Tuvalu Sea Cucumber (Funafuna)

Status Report

Bohadschia argus https://www.earth.com

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DECEMBER 2020

1 Acronyms and Terms

BDM	Beche-de-mer*
CFS	Coastal Fisheries Section
GIS	Geographic Information System
GPS	Global positioning system
ha	Hectare
mt	Metric tonnes
PROCFish	Pacific Regional Oceanic and Coastal Fisheries Development Programme
SPC	Pacific Community
TFD	Tuvalu Fisheries Department
UNDP	United Nations Development Programme

*In this report we use BDM and sea cucumbers interchangeably. Generally, the term 'sea cucumber' refers to the living resource, while beche-de-mer (BDM) refers to the dried product ready for sale.

Contents

2 Summary

Sea cucumbers have been exploited in Tuvalu on and off from 1978, after the United Nations Development Programme (UNDP) provided assistance to develop the industry. Between 1979 and 2010 a total of 49.3 metric tonnes have been exported over 11 fishing years. There was a closure from 1983 to 1992, and the fishery has been closed since 2010 due to low stocks and SCUBA accidents.

Since 2017 the Government of Tuvalu has been considering re-opening the beche-de-mer fishery, but consideration of environmental impacts, economic benefits, human safety and state of the resources needed to be examined.

In the period since 2004, SPC (as part of PROCFish) and Alofa Tuvalu have assisted TFD with BDM surveys based on manta tows and a range of other methods such as deep water timed swims and reef walks. Together with TFD's own surveys conducted in 2018-2019, surveys were undertaken over 6 years, covering 4 islands to document the distribution and abundance of BDM in Tuvalu. Data from all 3 sources (SPC, Alofa Tuvalu and TFD) were consolidated into a single dataset and analysed to assess the status of sea cucumber stocks in terms of species present, density and changes through time since the first survey in 2004. Data on raw counts were used in addition to average densities per hectare to allow for comparisons through time and at different sites, and against simple regional reference densities of BDM (<30 = Critical; 30-100 = Low and >100 = OK).

Overall, the sea cucumber populations on all four surveyed islands of Tuvalu are in critical condition and cannot for the foreseeable future support a BDM fishery. The total number of BDM counted between 2004 and 2019 at all sites on 4 islands was just 2,432 animals across a total of 260 BDM counts carried out at 139 unique transects (i.e. some transects were evaluated in several years). These are raw numbers counted and not densities, so are dependent on the number of transects completed and their size. Overall, over half of all BDM counted were on Funafuti, with the greatest number counted in a single year in 2011. The most common species observed during the study was *Holothuria atra* or Lollyfish, which is also the least valuable from a commercial standpoint. At 1,167 animals recorded, it accounted for 48% of all BDM observed through all of these surveys. Four of the species had just one occurrence each over the entire series of surveys.

The average number of BDM per hectare was critically low for nearly all species at all of the sites and habitats surveyed and across the years (Figure 4). Compared with the simplified reference densities only two species reached "OK" densities of >100/hectare at just a few sites (Lollyfish *Holothuria atra* at 6 sites and Surf redfish *Actinopyga mauritiana* at one site). Of the remaining species, five had "Low" densities (30-100/ha) at just one or two sites. At the majority of sites, the density of BDM was in the "Critical" range of <30/ha. For Funafuti where data were available for multiple years, the low numbers of BDM did not show any changes over time. Significantly, since the closure in 2010 there has been no sign of recovery (increase in density) of any species.

Despite Tuvalu's relatively low sea cucumber exploitation in the past, the fishery is currently in a state of collapse. BDM provide ecosystem services which need to be balanced against the benefits of exploiting them and the Tuvalu BDM populations are currently clearly unable to support any kind of fishery and should remain closed until sufficient recovery has occurred to support a fishery.

The recommendations for BDM in Tuvalu are to:

1. Continue the current ban in Tuvalu until surveys show that the sea cucumbers have recovered to resilient levels and are able to breed reliably. Unfortunately these conditions are not likely to occur for quite some time in the future (perhaps 10-20 years).
2. Regional Reference Densities could be used as benchmarks for deciding when the BDM fishery could be re-opened and for adaptive management of the stocks.
3. Consideration should be made of the potential beneficial roles that sea cucumbers play in improving sediment and water quality and the possible deleterious impact of their removal or extinction.
4. Immediate action may be needed in an effort to recover BDM stocks in Tuvalu because current indications are not just that the resources are overfished, but that they are severely depleted. This could include collecting adults and concentrating them in the FCA and LMMAs to increase densities.
5. The Funafuti Conservation Area (FCA) is more than large enough to act as a refuge or breeding populations of sea cucumbers and may be a good place to take immediate action to increase densities of BDM so that reproduction can improve.
6. A BDM Management Plan should be developed for the long term once stocks have recovered and which controls the take of sea cucumbers based on minimum densities and sizes. Control in Tuvalu could include restricting exports (sizes and numbers) and banning SCUBA for collection for this and other marine resources. Other management measures may also be needed and adaptive management will need to be supported by monitoring of the stocks. The Management Plan may include designating the fishery as being of national interest, per the Marine Resources Act 2008 and amendments. Any future plans to reopen this fishery should be based on advice from TFD and potentially SPC.
7. Excellent guidance for the development of a national BDM Management Plan has been provided by SPC. A good start would be to use the Manager's Toolbox (Friedman et al., 2008).

3 Introduction

Beche-de-mer (BDM) have been exploited for at least 400 years, involving 66 species globally and around 70 countries (Carleton et al., 2013b). Of seventy-seven global DBM fisheries reviewed, 66% were small-scale fisheries for export and over 2 million fishers were involved in 39 of the fisheries (Purcell et al., 2011).

Widespread overexploitation of stocks has occurred since the 18th century and has led to the depletion of sea cucumber fisheries in many areas (Mrowicki, 2006). Sea cucumbers are particularly susceptible to overexploitation due to their limited mobility, late maturity, density-dependent reproduction, habitat preferences and low rates of recruitment (Lawrence et al., 2004).

In many pacific island Countries, particularly those with high islands and complex habitats, sea cucumber fisheries support a significant industry which provides important income for rural communities, and foreign exchange revenue for the country. However, throughout the Pacific, fishing pressure and ineffective management has also led to overexploitation (Pakoa et al., 2014), collapse of the fishery and closures. Rather, diver accidents are a common feature of BDM fisheries (Pakoa et al., 2014), and Tuvalu has had its share of loss of life.

One key recommendation in any bid to manage BDM stocks is to undertake stock assessments using standardised methods before fisheries commence, in order to obtain essential information regarding the size and extent of holothurian stocks (Mrowicki, 2006).

3.1 History of BDM exploitation in Tuvalu

The history of sea cucumber fisheries in Tuvalu is relatively poorly documented. Tuvalu periodically harvested BDM prior to 2007, exporting to Fiji from which it is likely the BDM were re-exported as Fiji product.

In 1978 TFD received funding from The United nations Development Programme (UNDP) to assist with the development of the BDM industry in Tuvalu (Belhadjali, 1997). At that time resource surveys were conducted on all islands of Tuvalu, but only Funafuti and Nukufetau were identified as having stocks of commercially-valuable BDM. Through its extension section, TFD began training fishers in Funafuti and on outer islands and produced a leaflet in Tuvaluan entitled ‘A tupe e mafai o maua mai funafuna’ (The amount of money you can get from selling beche-de-mer), to encourage and promote the beche-de-mer fishery. As a result of these efforts TFD purchased BDM from fishers in Nukufetau and sold them to overseas markets, but Funafuti fishers were not interested in the fishery. Production declined in following years, ending after 1982 because fishers in Nukufetau decided to focus on other projects (Table 1).

Production of BDM resumed in 1993 with a local fisher harvesting in Funafuti and Nukufetau, exporting to Singapore and Hong Kong. In 1994-5 another local fisher exported to Fiji in a joint venture, with both fishers stopping in 1995. The main species harvested were Ho*lothuria fuscogilva*, and black teatfish *Holothuria nobilis*, because they were highly valued in the Asian markets.

Table 1: BDM catches 1979-1995 (Belhadjali, 1997) and 2007-2010 from SPC data

Year	**Exports (kg)**	**Total value**	**Currency**
1979	1800	7,100	AUD
1980	805	4,000	AUD
1981	90		
1982	198.5		
1993	871	12,461	USD

1994	3,678	40,004	USD
1995	3,228	45,737	USD
2007	14,700		
2008	17,000		
2009	5,000		
2010	2,000		

By November 2007, Tuvalu was approached by foreign interests to process and export sea cucumber and TFD began to develop a management framework for the fishery. Sea cucumber exports rose from 14.7 mt in 2007 to a peak of 17 mt in 2008 before dropping down to 5 mt and 2 mt in 2009 and 2010, respectively (SPC Data and see also (SPC, 2019)).

Traders came to Tuvalu in 2009-2010, encouraging fishing for White teatfish (*Holothuria fuscogilva*) and Prickly Redfish (*Thelenota ananas*) using SCUBA at depths reaching 50-70 m. The use of SCUBA resulted in the loss of six lives in total. Most of the accidents occurred around Funafuti, and one in Nukufetau. This was one of the key reasons why the Tuvalu Government decided to put a national moratorium on harvesting sea cucumber. The BDM fishery in Tuvalu was closed at the end of 2010 (Pakoa and Bertram, 2013)(Lee, 2019). An earlier case of a diver dying whilst collecting BDM was also recorded in 1999 (Sauni et al., 2008), bringing the total number of people who lost their lives to seven.

3.2 Purpose of this Report

Since around 2017 the Tuvalu Fisheries Department (TFD) has considered re-opening the sea fishery in Funafuti lagoon (Govan, 2017). However, before a decision would be made on whether to reopen the fishery it was suggested at the Heads of Fisheries Meetings in 2017 and 2018 that the environmental impact(s) and economics of reopening the fishery be examined and a study was commissioned (see also (SPC, 2019)).

The SPC PROCFish/C programme has trained fisheries officers in underwater survey methods for sea cucumbers in the Pacific Region. This report represents an overall analysis of several surveys undertaken on BDM distribution and abundance in Tuvalu since 2004, partly with assistance from SPC, partly with assistance from Alofa Tuvalu, and more recently without external assistance.

This analysis has been carried out to assess the status of sea cucumber stocks in terms of species present, density and changes through time since the first survey in 2004.

4 Methods

4.1 Survey Methods

Surveys for BDM were undertaken on 4 of Tuvalu's islands during 6 years since 2004 (Table 2) and carried out by different groups working with TFD. Surveys were undertaken in 2004, 2005, 2011 and 2013 by SPC through the Pacific Regional Oceanic and Coastal Fisheries Development Programme (ProcFish) Project on 4 islands. The NGO *Alofa Tuvalu* worked with TFD in 2010 on 2 islands where they surveyed BDM, and in 2018-2019 TFD carried out the surveys on Funafuti independently of outside assistance. Funafuti was the only island surveyed by every group in every year there was a survey, so has the most complete time series.

Over the years and surveys a range of methods was used to estimate the abundance of BDM, with all surveys including manta tows, and some including reef walks and timed swims (Table 2). Most counts of BDM were made in transects for which length, width and GPS location was recorded. This allowed the data collected to be recalculated to a density per hectare for comparisons, and all transects were plotted onto a Geographic information system (GIS) and clustered into a single system of sites on all the islands, referring to features of the atoll such as islets, patch reefs and channels. The sites were further divided into outer reef (ocean side), inner reef, lagoon floor, patch reef and channel areas to stratify the data according to habitat. This allowed all transects to be analysed as a single dataset across the years, islands and surveys so that trends could be identified.

Table 2: Surveys of BDM undertaken since 2004 in Tuvalu

Survey	Islands	2004	2005	2010	2011	2013	2018	2019	Methods
Alofa Tuvalu	Funafuti			12					Manta
	Niutao			1					
SPC PROCFish	Funafuti		56		26	31			Manta, Day reef search, Reef walk
	Niutao	27							
	Nukufetau	38							
	Vaitupu		34						
Tuvalu Fisheries	Funafuti						38	31	Manta, Deepwater Timed Swims (DWTS)

The data acquired from SPC, Alofa Tuvalu and TFD were imported to an Access database in 2020 for storage and analysis. Data were summarised using descriptive statistics, mostly as totals observed and averages per hectare at each site and habitat. These were examined in graphs, mapped using QGIS and compared with density guides. For more details of the methods used by SPC and Alofa Tuvalu see (Sauni et al., 2008) and (Job and Ceccarelli, 2012).

4.2 Regional Reference Densities

For at least some species for BDM, successful reproduction and population maintenance or growth can only happen in relatively dense populations. The 'Allee effect' occurs where the population densities are reduced to the point where reproductive success trails behind natural mortality. Once this happens, conventional management measures alone, such as closed seasons/areas, size limits and gear restrictions, will usually fail to repair the damage. A different suite of active management interventions must be considered to restore the spawning biomass of severely over-exploited populations, including restocking no-take zones with hatchery-reared juveniles, and aggregating remnant wild individuals in no-take zones (Bell et al., 2008).

For the purposes of this assessment, we compared the densities of BDM to some simple reference benchmarks (Friedman et al., 2008; Purcell, 2010) with a view to ensuring that the animals are at sufficient density to be able to breed and replenishment after losses through fishing.

In New Caledonia, Purcell found that the best sites surveyed had around 5,000 sea cucumber per hectare (ha), but that many sites had less than 500/ha (Purcell, 2010). The minimum viable densities or sea cucumbers is poorly documented, but the best estimates are that 10-50 individuals per hectare are needed over substantial areas, depending on species and location (Bell et al., 2008). Purcell's guidelines suggest <100/ha = low; <30/ha near critical for population maintenance – these are the reference limits we used for this assessment. More detailed reference densities were calculated by (Purcell et al., 2014) for some species, but were not used here for simplicity.

Healthy species densities were assessed for 17 species by fine-scale assessment (Table 4) and by broad-scale assessment (Table 5). Regional reference densities for sea cucumbers are the mean densities for the upper 25% of densities taken from 90 sites assessed across the Pacific

Islands from 2002 to 2012. These regional mean densities are used as a guide for determining healthy stock populations based on a "rule of thumb" for management use (Pakoa et al., 2014).

5 Results

5.1 Overall sampling effort and counts

The sea cucumber populations on all four surveyed islands of Tuvalu are in critical condition and cannot for the foreseeable future support a BDM fishery. The total number of BDM counted between 2004 and 2019 at all sites on 4 islands was just 2,432 animals across a total of 260 BDM counts carried out at 139 unique transects (i.e. some transects were evaluated in several years). These are raw numbers counted and not densities, so are dependent on the number of transects completed and their size. Overall, over half of all BDM counted were on Funafuti and the greatest number of BDM counted in a single year was in 2011 (Figure 1, Figure 2).

Figure 1: Sampling effort as number of transects evaluated per island and year
Note that the transects are not all the same size, so this should just be taken as a guide

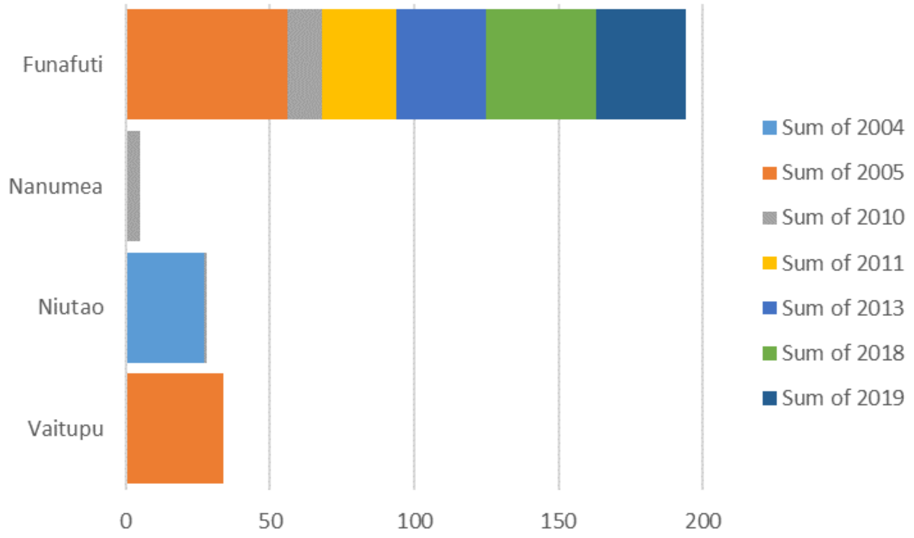
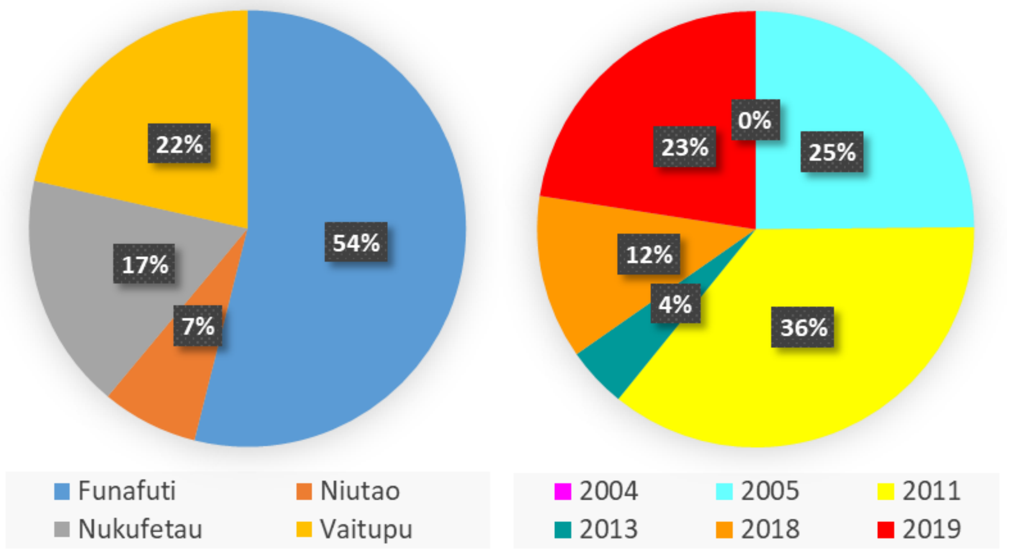


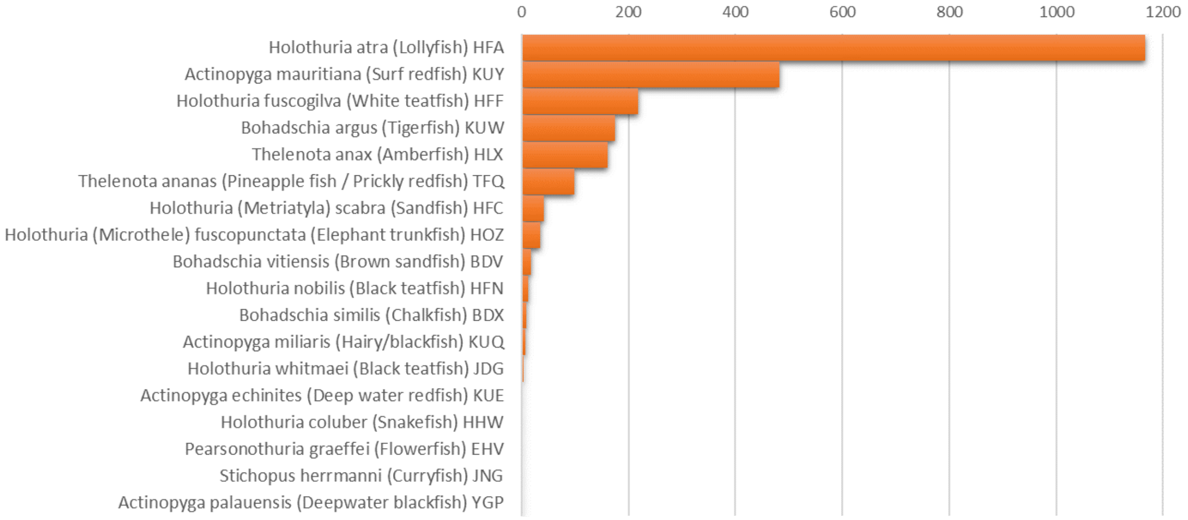
Figure 2: Percentage of BDM counted (a) on each island and (b) by each year


(a) (b)

5.2 Raw Counts by Species

The most common species observed during the study was *Holothuria atra* or Lollyfish, which is also the least valuable from a commercial standpoint (Figure 3). At 1,167 animals recorded, it accounted for 48% of all BDM observed through all of these surveys. Four of the species had just one occurrence each over the entire series of surveys.

