Assessment of Seychelles' Sea Cucumber Fishery

SEYCHELLES FISHING AUTHORITY

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Submitted by

MRAG

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Acronyms

AMSSI	Association of Members of Seychelles Sea Cucumber Industry
CPUE	Catch-per-unit-effort
EEZ	Exclusive Economic Zone
MAF	Ministry of Agriculture & Fisheries
MSY	Maximum Sustainable Yield
NGO	Non-governmental organisation
SFA	Seychelles Fishing Authority
VMS	Vessel Monitoring System

1 Introduction

Blue economy has become an important element of the development agenda of Seychelles and focuses on the growth of ocean-based economies that are environmentally and socially sustainable. A key strategy of the blue economy roadmap is to meet international best practice for sustainable development of the tourism and fisheries sectors, the two main pillars of the economy. In the fisheries sector, focus is being placed on improved governance of priority fisheries, including the adoption of co-management plans and rights-based approaches that are informed by robust management advice.

Traditionally, sea cucumbers have been fished on a small scale for over a thousand years in the Indo-Pacific However, over the last 15-years, there was a rapid development of an export-driven sea cucumber fishery with the main demand stemming from East Asia, where the main product is the dried body wall of sea cucumbers, marketed as bêche-de-mer. This increase has significantly enhanced revenue and employment from artisanal fisheries, but concerns have been raised over stock declines and the ecosystem impacts of overfishing. The main species caught in the fishery are *Holothuria atra, H. nobilis*, *H. fuscogilva*, *Thelenota ananas*, *Actinopyga miliaris*, and pentard (undescribed sp) and they comprise more than 90% of the total landings.

The Ministry of Agriculture & Fisheries (MAF) and Seychelles Fishing Authority (SFA) are the principal public institutions for fisheries in Seychelles, overseeing policy, management, development, research and capacity building. Fisheries governance is further supported by an active community of fisher associations and conservation NGOs, with decision-making increasingly devolved to co-management bodies.

Access to the sea cucumber fishery is controlled through a restricted number of fishing licenses, specifically, there are 25 licenses for sea cucumber fishing that have all been allocated. SFA has also set the months of July to September as a closed season for sea cucumber fishing (since 2008) and there is also a limit in the number of divers in the fishery. The fishery is governed by a co-management committee comprising key public institutions, NGOs and representatives of the industry, including the Association of Members of Seychelles Sea Cucumber Industry (AMSSI).

In 2012, MRAG undertook a stock assessment of the sea cucumber fishery stock in Seychelles and provided recommendation for management and research to the Seychelles Fishing Authority. The assessment comprised a spatially-disaggregated analysis of catch and effort data, standardization of catch-per-unit-effort (CPUE) as an index of abundance, and the application of surplus production models to estimate biomass and maximum sustainable yield. A number of constraints limited the provision of management advice from this analysis, including the length of the time-series and resolution of both spatial and effort data. Following the assessment, the Seychelles fisheries authorities reviewed the management plan for the sea cucumber fishery in 2012 and an agreement was reached with stakeholders to revise the plan after 3 years of enhanced data collection.

This document presents the results of latest assessment of sea cucumber stocks using data to cover fishing activity up to 2016 and discuss their use to provide management advice and inform revisions of the management plan.

2 Methodology

The data used for this analysis comprised of 3 different temporal components: catch records from 2000 to 2012; 2012-2013, and finally 2013 to 2017. The format of the entries differ among components and therefore, the first step in the analysis was to ensure that all 3 datasets included the same fields as it was impossible to combine as they were.

Data from some years were limited and therefore, those were identified early on and were excluded from part of the analysis as needed. Those years were 2000, 2001, and 2017; concerns about the reliability of the data from years 2000 and 2001 have also been expressed in previous studies (Koike *pers comm*).

The information the database provided included data on species and numbers of sea cucumbers caught per trip, vessel ID, date and area where fish were caught, number of divers, and dive time and depth. For the reporting of fishing position, the data included information by statistical region (see Figure 1). Within each region, detailed reporting grid squares are used to locate fishing effort (see Annex 1). The 2012 assessment of Seychelles' sea cucumber fishery also developed a set of new sub-regions according to the distribution of likely fishing grounds, 1a-5a (Figure 2).

A separate dataset provided information on the geographic position of vessels collected from VMS; these data were only available for the past 4 years but provided location information at a much finer scale than that in the data provided in logbooks.

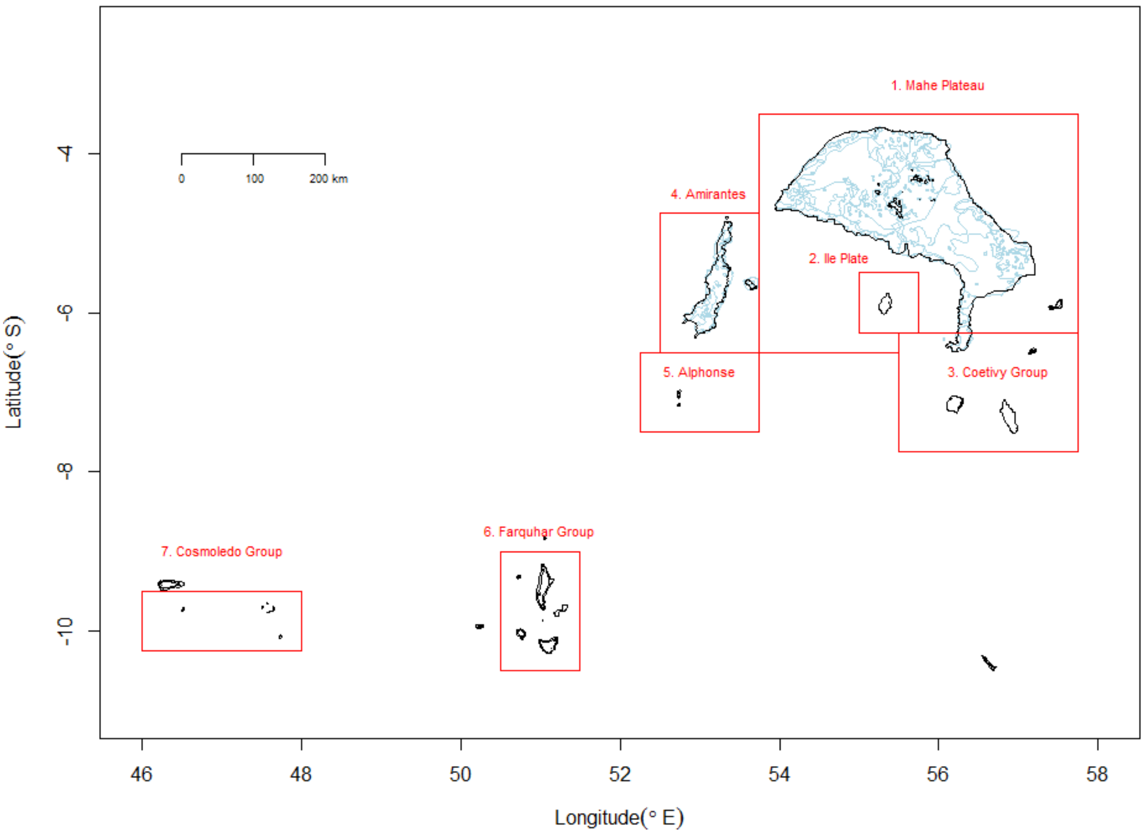


Figure 1: Names and numbers of statistical regions used for reporting in the Seychelles EEZ.

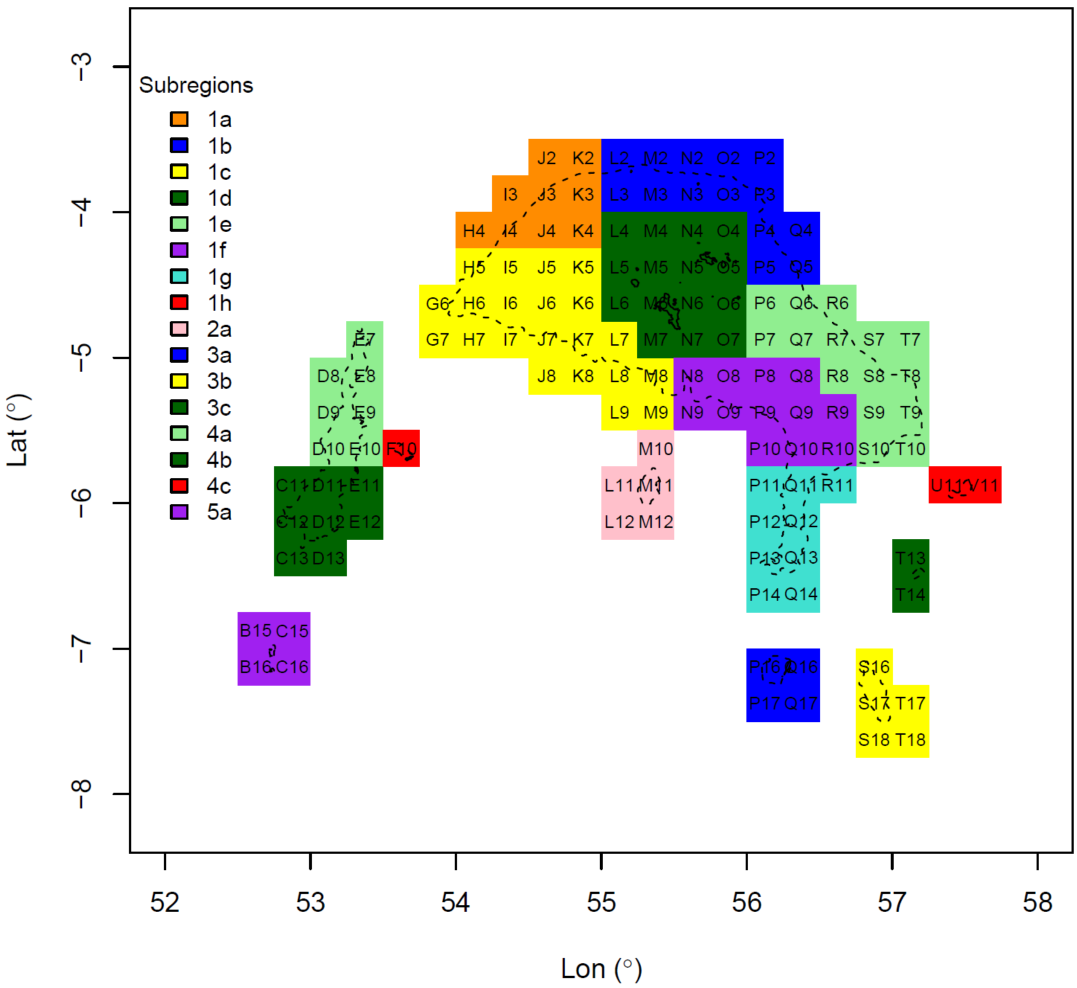


Figure 2: Map of the sub-regions (coloured blocks) and names of grid blocks of the Seychelles EEZ.

2.1 Verification of data

2.1.1 Logbook data cleaning and assumptions

A number of tests were run using the 3 components of the datasets to test for accuracy in the reporting codes, erroneous records/values, missing information, and other issues that could affect the analysis. A list of problems encountered with the data is shown in Table 2. Several of these problems could be easily addressed by restricting the options that people who enter data have (e.g. drop down menus with the permitting field codes). It is recommended that such restrictions are incorporated in the data reporting system as they can increase the reliability of the dataset.

Table 1: Issues encountered with the dataset (non-exhaustive list).

Data issue	Handling/ Assumption used
Holothuria nobilis appear with 3 different names: Black fish / Black teat fish / Spork	Catch records for this three names have been merged and now appear as Black teat fish.
A number of species appear in the database but have no records	They have been ignored for the analysis but listed below to help with future cleaning of the data (Table 2)
Difficult to co-join the original dataset with the latest data due to differences in data recording	We made several modifications (see details below) and fields were changed
Record numbers (of log books) are no longer unique (primary key). Some of the numbers reported in 2014 were used in previous years	New field was created to generate a unique record number
The statistical grid_id field (e.g. 1047) has been completed using the grid_ref code (e.g. G10).	Corrected
Region_text field has been reported as "NA" (not available) although the region_id has been entered	Corrected
Data showing activity in odd areas (e.g. too deep waters). Such areas include grids: D16; E14; F7; F8; F9; F12; G8; G10; G11; I12; I13; J9; J11; K9; K11; L9; N11; N12; Q2; Q3; Q14; R14; T6; V5	Records were kept but highlighted here so SFA can look into them in more detail and remove if needed.
Use of lower case when recording sub-regions	Corrected
Two different types of recording grid id. One without a 0 before a single digit and one with a 0. E.g. L05 and L5	Corrected
Very high dive times (e.g. as high as 500 mins) have been recorded and it is not clear if they represent total dive time or dive time per diver	Records were kept but filtered for the calculation of catch per unit of effort series (see section 2.2.2)
Number of divers has been recorded as 0 or missing	Records were kept but modified for the calculations (see section 2.2.2)

The next step was to group the data based on the detail they contained. For example, some records had information about the statistical regions but not the sub-region or individual grid and therefore could only be used for analysis at the higher level (statistical region level). This data were also plotted at the finer level to identify areas with higher effort concentration and will guide our choice of the areas to use as reference when developing stock assessment runs (e.g. treat as single stock and do a stock assessment for that individual area).

Table 2: Sea cucumber species with no recorded catches in the database.

Scientific Name	English Name
Thelenota anax	Amber Fish
Holothuria impatiens	Bottleneck sea cucumber
Bohadschia vitiensis	Brown sandfish
Bohadschia similis	Brownspotted sandfish
Bohadschia marmorata	Chalky cucumber
Holothuria tubulosa	Cotton spinner
Stichopus variegatus	Curryfish
Actinopyga echinites	Deepwater redfish
Parastichopus californicus	Giant red sea cucumber
Isostichopus fuscus	Giant sea cucumber
Holothuria scarba var. versicolor	Golden Sandfish
Actinopyga miliaris	Hairy blackfish
Stichopus japonicus	Japanese sea cucumber
Holothuria atra	Lollyfish
Actinopyga spinea	New Caledonia blackfish
Actinopyga palauensis	Panning's blackfish
Holothuria spp	Pentard
Stichopus regalis	Royal cucumber
Holothurioidea	Sea cucumbers nei
Stichopus horrens	Selenka's sea cucumber
Holothuria coluber	Snake fish
Holothuria leucospilota	White threads fish

2.2 Analysis of catch and effort

Catches were grouped per region, sub-region and individual grid box using the updated dataset and we also calculated the effort assigned to each area. Effort data from both the VMS records and log books were plotted against different parameters to better understand the spatial distribution of effort and rotational / temporal characteristics of the fishery. This part of the analysis focused on changes that can provide signs of effects of fisheries and way they operate including

- sequential depletion
- deeper diving
- migration to new fishing grounds
- catch composition

Such information is useful because can help us decide whether phenomena such as hyper-stability might be influencing the results of the stock assessment.

For the grouping of catches, two groups were created based on relative value:

- High value catch - black teat, sand, white teat, prickly red and pentard.
- Low value species - red surf, lolly, pink, elephant trunk, deep water red, brown sand, curry, and tiger.

The catch and effort data produced through this process were then used to develop CPUE series and also test the effects of different factors such as depth and year on the CPUE results (CPUE standardisation) using generalised additive models.

For the analysis of effort distribution at a finer scale, VMS data reported for 2014-2016 have been analysed to show changes in effort. The assumption used was that VMS records of less than 2 knots were indicative of fishing effort. The next section provides more details on the analysis of the VMS records.

2.2.1 VMS analysis

Logbook data from the latest Seychelles database have been linked to VMS data provided based upon an algorithm that identified the "closest" VMS position to an individual logbook record based on the time recorded for the logbook record. The differences in distance between these two sets of points, logbook position as recorded by the master and VMS position based on GPS were then calculated to ascertain the accuracy of logbook positions.

From the total 15707 logbook records in the database for the period 2014 -2016 only 8328 had matching VMS records. Of these records 71.25% were within 4nm of each other which would be a reasonable and understandable distance. Of the remainder, 10.98% of the logbook positions are reported over 64 nm away from the closest VMS position, which would potentially lead to errors when conducting stock assessment. As a result we were able to verify less than 50% of the position records provided through cross referencing. This could indicate mis-recording issues with the logbook data and therefore, further consideration of the discrepancies between the two datasets is recommended. Similarly, although the logbook records that could not be verified using VMS information have been included in the stock assessment analysis, it is noted that there is still considerable uncertainty in the geographical distribution of the fishing effort (3 minutes grid) (0.25 of a degree).

The VMS data were used to identify fine scale fishing pressure and plots were produced showing the fishing distribution in each year in a scale of (3 x 3 minutes grid). Those were considered in conjunction with the more conventional effort plots (025 x 0.25 degrees grid). One of the aims of this exercise was to look into the potential of introducing bias or masking localised fishing pressure when the analysis is done at the less fine grid level or region level.

2.2.2 Definition of effort for stock assessment purposes (CPUE series)

The logbook data until 2013 include information about the duration of the dives for each trip but the way that data are recorded is ambiguous as they record the time the dive started to the time it ended. That is not the same as the time spend fishing as that will change depending on things such as the depth of the dive. Similarly, the dive time varies considerably with records shown dive times ranging from a few mins to several hours. Therefore, it is not clear whether that recorded dive time is per diver or per trip/day.

Earlier analysis (MRAG, 2012) looked to reduce the dependency on effort data by introducing the concept of diver-days as a unit of effort; this assigned an effort unit of 1 day to a vessel that on a given day has gone to sea regardless of whether that trip lasted 30 mins or several hours but was adjusted to account for the number of divers in that vessel. That cruder way of assigning effort meant that the recorded dive time was not needed but it also reduced the sensitivity of the resulting CPUE as it moved to a much less fine scale of measurement.

However, more recent data include an additional field that record the dive time explicitly. Therefore, the current analysis makes use of the recorded dive times to take advantage of the finer scale that such transition can achieve but uses pre-defined rules to address some of the concerns about accuracy of reporting of dive times in earlier records. Specifically, the following rules were applied when calculating the total dive time per trip:

- Dive time (time ended –time started) of more than 70 min were treated as total dive time for the trip regardless of the number of divers recorded.
- Where dive time > 0 but number of divers was 0, dive time was treated a total dive time.
- In all other cases, total dive time = recorded dive time multiplied by the number of divers.
- Trips that have recorded a dive time of less than 10 mins were not included in the calculations of CPUE as they were assumed to represent "searching time" rather than proper fishing time.

The choice of 70 mins as a cut-off point is loosely based on records provided in the latest part of the dataset (2013- 2016). All records that have provided that information have recorded a dive time of 70 min or less. Only 3 out of the 15,000 records that provided that information have recorded dive time that is higher than 70 min. However, we cannot verify that such a cut-off point is appropriate for earlier years so, this is an area that further work is needed unless more information on the reliability of the dive time data in the dataset is provided.

2.3 Stock assessment

Catches in number and CPUE series remain the main sources of information on fishing pressure for sea cucumbers in the Seychelles waters. With regards to species biology, there is limited knowledge of key processes such as growth, mortality, and productivity. This narrows the range of quantitative approaches that can be effectively used to assess the status of the stocks. The surplus production model has been considered previously (MRAG 2012) for these stocks and it is a model often considered for data-poor species due to the small number of parameters and inputs that it requires.

Similarly, stock reduction analysis as applied by Martell and Froese (2013) is another approach with low input requirements. It also used the surplus production model to calculate annual biomass and provide estimates of key parameter's often used for management purposes such as MSY.

Both of these methods were explored in this analysis using the catch and CPUE series available for the sea cucumber species. However, it is important to highlight that this application is a diversion from the conventional use of these model, this is because the surplus production model is a biomass tracking model and therefore, it is used with series expressed in biomass. However, catches in biomass are not available for the species considered in this analysis and thus, catch and CPUE series expressed in numbers had to be used instead. One of the important implications of that diversion is that changes in biomass (e.g. average weight) of the population due to exploitation are not explicitly reflected in catch or CPUE series that use number of fish so, they cannot be captured in the assessment.

Essentially, the assumption we make is that average weight of the population remains the same over the years; it is unlikely that such an assumption will not be violated especially for species that have been experiencing heavy exploitation and that undermines the robustness of the analysis.

Another assessment approach that could also be suitable for the type of data available is the DeLury model in each original (depletion) form or in its modified version to allow for constant recruitment. The advantage of using this approach is that it is expressed in numbers of fish and therefore it matches the units of the input series that are available for the sea cucumber stock assessment.

2.3.1 Surplus production model

The stock assessment analysis applied the surplus production model from an earlier study (MRAG 2012) to the updated data series (4 more years added) to determine if the longer data-series improved model fits and provide a signal about the status of the stock and the impact of fishing. The analyses uses the Schaefer production model which assumes that there is a symmetric production function (relationship between stock size and production), and that production depends on the unexploited population size (or carrying capacity) K, and the intrinsic growth rate *r*. The model is used in a non-equilibrium format.

A number of scenarios were explored using the surplus production model to reflect new parametrisation, structure assumptions, and CPUE clustering. The components that will contribute to the alternative parametrisations are listed in Table 3 below.

Table 3: Different model parametrisations considered.

Model component	Parametrisation	Comment /Notation
Initial stock size (relative to K)	Range from 0.8 to 1.	N1
Time lag between stock size and recruitment to the fishery	Range from 0 to 3 years.	
Model	Schaefer or Pella.	
Variance in input data	Two options for CPUE: No error (unweighted) or use of CVs as weights in minimisation.	U, W
Minimisation methodology	Least Squares (unweighted) or Log-likelihood using the CVs to weigh the CPUE.	LSU, LoglkhdW
Species grouping	Two options: assess the status of valuable species as a group or assess the stock status of individual species.	
Special disaggregation	Assessment of fishery at statistical area level, sub region, or single grid box.	

