An assessment of the viability of fisheries independent data for determining stock status and deriving management advice for Seychelles inshore coral reef fisheries.

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Executive Summary

Context

In recent years, the Seychelles Fishing Authority (SFA), the executive body of the Government for fisheries, has focused on developing management plans for inshore artisanal fisheries. While some fisheries-dependent data are available to assess the impacts of the inshore fishery, these data are low resolution and do not represent the spatial distribution of fishing. This lack of data seriously undermines fisheries management for reef associated fish species such as rabbitfish, which are important to the fishery, and are key functional groups in coral reef ecosystem resilience. In the absence of fisheries-dependent data for these important reef families, SFA were seeking to determine if fisheries-independent datasets might be used to derive exploitation status and management advice.

There have been several advances in the use of fisheries-independent indicators for data-poor fisheries in recent years, although many of these tools have not been extensively tested in the context of coral reefs. We examined available indicators for suitability, and implemented the chosen tools in the context of the Seychelles inshore fishery using underwater visual census (UVC) data collected from 1994 to 2014. This evaluation led to the development of a series of recommendations for management of Seychelles reef fisheries.

Approach and main outcomes

The first step was to develop three proxies of fishing pressure against which trends in indicators of various fish community attributes could be assessed to determine fishing effects. These proxies were catch, the spatial distribution of fishing effort, and catch weighted by the spatial distribution of fishing effort. These proxies suggested that fishing pressure was highest in Mahe E and Mahe NW.

Indicator analyses were typically carried out at the community-level as there were insufficient data to explore species-level trends and patterns for important target species. However, a vulnerability analysis provided a first screening of those species that are likely to be more vulnerable to fishing and therefore may require more in-depth monitoring. This analysis highlighted the potentially high vulnerability of certain target species such as *Lutjanus bohar* (Vara Vara) and *Aprion virescens* (Zob Gri) (Figure ES1).

We then explored the effects of fishing and the benthic habitat on a range of ecological indicators that represent important attributes of a productive fishery and a functioning ecosystem, such as the mean size of fish and functional richness of the community. This investigation highlighted the poor performance of our proxies of fishing pressure, likely due to i) the scale mismatch between the fishing pressure data and the fisheries-independent data and ii) the low gradient in fishing pressure among UVC sites. Importantly, these analyses clearly showed the strong effect of the benthic habitat (in particular macroalgal cover and structural complexity of the reef) on most of the ecological indicators, suggesting that habitat management is critical to support ecosystem attributes important for a productive and sustainable fishery (Figure ES2).

