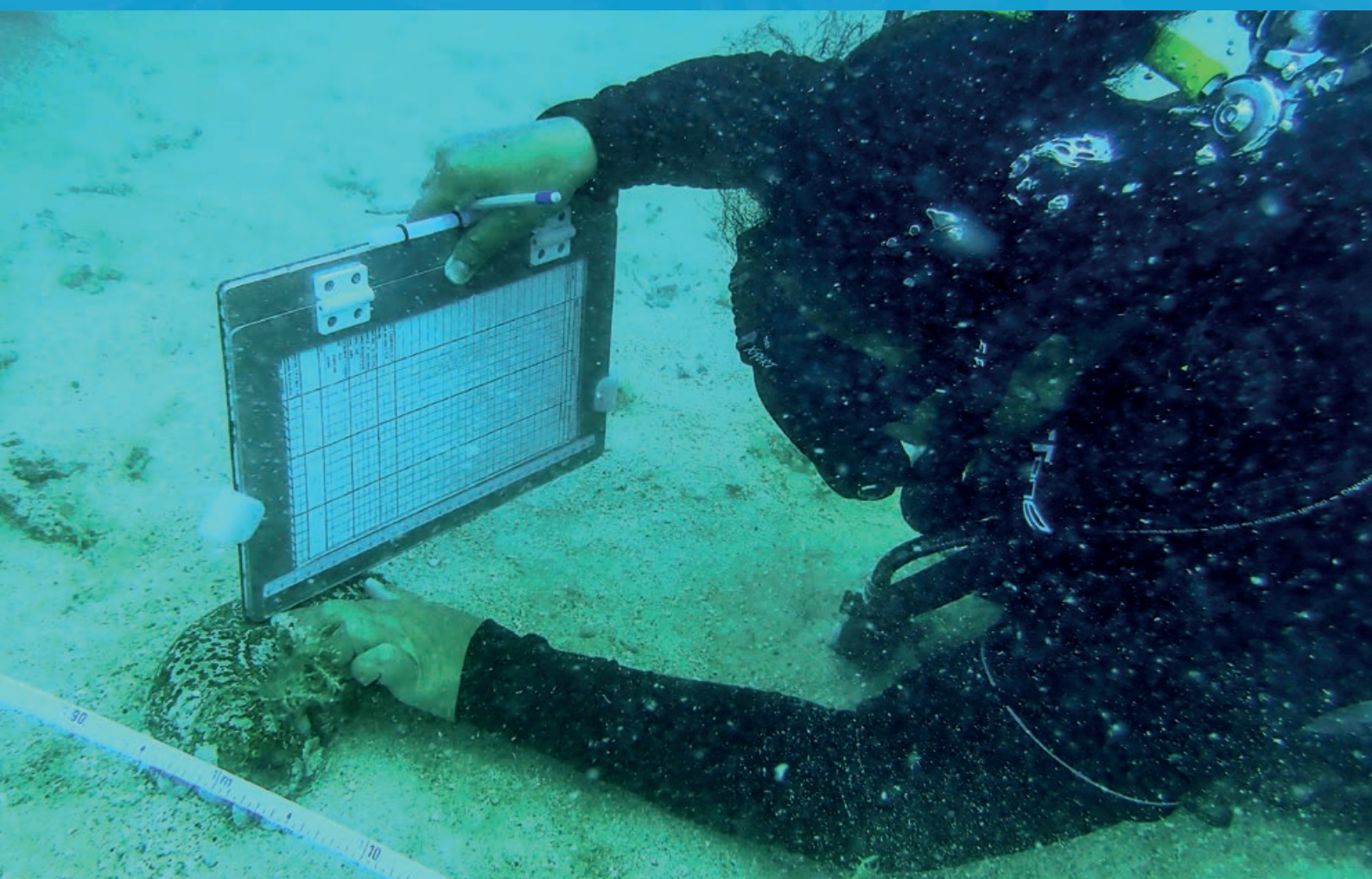




The status of sea cucumber populations in Samoa in 2019

George Shedrawi, Chris Molai, Esmay Tanielu, Faasulu Fepuleai, Audrey Katalina Tone, Lillian Joe Taulapapa, Sapeti Tiitii, Selau Falemai, Rilloy La'anna, Moso Lesa, James Kora, Pauline Bosserelle, Sébastien Gislard and Andrew Halford



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Disclaimer

The contents of this report are the sole responsibility of the authors and do not necessarily reflect the views of the European Union, the Government of Sweden or the Government of New Zealand.

Summary

- The results of the 2019 sea cucumber assessment clearly indicate that densities of most sea cucumber species have not improved since 2005. Those species that did show an increase between 2005 and 2012, subsequently declined between 2012 and 2019: *Stichopus chloronotus* (greenfish) and *Holothuria atra* (lollyfish). While *S. chloronotus* declined at both Savai'i and Upolu islands, the decline at Savai'i was considerably larger. *Holothuria atra* had severely declined at both Savai'i and Upolu. Densities of *Bobadschia vitiensis* (brown sandfish) were higher in 2019 and comparable to 2005 densities. All other species densities were lower in 2019 than in previous surveys.
- Our results indicate the survey methods that have been used may not be well suited to assess species such as *Stichopus herrmanni* (curryfish), *S. horrens* (dragonfish) and *Holothuria scabra* (sandfish), which display cryptic and nocturnal behaviours. Accurate assessments of these species will require night surveys in key habitats. We suggest that guidance be sought from local fishers who will be most familiar with the locations of these species.
- For the two species with sufficient data for making comparisons between years – *Holothuria atra* and *Stichopus chloronotus* – the size structure of their populations did not change, which is consistent with the normal processes of recruitment and mortality over this time period. Yet overall densities declined substantially below regional reference densities. Such a decline suggests that illegal harvesting or other major disturbances have caused significant mortality to these populations between the two survey periods, and animals of all sizes were targeted. While it is not possible to make a definitive judgement on what was the major driver of the declines, the continual newspaper reports detailing arrests of individuals for illegally harvesting sea cucumbers point to illegal harvesting as the principal effect.
- Lack of sufficient data on either abundance and/or lengths prevented detailed assessments being made of any other species.
- Habitat assessments indicated that key sea cucumber habitats are well represented across each of the two main islands, albeit with differing proportions. Despite this, there were large differences in density of individual species within similar habitat types but in different locations. These local-scale differences will not only reflect differing degrees of harvesting pressure but also differences in environmental influences. The only way to effectively understand the main drivers of sea cucumber population increases and declines is to have a targeted monitoring and surveillance programme that collects appropriate data on sea cucumbers and closely monitors the trade of animals being eaten locally and/or exported.

Management recommendations

Based on the outcomes of the 2019 surveys, which highlighted the state of sea cucumber stocks across Samoa, we make the following recommendations and suggestions, including conducting a review and revision of the Samoa Sea Cucumber Fisheries Management and Development Plan. The recommendations are aimed at introducing management practices to improve sea cucumber populations so that sustainable harvests can begin providing much needed economic benefits to communities across Samoa.

- Using the data from this study (refer to Tables 3 and 4, and also Fig. 13) no species were found above regional reference densities (see Pakoa et al. 2014) or local reference densities (see Sapatu and Pakoa 2013). Therefore, it is recommended that Samoa continue the ban on exports until fishery-independent surveys can establish that sea cucumber populations are at sufficient levels to sustain a small and well-managed sea cucumber fishery.
- A heightened focus be placed on monitoring, control, surveillance and enforcement targeting illegal and unreported sea cucumber harvesting and processing.
- After consultation with local collectors, fishery-independent surveys should be carried out at night targeting species harvested by the subsistence fishery so as to ascertain areas of high and low productivity and guide ongoing fishery-independent population assessments, especially for those species such as dragonfish and curry fish.
- A review the Samoa Sea Cucumber Fisheries Management and Development Plan be conducted. A review may include introducing density thresholds outlined in Pakoa et al. (2014) as a trigger for opening or closing the fishery for exports of beche-de-mer. The review could also include improved management oversight on harvesting sea cucumber for local consumption, including species where the viscera are sold commercially or collected and consumed in households. The management plan could include restructuring the fishery so that harvesting is opened for a short period and the number of exporters is limited to two.
- Fishery-dependent market and creel surveys should be implemented so that trends in market sales and the catch per unit effort can be recorded.
- Use regional reference densities as the trigger for opening the fishery. Until such a time that sea cucumber densities stabilise in Samoa, using localised reference densities calculated from a limited number of stations within only a few areas (e.g. Asau or Manono) may over- or under-estimate natural densities that occur across Samoa, as suggested in this assessment.
- When reference densities are above regional reference densities, the total allowable catch can be calculated as 30% of total adult stock, where adult stock is calculated as 80% of the population estimate above size at maturity. Detailed methods for conducting a stock assessment are described in Pakoa et al. 2014.
- Initiate or support more research to ascertain links between sea cucumber populations and natural disturbance events, such as marine heatwaves and cyclones.
- Investigate the viability of aquaculture (including sea ranching or others) of higher valued species such as teatfish as an alternative to harvesting wild populations. Sea ranching in community managed areas across Samoa could use sea pens or other enclosures to raise juveniles to commercially viable sizes. A high level of scientific, community (via the Ministry of Agriculture and Fisheries), and private sector investment will be required, with dedicated science to identify suitable drivers of juvenile survival (e.g. habitat, temperature, water flow, zoning) and optimum grow-out size that will maximise economic benefits. Promising examples of aquaculture ventures for larval and juvenile rearing are in Kiribati, New Caledonia and Papua New Guinea.

Introduction

Samoa is located in the central-west Pacific and consists of eight islets and two main islands, Upolu and Savai'i. The total land area is approximately 2950 km², with the two main islands making up the bulk of the habitable land area (Vunisea et al. 2008). Samoa has the smallest exclusive economic zone in the Pacific Islands region at 120,000 km², with approximately 97% of the population (200,874 in 2020) living within 5 km of the 45-km-long coastline.¹ Adjacent to the coast are shallow, coral reef lagoons (2–6 m depth) that consist of coral reef flats, back reefs, consolidated and unconsolidated coral rubble, limestone platforms, sand, and seagrass beds. The many lagoons are enclosed by a near-continuous fringing coral reef that extends up to 3 km seaward, quickly dropping off to depths of over 150 m.

Samoa's coastal geomorphology and narrow fringing reefs play a vital role in determining the distribution, abundance and composition of many important fishery species. Despite the importance of this habitat, however, existing data linking habitat characteristics with the presence and abundance of important fishery species is limited. Moreover, because of Samoa's relatively narrow fringing reefs, large disturbances (e.g. cyclones, tsunami, bleaching, overfishing) and small disturbances (e.g. local-scale anthropogenic pressures such as coastal zone development or nutrient runoff) can have relatively major impacts on key habitats as well as on fishery species reliant on these habitats. Climate models suggest that some disturbances affecting marine and other ecosystems are occurring more often and with increasing intensity (Murakami et al. 2013; AghaKouchak et al. 2018; Hughes et al. 2019; Clark et al. 2020). Long-term monitoring of habitats under ecosystem-based fishery management programmes can help explain when changes in the abundance and distribution of fishery species are the result of changes in habitat condition, fishing pressure, or both.

Samoa's economy includes tourism, textiles, agriculture, and fisheries, with agriculture and fisheries contributing 5% to gross domestic product¹ in 2018. The coastal fisheries sector is currently valued at approximately USD 14 million per annum and plays an important role in the livelihoods of Samoan communities engaging over 16% of households.² The harvesting of sea cucumbers, although exports are banned in Samoa, is a vital component of the coastal fisheries sector and an important source of household revenue for many Pacific Island countries and territories. In Samoa, as elsewhere, sea cucumber viscera are also consumed as a component of subsistence fisheries, and are considered a local cultural delicacy. Sea cucumber stocks, however, have been subject to regular overharvesting so to assist with rebuilding stocks, many Pacific Island countries, including Samoa, have implemented temporary bans on exporting sea cucumbers.

