graeffei	Flowerfish		Likely at near virgin levels	Unlikely to be commercially viable in Seychelles
Thelenota anax	Amberfish		Likely at near virgin levels	Unlikely to be commercially viable in Seychelles
Stichopus herrmanni	Curryfish		Likely at near virgin levels	Allow TAC <2% pop estimate. Requires specialist processing.
Stichopus chloronotus	Greenfish		Likely at near virgin levels	Allow TAC <25% pop estimate. Requires specialist processing.

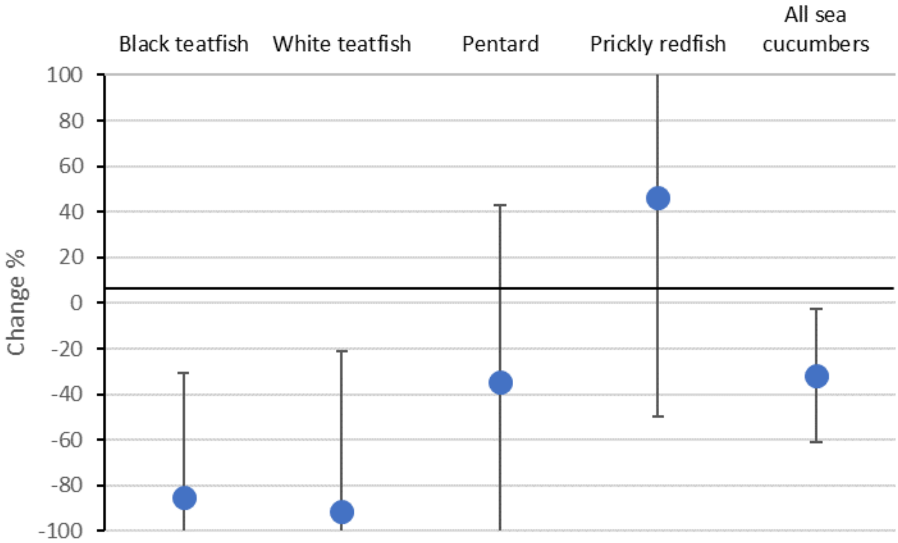


Figure 36. Density changes between the 2004 and 2021-22 surveys at 182 repeated sited throughout the Seychelles sea cucumber fishery for priority species. Error bars are 90% CI of the change statistic – indicating the significance of the difference at the 0.05 level (one tailed).

There are also some discrepancies in the catch data from various sources. The "cleaned" logbook data that was used in the fishery data catch assessment (MRAG, 2017) and recent logbook data (Figure 37) shows lower numbers in the catch than the corresponding export landings data submitted to SFA – logbook catch is on average only 86% of the landings catch (Figure 1). The catch from 2012 and 2013 is much lower, and the early catch records for Black teatfish are higher – this likely due to assignment of records for Spork to Black teatfish (MRAG, 2017).

The use of common names in the fishery logbook is a source of confusion for several species e.g. Spork and Lakol are likely made up of several species; being dark Actinopyga species and Bohadschia species respectively. It is a strong recommendation that the fishery moves to a single species designation for the fishery logbook, catch recording and scientific data collection based on standardised species names, including the production of a fishery species ID guide, which could also be augmented by species diagnostic characteristics, information about the species ecology and reproductive biology, and best practice processing approaches (for an example, see the Torres Strait Beche-de-mer (Sea cucumber) species ID guide (Murphy et al., 2019). The sustainability of individual species, and therefore the fishery, cannot be achieved without this.

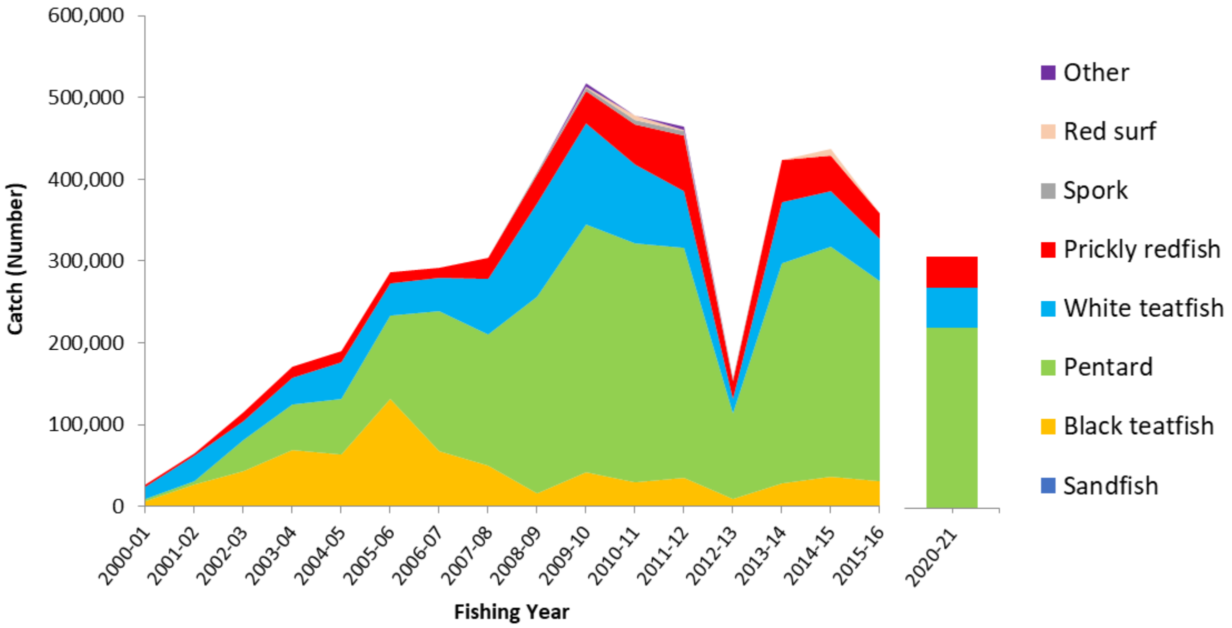


Figure 37. Catch from logbook data for period 2000 to 2016 (MRAG, 2017) and for 2020-21 (SFA).

Despite these challenges, the recent survey and other research efforts over the years (Aumeeruddy et al., 2005; MRAG, 2012; Koike, 2017; MRAG, 2017) has provided important information on the status of the stock and recent stock trends, especially for the current target species, White teatfish, Pentard and Prickly redfish.

In addition to management recommendations for each of the current fishery species, we also recommend the implementation of a sea cucumber fishery harvest strategy, which would include the following components:

i. A shared vision and objectives (stock, environmental, economic, social and occupational) for the fishery for all fishery stakeholders

ii. Indicators (how will the fishery performance be measured?)
iii. Reference levels (what are the target and limit points for the indicators?)
iv. Harvest Control Rules (what are the agreed actions that will be taken if a reference level is reached?)

A harvest strategy will provide the opportunity for the co-design of monitoring and response frameworks that is critical to get industry engaged and united. It would also promote a more “wholistic” approach to the fishery.

A key approach to lower the risk to fisheries generally is to implement a comprehensive and representative (e.g. by fishery zone, depth zone, habitat type) system of closed areas. This provides areas where populations can remain at near natural densities to ensure a consistent supply of fishery recruits. Recent research suggests that a good target would be to protect 30% of each fishery zone as no-take areas (O’Leary et al., 2016), however, a target of 10% would be an prudent interim target in the short to medium term. There is already implemented such a system in the Seychelles for shallow reefs, and this should be sufficient for reef associated species such as Black teatfish (and may have already contributed to the apparent recovery of this species already) however, there is currently no implemented equivalent for deeper species such as Pentard.

A rotational harvest strategy has been shown to be a useful management strategy for reducing risk and increasing productivity in the Queensland east coast sea cucumber fishery (Skewes et al., 2014; Plaganyi et al., 2015), and this could be an approach worth investigation for the Seychelles sea cucumber fishery. In the Queensland example, fishing is rotated throughout 154 zones on a three-yearly cycle; however, modelling shows that benefits accrue up to a 6 year cycle. Implementing such a strategy would likely be challenging in the Seychelles with the number of operators and compliance challenges, however, this could be investigated.

5.1 Recommendations:

1. Cease fishing immediately on White teatfish and monitor again in 3 years.
2. Reduce the quota for Pentard by 10% and urgently implement targeted stock assessment using the recent survey and logbook data to establish stock status in relation to B_{MSY} and sustainable levels of fishing mortality F_{MSY}.
3. Carry out additional stock modelling on Prickly redfish, using the recent survey and fishery logbook data to investigate a possible increase in fishing pressure for this species.
4. Continue to monitor the recovery of Black teatfish.
5. Investigate the potential reintroduction of small experimental quotas (with TACs at <2% of population estimates) for underexploited or recovered species (e.g. red/yellow surffish) with additional catch reporting requirements.
6. Formulate and apply standardised species names for the fishery; and produce a comprehensive fishery species ID guide.
7. Implement a multispecies fishery harvest strategy for the Seychelles sea cucumber fishery
8. Implement a comprehensive and representative system of closed areas in deeper non-reef areas throughout the fishery area (target 30% of each fishery area).
9. Investigate the utility of a rotational harvest scheme to reduce risk.

10. Investigate potential for stock enhancement approaches (reseeding, broodstock aggregation etc).

Conclusion

The Seychelles sea cucumber fishery could be characterised as being at somewhat of a crossroads in many ways. It has forged ahead while fishing down its natural capital and now finds itself sliding rapidly into fishery "dept" – despite several studies over the years advising lower catch rates. It is fortunate that some species appear to be somewhat resilient to heavy fishing pressure (e.g. Pentard, Prickly redfish); however, even some of those are now showing signs of over-exploitation.

This has been driven by the short-term economic imperative to maximise the catch and profits, and while there may be some economic advantage to fishing hard now, even with some risks (considering economic discounting, efficiency etc), that approach is almost guaranteed to deprive future generations to economic opportunities that a healthy fishery would provide.

Also, the reputation of the Seychelles sea cucumber fishery and Seychelles fisheries in general is at stake. There is increasing scrutiny on sea cucumber fisheries globally (e.g. through CITES listing), mostly in response to global overexploitation and stock collapses. If the Seychelles sea cucumber fishery can act and demonstrate sustainable fishing practices, then access to global markets will remain open, and possibly at a premium given the Seychelles growing reputation for environmental stewardship.

References

Allen Coral Atlas. 2020. Imagery, maps and monitoring of the world's tropical coral reefs. doi.org/10.5281/zenodo.3833242

Aumeeruddy, R., and R. Payet. 2004. Management of the Seychelles sea cucumber fishery: status and prospects. Rome (Italy) FAO. http://www.fao.org/docrep/007/y5501e/y5501e00.htm.

Aumeeruddy, R., T. Skewes, J. Dorizo, F. Carocci, H. A. de Lion, and M. Cedras. 2005. Resource assessment and management of the Seychelles sea cucumber fishery. Pages 1–37.

Aumeeruddy, R., and C. Conand. 2008. Seychelles: a hotspot of sea cucumber fisheries in Africa and the Indian Ocean region. Sea Cucumbers: A Global Review of Fisheries and trade. Fisheries and Aquaculture Technical Paper 516:195–209.

Becker, J. J., Sandwell, D. T., Smith, W. H. F., Braud, J., Binder, B., Depner, J., ... & Weatherall, P. (2009). Global bathymetry and elevation data at 30 arc seconds resolution: SRTM30_PLUS. Marine Geodesy, 32(4), 355-371.

Cahuzac, S., C. Conand, R. Govinden, A. Ebrahim, S. Marie, and M. Léopold. 2019. Size at sexual maturity of the Flower teatfish Holothuria (Microthele) sp. in the Seychelles. Beche-de-Mer information bulletin:8.

Cariglia, N., S. K. Wilson, N. A. J. Graham, R. Fisher, J. Robinson, R. Aumeeruddy, R. Quatre, and N. V. C. Polunin. 2013. Sea cucumbers in the Seychelles: effects of marine protected areas on high-value species. Aquatic Conservation: Marine and Freshwater Ecosystems 23:418–428.

Cochran, W. G. (1977). Sampling techniques. 3rd ed. John Wiley & Sons, New York

Koike, H. 2017. Fishery ecology of Seychelles' sea cucumber fishery. Doctor of philosophy in Zoology, University of Hawaii, Manoa. https://scholarspace.manoa.hawaii.edu/bitstream/10125/62829/2017-05-phd-koike.pdf.

Leopold, M. 2017. Estimating sea cucumber resource abundance in the Seychelles using spatially explicit fishery-dependant data. https://symposium.wiomsa.org/wp-content/uploads/2017/10/Leopold-M_Estimating-sea-cucumber-resource-abundance-in-the-Seychelles-using-spatially.pdf.

Leopold, M. 2019. Estimating sea cucumber resource abundance in Seychelles using fishery-dependent data. https://symposium.wiomsa.org/wp-content/uploads/2017/10/Leopold-M_Estimating-sea-cucumber-resource-abundance-in-the-Seychelles-using-spatially.pdf.

MRAG. 2012. Stock Assessment for the Sea Cucumber Fishery of the Seychelles. Page 75. MRAG Ltd, London.

MRAG. 2017. Assessment of Seychelles' Sea Cucumber Fishery. Page 58. MRAG Ltd, London.

MSC. 2018. MSC Fisheries Standard and Guidance v2.01.

Murphy, N., E. Plaganyi, S. Edgar, K. Salee, and T. Skewes. 2021. Stock survey of sea cucumbers in East Torres Strait. Page 138. Final report., CSIRO, Australia.

Murphy, N., M. Fischer, and T. Skewes. 2019. Torres Strait Beche-de-mer (Sea cucumber) species ID guide. Australian Fisheries Management Authority :60.

Muthiga, N.A., and C. Conand. 2014. Sea cucumbers in the western Indian Ocean: Improving management of an important but poorly understood resource. WIOMSA Book Series No. 13.:84.

O'Leary, B. C., M. Winther-Janson, J. M. Bainbridge, J. Aitken, J. P. Hawkins, and C. M. Roberts. 2016. Effective Coverage Targets for Ocean Protection. Conservation Letters 9:398–404.

Oury, N., M. Léopold, and H. Magalon. 2019. Isolation and characterization of microsatellite loci from three widespread tropical sea cucumbers of the genus Holothuria (Echinodermata, Holothuroidea), and cross-amplification among them. Molecular Biology Reports 46:3501–3510.

Plagányi, É. E., T. Skewes, N. Murphy, R. Pascual, and M. Fischer. 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.

Purcell, S. W., P. Ngaluafe, G. Wang, and W. Lalavanua. 2017. Market value of flower teatfish ("Pentard"): A highly exploited Indian Ocean holothuroid. Beche-de-mer Bulletin:5.

Purcell, S.W., Y. Samyn, and C. Conand. 2012. Commercially important Sea Cucumbers of the World. FAO, Rome.

SFA. 2021. Economic Impact of the Seychelles Sea Cucumber Fishery and Industry. Page 37. Seychelles Fishing Authority Fisheries Economics. https://www.sfa.sc/index.php/e-library/fisheries-report?task=download.send&id=131&catid=21&m=0.

Skewes, T.D., and R. Aumeeruddy. 2006. Seychelles sea cucumber species guide.

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

Uthicke, S., D. Welch, and J.A.H. Benzie. 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 18:1395–1404.

Appendix A Survey timing issues

Reasons to start survey at same time:

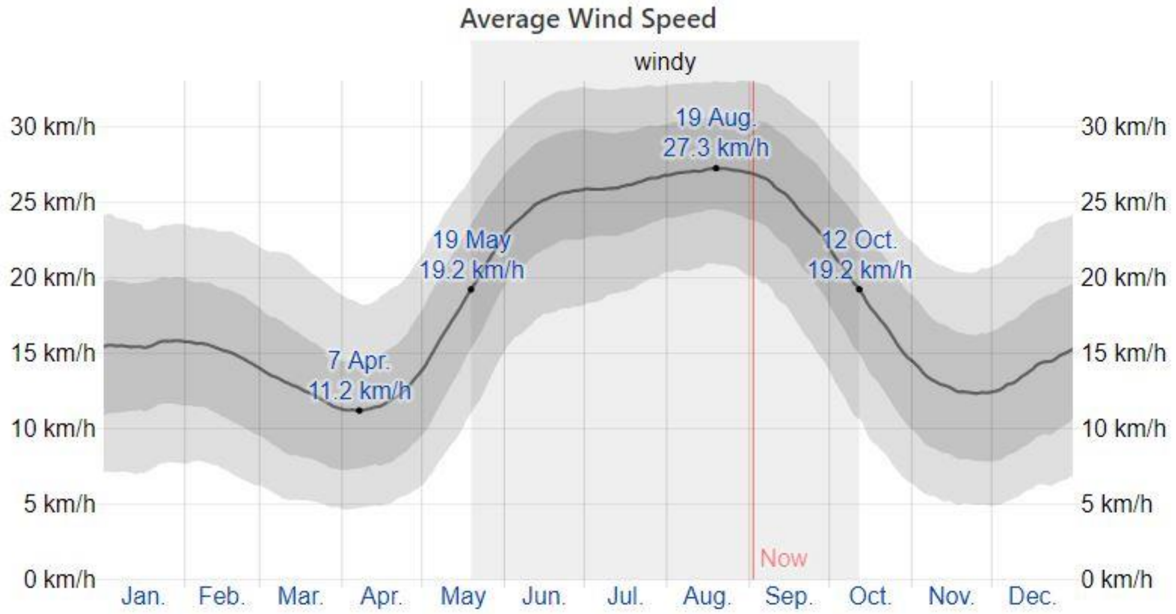
- Fisheries that target short lived species where there is a high exploitation rate
- Fisheries where fishing activity may influence stock behaviour
- Where the assessment of status relies on depletion of some kind (i.e. depletion experiments)
- Where the results of the survey could be used to manage the fishing activity later in the season.