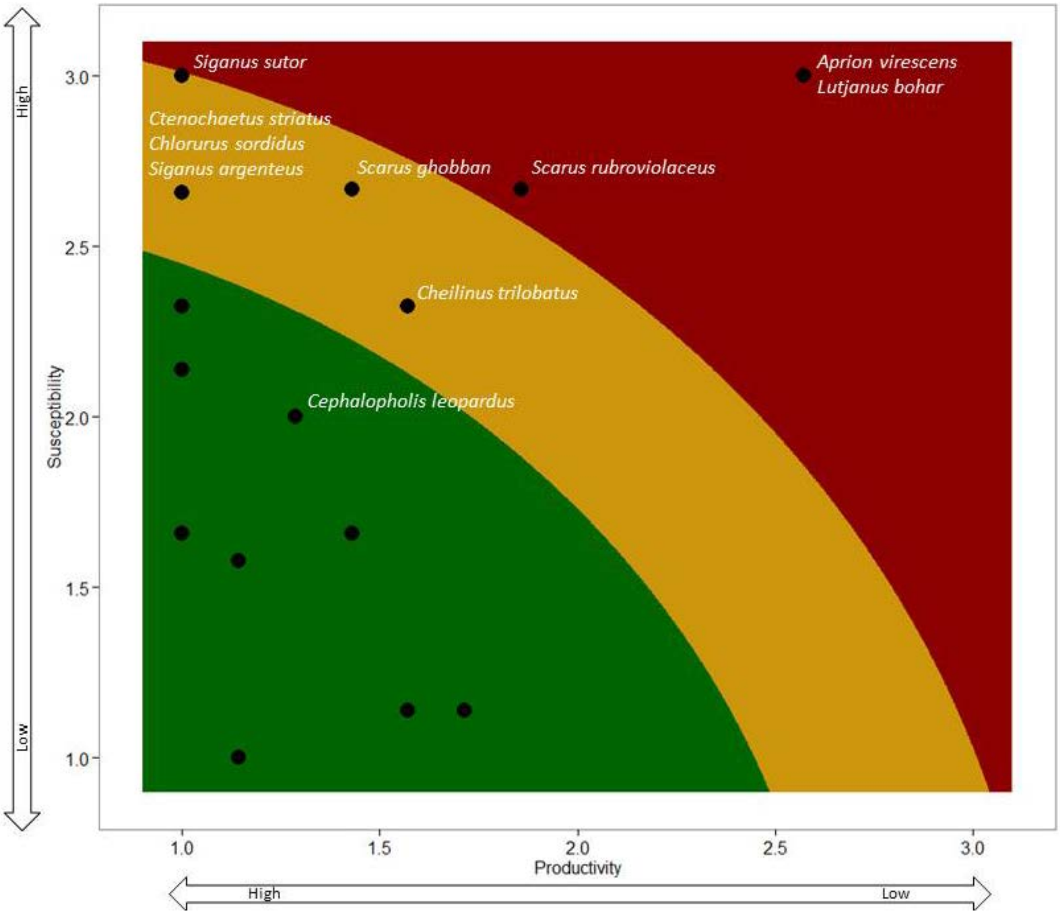

Figure ES1: Potential vulnerability of target species to fishing based on fish life-history characteristics and susceptibility to fishing estimated in section 3. Highlighted species are primary targets of the fishery.

These results were used to investigate 3 main avenues for setting reference points for the inshore fishery.

- First, we examined the ratio between fish biomass inside versus outside high-compliance no-take areas. This allowed us to highlight areas of concern with respect to the decline in fish biomass e.g. Praslin NE, and suggest potential unexploited and limit reference points (Figure ES3).
- Second, we evaluated the fish biomass and other fish community and habitat indicators at Seychelles sites in relation to fitted relationships between fish biomass and these indicators, already determined for coral reefs in the Indo-Pacific region. This analysis suggested that most sites are being fished at what has been proposed to be sustainable levels, based on their fish biomass (Figure ES4). However, other characteristics of the fish communities such as size and growth of fish provides a more worrying picture with fishes exhibiting characteristics more commonly found in areas with unsustainable levels of fishing.
- Third, we evaluated the fitted relationships we had found between the benthic environment and the ecological indicators to highlight the likely changes to catches through size, growth and productivity differences, arising from habitat change (Figure ES2). A key finding was that fish communities at sites dominated by algae

were lower in productivity (low growth rate, long lifespan etc) than sites with high structural complexity. This difference was predominantly due to the lack of small fish at macroalgal dominated sites, rather than an increase in large fish. This suggests that catches at macroalgal dominated sites will not be characterised by larger fish, just lower productivity.

The outcome of this investigation was a series of recommendations for monitoring the state of the Seychelles inshore-fishery and for managing it into the future.