Figure 3: Relative abundance of all BDM species recorded during the 2004-2019
Data are total numbers seen across all surveys, regardless of method used for transects or walks, or the total area sampled for each.



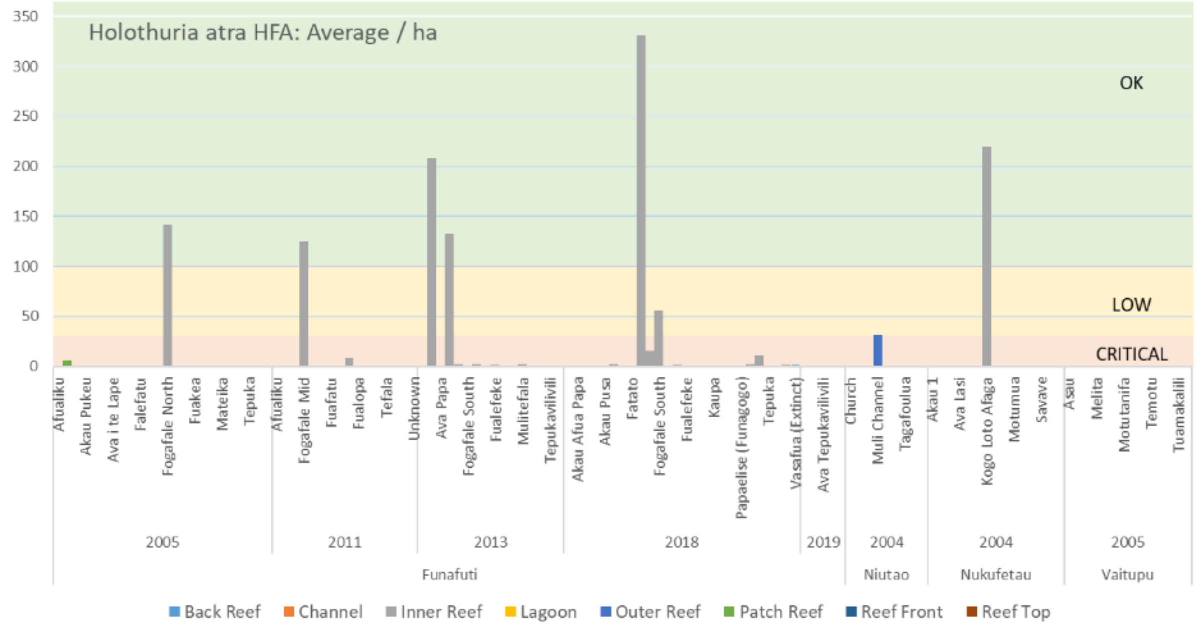
5.3 Average Densities (per ha) by Species

The average number of BDM per hectare was critically low for nearly all species at all of the sites and habitats surveyed and across the years (Figure 4). Compared with the simplified reference densities only two species reached “OK” densities of >100/hectare at just a few sites (Lollyfish *Holothuria atra* at 6 sites and Surf redfish *Actinopyga mauritiana* at one site). Of the remaining species, five had “Low” densities (30-100/ha) at just one or two sites. At the majority of sites, the density of BDM was in the “Critical” range of <30/ha.

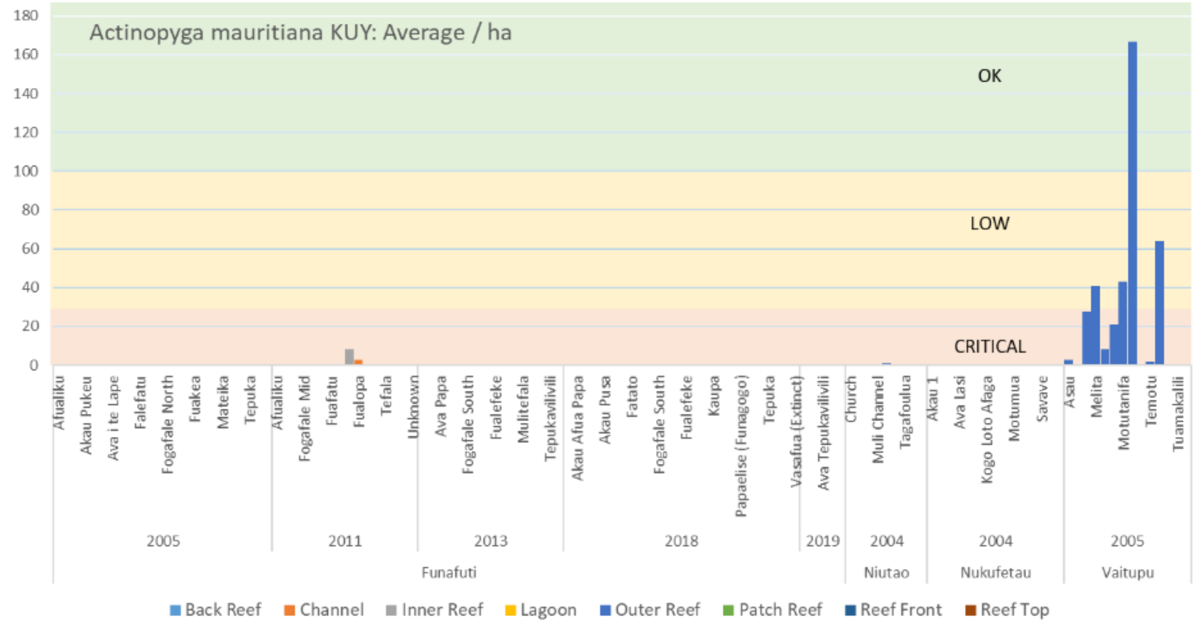
For Funafuti where data were available for multiple years, the low numbers of BDM did not show any changes over time. Significantly, since the closure in 2010 there has been no sign of recovery (increase in density) of any species.

Figure 4: Average densities of BDM over all of the studies as number per hectare at each site, habitat and year.
Note that in order to display all of the results in a single graph, habitats were displayed as stacked values where strictly they should have been displayed on their own bar at each site. The benchmarks for OK, Low and Critical are from (Friedman et al., 2008) and (Purcell, 2010).

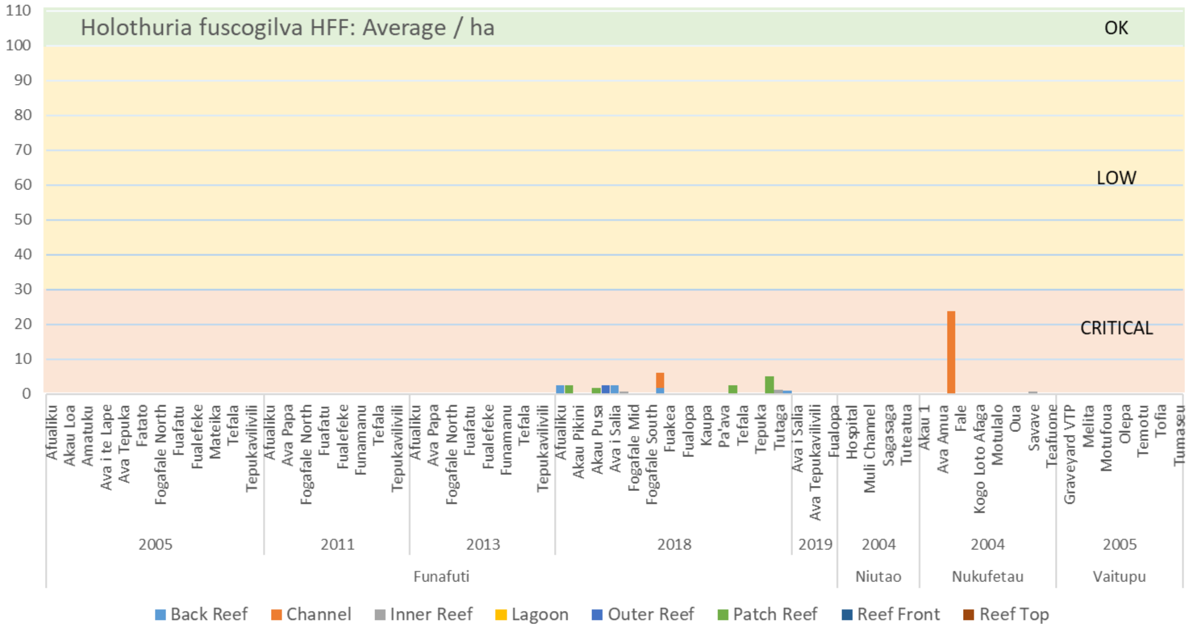
Holothuria atra HFA Lollyfish



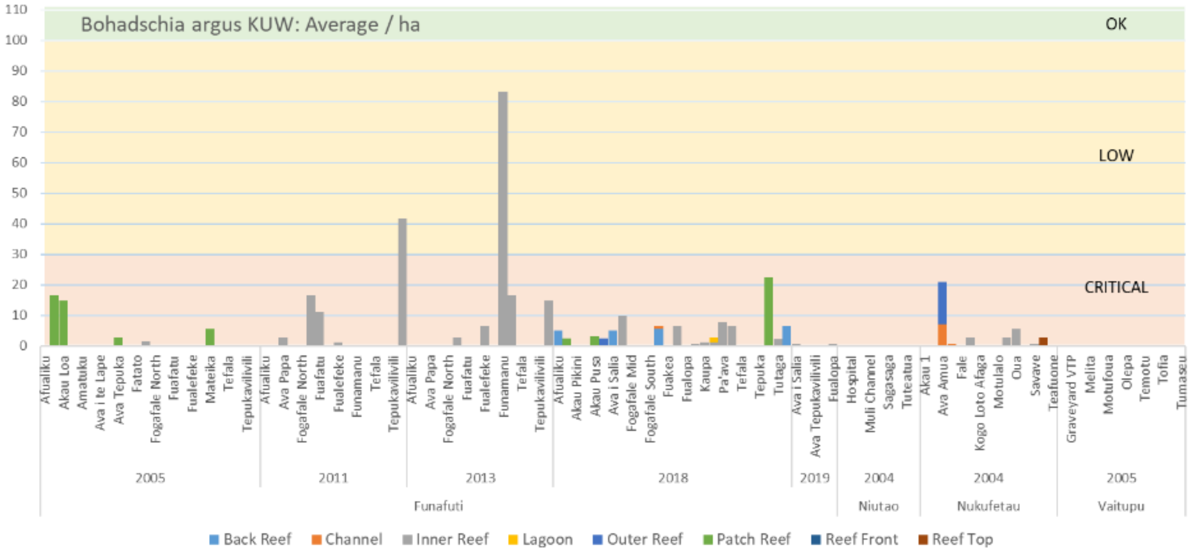
Actinopyga mauritiana KUY Surf redfish



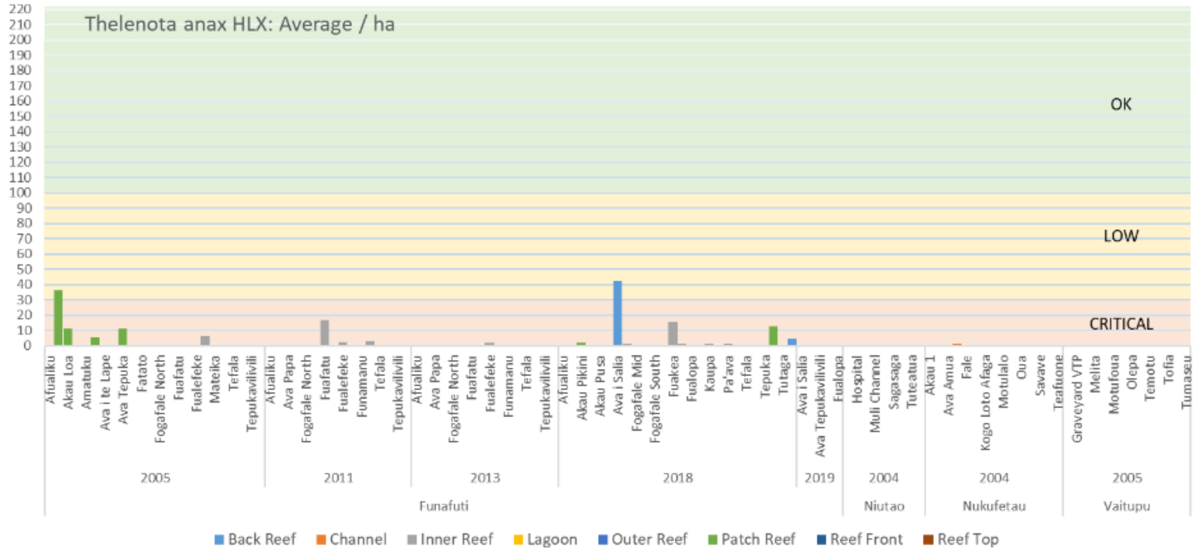
Holothuria fuscogilva HFF White teatfish