Model component	Parametrisation	Comment /Notation
CPUE sub-setting	The CPUE used was either that from all the vessels in the area or from a small number of vessels that were selected by the SFA.	CPUE_all CPUE_sub

For each run, important management parameters such as MSY and current population size and depletion level will be recorded while we will use bootstrapping methods to characterise the uncertainty in the model predictions.

2.3.2 Stock reduction analysis

Some of the runs considered using the surplus production model were also repeated using the stock reduction model (Martell and Froese, 2013). This approach is based on a simple Schaefer production model and aims to approximate MSY using a catch time series and a range of initial and current depletion levels (relative to the unfished carrying capacity) (see Table A1 in Martell and Froese, 2013 for the technical description).

Although, CPUE data are not explicitly used as an input in this model, the trend in the CPUE data was used to define the boundaries for the range of plausible values for the depletion at final year of calculations. Other information needed for this model includes boundaries for growth potential (r) and Carrying capacity (K) as well as range of values for natural mortality. We used maximum catches to define lower boundaries for the Carrying capacity and used a very broad range of values for the growth potential, broader than one would define if the input parameters were expressed in biomass. This is to explore the impact that the diversion in the parametrisation of the model (i.e. numbers instead of biomass) might have on estimates of key biological parameters such as the growth potential.

A very useful characteristic of this model is that it focuses on estimating management parameters such as MSY and stock size at MSY. Both these parameters together with results on stock size/depletion and values of biological parameters will be included in the results. The same notation as shown in Table 3 will also be used here to describe the scenarios considered. Uncertainty in the parameters will again be characterised using bootstrapping to provide probability distributions for key model parameters.

3 Findings

3.1 Catches

The amount of fish caught in each statistical area (area 1-7) was derived from the clean data and are shown in Table 4 for the 7 species with the higher catches based on the catch records. Given that a number of records did not specify a region from which the catches were taken the total catches used in the calculations are less than the catches in the database. This means that the fishing pressure might be underestimated in our calculations. As mentioned already, the records for years 2000 and 2017 are incomplete so, although they are presented here for completeness, they have been excluded from the stock assessment analysis. The same is true for 2001, depending on the subgrouping applied (e.g. grid level).

Table 4: Catches per year and species. Note that records for 2000 and 2017 are incomplete.

Year	Pentard	White teat	Black teat	Prickly red	Lolly	Red surf	Sand
2000	82	9,821	3,496	3	0	0	704
2001	2,951	16,768	7,544	2,802	0	0	120
2002	9,589	36,432	35,331	5,463	0	0	142
2003	47,457	24,610	68,708	14,589	3	0	33
2004	58,667	40,635	61,543	12,186	0	0	622
2005	79,554	45,601	104,524	16,354	0	0	100
2006	159,670	38,477	116,186	15,497	0	0	2,047
2007	178,777	57,691	70,297	19,473	0	0	433
2008	151,262	56,356	29,384	20,640	476	161	1,852
2009	277,230	127,550	16,517	44,118	2,451	309	292
2010	289,257	116,542	44,493	32,205	6,053	599	1,474
2011	307,853	100,688	31,586	72,268	8,326	4,785	830
2012	242,604	50,314	26,167	43,960	4,386	0	631
2013	165,432	36,897	17,593	32,388	1,563	87	489
2014	277,613	73,763	28,997	48,552	0	8,119	99
2015	258,930	63,206	36,231	43,008	0	1,307	131
2016	197,868	40,759	25,289	27,780	0	457	35
2017	1,261	716	232	267	0	0	0
Total	**2,706,057**	**936,826**	**724,118**	**451,553**	**23,258**	**15,824**	**10,034**

3.2 Spatiotemporal evolution of effort and catches

This section shows a summary of the results obtained for the spatial and temporal distribution of fishing effort and associated catches between 2001 and 2016. Further analysis of individual vessel effort and catches trends will be included in the final report.

3.2.1 Distribution of effort based on VMS data

VMS aggregated on a 3 minute grid have been plotted to show the hotspots of effort (on a green to red increasing scale) in Figure 3 (2014), Figure 4 (2015) and Figure 5 (2016). These three figures show a number of key points on the effort distribution that may not be seen based on the analysis by grid square:

- Clear differences are observed over small distances; that means that the pressure is more localised than reflected by the sub-region level used to report fishing activity. Given the area covered in each sub-region grid, that's not surprising but it might highlight the spatial distribution of sea cucumber and how small hot spots for sea cucumber might be.
- The plots show that the areas of high activity change from one year to the next. Movement of the fishery between years to exploit "new" fishing grounds may mask highly localised depletions. Having said that, there are area that seem to be targeted more often; that includes the area between Mahé and Praslin while area 4 seems to be exploited every year.
- Some additional thought may be given to the regions defined based on the distribution of effort. In particular the spur of effort southeast from Mahé and Praslin appears to split two previous sub-regions and probably requires a different spatial grouping to properly capture the effect of fishing in that area.

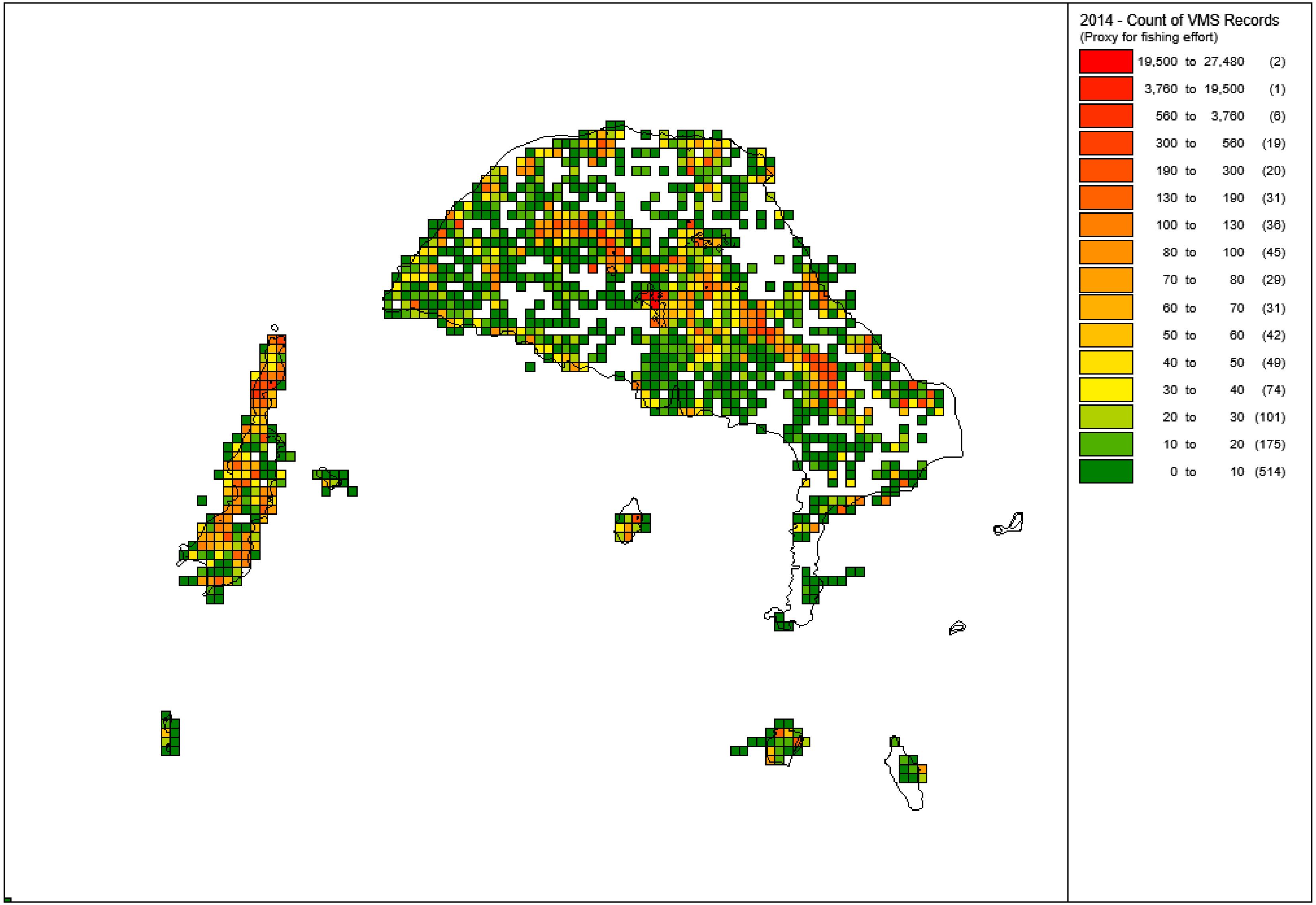


Figure 3: Effort based on count of VMS records (<2kts) in 2014.

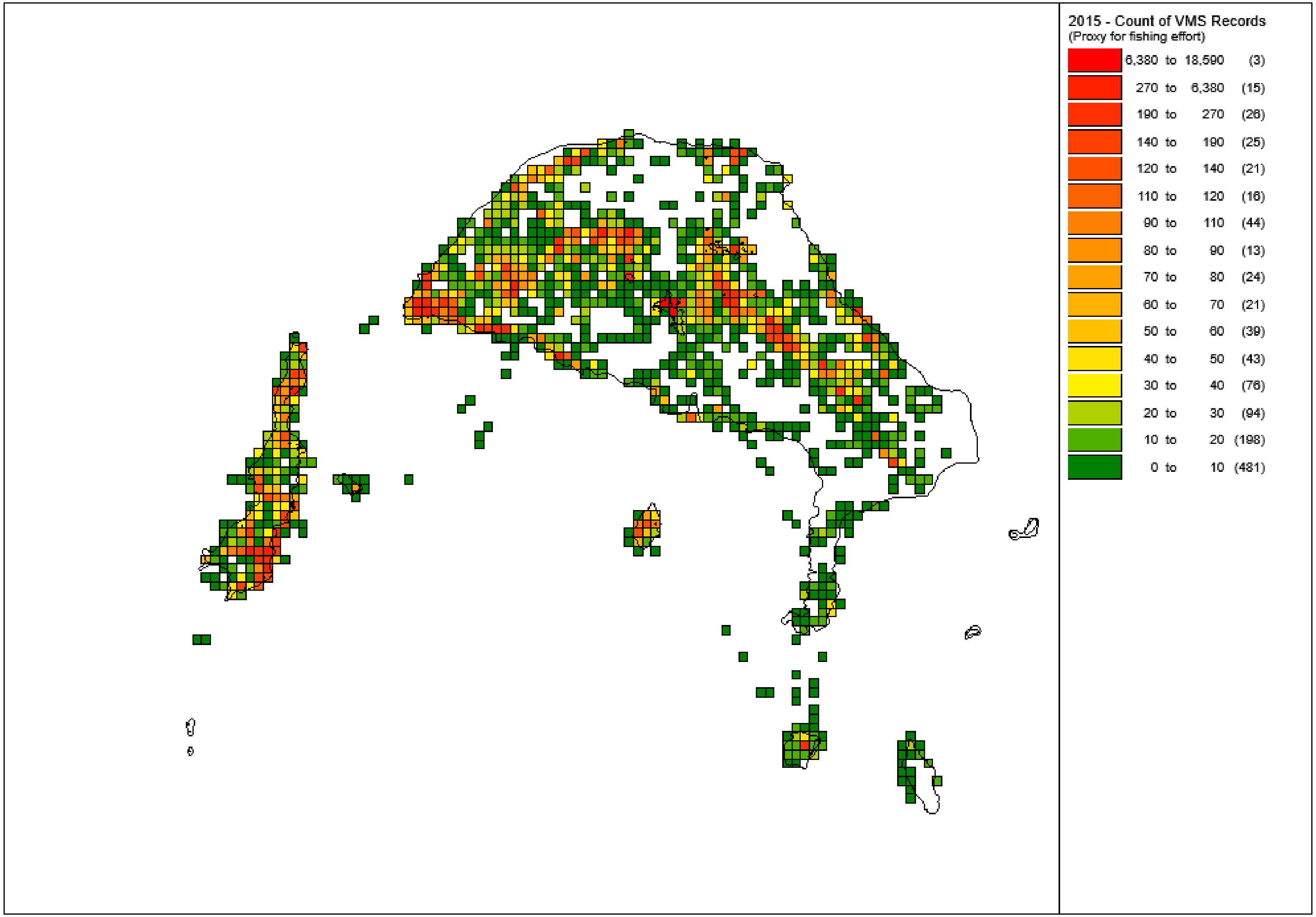


Figure 4: Effort based on count of VMS records (<2kts) in 2015.

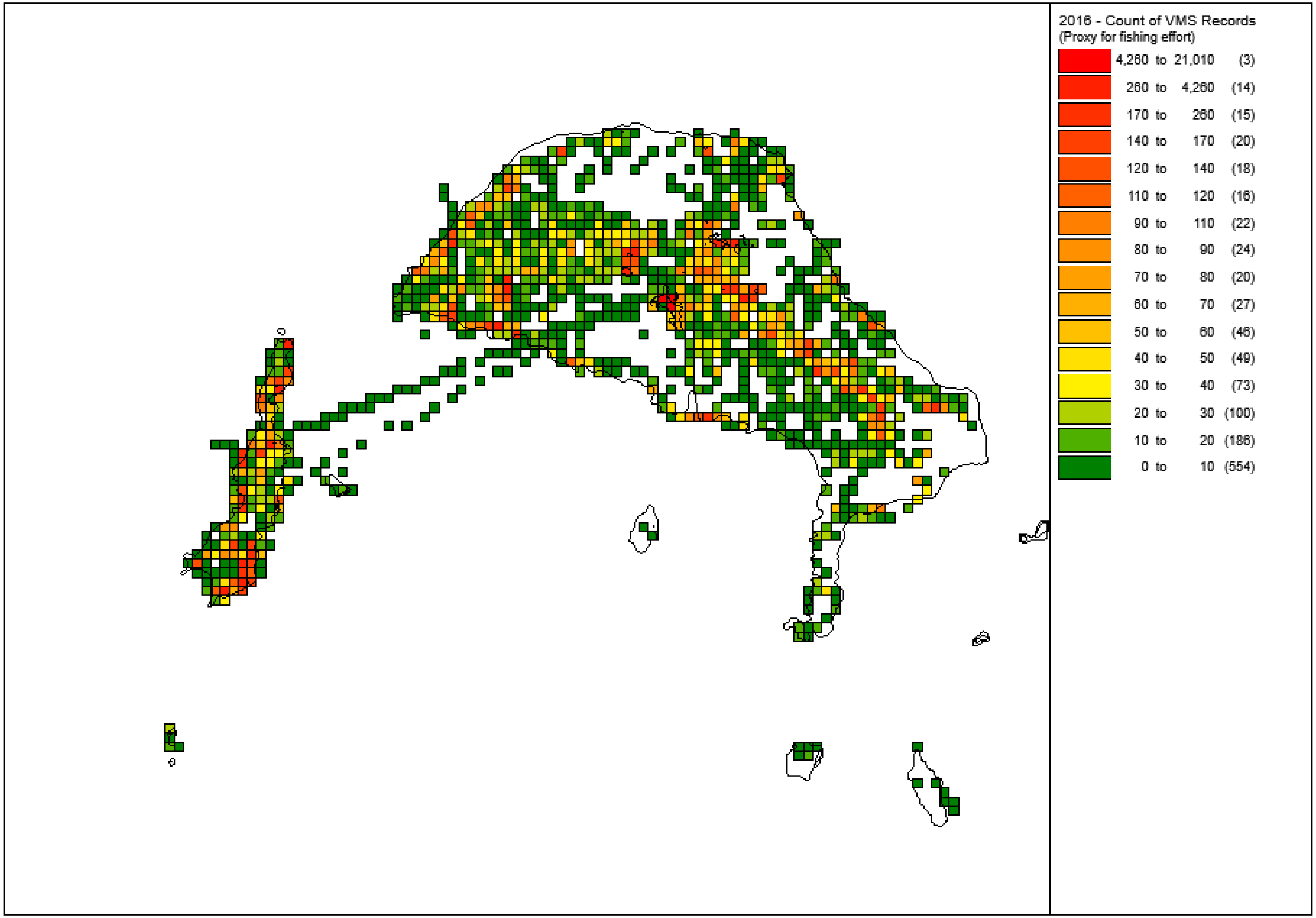


Figure 5: Effort based on count of VMS records (<2kts) in 2016.

3.2.2 Distribution of fishing effort based on log book data

Monitoring the spatiotemporal distribution of fishing effort is helpful to show how the fishery has evolved over time and to determine fishing patterns and the behaviour of commercial vessels that can help better understand trends in catch-per-unit-effort data.

As described in section 2.2.2, the original calculation of fishing effort was determined using diver-days. Given the uncertainty in the data for fishing effort during the initial data series, this definition allowed for the time spent both searching and actual fishing. More recently, more accurate information on the actual bottom dive time (minutes) has been recorded, in addition to the overall dive time (including decompression stops). This does not however, include information on search time, although records showing dives times less than 5 minutes may be indicative of this behaviour.

Estimates of total annual fishing effort has been updated to include additional data from 2013 to 2016. Total fishing effort has been calculated as both diver-days and total dive time. For comparison, a summary of the spatial distribution of total fishing effort between 2001 and 2016 is shown in Figure 6 below. It is important to note they show almost identical patterns of fishing behaviour, with the highest record fishing effort occurring in particular 'hot-spots' on the Mahé Plateau, Ile de Plate, Amirantes and Coevity. Further details of the spatial and temporal changes in fishing effort are presented for each effort metric in Annex 2.

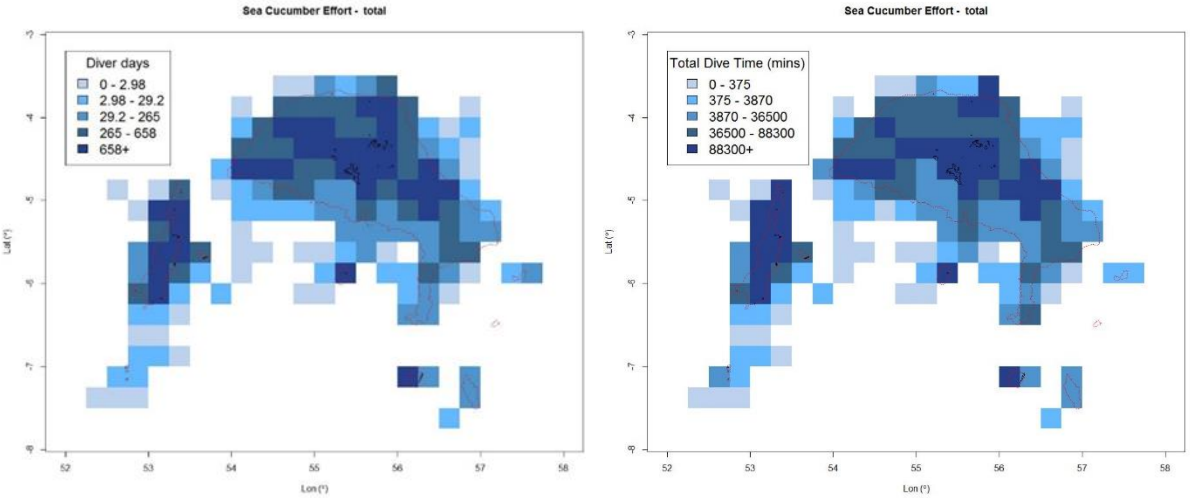


Figure 6: The total effort from all active vessels calculated as diver days (left) and total dive time (right) by SFA grid for 2001 to 2016.

The addition of the 2013 to 2016 data series enables a more detailed analysis of fishing effort to be conducted, and has highlighted a 'hot-spot' between two previous sub-regions, 1e and 1f (see Figures 3-5). Thus, the fishing areas used to determine some of the original sub-regions may no longer be appropriate for calculating catch-per-unit-effort series. This has been partly mitigated by investigating catch rates within specific grid squares.

In addition to the spatiotemporal distribution of fishing effort for the total fleet, further detailed analysis has been performed for individual vessels, reported by SFA to provide more accurate data reporting. An example of this analysis is shown in Figure 7 for years 2006 to 2016. While this individual vessel data exclude years 2001 to 2005, it is interesting to note the pattern of total fishing effort is quite representative of the entire fleet. This type of analysis is important where individual vessels are used to calculate an index of abundance, which should reflect patterns of behaviour of the entire fleet.

Similar to the total fleet, further details of the spatial and temporal changes in fishing effort for an individual vessel are presented for each effort metric in Annex 2.