Reasons to maintain flexibility:

- Logistical considerations
- Getting industry participation
- Choosing the best weather window
    - Relate issues such as:
    - Safety
    - Efficiency
    - Morale
    - Risk

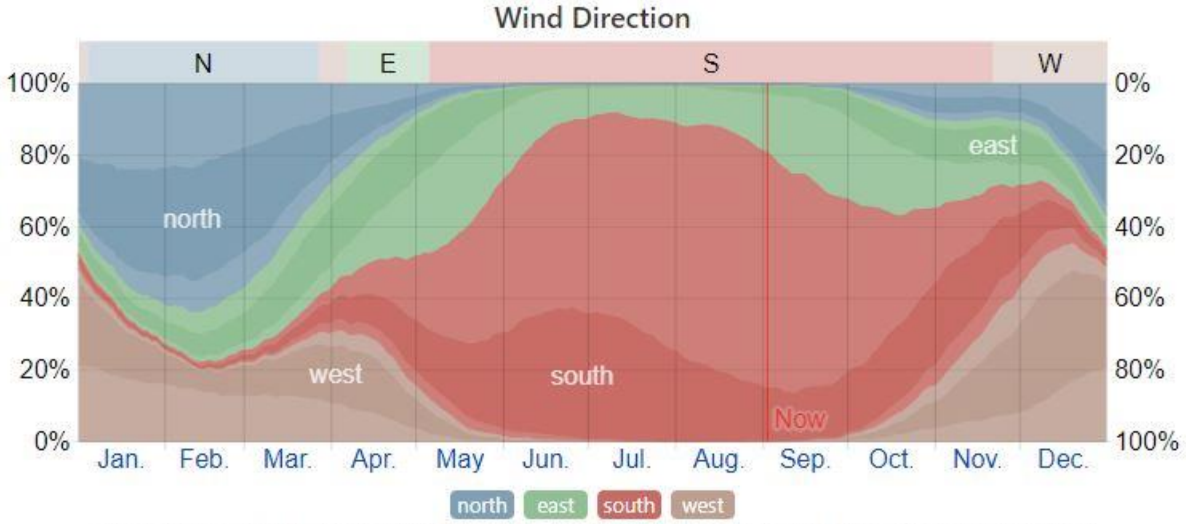
Table 12. Average catches for the period 2009-2017 and population estimates from surveys in 2004 and 2011-12.

Species	Average catch 2009 - 2017	2004 Survey	2011-12 Survey
White teatfish	0.076M	3.045M	2.262M
Pentard/Flower teatfish	0.252M	2.334M	1.402M
Prickly redfish	0.043M	2.529M	2.107M



Average Wind Speed

The average of mean hourly wind speeds (dark gray line), with 25th to 75th and 10th to 90th percentile bands.



Wind Direction

The percentage of hours in which the mean wind direction is from each of the four cardinal wind directions, excluding hours in which the mean wind speed is less than 1.6 km/h. The lightly tinted areas at the boundaries are the percentage of hours spent in the implied intermediate directions (northeast, southeast, southwest, and northwest).

Figure 38. Average wind speed and direction for Mahe Island (https://weatherspark.com/)

Appendix B Depth Analysis

Two broadscale region bathymetry maps were available: the GEBCO 2021 bathymetry and the Global Multi-Resolution Topography (GMRT) dataset, with the later considered as being the best available (NOAA) (Figure 39). The spatial resolution of the GEBCO2021 is 15 arc-second interval grid (approximately 500 m) and the spatial resolution of the GMRT v3.9 is approximately 120 m.

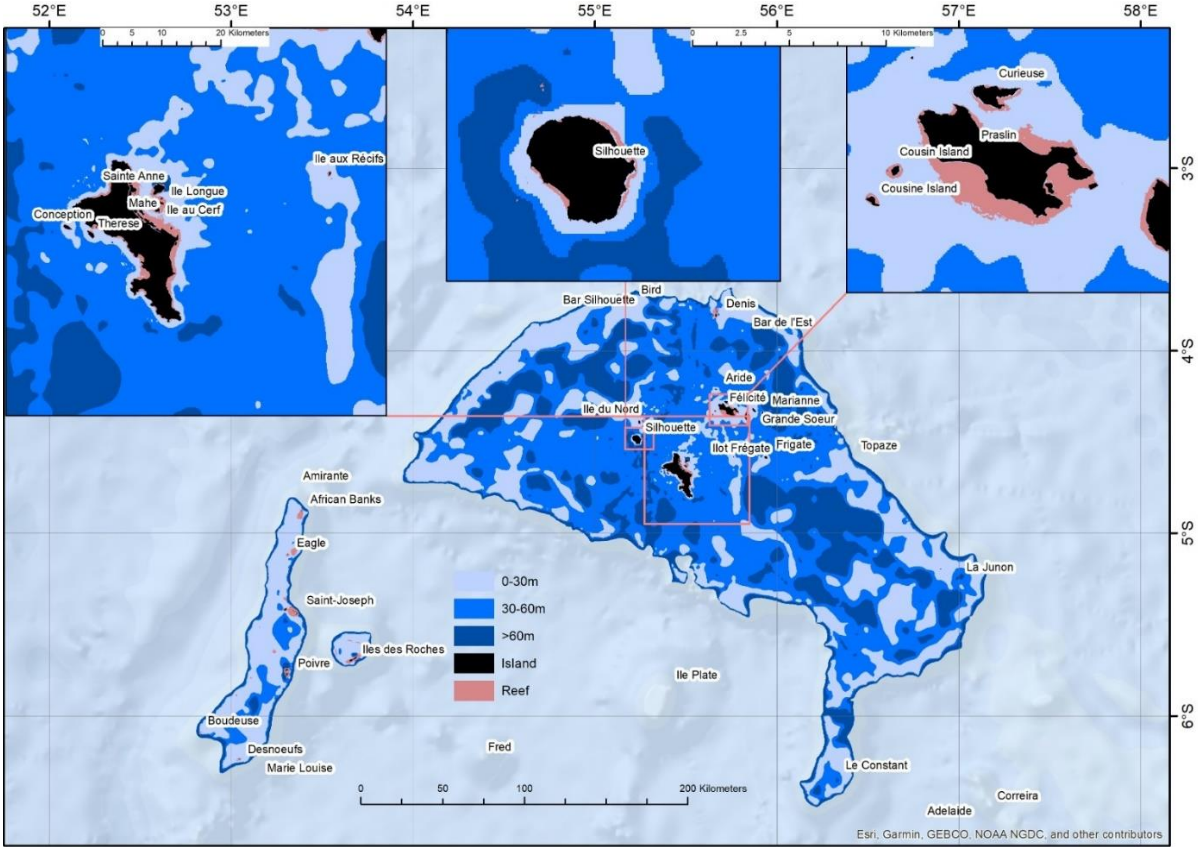


Figure 39. GMRT V3.9 depth map from NOAA.

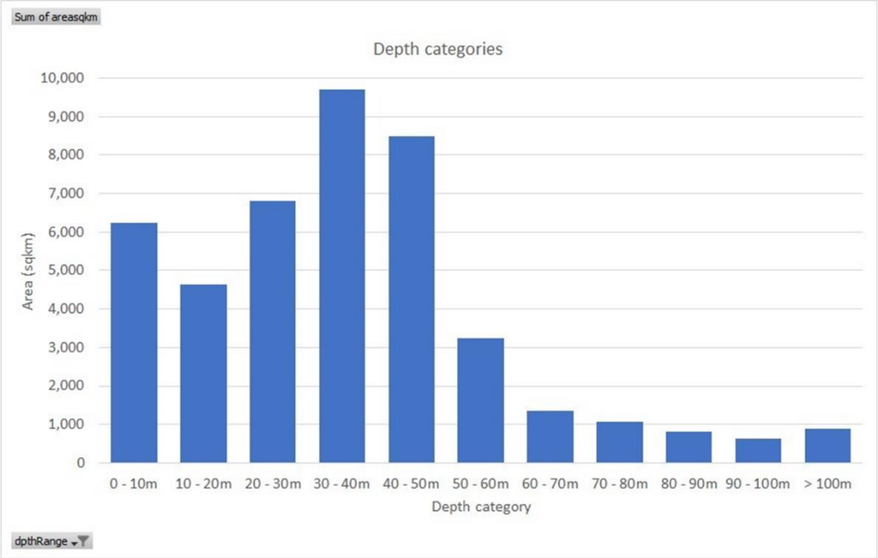


Figure 40. Area of depth categories from GMRT.

Depth sounder data was collected during the 2004 survey. This was regressed against the GEBCO2021 and GMRT v3.9 spatial layers (Figure 41, Figure 42). The purpose of the analysis was to test the bathymetry data to determine if it was suitable for creating depth categories for estimating stratified density estimates.

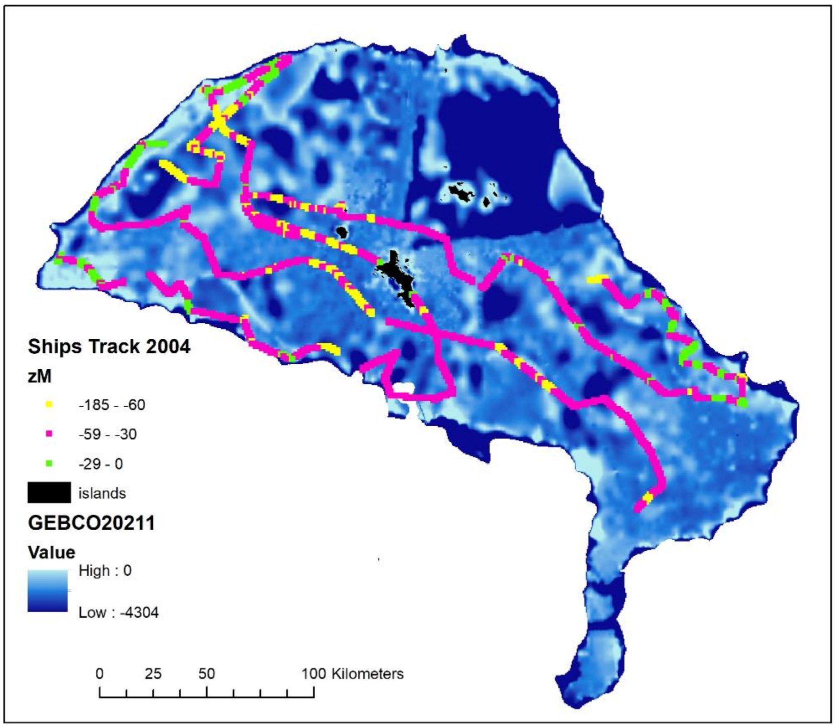


Figure 41 Ships track depth soundings for 2004 survey overlain on GEBCO 2021-22 bathymetry.

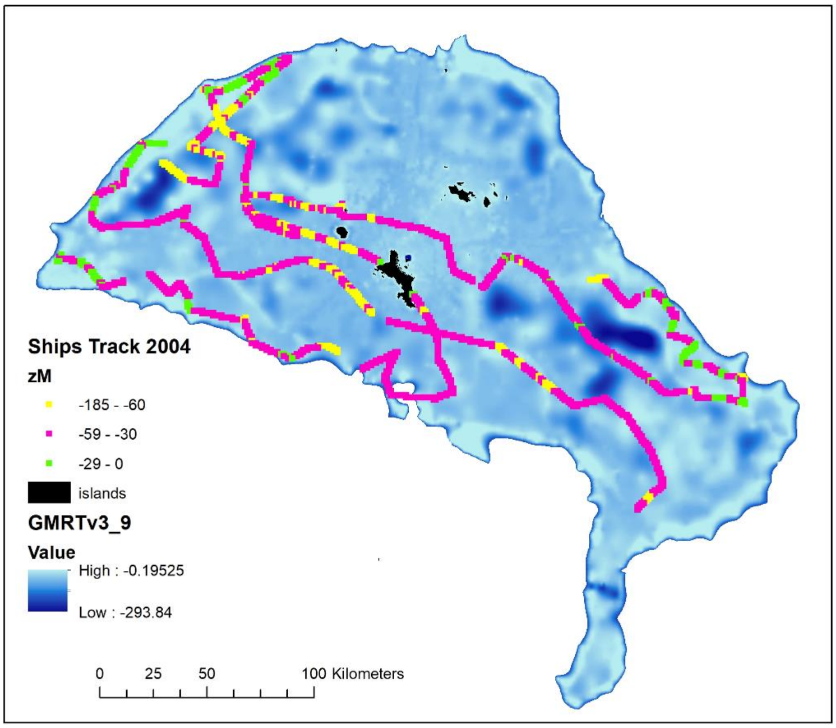


Figure 42 Ships track depth soundings for 2004 survey overlain on GMRT v3.9 bathymetry.

The regression of GEBCO 2021 depths against depth soundings from the 2004 survey indicated that there was a poor fit with an R^2 of 0.14 (Figure 43). Similarly, the regression of GMRT v3.9 depths against intermittent depth soundings from the 2004 survey indicated that there was a poor fit with an R^2 of 0.06.

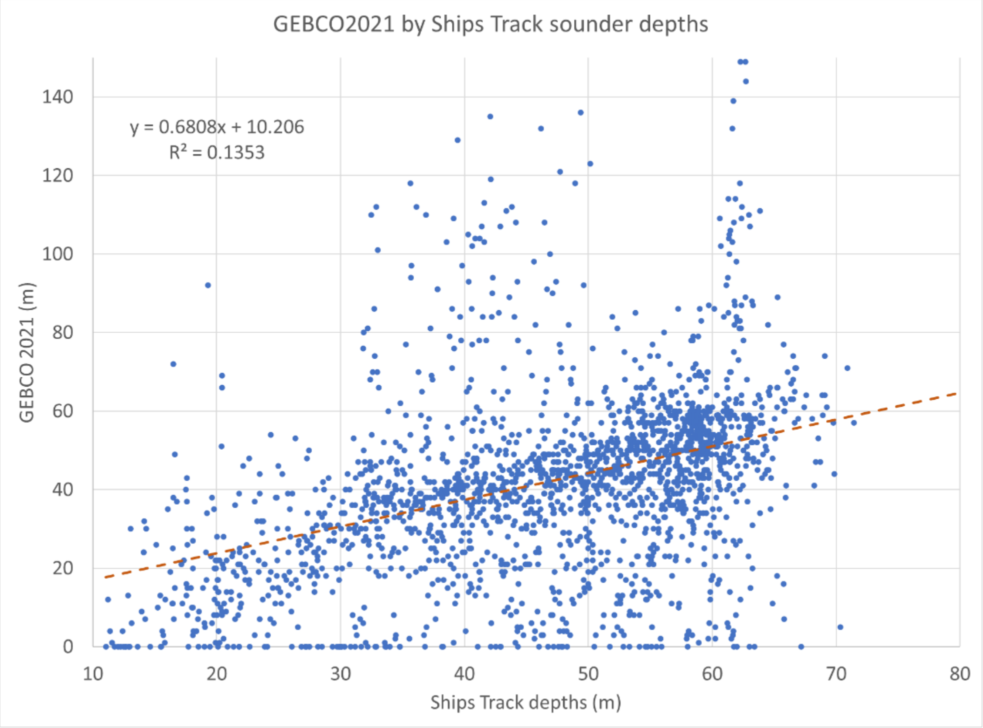


Figure 43 Regression analysis of GEBCO 2021 bathymetry against 2004 survey ship tracks depth soundings.

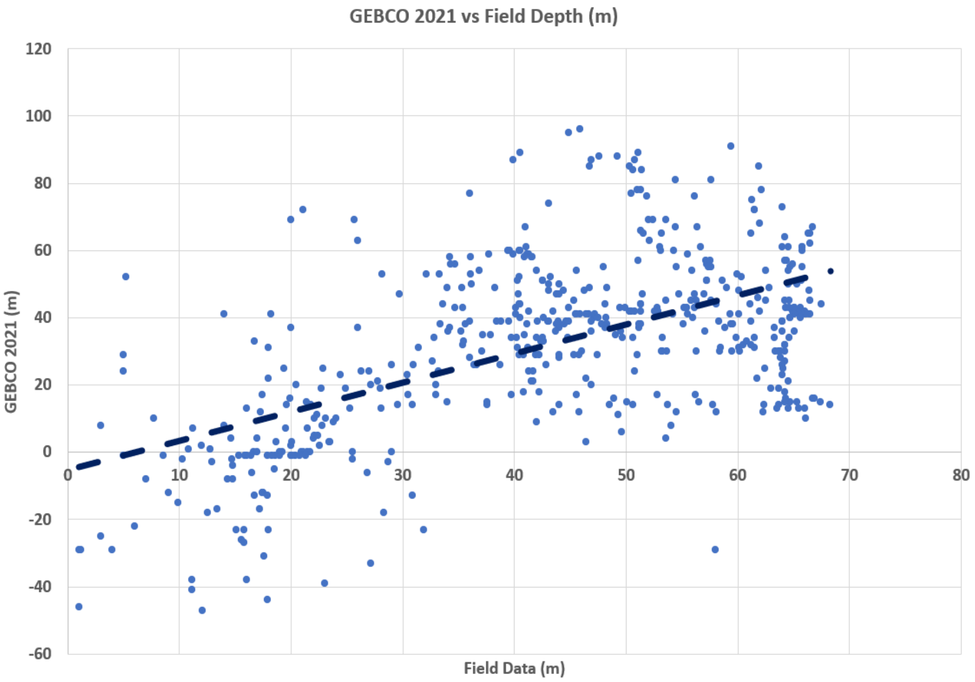


Figure 44. Regression of GEBCO2021 bathymetry data against survey field data (R^2 = 0.334).

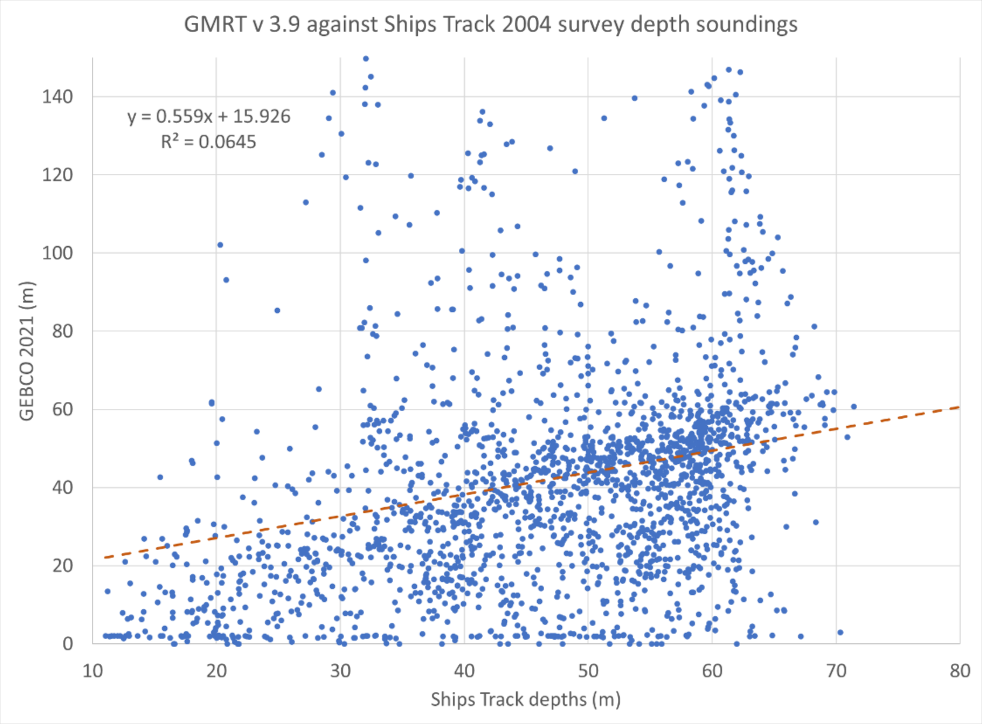


Figure 45 Regression analysis of GMRT v 3.9 bathymetry against 2004 survey ship tracks depth soundings.