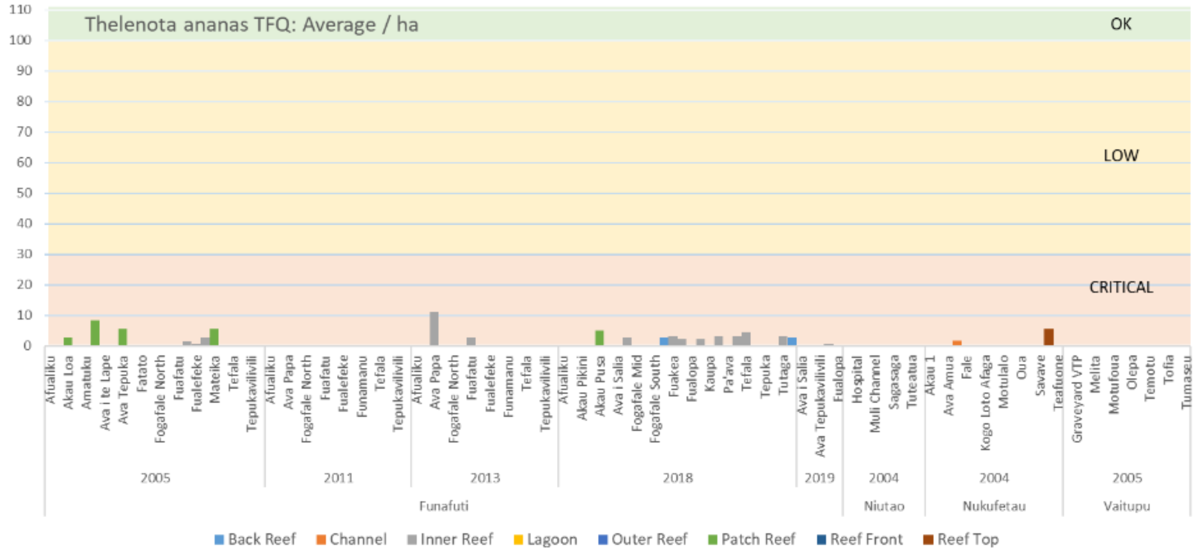
Bohadschia argus KUW Tigerfish



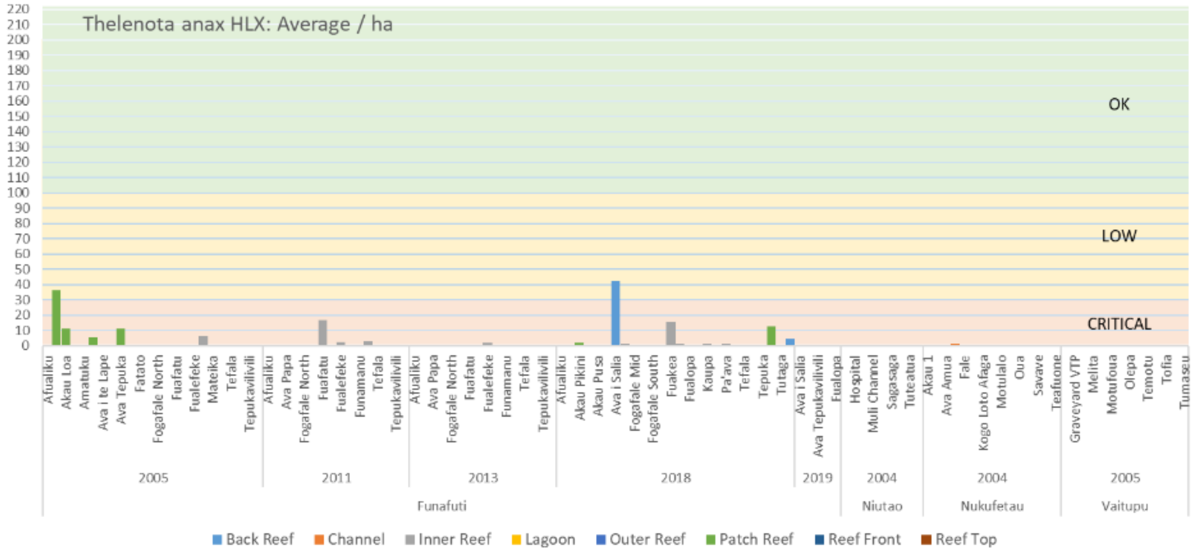
Thelenota anax HLX Amberfish



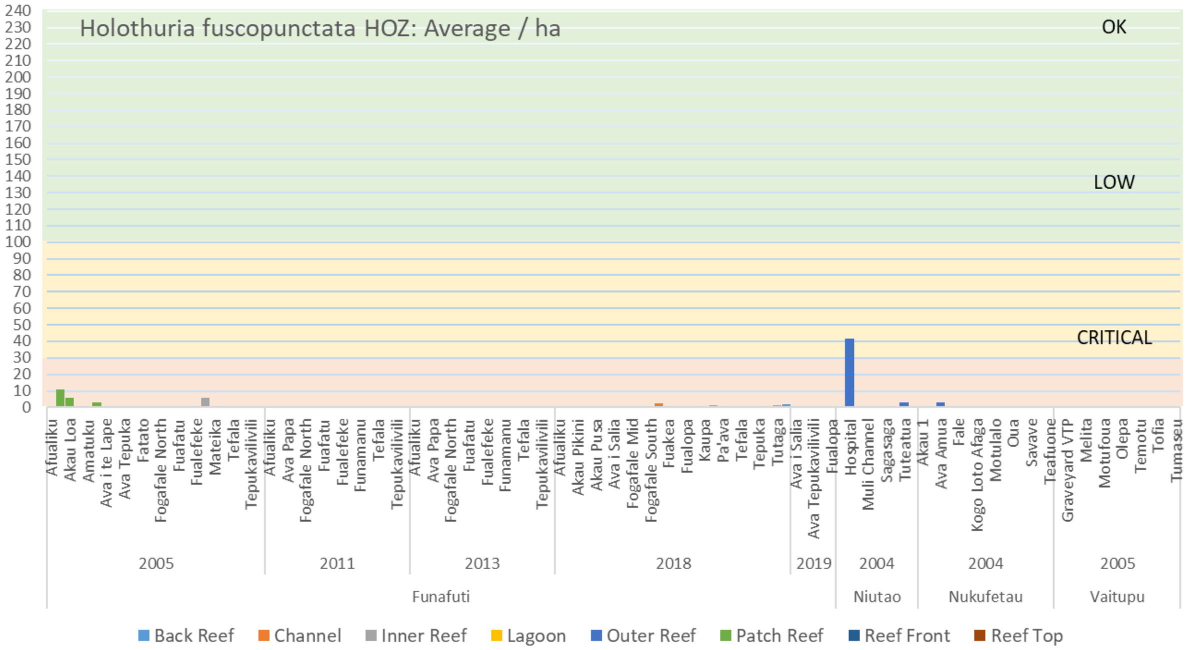
Thelenota ananas TFQ Pineapplefish



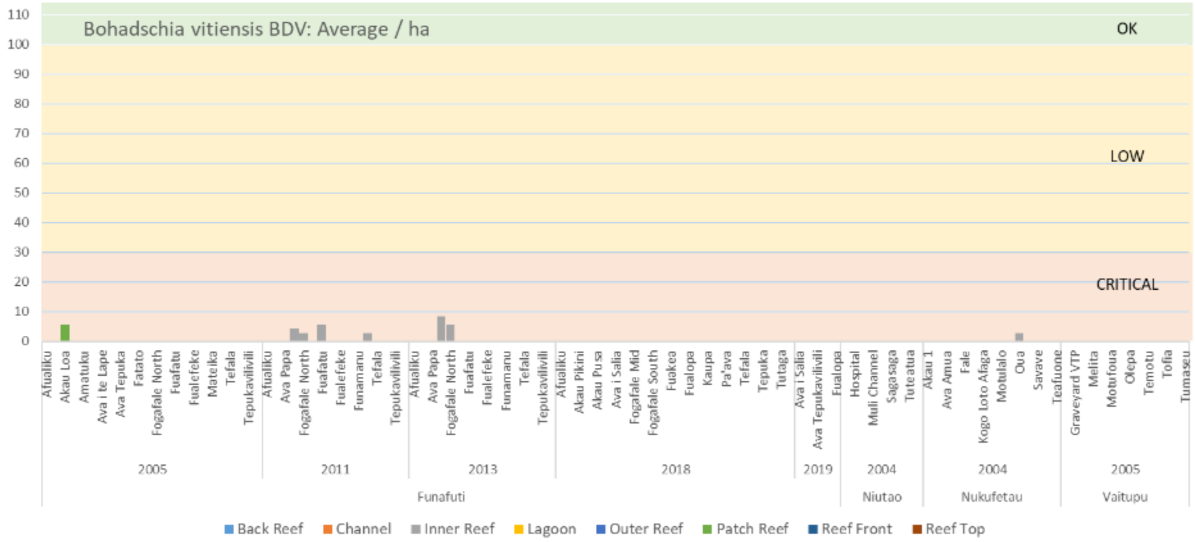
Holothuria scabra HFC Sandfish



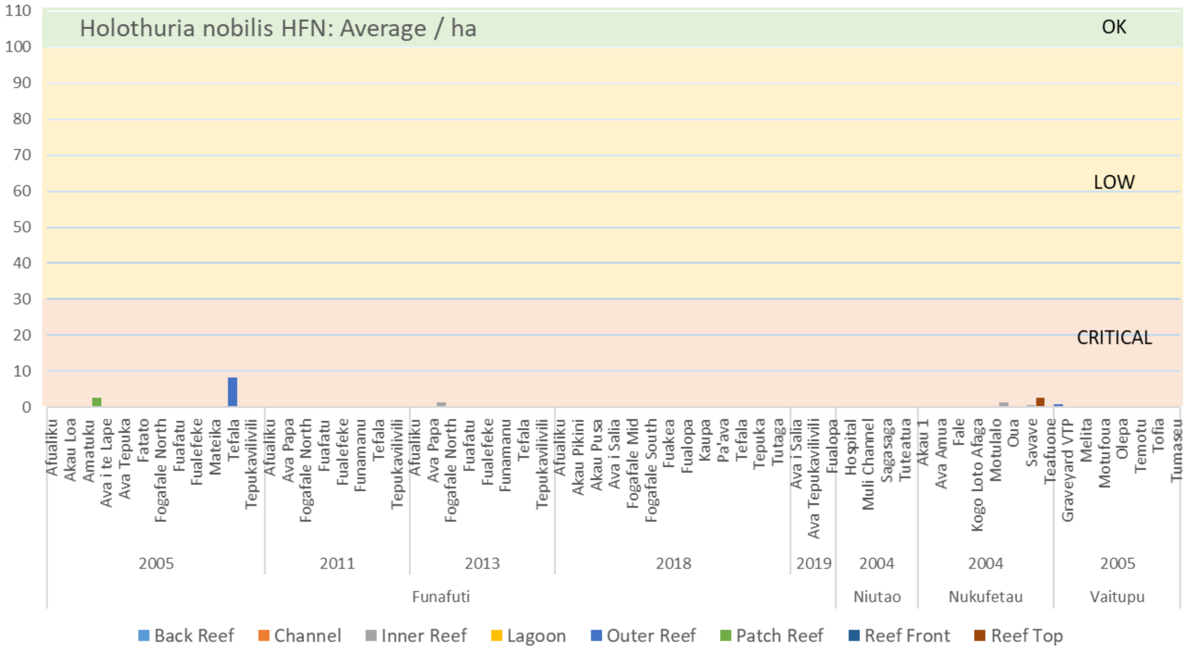
Holothuria fuscopunctata HOZ Elephant trunkfish



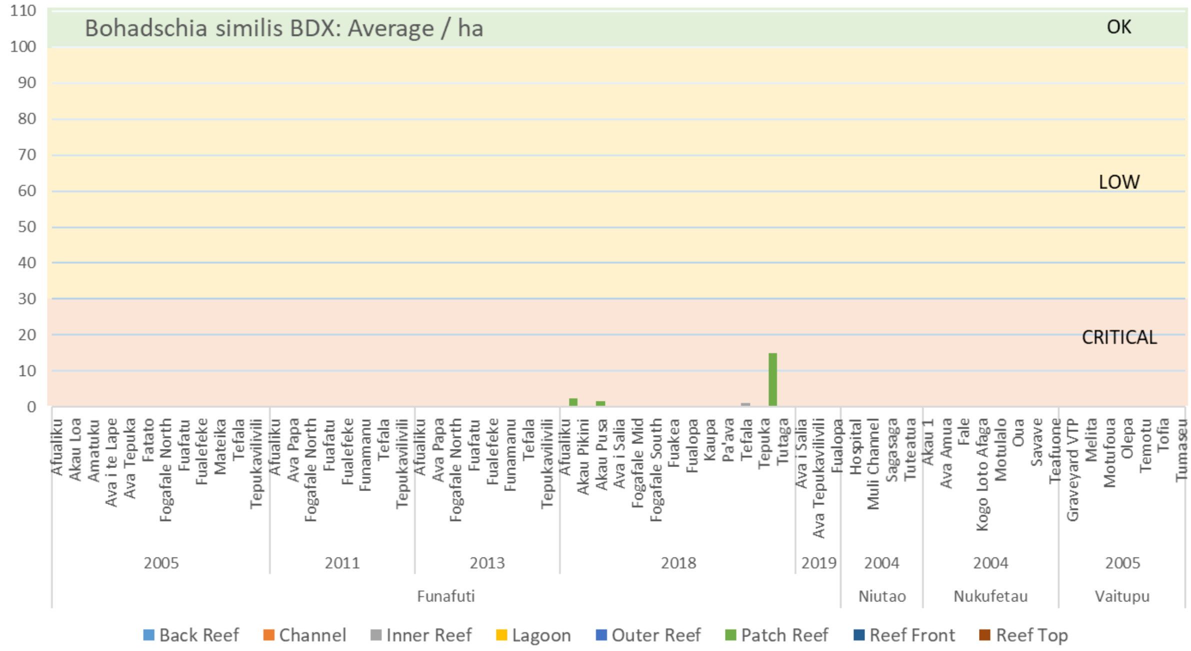
Bohadschia vitiensis BDV Brown sandfish



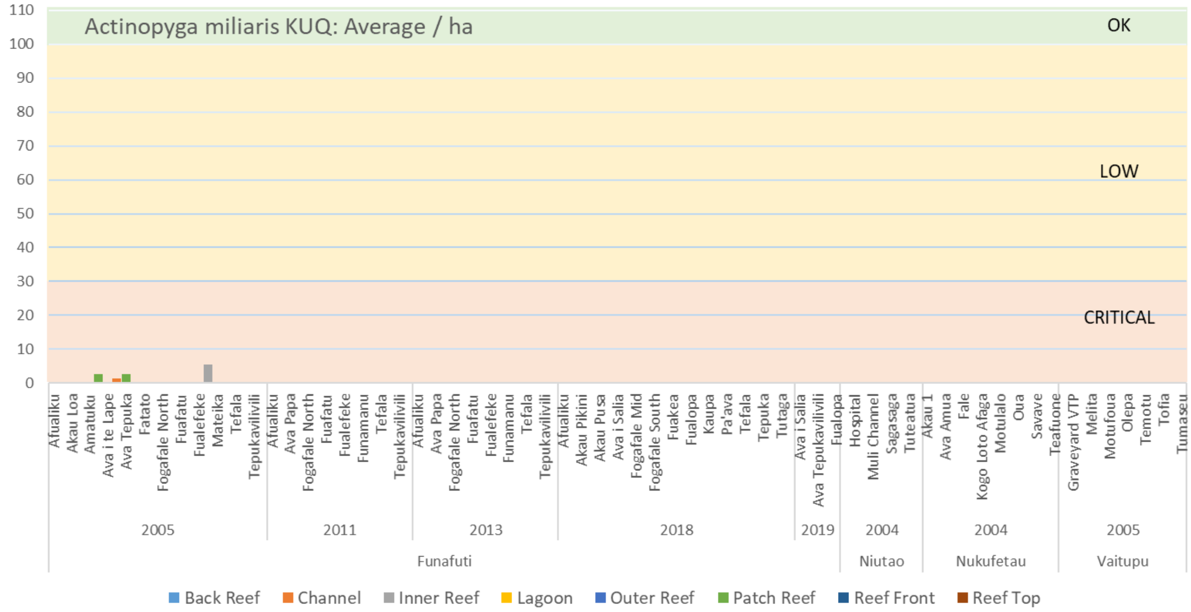
Holothuria nobilis HFN Black teatfish



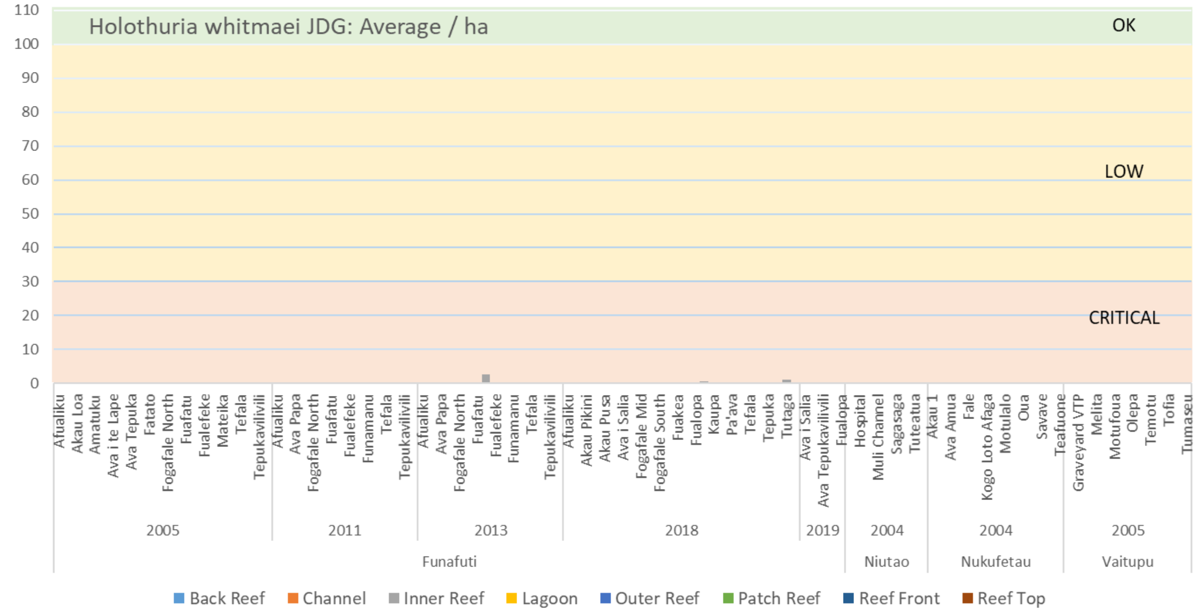
Bohadschia similis BDX Chalkfish



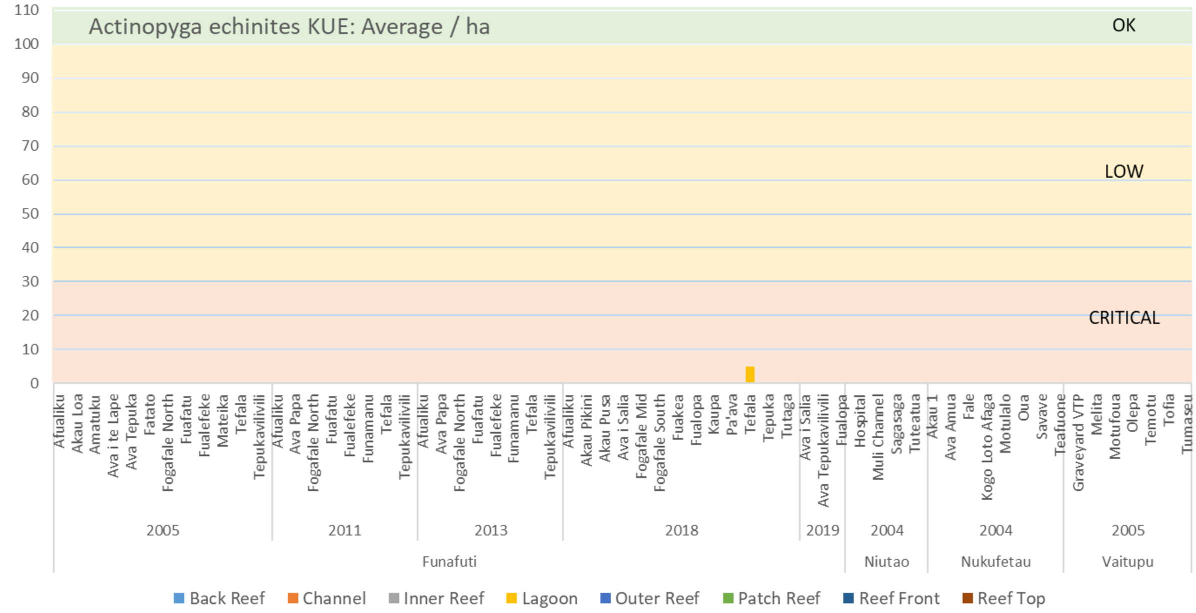
Actinopyga miliaris KUQ Hairy/Blackfish



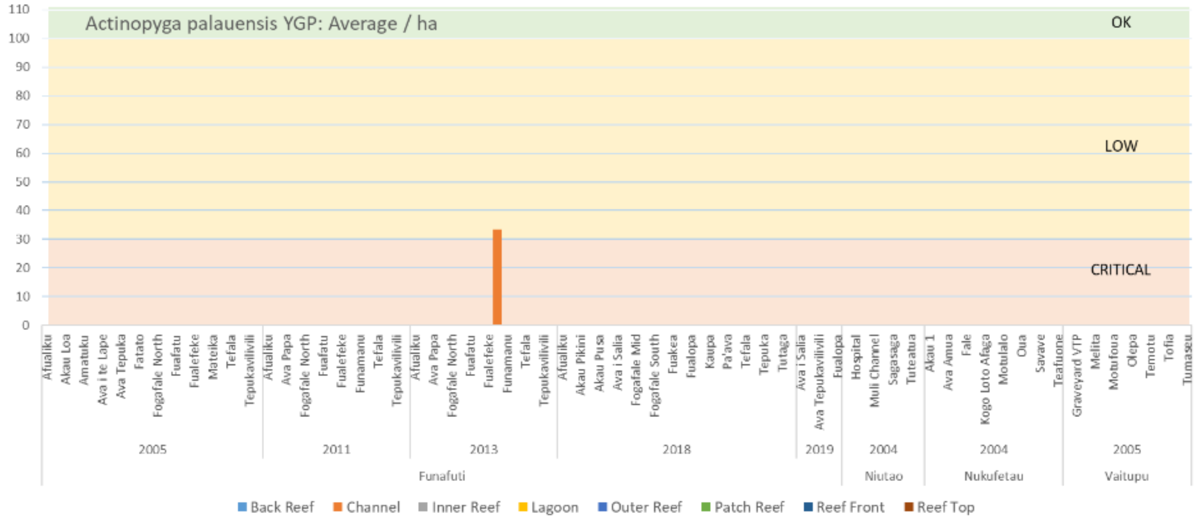
Holothuria whitmaei JDG Black teatfish



Actinopyga echinites KUE Deepwater redfish



Actinopyga palauensis YGP Deepwater blackfish



6 Discussion

Despite Tuvalu's relatively little sea cucumber exploitation in the past the fishery is currently in a state of collapse. There are very low densities of sea cucumbers on all islands, and despite being closed since 2010, there is currently little sign of recovery. Further, it is unlikely stocks will ever be large enough or robust enough to support the kind of significant fishery seen in PNG or Solomon Islands, though at a lower level, exploitation could provide some income to fishers, after the stock has recovered.

SPC's PROCfish project found that there were limited species and stock densities available for commercial fishing (Sauni et al., 2008).

6.1 Sea Cucumbers, Ecosystem Health and Food Webs

The benefits of exploiting BDM in Tuvalu and elsewhere need to be balanced against the ecosystem services that sea cucumbers provide.