Sea cucumber biology

Easy access to sea cucumber habitats, combined with their biological reproductive characteristics and the effect of large-scale historically unregulated fisheries, have made some sea cucumbers especially vulnerable to overharvesting. While a variety of reproductive strategies are used by sea cucumbers, most are broadcast spawners that reproduce sexually. Some species are sequential hermaphrodites (changing from males to females) and are known to reproduce asexually, including *Holothuria atra*, *H. edulis*, *Stichopus chloronotus*, *S. horrens* and *Bohadschia marmorata*. However, the catalyst behind asexual reproduction and its contribution to replenishing fisheries populations and stocks is not well understood (Dolmatov 2014; Charan-Dixon et al. 2019). Most sea cucumbers can live for 5 to 10 years, while some slow-growing species may live to 15 years (Sloan 1984; Sewell 1990). Most species attain sexual maturity between two and six years, although heavy fishing pressure is thought to reduce the size and age at sexual maturity of some species, resulting in the reduction of the maximum growth size (Charan-Dixon 2016; Charan-Dixon et al. 2019) and, thus, economic value.

Species that use broadcast spawning as a reproductive strategy require adequate rates of fertilisation and adequate recruitment to populations for them to be resilient to harvesting within a fishery. Overharvesting lowers the density of reproductively capable adults and lowers the probability of fertilisation and recruitment, which inhibits population growth and stock recovery. If densities become low enough, recruitment and replenishment of populations can be severely impeded or absent; an outcome known as the "Allee" effect (Allee 1938; Kinch et al. 2008; Friedman et al. 2011; Purcell et al. 2013).

Study objectives

In the early 1990s, Samoa's sea cucumber fishery operated for only three years and large harvests quickly depleted the country's relatively small sea cucumber populations. This prompted Cabinet to halt exports of beche-de-mer in 1994, and exports have remained banned since then (Anon 2015). The moratorium aimed to allow sea cucumber populations to recover and protect sea

1 <https://www.sbs.gov.ws/population> date access 04/04/2020

2 <http://sdd.spc.int/mapping-coastal> date access 04/04/2020

cucumber species that are important for subsistence use. Recent pressure from communities to open the fishery resulted in the Ministry of Agriculture and Fisheries (MAF) requesting assistance from the Pacific Community (SPC) to resurvey sea cucumber populations and provide an update on the status of sea cucumber stocks.

This report presents the results of a fishery-independent sea cucumber survey conducted at multiple locations across Savai'i and Upolu in May and September 2019, respectively. Specific outcomes include:

- updated calculations of sea cucumber densities;
- a description of changes to populations of key species over time;
- an assessment of whether populations could support a commercial fishery;
- a summary of the training provided to MAF staff; and
- management recommendations to assist decision-makers and fishery managers with setting appropriate strategies in response to the current status of sea cucumbers in Samoa.

Methods

Survey methods

In-water invertebrate surveys were conducted at Savai'i and Upolu in May and September 2019, respectively, using the reef benthos transect (RBT) survey method (see Pakoa et al. 2014). Stations selected included those from earlier surveys (Hampus 2006; Sapatu and Pakoa 2013). Transects were laid in series and 2 m wide, rather than in parallel and 1 m wide as was done in previous surveys. This small change to the transect alignment and width at each station was done to avoid different habitats being surveyed when transects were located perpendicular to the reef direction. Positioning the transects in series allows for more of the same habitat to be surveyed, and decreases the likelihood of only surveying an area where an aggregation may occur, or conversely an area where it does not occur. Sea cucumbers are often found aggregated in small areas and hence a more extensive area of reef needs to be surveyed (i.e. over a larger section of the available habitat) to ensure that calculated densities better reflect a species that has a “clumped” distribution.

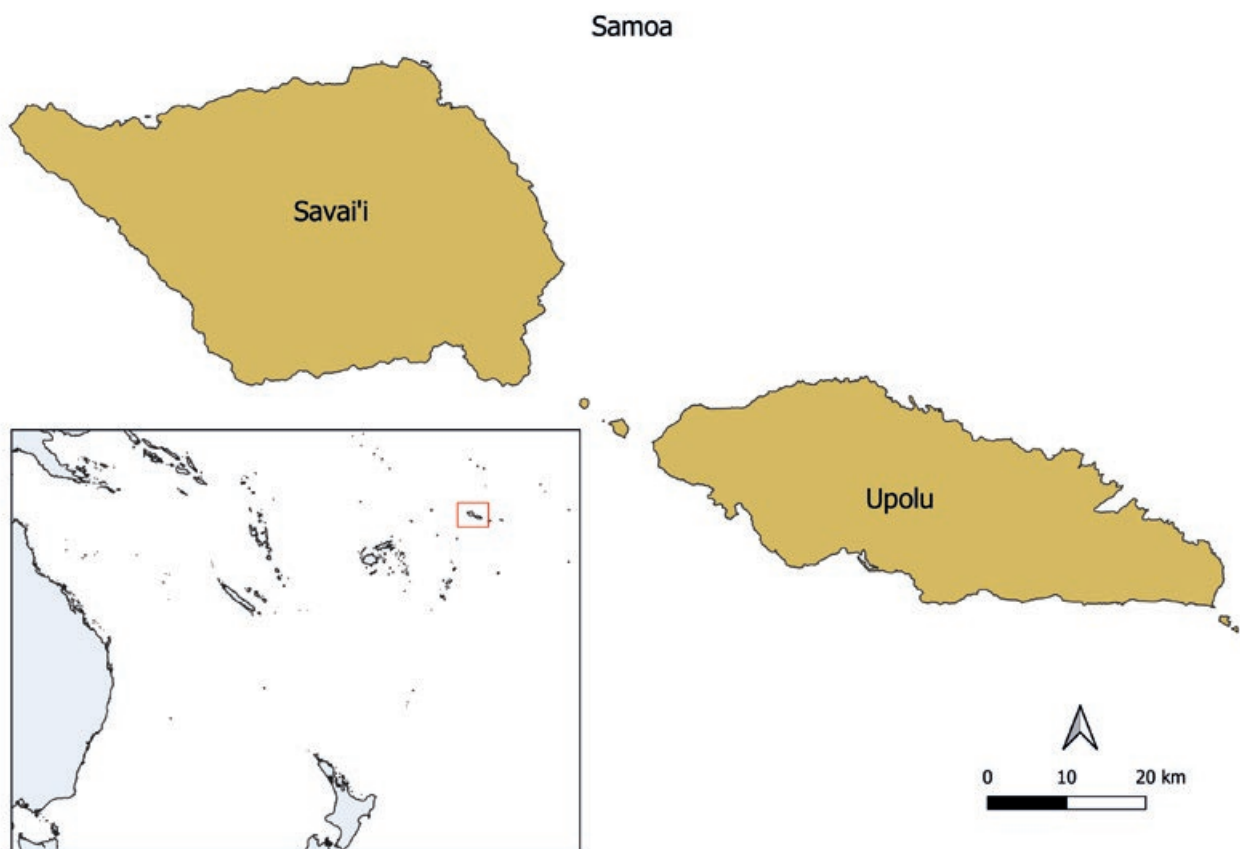


Figure 1. Regional overview map showing the location of Samoa and the survey location.

Each station surveyed consisted of six, 40 m x 2 m RBTs laid end-to-end, leaving a 5–10 m gap between each transect (Fig. 2). The surveyed habitat within each station was kept consistent; for example, all transects were completed on either a seagrass or coral reef habitat, and at a consistent depth. While stations were placed within as many sea cucumber habitats as possible, surveys at reef front habitats were limited due to wind, wave exposure and time constraints. Stations were surveyed by three snorkelers or scuba divers, with one individual setting the transect line, a second recording the data, and one photographing the benthic community. All sea cucumbers encountered within the transect belt were identified to species level, tallied, and lengths measured to the nearest centimetre (cm) using a rigid plastic ruler. Length was characterised as the distance from mouth to anus along the ventral side of the body. Due to time constraints, only the lengths of the first 30 individuals of each identified species were measured within each transect, although the remaining individuals were tallied to obtain total abundance. At the end of each day's survey, all data were entered into SPC's Reef Fisheries Integrated Database (RFID).

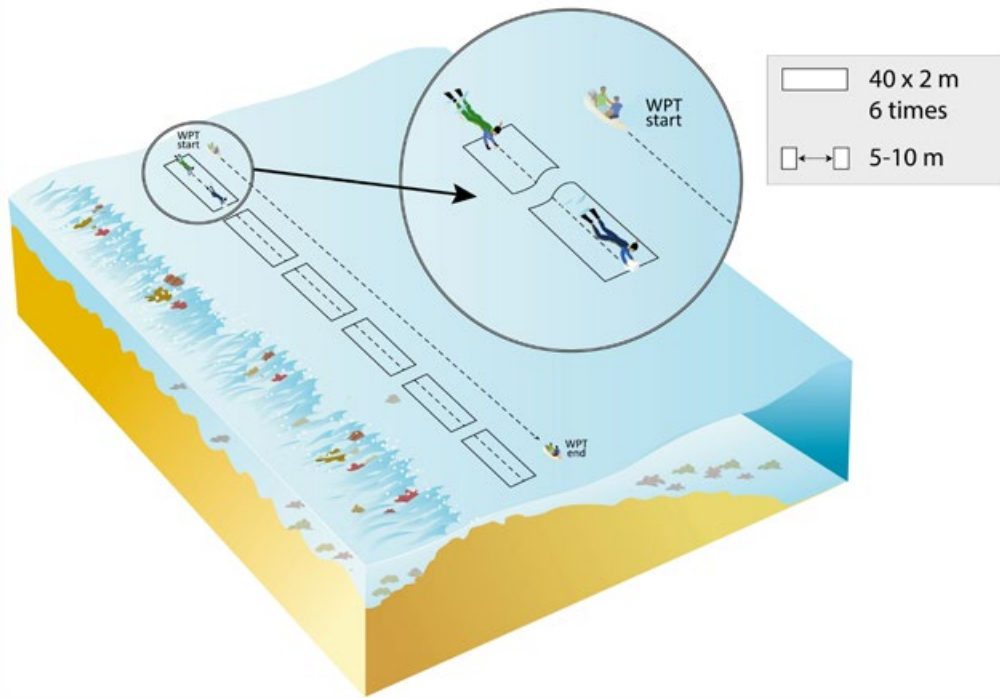


Figure 2. The six 40 m X 2 m reef benthos transect lines aligned in series within the same habitat type. WPT stands for GPS waypoint position at the start of the transect or station.

To identify the composition and condition of the habitat at each station, a single photo was taken every 1 m along each transect using a digital underwater camera with 12-megapixel resolution (Fig. 3). To ensure each of these “photo-quadrats” were taken from the same height above the substratum, a 1 m calibration rod was attached to the camera (Fig. 3). In situations where water depth was less than 1 m, the calibration rod was shortened to 50 cm. The camera was set to the widest field-of-view. Images were analysed for habitat details using the point count method (Jonker et al. 2020). We recommend that all future surveys should standardise the distance above the substratum to take photos at 50 cm (Jonker et al. 2020).