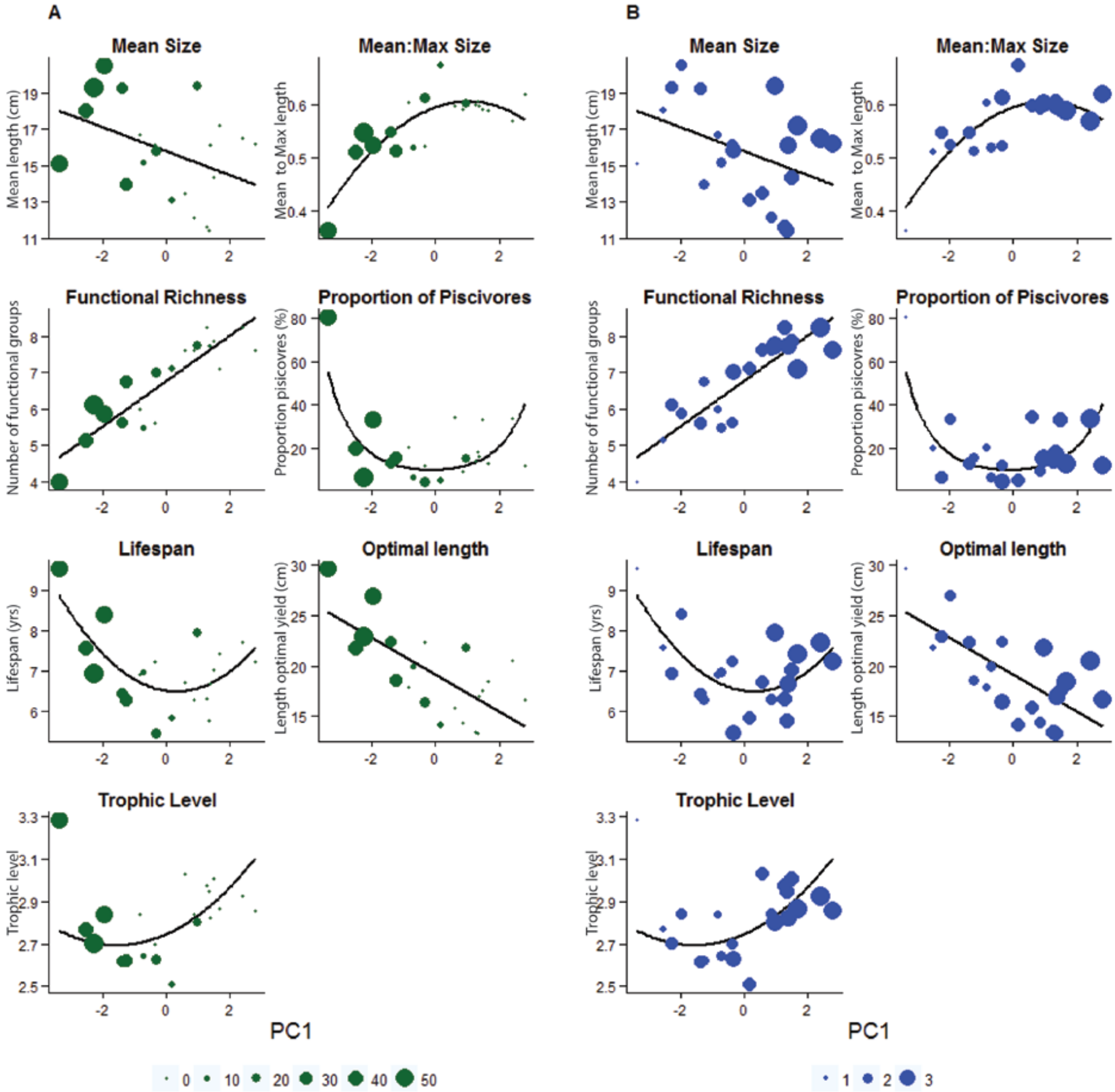

Figure ES2: Relationship between benthic condition (PC1; see section 4-4) and the different indicators. Fitted lines are those estimated in regressions in section 4-4. Circles represent data for the 21 sites in Seychelles in 2014. Size of the symbols represents values for A) macroalgal cover, or B) structural complexity at the sites.

Recommendations – Monitoring the state of fishery and ecosystem

The proxies of fishing pressure used in the consultancy performed poorly, and were not related to the majority of the ecological indicators used in the assessment. This may have been because: i) the fishing pressure gradient at the UVC sites is relatively small and therefore there are not strong differential effects on the indicators; or ii) the fishing pressure differences in time and space are not adequately reflected by the proxies used. Comparison of fishable biomass at the Seychelles sites with unexploited reference points from the Indian Ocean suggests that there is significant fishing pressure, underscoring that better proxies need to be developed:

1. The catch surveys record the fish caught according to their landing region e.g. landed in Mahe E. The 'Fishers in Space' data shows that fish landed in Mahe E may be caught around Praslin, thus information on the number of boats and fishing effort from Praslin underestimates the current level of fishing in the waters surrounding the island. **There is a need to assign landings to region caught not region landed.**