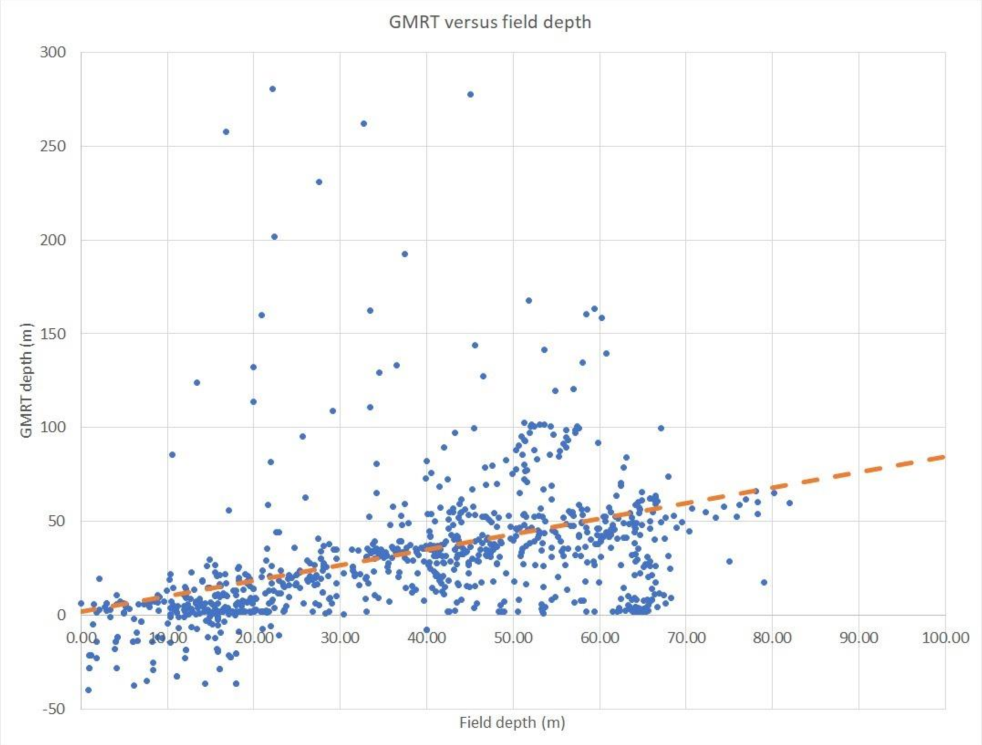


Figure 46. Regression analysis of GMRT v 3.9 bathymetry versus survey field data depths (R^2 = 0.037).

Based on these poor fits a decision was made to base area estimates for depth categories on the depth soundings from the ships track (Figure 47). It assumes that the ships track is a representative sample of depths on Mahe and Amirante plateaus.

The Amirantes was generally shallower than the Mahe Plateau (Figure 48, Figure 49). Three quarters of the Mahe plateau had depths between 30 and 60m (Figure 49)

Note that the ship track data can only be applied non-reef benthic areas as ships don't like going into shallow water, but for the deeper areas it is useful, and shows there is a lot of fishing ground in the 50-60 m depth range.

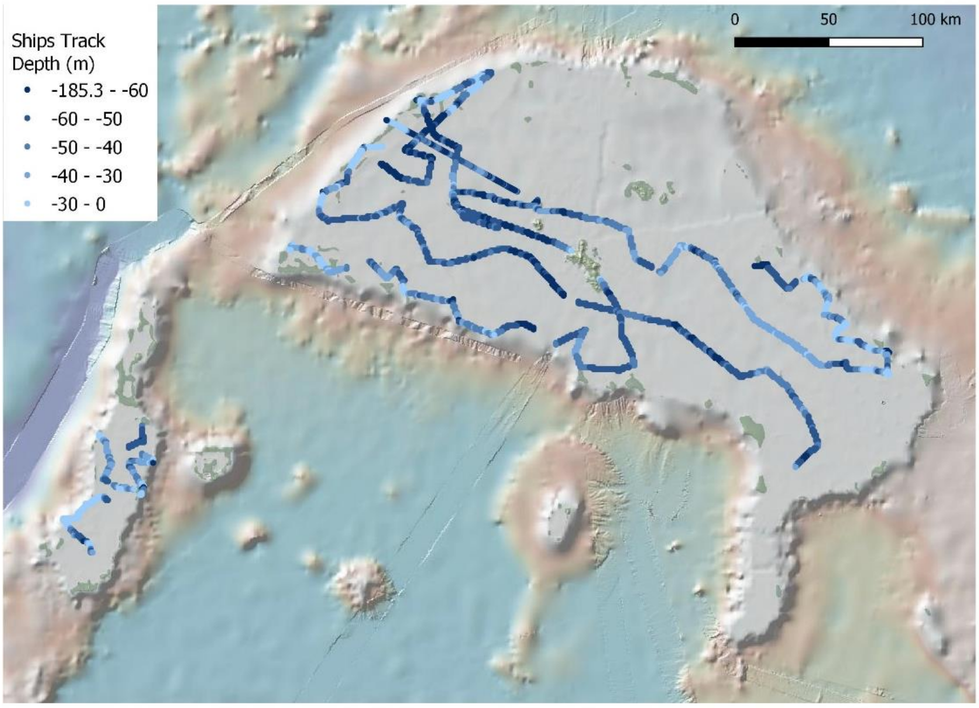


Figure 47. Ships track and depth from 2004 survey.

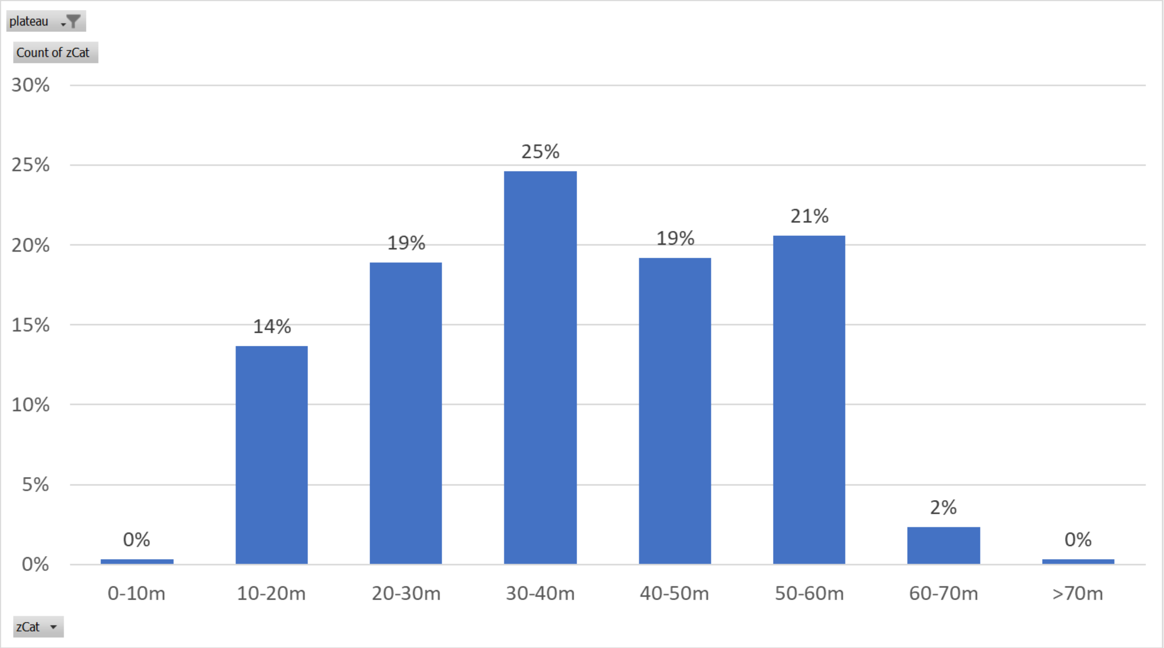


Figure 48. Proportion of Amirante plateau by depth category based on ships depth soundings 2004 survey.

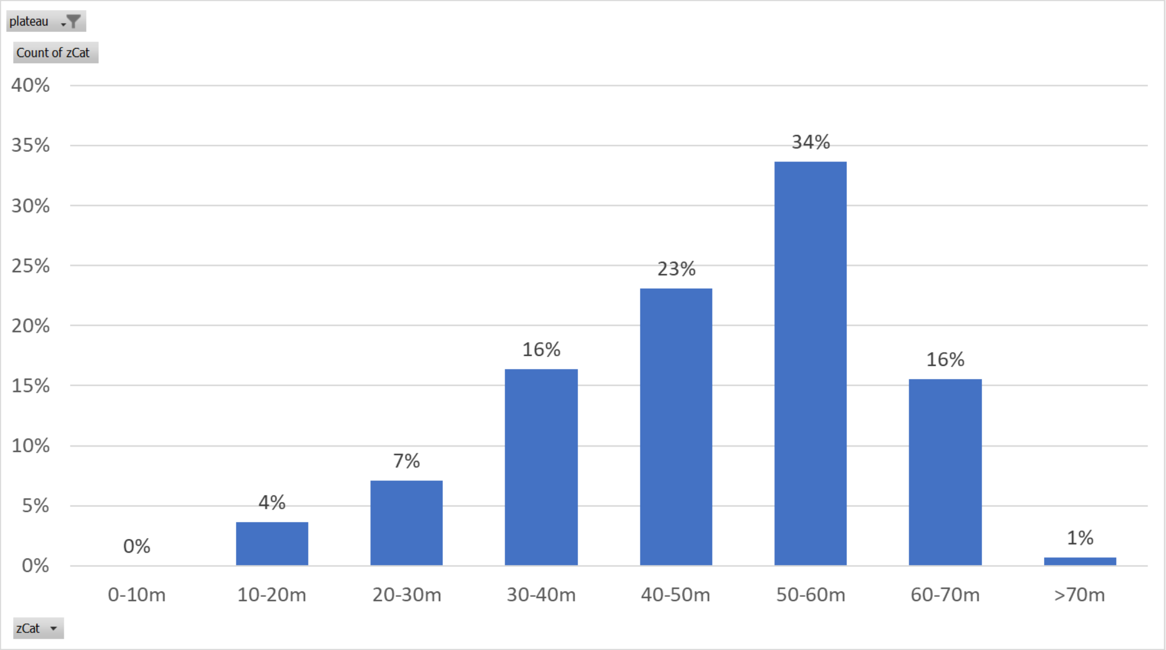


Figure 49. Proportion of Mahe plateau by depth category based on ships depth soundings 2004 survey.

Appendix C Bathymetry profiles

The following shows bathymetry profiles for selected ships tracks from the 2004 survey.

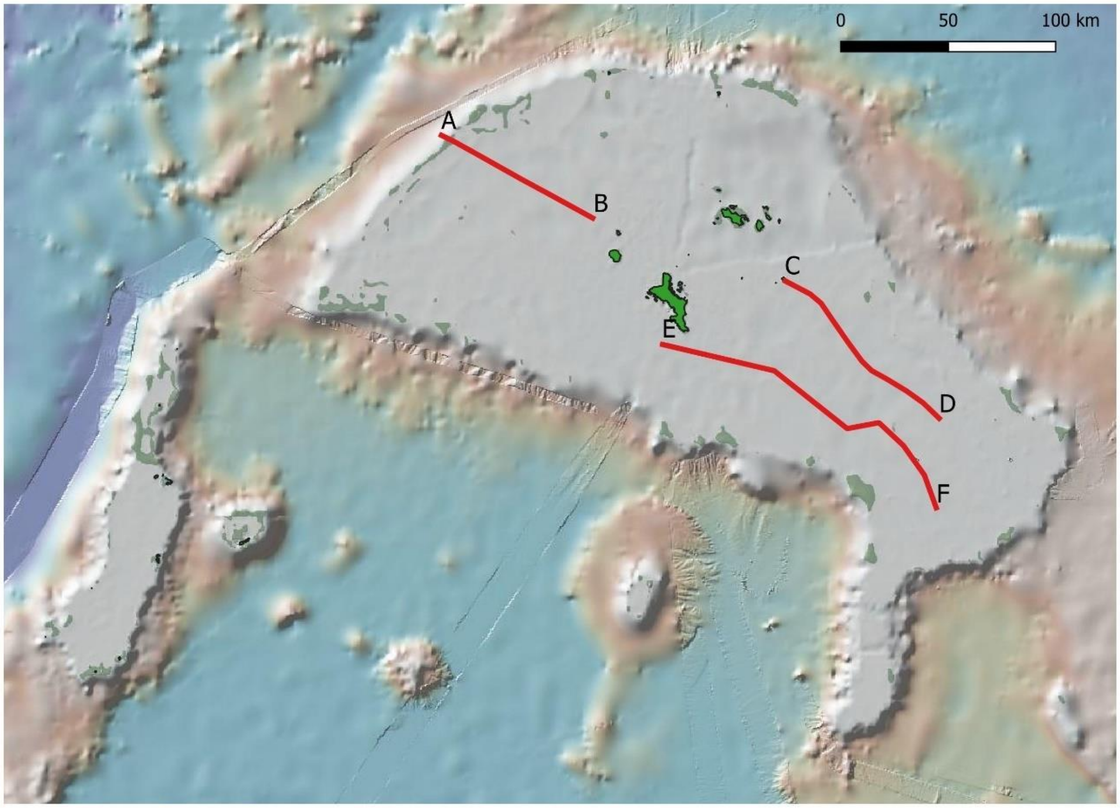


Figure 50. Bathymetric depth profiles from ships tracks recorded in 2004.

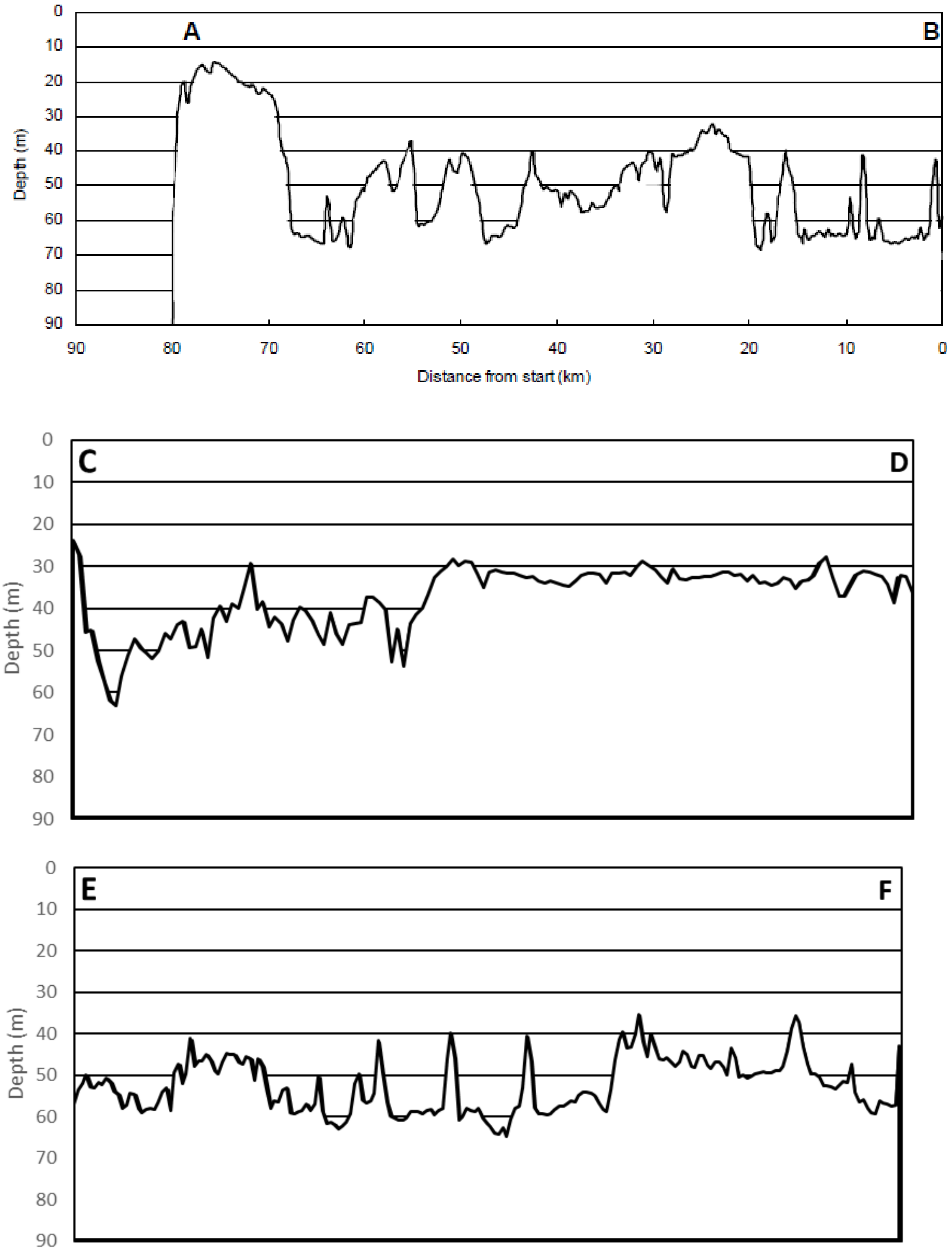


Figure 51. Depth profiles from 2004 survey. Letters refer to locations on map in Figure 50.