Most species of sea cucumbers are benthic detritivores, as such they have a direct impact on the function and quality of the substrate they inhabit. Juvenile sea cucumbers are important prey and adults are important nutrient cyclers, especially on coral reefs where they are involved in oxygenation, nutrient recycling and algal mat removal (Uthicke, 2001; Carleton et al., 2013b; Lee, 2018; Lee et al., 2018a). Bioturbation (working through the sediment floor) allows oxygen-rich water deeper into the sediment (Purcell et al., 2016) and creates a more habitable environment for infauna, increasing biodiversity, biomass and food webs for fishes and other organisms.

There are also suggestions that sea cucumbers can prevent the establishment of cyanobacterial (blue-green algae) mats (Uthicke, 1999; Purcell et al., 2016) which can grow over and smother corals and other benthic organisms, produce toxins that render them inedible to several herbivorous fishes, kill off corals and inhibit coral settlement (Ford et al., 2018).

The sea cucumbers themselves are also susceptible to environmental factors affecting their population numbers. A kill of large numbers of mainly *Holothuria atra* Lollyfish was recorded in Funafuti on 8th March 2017, though the cause was not identified[1]. A regional expert on this

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[1] https://www.tuvalufisheries.tv/2017/03/a-large-number-of-lollyfish-holothuria-atra-washed-ashore/

subject (Steven Lee) was commissioned to provide advice for TFD, his report is provided in full in Annex 3: Environmental considerations relating to the role of sea cucumbers in Funafuti Lagoon, Tuvalu on page 36, and concluded "it would not be advisable to reopen the sea cucumber fishery".

6.2 Length at Maturity (Lm) Data

Some species may be relatively short-lived (several to 10 years, such as Greenfish) with regular recruitment (settlement of juveniles from the plankton). But others such as surf redfish and deepwater redfish are thought to live at least 10-15 years and have unpredictable recruitment, making them highly vulnerable to overfishing (Conand, 1989). As for fish species, preserving the breeding population will be a key part of management. Although some Lm data were collected during the surveys reported here, the data are sporadic and there may be a need to collect length and weight information in future surveys.

6.3 The Allee Effect and Reproductive Success

Overfishing threatens local fisheries for valuable tropical sea cucumbers by reducing population densities to the point where reproductive success is slower than natural mortality (known as *depensation* or the 'Allee effect'). Once this happens, conventional management measures alone, such as closed seasons/areas, size limits and gear restrictions, will usually fail to repair the damage. A different suite of active management interventions must be considered to restore the spawning biomass of severely over-exploited populations (Bell et al., 2008). This study shows that Tuvalu's BDM stocks appear to already be in this state. Since closure in 2010 there appears to have been little recovery of BDM densities and it may be necessary to consider the following options as a first step to recovery before fishing recommences and day-to-day management measures are introduced. Recovery measures, likely to take some years to restore the populations include:

- Restocking the FCA with hatchery-reared juveniles; and
- Aggregating what remains of the wild populations in the FCA to increase their density.

Bell & Nash (2004) clearly identified the conditions under which producing and releasing juveniles for restocking of BDM would make sense, and those conditions do not include simply having access to the technology. *Restocking* is seen as a way of restoring stocks to the point where they can sustain regular harvests or of enhancing stocks by overcoming recruitment limitation and increasing yields (Bell and Nash, 2004). They suggested that it would be essential to determine whether the release of cultured juveniles would significantly reduce the time needed for replenishment compared to other forms of management, such as a total moratorium on fishing or artificially aggregating and protecting some of the wild adults to promote spawning success. This would require significant data-hungry field research. Investments in hatchery production for restocking should only proceed when the research they describe demonstrates that releases of cultured animals will "fast-track" replenishment considerably.

On the other hand, *stock enhancement* could be considered *once sea cucumber fisheries have been rebuilt to the desired level of spawning biomass*, although it can only be expected to be of benefit where the supply of juveniles regularly falls well short of the desired levels of recruitment. To assess whether stock enhancement is likely to be effective, managers need sound information on carrying capacity, optimal stocking densities, abundance and age structure, natural supply of juveniles, cost of culturing and post-release survival rates. Even where the supply of juveniles falls short of the desired level, stock enhancement will not be appropriate if the cost of producing the juveniles exceeds the value of the additional harvests expected to result from the releases.

Tuvalu is a long way off being in the position of considering either restocking or stock enhancement and evaluating the costs and benefits of doing either.

7 Conclusions

BDM are sedentary, shallow-water, readily accessible animals that are easy to over-fish because they are:

1. Long-lived, slow to mature, broadcast spawners that are easy to harvest;
2. Dependent on minimum density for successful reproduction below which the population can crash or even become extinct (the “Allee effect”);
3. A mixed species fishery so that when target species fall below commercial densities, fishers shift to other species, but can continue to catch previous target species, pushing them further below viability, and possibly towards local extinction (Carleton et al., 2013a).

The poor state of regional stocks (Kinch et al., 2008; Purcell et al., 2011; Carleton et al., 2013b) and widespread introduction of moratoria, shows that most management, whether traditional or modern, has failed to protect and ensure the economic yield and social benefits from sea cucumber harvesting. This is particularly true in Tuvalu, where natural reef productivity is likely low and recovery of BDM over the past 10 years has been virtually non-existent. At this time, the Tuvalu BDM populations are clearly unable to support any kind of fishery and should remain closed until sufficient recovery has occurred to support a fishery.

8 Recommendations

1. The current ban on BDM in Tuvalu should be maintained until surveys show that the sea cucumbers have recovered to resilient levels and are able to breed reliably. That is, the fishery should only be opened after a periodic manta tow survey can show that the densities of the fished species have recovered, and there is excess in the population that could be taken without damage to breeding populations. Unfortunately these conditions are not likely to occur for quite some time in the future (perhaps 10-20 years).
2. Regional Reference Densities should be used as benchmarks for deciding when the BDM fishery could be re-opened and for adaptive management of the stocks.
3. Consideration should be made of the potential beneficial roles that sea cucumbers play in improving sediment and water quality and the possible deleterious impact of their removal or extinction.
4. Immediate action may be needed in an effort to recover BDM stocks in Tuvalu because current indications are not just that the resources are overfished, but that they are severely depleted. This could include collecting adults and concentrating them in the FCA and LMMAs to increase densities.
5. The Funafuti Conservation Area (FCA) is more than large enough to act as a refuge or breeding populations of sea cucumbers (Carleton et al., 2013b) and may be a good place to take immediate action to increase densities of BDM so that reproduction can improve.
6. A BDM Management Plan should be developed for the long term once stocks have recovered and which controls the take of sea cucumbers based on minimum densities and sizes, see (Lee et al., 2018b; Lee et al., 2020). Control in Tuvalu could include restricting exports (sizes and numbers) and banning SCUBA for collection. Other management measures may also be needed and adaptive management will need to be supported by monitoring of the stocks. The Management Plan may include designating the fishery as being of national interest, per the Marine Resources Act (GoT, 2008, 2012). Any future plans to reopen this fishery should be based on advice from TFD and potentially SPC.

7. Excellent guidance for the development of a national BDM Management Plan has been provided by SPC. A good start would be to use the Manager’s Toolbox (Friedman et al., 2008).

9 Annexe 1: Regional Reference Densities of BDM/ha

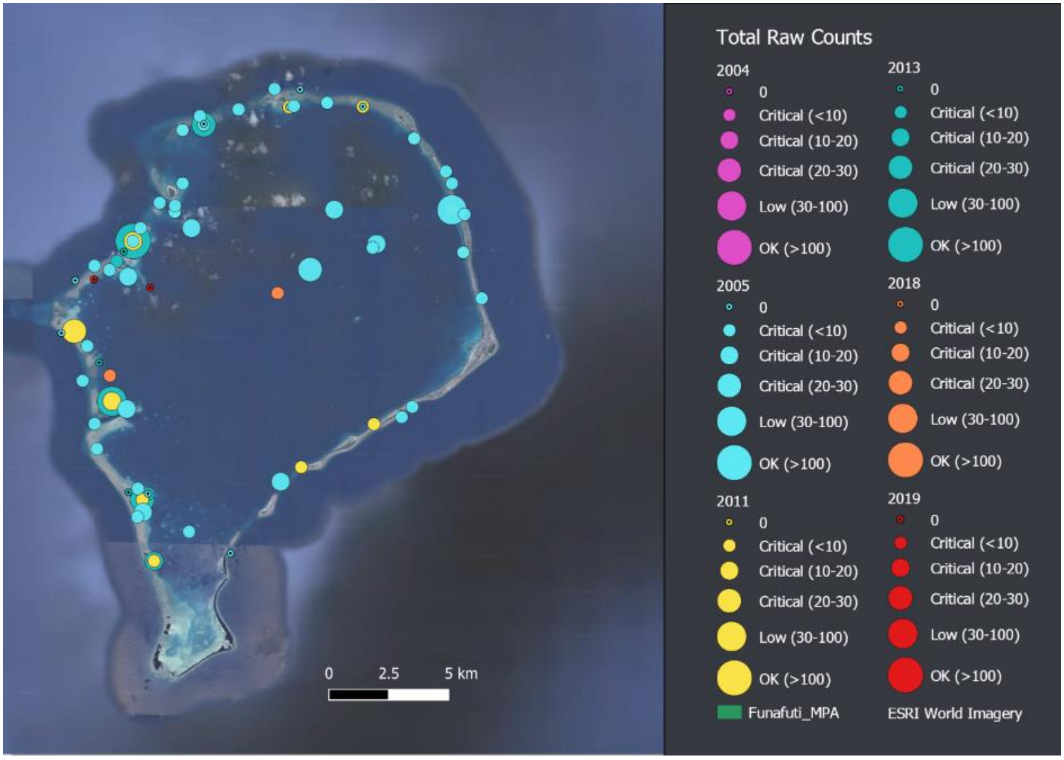
Reference densities of BDM per hectare from (Pakoa et al., 2014) derived by using Reef benthos and Manta tow methods. These reference densities may be useful for the BDM Management Plan once densities have been recovered above the Critical level at which they are now found. Lm information (length at which half of the animals have reached maturity) from (Carleton et al., 2013b).

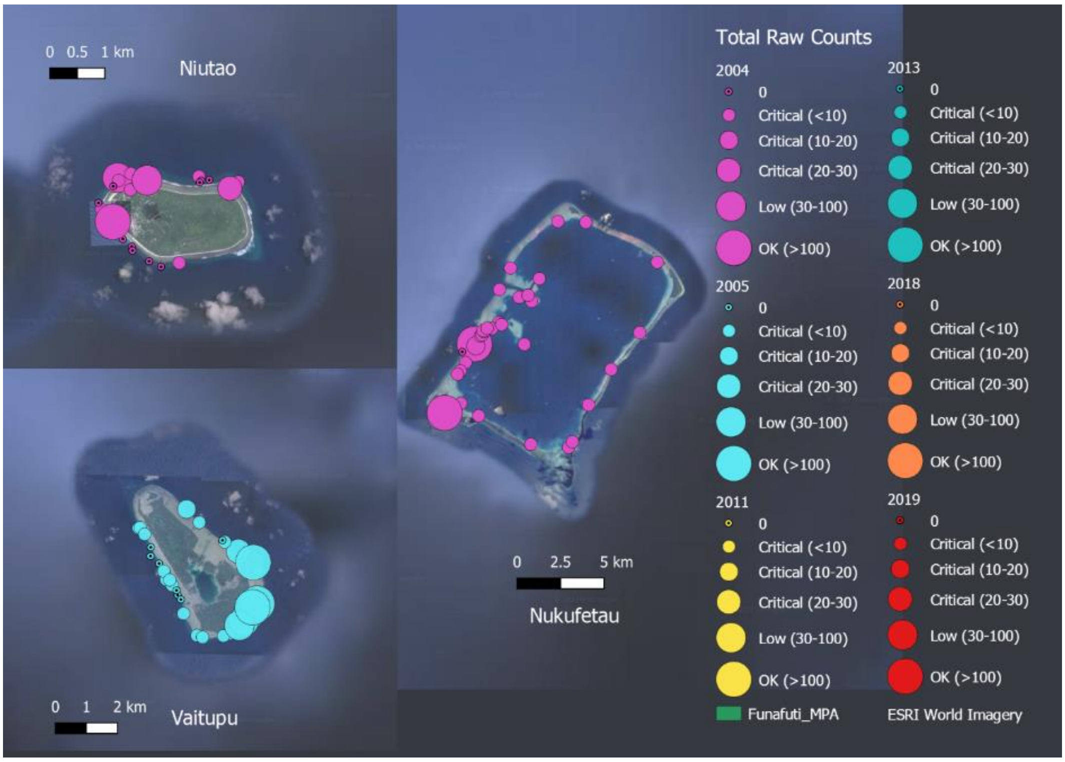
Family	Species | FAO Code | Common name	Reef benthos (ha)	Manta tows (ha)	Lm (cm)
Holothuridae	Actinopyga echinites KUE Deep water redfish			12
	Actinopyga lecanora YVV Stonefish	10		
	Actinopyga mauritiana KUY Surf redfish	200	20	22
	Actinopyga miliaris KUQ Hairy/blackfish	150		
	Actinopyga palauensis YGP Deepwater blackfish			
	Actinopyga spinea YGS Burying blackfish			
	Bohadschia argus KUW Tigerfish	120	50	
	Bohadschia similis BDX Chalkfish	1400		
	Bohadschia vitiensis BDV Brown sandfish	100	160	
	Holothuria atra HFA Lollyfish	5600	2400	16.5
	Holothuria coluber HHW Snakefish	1100		
	Holothuria edulis HFE Pinkfish	260	250	
	Holothuria fuscogilva HFF White teatfish	20		32
	Holothuria fuscopunctata HOZ Elephant trunkfish	10	10	35
	Holothuria lessoni JCO Golden sandfish			
	Holothuria nobilis HFN Black teatfish			26
	Holothuria scabra HFC Sandfish	700		16
	Holothuria scabra var versicolor			22
	Holothuria whitmaei JDG Black teatfish	50	10	
	Pearsonothuria graeffei EHV Flowerfish	100	50	
Stichopodidae	Stichopus chloronotus JCC Greenfish	3500	1000	
	Stichopus herrmanni JNG Curryfish	100	130	
	Stichopus horrens KUN Peanutfish			
	Stichopus monotuberculatus (acc Purcell) JPQ Dragonfish			
	Stichopus naso JPR Dragonfish			
	Stichopus ocellatus JPT Eye-spot curryfish			
	Stichopus pseudohorrens JPU Hawaiian Spiky Cucumber			
	Stichopus vastus KPW Brown curryfish			
	Thelenota ananas TFQ Pineapple fish / Prickly redfish	30	10	30
	Thelenota anax HLX Amberfish		20	

10 Annexe 2: Atlas of BDM Densities per Transect

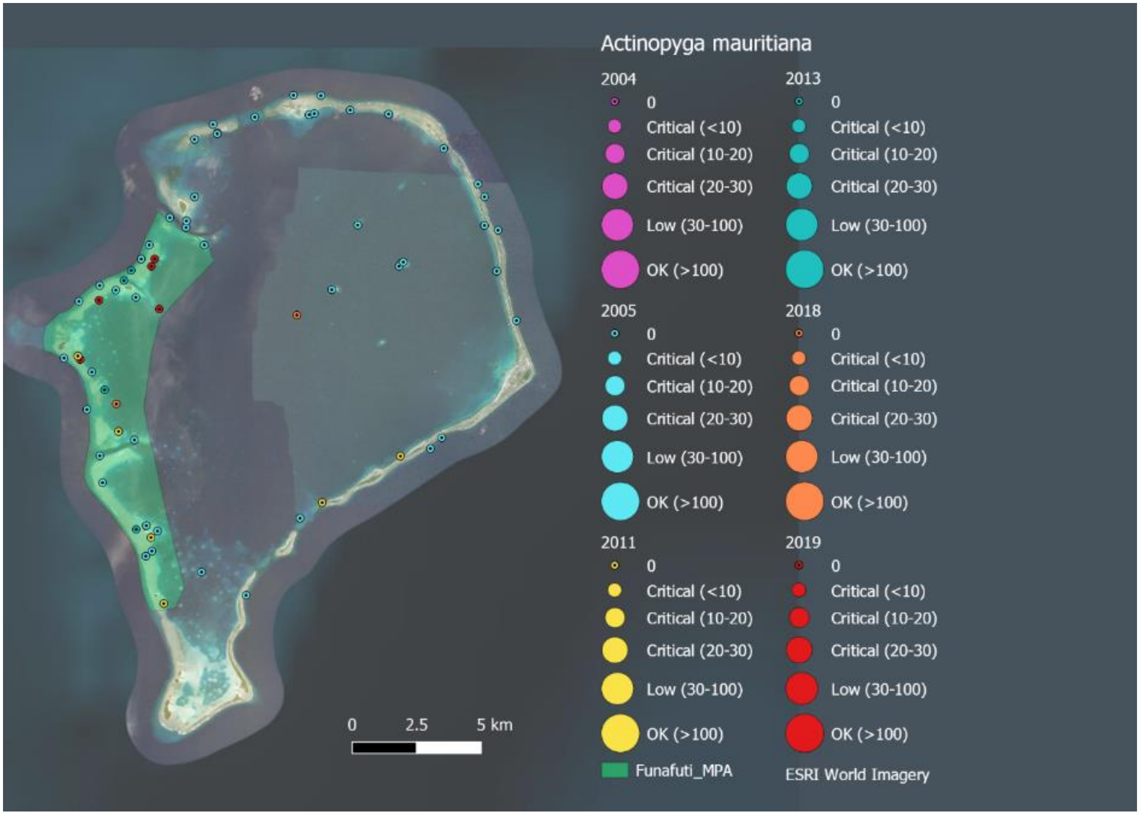
The GIS maps below show total numbers or average densities (per hectare) for all years of the survey. Values are average numbers per hectare calculated over replicates for each transect, not grouped into sites. Note that the smallest symbol in each year represents zero found at that location and time. These plots allow for visualisation how BDM are distributed in space and over time.