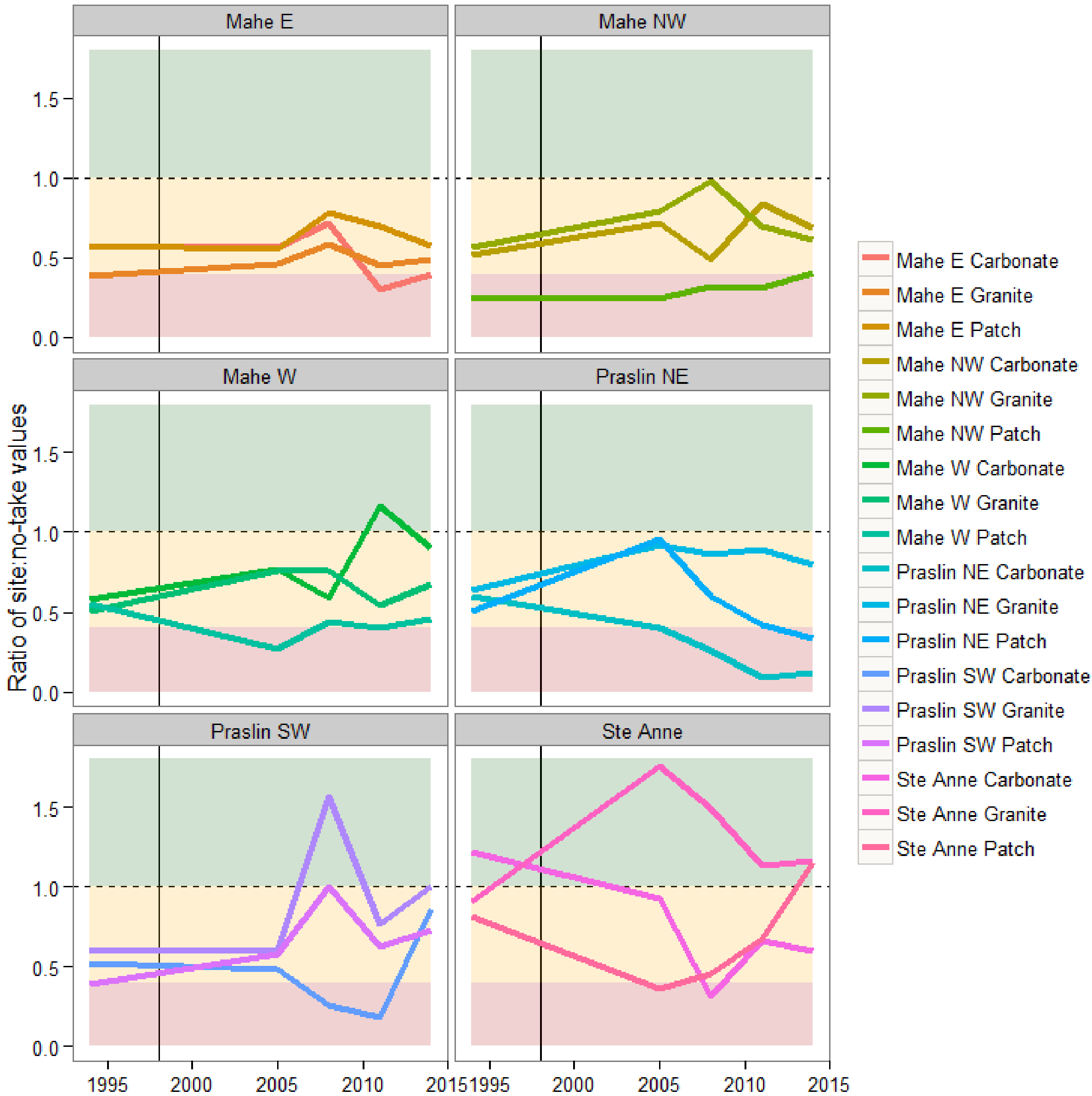

Figure E3: Ratios in total fish biomass of fished and high compliance no-take areas over time. Shaded regions represent different potential reference points or regions, e.g. the green area shows the unfished state, whereas the red area is indicative of low biomass that may require management attention.

2. There is a spatial- and scale-disconnect between the UVC data and the catch data. Specifically, the UVC sites are located at the edges of the fishing areas (spatial-disconnect) and the UVC data is collected at the site level, whereas the fishing data is collected at the region or island level (scale-disconnect). Greater spatial and scale overlap is needed to strengthen the use of UVC data to inform inshore fisheries management in Seychelles. **Splitting catch surveys by catch site rather than region, and increasing the number of UVC sites to encompass a greater proportion and broader intensity of the fished areas is needed.**
3. Addressing these two recommendations would allow **the development of new fishing pressure proxies that are representative of the relative differences in exploitation over space and time, and provide a wider range of fishing pressures.**