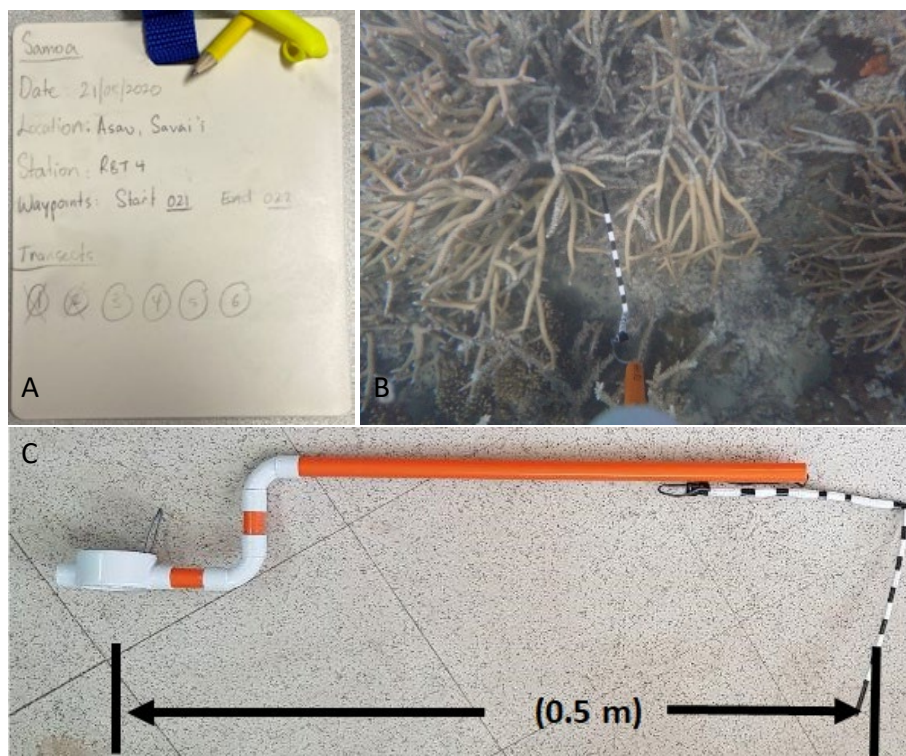


Figure 3. A: A dive slate after all transects are complete. The information recorded includes station code and number of transects, and the station start and end waypoint numbers. B: Downward facing photograph of the substratum and an example of a simple 0.5 m height guide with a black and white scale bar that should be present in each image. C: 0.5 m height guide that can be mounted to a camera, and black and white (17 mm segments) scale bar.

Survey design

Station locations were randomised and nested within a habitat and location at each island (Fig. 4). In total, 15 locations were surveyed across Samoa's two main island: three locations at Savai'i and 12 locations at Upolu; 125 RBT stations were completed, 50 at Savai'i and 75 at Upolu (Table 1). Stations from the 2005 and 2012 surveys that were revisited in this survey included Asau, from Saleloga to Tuasivi, and Vaisala. Because of the increase of transect width, the total area surveyed at each location was doubled from 240 m² per station to 480 m² per station.

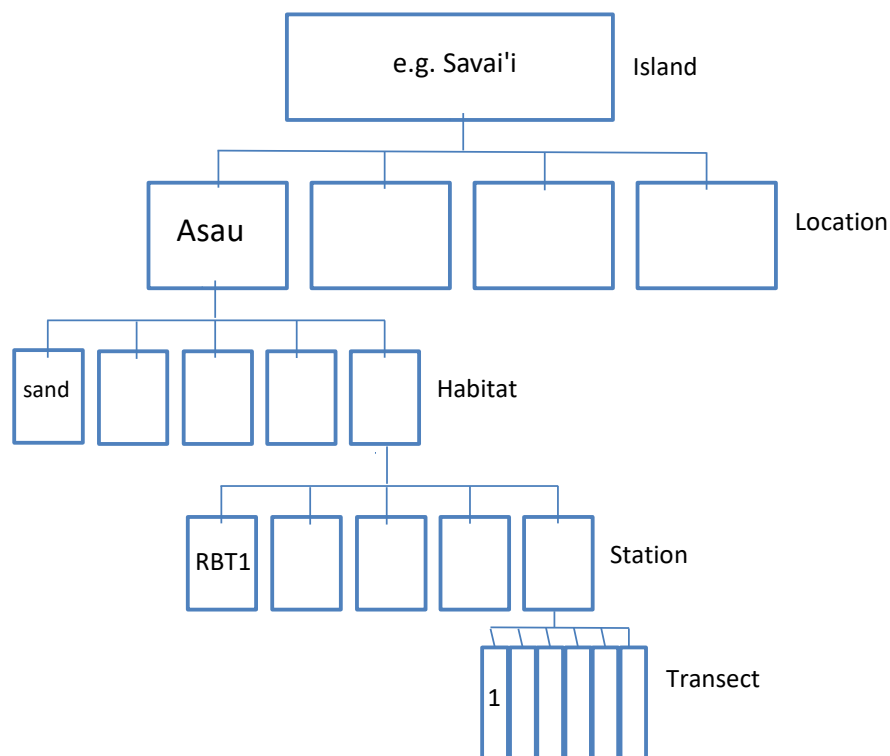


Figure 4. Survey sampling design. Location is fixed across each island, and stations were nested within each habitat class.

Table 1. The number of reef benthos transect stations surveyed at Savai'i and Upolu.

Island	2005	2012	2019
Savai'i	49	32	50
Upolu	80	48	75
Total	129	80	125

Habitat

While the surveyed area per station was doubled from earlier surveys, it is still only a small proportion of the total area of sea cucumber habitat, and extrapolating densities upwards from hundreds of metres to large spatial areas (e.g. thousands of hectares) could introduce sampling biases associated with species aggregations. Aggregations can occur due to a number of factors, including chemical cues, spawning and habitat preferences, or some other unidentified factor that we do not account for (Hamel and Mercier 2005; Marquet et al. 2018). Inadvertently sampling aggregations without sufficiently sampling other areas could overestimate total stock size, especially as some species are strongly associated with specific habitats; for example, nearshore seagrass beds. To reduce the likelihood of this occurring, stations were chosen to balance the number of stations between the various habitats. Habitats across Samoa were assigned categories according to the Allen Coral Atlas³, and the area in hectares (ha) for each category was calculated in the spatial data management freeware program QGIS, by summing each habitat category across the two islands.

Satellite-derived data that are used to determine the area of available habitat for sea cucumbers have inherent limitations such as bathymetric constraints. These occur when displaying reef features deeper than 15 or 20 m, because satellites cannot reliably

³ <https://www.allencoralatlas.org> accessed 02-02-2020

collect reflectance at depth (i.e. light reflected to the satellite sensors) due to light absorbance through the water column. This means that features beyond 20 m – for example, deepwater reefs and platforms found from 20 to 150 m depth – will not be visible on the map and, therefore, habitats for deepwater species such as *Holothuria fuscogilva* (white teatfish) will be under-represented. Very steep reef features, such as reef walls, may also not appear on the map, or their true three-dimensional extent will be under-represented. Because deep-water habitat is under-represented or non-visible, it is challenging to accurately estimate the population size of associated sea cucumber species as required for stock assessments.

Analyses

Density

Historical long-term data collected at a representative number of stations in various habitats across Samoa from 2005 and 2012 were compared with data from 2019 to ascertain if each species' population had increased sufficiently to support a fishery. The mean density, measured as the number of individuals per hectare (ind.ha⁻¹), of each sea cucumber species were also compared to previously published regional reference densities for healthy sea cucumber stocks (Toral-Granda et al. 2008; Pakoa et al. 2014). Mean density data were also compared with reference densities calculated from the 2012 survey data and published in Sapatu and Pakoa (2013). Mean density (\bar{x}) at each of the two main islands was calculated by averaging the density (ind.ha⁻¹) at each station extracted from RFID. Standard error (SE) was calculated by dividing the standard deviation of the mean density by the square root of the number of stations (n) at each island within each habitat. The steps used to calculate density and the mean per island for each species were as follows:

- Station density (y) is given by

$$y = \sum_{t=1}^t \text{count per transect} \quad \dots \text{eq.1}$$

Where t is the transect

(e.g. six transects: $y = 2+2+0+0+0+0$
 $y = 4$)

- Density at each station D. is given by

$$D. \text{ st} = \left(\frac{y}{y = \sum_{t=1}^t \text{surface area of the transect}} \right) \times 10,000 \quad \dots \text{eq.2}$$

Where y is the station density and t is the transect

e.g. 80 m² per transect with a total of four individuals of a species was observed;

$$D. \text{ st} = \left(\frac{4}{80+80+80+80+80+80} \right) \times 10,000$$

$$D. \text{ st} = \left(\frac{4}{480} \right) \times 10,000$$

$$D. \text{ st} = 83.33 \text{ individuals per hectares (ind.ha}^{-1}\text{)}$$

- Mean density (\bar{x}) at each island habitat group in each island is given by

$$x = \left(\frac{y = \sum_{i=1}^n D.st}{n} \right) \quad \dots \text{eq.3}$$

Where n is the number of stations surveyed across each of the habitats at each island.

e.g. with only three stations:

$$\bar{x} = \left(\frac{80.33 + 20.83 + 41.67}{3} \right)$$

$$\bar{x} = 41.61 \text{ ind.ha}^{-1}$$

Note: The calculation of the density per transect could also be used instead of the total count for the station. If count per transect is used for rather than the sum of all transects, then the surface area of the transect (e.g. 80 m²) in equation 2 above is used without summing.

- Standard error (SE) of the mean is given by:

$$SE = (\sigma / \sqrt{n}) \quad \dots \text{eq.4}$$

Where σ is the standard deviation (SD) of the mean \bar{x} (calculated by the Microsoft Excel function “*stdev*(80.33+20.83 + 41.67)”, and n is the number of stations surveyed within each group.

e.g. With only three stations and a SD of 30.19:

$$SE = \left(\frac{30.19}{\sqrt{3}} \right) = 17.43 \quad SE = 17.43$$

Length comparisons

Length data were compared between 2005, 2012 and 2019 for Savai'i and Upolu. Lengths of individuals that were measured were tallied to 20-mm bins, plotted and compared visually. Although very few measurements were taken of the high-value species *Holothuria whitmaei*, it was nevertheless included for reference. Tracking the relative abundance of length cohorts through time allows interpretation of whether remnant adults have reproduced sufficiently to supply recruits, which is especially important in heavily fished populations where fertilisation and recruitment success is dependent on the density of breeding adults (Shepherd and Partington 1995). In the early stages of stock recovery, sea cucumber populations may be characterised by an increase in abundance of smaller-sized individuals, either through sexual or asexual (fission) reproduction (Shepherd and Partington 1995; Ramofafia et al. 2000).

Capacity development

Training for MAF staff (four women and eight men) took place at the beginning, during and completion of the three-week field survey. The three major objectives of the training were to build capacity in:

- survey design;
- data collection, entry and analysis; and
- database management.

Before the survey, a presentation and hands-on training with MAF and SPC staff took place over the first two days of the survey. Training in historical data review and subsequent utilisation for planning surveys was completed. Survey design – including habitat selection, survey methods, and logistics – were discussed, as well as training in the use of a handheld global positioning system (GPS).

During the survey, daily briefs and training in data collection and entry into RFID was completed. The setup and application of survey equipment, transect placement, and search techniques were demonstrated and tested. Upon completion of the survey and training, MAF staff completed the remaining survey stations over a period of four weeks in August and September.

Results

Habitat

After removing areas that included deepwater habitats that were more than 20–25 m depth, approximately 13% of the habitats above 20 m depth remained unclassified (Table 2). Sand, coral and coral and algae-consolidated reef platforms were the dominant habitats in lagoon areas, followed by small areas of turf algae on reef and seagrass habitats. The unclassified habitats (white space on maps) usually fell within existing habitat classes (e.g. seagrass, coral, macroalgae etc), and is the result of the limitations of using satellite derived habitat classifications. The unclassified categories are caused by the inability of light to penetrate below approximately 15 to 20 m deep through the water column, which limits reflectance and hence, the light-based classification algorithm utilised by Allen Coral Atlas resulted in a no-classification score. Most locations surveyed were represented by all habitat types, although Asau, Manono and Salaimoa were dominated by sand (Figs. 5–11).

Table 2. Total area in hectares of habitat across the two major islands of Savai'i and Upolu.

Habitat classification	Savai'i		Upolu	
	Area (ha)	% of total habitat	Area (ha)	% of total habitat
Algae	8	0%	50	0%
Turf	296	2%	1919	8%
Coral	1455	10%	1887	8%
Coral/Algae	4209	28%	5357	22%
Rock	579	4%	1121	5%
Rubble	844	6%	2322	10%
Sand	5918	39%	6868	29%
Seagrass	245	2%	791	3%
Unclassified	1596	11%	3650	15%
Total	15,150		23,965	

Habitat maps sourced from Allen Coral Atlas (<https://www.allencoralatlas.org> accessed 02-02-2020) were used to calculate total area of each habitat category.