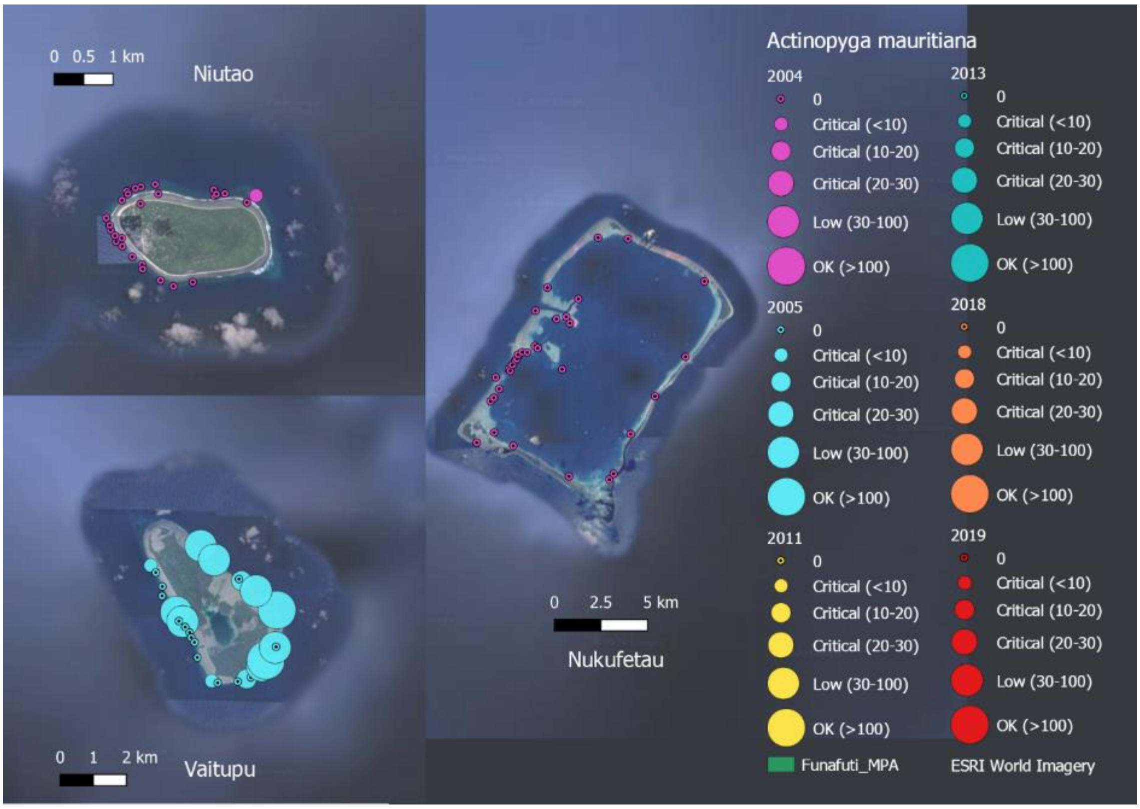
10.1 Total numbers of BDM including all species, separated by year



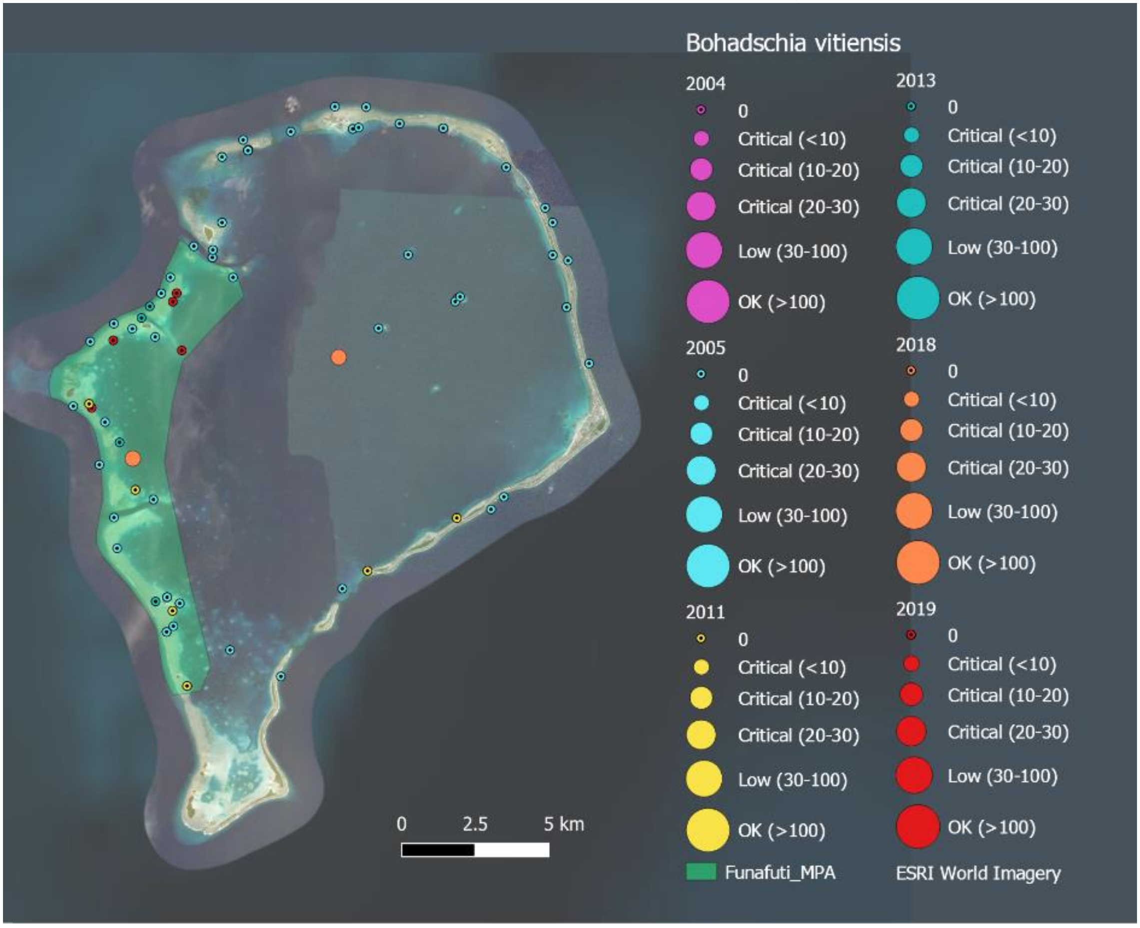


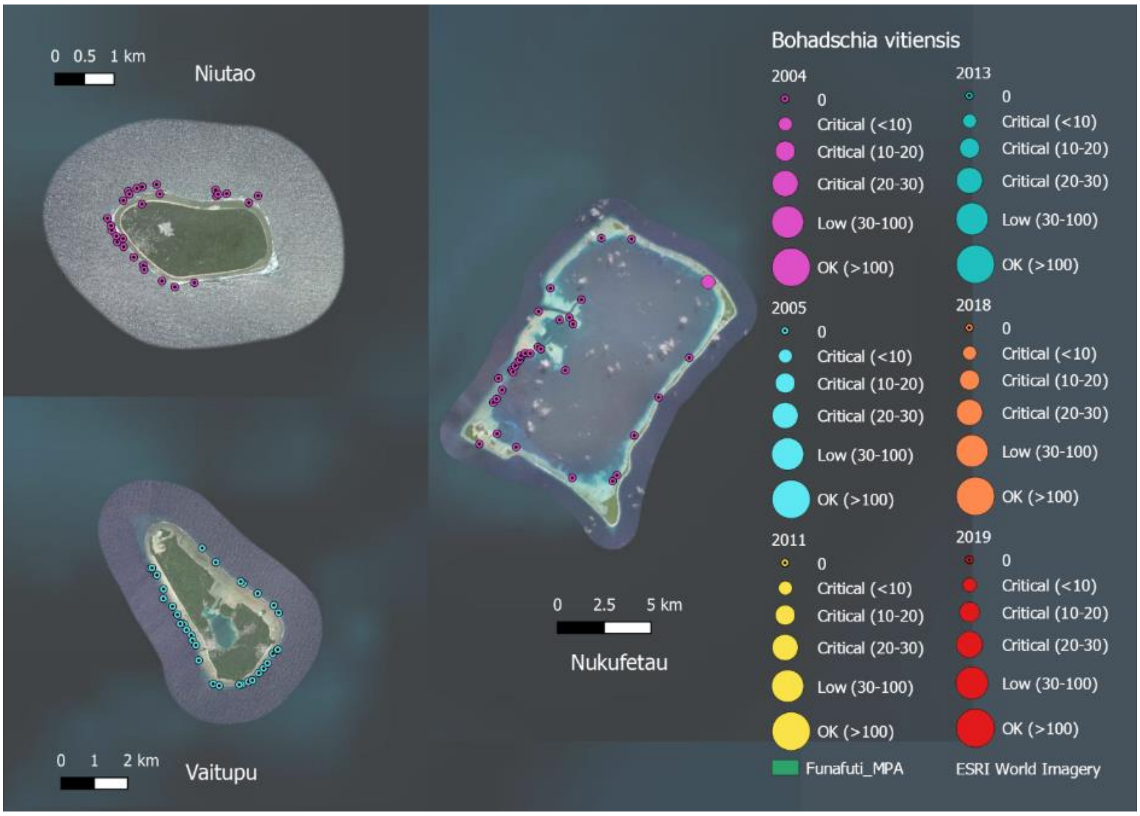
10.2 *Actinopyga mauritiana* KUY Surf redfish (average/ha)



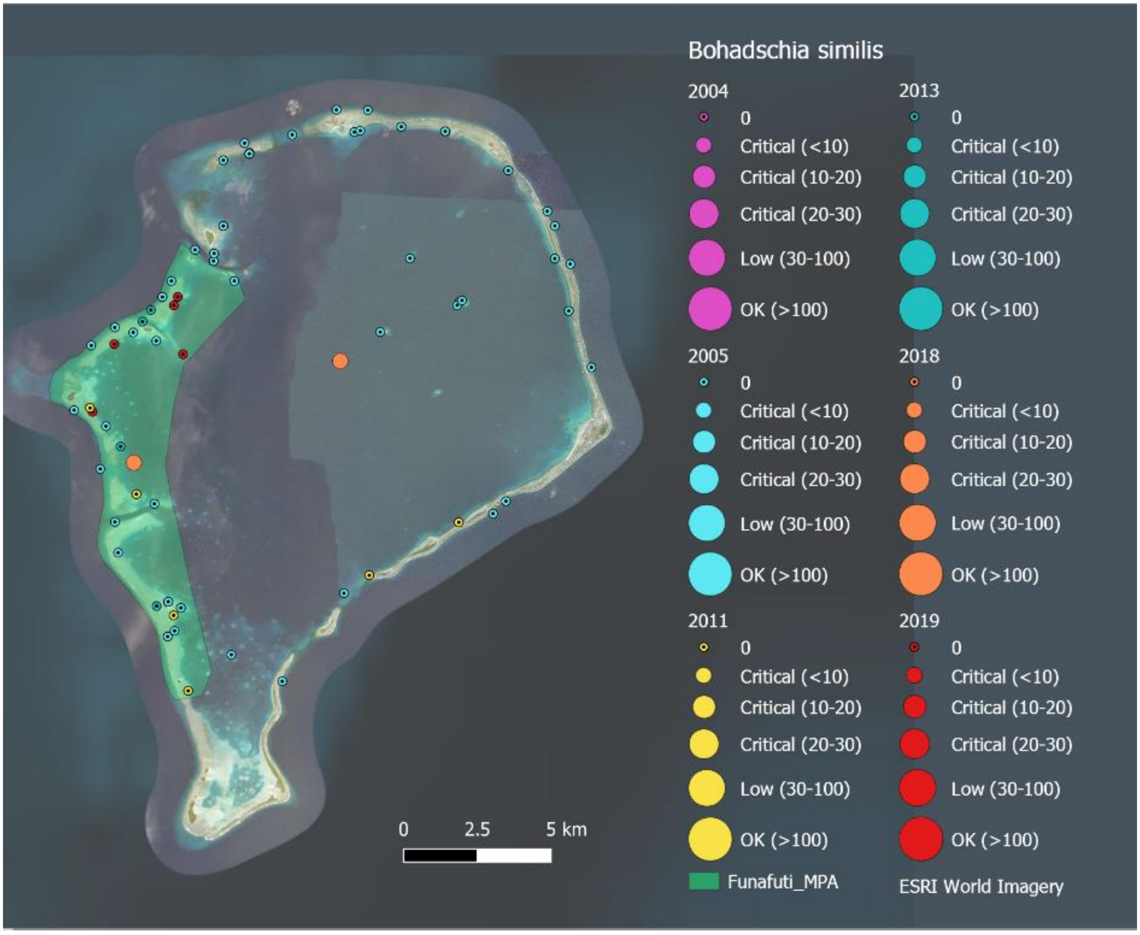


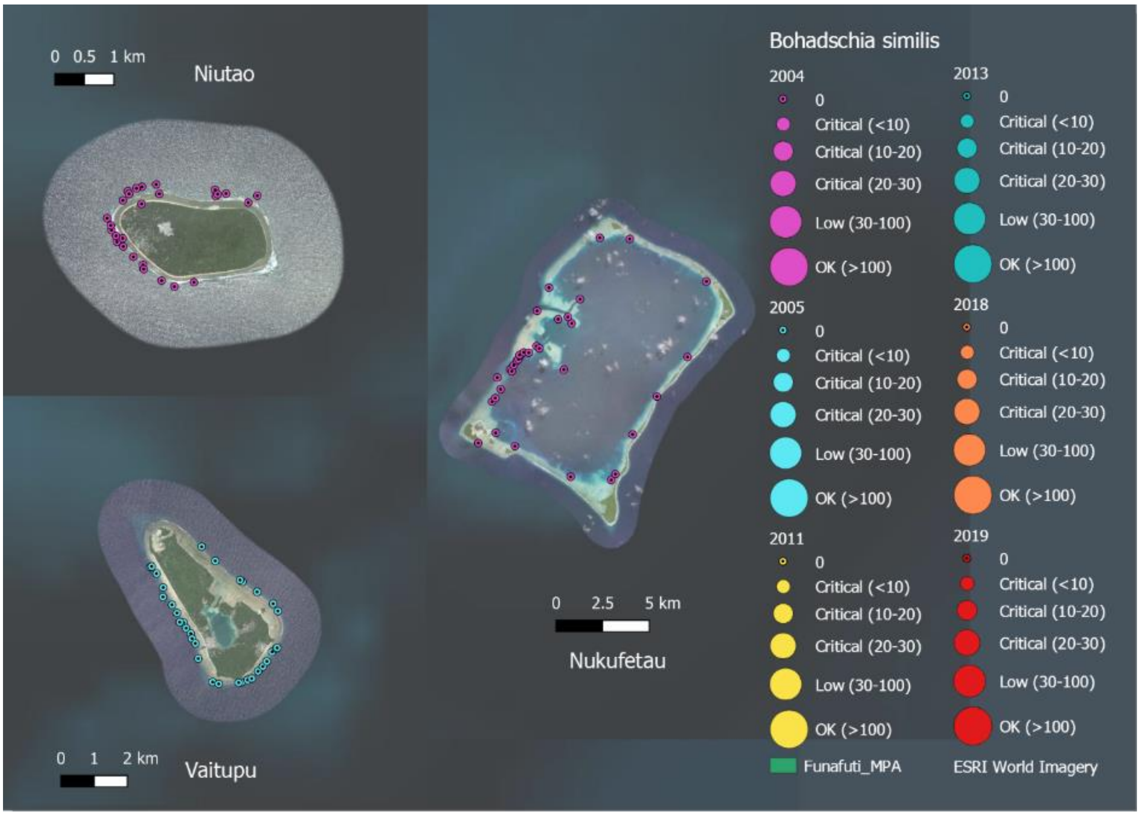
10.3 *Bohadschia vitiensis* BDV Brown sandfish (average/ha)



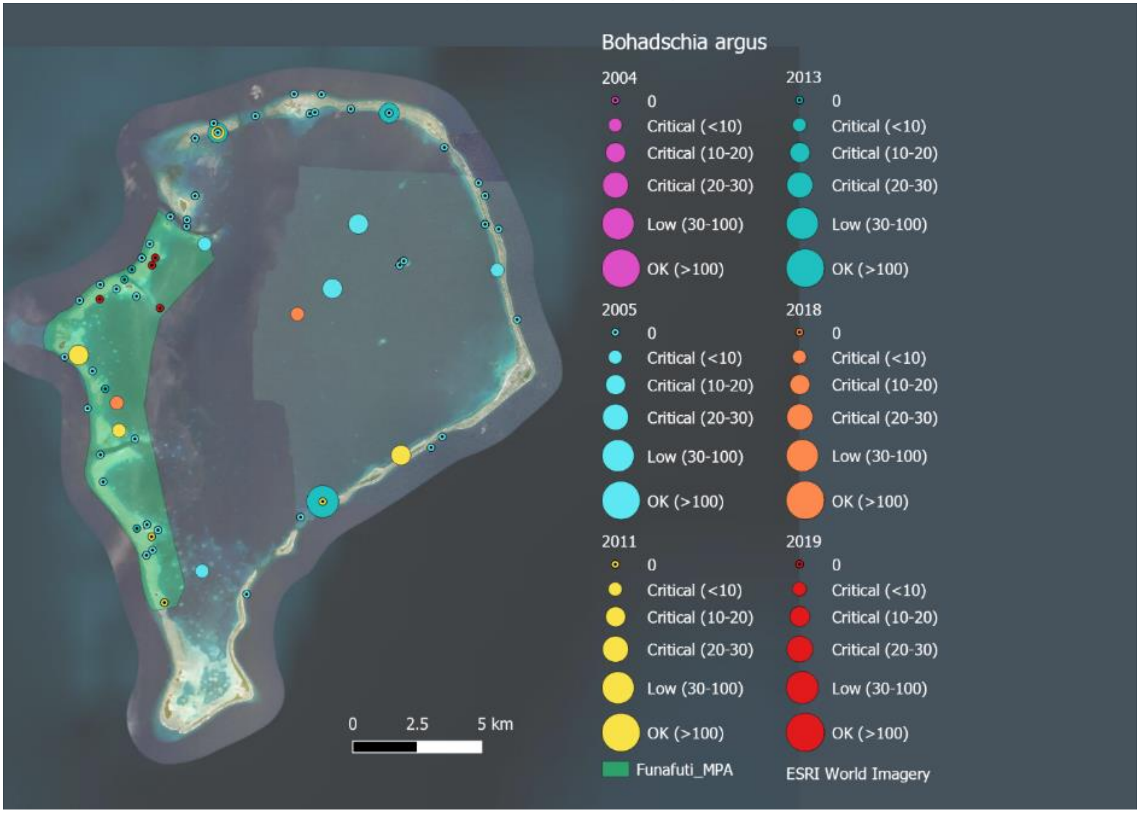


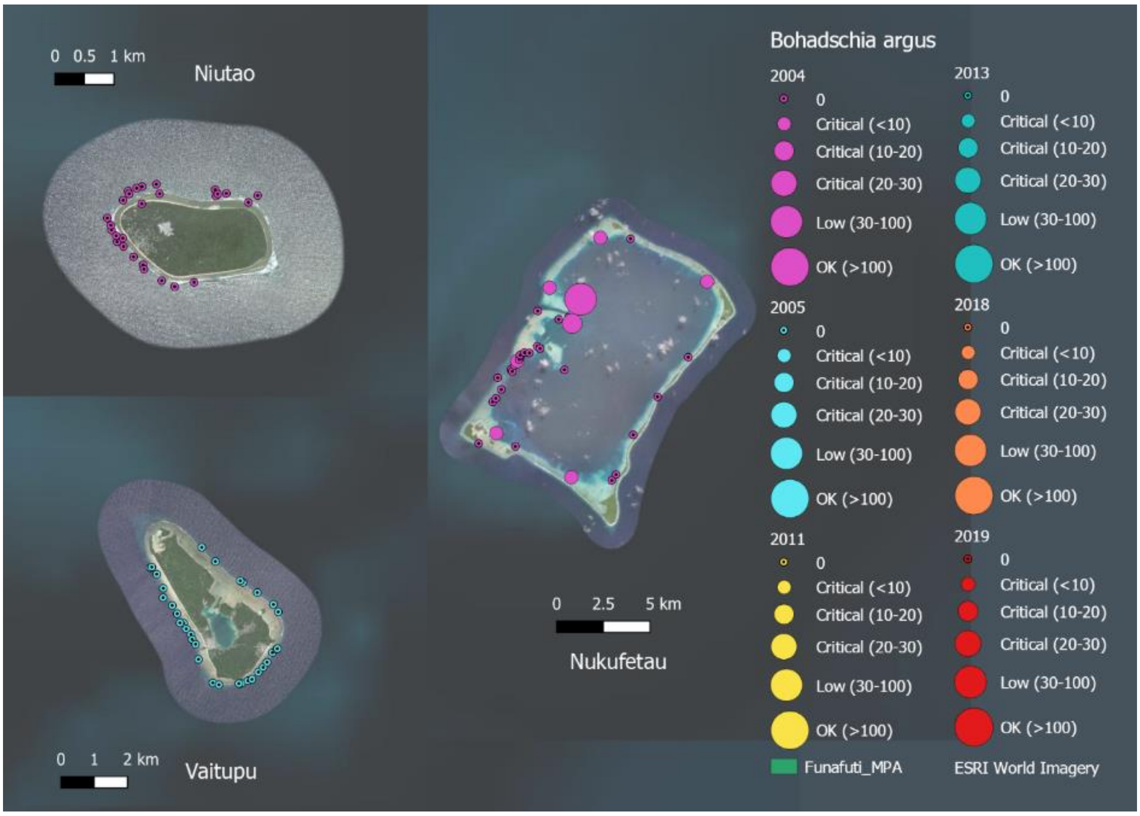
10.4 *Bohadschia similis* BDX Chalkfish (average/ha)