Appendix D Survey sites

Site	Latitude (S) (d.ddddd)	Lonitude E (d.ddddd)	Type	Depth (m)	Strata name	Leg
S005	-6.16718	52.97833	Additional ROV	-	Amirantes Non-reef 30-60m	3
S006	-6.07725	52.90192	Additional ROV	-	Amirantes Non-reef 30-60m	3
S008	-6.16416	53.06826	Additional ROV	-	Amirantes Non-reef 30-60m	3
S009	-5.98430	53.00038	Priority ROV	40.4	Amirantes Non-reef 30-60m	3
S015	-5.70710	53.12866	Priority ROV	36.0	Amirantes Non-reef 30-60m	3
S016	-5.52723	53.15271	Priority ROV	45.9	Amirantes Non-reef 30-60m	3
S017	-6.01927	53.18024	Additional ROV	-	Amirantes Non-reef 0-30m	3
S018	-5.92934	53.19826	Additional ROV	-	Amirantes Non-reef 30-60m	3
S020	-5.74948	53.21859	Priority ROV	40.5	Amirantes Non-reef 30-60m	3
S021	-5.65954	53.16464	Priority ROV	39.5	Amirantes Non-reef 30-60m	3
S022	-5.56961	53.24265	Additional ROV	-	Amirantes Non-reef 0-30m	3
S025	-5.20988	53.19189	Priority Dive	21.6	Amirantes Non-reef 0-30m	3
S027	-5.71602	53.30852	Priority ROV	44.5	Amirantes Non-reef 30-60m	3
S030	-5.44622	53.27461	Priority ROV	46.3	Amirantes Non-reef 30-60m	3
S031	-5.35629	53.25892	Priority Dive	29.1	Amirantes Non-reef 30-60m	3
S036	-5.77201	53.30025	Priority Dive	13.4	Amirantes Reef 0-30m	3
S038	-5.76812	53.32040	Priority Dive	16.0	Amirantes Reef 0-30m	3
S042	-5.45014	53.33999	Priority Dive	14.0	Amirantes Reef 0-30m	3
S047	-5.07624	53.36218	Priority Dive	12.5	Amirantes Reef 0-30m	3
S055	-5.91130	52.94560	Priority Dive	22.2	Amirantes Non-reef 0-30m	3
S056	-5.90275	53.01305	Priority Dive	19.6	Amirantes Non-reef 0-30m	3
S060	-5.76456	53.09341	Priority Dive	22.1	Amirantes Non-reef 0-30m	3
S061	-5.49476	53.10834	Priority Dive	17.4	Amirantes Non-reef 0-30m	3
S064	-5.28959	53.21617	Priority Dive	17.6	Amirantes Non-reef 0-30m	3
S065	-5.28410	53.28336	Priority Dive	28.3	Amirantes Non-reef 0-30m	3
S066	-4.94685	53.31611	Priority Dive	18.5	Amirantes Non-reef 0-30m	3
S067	-5.08831	53.38193	Priority Dive	26.0	Amirantes Non-reef 30-60m	3
S068	-5.70701	53.61055	Priority ROV	31.9	Amirantes Non-reef 30-60m	3
S069	-5.63956	53.58904	Priority Dive	14.6	Amirantes Non-reef 0-30m	3
S074	-4.45741	54.87717	Priority ROV	58.7	Mahe Non-reef 30-60m	2
S076	-4.66140	54.70798	Priority ROV	60.0	Mahe Non-reef >60m	2
S080	-3.76708	55.48387	Additional ROV	-	Mahe Non-reef 0-30m	2
S091	-4.80121	56.43350	Priority ROV	48.2	Mahe Non-reef 30-60m	4

Site	Latitude (S) (d.ddddd)	Lonitude E (d.ddddd)	Type	Depth (m)	Strata name	Leg
S093	-4.92606	56.60834	Priority ROV	42.5	Mahe Non-reef 30-60m	4
S097	-4.66059	54.42650	Priority ROV	53.0	Mahe Non-reef 30-60m	2
S098	-4.69957	54.55366	Priority ROV	52.8	Mahe Non-reef 30-60m	2
S100	-4.51366	54.64985	Priority ROV	58.1	Mahe Non-reef 30-60m	3
S101	-4.67025	54.80799	Priority ROV	44.1	Mahe Non-reef 30-60m	2
S107	-4.00535	55.23214	Additional ROV	-	Mahe Non-reef 30-60m	2
S109	-4.07592	55.48647	Additional ROV	-	Mahe Non-reef 0-30m	2
S110	-5.03253	55.64153	Priority ROV	57.2	Mahe Non-reef 30-60m	1
S111	-4.90537	55.62483	Priority ROV	55.2	Mahe Non-reef 30-60m	1
S112	-4.01522	55.61364	Additional ROV	-	Mahe Non-reef 30-60m	2
S113	-3.88805	55.70305	Additional ROV	-	Mahe Non-reef 30-60m	2
S116	-4.02326	55.74080	Priority ROV	53.2	Mahe Non-reef 30-60m	2
S117	-3.76893	55.74850	Priority ROV	49.6	Mahe Non-reef 30-60m	2
S119	-4.84839	55.87916	Priority ROV	58.0	Mahe Non-reef 30-60m	4
S120	-4.08541	55.86727	Priority ROV	51.5	Mahe Non-reef 30-60m	2
S121	-3.95824	55.86797	Priority ROV	57.6	Mahe Non-reef 30-60m	2
S123	-4.79796	55.96767	Priority ROV	59.4	Mahe Non-reef >60m	4
S124	-4.67080	56.07963	Priority ROV	50.6	Mahe Non-reef 30-60m	4
S128	-5.21822	56.20846	Priority ROV	56.4	Mahe Non-reef 30-60m	4
S129	-4.83673	56.09484	Priority ROV	30.9	Mahe Non-reef 30-60m	4
S130	-4.58240	56.17582	Priority ROV	35.2	Mahe Non-reef 30-60m	4
S134	-5.18954	56.33563	Priority ROV	34.8	Mahe Non-reef 30-60m	4
S135	-4.93522	56.26065	Priority ROV	32.8	Mahe Non-reef 30-60m	4
S139	-5.27546	56.43854	Priority ROV	48.9	Mahe Non-reef 30-60m	4
S142	-5.54721	56.58214	Priority ROV	44.7	Mahe Non-reef 30-60m	4
S143	-5.42005	56.53194	Priority ROV	55.1	Mahe Non-reef 30-60m	4
S145	-5.16572	56.58995	Priority ROV	34.1	Mahe Non-reef 30-60m	4
S150	-5.15831	56.71712	Priority ROV	55.9	Mahe Non-reef 30-60m	4
S156	-4.45033	54.56037	Priority Dive	24.9	Mahe Non-reef 0-30m	2
S157	-4.62233	55.37048	Priority ROV	44.9	Mahe Non-reef 30-60m	1
S160	-4.61487	55.38938	Priority ROV	33.2	Mahe Non-reef 30-60m	1
S161	-4.51916	55.45835	Priority ROV	38.8	Mahe Non-reef 30-60m	1
S162	-4.59602	55.52256	Priority Dive	22.6	Mahe Non-reef 0-30m	1
S163	-4.31965	55.68166	Priority Dive	18.7	Mahe Reef 0-30m	4
S164	-3.78005	55.67687	Priority Dive	10.3	Mahe Reef 0-30m	2
S165	-4.36718	55.72381	Priority Dive	14.0	Mahe Non-reef 0-30m	4

Site	Latitude (S) (d.ddddd)	Lonitude E (d.ddddd)	Type	Depth (m)	Strata name	Leg
S166	-4.34363	55.79126	Priority Dive	20.0	Mahe Reef 0-30m	4
S167	-3.80403	55.81702	Priority Dive	24.5	Mahe Non-reef 0-30m	2
S179	-4.27910	54.31113	Priority ROV	53.6	Mahe Non-reef 30-60m	2
S180	-4.44524	54.44835	Priority ROV	55.6	Mahe Non-reef 30-60m	2
S186	-4.28876	54.69263	Priority ROV	51.6	Mahe Non-reef 30-60m	2
S189	-4.63791	54.93516	Priority ROV	57.4	Mahe Non-reef 30-60m	1
S190	-4.25642	54.81979	Priority ROV	37.1	Mahe Non-reef 30-60m	2
S191	-4.12925	54.84996	Priority ROV	54.5	Mahe Non-reef 30-60m	2
S194	-4.59933	55.06232	Priority ROV	57.2	Mahe Non-reef 30-60m	1
S196	-4.21784	54.94695	Priority ROV	36.2	Mahe Non-reef 30-60m	2
S197	-4.09067	54.97712	Priority ROV	57.4	Mahe Non-reef 30-60m	2
S203	-4.25833	55.07412	Priority ROV	33.4	Mahe Non-reef 30-60m	2
S206	-4.38684	55.21134	Priority ROV	38.7	Mahe Non-reef 30-60m	1
S209	-4.47512	55.41284	Priority ROV	43.5	Mahe Non-reef 30-60m	1
S212	-4.71175	55.57098	Priority ROV	41.3	Mahe Non-reef 30-60m	1
S213	-4.58458	55.54000	Priority ROV	33.0	Mahe Non-reef 30-60m	1
S214	-4.45742	55.46566	Priority ROV	50.5	Mahe Non-reef 30-60m	1
S215	-4.33025	55.45561	Additional ROV	-	Mahe Non-reef 30-60m	2
S216	-4.65104	55.69814	Priority ROV	35.4	Mahe Non-reef 30-60m	1
S217	-4.52388	55.66716	Priority ROV	37.1	Mahe Non-reef 30-60m	1
S221	-4.65908	55.82531	Priority ROV	40.2	Mahe Non-reef 30-60m	4
S225	-4.59406	55.95247	Priority Dive	11.3	Mahe Non-reef 0-30m	4
S231	-5.15970	55.69980	Priority ROV	49.1	Mahe Non-reef 30-60m	1
S237	-6.44320	56.30436	Priority ROV	36.0	Mahe Non-reef 30-60m	4
S238	-4.58850	54.04678	Priority ROV	31.4	Mahe Non-reef 30-60m	3
S239	-4.61452	54.13816	Priority Dive	22.4	Mahe Non-reef 0-30m	3
S240	-4.70741	54.22423	Priority ROV	30.9	Mahe Non-reef 30-60m	3
S242	-4.43761	54.17724	Priority ROV	49.3	Mahe Non-reef 30-60m	2
S244	-4.24039	54.31321	Priority ROV	46.9	Mahe Non-reef 30-60m	2
S245	-4.74018	54.49403	Priority ROV	38.3	Mahe Non-reef 30-60m	2
S246	-4.10970	54.47857	Priority Dive	18.2	Mahe Non-reef 0-30m	2
S248	-4.75774	54.58396	Priority ROV	47.2	Mahe Non-reef 30-60m	2
S250	-4.80695	54.65193	Priority Dive	21.6	Mahe Non-reef 0-30m	2
S251	-3.87275	54.77822	Priority Dive	12.9	Mahe Non-reef 0-30m	2
S254	-3.87574	54.86814	Priority ROV	46.5	Mahe Non-reef 30-60m	2
S255	-4.97525	54.91915	Priority ROV	50.5	Mahe Non-reef 30-60m	1

Site	Latitude (S) (d.ddddd)	Lonitude E (d.ddddd)	Type	Depth (m)	Strata name	Leg
S257	-3.80698	54.95008	Priority Dive	16.7	Mahe Non-reef 0-30m	2
S259	-3.75920	55.00620	Priority ROV	56.5	Mahe Non-reef 30-60m	2
S262	-5.05648	55.32004	Priority ROV	51.7	Mahe Non-reef 30-60m	1
S264	-5.09974	55.40997	Priority ROV	36.9	Mahe Non-reef 30-60m	1
S265	-5.17561	55.44019	Priority ROV	42.0	Mahe Non-reef 30-60m	1
S267	-4.99575	55.45874	Priority ROV	51.5	Mahe Non-reef 30-60m	1
S268	-5.18858	55.62006	Priority ROV	57.0	Mahe Non-reef 30-60m	1
S269	-5.09865	55.67977	Priority ROV	55.5	Mahe Non-reef 30-60m	1
S273	-4.73449	56.29267	Priority ROV	45.5	Mahe Non-reef 30-60m	4
S275	-6.28653	56.33110	Priority ROV	32.7	Mahe Non-reef 30-60m	4
S276	-5.92680	56.34589	Priority ROV	43.0	Mahe Non-reef 30-60m	4
S277	-5.83687	56.36222	Priority ROV	36.4	Mahe Non-reef 30-60m	4
S280	-4.76269	56.47254	Additional ROV	60.3	Mahe Non-reef >60m	4
S281	-4.75865	56.56247	Priority ROV	43.8	Mahe Non-reef 30-60m	4
S282	-4.93253	56.65295	Priority ROV	46.7	Mahe Non-reef 30-60m	4
S283	-4.84260	56.63043	Priority ROV	40.6	Mahe Non-reef 30-60m	4
S284	-5.05328	56.75895	Priority ROV	37.6	Mahe Non-reef 30-60m	4
S285	-4.96335	56.71779	Priority ROV	30.4	Mahe Non-reef 30-60m	4
S286	-5.18623	56.78918	Priority ROV	53.7	Mahe Non-reef 30-60m	4
S287	-5.09630	56.84889	Priority ROV	34.3	Mahe Non-reef 30-60m	4
S289	-5.19487	56.87911	Priority ROV	53.2	Mahe Non-reef 30-60m	4
S299	-4.62738	55.48993	Priority Dive	18.0	Mahe Reef 0-30m	1
S301	-4.61123	55.50965	Priority Dive	20.4	Mahe Reef 0-30m	1
S302	-4.29283	55.71010	Priority Dive	11.1	Mahe Reef 0-30m	4
S303	-4.30775	55.72510	Priority Dive	11.1	Mahe Reef 0-30m	4
S305	-4.30961	55.74524	Priority Dive	4.2	Mahe Reef 0-30m	4
S307	-4.46669	54.22312	Priority ROV	54.0	Mahe Non-reef 30-60m	2
S308	-4.33179	54.19778	Priority ROV	44.1	Mahe Non-reef 30-60m	2
S309	-4.11839	54.39174	Priority ROV	58.0	Mahe Non-reef >60m	2
S311	-3.89923	54.70708	Priority ROV	42.9	Mahe Non-reef 30-60m	2
S314	-6.10935	56.31183	Priority ROV	40.2	Mahe Non-reef 30-60m	4
S317	-4.68152	56.32349	Additional ROV	66.1	Mahe Non-reef >60m	4
S319	-4.74426	56.52584	Priority Dive	19.4	Mahe Non-reef 0-30m	4
S323	-4.67200	55.52075	Priority Dive	7.0	Mahe Reef 0-30m	1
S324	-4.73566	55.52824	Priority Dive	4.0	Mahe Reef 0-30m	1
S325	-4.71551	55.52394	Priority Dive	6.0	Mahe Reef 0-30m	1

Site	Latitude (S) (d.ddddd)	Lonitude E (d.ddddd)	Type	Depth (m)	Strata name	Leg
S326	-4.33803	55.70078	Priority Dive	5.0	Mahe Reef 0-30m	4
S328	-4.33312	55.70953	Priority Dive	3.0	Mahe Reef 0-30m	4
S333	-4.63282	55.52153	Priority Dive	16.6	Mahe Non-reef 0-30m	1
S337	-4.59289	55.42847	Priority Dive	10.4	Mahe Reef 0-30m	1
S339	-4.60402	55.41475	Priority ROV	30.1	Mahe Non-reef 30-60m	1
S343	-4.61388	55.40873	Priority Dive	17.8	Mahe Non-reef 0-30m	1
S345	-4.61687	55.39863	Priority Dive	11.1	Mahe Reef 0-30m	1
S346	-4.57968	55.43097	Priority Dive	13.6	Mahe Reef 0-30m	1
S348	-4.48133	55.53515	Priority Dive	15.4	Mahe Non-reef 0-30m	1
S350	-4.48702	55.53593	Priority Dive	17.4	Mahe Non-reef 0-30m	1
S355	-4.38752	55.30893	Priority ROV	37.0	Mahe Non-reef 30-60m	1
S357	-4.36505	55.31290	Priority Dive	22.7	Mahe Non-reef 0-30m	1
S358	-4.00230	54.54187	Priority Dive	14.8	Mahe Non-reef 0-30m	2
S359	-4.00718	54.54218	Priority Dive	14.6	Mahe Non-reef 0-30m	2
S360	-4.00927	54.54680	Priority Dive	15.9	Mahe Non-reef 0-30m	2
S361	-4.00650	54.55198	Priority Dive	17.4	Mahe Non-reef 0-30m	2
S362	-3.90025	54.66277	Priority Dive	16.4	Mahe Non-reef 0-30m	2
S363	-3.90473	54.66360	Priority Dive	15.6	Mahe Non-reef 0-30m	2
S364	-3.90503	54.66602	Priority Dive	14.8	Mahe Non-reef 0-30m	2
S365	-3.90612	54.67107	Priority Dive	20.1	Mahe Non-reef 0-30m	2
S366	-4.91730	53.39206	Priority Dive	16.2	Amirantes Reef 0-30m	3
S368	-4.88930	53.39675	Priority Dive	17.1	Amirantes Reef 0-30m	3
S369	-4.88403	53.39527	Priority Dive	5.2	Amirantes Reef 0-30m	3
S372	-5.01508	55.01583	Priority ROV	33.0	Mahe Non-reef 30-60m	1
S373	-4.64972	55.49515	Priority Dive	5.0	Mahe Reef 0-30m	1
S377	-4.35588	55.72133	Priority Dive	8.6	Mahe Reef 0-30m	4
S378	-4.30848	55.73077	Priority Dive	12.1	Mahe Reef 0-30m	4
S379	-3.72850	55.21092	Priority Dive	12.8	Mahe Reef 0-30m	2
S380	-3.72272	55.21537	Priority Dive	10.8	Mahe Reef 0-30m	2
S381	-4.46397	55.22207	Priority Dive	17.9	Mahe Reef 0-30m	1
S382	-4.47288	55.20660	Priority Dive	18.0	Mahe Reef 0-30m	1
S383	-4.51430	55.23487	Priority Dive	18.0	Mahe Reef 0-30m	1
S384	-4.50723	55.24947	Priority Dive	23.4	Mahe Reef 0-30m	1
S385	-4.49308	55.20963	Priority Dive	17.3	Mahe Reef 0-30m	1
S386	-6.03737	53.07025	Priority Dive	26.3	Amirantes Non-reef 0-30m	3
S388	-5.58800	53.66128	Priority Dive	7.7	Amirantes Reef 0-30m	3