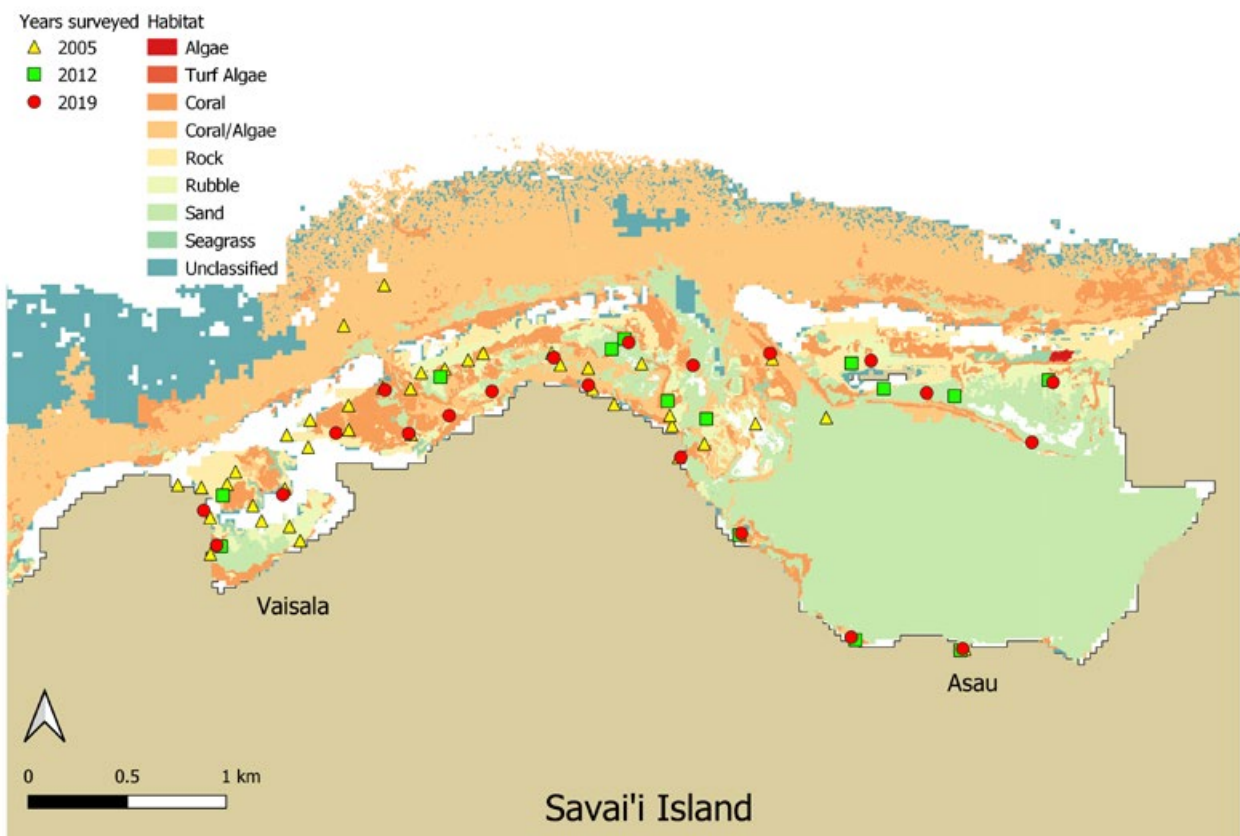


Figure 5. Habitat classification and stations at surveyed locations at Vaisala and Asau in 2005, 2012 and 2019. Coloured labels are stations within each location for each year surveyed. Habitat data were sourced from Allen Coral Atlas (<https://www.allencoralatlas.org> date accessed 02-02-2020).

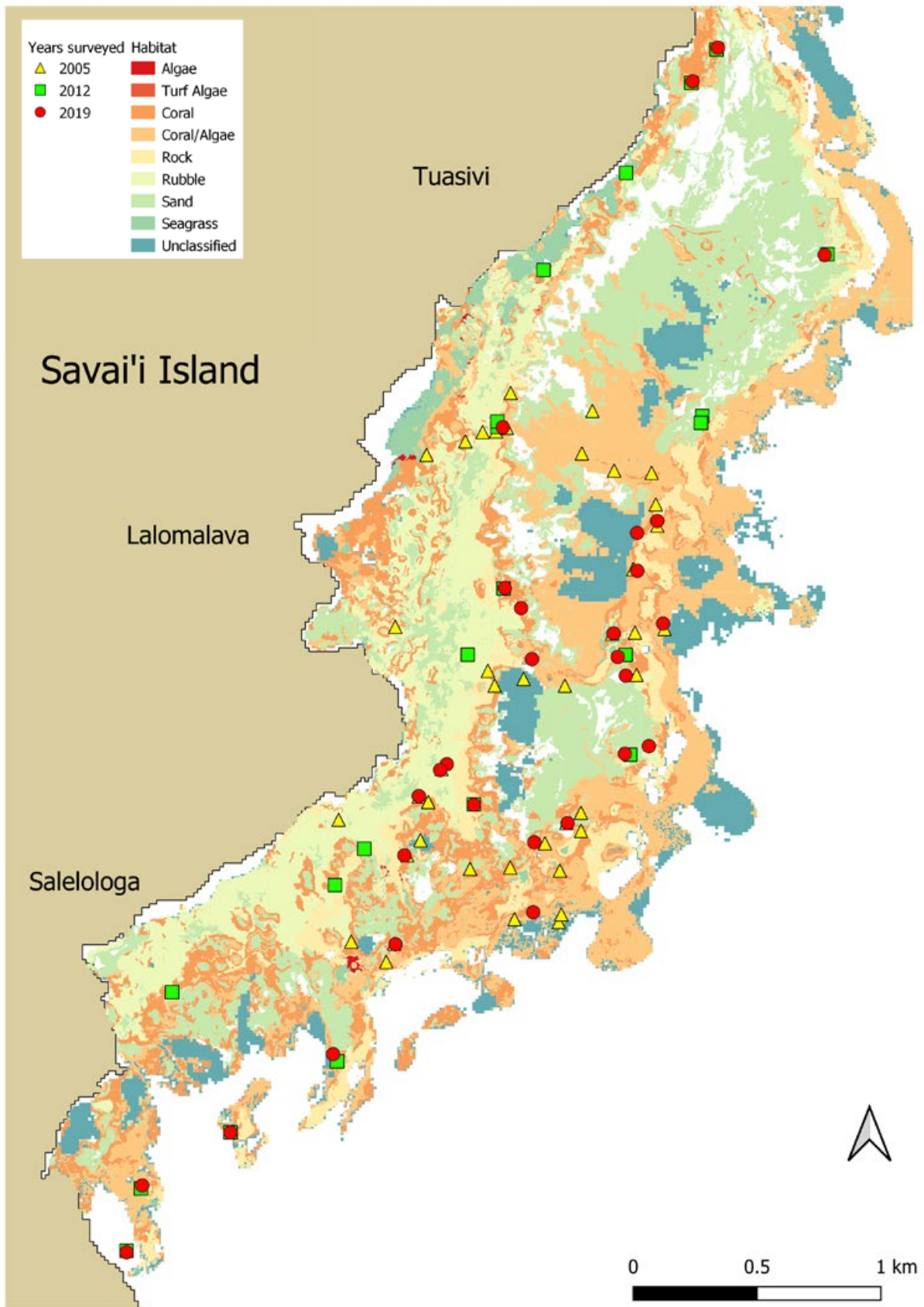


Figure 6. Habitat classification and stations at surveyed locations between Tuasivi and Salelologa 2005, 2012 and 2019. Coloured labels are stations within each location for each year surveyed. Habitat data were sourced from Allen Coral Atlas (<https://www.allencoralatlas.org> date accessed 02-02-2020).

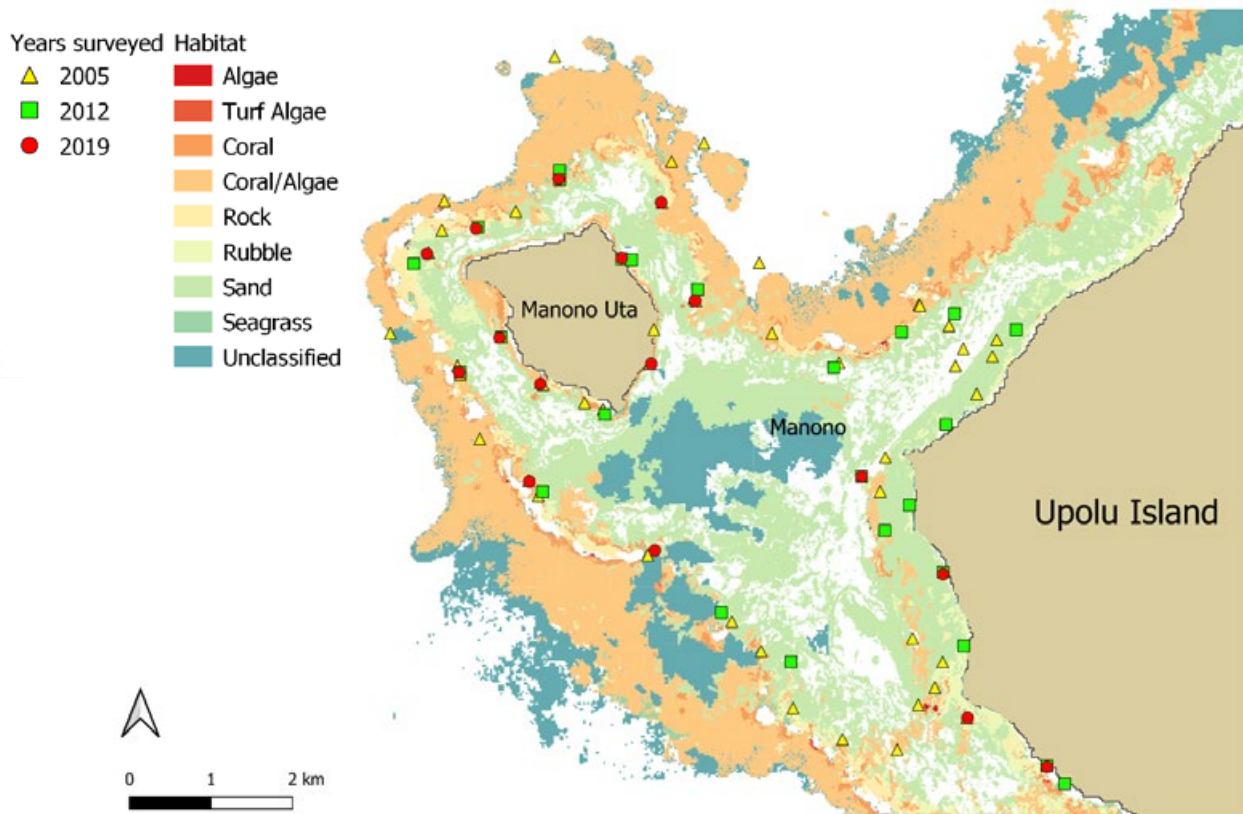


Figure 7. Habitat classification and stations at surveyed locations at Manono Uta, Manono and Samatau in 2005, 2012 and 2019. Coloured labels are stations within each location for each year surveyed. Habitat data were sourced from Allen Coral Atlas (<https://www.allencoralatlas.org> date accessed 02-02-2020).