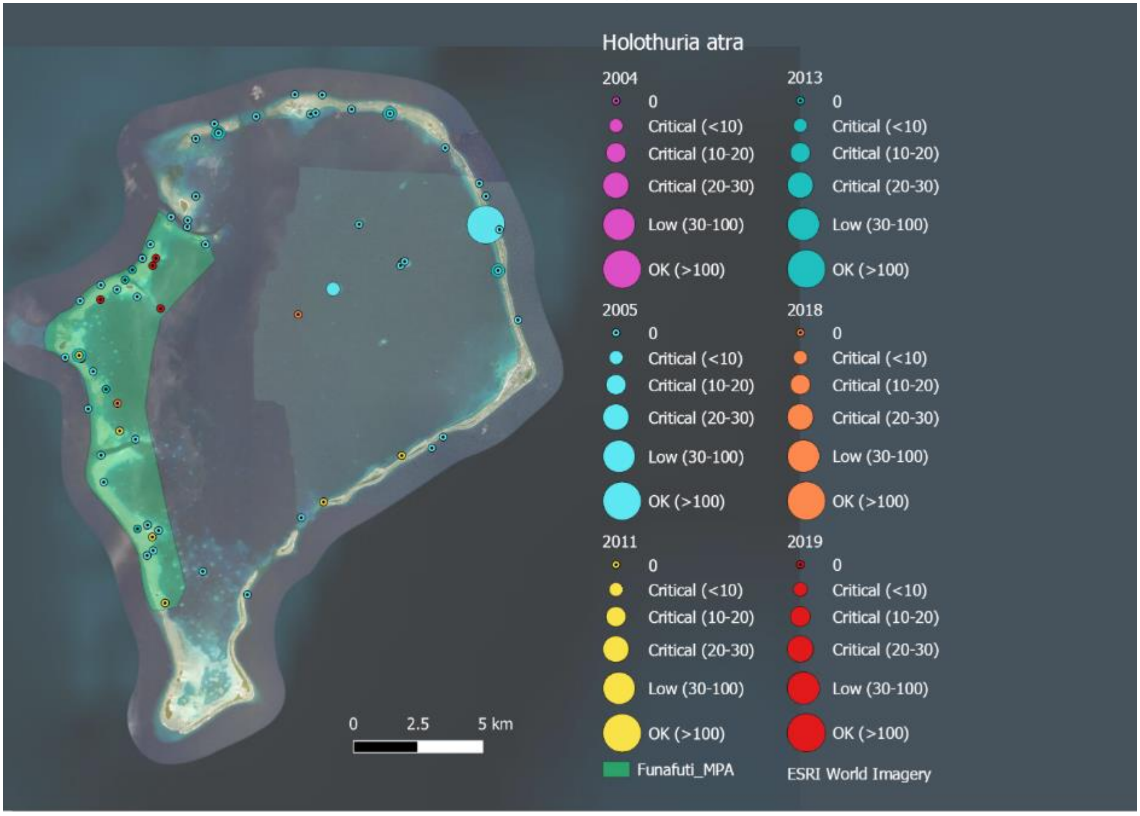


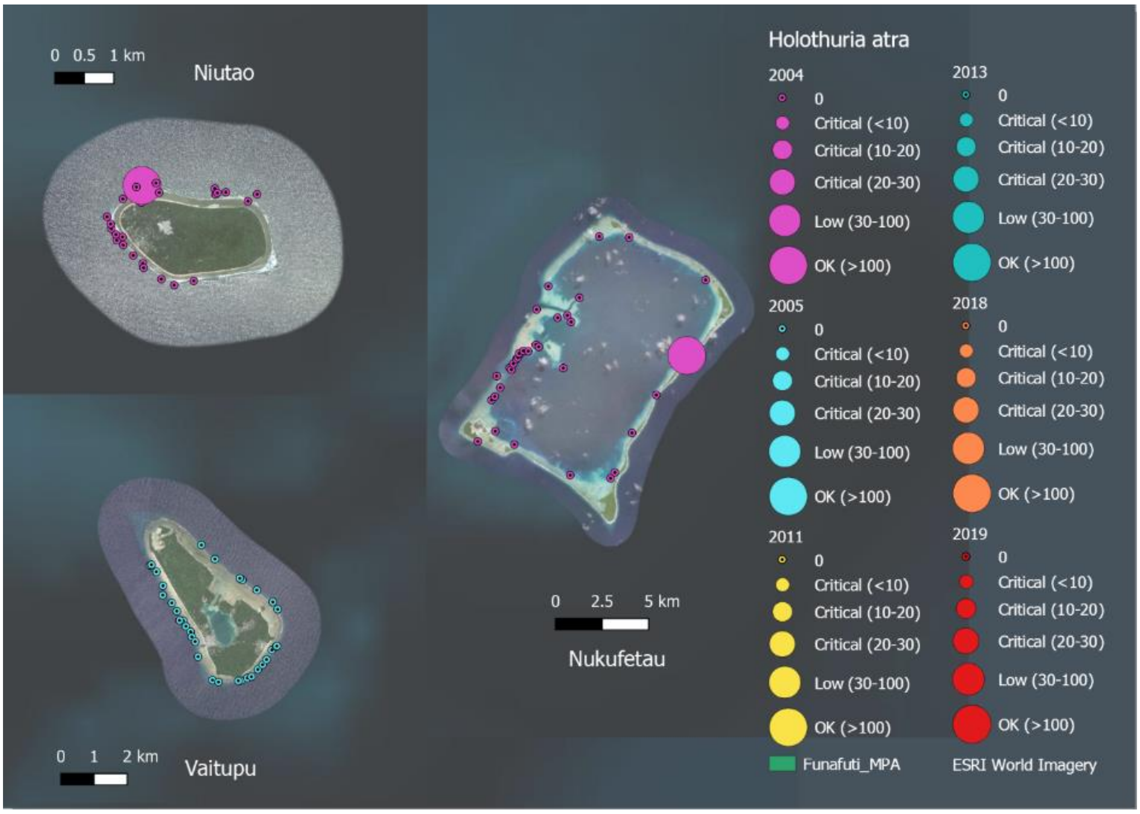
10.5 *Bohadschia argus* KUW Tigerfish (average/ha)



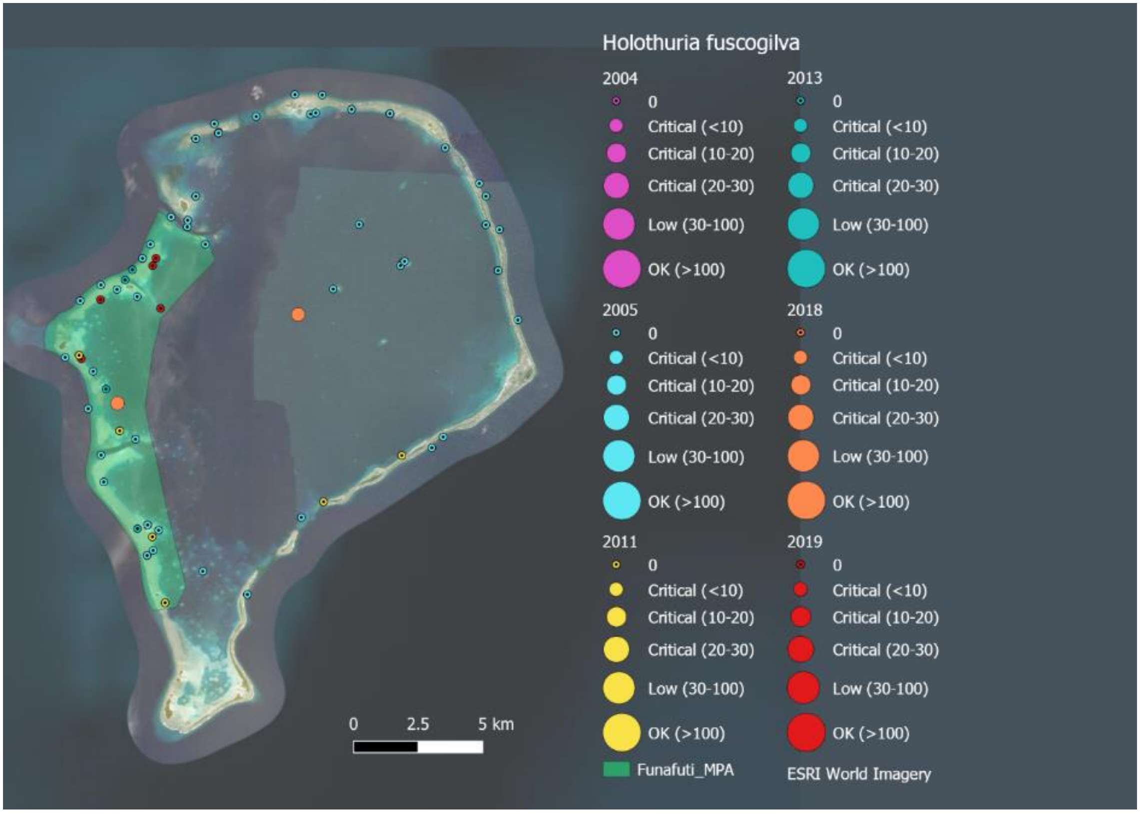


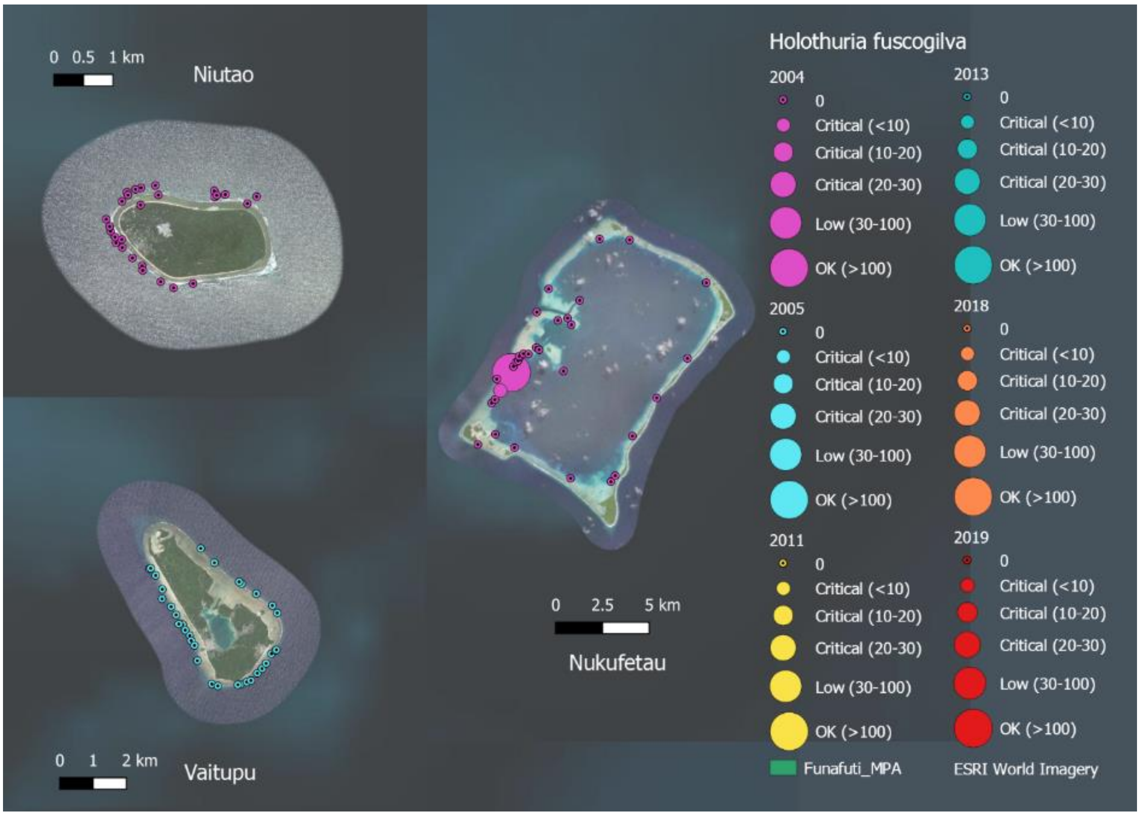
10.6 *Holothuria atra* HFA Lollyfish (average/ha)



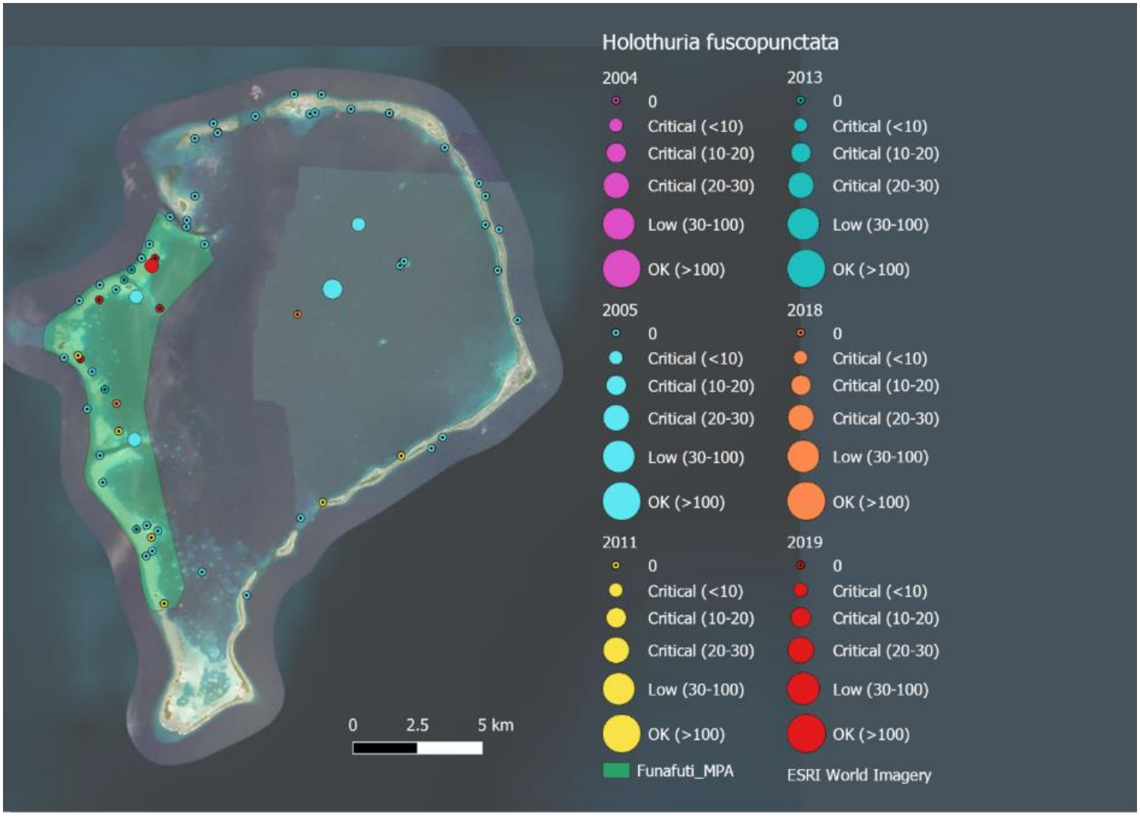


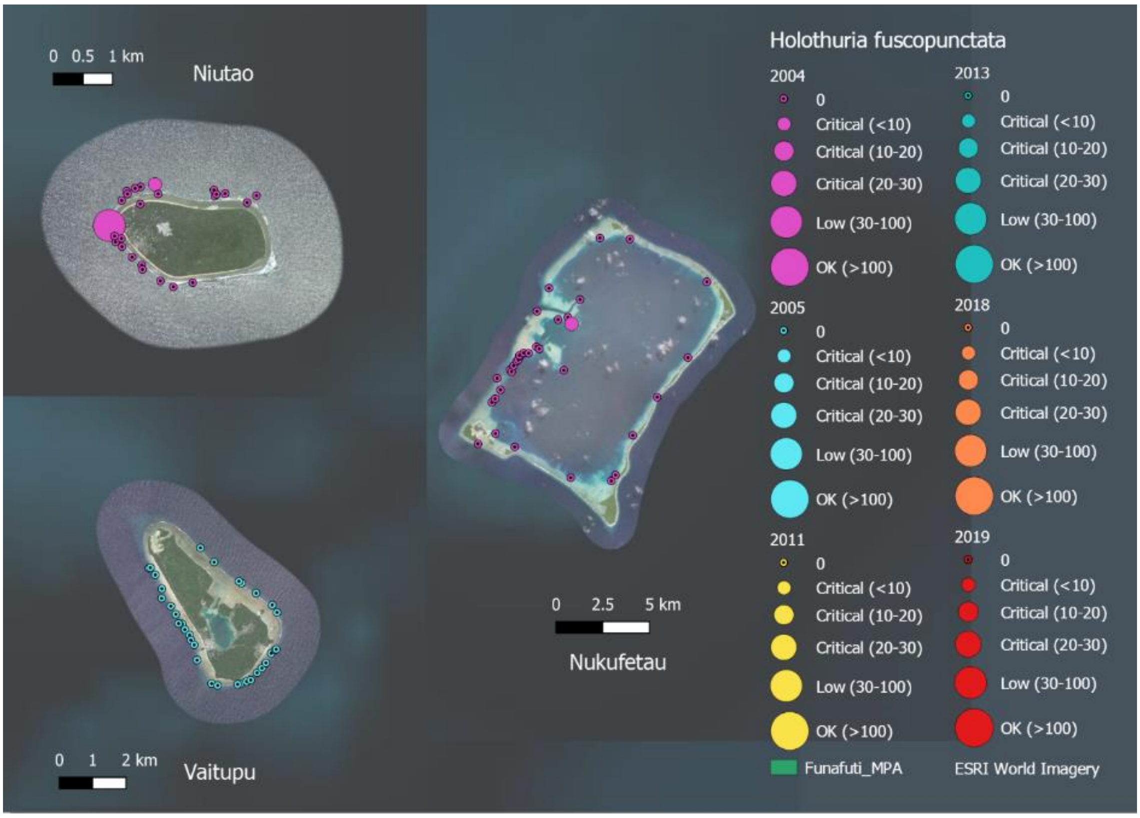
10.7 *Holothuria fuscogilva* HFF White teatfish (average/ha)