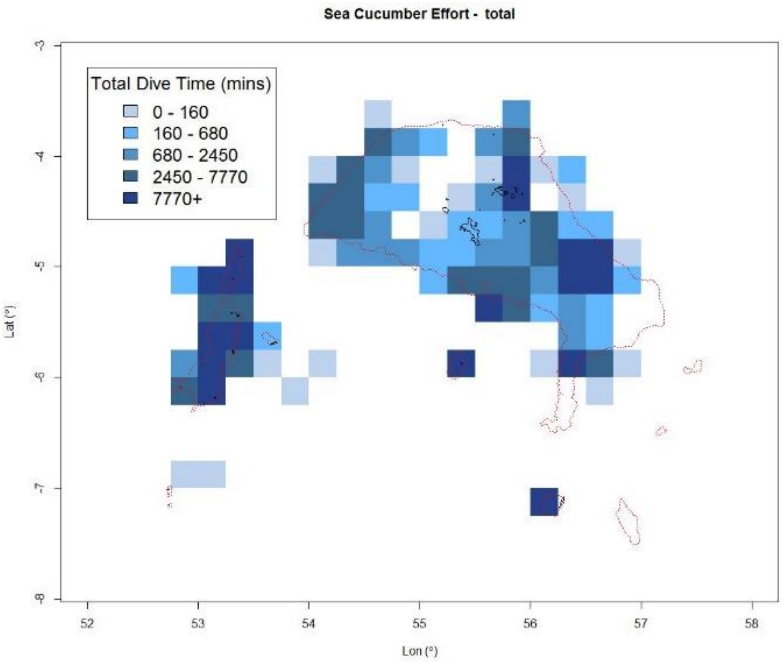


Figure 7: The total effort (dive time, minutes) calculated for an individual vessel by SFA grid between 2006 and 2016.

3.2.3 Distribution of catch species

Total annual catches of key commercial species are presented in Table 4 above. Pentard, black teatfish and white teatfish continue to dominate reported catches from 2000 to 2016. The areas that show the highest level of catches include Owen Bank (grid H6), the Granitic Islands (the grids comprising sub-region 1d), the Amirantes (the grids comprising region 4) and the area surrounding Coetivy Island (grid P16). Pentard continues to dominate catches across the majority of the Seychelles, while higher catches of black teatfish occurs around the main Granitic Islands (Figure 8). The observed change in species composition within sub-region 1d is thought to be due to localised depletion of other commercial species, such as pentard.

Variation in catch composition over the years was also explored looking at changes in species composition per individual grid. We focused on grids that receive high fishing activity and the results for two of them, L5 and M6, are presented (Figure 9 and Figure 10). Both grids show that the contribution of pentard to catches has increased over the years through a switch from other species such as white teat and black teat. Although the changes in composition are pronounced these type of graphs cannot explain the reason behind the change (e.g. depletion or change in market demand). They can however help identify areas where overexploitation might have taken place to prioritise further work.

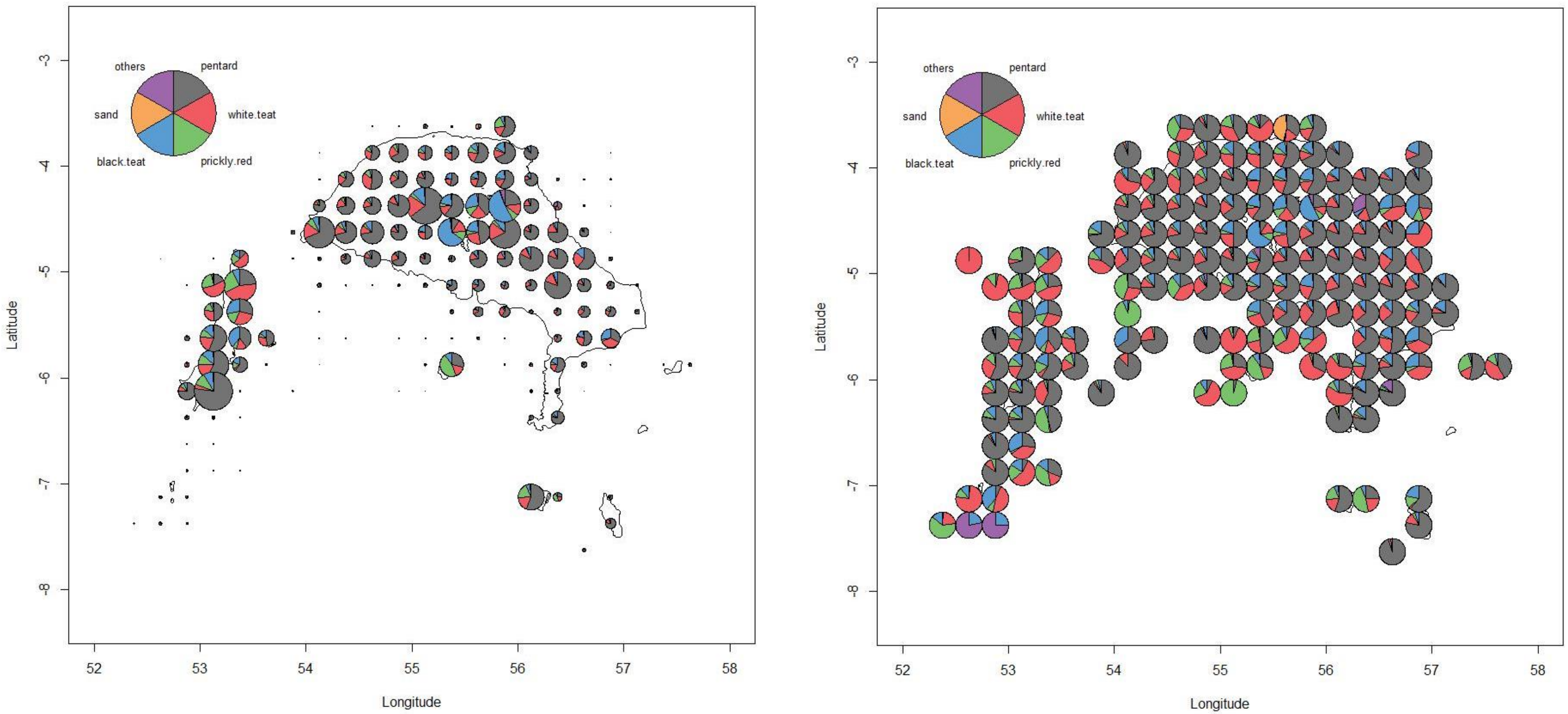


Figure 8: Species composition of total catches between 2001 and 2016 by grid with catch graduated (left) and ungraduated (right) pie charts. The 200m contour is shown as a solid black line.

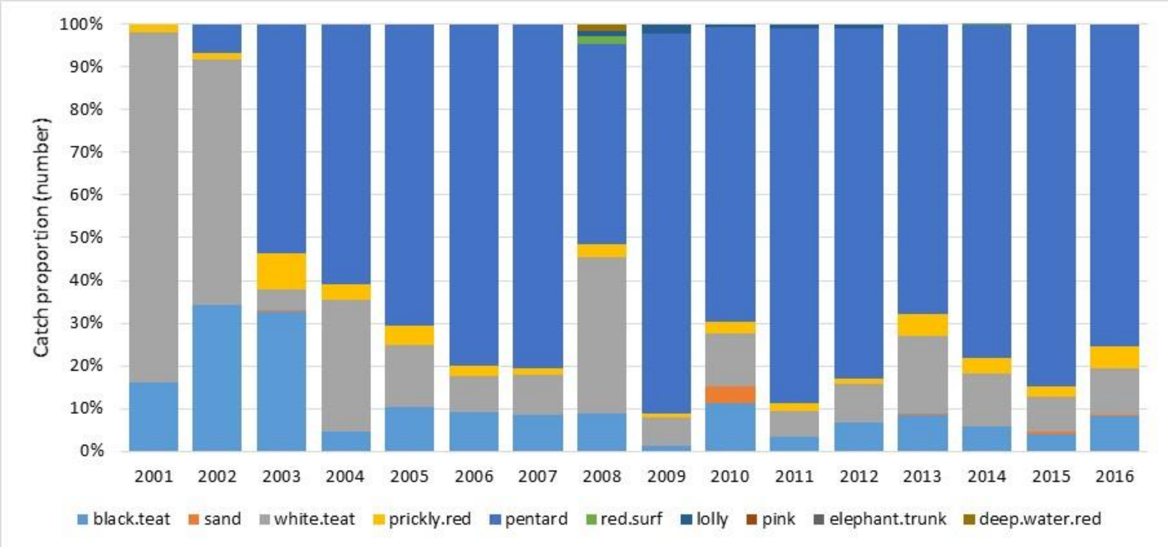


Figure 9: Catch composition in area L5 over the years.

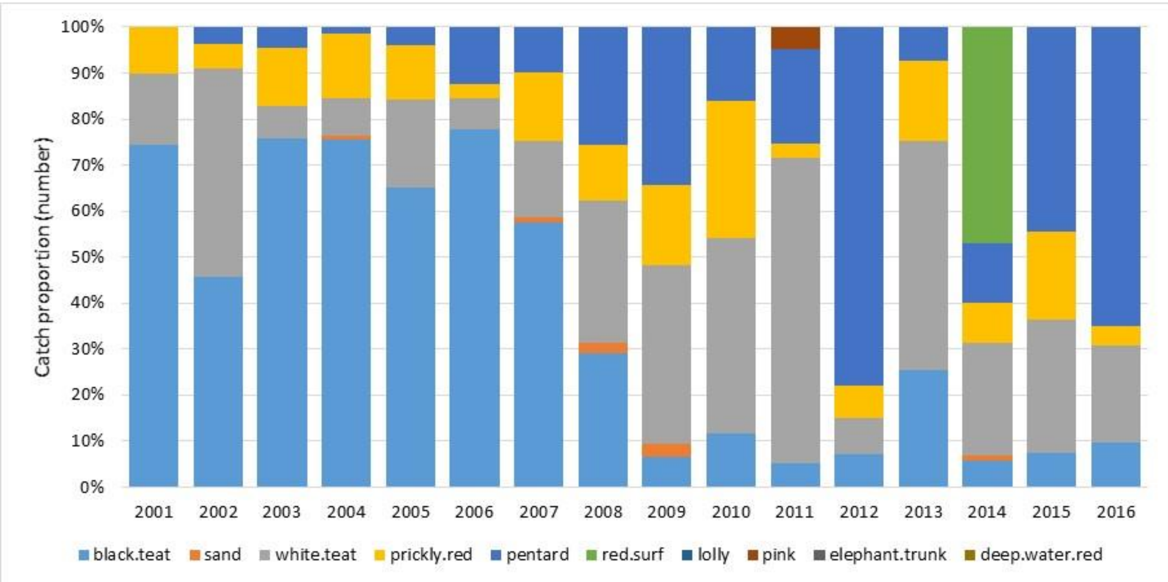


Figure 10: Catch composition in area M6 over the years.

3.2.4 Exploration of other effort characteristics

The relationship of fishing depth and year was examined visually using plots (Figure 11), which showed a jump in mean depth from 2012 to 2013 data. Statistical analysis of depth records also showed a significant difference between the mean (ANOVA: F= 4445, p=<0.001) and maximum (ANOVA: F= 190, p<0.001) depth reported between the years 2004-2016. The first three years and 2017 were excluded from the analysis, due to likelihood of error in reporting and the lack of data, respectively.

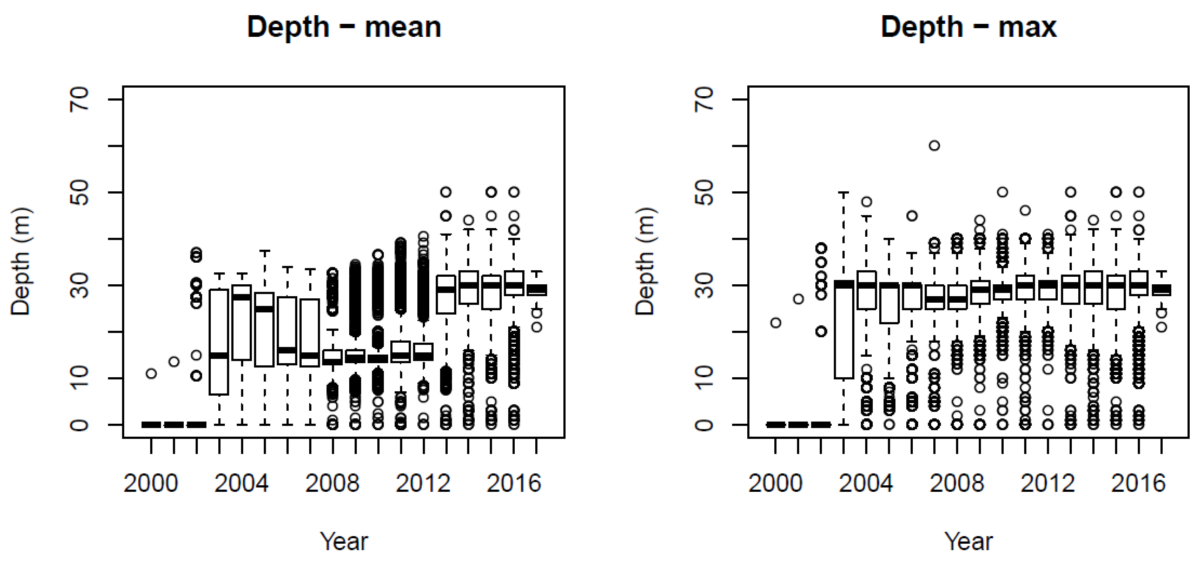


Figure 11: Mean value of dive depth and maximum depths for each year.

Dive time does not seem to change much over the years (Figure 12) with the more profound change observed between years 2012 and 2013 when the mean dive time declined. That does not seem to relate well to the fact that mean depth has gone up from 2012 to 2013 as one would expect that to have resulted in a trip that lasted longer. That might be an artefact of the report standards and could relate to the big records for dive time that have been reported in earlier years. As mentioned already, those records do not seem to be verified so, further consideration of the dataset to remove erroneous/incorrect entries could change the results presented here.

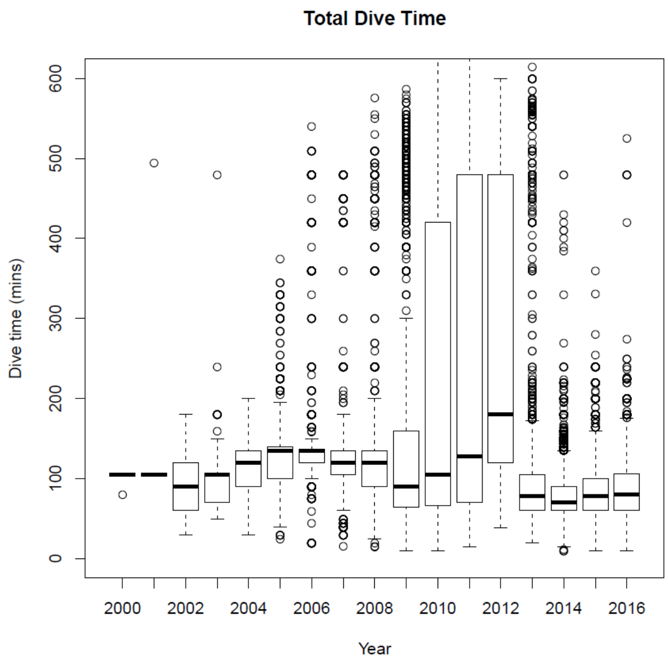


Figure 12: Dive time recorded in each year.

3.3 Nominal CPUE

Using the previous metric for CPUE (numbers per diver-day), the total un-standardised CPUE of all species remained reasonably consistent from 2000 to 2012, with the mean CPUE remaining in the region of 50 to 70 individuals per diver-day. However, the new metric of CPUE (numbers /minutes dived) shows a steady decrease in CPUE from a mean of more than 1 fish / minute between 2000 and 2003, to less than 0.5 fish / minute after 2012 (Figure 13).

Much of this change in CPUE is driven by relatively large reductions in species specific CPUEs over the same period, particularly of black teat fish and white teat fish between 2000 and 2003. The CPUE of pentard increased dramatically from 2002 to 2003 and has been relatively consistent since. It is unclear if trends in reported CPUEs in the early 2000s reflect actual changes in CPUE for the fishery as a whole due to the low levels of data, in terms of quantity and quality, in these years, or whether the trends are due to sampling error.

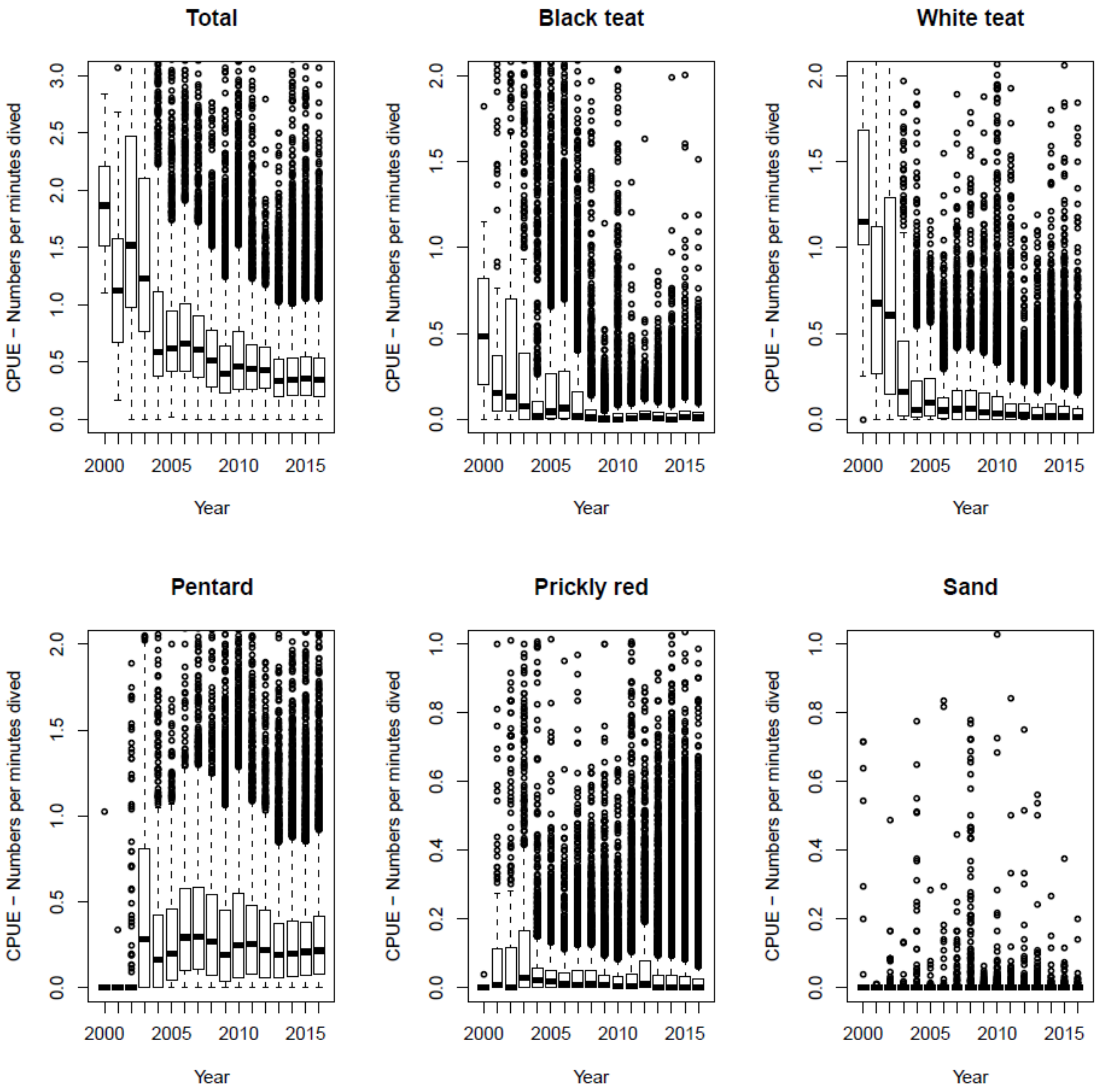


Figure 13: Species-specific un-standardised CPUE (number per minutes dived) for the most important commercial species and the un-standardised CPUE for all species.

There is some evidence that total CPUE, and species-specific CPUE, can vary strongly within years as well as between years. It is worth noting that fishing effort between June and September has historically been restricted by weather conditions (e.g. Aumeeruddy & Conand, 2008) so there is large uncertainty in CPUE during these months. This could explain the reduction in CPUE often seen prior to the closed season (Figure 14 and 15).

There are also spatial variations in CPUE between years. With clear reductions in CPUE being seen in Amirantes since 2000. There have also been steady reductions in Mahé, however, these are less clear, and CPUE appears to be stable over a number of years. The region of Coetivy, has seen a reduction in CPUE down to very low levels in 2013, but appears to have increased over the last three years, back to similar levels as 2007.