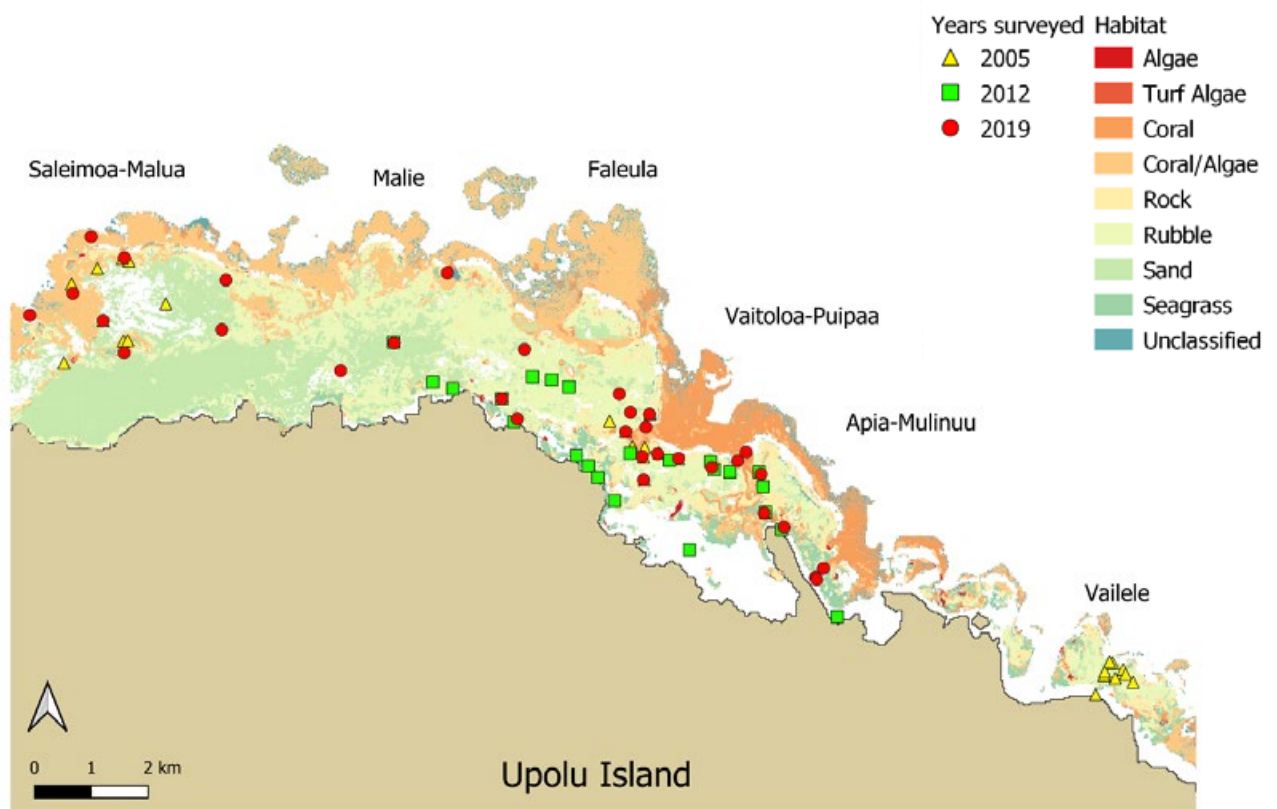


Figure 8. Habitat classification and stations at surveyed locations from Saleimoa to Vailele in 2005, 2012 and 2019. Coloured labels are stations within each location for each year surveyed. Habitat data were sourced from Allen Coral Atlas (<https://www.allencoralatlas.org> date accessed 02-02-2020).

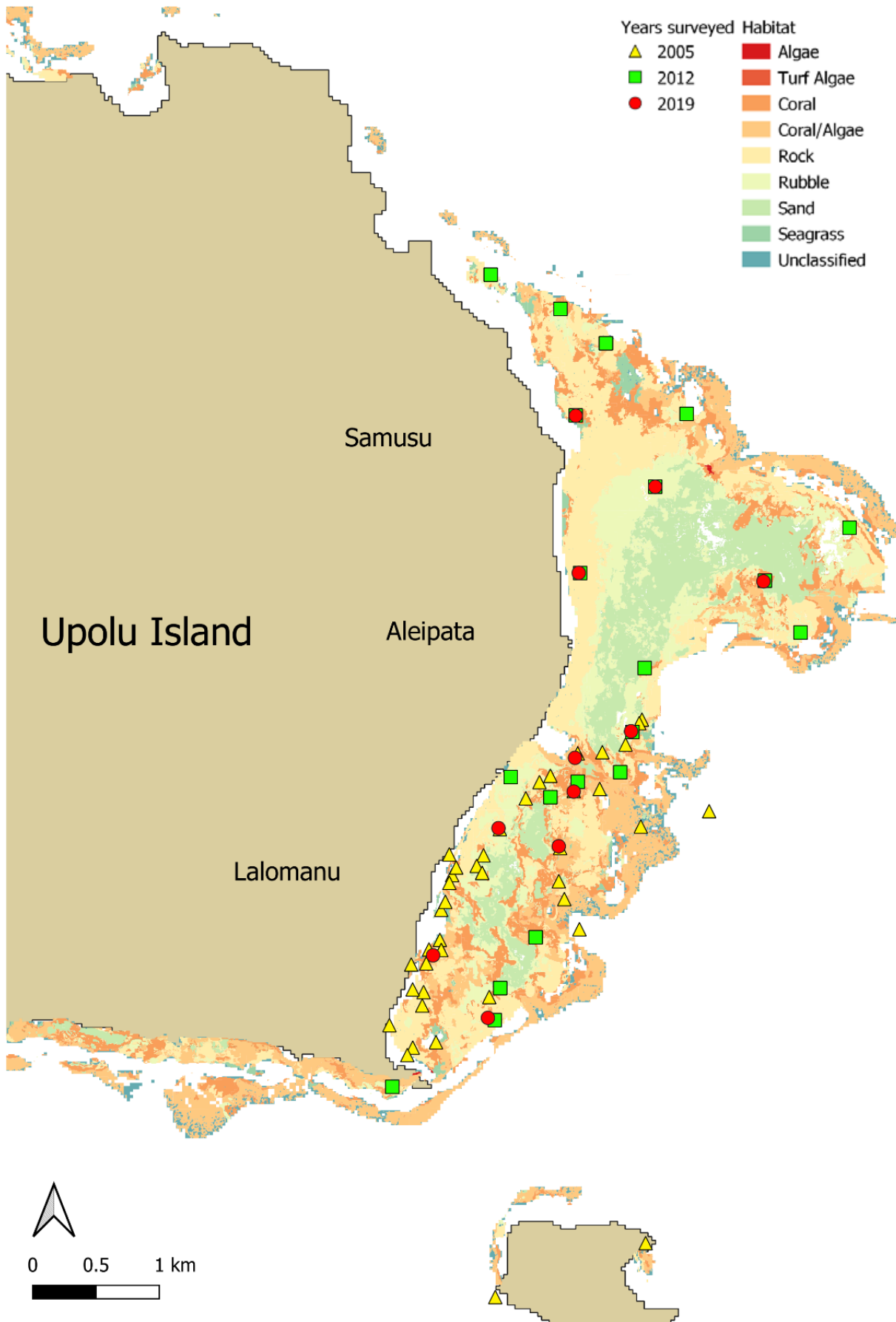


Figure 9. Habitat classification and stations at surveyed locations from Samusu to Lalomanu in 2005, 2012 and 2019. Coloured labels are stations within each location for each year surveyed. Habitat data were sourced from Alan Coral Atlas (<https://www.allencoralatlas.org> date accessed 02-02-2020).

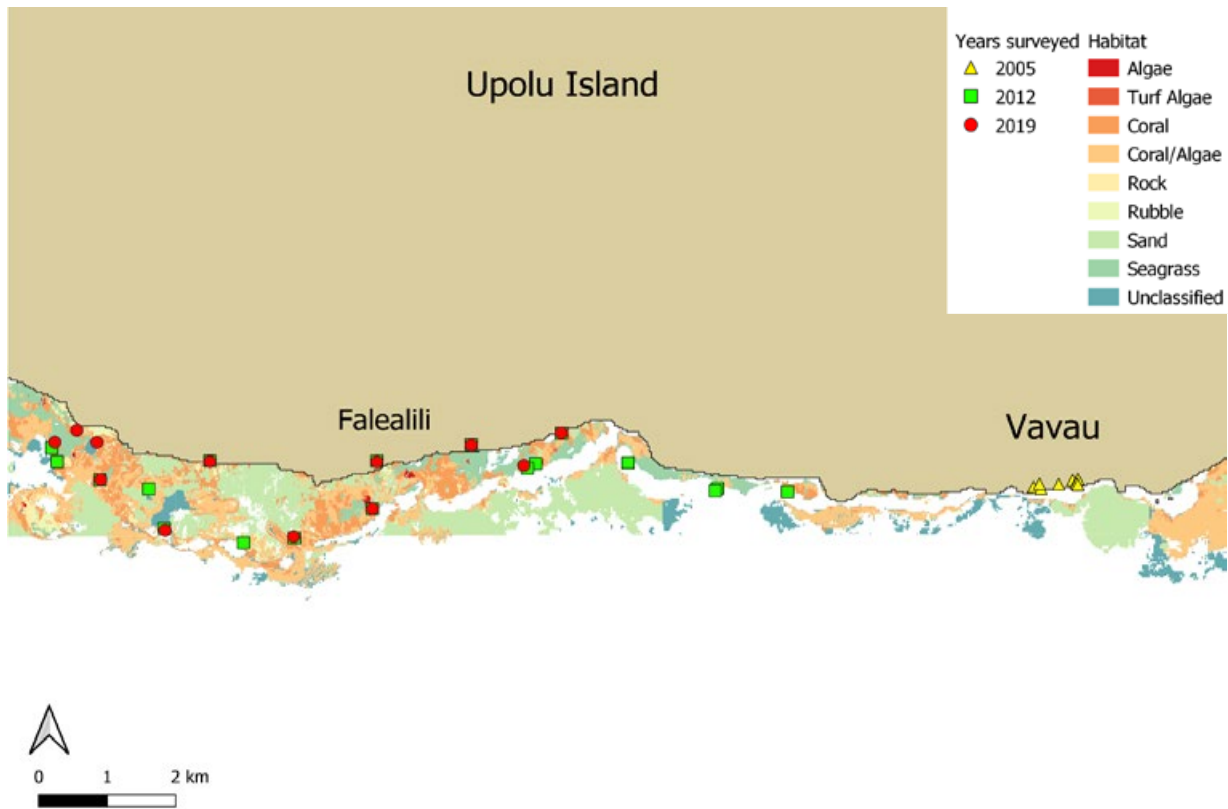


Figure 10. Habitat classification and stations at surveyed locations from Falealili to Vavau in 2005, 2012 and 2019. Coloured labels are stations within each location for each year surveyed. Habitat data were sourced from Allen Coral Atlas (<https://www.allencoralatlas.org> date accessed 02-02-2020).