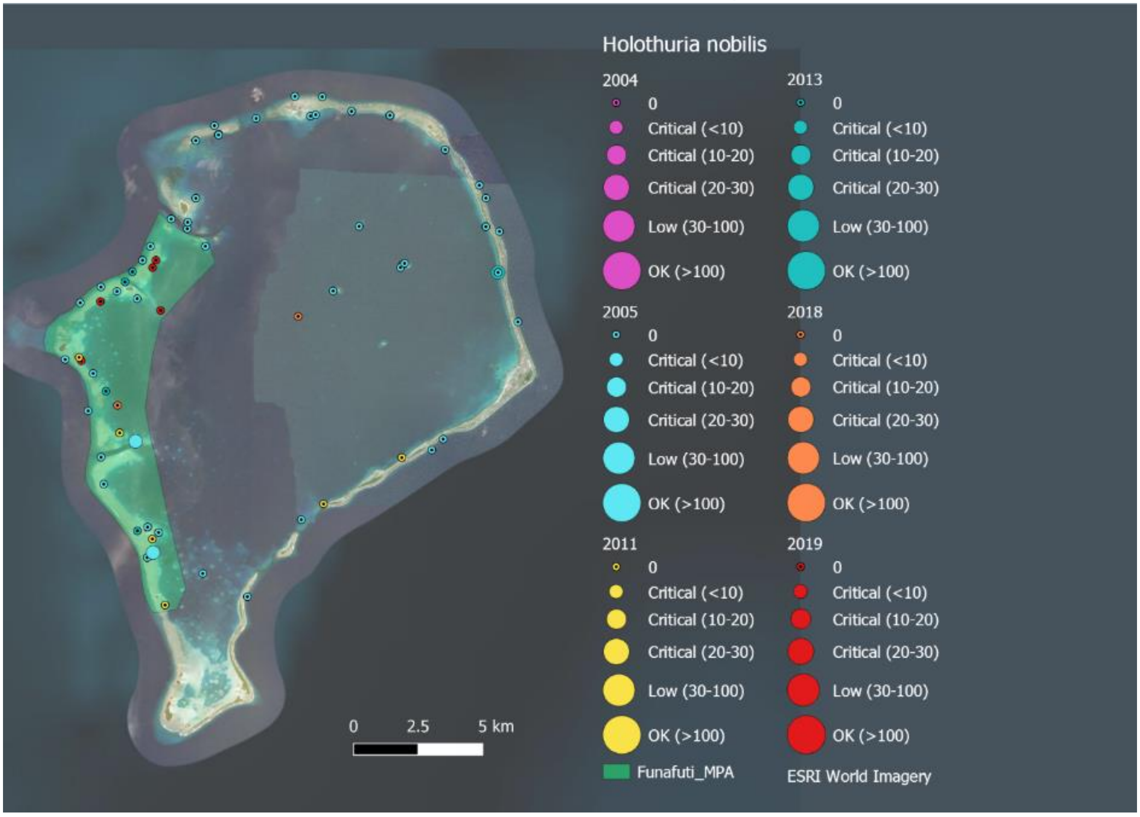


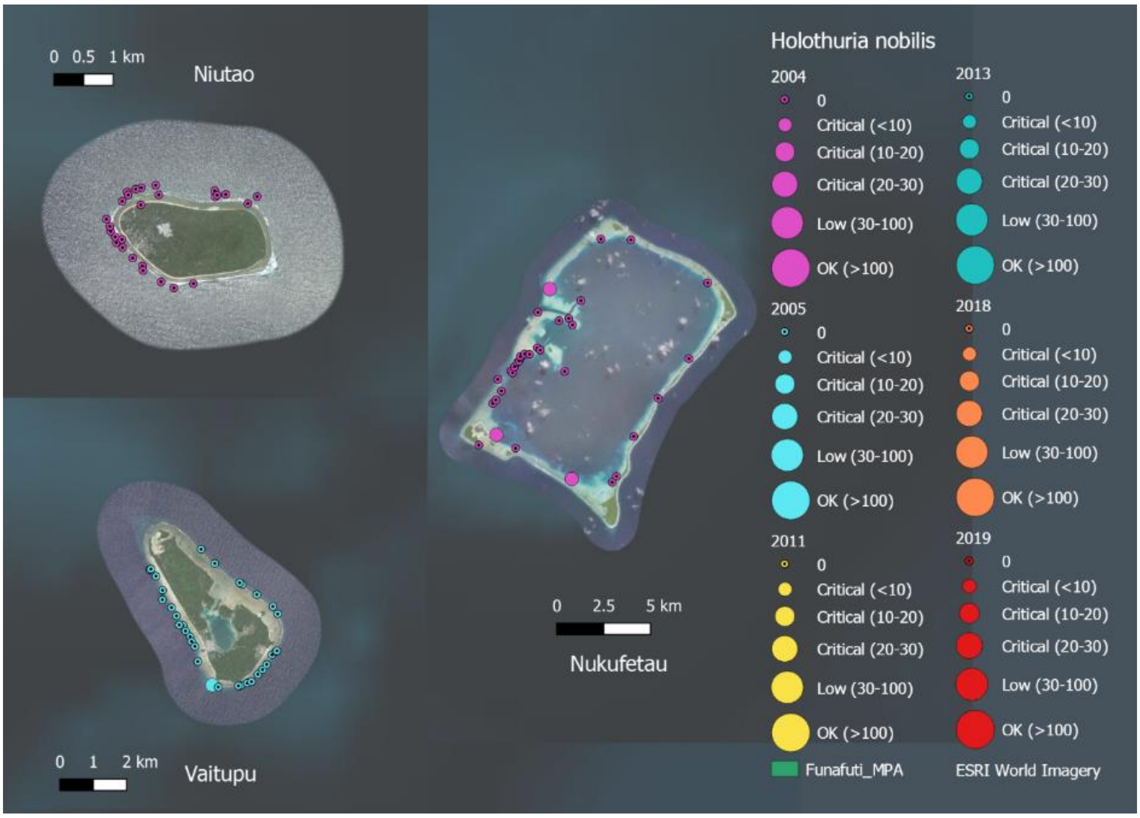
10.8 *Holothuria fuscopunctata* HOZ Elephant trunkfish (average/ha)



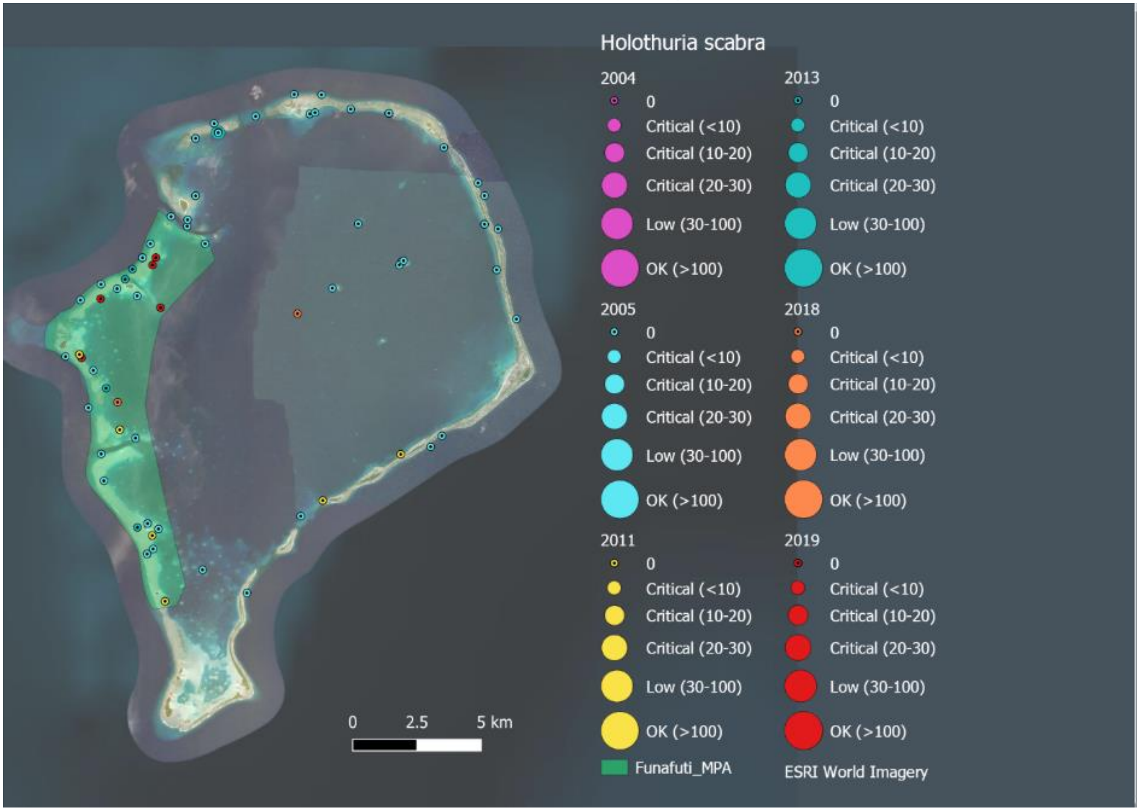


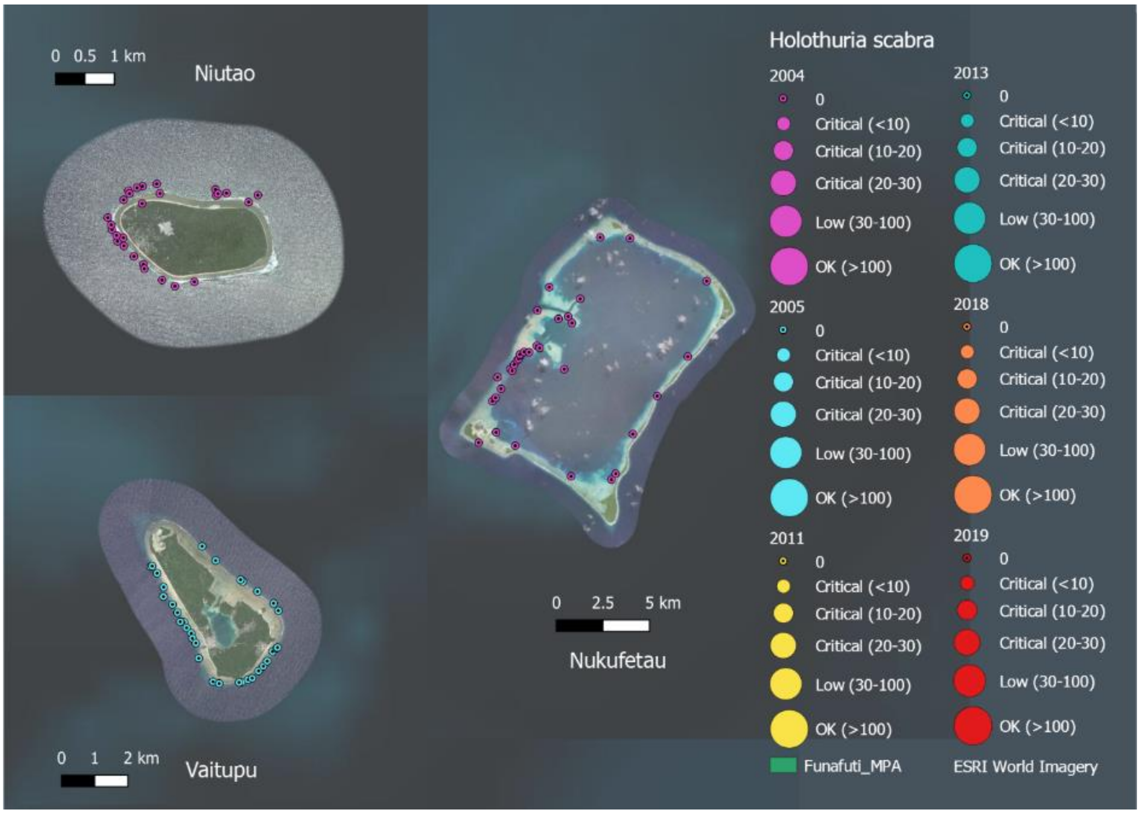
10.9 *Holothuria nobilis* HFN Black teatfish (average/ha)



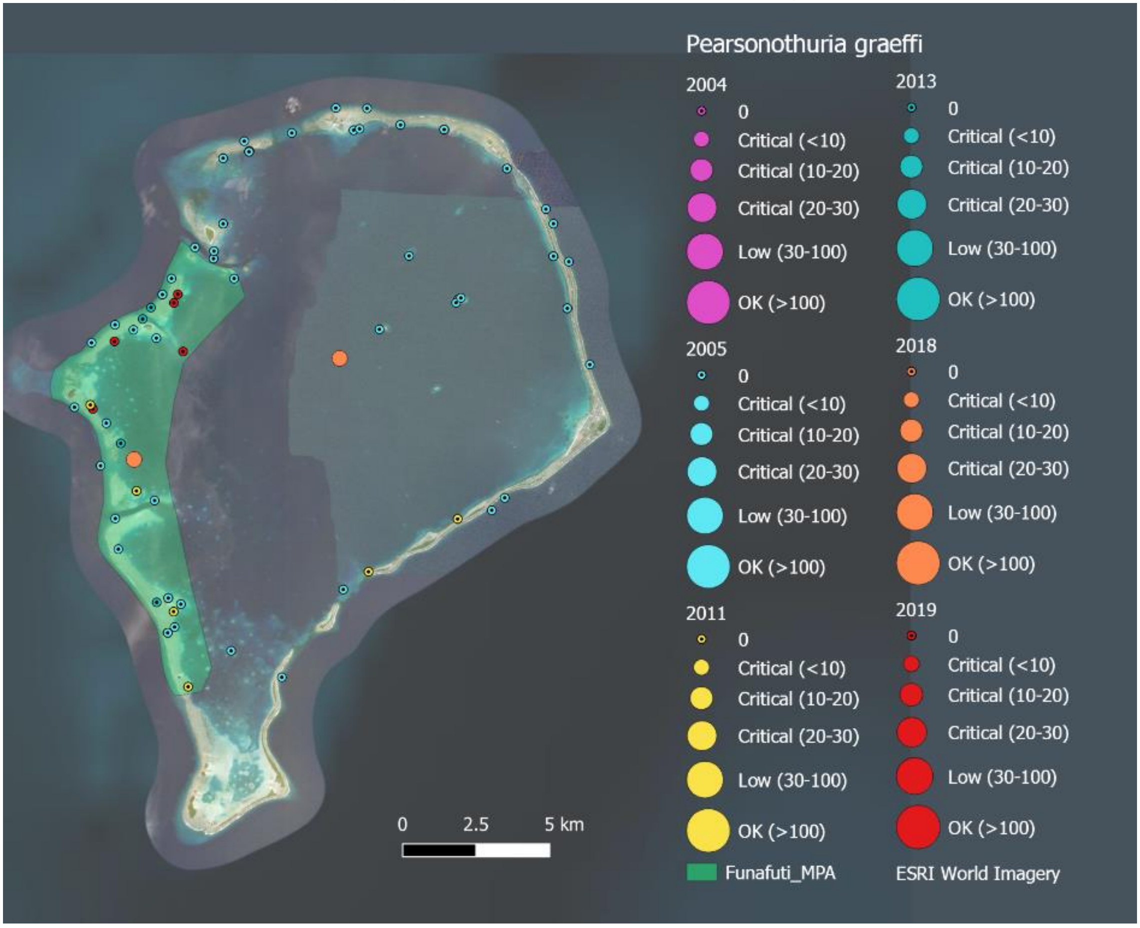


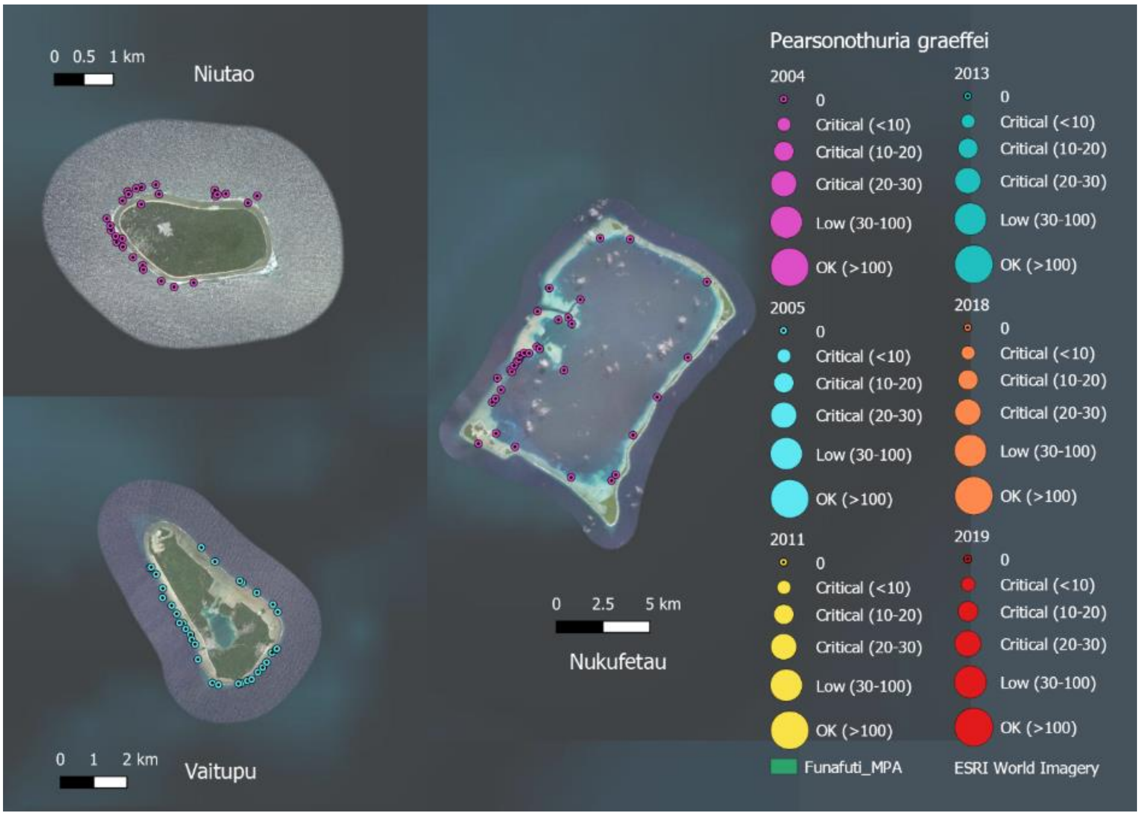
10.10 *Holothuria scabra* HFC Sandfish (average/ha)