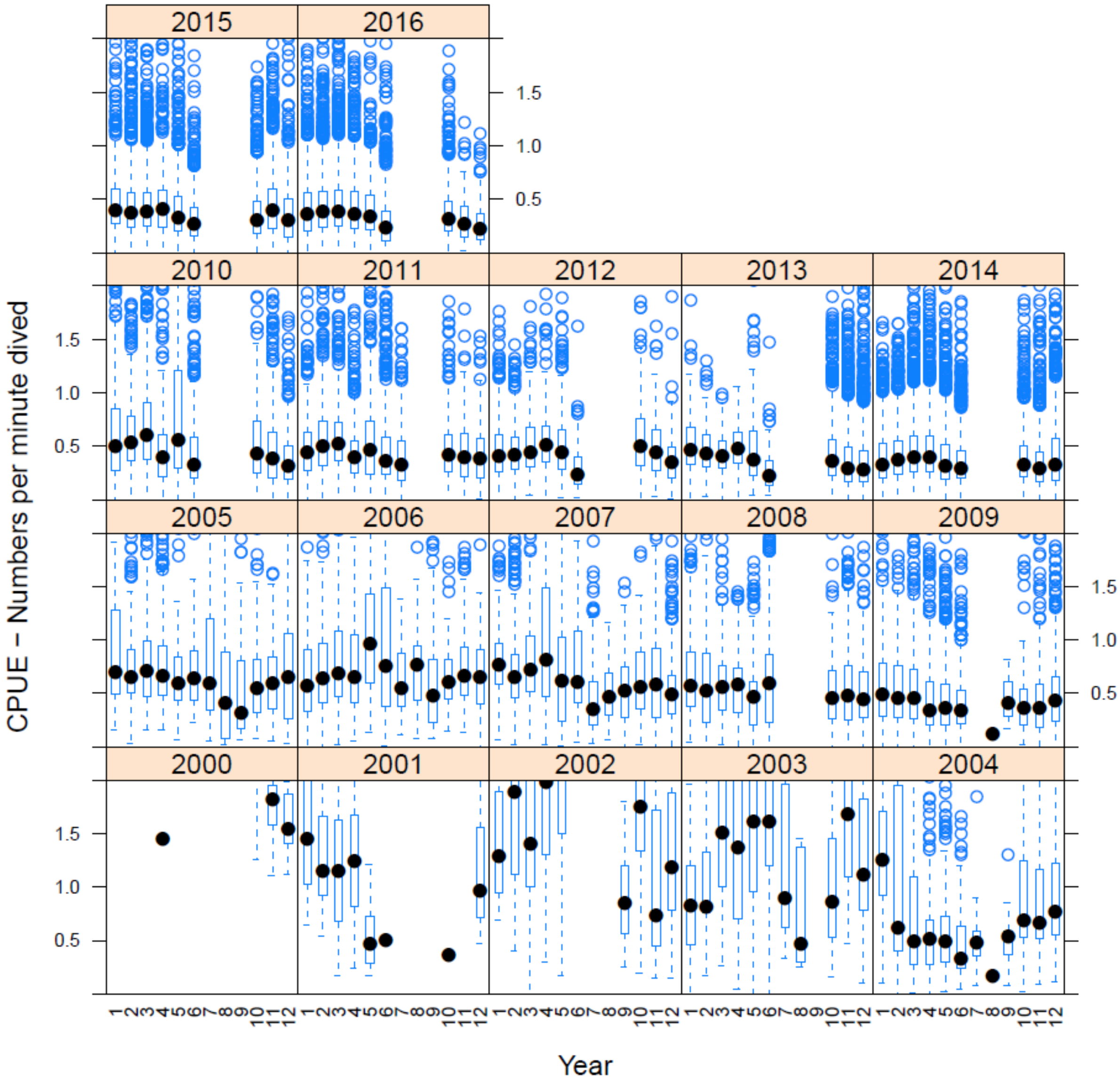


Figure 14: Un-standardised total CPUE for all species, by year and by month.

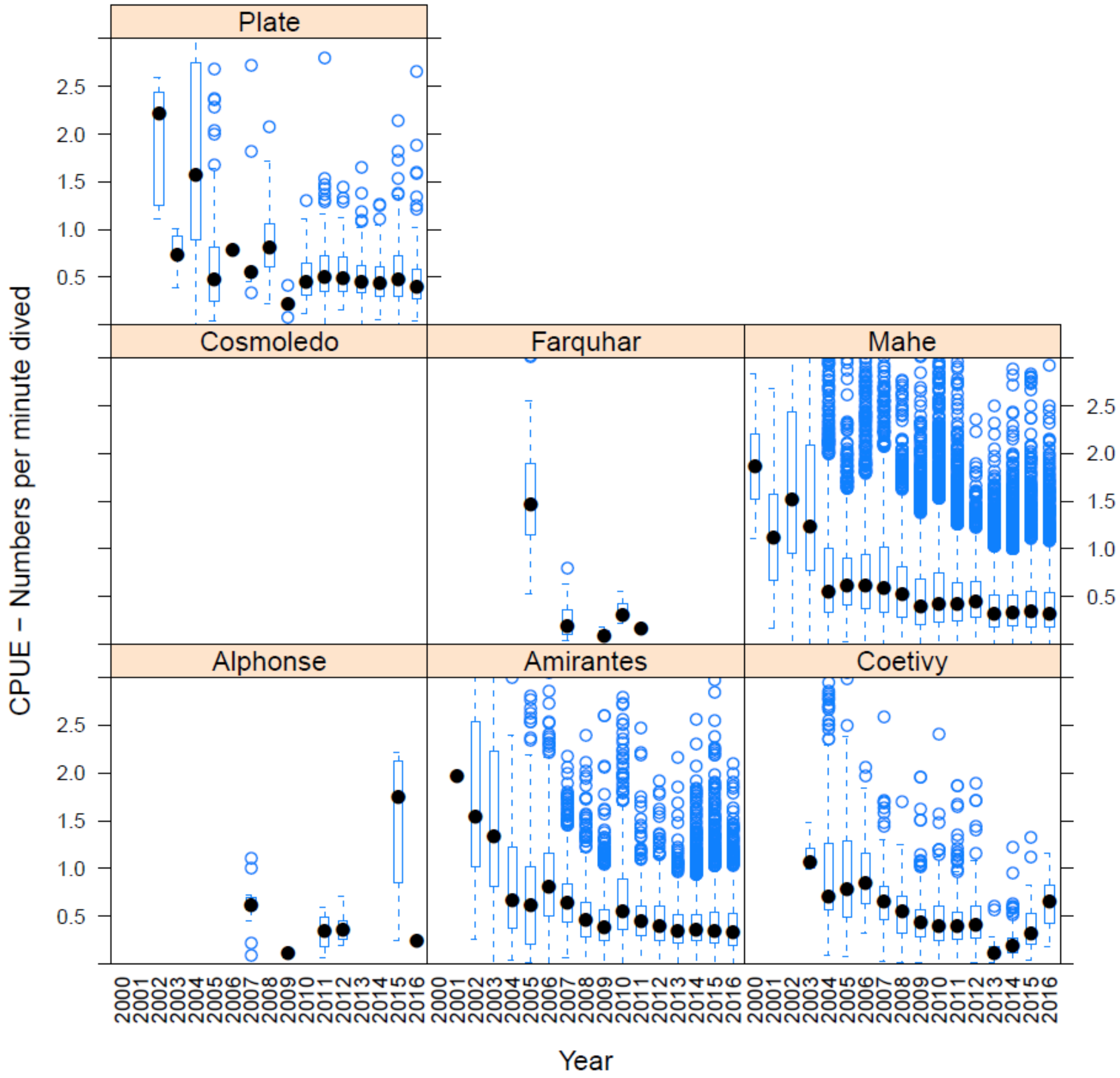


Figure 15: Un-standardised total CPUE for 'high-value' species, by year and by region.

Preliminary analysis suggested that CPUE did not appear to be significantly correlated with either dive time or depth. However, attempts to standardise the CPUE and identify significant factors have not succeeded as the models used to represent the influence of different variables failed to converge. Further cleaning of the raw data as well as trying different combinations of data could be of help for this part of the analysis but it requires dialogue with data/fishery experts and their contribution in identifying different ways to group the data for CPUE standardisation.

3.4 Stock assessment

3.4.1 Current status

As discussed already, catch and effort data were prepared for 3 different spatial levels, statistical area rea, sub-area and grid level and the CPUEs were also constructed for those three levels. We also calculated CPUEs using the data for a select group of vessels as an alternative representation of the stock abundance. The CPUEs were prepared for individual species and for species complex (e.g. valuable species)

A number of CPUE series show a one direction trend and that makes it very difficult for the surplus production model to converge when it is fit to those series. However, the results of the calculations for a selected set of input parameters and geographical areas for which convergence was achieved using the Schaefer production model are presented in Tables 5-8.

The level of depletion predicted in each run varies but it is less than 40% for all 6 runs. Of particular significance are the results of the model for black teat fish in area 4 as the model indicates that the population has disappeared or is very close to total depletion (Table 6). These results reflect the sudden and dramatic decline in the CPUE of that species in area 4; unless this CPUE reflects a change in target species or market preferences these results suggest that species-specific depletion might have already taken place in some parts of the Seychelles EEZ.

Looking at the impact of fishing at a fine scale, the results have also predicted considerable decline in the group of valuable species in grid L5 but with some signs of recovery in the past year or so. Both runs estimate a current stock size of less than 20% of its pre-exploitation size (Table 7).

The transition from a CPUE that relies on the entire fleet to using a CPUE based on a selection of fleets from the fishery produced different results in terms of stock size and productivity (Run 2, Table 5), with the run using the latter CPUE producing more optimistic results. Both runs indicated that the current stock is below 40% of its unexploited size but the estimated value for productivity (*r*) under Run 2 is unrealistically high. For this reasons, and despite the fact that the model converged, this run is not considered reliable.

The same catch data used for Run 1 were also used to run the stock reduction analysis model (Table 9). The results point to a bigger initial population than that found with the surplus production model but a less productive one. As a result, the mean values of MSY calculated with the two models are similar and below 100, 000 individuals which is much less than the catches observed in some of previous years in that area. Specifically, 6 out of the 15 years considered in the calculations had catches at or above the mean MSY value predicted with the stock reduction model.

Table 5: Results of the surplus production model using data from statistical area 4 and the valuable species group. The first line of the table provides details of the parametrisation of the model. N_f denotes the size of the population at the final year.

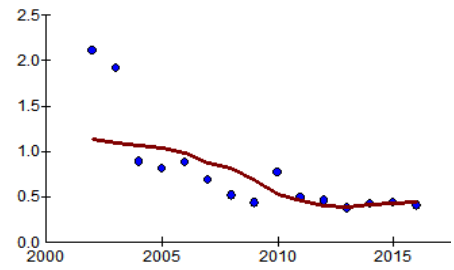
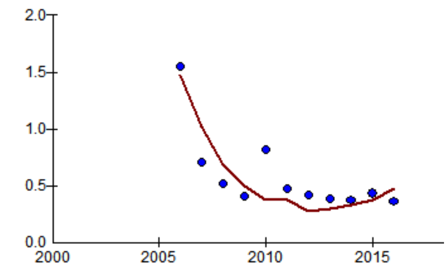
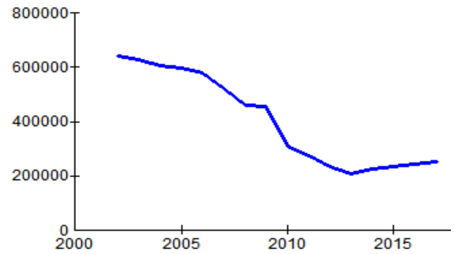
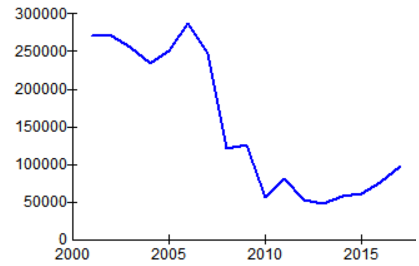
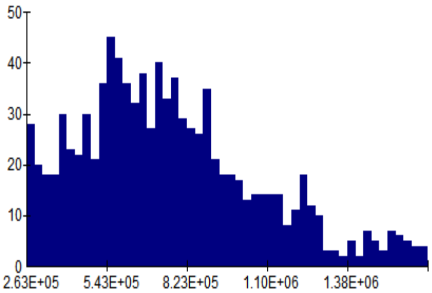
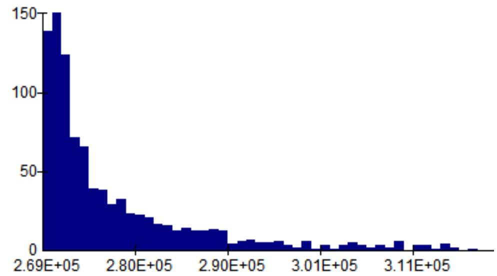
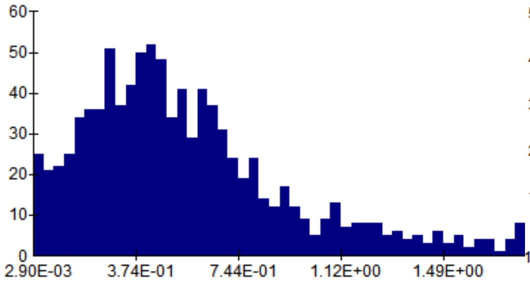
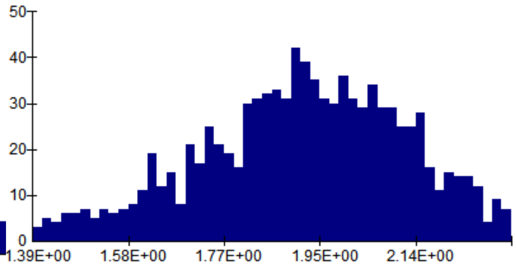
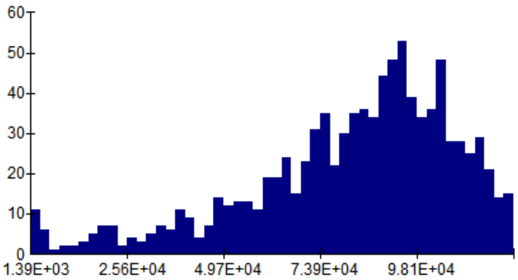
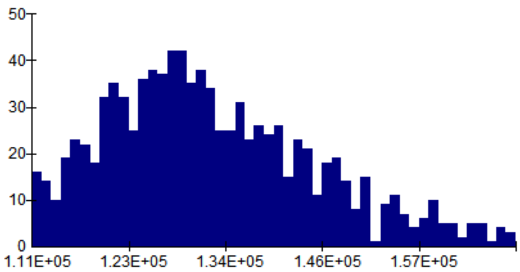
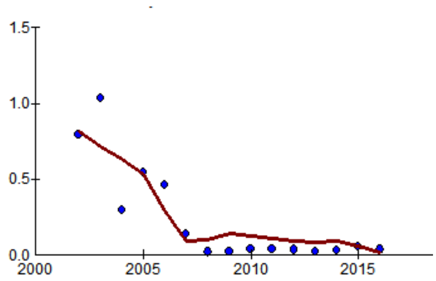
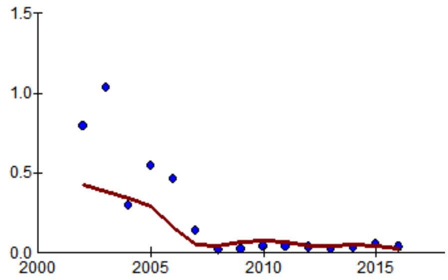
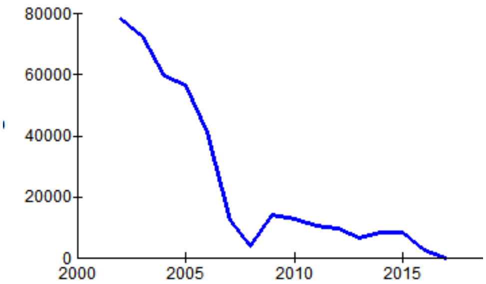
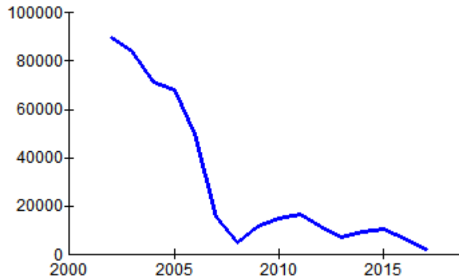
	Run 1: Area 4, Valuable species, N_1=K, Time lag = 2 y, LoglkhdW	Run 2: Area 4, Valuable species, N_1=K, Time lag = 1 y, LSU, CPUE_sub
CPUE fit x-axis: years y-axis: Fish caught /dive mins		
Stock size x-axis: years y axis: number of fish		
Carrying capacity (K) x-axis: *K* y-axis: frequency		
Growth potential (r) x-axis: *r* y-axis: frequency		
MSY x-axis: MSY y-axis: frequency		
Mean values	K=642376 , r = 0.57, MSY = 92450, N_f = 39% K	K=269,982 , r = 1.97, MSY = 133,625, N_f = 30% K

Table 6: Results of the surplus production model for area 4 and one of the valuable species (black teat). The first line of the table provides details of the parametrisation of the model. N_f denotes the size of the population at the final year.

<table>
<tr><th></th><th>Run 3: Area 4, Black teat, N_1=K, Time lag = 2 y, LS no error in CPUE</th><th>Run 4: Area 4, Black teat, N_1=K, Time lag = 3 y, Loglkhd with error in CPUE</th></tr>
<tr><td>CPUE fit
x-axis: years
y-axis: Fish caught /dive mins</td><td>
</td><td>
</td></tr>
<tr><td>Stock size
x-axis: years
y axis: number of fish</td><td>
</td><td>
</td></tr>
<tr><td>Carrying capacity (K)
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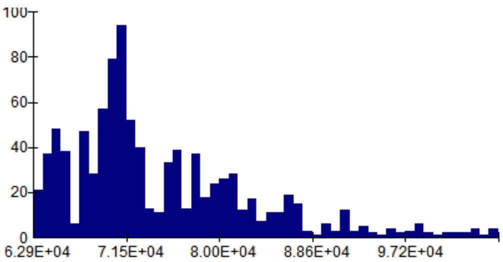
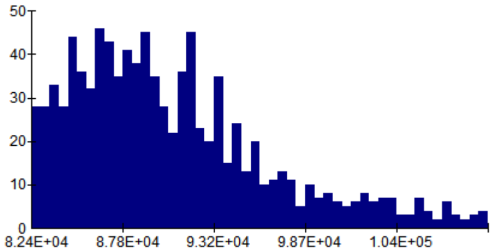
y-axis: frequency</td><td>
</td><td>
</td></tr>
<tr><td>Growth potential (r)
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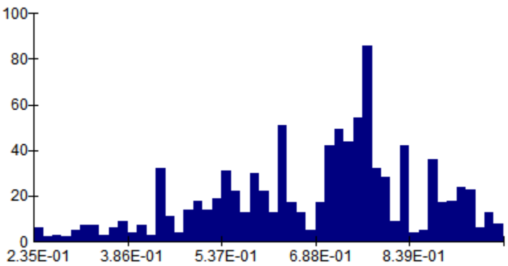
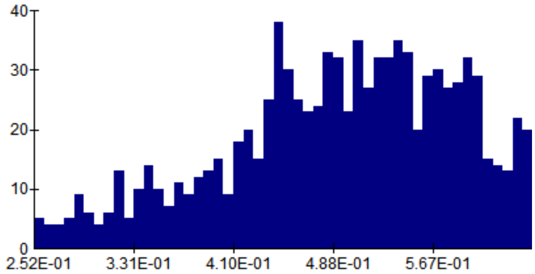
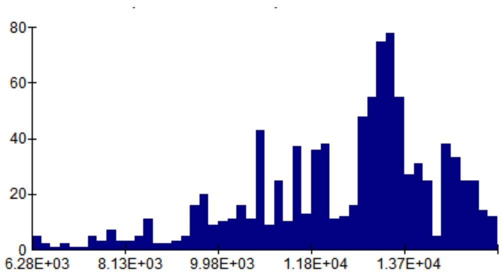
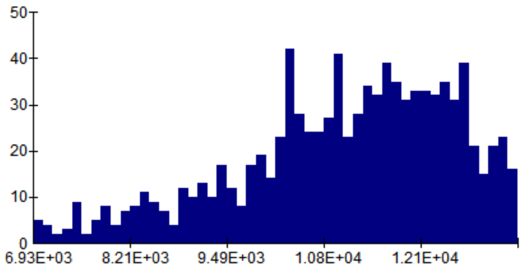
y-axis: frequency</td><td>
</td><td>
</td></tr>
<tr><td>MSY
x-axis: MSY
y-axis: frequency</td><td>
</td><td>
</td></tr>
<tr><td>Mean values</td><td>K=78,298 , r = 0.58, MSY = 11,461, N_f = 0% K</td><td>K=89,974, r= 0.48, MSY = 10,952, N_f = 5% K</td></tr>
</table>

Table 7: Results of surplus production model for grid L5 (area 1) for the valuable species as a group. The first line of the table provides details of the parametrisation of the model. N_f denotes the size of the population at the final year.