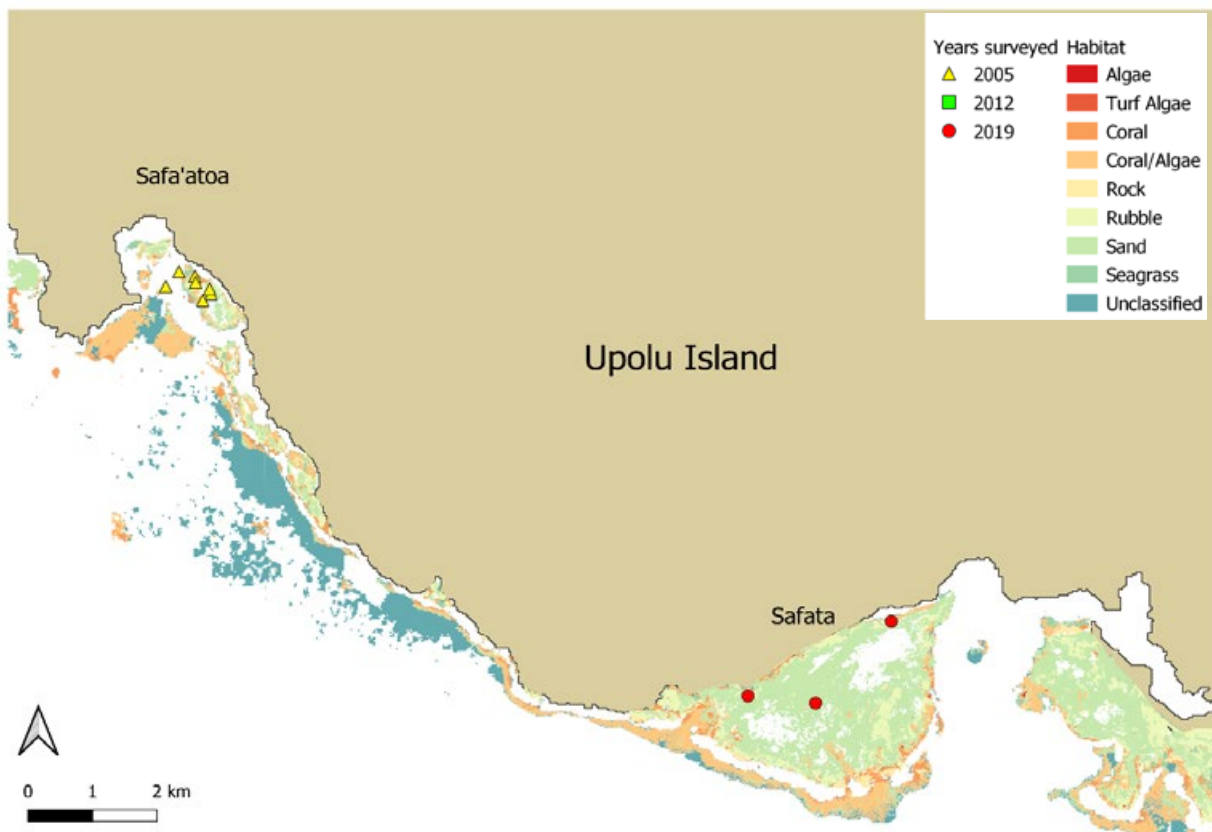


Figure 11. Habitat classification and stations at surveyed locations at Safata and Safa'atoa in 2005 and 2019. Coloured labels are stations within each location for each year surveyed. Habitat data were sourced from Allen Coral Atlas (<https://www.allencoralatlas.org> date accessed 02-02-2020).

Species composition, distribution and density

There were large differences in the density of all species combined at each station, ranging from an average of 0 through to 4200 ind.ha⁻¹. To visualise the relative difference in densities between locations across Samoa, data were grouped into four equal categories ranging from 1 to 4200 ind.ha⁻¹ (Fig. 12). Sea cucumbers were absent at 8 out of 45 stations at Savai'i, and 22 out of 68 at Upolu and not confined to a particular habitat or location (Fig. 12). Mean densities ranging from 1 to 1050 ind.ha⁻¹ were common across both Savai'i and Upolu islands. Stations recording densities higher than 1050 and under 2100 were less common. Densities above 2100 and under 3150 ind.ha⁻¹ were recorded at five stations (Faleula, Manono Uta, Asau, Vaisala and Vaitoloa-Puipaa), and only four stations (at Asau, Samatau and Malie) recorded densities above 3150 ind.ha⁻¹ (Fig. 12).

With the exception of two or three species, the composition of the sea cucumber community in 2019 was comparable to previous years, with 12 species recorded in 2019, 10 in 2012, and 13 in 2005. *Actinopyga miliaris* was not observed in 2005 or 2012 but observed in the 2019 survey (Table 3). *Bohadschia vitiensis*, *Actinopyga palauensis* and *Holothuria lessoni* recorded in 2019 were not observed in 2012. The most frequently encountered species in all years were *Holothuria atra* and *Stichopus chloronotus*, which were observed across 39 and 61 stations, respectively, in 2019 (Table 3). Asau, Vaisala, Saleimoa, and eastern regions of Upolu were dominated by *S. chloronotus*, whereas the central-north and west of Upolu was dominated by *H. atra*. These two species were also those that contributed most to those high-density stations (Fig. 13).

Mean sea cucumber densities from the 2019 surveys were compared to: 1) mean densities from the two previous assessments in 2005 and 2012; 2) regional Pacific reference densities; and 3) reference densities specifically calculated for the two main islands of Samoa (Friedman et al. 2006; Sapatu and Pakoa 2013; Pakoa et al. 2014). In 2019, mean densities of all recorded species were below their respective regional and local reference densities (Table 3 and Table 4). The mean density for *Holothuria atra* was 1835 (± 755) ind.ha⁻¹ and the mean density for *Stichopus chloronotus* was 1166 (± 461.2) ind.ha⁻¹. The mean density of *S. chloronotus* in 2019 was similar to that in 2005, with an estimated 2500 ind.ha⁻¹. The density in 2019, however, was approximately five times lower than that calculated for 2012, which was reported to be 15,000 ind.ha⁻¹ at reefs on Savai'i. There was an apparent decline in density from 2005 to 2019 for *S. horrens*, *S. chloronotus*, *H. whitmaei*, *H. atra* and *B. argus* at all islands, except for *H. whitmaei* at Savai'i and *Bohadschia vitiensis* at both Savai'i and Upolu islands. The higher density of *H. whitmaei* is the result of observations of only three individuals at two stations (Table 4). *Bohadschia vitiensis* increased in density from 2012 to 2019 and was comparable to densities recorded in 2005, yet remains below regional reference densities for healthy populations.



Figure 12. Survey stations (green) with mean species densities during assessments in May and September 2019.

Table 3. Mean density, Pacific regional reference density, and prevalence of all species encountered across Samoa. Species marked with (*) were not observed in 2012 and those marked with (**) were not observed in 2005 or 2012.

Species	Mean density (ind.ha ⁻¹)	SE	Pacific regional reference (density (ind.ha ⁻¹))	# stations observed out of 125 stations
<i>Holothuria atra</i>	1835.8	754.6	5600	39 (31.2 %)
<i>Stichopus chloronotus</i>	1166.3	461.2	-	61 (48.8 %)
<i>Bohadschia argus</i>	20.0	5.4	120	28 (22.4 %)
<i>Synapta maculata</i>	13.2	6.7	-	13 (10.4 %)
<i>Actinopyga miliaris</i> **	10.2	10.0	-	2 (1.6 %)
<i>Bohadschia vitiensis</i> *	9.8	3.0	-	19 (15.2 %)
<i>Actinopyga palauensis</i> *	5.7	2.1	-	11 (8.8 %)
<i>Holothuria whitmaei</i>	1.3	0.5	50	9 (7.2 %)
<i>Holothuria lessoni</i> *	0.7	0.7	-	1 (0.8 %)
<i>Stichopus horrens</i>	0.7	0.3	-	4 (3.2 %)
<i>Thelenota ananas</i>	0.5	0.3	-	3 (2.4 %)
<i>Actinopyga mauritiana</i>	0.2	0.2	200	1 (0.8 %)
<i>Holothuria flavomaculata</i>	0.2	0.2	-	1 (0.8 %)

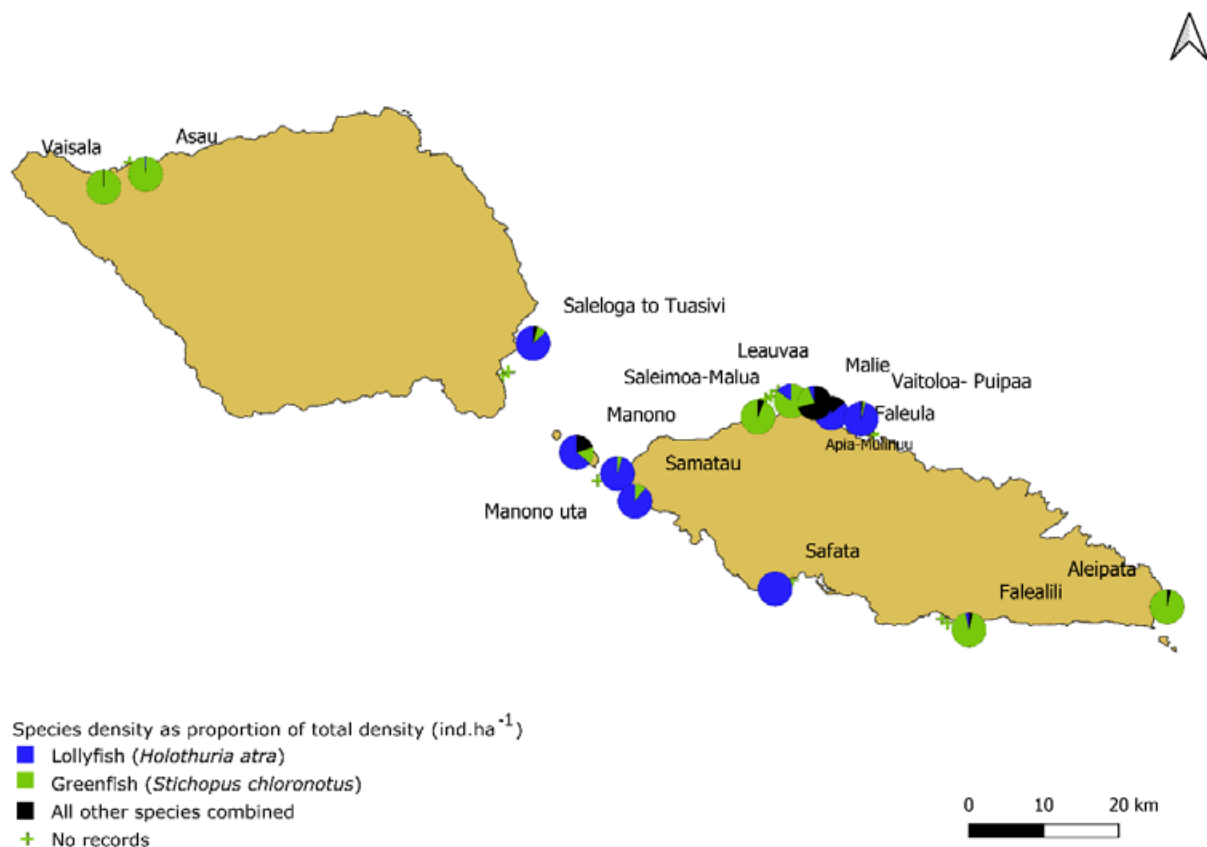


Figure 13. Mean relative density of the two dominant species *Holothuria atra* (lollyfish) and *Stichopus chloronotus* (greenfish), and other species grouped at each location.

Table 4. Comparisons between mean densities from the 2019 survey and their respective local reference densities for healthy populations of the top three species recorded in Samoa.