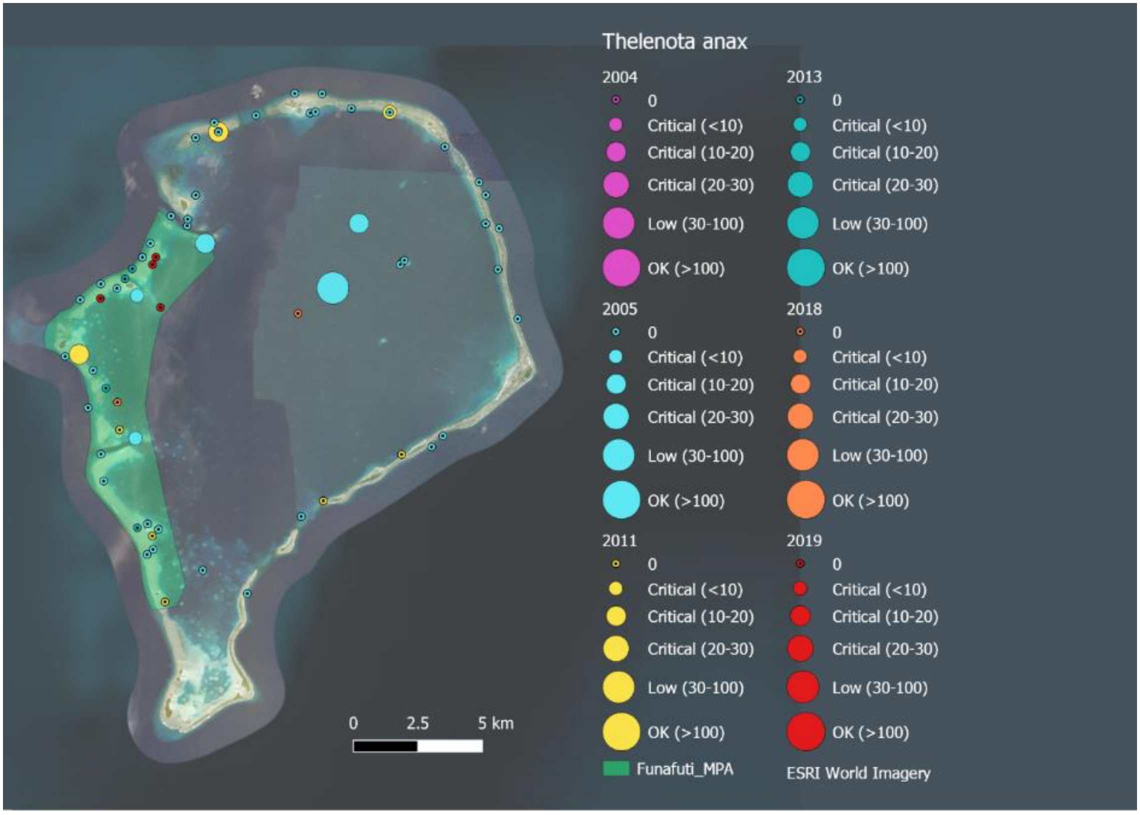


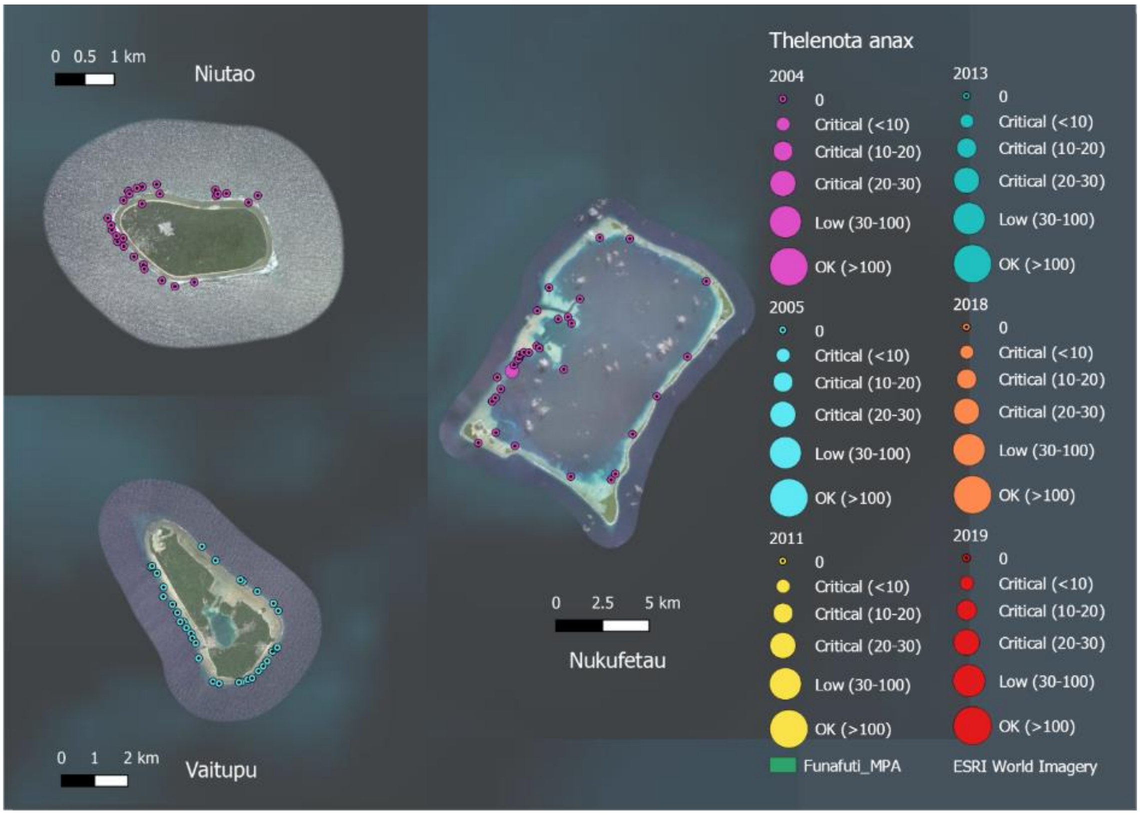
10.11 *Pearsonothuria graeffei* EHV Flowerfish (average/ha)



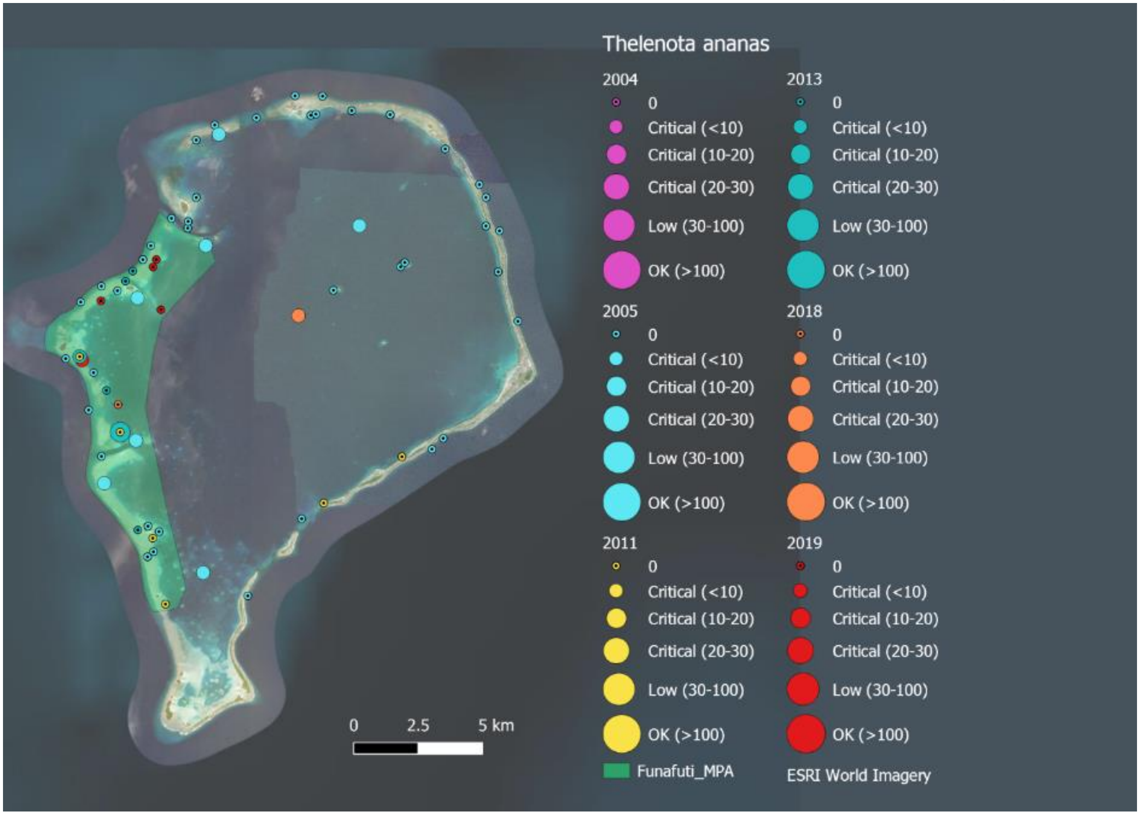


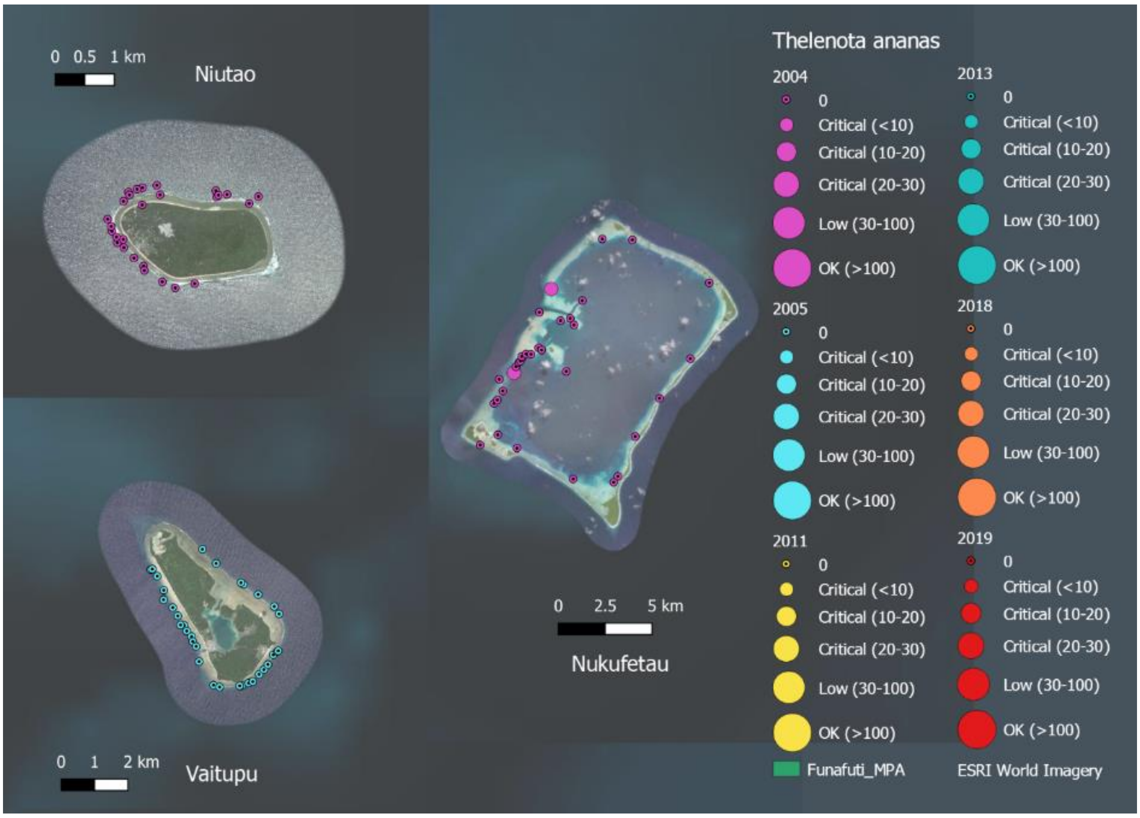
10.12 *Thelenota anax* HLX Amberfish (average/ha)





10.13 *Thelenota ananas* TFQ Pineapple fish / Prickly redfish (average/ha)





11 Annex 3: Environmental considerations relating to the role of sea cucumbers in Funafuti Lagoon, Tuvalu

STEVEN LEE[2], JULY 2019

11.1 Sea cucumbers and the environment

In marine coastal ecosystems, permeable reef sands act as a filter system facilitating the efficient recycling of organic matter and nutrients within the sediment and consequently the overlying water quality (Lee, 2018; Lee et al., 2018a). The implication being that if this natural filter system does not operate efficiently water quality will degrade, akin to having a faulty sand filter for a water dispenser or aquarium.

Most species of sea cucumbers are benthic detritivores, as such they have a direct impact on the function and quality of the substrate they inhabit. These animals influence sediment quality through two main channels: bioturbation and feeding (Lee et al., 2018a).

Bioturbation; the mixing of sediment layers by organisms affect sediment permeability and water content, chemical gradients, particle composition, and rates of nutrient breakdown and recycling (Purcell et al., 2016). Organic matter is broken down faster in the presence of oxygen (aerobic respiration) (Lee et al., 2018a), however as this matter is broken down oxygen is consumed. If organic matter builds up eutrophication can occur, if the oxygen supply to sediments is not replenished hypoxia may ensue.

Bioturbation allows oxygen rich water deeper into the sediment and exposes lower sediments to the surface where oxygen is more abundant (Purcell et al., 2016). Furthermore, the increased sediment oxygen concentration that bioturbation facilitates creates a more habitable environment for a host of infauna thus increasing their biodiversity and biomass, these organisms play a key role in the breakdown of organic matter (Wild et al., 2004).

Through feeding on organic matter deposited on the sediment sea cucumbers reduced the concentration of organic matter on and within the sediment, and in doing so all break it down into nutrients that can be readily utilised by plants and other organisms (Purcell et al., 2016). This enhanced nutrient cycling that sea cucumbers facilitate was shown to improve the growth of seagrasses (Wolkenhauer et al., 2010) – a critical habitat for fish and invertebrates. Lab experiments and anecdotal reports from the field suggest sea cucumbers can prevent the establishment of cyanobacterial mats (Uthicke, 1999; Purcell et al., 2016). Cyanobacterial mats are particularly detrimental to coral reef health as they can grow over and smother corals and other benthic organisms, produce toxins that render them inedible to several herbivorous fish, and kill off corals and inhibit coral settlement (Ford et al., 2018). The toxins produced by cyanobacterial mats when ingested by fish can cause ciguatera-like illness when the fish are eventually consumed by humans (Ford et al., 2018).

Sea cucumbers are relatively small animals however, through feeding they are capable of 'cleaning' an impressive amount of sediment (9-82 kg ind^{-1} yr^{-1}) (Purcell et al., 2016). When

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[2] Steven Lee was commissioned by SPC FAME under the PROP World Bank Beche de Mer project and in the course of his work provided this report. This article is a legacy of Steven Lee who was working on this and other projects at the time of his tragic passing last year. A talented young marine biologist with a passion for the ocean, Steven had so much to offer, and his presence will be missed by the seas and all who knew him.

found in relatively unfished densities this scales up immensely. A study of *Holothuria atra* and *Stichopus chloronotus* in Australia found these two species were capable of cleaning the entire surface sediment of the reef flat once a year (Uthicke, 1999). *Holothuria scabra* on a Fijian reef flat were found to be capable of cleaning 105 900 kg of sediment per hectare, equivalent to cleaning the surface sediment of the entire reef flat more than two and a half times each year (Lee et al., 2018a).

11.2 Environmental concerns

Tuvalu's biodiversity and ecosystem services are threatened by overfishing within and near lagoons, waste and waste-water management (Thaman et al., 2016). Tuvalu's population rely on rainfall and a limited ground water supply when rainfall is low. Wastewater pollution of ground water and lagoons are serious concerns; human and animal (71% of Funafuti households own pigs) wastewater seep into the ground or run off into the lagoon contaminating the limited groundwater supply and degrading the lagoon and nearshore ecosystems (Thaman et al., 2016). Contamination by this nutrient-rich wastewater has been linked to outbreaks of seaweed (*Sargassum polycystum*), the formation of slime algae, and cyanobacterial mats and blooms, which can devastate marine ecosystems (N'Yeurt and Iese, 2013; De Ramon N'Yeurt and Iese, 2014; Ford et al., 2018). The Tuvalu Fisheries Department have also expressed similar concerns in their annual reports (TFD, 2016, 2017, 2018).

11.3 Potential effects of sea cucumber removal

Prior to 2011 there was an extensive sea cucumber fishery in Marovo Lagoon, Solomon Islands that had operated for 15 years (Albert et al., 2011; Albert et al., 2012). As a result, sea cucumber densities were low (Pakoa et al., 2014). Agriculture and logging had increased nutrient runoff into the lagoon (Albert et al., 2012), nutrients which then spurred on a large-scale harmful algal bloom in June 2011. As the algae died and decomposed the limited oxygen supply in the surrounding water was consumed. Calm and warm weather ensured this oxygen was used up faster than it could be replenished. Eventually oxygen levels became so low there were large-scale die-offs of fish and invertebrate within the lagoon. Organisms that had not died from hypoxia had ingested toxins from the algal bloom. As such, not only had parts of the reef ecosystem been degraded, and stocks of fish and invertebrate been killed off, the fish and invertebrate that had survived could not be consumed for risk of illness. Following this event cyanobacterial mats had established on the reef and surrounding sediment, prohibiting the ecosystem from recovering (Albert et al., 2011; Albert et al., 2012).

In Fiji, conditions like that reported by Albert, et al (Albert et al., 2011) had been experienced during a study in which sea cucumbers were removed from sections of a reef flat. When nutrient input had increased (through coastal flooding) and when the weather had become calm and warm for extended periods oxygen levels in sediment reduced, organic matter had built up and formed a visible layer on the sediment, and bacterial mats began to establish themselves. Areas with high densities of sea cucumbers were able to recover from these changes in nutrient input and water temperature, returning to undisturbed levels (Lee et al., 2018a).

It is likely the series of events recorded by (Albert et al., 2011; Lee et al., 2018a) would have severe consequences if they were to occur in Tuvalu's lagoons. Given the limited water circulation within lagoons, high rates of evaporation, high temperatures, and increasing number of prolonged droughts (Anon., 2007).

Given their vital role in maintaining sediment and water quality, the removal of sea cucumbers could exacerbate the degradation of environmental quality (Purcell et al., 2016; Lee et al., 2018a). Negatively effecting the organisms that share those environments, and consequently the livelihoods of the people that rely on these environments and ecosystem services. As sea cucumbers are known to mediate two major factors affecting the health of Funafuti lagoon; nutrient input (through wastewater e.g. sewage), and harmful algal blooms, from an environmental and public health standpoint it would not be advisable to reopen the sea cucumber fishery.

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