Site	Latitude (S) (d.ddddd)	Lonitude E (d.ddddd)	Type	Depth (m)	Strata name	Leg
S389	-5.59947	53.71000	Priority Dive	23.8	Amirantes Reef 0-30m	3
S390	-5.65307	53.71817	Priority Dive	12.0	Amirantes Non-reef 0-30m	3
S391	-6.35625	56.36947	Priority Dive	29.0	Mahe Non-reef 0-30m	4
S392	-4.39685	54.18170	Priority Dive	20.1	Mahe Non-reef 0-30m	2
S393	-4.29833	54.27027	Priority Dive	27.8	Mahe Non-reef 0-30m	2
S394	-4.22383	54.32143	Priority Dive	21.4	Mahe Non-reef 0-30m	2
S395	-3.76343	54.96857	Priority Dive	27.0	Mahe Non-reef 0-30m	2
S396	-3.84950	54.81413	Priority Dive	16.5	Mahe Non-reef 0-30m	2
S397	-4.63807	55.37390	Priority Dive	16.0	Mahe Reef 0-30m	1
S398	-4.33127	54.81235	Priority ROV	30.5	Mahe Non-reef 30-60m	2
S399	-5.01892	53.26243	Priority Dive	23.0	Amirantes Non-reef 0-30m	3
S400	-5.17133	53.26597	Priority Dive	25.5	Amirantes Non-reef 0-30m	3
S402	-5.46038	53.33580	Priority ROV	31.0	Amirantes Non-reef 30-60m	3
S403	-5.52280	53.31347	Priority ROV	40.5	Amirantes Non-reef 30-60m	3
S404	-5.63390	53.25855	Priority Dive	29.8	Amirantes Non-reef 30-60m	3
S405	-5.59040	53.15993	Priority ROV	35.6	Amirantes Non-reef 30-60m	3
S406	-4.66480	54.18693	Priority Dive	21.8	Mahe Non-reef 0-30m	3
S407	-4.83553	54.70877	Priority ROV	49.5	Mahe Non-reef 30-60m	2
S408	-4.84907	54.81910	Priority ROV	58.9	Mahe Non-reef 30-60m	1
S409	-4.94388	54.85100	Priority ROV	50.8	Mahe Non-reef >60m	1
S410	-4.81263	56.22740	Priority ROV	43.1	Mahe Non-reef 30-60m	4
S411	-5.09623	56.90640	Priority ROV	50.1	Mahe Non-reef >60m	4
S412	-5.21300	56.92287	Priority Dive	22.7	Mahe Non-reef 0-30m	4
S413	-5.10582	56.51847	Priority ROV	35.5	Mahe Non-reef 30-60m	4
S414	-5.07383	56.47870	Priority ROV	36.1	Mahe Non-reef 30-60m	4
S415	-4.35932	55.01405	Priority ROV	44.9	Mahe Non-reef 30-60m	2
S416	-4.34013	54.92817	Priority ROV	44.9	Mahe Non-reef 30-60m	2
S417	-4.50347	55.09817	Priority ROV	59.6	Mahe Non-reef >60m	1
S418	-4.49903	55.20703	Priority ROV	41.1	Mahe Reef 30-60m	1
S419	-4.56188	55.36345	Priority ROV	46.9	Mahe Non-reef 30-60m	1
S420	-4.54575	55.49475	Priority ROV	36.7	Mahe Non-reef 30-60m	1
S421	-3.87033	55.85977	Priority ROV	45.9	Mahe Non-reef 30-60m	2
S422	-4.17978	54.95895	Priority ROV	41.0	Mahe Non-reef 30-60m	2
S423	-5.80177	53.14067	Priority ROV	33.4	Amirantes Non-reef 30-60m	3
S424	-6.40398	56.26725	Priority ROV	38.4	Mahe Non-reef 30-60m	4
S425	-5.65423	56.47467	Priority ROV	37.9	Mahe Non-reef 30-60m	4

Site	Latitude (S) (d.ddddd)	Lonitude E (d.ddddd)	Type	Depth (m)	Strata name	Leg
S426	-3.88655	54.66122	Priority ROV	51.1	Mahe Non-reef 30-60m	2
S428	-5.11840	53.32037	Priority Dive	17.0	Amirantes Reef 0-30m	3
S429	-5.62283	53.37565	Priority ROV	32.5	Amirantes Non-reef 30-60m	3
S430	-4.91745	53.39180	Priority Dive	9.0	Amirantes Reef 0-30m	3

Appendix E Provisional Cruise Schedule

E.1 Cruise 1, Legs 1 and 2.

Seq.	Date	Day	Activity
1	3/11/2021	Wed	Depart Mahe Island, Leg 1
2	4/11/2021	Thu	DIVE and ROV UVC
3	5/11/2021	Fri	DIVE and ROV UVC
4	6/11/2021	Sat	DIVE and ROV UVC
5	7/11/2021	Sun	DIVE and ROV UVC
6	8/11/2021	Mon	DIVE and ROV UVC
7	9/11/2021	Tue	DIVE and ROV UVC
8	10/11/2021	Wed	DIVE and ROV UVC
9	11/11/2021	Thu	DIVE and ROV UVC
10	12/11/2021	Fri	DIVE and ROV UVC
11	13/11/2021	Sat	DIVE and ROV UVC
12	14/11/2021	Sun	Return to Mahe Island, Leg 1
13	15/11/2021	Mon	Restock and repair
14	16/11/2021	Tue	Restock and repair
15	17/11/2021	Wed	Restock and repair
16	18/11/2021	Thu	Depart Mahe Island, Leg 2
17	19/11/2021	Fri	DIVE and ROV UVC
18	20/11/2021	Sat	DIVE and ROV UVC
19	21/11/2021	Sun	DIVE and ROV UVC
20	22/11/2021	Mon	DIVE and ROV UVC
21	23/11/2021	Tue	DIVE and ROV UVC
22	24/11/2021	Wed	DIVE and ROV UVC
23	25/11/2021	Thu	DIVE and ROV UVC
24	26/11/2021	Fri	DIVE and ROV UVC
25	27/11/2021	Sat	DIVE and ROV UVC
26	28/11/2021	Sun	DIVE and ROV UVC
27	29/11/2021	Mon	DIVE and ROV UVC
28	30/11/2021	Tue	Return to Mahe Island, Leg 2

Note: dive rest days will be scheduled where only ROV sites are done once every 5 days.

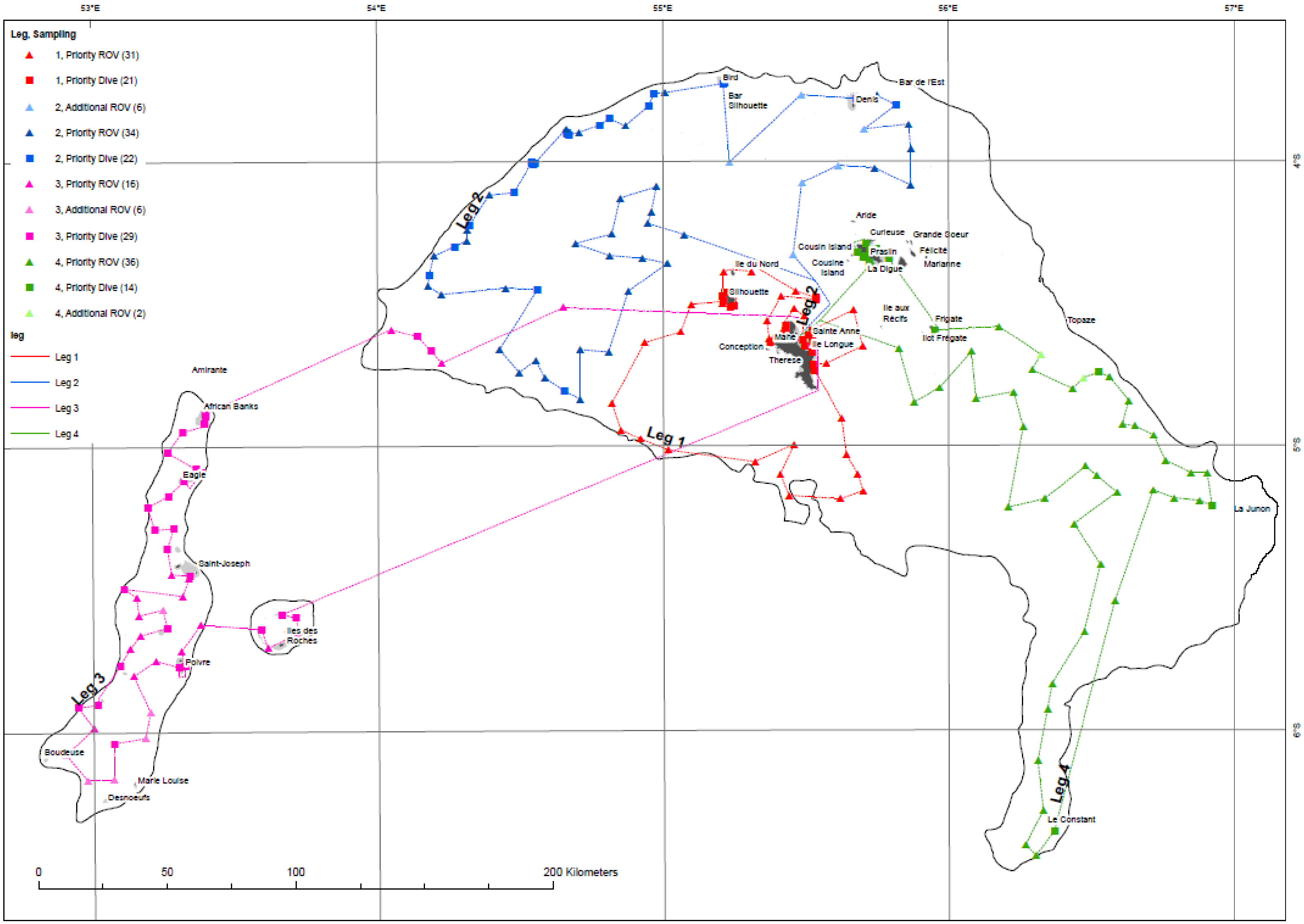
E.2 Cruise 2, Legs 3 and 4.

Seq.	Date	Day	Activity
1	28/02/2022	Mon	Depart Mahe Island, Leg 3
2	1/03/2022	Tue	DIVE and ROV UVC
3	2/03/2022	Wed	DIVE and ROV UVC
4	3/03/2022	Thu	DIVE and ROV UVC
5	4/03/2022	Fri	DIVE and ROV UVC
6	5/03/2022	Sat	DIVE and ROV UVC
7	6/03/2022	Sun	DIVE and ROV UVC
8	7/03/2022	Mon	DIVE and ROV UVC
9	8/03/2022	Tue	DIVE and ROV UVC
10	9/03/2022	Wed	DIVE and ROV UVC
11	10/03/2022	Thu	DIVE and ROV UVC
12	11/03/2022	Fri	DIVE and ROV UVC
13	12/03/2022	Sat	Return to Mahe Island, Leg 3
14	13/03/2022	Sun	Restock and repair
15	14/03/2022	Mon	Restock and repair
16	15/03/2022	Tue	Restock and repair
17	16/03/2022	Wed	Depart Mahe Island, Leg 4
18	17/03/2022	Thu	DIVE and ROV UVC
19	18/03/2022	Fri	DIVE and ROV UVC
20	19/03/2022	Sat	DIVE and ROV UVC
21	20/03/2022	Sun	DIVE and ROV UVC
22	21/03/2022	Mon	DIVE and ROV UVC
23	22/03/2022	Tue	DIVE and ROV UVC
24	23/03/2022	Wed	DIVE and ROV UVC
25	24/03/2022	Thu	DIVE and ROV UVC
26	25/03/2022	Fri	DIVE and ROV UVC
27	26/03/2022	Sat	DIVE and ROV UVC
28	27/03/2022	Sun	DIVE and ROV UVC
29	28/03/2022	Mon	Return to Mahe Island, Leg 4

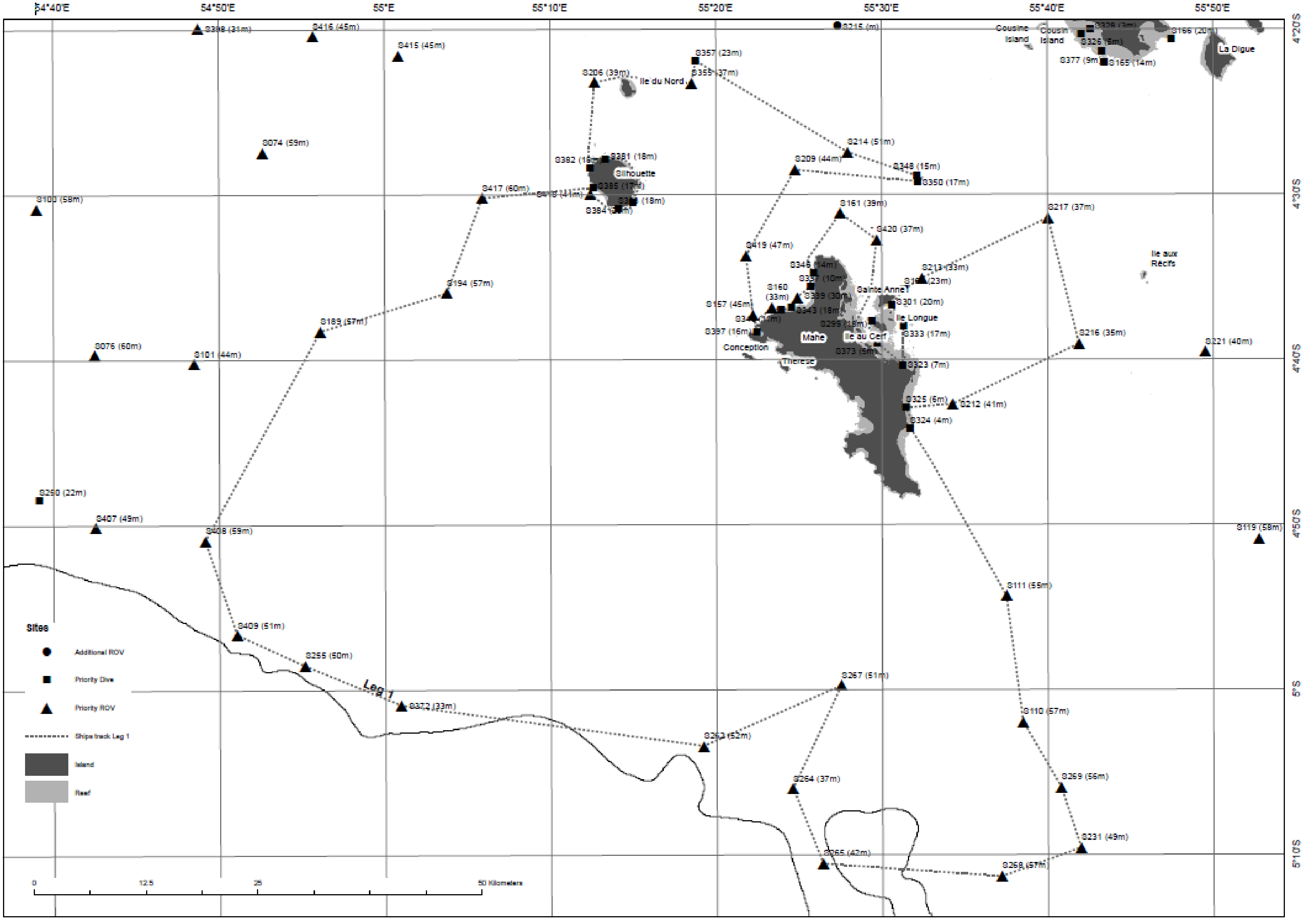
Note: dive rest days will be scheduled where only ROV sites are done once every 5 days.