Species	Local reference density (from Sapatu and Pakoa 2013)		Mean density (2019)	
	Savai'i	Upolu	Savai'i	Upolu
<i>Holothuria atra</i>	1600	6000	26	3042
<i>Stichopus chloronotus</i>	11,200	1100	2423	328
<i>Bohadschia argus</i>	60	50	43	4

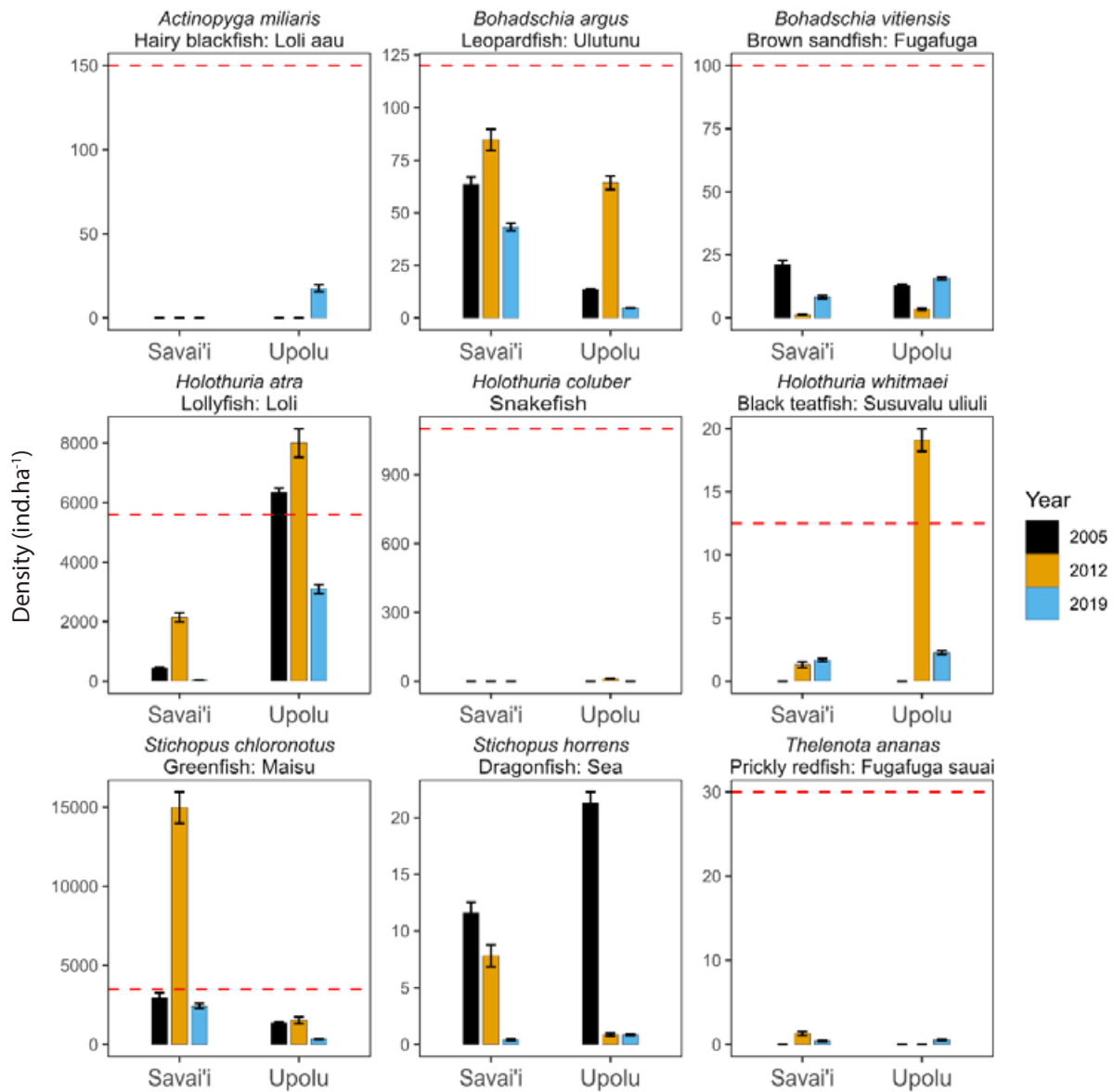


Figure 14. Mean density (ind.ha⁻¹ ± SE) for nine sea cucumber species at Savai'i and Upolu islands from surveys carried out in 2005, 2012 and 2019. Plot titles are scientific, common, and Samoan names, respectively; red dashed line indicates regional reference density thresholds for healthy populations sourced from Pakoa et al. (2014).

Length-frequency patterns

Savai'i

Like the number of records in Upolu, the low densities of many species in Savai'i meant very few length measurements were made at individual stations and locations across the island; therefore, to increase the sample size, data from all locations across Savai'i were aggregated. After aggregating data for individual species, the number of length measurements in 2019 were only sufficient for *Stichopus chloronotus*. *Holothuria atra* and *Bohadschia argus* were only included in the plots for reference and to visualise the maximum, minimum and mean lengths of measured individuals. All other species were at such low densities that plotting was uninformative at any level. The length distribution measurements of *S. chloronotus* were similar between 2005 and 2019, although in both of these years, individuals were significantly larger than those in 2012 (Kolmogorov Smirnov bootstrap of distribution tests; $p < 0.01$) (Fig. 15). However, approximately 90% of these individuals remained below the estimated size at maturity (L_{50}). The maximum length recorded for *B. argus* was larger in 2019 than in 2012, but similar between years for both *H. atra* and *S. chloronotus*.

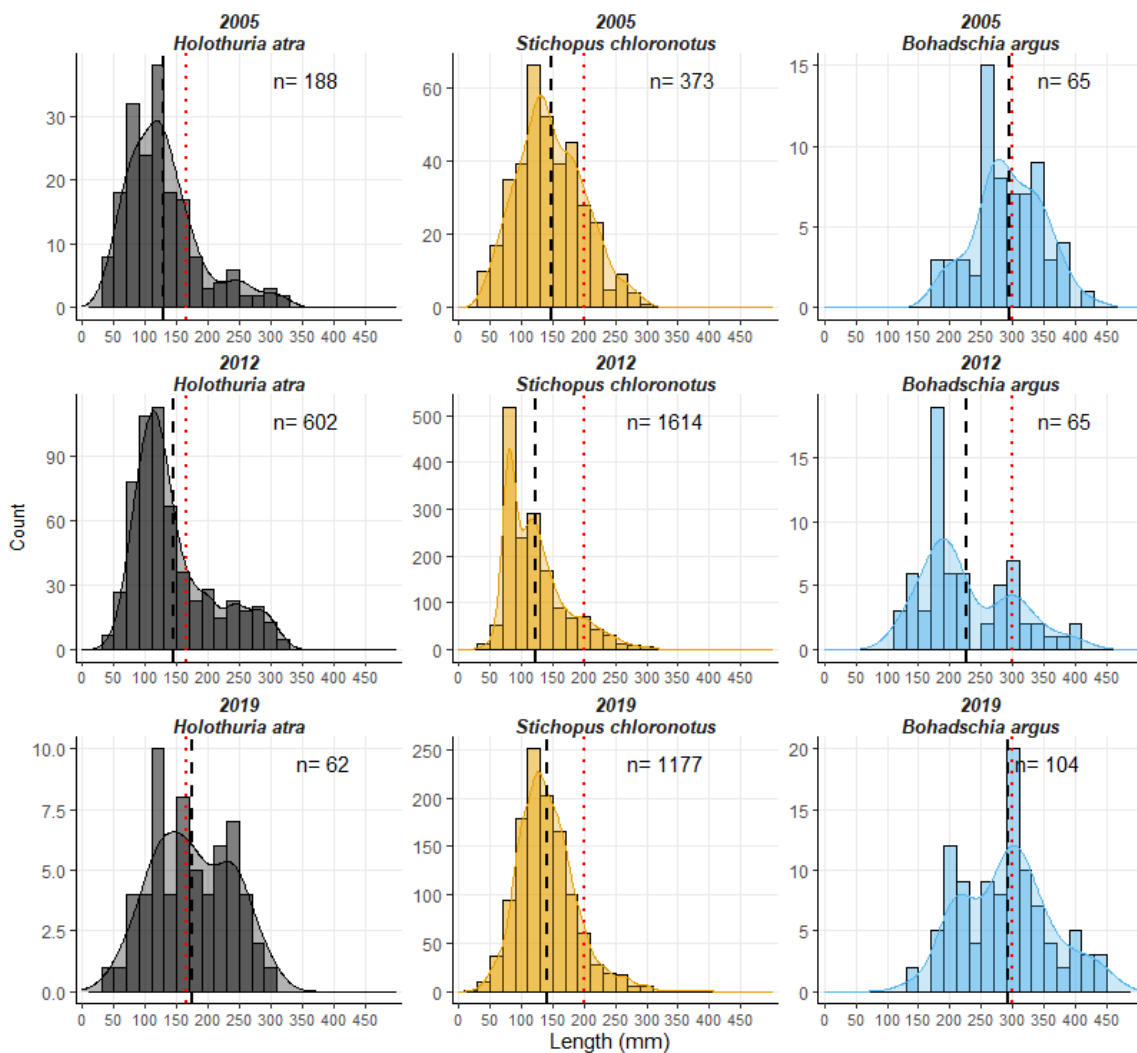


Figure 15. Length-frequency and density curves for three sea cucumber species pooled across Savai'i Island. Black dashed lines indicate mean length for each period, red dotted line indicates length at first maturity (Conand 1989; Conand and Byrne 1993; Purcell et al. 2012). Plot titles are year surveyed and scientific name. (n) represents the total number of length measurements for each species in that year's survey.

The low densities of many species meant very few length measurements were made at individual stations and locations across Upolu Island; therefore, to increase the sample size, data from all locations across Upolu were aggregated. After aggregating data for individual species, the number of length measurements were only sufficient for *Holothuria atra* and *Stichopus chloronotus*. *Bohadschia argus* and *B. vitiensis* were only included in the plots for reference and to visualise the maximum, minimum and mean lengths of measured individuals (Fig. 16). All other species were at such low densities that plotting was uninformative at any level. The length distribution of both *H. atra* and *S. chloronotus* shows that most individuals are below length at first maturity (L_{50}). Records of *H. atra* above L_{50} were fewer in 2019 than in 2012 yet similar to records from 2005. Approximately 80% of records were also below L_{50} . Similarly, records of *S. chloronotus* were similar between 2005 and 2019, although in 2019, individuals were significantly larger than those in 2012 (Kolmogorov Smirnov bootstrap of distribution tests; $p < 0.01$) but most individuals remained below L_{50} .

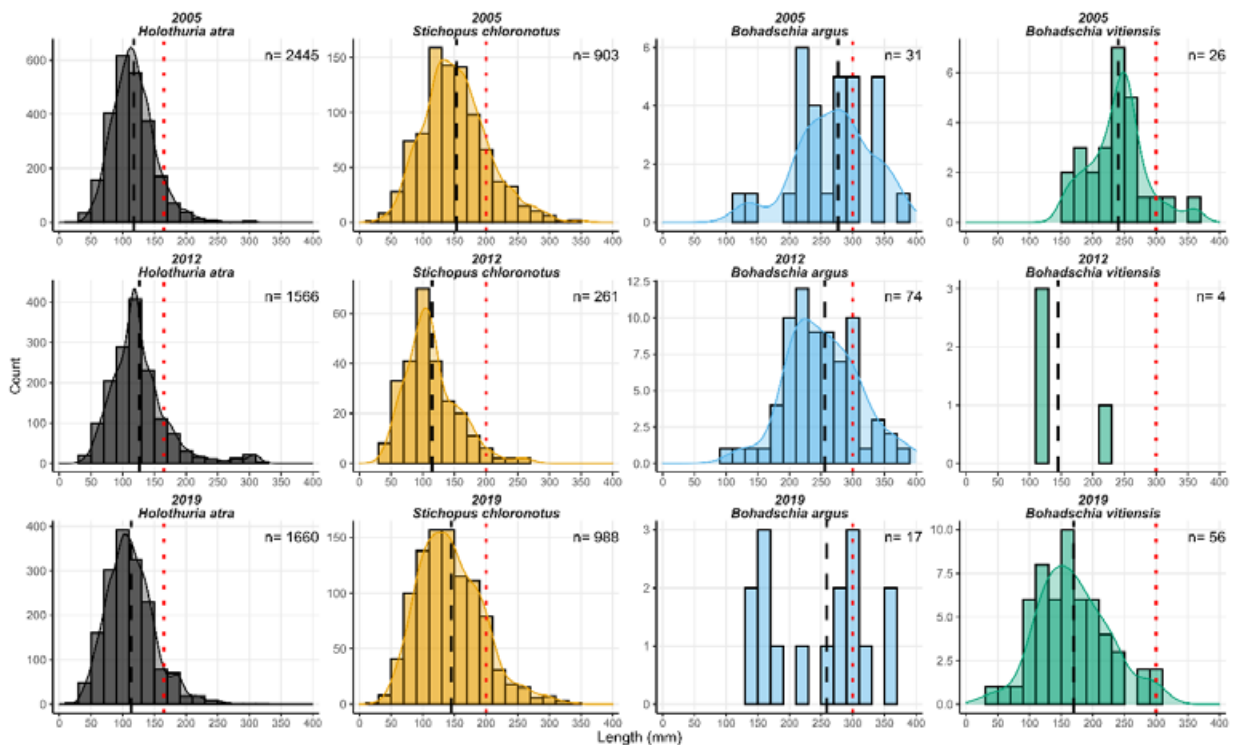


Figure 16. Length-frequency and density curves for four sea cucumber species pooled across Upolu Island. Black dashed lines indicate mean length for each period, red dotted line indicates length at first maturity (Conand 1989; Conand and Byrne 1993; Purcell et al. 2012). Plot titles are year surveyed and scientific name. (n) represents the total number of length measurements for each species in that year's survey.