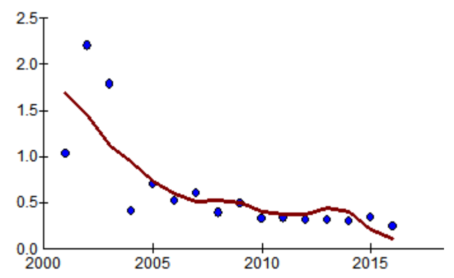
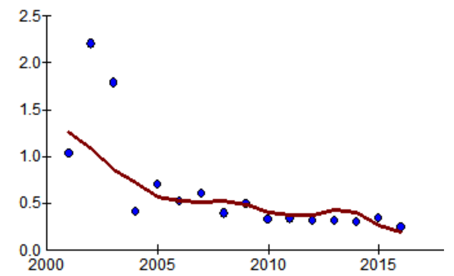
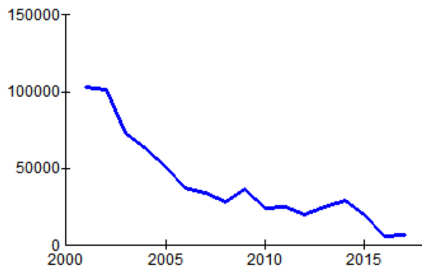
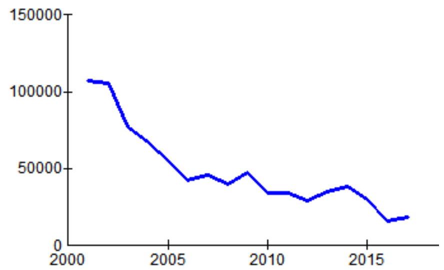
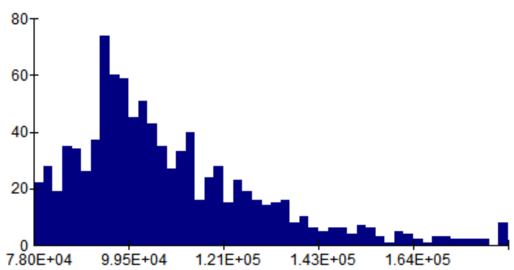
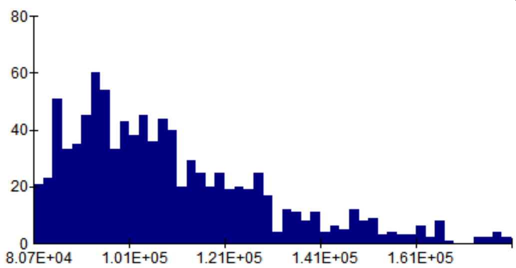
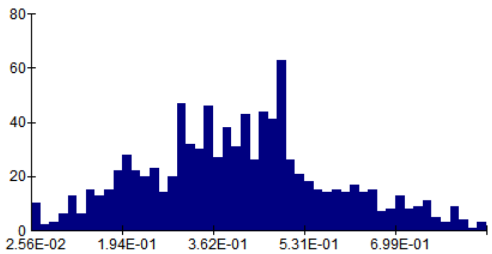
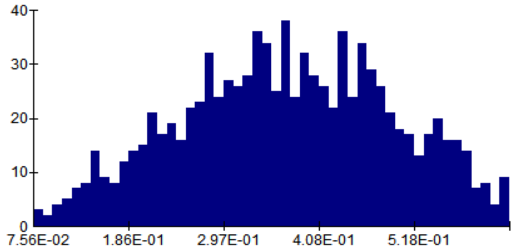
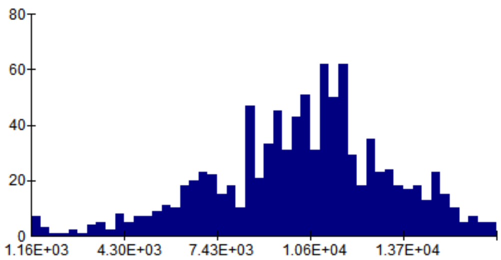
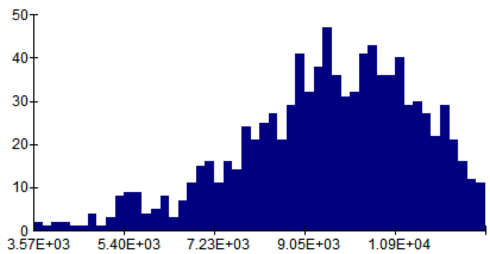
	Run 5: Area L5, Valuable, N_1=K, Time lag = 4 y, LS no error in CPUE	Run 6: Area L5, Valuable, N_1=K, Time lag = 3 y, Loglkhd with error in CPUE
CPUE fit x-axis: years y-axis: Fish caught /dive mins		
Stock size x-axis: years y axis: number of fish		
Carrying capacity (K) x-axis: *K* y-axis: frequency		
Growth potential (r) x-axis: *r* y-axis: frequency		
MSY x-axis: MSY y-axis: frequency		
Mean values	K=103,254 , r = 0.40, MSY = 10,381, N_f = 6 % K	K=107,232, r= 0.35, MSY = 9,424, N_f = 17% K

Table 8: Results of surplus production model for grid M6 (area 1) for the valuable species as a group. The first line of the table provides details of the parametrisation of the model. N_f denotes the size of the population at the final year.

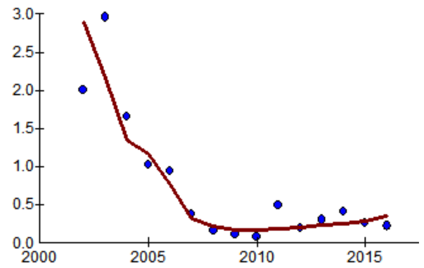
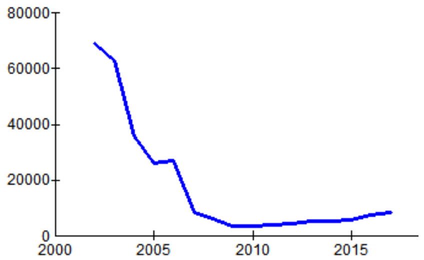
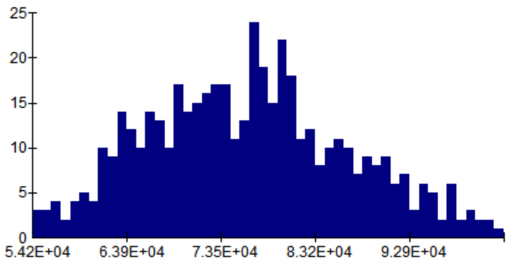
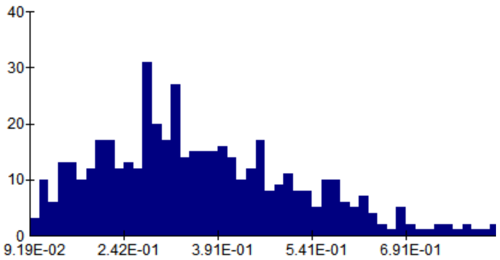
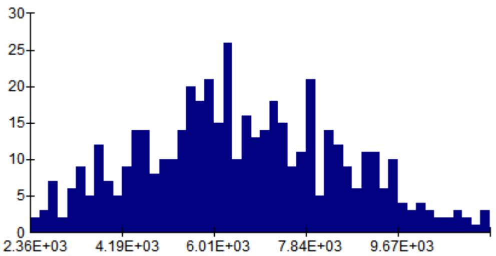
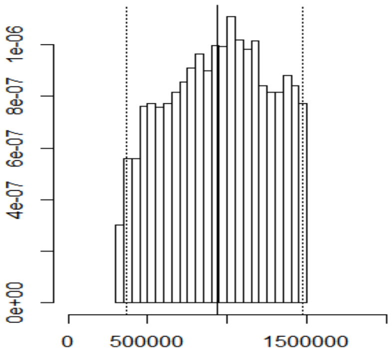
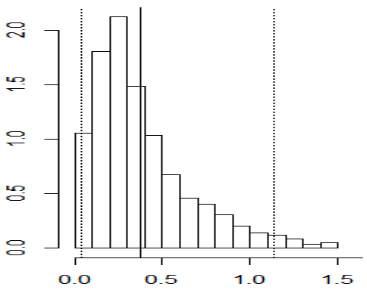
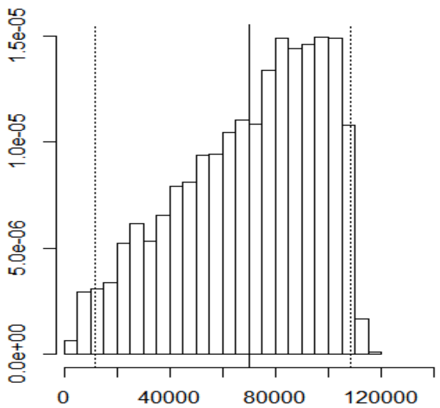
<table>
<tr><th></th><th>Run 7: Area M6, Valuable, N_1=0.9 K, Time lag = 1 y, LoglkhdW</th></tr>
<tr><td>CPUE fit
x-axis: years
y-axis: Fish caught /dive mins</td><td>
</td></tr>
<tr><td>Stock size
x-axis: years
y axis: number of fish</td><td>
</td></tr>
<tr><td>Carrying capacity (K)
x-axis: K
y-axis: frequency</td><td>
</td></tr>
<tr><td>Growth potential (r)
x-axis: r
y-axis: frequency</td><td>
</td></tr>
<tr><td>MSY
x-axis: MSY
y-axis: frequency</td><td>
</td></tr>
<tr><td>Mean values</td><td>K=76,625 , r = 0.33, MSY = 6,423, N_f = 11 % K</td></tr>
</table>

Table 9: Results of stock reduction model using data from statistical area 4 and the valuable species group. The first line of the table provides details of the parametrisation of the model. N_f denotes the size of the population at the final year.

	Run 8: Area 4, Valuable, N_1=0.8 K, Catch only, No error
Carrying capacity (K) x-axis: *K* y-axis: frequency	
Growth potential (r) x-axis: *r* y-axis: frequency	
MSY x-axis: MSY y-axis: frequency	
Mean values	K=939,997, r =0.379, MSY =69,888, Bmsy= 469,998, N_f = 40% K

3.4.2 Projections

The outcomes of the stock assessment to predict current status were used to conduct simple projection scenarios for 3 of the runs presented above (Run 1, 4 and 7). The main projection scenario assumes that catches remain the same at the last year for which catch records were available (i.e. 2016) and calculates the stock size 5 years into the future. The alternative scenarios involve calculating the future size of the population when the catches are greater or less than the 2016 catches.

The results for the projections using the model assumptions of Run 1 (area 4, valuable species, etc.) are presented in Figure 16 and Figure 17. The model predicts that if the catches remain at the 2016 level the population will show further recovery and that recovery will be quicker if the catches are reduced to below the 2016 level. Conversely, an increase in catches at levels seen in 2011 and 2012 (about 1.5 times the catch in 2016) will lead to further decline of the population (Figure 17). It is important to highlight the size of the confidence interval bars that show that there is considerable uncertainty about the current status but also about the size of the stock in the future under a given catch scenario.

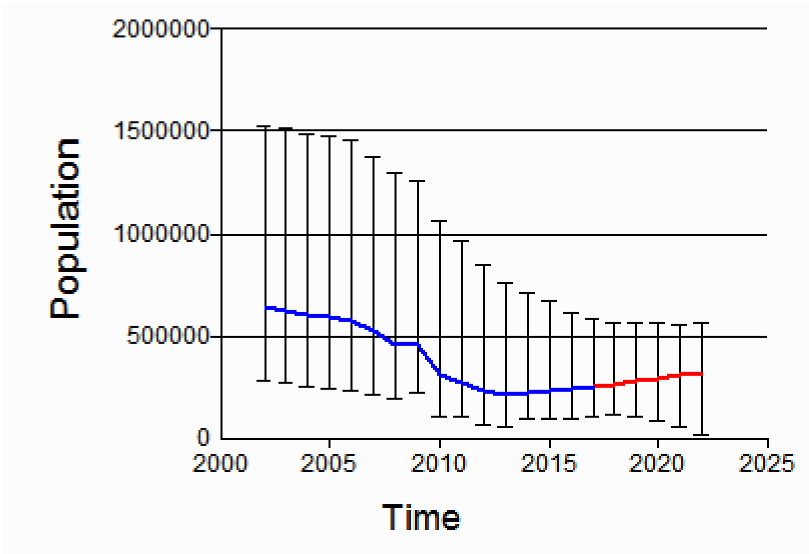


Figure 16: Population size (number of fish) and 95% CI as predicted under Run 1 for valuable species in area 4 and with projections for 5 years into the future assuming catches remain the same as in 2016. The results of the projections for the stock size are shown in red.

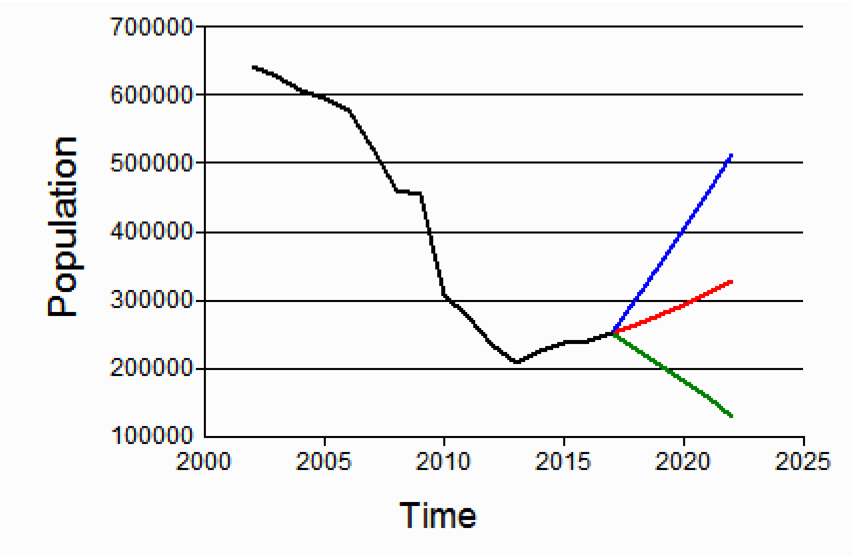


Figure 17: Deterministic results of future stock size under 3 scenarios for future catches using the assumptions from Run 1 about the structure of the population. Red line: Future catches equal to 2016, Blue line: Future catches equal to half of catches in 2016 and Green line: catches equal to 1.5 times the catches in 2016.

A similar exercise for black teat in area 4 highlights the susceptibility of the stock which is expected to crush if catch levels remain as in 2016 (Figure 18). When smaller amount of catches are considered, the projection suggest that considerable reduction in catches is needed to achieve some increase in the population and start its recovery. The scenarios considered showed that even a reduction in catches to half of the catches in 2016 will not be enough to start the recovery and further reductions are thus needed (Figure 19).

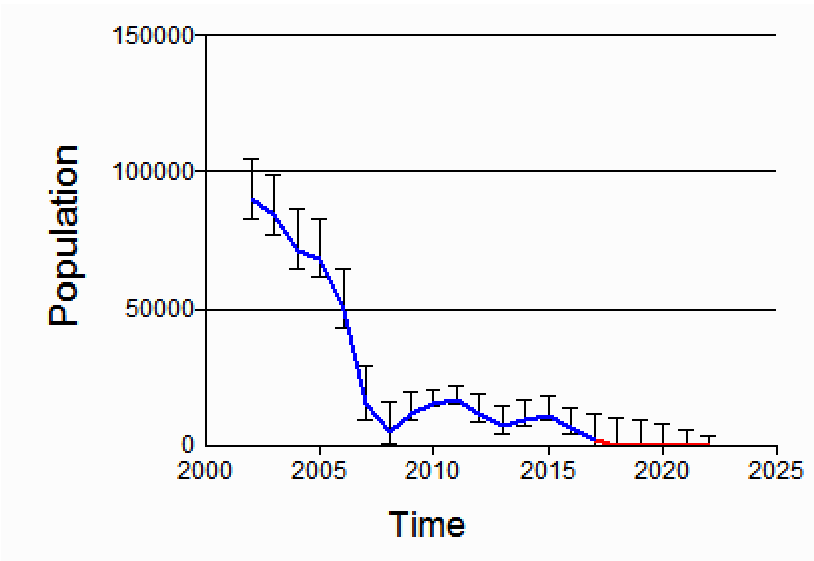


Figure 18: Population size (number of fish) and 95% CI as predicted under Run 4 for black teat and with projections for 5 years into the future assuming catches remain the same as in 2016. The results of the projections for the stock size are shown in red.

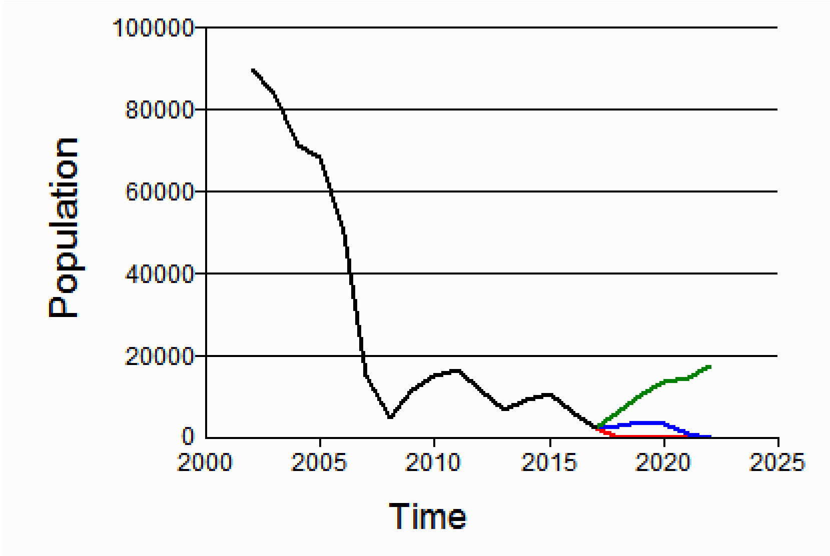


Figure 19: Deterministic results of future stock size for black teat in area 4 under 3 scenarios for future catches. Red line: Future catches equal to 2016, Blue line: Future catches equal to half of catches in 2016 and Green line: catches equal to 0.25% of catches in 2016.

Projections for valuable fish in grid M6 indicate that the slow recovery exhibited in the past 3 years will continue if future catches remain the same as the catches in 2016. However, it is unlikely that the population will recover to more than 40% of its pre-exploited stock size in the next 5 years with that level of catches (Figure 20). Even is catches are cut to 0 the recovery that can be expected in 5 years is probably to levels below the 40% of pre-exploited population (Figure 21). Nevertheless, the projections suggest that current fishing pressure levels will not reverse the recovery trend. That is expected as the catches in 2016 are very low after a significant reduction in catches was observed in the past 10 years.

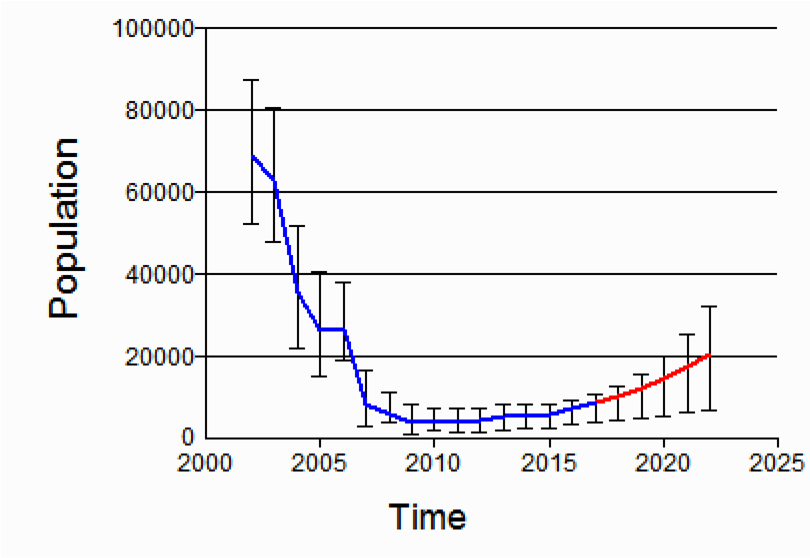


Figure 20: Population size (number of fish) and 95% CI predicted under Run 7 for valuable species in grid M6 assuming catches in the next 5 years remain the same as in 2016. The results of the projections for the stock size are shown in red.

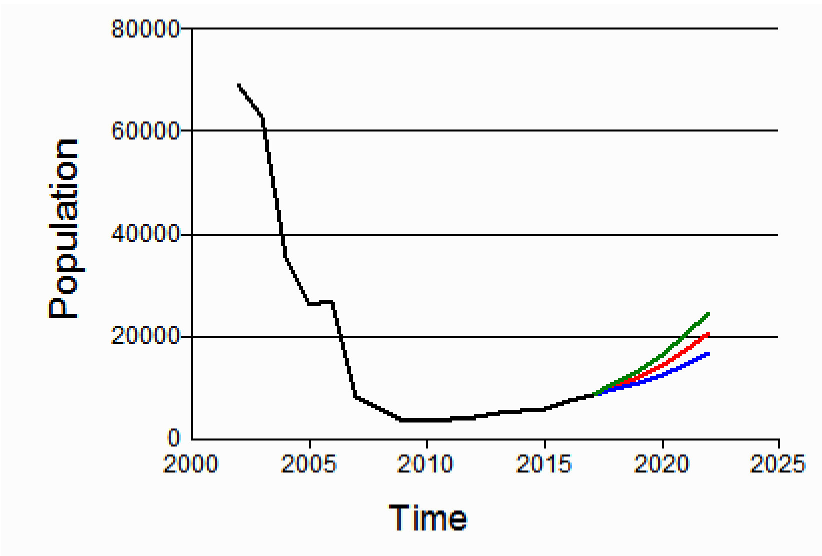


Figure 21: Deterministic results of future stock size for valuable fish in area M6 under 3 scenarios for future catches. Red line: Future catches equal to 2016, Blue line: Future catches are twice the catches in 2016 and Green line: catches are equal to 0.

4 Conclusions

This study looked at catch and effort data for more than 10 sea cucumber species and from 5 statistical area in the Seychelles EEZ. The aim was to undertake an assessment of stock status and provide advice to support future decision making. The great volume of data and analysis required to produce stock assessments for all sea cucumber stocks exploited within the Seychelles EEZ together with varying quality of data at stock level and time limitations meant that a selective process was followed to develop assessments.

Specifically, available data were processed to address any errors or problems and compiled into a single set of information which was them interrogated to find stocks/areas of higher quality of data. Within that sub-set we chose reference cases to reflect the variety of scales and data configurations that were possible. CPUE series and assessment analysis was conducted for areas ranging from a single grid to an entire statistical area and for single species as well as combination of species.

All the reference cases examined, showed evidence of population decline and although the extent of the decline varied, their population size had been reduced significantly from its pre-exploited state. Projections using future catches also showed that reduction or capping of catches might be advisable to prevent further reduction or allow the stocks to recover.

Even though this study focused on a sample of the areas/stocks exploited to showcase the approaches and states of nature for sea cucumber that might be representative of the situation in the Seychelles waters, some exploitation patterns did emerge and those need to be followed more closely to understand the reasons behind trends calculated and identify appropriate action. Of more concern is the assessment results for black teat in area 4 which show a massive decline in the stock size. The contribution of black teat to catches in areas L5 and M6 has also gone down over the years providing one more signal that could point to overexploitation of that species.