Appendix F Provisional cruise ship paths

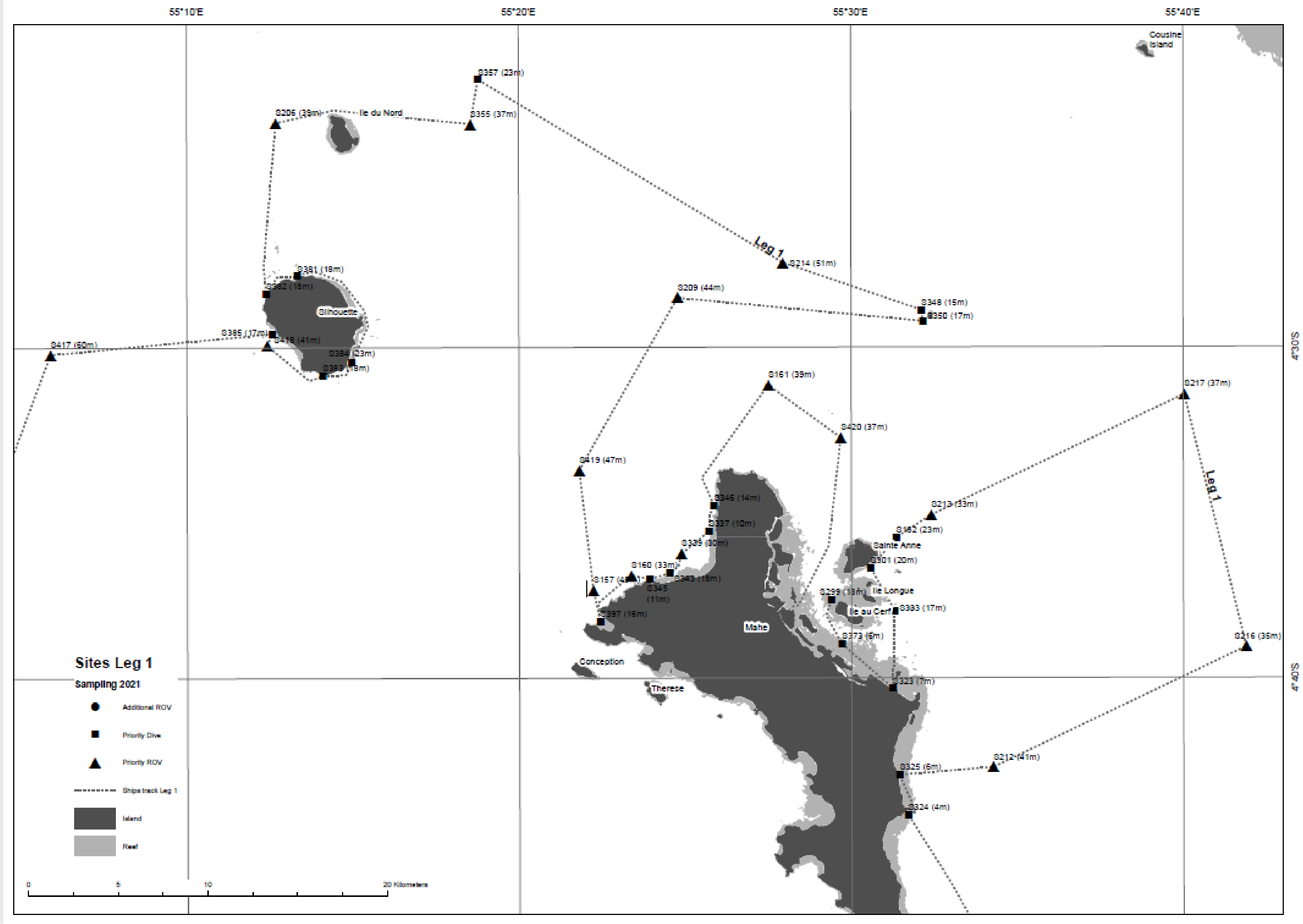
F.1 Overview Legs 1 to 4



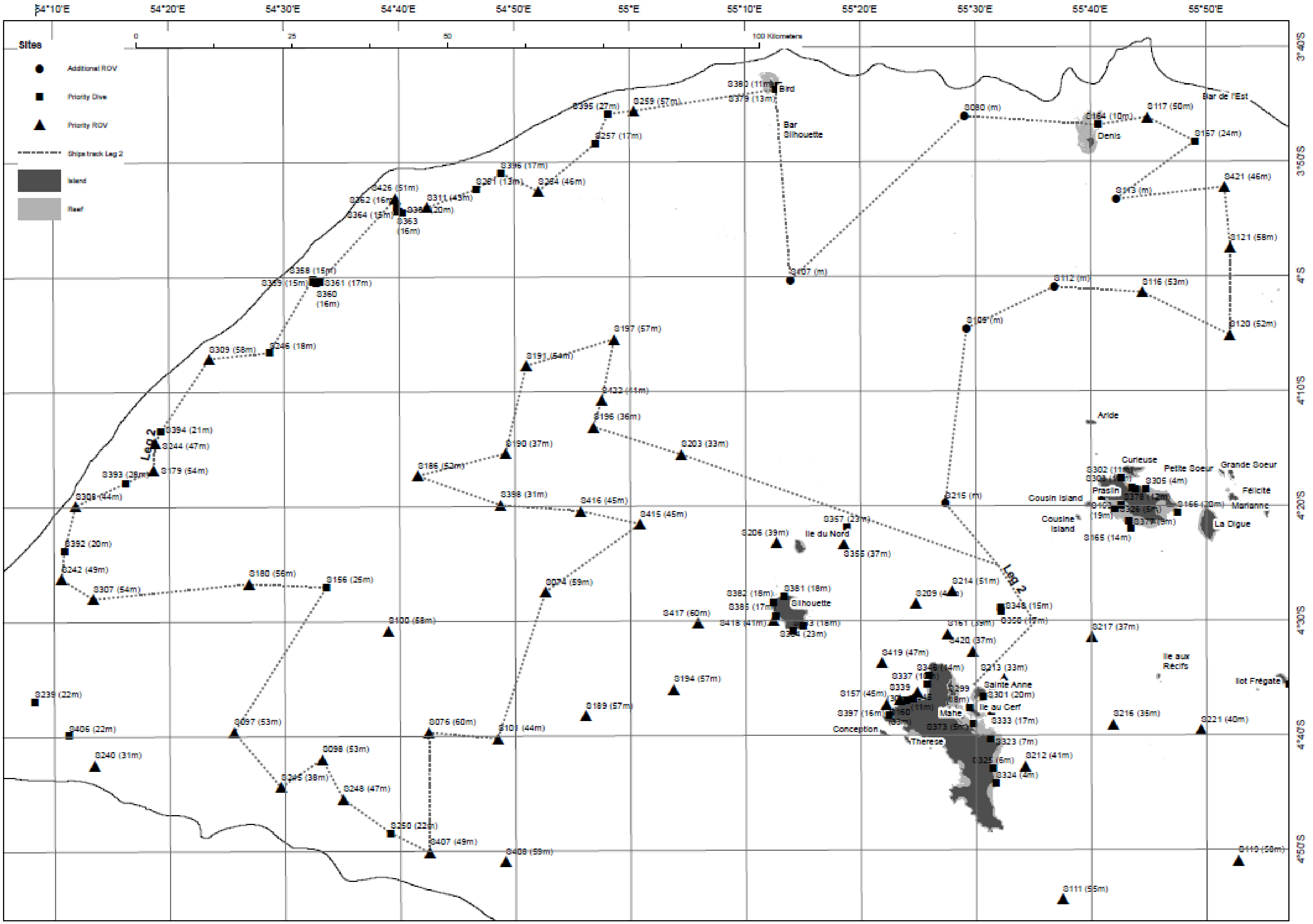
F.2 Leg 1 (52 sites)



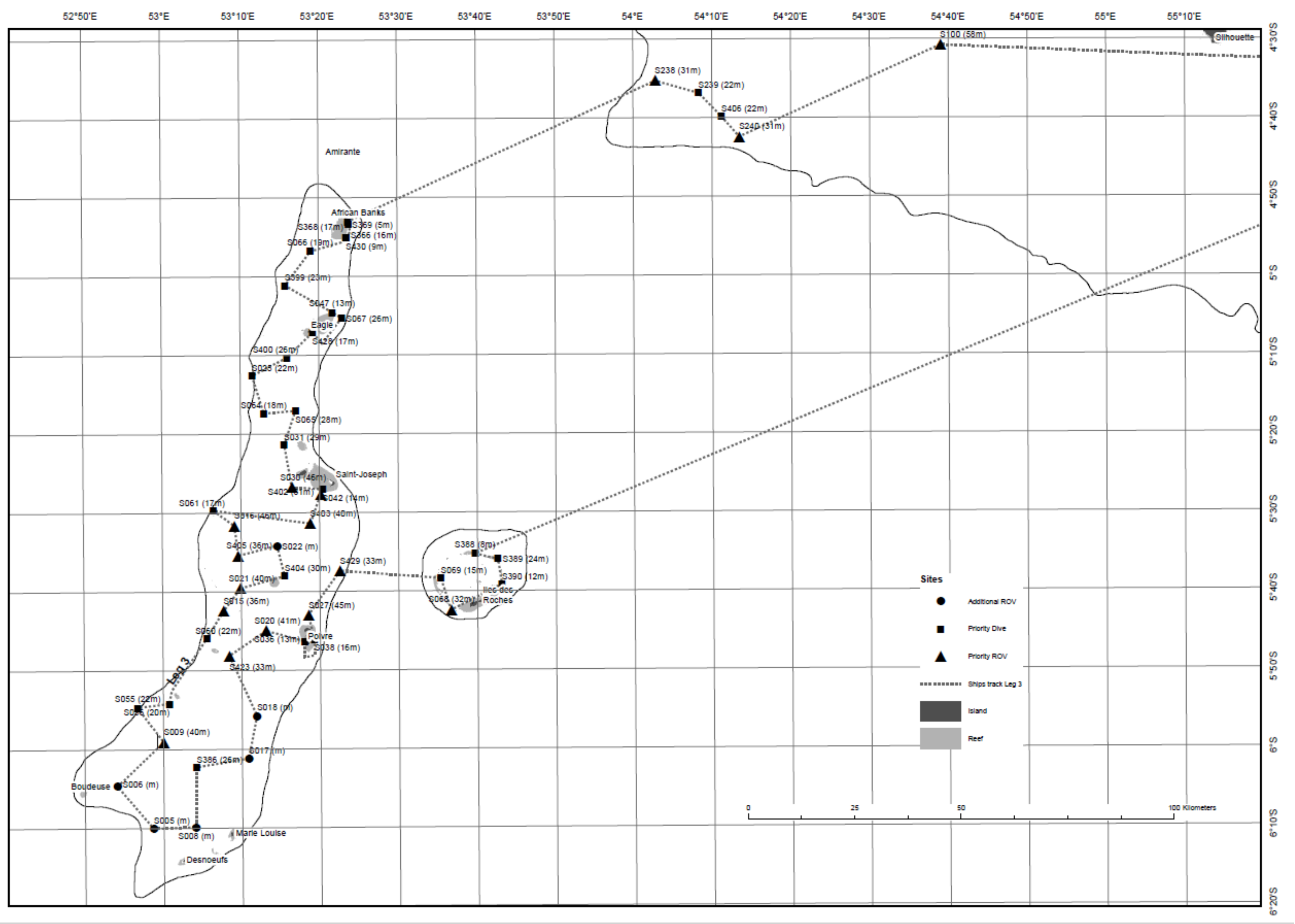
F.3 Leg 1 Mahe and Silhouette Islands



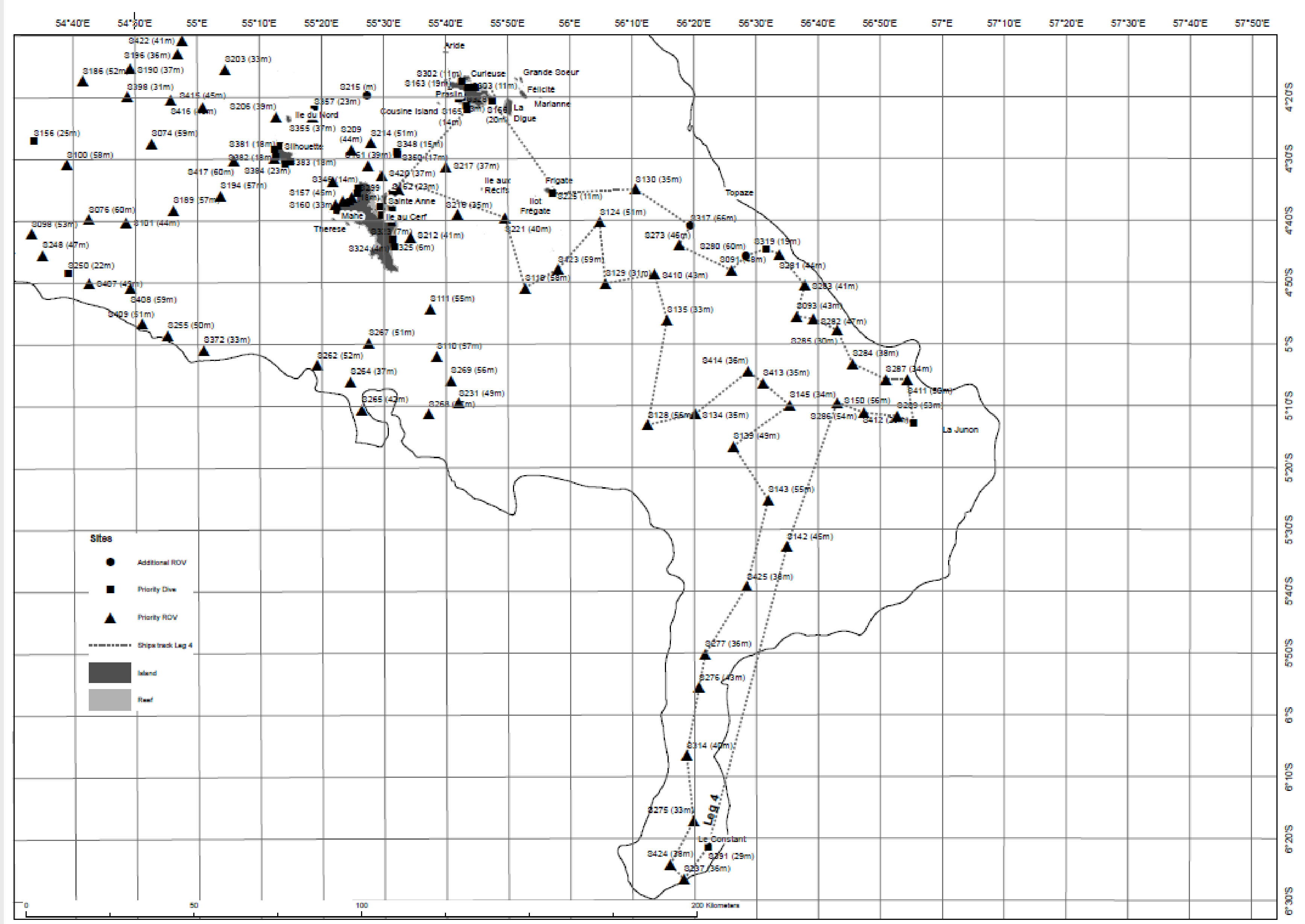
F.4 Leg 2 (62 sites)



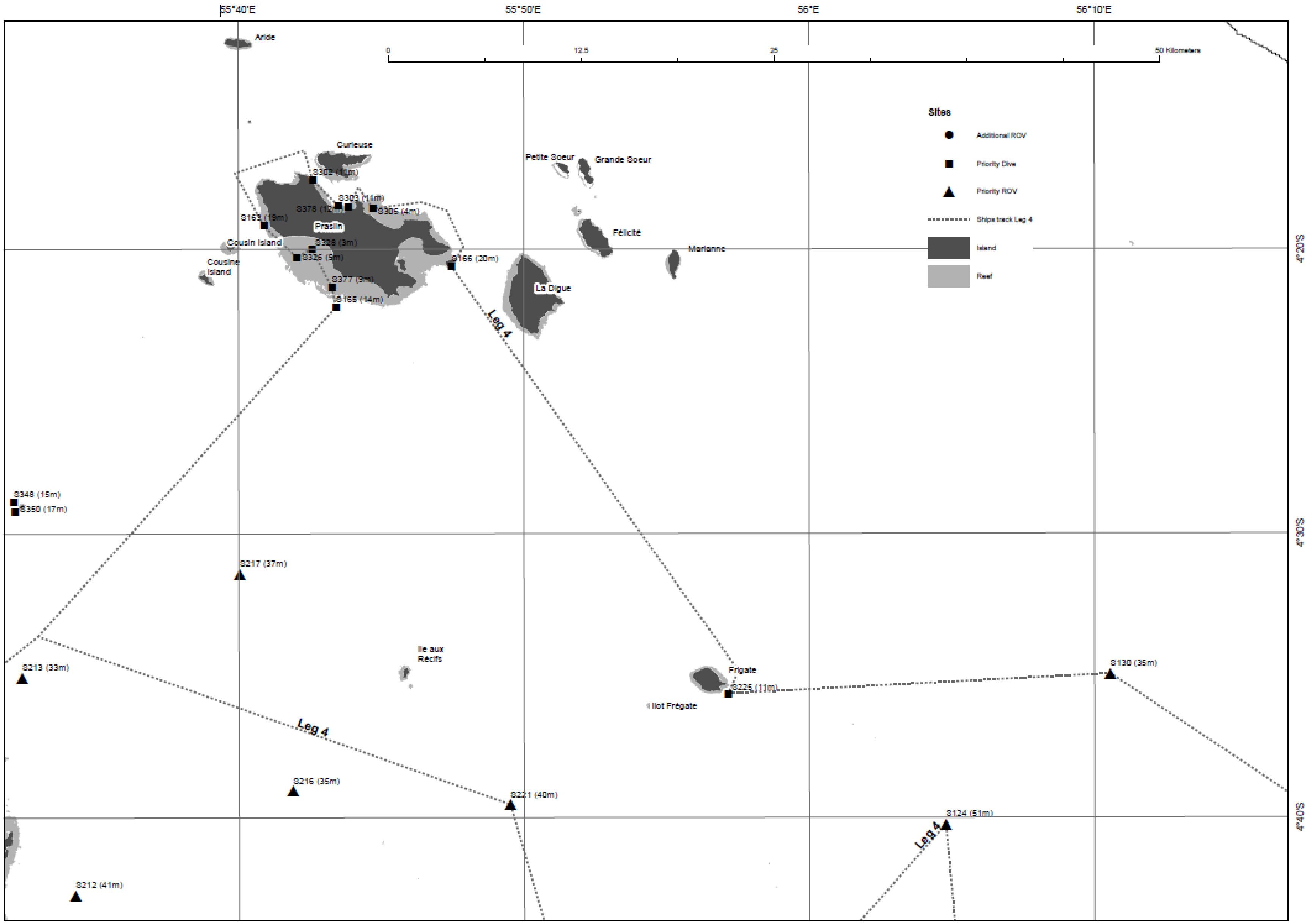
F.5 Leg 3 (50 sites)



F.6 Leg 4 (50 sites)



F.7 Leg 4 Praslin Island



Appendix G Species survey codes

Species survey code will be as follows

Survey Code	Scientific Name	Common Name	Local name
hNobi	*Holothuria nobilis*	Black Teatfish	Kokosye Nwanr
hFusg	*Holothuria fuscogilva*	White Teatfish	Kokosye Blan
hPent	*Holothuria spp.*	Flower Teatfish	Pentard
hFusp	*Holothuria fuscopunctata*	Elephant Trunkfish	Safran
hAtra	*Holothuria atra*	Lollyfish	Spork, Spork koray, Disan
hEdul	*Holothuria edulis*	Pink Fish	
hScab	*Holothuris scabra*	Sandfish	Kokonm
hLess	*Holothuria lessoni*	Golden Sandfish	Kokonm
hAmau	*Actinopyga mauritiana*	Surf Redfish	Brisan
hYsur	*Actinopyga sp.*	Yellow surfish	
hAmil	*Actinopyga miliaris*	Hairy blackfish	Spork
hAech	*Actinopyga echinites*	Deepwater redfish	Spork
hApal	*Actinopyga palauensis*	Deepwater blackfish	Spork
hBvit	*Bohadschia vitiensis*	Brown Sandfish	Lakol
hBarg	*Bohadschia argus*	Tiger Fish	Not found in Sey
hBatr	*Bohadschia atra*	Tiger fish	Lakol
hBsub	*Bohadschia subrubra*	Bohadschia white belly	Lakol
hPgra	*Pearsonothuria graeffei*	Flower Fish	
hAnan	*Thelenota ananas*	Prickly Redfish	Sanpye
hAnax	*Thelenota anax*	Amber Fish	
hHerm	*Stichopus herrmanni*	Curry Fish	
hChlo	*Stichopus chloronotus*	Green Fish	