Discussion

Results of this survey highlighted that sea cucumber populations remain depleted across much of Samoa. Moreover, in some cases there are fewer individuals in 2019 than there were in 2012 despite there being a ban on exports. These populations are too impoverished to sustain an export fishery, and if sustainability targets are to be achieved, the fishery should remain closed and current management strategies should be reviewed for appropriateness and effectiveness.

We found that the species composition of wild sea cucumbers was generally similar between Savai'i and Upolu and consistent with previous surveys; nevertheless, at some locations there was a clear distinction between species. For example, there was a clear differentiation in commercial species densities in the northwest of Savai'i at Asau and Vaisala, which was dominated by high densities of *S. chloronotus* (greenfish) and *B. argus* (leopardfish), while Upolu locations Manono, Faleula and Apia were dominated by *H. atra* (lollyfish). Stations at Malie and Vaitoloa recorded high densities of the snakefish *Synapta maculata*, which has no commercial or subsistence value.

The spatial differences in sea cucumber densities and composition across the surveyed locations are likely due to differences in the preferred habitat of each of these species. The habitat assessment found that these locations differed in the dominance of sand, seagrass, or sand interspersed with either some coral or coral-rubble. For example, *Holothuria atra* was found across mostly coarse sand habitats interspersed with coral, coral-rubble and some seagrass beds. *Stichopus chloronotus* was found in habitats consisting mostly of coarse and fine sands and seagrass, while *B. argus* was associated with coral reef and coarse sand habitats in western areas of Vaisala. It is also likely that each species had a preference towards unaccounted for physical characteristics at each location such as exposure to oceanic currents or proximity to land, the latter of which would influence sediment properties on which the sea cucumbers feed.

Samoa's average per annum export volume from 1991 to 1994 was 30 metric tonnes (mt), similar to Tonga's at 40 mt but significantly lower than Fiji's at 280 mt. The relatively small export volume was, nevertheless, enough to exceed carrying capacity very quickly. As a result, the government of Samoa prohibited commercial exports in 1994 to allow stocks to recover; the fishery has not been opened for exports since (Anon 2015). The small export volumes and rapid depletion of stocks is due, in part, to small reef areas of key habitat that can only sustain relatively small sea cucumber populations.

Although the export of sea cucumbers is banned, three species continue to be a significant part of a subsistence fishery, with *Stichopus horrens* (dragonfish), *S. herrmanni* (curryfish) and *Bobadschia vitiensis* (brown sandfish) being caught and consumed in households or sold at local markets as bottled viscera. This continual harvesting pressure has seen volumes of *B. vitiensis* and *S. herrmanni* sold at markets steadily decline between 2003 and 2012 (Anon 2015). *Stichopus herrmanni* has not been recorded in fishery-independent surveys since 1994, which may indicate that densities and recruitment of this species has declined below thresholds, such that the replacement of harvested individuals has been severely impeded.

A more complete survey is needed, however, before a definitive outcome on both *S. herrmanni* and *S. horrens* can be made. Previous surveys in appropriate habitats for this species were all conducted during daylight hours, but both *S. herrmanni* and *S. horrens* are cryptic and emerge mostly at night, making them difficult to survey during the day, especially when densities are low (Friedman et al. 2006). Additionally, another usually cryptic nocturnal species, *Holothuria scabra* (sandfish), is known to occur but has not been recorded in fishery-independent surveys, even though stations were in appropriate sand habitats. These species are, therefore, not well documented with the sampling methods used in all surveys to date. Friedman et al. (2006) did highlight that these species can be sampled in seagrass areas at all times of the day, although the likely low densities coupled with limited seagrass habitat during our surveys meant encounters were limited or absent.

In 2012, the report compiled by SPC and MAF showed that during the 18-year moratorium on commercial exports of sea cucumbers, two commercial species *H. atra* (lollyfish) and *S. chloronotus* (greenfish) were reported to be above regional reference density thresholds (Sapatu and Pakoa 2013). However, results from the 2019 survey indicate that populations of all sea cucumber species, including the two low commercial value species *H. atra* and *S. chloronotus*, have declined below 2012 levels. This suggests that in 2012, the 18-year moratorium on exports allowed populations of these species to recover. As of 2019, the fishery has been officially closed for over 25 years, which should have resulted in significant recovery for these two species and many others.

This time frame exceeds the maximum lifespan of many species and, hence, provides ample time to allow for the recovery of stocks. It is, therefore, highly probable that sea cucumber stocks have been impacted over this period. The most likely explanation is illegal harvesting. Illegal harvests and attempted illegal exports have been documented in Samoa, with buyers most often being foreign businessmen.⁴ and⁵ In 2016, an illegal harvest of predominantly *Holothuria scabra*, valued at USD 360,000 was seized⁵, while in May 2020, Radio New Zealand reported that a Chinese businessman was charged with attempting to bribe a custom's official when trying to export an illegal beche-de-mer harvest valued at over USD 3.6 million.⁵ Based just on the value of these two documented

4 https://pacificguardians.org/blog/2016/03/18/samoa-fisheries-operation-rico-catches-est-900k-illegal-sea-cucumber-harvest-in-samoa/?utm_campaign=shareaholic&utm_medium=email_this&utm_source=email

5 <https://www.rnz.co.nz/international/pacific-news/416082/arrest-in-samoa-after-discovery-of-sea-cucumbers-ready-for-export>

illegal harvests, there has been a significant number of sea cucumbers removed from the fishery. Illegal harvests, if left undetected, could quickly result in large declines due to Samoa's very limited sea cucumber habitat.

The length distribution of *Holothuria atra* and *Stichopus chloronotus* in 2005 and 2012 suggests that recruitment rates were sufficient for these populations to increase or stabilise by 2019. However, length data from 2005 to 2019 show that populations remain left-skewed and without an observable increase in the number of large individuals above size at maturity, meaning some larger individuals continue to be absent from the population. In some cases, densities declined between 2005 and 2019 and/or 2012 and 2019 across only part of their entire length distribution. In recovering or undisturbed sea cucumber populations, the higher proportion of smaller individuals should have grown to adult lengths, which would stabilise over the long-term as they reached their habitat's carrying capacity. In 2019, another species, *Bobadschia argus*, showed a proportionally larger number of individuals in smaller sizes compared to larger individuals, although the number of observations for this species was so low in some cases, that inference of recruitment patterns is only subjective. However, the range of lengths observed over the three survey periods indicates recruitment had occurred; yet despite this, *B. argus* declined from 2012 to 2019. These patterns in density and length across the different species indicates that large, commercially valuable individuals continue to be absent from surveys and are likely subject to illegal and unreported harvests.

Another less likely but still plausible reason that could have contributed to the observed declines is severe environmental disturbances. Very little literature has specifically linked sea cucumber mortality with environmental disturbances such as marine heatwaves or cyclones, including a general lack of understanding of the direct and indirect pathways by which invertebrates are impacted by climate-related disturbances. However, the relatively few studies that have investigated climate-related disturbances on invertebrate communities have shown that marine heatwaves have resulted in mortality of echinoderms (sea stars and urchins), bivalves (giant clams) and gastropods (trochus and abalone) (Hutchings et al. 2007; Garrabou et al. 2009; Prather et al. 2013; Jurgens et al. 2015). Additionally, in 2011, it was reported by commercial sea cucumber fishers that Cyclone Yasi decimated sea cucumber stocks across shallow lagoon reefs off the coast of Queensland, Australia.

Since 2012, a number of disturbance events have impacted reefs and seagrass areas across Samoa. In 2016, a category 1 cyclone (Cyclone Amos) passed within 50 km of Samoa (Apia). Additionally, a series of extreme marine heatwaves occurred from 2015 to 2020. These marine heatwave events were shown to impact reefs, causing coral bleaching and declines in the extent and abundance of both coral and seagrass (Ziegler et al. 2018). High seawater temperature and cyclones resulting in the decline of key sea cucumber habitat may therefore have indirectly affected sea cucumber populations. Yet given these events, there has not been an assessment of their effects on sea cucumber populations specifically, which went either unreported or were not identified. As a result, we are unable to link these disturbance events with the observed decline in sea cucumber density at these locations.

Local reference densities calculated specifically for Samoa and published in Sapatu and Pakoa (2013) appear to overestimate natural densities and may not account for natural variations in sea cucumber densities. Understanding the health of sea cucumber stocks requires an accurate estimate of what are locally normal or "healthy" density levels for each species. Ideally, these estimates will be representative of the different geomorphology and sea cucumber habitats of the Pacific Islands (e.g. high islands vs atolls). Local reference densities should also be based on estimates that capture the natural variation of individual species across their entire habitat range. Comparison between local reference densities with regional reference densities shows that local calculations were, in some cases, 3.5 times higher; for example, the local reference density for *S. chloronotus* is 11,200 ind.ha⁻¹ while the regional reference density is 3500. These large local reference density values were the result of using a limited number of stations at Asau on Savai'i, which is not a representative sample of the total area of suitable habitat across the island. By not considering the natural variation of the species across its entire habitat range, estimates of reference densities calculated from an insufficient number of stations across the habitat range can be inaccurate. Furthermore, these species are usually widely dispersed but can aggregate for a number of reasons (e.g. spawning or concentration of food), and sampling only a small proportion of their habitat could lead to over or underestimation of their abundances when extrapolating total stock sizes from areas of available habitat. Local reference densities of individual species must, therefore, be calculated from a sufficient number of replicates over their habitat range to ensure the full range of variation has been accounted for; this should include night surveys for those species most active at this time.

Capacity building

Training local fisheries officers in survey design, data collection, entry and database management was provided as part of the survey programme. Due to an outbreak of measles in Samoa, however, and subsequent travel restrictions to combat the COVID-19 pandemic, training in data analysis – which is usually done at SPC headquarters in Noumea, New Caledonia – was not completed. Nevertheless, the success of the training provided in-country has enabled the establishment of a long-term monitoring programme in Samoa. MAF staff who underwent training in survey design and data collection, successfully carried out more surveys in other locations across Samoa in the absence of trainers. With the establishment of a monitoring programme in Samoa, MAF staff will continue to collect data on key invertebrate populations and on the health of reef habitats. These data will highlight shifting trends in populations as well as changes in key habitats from major disturbances such as cyclones and marine heatwaves.

Conclusions

Sea cucumber stocks in Samoa remain below established regional healthy reference densities and have not improved since monitoring began in 2005. While we have indicated that there are multiple possible reasons for why this has happened, illegal and/or excessive harvesting would seem to be the most likely cause. While we cannot discount natural large-scale disturbances having a detrimental effect on stocks, the evidence for this as the primary driver of depleted stocks is less convincing. In the face of increasing climate-related impacts, which will only exacerbate overharvesting depletions, robust management strategies need to be implemented. These strategies should include the use of appropriately located and sufficiently large marine protected areas to provide a space for sea cucumber populations to grow and reproduce normally, free from harvesting pressure. There should also be a reduction in local harvesting levels (via appropriate mechanisms such as licencing and quotas), and increased monitoring, control, surveillance and enforcement to ensure that such measures are implemented effectively. It is also recommended that the current moratorium be maintained until fishery-independent surveys can establish that sea cucumber populations have recovered.



The field survey team - Front row, from left to right: Audrey Katalina Tone, Esmay Tanielu, Faasulu Fepuleai, Chris Molai, Lillian Joe Taulapapa. Back row left to right: Moso Lesa, Asomaliu Selesele, Selau Falemai, Urima Talaumi, Solomonu Tufuga, George Shedrawi, Atapana Tony, and Fe'u'u Leilua. Photo © Chris Molai.

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