Given uncertainties in raw data and difficulties in getting the stock assessment models to convergence the analyses presented here should be seen as a first step to help guide further exploration and prioritise efforts. It is also important to note that both models used in the analyses are biomass-based models but our data did not have information about stock/catch biomass. Using such models with number of fish instead of biomass, although done before, is not common and therefore, the degree of error or bias that it might introduce is not well understood. It also means that the model can only catch signals in catch numbers so, a stock with many young/immature fish will be considered to be the same (e.g. resilience, productivity, etc.) as one with many mature fish as far as the population numbers are the same (and the fishery is not very selective). Making the transition to a biomass based model will address such issues and can improve the model's ability to detect change/overexploitation.

Areas for additional work and recommendations

In addition to more detailed work on the reference cases used in this study, the following recommendations highlight some of the gaps and opportunities for improvement identified through this process:

- Focused assessment - Going forward, it is strongly recommended that assessments are conducted for a small number of species (2-3 a time) to facilitate more in-depth analysis especially if resources are limited. That of course, will require identification of species to take priority but that can be done based on high level biological and market information. Such exercise could also lead to identification of indicator species that can provide signals about the overall health of the ecosystem and other fish stocks.

- Consistent interrogation and handling of past data – This study had to use assumptions and run a number of tests to clean the data available especially from earlier years. If different assumptions are used every time these datasets are analysed it will compromise the consistency of the process. Similarly, a significant amount of time was spent identifying erroneous/unrealistic entries and filling gaps using different section of the dataset. If this work is done in the source database following agreed assumptions and formats that will reduce time spent on that part of the analysis in the future making stock assessment work much more efficient. Producing a single database (i.e. same fields used for all years from 2000 to present) will also speed work up in the future.

- Robust recording of data in the future – Although quality of data has improved in recent years there is still room for streamlining of the process especially with regards to monitoring weight or other features of the individuals that can help identify structural/composition changes in stocks (also see next paragraph). Also, incorporation of internal checks in the database could help spot errors quickly or flag entries that might require further investigation (e.g. reporting fishing in areas where sea cucumbers are unlikely to be found). On the latter, linking of VMS data to logbooks is also recommended as it provide useful insight into logbook accuracy.

- Filling gaps in data – One of the key issues identified early on in the analysis was the lack of weight information; this meant that biomass-based models had to be reduced to number-based analysis so, changes in biomass due to the effects of fishing down the stock could not be captured in the analysis. Other information such as proportion of mature individuals in the catches could also provide signals of changes in the stock structure. Therefore, development of plans to strengthen collection of such information (firstly, deciding on the best type of such info to collect possibly, through an expert workshop or expert advice) will benefit future assessments.

- Fishery independent data – The analysis presented here relied on catch and effort data from fishery-dependent sources. We are not aware of work to verify the accuracy/ reliability of such data but our attempts to cross reference logbook records with VMS positioning data were successful for less than 50% of the records. Collection of fishery independent data can reduce bias from incorrect records but can be costly especially for less mobile species with a wide spatial distribution such as the sea cucumber in Seychelles EEZ. Nevertheless, industry-Government collaborations have been explored in other countries to develop robust sampling programs in a cost-efficient way and that could be of value here as well. As with the previous recommendation, combining knowledge of experts in data collection with knowledge of the local fishery and overall situation (either through a workshop or other interaction) can provide an efficient way forward.

- Adaptive management – The level of depletion found in the reference cases we considered varied and our analyses of spatial distribution of vessels over the years showed some rotational fishing behaviour; that is, fishermen tend to explore different grounds rotating from one to the other and not going back to the same ground for a while. It is not clear how successful such a technique is but could provide a tool for adaptive management using closed areas and more focused data collection programmes (e.g. see scallop fishery on the eastern coast of USA).

- There is limited information about the biology of sea cucumber and that supports the use of simpler models such as the surplus production model and stock reduction model to simulate the stock and assess its status. However, even such simple models require some knowledge of the population biology such as reproductive capacity and mortality. Therefore, such considerations need to be captured in work to design/shape future collection of data programs.

5 References

Aumeeruddy R. and Conand C. 2008. Seychelles: a hotspot of sea cucumber fisheries in Africa and Indian ocean. p. 207–221. In: Toral-Granda V., Lovatelli A., Vasconcellos M. (eds). Sea cucumbers. A global review on fishery and trade. FAO Fisheries Technical Paper No. 516. FAO, Rome. 319 p.

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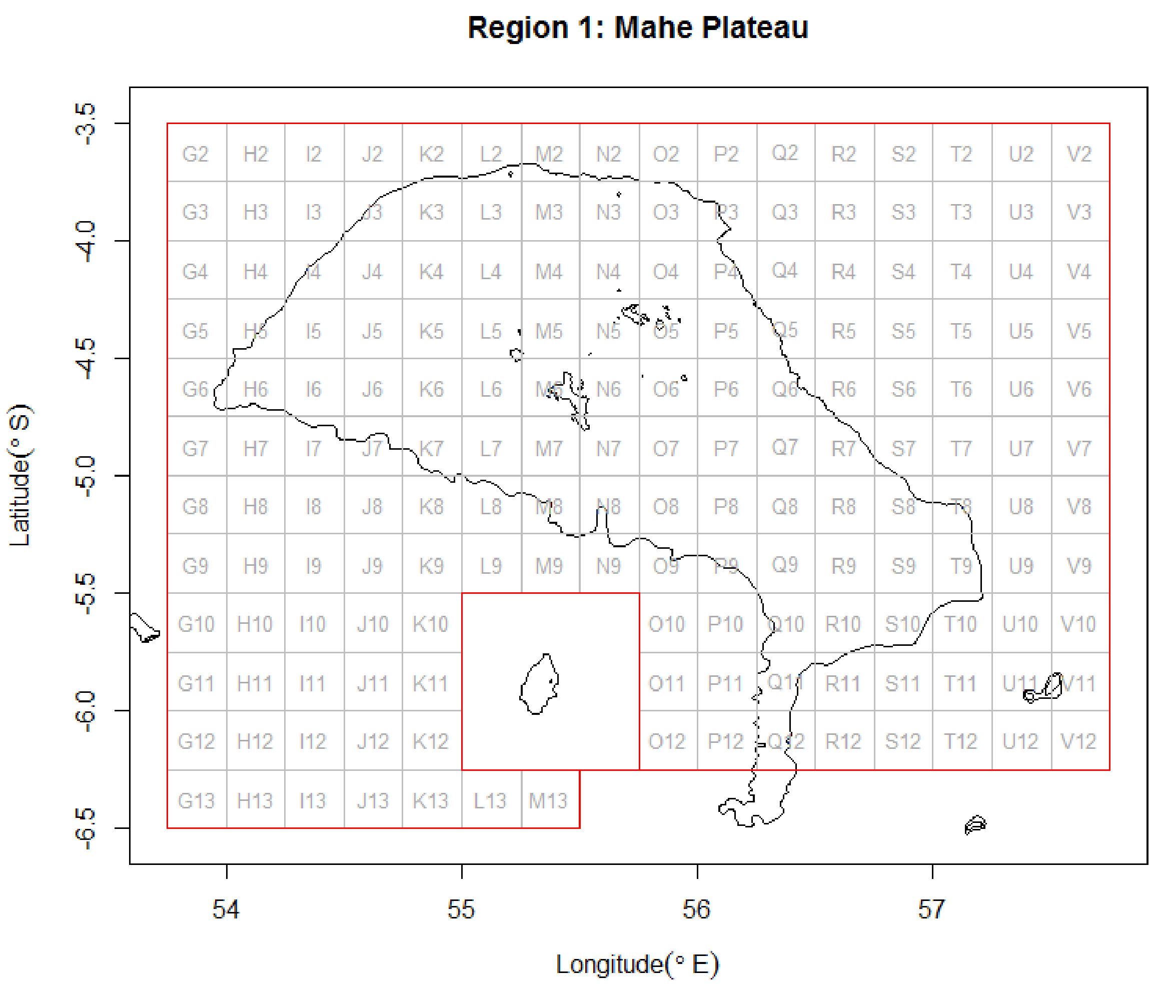
Martell, S and Froese, R. 2013. A simple method for estimating MSY from catch and resilience. Fish and Fisheries, Vol. 14: 504-514

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

Annex 1: SFA statistical grid squares



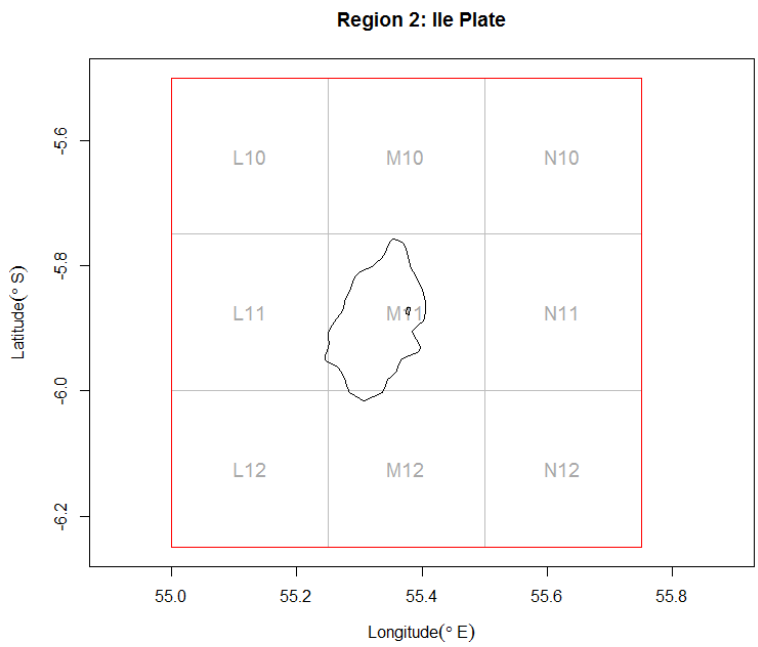


Figure 20: SFA statistical grid squares used for reporting fishing activities in Regions 1 to 7.

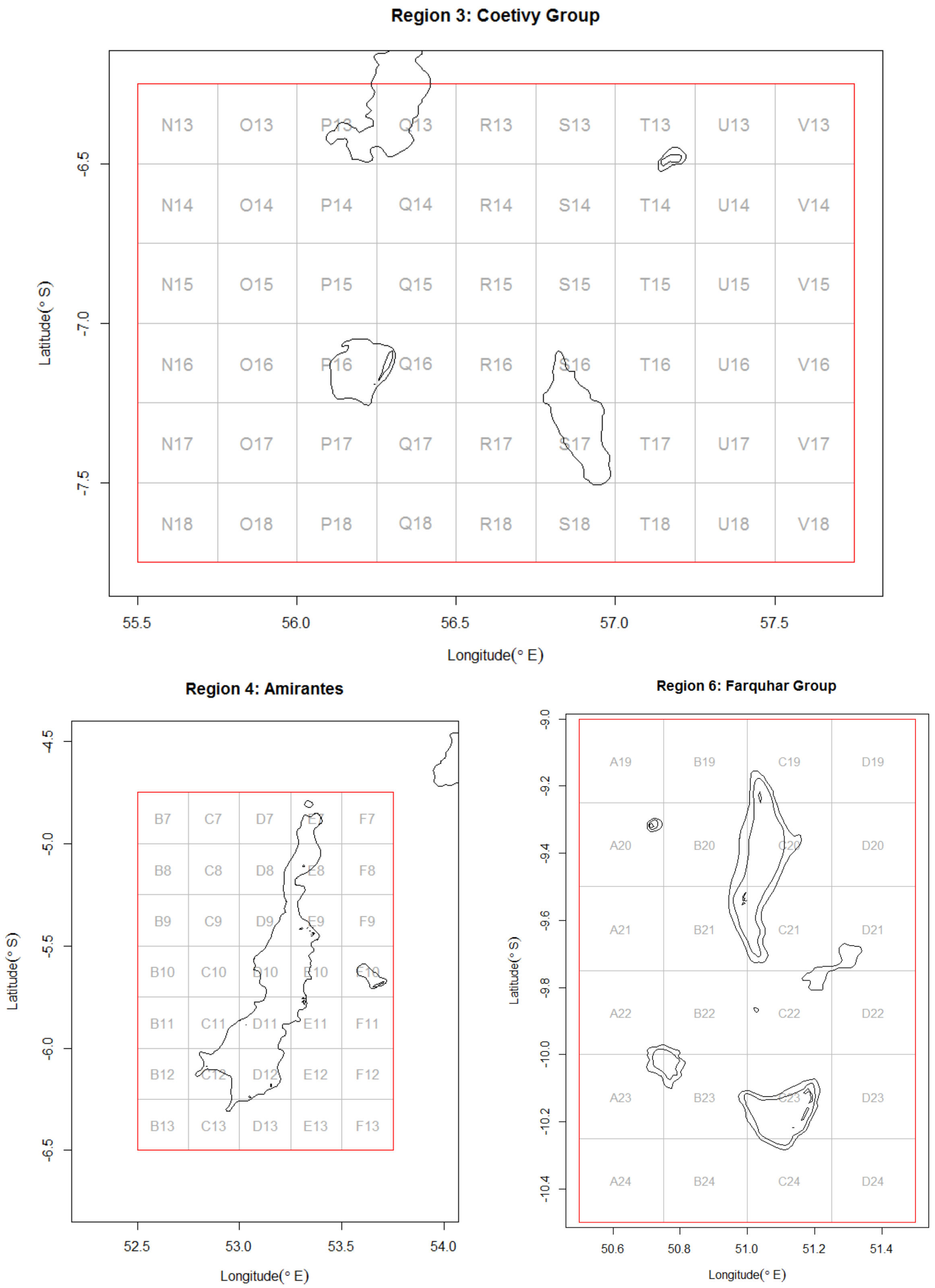
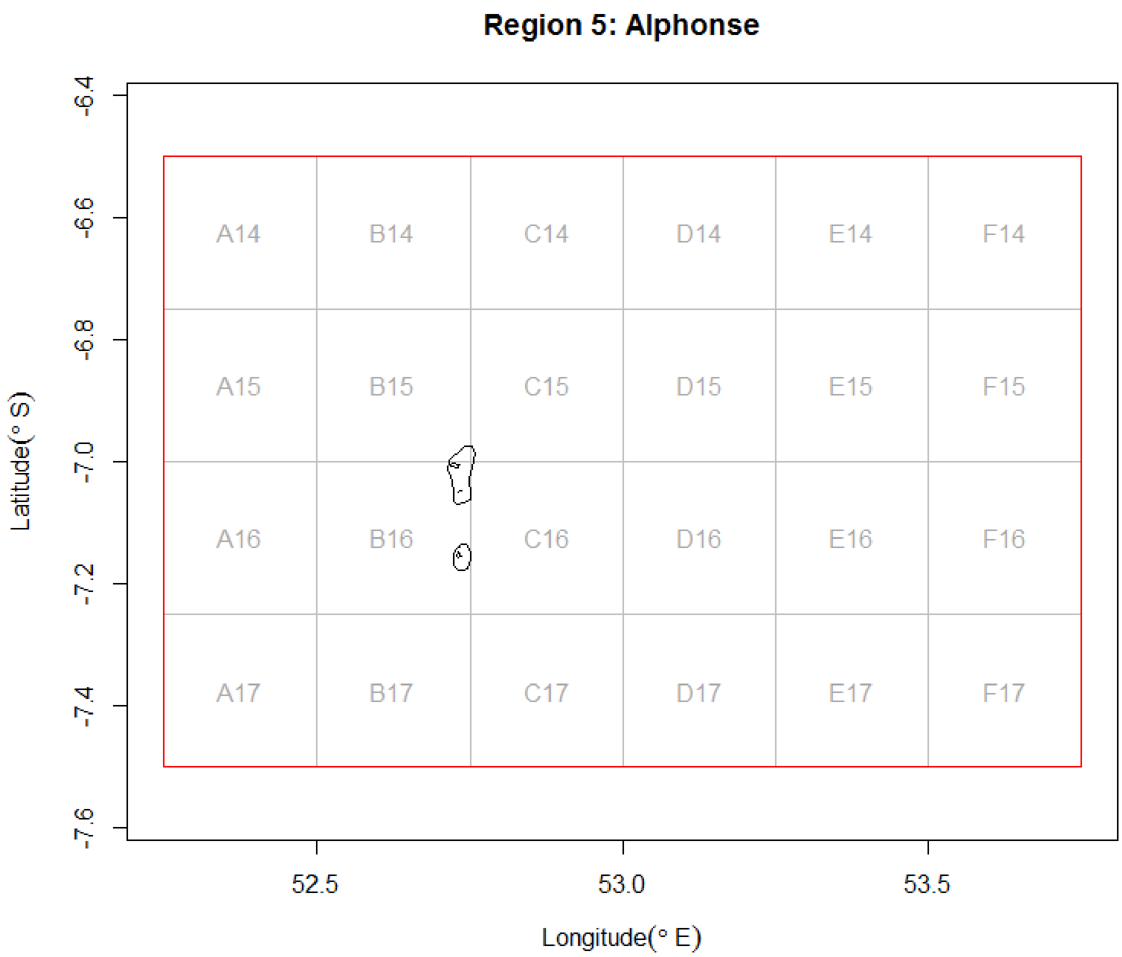


Figure 20 (cont'd): SFA statistical grid squares used for reporting fishing activities in Regions 1 to 7.



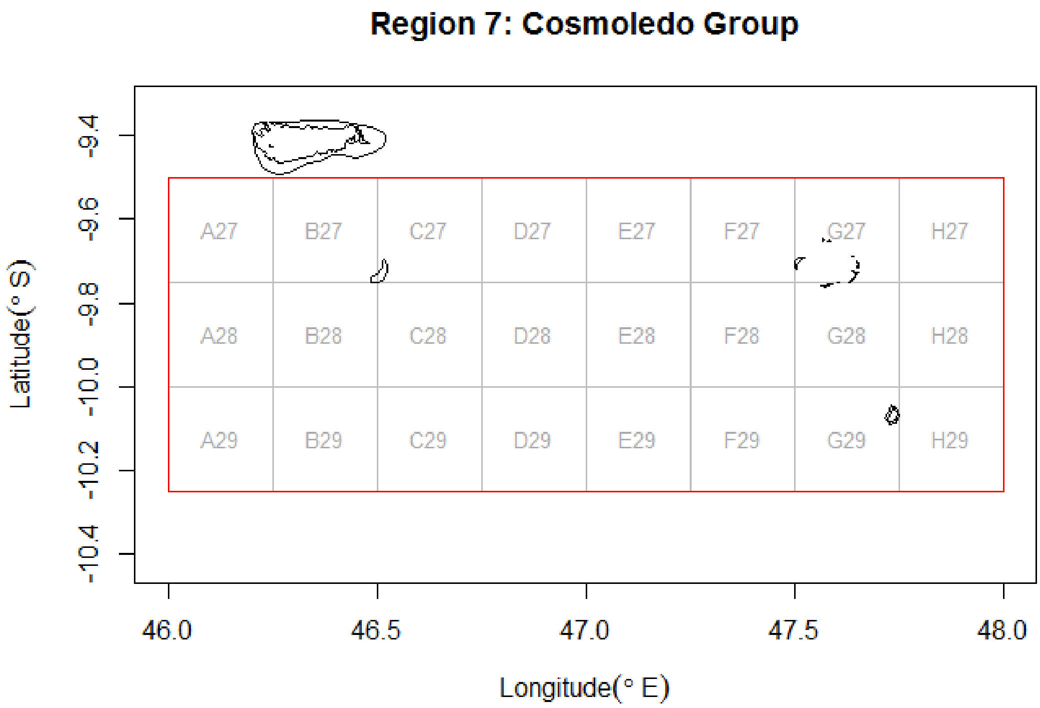


Figure 20 (cont'd): SFA statistical grid squares used for reporting fishing activities in Regions 1 to 7.