G.1 List of biota and classification codes

See species identification guide to familiarise yourself with what needs to be observed

Category	**Level**	**Abundance measure**
Substratum		% cover
	Soft sediment	
		Mud (M)
		Sandy mud (SM)
		Muddy sand (MS)
		Sand (S)
	Rubble (2 - 30 cm diameter loose particles)	
	Boulders (>30 cm diameter loose particles)	

	Consolidated rubble (rubble concretion fixed to bottom)	
	Hard substrate (general fixed substrate)	
		Carbonate
		Granite
	Limestone pavement (hard substrate eroded flat)	
	Live coral	
	Dead standing coral	
Fungids	All Fungidae	% cover
Soft coral	All Alcyonacea	% cover
Sponges	All Porifera	% cover
Gorgonians	All Gorgonacea	% cover
Seagrass	All species	% cover
	HOV - *Halophila ovalis*	Relative % of All species
	HSP - *Halophila spinulosa*	Relative % of All species
	CYS - *Cymodocea serrulata*	Relative % of All species
	CYR - *Cymodocea rotundata*	Relative % of All species
	HUN - *Halodule uninervis*	Relative % of All species
	TAD - *Thalassodendron ciliatum*	Relative % of All species
	SYR - *Syringodium isoetifolium*	Relative % of All species
Algae	Macro species, all classes	% cover
	HAL - *Halimeda*	
	TOR - *Turbinaria ornata*	
	CAU - *Caulerpa*	
	LAU - *Laurencia*	
	PAD - *Padina*	
	SAR - *Sargassum*	
	GRN - Green	
	BRN - Brown	
	RED - Red	
Holothurians	All species	Counts
	(see sea cucumber species list)	
Clams	All Tridacnids	Counts
	GIGA – *Tridacna gigas*	
	CROC - *Tridacna crocea*	

Clam	SQUA - *Tridacna squamosa*	
	MAXI - *Tridacna maxima*	
	DERA - *Tridacna derasa*	
	HIPH - *Hippopus hippopus*	
Lobsters	All Palinurids	Count
	PEN - *Panulirus penicillatus*	
	VER - *Panulirus versicolor*	
	ORN - *Panulirus ornatus*	
Trochus	TROCH - *Trochus niloticus*	Counts
Starfish (Asteroids)	CULC - *Cucita* sp	Counts
	COT - *Acanthaster planci*	
	OTH - All other species	
Urchins (Echinoids)	All species	% cover

Appendix H Cruise plan

Sea Cucumber Resources Assessment Cruise Plan

November 2021 and March 2022

Introduction

To improve management of the Seychelles sea cucumber fishery, the Seychelles Fishing Authority (SFA) will, in collaboration with the sea cucumber industry, conduct a fisheries-independent stock survey and assessment. The survey will include the fishery area on the Mahé Plateau and Amirantes Bank.

The survey approach will be based on an underwater visual census (UCV) by scientists and sea cucumber commercial divers in shallow areas (<30m) and a remotely operated vehicle (ROV) in deeper areas (>30m). The surveys will assess the density and standing stock of all sea cucumber species and also estimate the stock status for commercial species.

The survey will be based on a repeated measures design, with survey sites being chosen from the same sites surveyed in 2004. This will increase the power to detect change in the populations over time, and also allow for better cruise planning.

The results from this study will be used to provide management advice for the fishery going forward, and will also provide a useful set of indicator sites that could be used as sustainability measures for the fishery so that it can become more sustainable.

Objectives

1. Survey the density of all commercial sea cucumbers on the Mahe Plateau and Amirantes Bank
2. Collect important habitat data
3. Collect sea cucumber biological data

Aim

The aim of the survey is to carry out a UVC at 200 sites throughout the study area using divers at sites <30m and ROV at sites >30m, to a maximum depth of 100m. This includes:

- Count sea cucumbers and record observations of other biota and habitat along fixed length and width DIVE transects at all shallow (<30m) sites
- Collect sea cucumbers on dive transects for measurement of size, weight and other biological parameters
- Count sea cucumbers and record observations of other biota and habitat along timed ROV transects

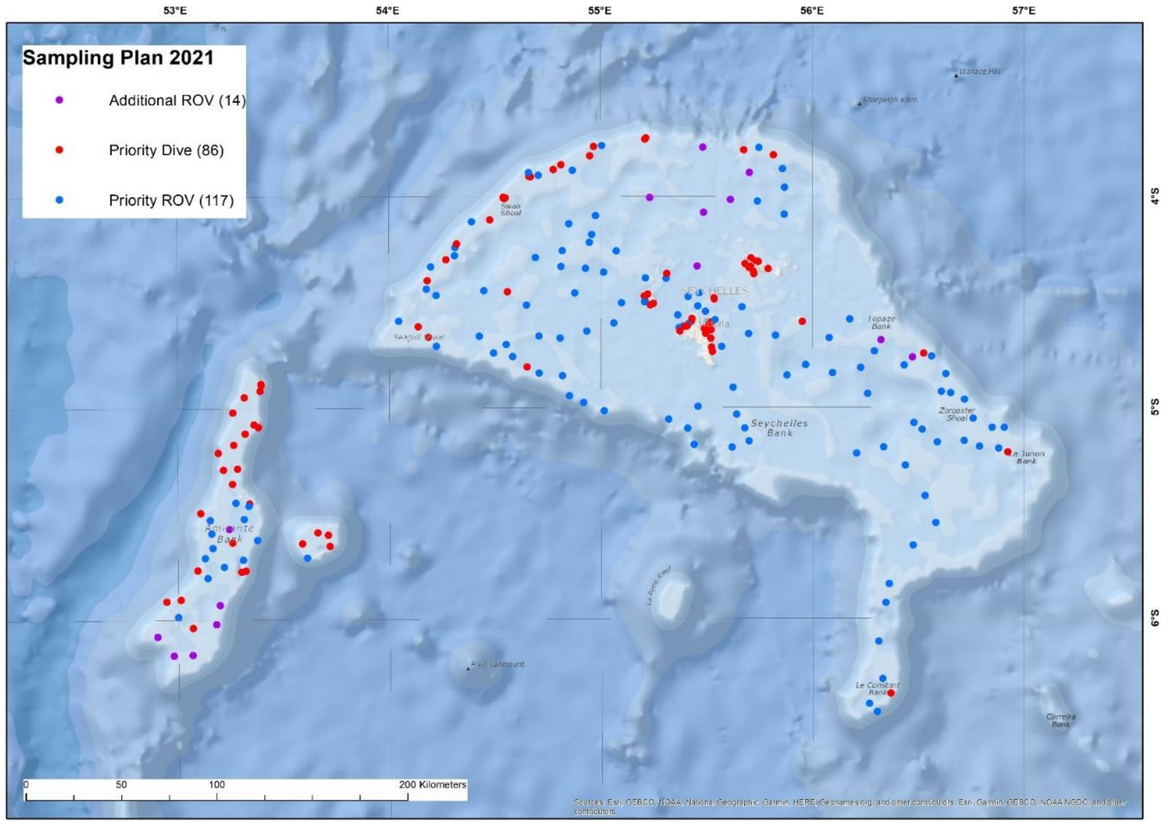
Sample sites

There are 200 priority sample sites mapped across the Mahe Plateau and Amirantes Bank (Figure 33). These have been categorised into 8 site strata (types), based on depth, wether they are located on emergent reef, and plateau (Mahe and Almirantes). The sampling protocols for each strata are either DIVE or ROV sampling protocols (Table 15). There are 17 additional sites that can be sampled if time permits. Theses have been included to cover potential sampling gaps in the 2004 site coverage.

Table 13. Site strata types, priority sites and additional sites

Strata code	Strata name	Method	Priority sites	Additional sites	Total
APRFZ00	Amirantes Reef 0-30m	DIVE	10	0	10
APNRZ00	Amirantes Non-reef 0-30m	DIVE	15	0	15
APNRZ30	Amirantes Non-reef 30-60m	ROV	14	6	20
APNRZ60	Amirantes Non-reef >60m	ROV	0	1	1
MPRFZ00	Mahe Reef 0-30m	DIVE	15	0	15
MPNRZ00	Mahe Non-reef 0-30m	DIVE	50	0	50
MPNRZ30	Mahe Non-reef 30-60m	ROV	86	10	96
MPNRZ60	Mahe Non-reef >60m	ROV	10	0	10
	Amirantes Bank		**39**	**7**	**46**
	Mahe Plateau		**161**	**10**	**171**
	TOTAL		**200**	**17**	**217**

Figure 52. Map of sampling locations for DIVE and ROV priority and additional survey sites during the 2021-22 sea cucumber survey.



Survey plan

The plan is to sample the 200 priority sites over two field trips of one month each, with each field trip being split into two legs, beginning and ending at Mahe Island (100 sites per trip, approx. 50 sites per leg). The field trip will carried out by two vessels, working in tandem – the SFA research vessel L'Amitie; and a commercial sea cucumber vessel contracted to the survey.

The two vessels will travel together, visiting as many sites as possible each day (Note: to meet the project goal of 200 sites will require at least 5 sites per day) – with the final ships path and anchor sites to be determined by the Captain/s in consultation with the cruise leader. A provisional cruise schedule is included in **Appendix B**, and a provisional ships path (based on least distance travelled principal) for the four Cruise Legs is contained in **Appendix C**. These will both be subject to discussion by the cruise leader and vessel captains. The vessels will travel to each site and position the vessel/s in the best location to carry out the survey.

Protocol I: DIVE survey transects

Dive surveys will only be carried out at sites <30m deep.

The dive survey will be carried out by a pair of divers made up of a commercial and a scientific diver. The two divers will work as a pair to survey a 4m wide transect, with each diver being primarily responsible for surveying 2m either side of a pre-laid transect line.

While both divers will be responsible for collecting the survey data to the highest standards, the commercial diver will particularly ensure that no sea cucumbers are missed during the survey. The scientific diver will also count/collect sea cucumbers and record habitat information, but will also particularly focus on ensuring that the survey is carried out according to rigorous random survey principles, for example, including only sea cucumbers within the transect boundaries. The divers should co-operate using established underwater communication to ensure that all the sea cucumbers in the transect are counted. This partnership will potentially set a world's best standard for carrying out sea cucumber surveys.

Before each dive

Check that all diving equipment are in perfect working condition.

Check that all safety equipment including those onboard L'Amitie are in perfect working condition and within accessible reach in case of an emergency.

Check that all on-board roles regarding diver safety are established and clear to those involved.

Dive survey

The divers will be transported to the site location in a suitable dive tender vessel.

Each dive will consist of a lead diver to lay the transect tape and a pair of divers that will be made up of a commercial and a scientific diver.

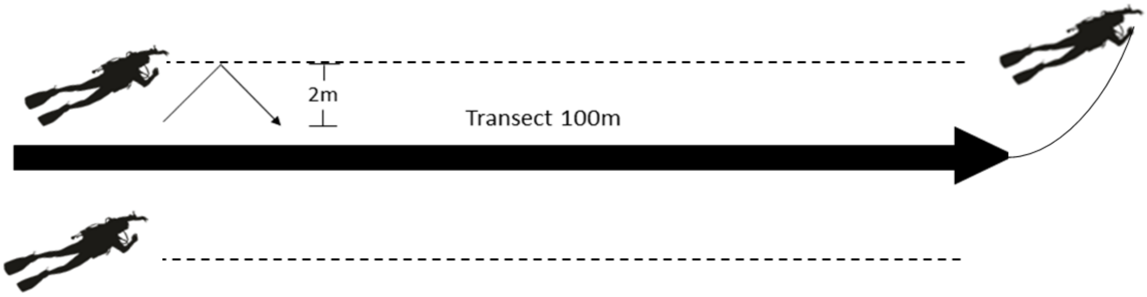
All three divers should enter the water together. Once on the bottom, the lead diver will anchor the transect tape, and then swim directly with the current, laying out the transect line behind them – but not interfering with the bottom. If there is no current then the lead diver should select a consistent compass bearing or direction in relation to the sun angle. It is important that the lead dover does not deviate from this line.

The dive survey pair will follow behind with each observer primarily responsible for one 2m side of the transect line.

At the end of the transect, the dive team will collect all equipment including transect tape and exit the water as per diving safety protocol.

The length of the transect will be 100m.

One transect will be carried out at each site.



Commercial diver protocol

Swim alongside one side of the transect tape and count and collect sea cucumbers up to 2m away from the transect tape. The distance of 2m can be measured using a 2m long tape made for the purpose, or by using the divers body length i.e. the tip of the flipper to the fingertip (or shorter if the diver is tall – it is important that the diver knows how long 2 m is when measuring in this fashion – calibrate this onboard the vessel beforehand).

The commercial diver should try and collect every sea cucumber within their side of the transect, however, if the sea cucumbers are plentiful, collect up to **six (6)** individuals of each species, and just count the remainder. Store the individuals in the provided dive bags and bring them back to L'Amitie for further processing.

NOTE: Training the commercial diver to constrain their counts to within 2 m of the transect line is **critical**, and any deviations will result in biased counts, and the data will be therefore un-usable, or worse, misleading. It's probably OK for them to collect some sea cucumber from outside the 2m transect width so long as they record this as "OUTSIDE" on the data sheet and return quickly to the transect line. It can still be used for size frequency and other sampling protocols.

After the dive, on the **commercial diver diving form (Form I)**, note the site number, their initials, the date, time that the transect began, their deepest depth, visibility (in m; as an estimate of how far they could see a sea cucumber away), the transect width, and which side of the transect tape they surveyed. Record the number of each sea cucumber species that were observed within the 2 m wide transect (and any that were outside).

Scientific diver protocol

Swim alongside one side of the transect tape and count sea cucumbers and observe habitat variables up to 2m away from the transect tape. If any sea cucumbers are encountered that cannot be identified immediately, take a picture of that individual underwater, and/or, collect and bring to the boat for further identification

After the dive, on the **scientific dive form (Form II)**, note the site number, the latitude and longitude where you entered the water, your initials, the date, time that the dive begin, transect deepest depth, visibility (in m; as an estimate of how far they could see a sea cucumber away), transect length and width and side of the tape that they surveyed.

Record the number of each sea cucumber species that were observed within the 2 m wide transect (and any that were OUTSIDE – but clearly labelled).

Record the habitat information of the transect area. This will include:

- Substratum descriptions
- Benthic flora cover
- Fauna counts other than for sea cucumber

It is important that the divers are well versed in sea cucumber species identification and the different codes that are being used to identify them. This is particularly important if the driver is only counting the sea cucumbers and not bringing them back to the surface. Underwater photography can be useful in this regard. For sea cucumber species codes, see **Appendix D.**

It is also important that scientific divers are well versed in different habitat identification, seagrass, algae and other species identification, as per the list in **Appendix E.**

Equipment

Vessel

1. Dive tender
2. Oxygen Tank
3. Compressor
4. Sufficient fuel and oil for dive vessel and compressor

Diver

1. Diving Tanks
2. BCD
3. Regulators
4. Snorkel
5. Flippers
6. Diving Computer
7. Weight + Weight Belt
8. Surface Marker Buoys (BSMB)
9. Masks
10. Gloves
11. Underwater flashlight
12. Rings
13. Safety knife

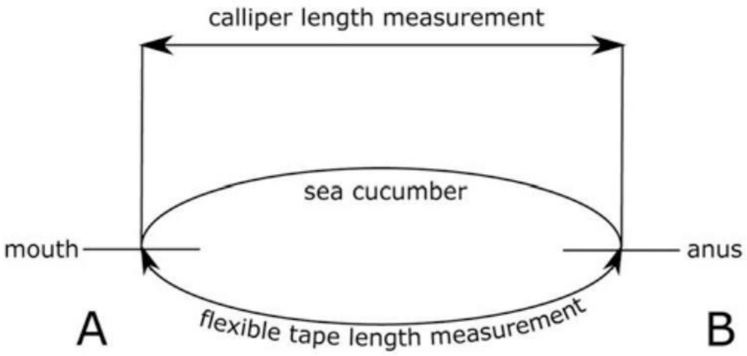
Sampling

1. Handheld GPS to travel to site and record actual position on every dive
2. Transect tape (must cover at least 100m)
3. Transect width measures (2m long – optional if using body length to measure transect width)
4. Slates (for underwater records/notes)
5. Pencils
6. Collecting bag
7. Camera/GoPro
8. Rope tied to surface buoy
9. Datasheets (Commercial diver and Scientific diver)

Protocol II: Onboard protocol for sea cucumber sampling

Sea cucumbers collected on the transect will be bought back to the L'Amitie for processing.

- Identify and record the individual species on the sea cucumber **onboard measurement form (Form III),** using the sea cucumber species codes in **Appendix D.**
- Allow the sea cucumber to rest on deck for 2 minutes
- Using a digital scale, weigh the sea cucumber to the nearest 0.05kg
- Measure the total "caliper" length of the sea cucumber using a measuring tape on a flat surface to the nearest 0.5cm (this is for comparison to previous survey length data)



- Measure the total curved length of the sea cucumber using a measuring tape from mouth to anus to the nearest 0.5cm

- Measure the circumference of the sea cucumber

- Make a cut on the dorsal side of the sea cucumber.

- Remove guts and gonad
- Weight the gonad and place them in a labelled jar containing 10% formalin. Store the jar well.
- Weigh the gutted sea cucumber.

Onboard Sampling identification code

- The codes that will be used to identify the sampled species would be structured as follows;
- Date-Site-Species survey code-Number
- For example, if a Pentard was caught at Beau Vallon site 1, on 3rd July 2020 and it was the first Pentard dissected that day, then the code would be **03072020-BV1-hPent-01**

Equipment

1. Measuring tape/board
2. Weighting balance
3. Dissecting kit
4. Sampling form
5. Sampling jars
6. Formalin
7. Permanent markers
8. Labels
9. Gloves
10. Knives
11. Pencils and eraser

Protocol III: ROV survey transects

The ROV will be operated as a drop camera mode, with a “transect” being surveyed as it drifts with the current for 10 mins. If ROV surveys are to be done from the research vessel, position the vessel as close as possible to the predetermined site location.