Annex 2: Analysis of SFA effort and catch data

Reported spatiotemporal distribution of total diver-days

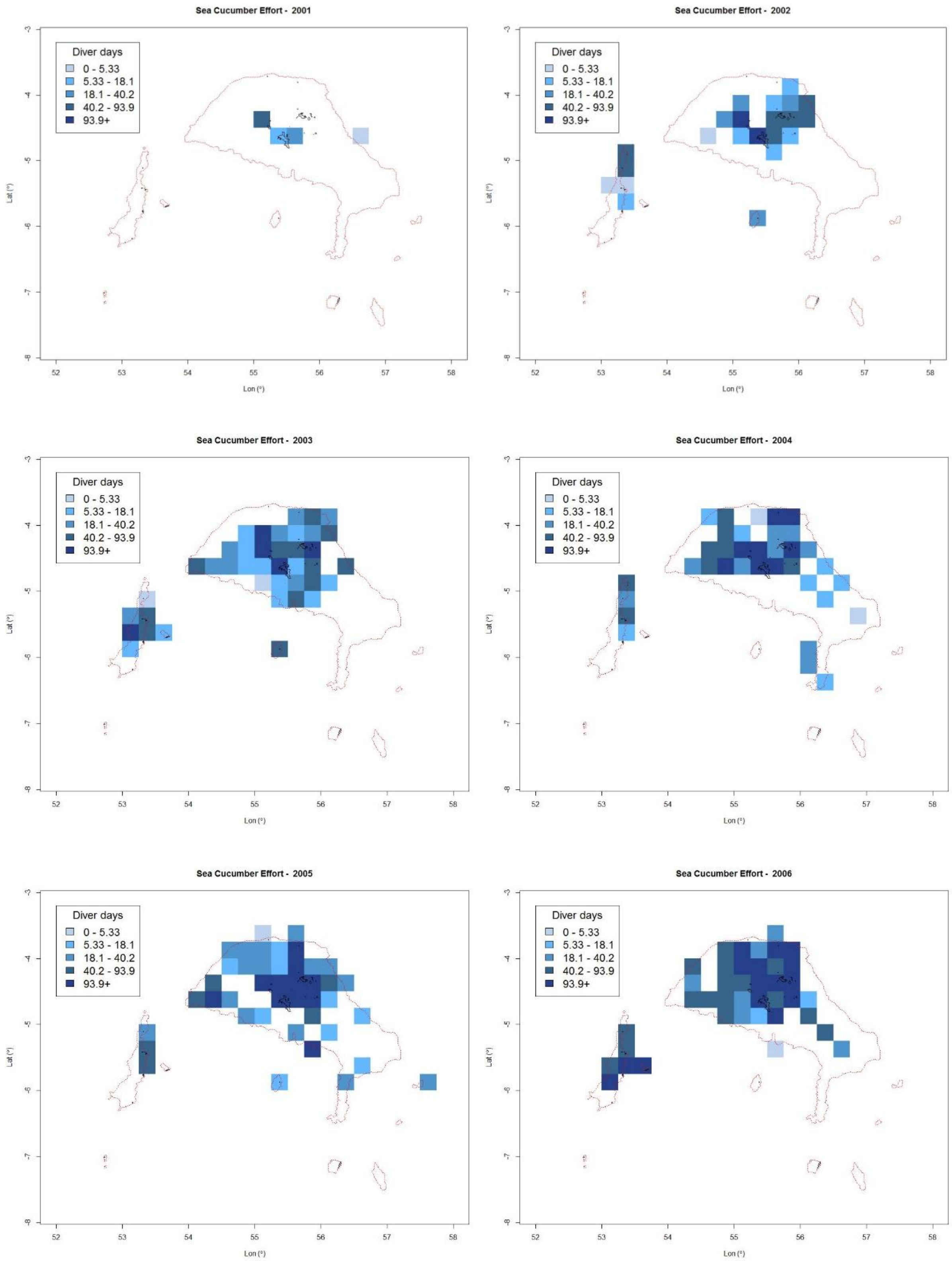


Figure 21: The total annual effort (diver days) by SFA grid for 2001 to 2016 with the 200m contour (broken red line).

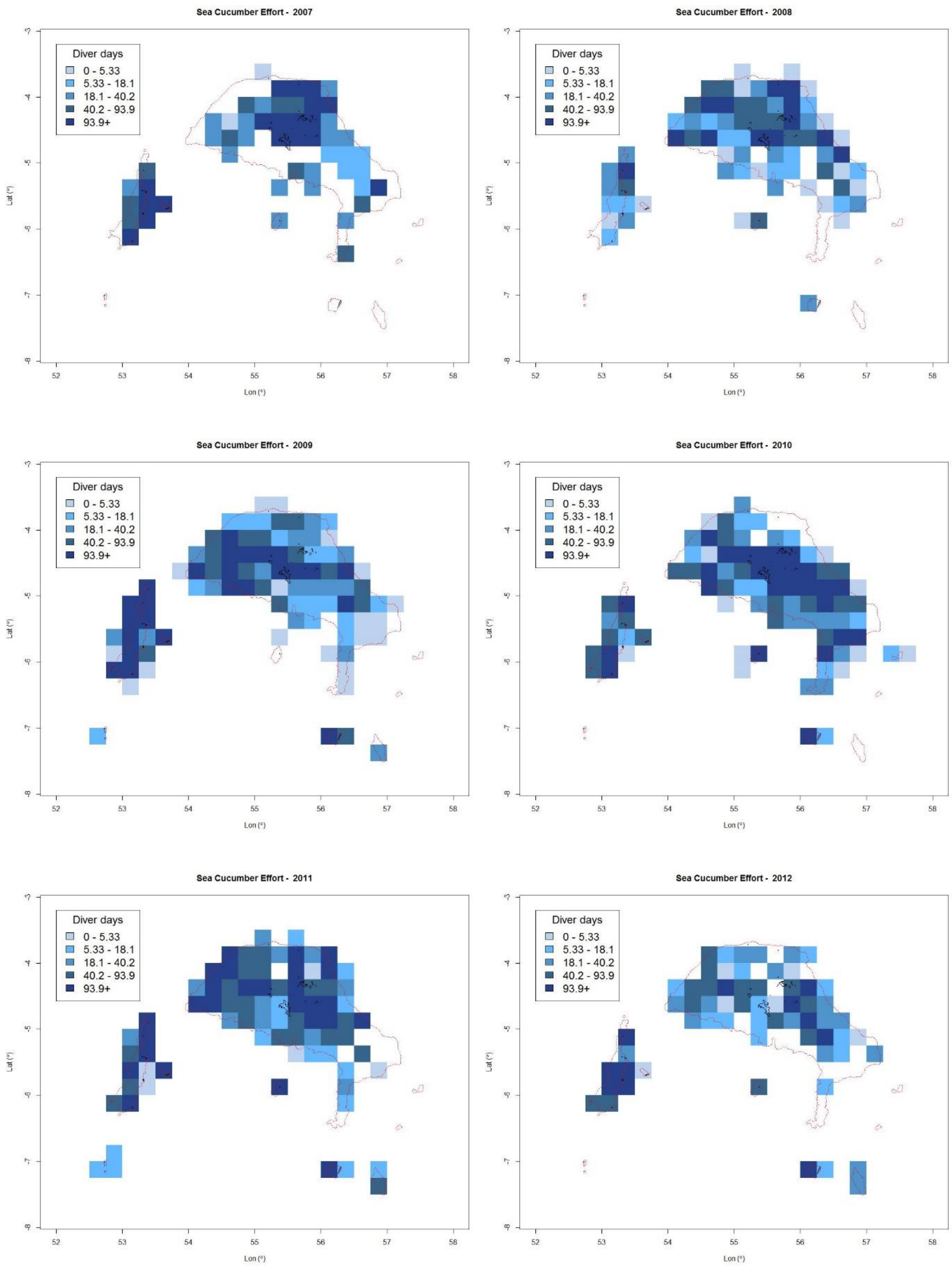


Figure 21 (cont'd): The total annual effort (diver days) by SFA grid for 2001 to 2016 with the 200m contour (broken red line).

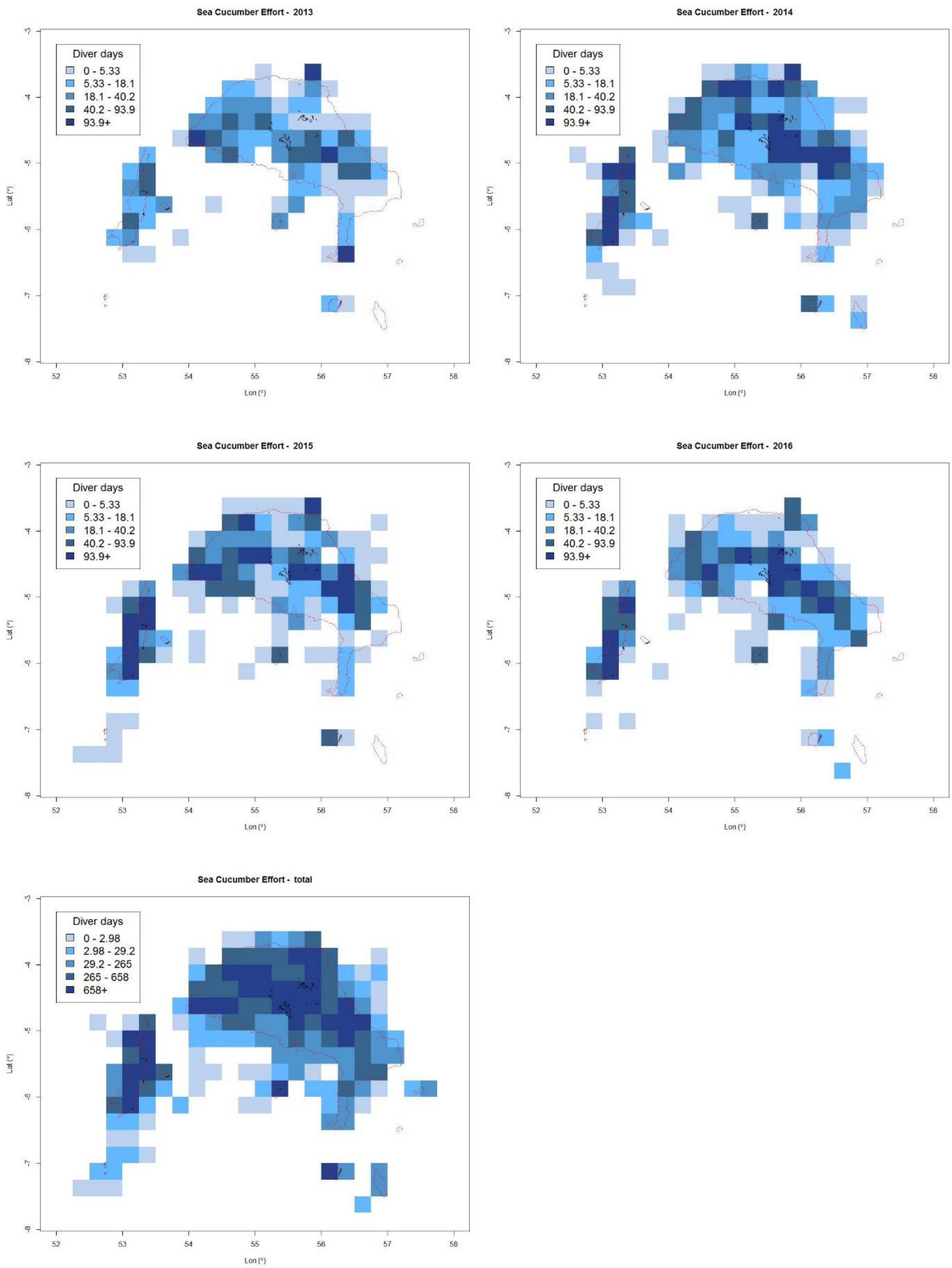


Figure 21 (cont'd): The total annual effort (diver days) by SFA grid for 2001 to 2016 with the 200m contour (broken red line).

Reported spatiotemporal distribution of total dive time

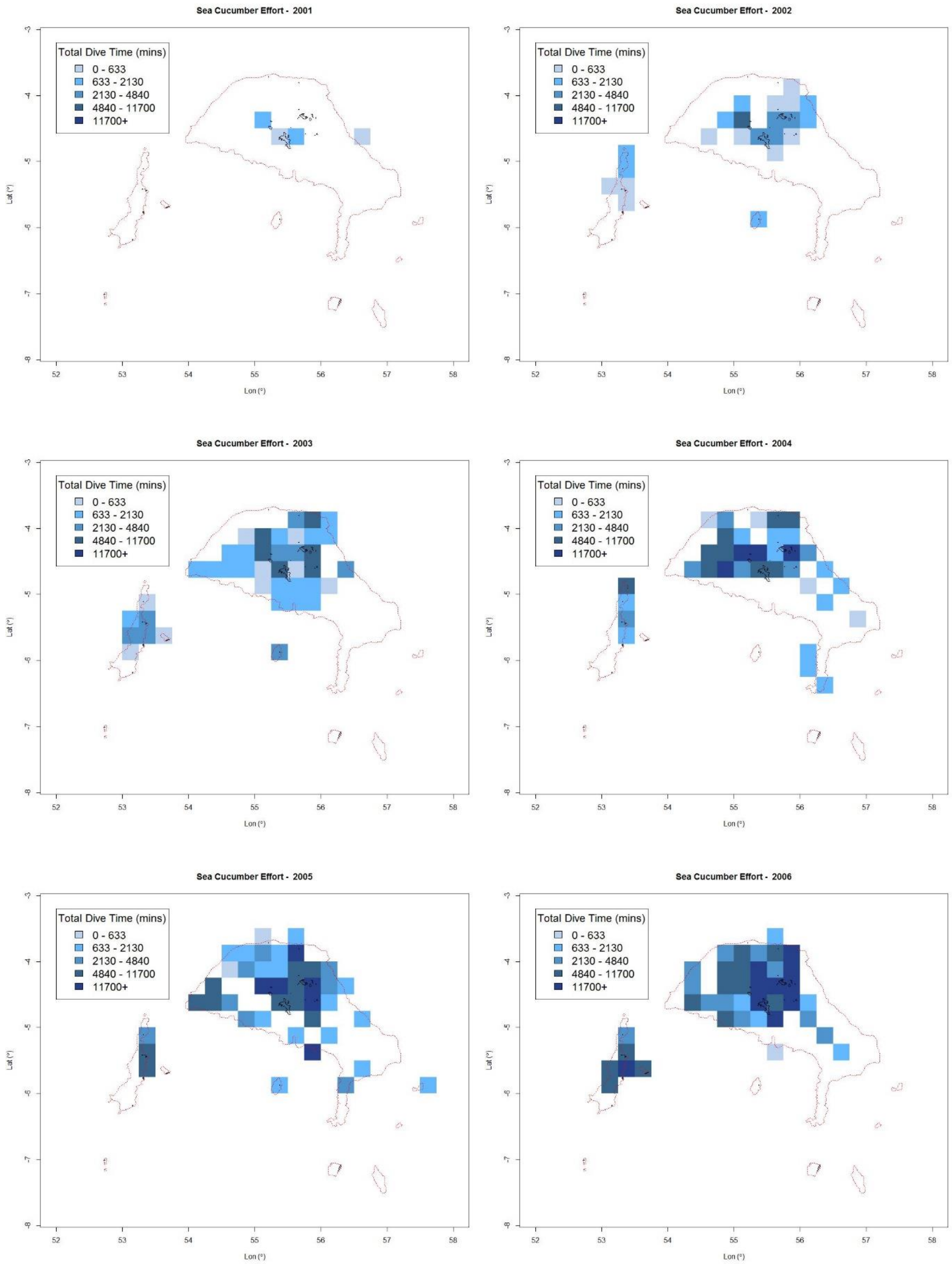


Figure 22: The total annual effort (total dive time, mins) by SFA grid for 2001 to 2016 with the 200m contour (broken red line).

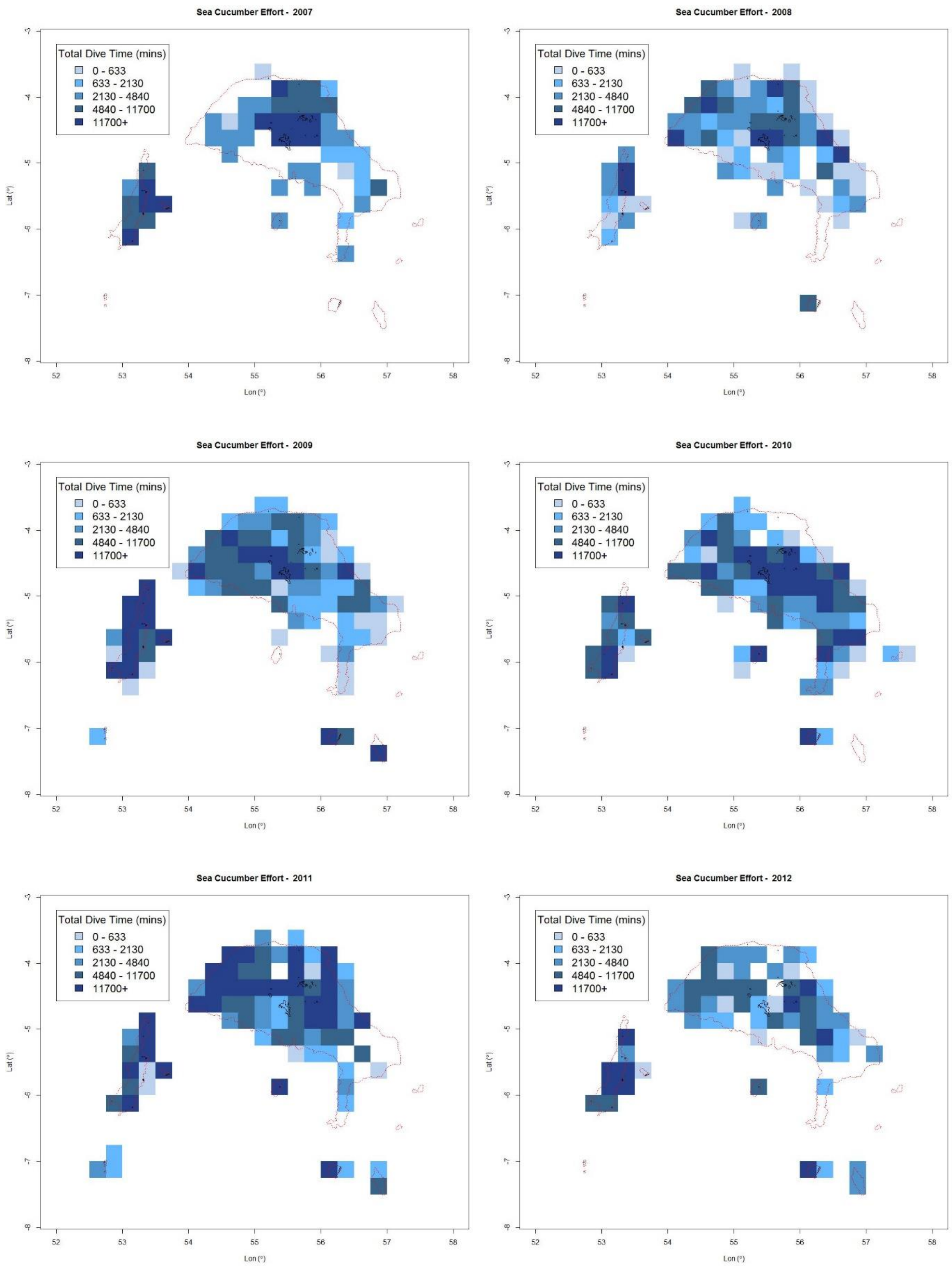


Figure 22 (cont'd): The total annual effort (total dive time, mins) by SFA grid for 2001 to 2016 with the 200m contour (broken red line).

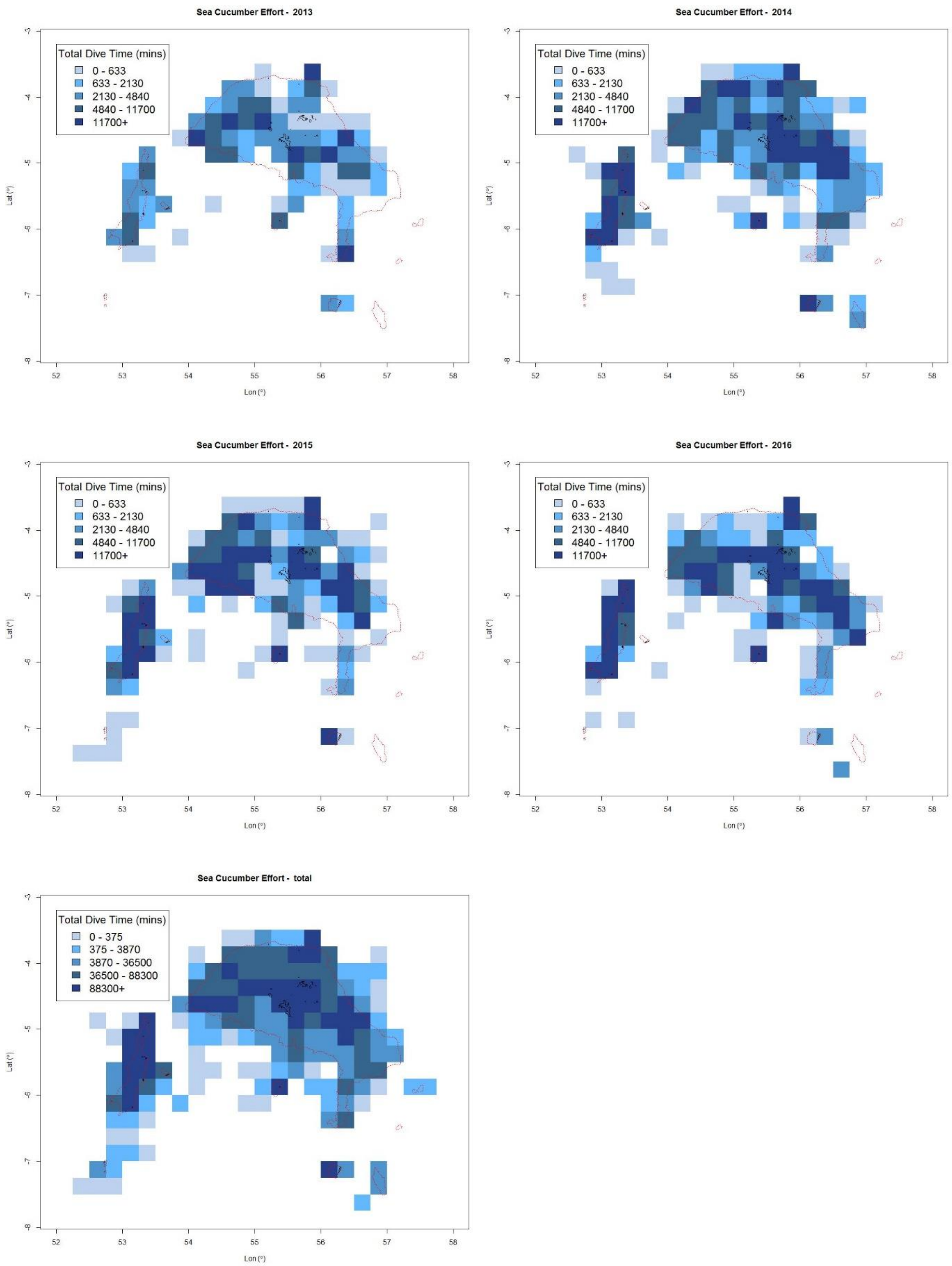


Figure 22 (**cont'd**)**: The total annual effort (total dive time, mins) by SFA grid for 2001 to 2016 with the 200m contour (broken red line).**

Reported spatiotemporal distribution of total dive time for individual vessel

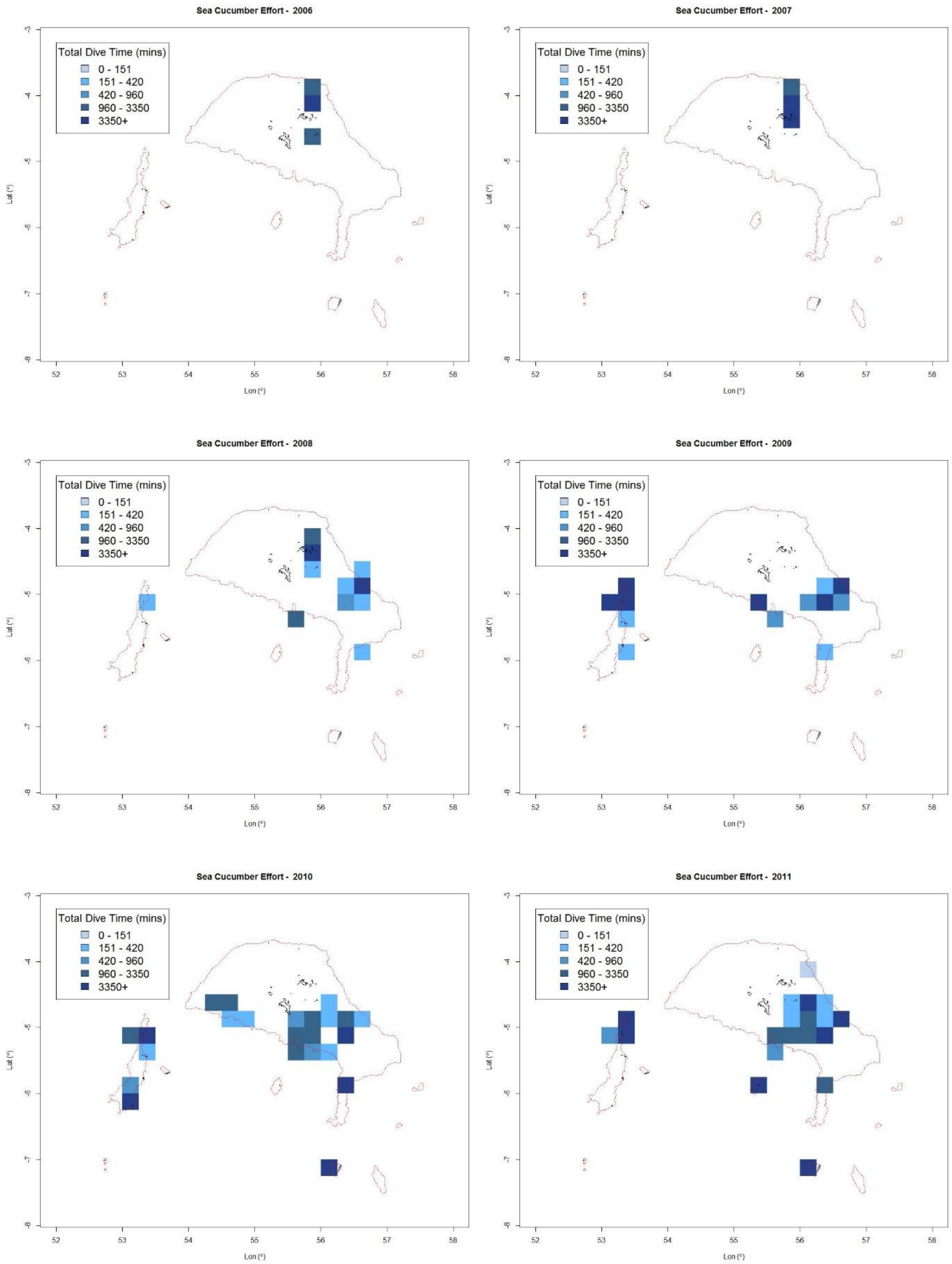


Figure 23: The total annual effort (total dive time, mins) by SFA grid for an individual vessel during 2006 to 2016 with the 200m contour (broken red line).

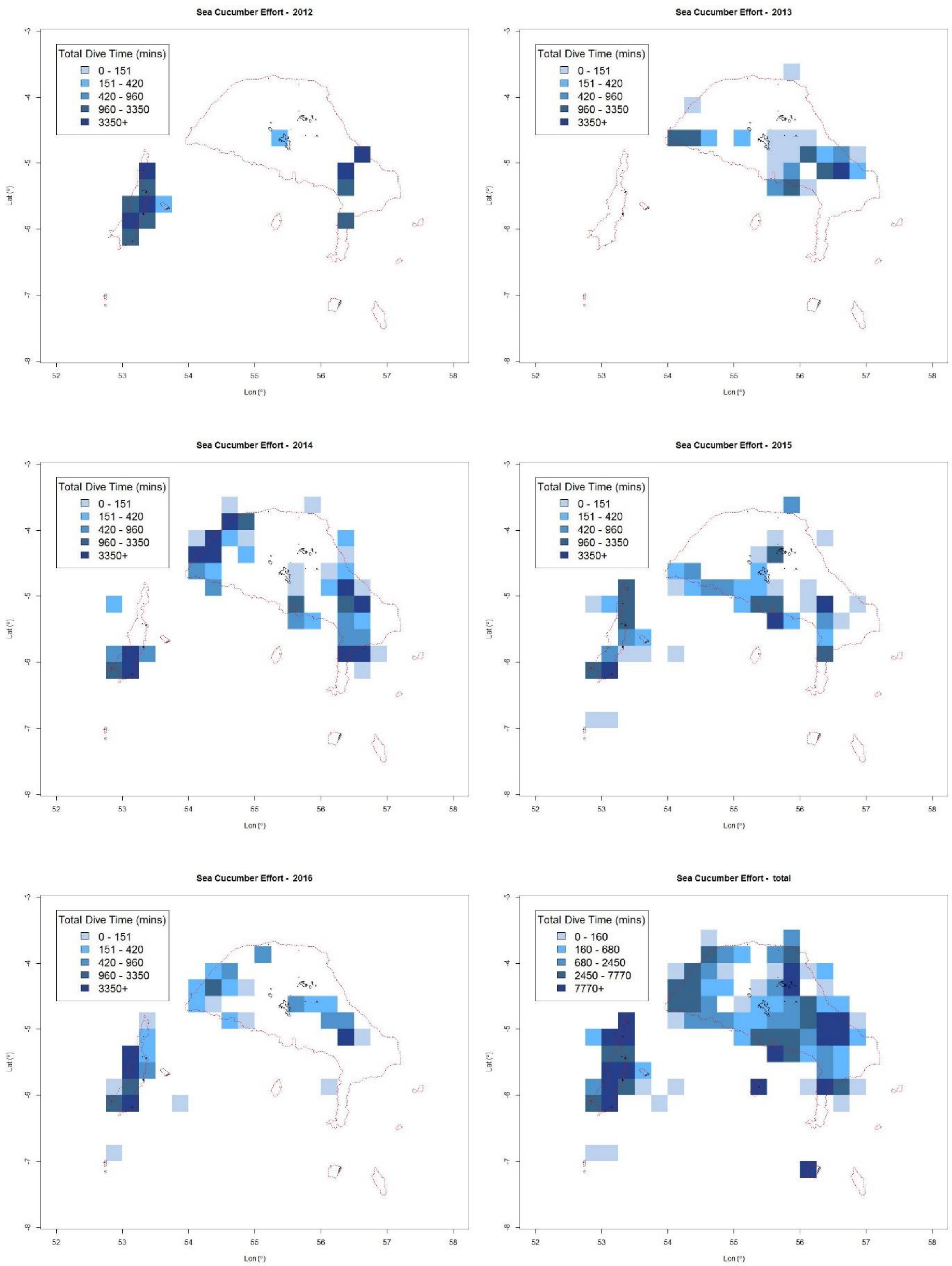
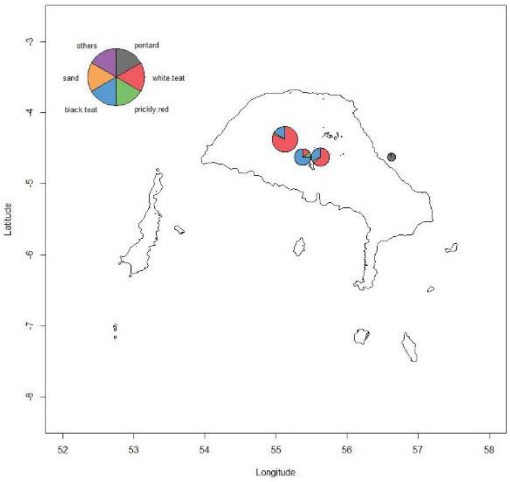


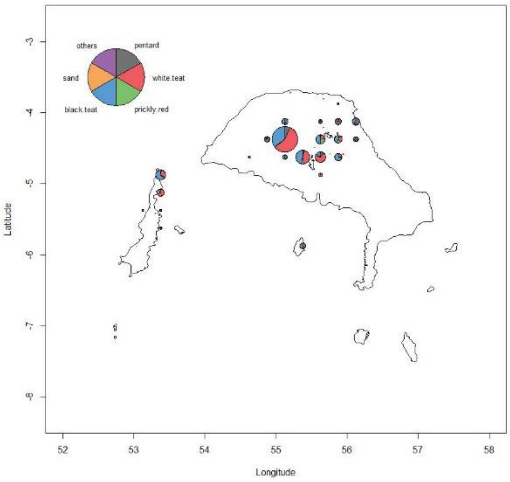
Figure 23 (cont'd): The total annual effort (total dive time, mins) by SFA grid for an individual vessel during 2006 to 2016 with the 200m contour (broken red line).

Reported spatiotemporal distribution of species composition

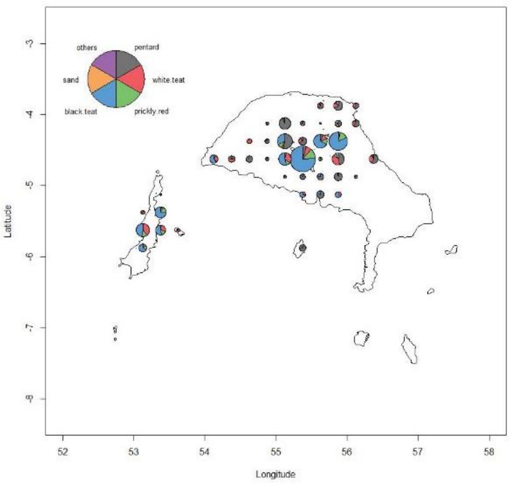
2001



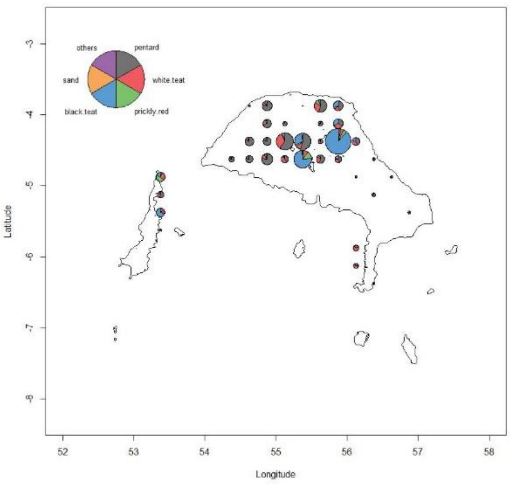
2002



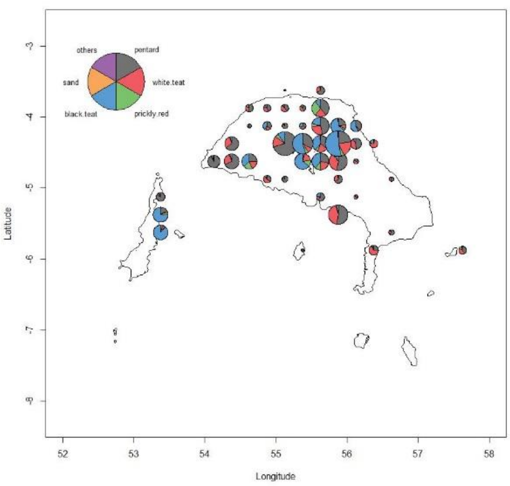
2003



2004



2005



2006

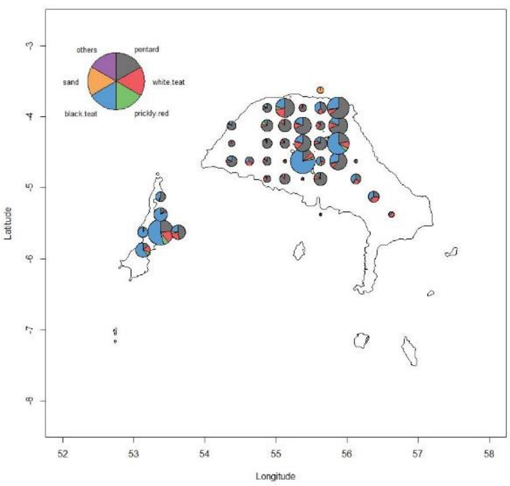


Figure 24: Species composition of total catches between 2001 and 2016 by grid with catch graduated pie charts. The 200m contour is shown as a solid black line.

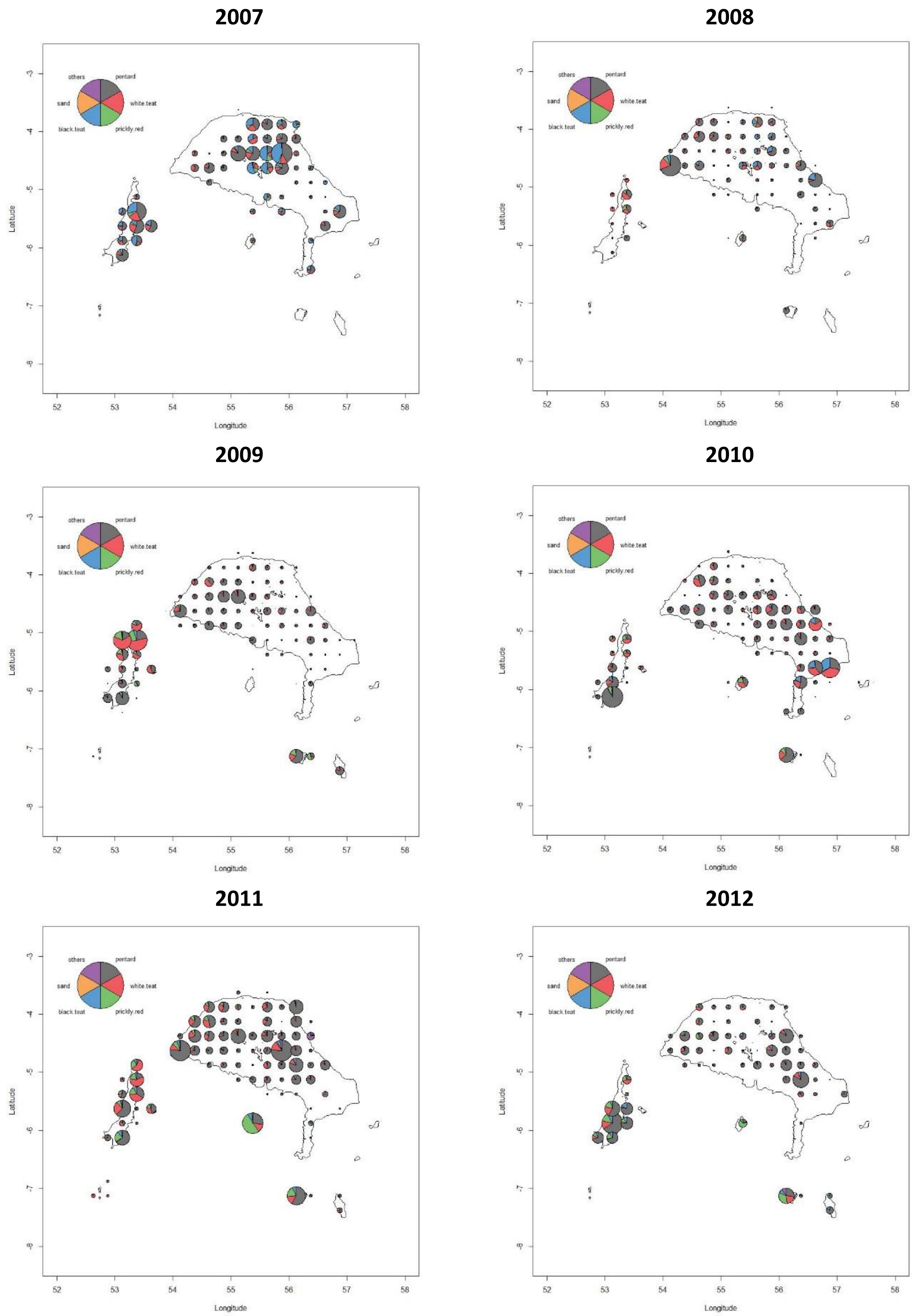


Figure 24 (cont'd): Species composition of total catches between 2001 and 2016 by grid with catch graduated pie charts. The 200m contour is shown as a solid black line.

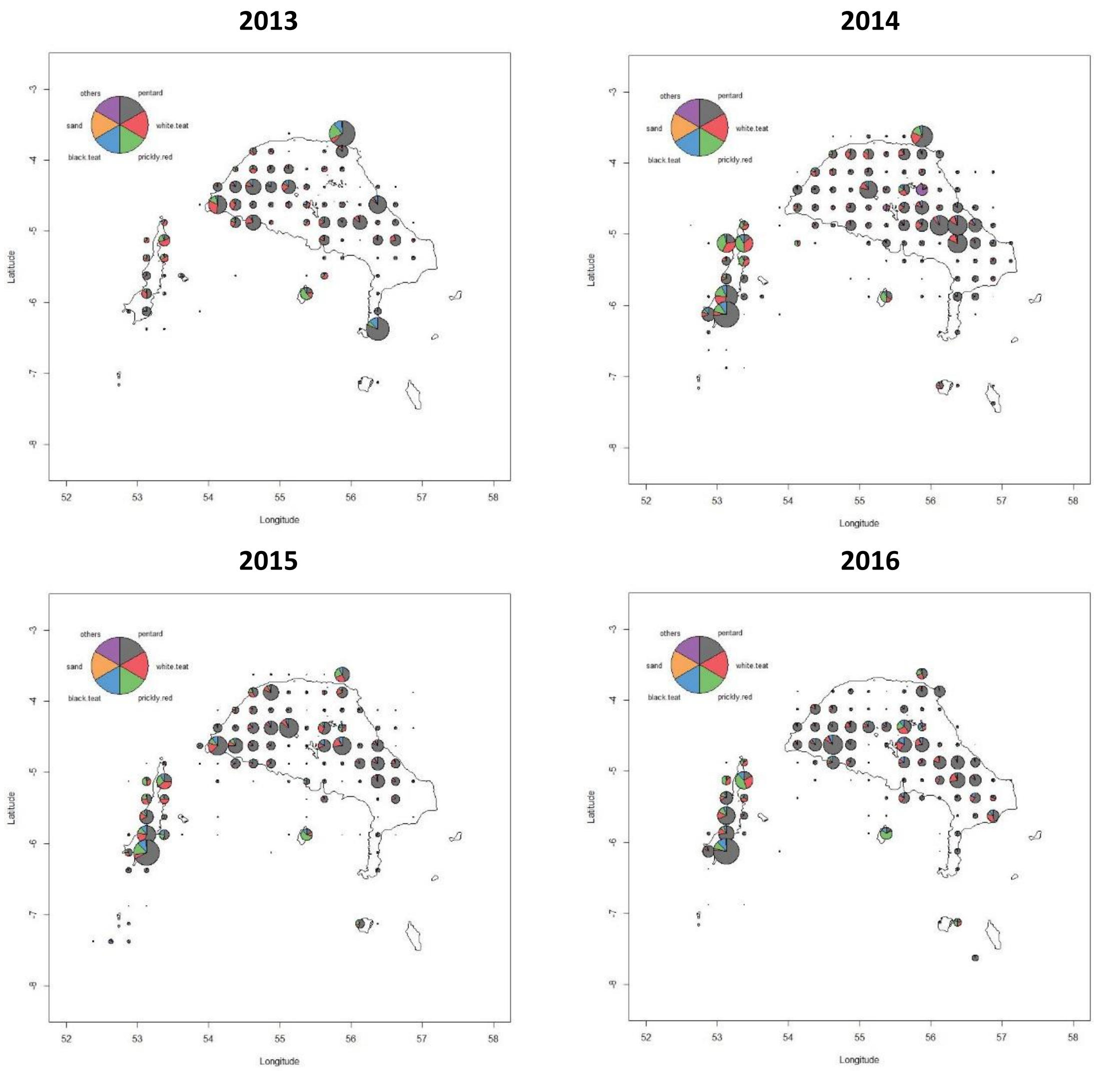


Figure 24 (cont’d): Species composition of total catches between 2001 and 2016 by grid with catch graduated pie charts. The 200m contour is shown as a solid black line.