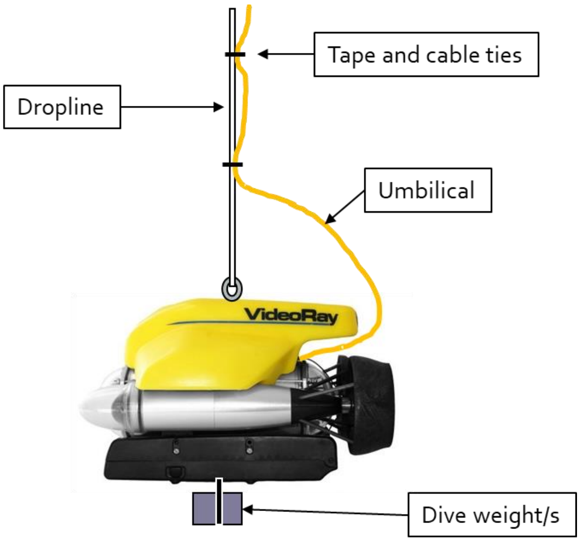
At the start of the transect, record the start position and depth on the **ROV video record form (Form IV)**. During the transect, record any sea cucumbers and other items of interest and the time stamp – this will allow later review of the ROV recording. At the end of the 10 min transect, record the finish position and depth, and fill in the rest of the form, including the deepest depth, visibility, transect effective width.

As for DIVE transects, it is important that the observers are well versed in sea cucumber species identification and the different codes that are being used to identify them. See **Appendix D.**

It is also important that observers are well versed in different habitat identification, coral types, seagrass, algae and other species identification as per the list in **Appendix E.**

ROV setup

- Negatively weight the ROV by attaching dive weights to the bottom of the ROV with cable ties
- Attach a dropline (e.g. 8-10mm silver rope) to the top of the ROV



- Attached ROV tether to dropline with tape and cable ties every 1.5 m. Leave some slack in the tether line.

- Store the dropline and umbilical loosely coiled into plastic bin to avoid kinks.

ROV deployment

- Transport vessel to as close to the site location as possible
- Switch on the ROV
- Deploy the ROV and lower to within 1-2m from the sea floor
- Start to record
- On the ROV video record form (Form IV) record the site name, starting time, starting position, water temperature, visibility, and depth
- Start a timer and allow the vessel to drift with the current for 10 minutes
- While the pilot views the video one person will have control of the tether and line to move the ROV up and down based on advice from the pilot regarding the changing sea floor
- The pilot will use the camera pitch and ROV rotation controls to investigate targets as the ROV passes them (Do NOT use the ROV in forward or reverse thrust mode)
- During the 10 minutes drift, observers onboard will check the video and they will count, identify, and record any sea cucumber species that they can see along with the time stamps for later verification
- Significant environmental data will also be recorded
- At the end of the 10 minutes record the end time, end position and depth
- Return the ROV to the surface and collect the ROV and tether
- Save the video and transfer a copy to an external drive
- Name the video with the transect label
- Switch off the ROV and sit in a safe place ready for the next deployment.
- At the end of each dive/day, rinse the ROV with fresh water

At the end of each cruise leg (not every day as seals can become worn):

- Disconnect the ROV from the tether
- Close the connecting ends with the provided cover

- Place the ROV for at least 30 minutes in fresh water and allow it to airdry afterwards
- Rinse the tether with fresh water, allow to dry, collect and store to prevent entanglement.

Pre-ROV deployment checks

- Visually check that all system is in order and carry out all safety check as per the manual
- Connect the ROV to the control system
- Make sure the system is connected to a working power source and the GFCI / Circuit Breaker and Power switches are turned on.
- Turn on the computer and wait for the system to complete the boot up process.
- After the computer has started, start VideoRay Cockpit using the desktop icon, or by selecting it from the Start->All Programs->VideoRay menu.
- When VideoRay Cockpit starts, you will see the Video Window, the Control Instruments and the Control Bar. For now, you will only need to focus on the video window.
- Test the ROV by turning on the lights (not more than 30 sec) and both the vertical and horizontal thrusters (not more than 30 sec)
- Verify the image on the software
- In the white rectangle at the bottom of the video screen (see image below), write the code for the site similar to what will be written on the form and press enter. This will allow for easier identification of the video.

3/30/2015 12:39:31 PM

H: 179.1 °
D: 0.00 ft
Temp: 98.6 °F

1 test target

Video Recording

- Press the Video Record button to start recording a video from the active camera (see image below)

.

- When the recording is active, the word "Active" is displayed in the video window title bar and a red circle flashes in the upper left corner of the video window.
- The number of video recordings captured during a session is also displayed in the Video Window title bar.
- Press the Video Record button again to stop recording a video from the active camera.

Equipment

1. ROV + controller + monitor + tether
2. 100 metre droprope (8-10mm silver rope or equivalent)
3. Dive weights (up to 4)
4. External drives
5. Sampling form
6. GPS
7. Cable ties for rope and attachment points (50 kg, and 10 kg breaking strain – 200)

Personnel

Cruise 1, Leg 1

L'Amitie Personnel

	Name	Title	Organisation	Role
1	Mr. Gerard Ernesta	Senior Skipper	SFA	L'Amitie Crew
2	Mr. Fred Mondon	Skipper	SFA	
3	Mr. Robert Dookley	Assistant Skipper	SFA	
4	Mr. Yashim Marday	Senior Mechanic	SFA	
5	Mr. Pejo Nicette	Able Seaman	SFA	
6	Mr. Rama Asba	Freelance cook	SFA	
7	Mr. Andrew Souffre	Fisheries Research officer	SFA	Cruise leader/Diver
8	Mr. Rodney Melanie	Research Technician	SFA	Diver
9	Ms. Rosabella Mangroo	Fisheries Scientist	SFA	Diver
10	Ms. Stephanie Marie	Research Technician	SFA	Diver
11	Mr. Achille Pascal	Research Technician	SFA	ROV pilot

Etelis Personnel

	Name	Role
1	Mr. Marcus Quatre	Skipper
2	Mr. Mervin Cedras	Cook
3	Mr. Dominique Thelermont	Diver
4	Mr. Eddy Quatre	Diver
5	Mr. Ashley Quatre	Diver
6	Mr. Jean-Marc Amelie	Diver
7	Mr. Dence Malter	Diver

Appendix I Data validation

Table 14. Data validation, including issue and rectification.

ISSUE	RECTIFICATION	RESOLVED?
Access file link	Link Access file to field data entry file	Y
Excel analysis file link	Link Excel analysis file to take output from Access database	Y
Some non-data cells in HolAb are converted to zero	Modify HolAb columns to make non-data cells NULL	Y
Make new flat file of all data for GIS		Y
Check all STOP row	All unused rows deleted	Y
Delete STOP row in CountAbs worksheet	All unused rows deleted	Y
Change way distance is calculated for lat and lon inputs (see below)	Apply the 'haversine' formula is used to calculate the great-circle distance between two points. $x = \Delta\text{Longitude} \times \cos \text{Latitude(mid)}$ $y = \Delta\text{Latitude}$ $d = R\sqrt{x^2 + y^2}$ R = 111,319.49	Y
Diver Comm. did not record habitat data.	Remove all habitat entries for Diver Comm.	Y
Comment: "Lat 4* 36' 833 Lon 55* 24' 524, A echinites hybrid, B white belly dark spots" is from previous survey	Removed	Y
Some cells have Notes attached e.g. where sea cucumbers are found out of transect	Moved Notes into Comments cell. All sea cucumbers found out of transect moved to Comments cell. Only sea cucumber within transect entered in database cells.	Y
SEY03 sometimes entered as Cruise	Changed all the SEY02	Y
There is something wrong with the start and finish Lat and Lon for many of the ROV transects – some transects are calculated as over 20 km long (e.g. S203), and most are 2 to 3 km long, which is long for a 10 min drift.	Recalculate decimal degrees from ships log.	Y
S109 sLon is in error.	Requires checking	Y
S403 (20/11/2021) is not correctly located	Actually should be S408.	Y
Some dates appear to be in mm/dd/yyyy format rather than specified dd/mm/yyyy format	Changes dates that were in mm/dd/yyyy format to dd/mm/yyyy format	Y
Lat and Long columns had been swapped	Swapped Lat and Lon columns back to original configuration.	Y
Some of the sites start Lat and Lon seem to be some distance from the sample design locations (see maps below).	CHECK using map and calculated distance from original sample site position.	Y
fung, sCor, spon, gorg, as % covers all look high – and add to 100% which looks like an error.	Enter correct values as "% cover of biota along transect"	Y

Some sites have a very high (100%) green algae cover.	Check the definition of 100% cover. [Response: some of the sites especially sandy bottom are completely covered with green algae or maybe cyanobacteria]	Y
Some sitesw use “sEY02” as CRUISE code	Changed to “SEY02”	Y
Some dates in incorrect format	Change all to dd/mm/yyyy	Y
Sites not complete due to current/etc. S030 (no end position) S091 S100 (no end position) S130 S150 S273 S280 (no end position) S284 S289 S317 S323 S411 S417 S422	Site set to “ABANDONED”. Clear all data. Do not use in analysis.	Y
Sites with no start or finish coords. S311	Check and confirm. Apply existing site location and current speed and transect duration. S311 -> 216 m	Y
Sites missing finish coord for ROV S006 (no end position) S249 (no end position)	Use average distance for ROV sites with the same drfTM (drift time). S006 -> 710 m S249 -> 216 m	Y
Sites with cTrl (calculated transect lengths) over 1 km. S080 (check start and end position) S150 (end latitude in error) S276 S277 S314	Check and confirm. S080 -> change start Lon from 55.49965 to 55.39965; and finish Lat from -3.70023 to -3.76023 S150 –> changed one number S276 -> changed end Lat from -5.8528 to -5.9228 S277 -> changed end Lon from 56.38328 to 56.35328 S314 -> OK	Y
Sites sampled twice? S056 – 5/3/2022 and 8/3/2022 S221 – 23/3/2022 and 18/3/2022	S056 on 8/3/2022 appears to be S066 -> changed in database. S221 on 23/3/2022 appears to be S225 -> changed in database.	Y
Site not labelled correctly S066 on 6/3/2022 – appears to be S061	S066 (orig) is actually S061 -> changed in database.	Y
fung, sCor, spon, gorg, are all estimated as a % of “livCor”.	Apply relative correction factors to these columns to convert to absolute % cover	Y
Given above issue, how are we going to estimate the cover of live hard coral?	Live coral was not estimated -> Make all livCor for SEY02 blank	Y

Transect width of ROV transects is listed at 10m.	Review 10 ROV transects and apply the average to the remainder (so long as there is not to much variation) = 2.125m.	Y
Sesgrass with “sgTad” (Thalasodendron) are listed as “sgTha” (Thalassia).	This is likely to be all “sgTad”, but check sites that previously had “sgTha” (S359 and S360-> didn’t do either in SEY02).	Y
There are 3 RMs in the UVC recorder columns – these are now numbered 1-3. They need updating in UVC.	Updated the Comm. Diver as RM3. The others will have to remain uncorrected.	Y
Ensure all “abandoned” transects have nulls in data columns.	Clear data from “abandoned” transects.	Y
How to exclude “ABANDONED” sites from analysis	Make sure abandoned sites have trWM set to zero	Y
Counts for non-holothurian biota for the commercial divers are nearly all zero	Clear data from commercial diver apart from sea cucumbers.	Y
Field data contains some calculated fields: Transect length for ROV Transect area Tot holothurians Hival holothurians	Move all calculated fields to MS Access	Y
Effective transect width for video.	Document current approach and reassess, especially in light of lower non-commercial species density. -> make SEY02 standard width 2 m (the modal width)	Y
Ensure that unfilled cells are not included in averages analysis – e.g. Comm diver environmental and “abandoned” transects	Put a >0 criteria in trWM (transect width) to filter out all “abandoned” transects.	Y
Database is using the “absolutes” data table from Excel.	Use Access queries to calculate absolutes from site data.	Y
Variation in observations of H. atra and H. edulis between two surveys. There is likely a difficulty in identifying atra from edulis, so this could be misidentification?	Show combined atra/edulis estimate. Tack onto the end of Q1_SiteAbolutes query.	Y
Variation in observations of dark Actinopygas: A. miliaris, A. echinites and A. palauensis between surveys. Is this mis-identification?	Likely they are lumped to gather as “spork” during the survey. Therefore, show combined A. miliaris, A. echinites and A. palauensis (spork) estimate. Tack onto the end of Q1_SiteAbolutes query.	Y
There are high counts of H. scabra (Sandfish) in the 2021-22 survey, especially in the Mahe Intermediate strata, which would be unusual. May be another species. Check all H. scabra entries and correlate with length frequency datasheet where possible.	Andrew says there were no sandfish seen during the survey. S129 ROV has 1 hScab in database. Site datasheet shows I “lakol”. -> change to hBvit. Done S303 Comm. diver has 3 hScab in database. Site datasheet shows 3 “lakol”, but no H. scabra. Size frequency datasheet and database has no entries. -> change to hBvit. Done S333 Comm. diver has 2 hScab in database. Site data sheet shows 2 “lakol”, but no H. scabra. Size frequency datasheet has 2 “lakol”. Size frequency database has 2 hBvit recorded. -> change to hBvit. Done S369 Comm. diver has 1 hScab in database. Datasheet shows 1 “White belly”. Size frequency datasheet lists one “white belly (H. scabra)”. Size frequency database has 1 hScab recorded. -> change to hBsub? Done	Y

	S383 Comm. diver has 1 hScab and 3 hAtra in database. Datasheet lists 3 Spork koray and 1 Brisan. Size frequency datasheet lists 3 spork and 1 brisan. Size frequency database has 3 hBvit and 1 hScab. (Scientifi diver also has 2 hAtra in database and 2 Spork koray on datasheet). Spork koray is usually the same as the usual spork (hAmil). There is also the possibility that spork has been identified on the data sheet as Lollyfish. -> change entries to hAtra and hAmau. Done. S429 ROV has 1 H scabra in database. Datasheet shows I “lakol”. -> change to hBvit. Done.	
A. mauritiana have increased considerably, especially for Amirantes 0-30 m strata. Check all entries and correlate with length frequency datasheet where possible.	S303 has 4 hAmau in database. Datasheet has 4 “RS”. Size frequency datasheets and database has no listings. -> OK. S305 has 3 hAmau in database. Datasheet has 3 “RS” (I for Comm. diver and 2 for scientific). Size frequency datasheets and database has no listings. -> OK. S328 Scientific diver has 18 A. mauritiana (the Comm. Diver zero). Datasheet lists 18 “RS”. Size frequency database has no listings. -> checked with Andrew, he remembers it clearly and this is correct. He says the commercial diver was off the reef and he was on the reef. -> OK S400 has 3 hAmau in database. Datasheet has 1 RS and 2 “disan”. Size frequency database has 2 hAmau. -> check that “disan” is hAmau –> yes this is correct. -> OK S430 has 4 hAmau in database. Datasheet has 4 RS. Size frequency database has 4 hAmau. -> check ->OK	Y
There were almost no Bohadschias: B. vitiensis, B. argus, and B. subrubra, recorded in the 2021-22 survey data compared to 2004.	Check that the Bohadschias were potentially misidentified. Looks like they were all recorded under “lakol”. Check entries in datasheets.	Y
There are high numbers of P. graeffei on the Mahe 30-60. Which is a large increase on 2004. This would be unusual as this is normally a shallow reef associated species.	Check that there has not been some misidentification e.g. they could be Bohadschias. -> Tim complete database perusal. -> OK	Y
S333 length frequency database has different species to the survey database.	Scan size frequency datasheet and check. Confirm 2 hBvit >- OK	Y
S055 data sheet, data base and size frequency do not match.	Check that “lakol” is not H. atra, but likely hBvit. -> Yes Andrew says all “lakol” are hBvit -> Corrected OK	Y
S269 is an ROV site but has an entry in size frequency database. I cannot find the scanned site datasheet.	-> Check site datasheet and size frequency entry. -> changed to S239	Y
S069 has a hFusp, hPent and hAmau listed in the size frequency database and datasheets, but nothing in the survey database.	-> Check site datasheet. Scanned the datasheet only for scientific diver as cannot find the sheet for commercial diver. Andrew is checking on his side if he can find it. -> Add species to site database OK	Y
“Safran”? on datasheets is recorded as H. fucopunctata (hFusp) in database.	Check common name and spelling. -> OK	Y
S397 Comm. diver data sheet, database and size frequency datasheet and database do not	S397 - The elephant/curry fish is elephant trunk. Andrew remembers it well as they were having some confusion and managed to identified it as elephants trunk afterwards. -> Looks like it was eventually	Y

match. (Only looked this up because it had high numbers of H atra.) Datasheet: 6 lakol 1 spork 8 elephant/curry Database: 8 hFusp 7 hAtra Size freq sheet: 6 Curryfish 6 Babara lakol 1 Spork 1 Brizan/lakol Size freq database: 6 hHerm 7 hBvit 1 hAech Scientific diver datasheet has: 2 spork, 1 elephant, 1 curry; and database has 2 hAtra, 1 hFusp and 1 hHerm -> OK.	identified as curry as per the size frequency sheet . -> Changed to 6 hHerm 7 hBvit and 1 hAech.	
Site 343 (Commercial diver).	Database has 3 Anan and 1 Atra. Datasheet has 1 prickly and 3 "Lakol". Size frequency datasheet has 1 each of (with annotations) Spork (hAech), Disan (hAtra), Lakol (hBvit), and Sanpye. They are listed as 1 each of Amil, 1 Amau, and 1 ABvit and Anan in size frequency table. -> could it be that "Disan" is Lollyfish? -> list as per size frequency datasheet. ->OK	Y

Appendix J Stratified analysis approach

(e.g. see Cochran, 1977). In stratified sampling the population of N units is divided into subpopulations of N1, N2, N3,... NL units respectively. Estimates of the stratum mean can be obtained by averaging the sites in that stratum. These estimates can then be combined to give a precise estimate for the whole population. The notation of terms used for stratified sampling follows below:

N	total number of possible sampling units in the study area;
N_h	total number of possible sampling units in stratum *h;*
n_h	actual number of samples taken in stratum *h;*
y_{hi}	value obtained from *i*th unit in stratum *h;*
$W_h = \frac{N_h}{N}$	stratum *h* weight;
$f_h = \frac{n_h}{N_h}$	sampling fraction in stratum *h;*
$\bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h}$	stratum *h* mean;
$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h$	stratified mean over all strata;
s_h^2	sample estimate of stratum *h* variance;

$$v(\bar{y}_{st}) = \sum_{h=1}^{L}\left(\frac{W_h^2 s_h^2}{n_h}\right) - \sum_{h=1}^{L}\left(\frac{W_h s_h^2}{N}\right)$$

estimated strata variance.

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