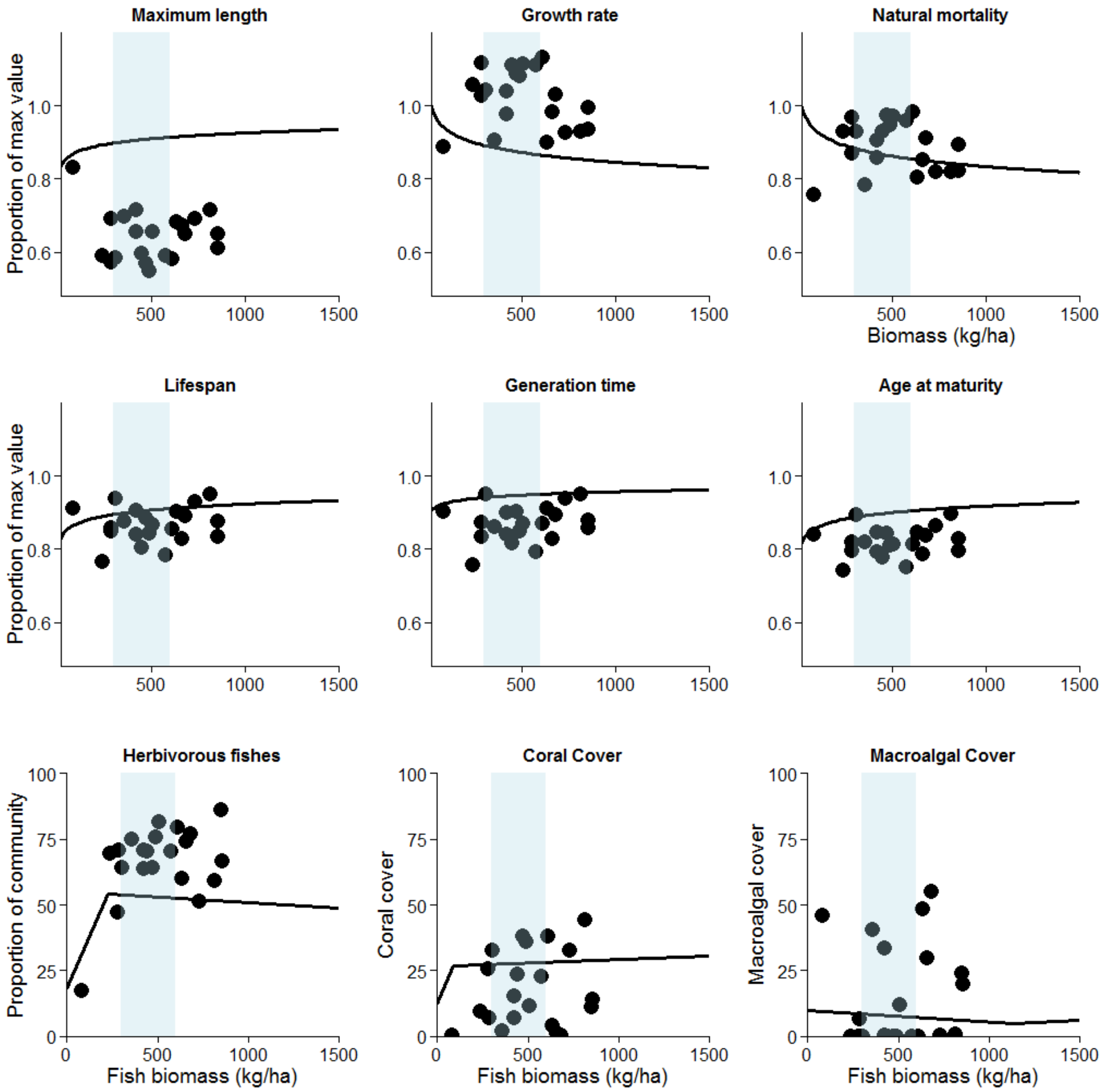

Figure E4: Relationship between fish biomass and the different indicators. Fitted lines represent relationships for data sourced from 9 countries across the western Indian Ocean (McClanahan et al. 2015, McClanahan et al. 2011). Symbols represent data for the 21 sites in Seychelles in 2014. Blue shaded areas represent Biomass based multispecies maximum sustainable yield (McClanahan et al 2011).

Due to grouping of species in catch surveys and inadequate surveying of certain key target species by the UVC methods, analysis of trends in important fishery species was not possible:

4. To allow a more refined ecosystem-level understanding of the effects of fishing pressure in space and time on important species, there is a **need for catch data to be collected and made available at the species level.** This is critical both for those species that are of importance to the fishery but also for functionally important species. This is particularly true for species that show high potential vulnerability to fishing but that are not adequately surveyed by the UVC methods, such as *Aprion virescens*, *Lutjanus bohar* and *Siganus sutor*.
5. **The vulnerability analysis carried out on target species should be revisited and revised as more information becomes available.** For example, information on the spatial overlap between the distribution of populations and fishing effort of different gears could be incorporated into the analysis to increase its relevance as a predictor of species vulnerability in Seychelles. Similarly, if information becomes available on data quality for each attribute for each species, this would allow interpretation of the relative uncertainty we can place on the vulnerability measures for each species.

Twenty one UVC sites are currently surveyed. This number is quite low when compared to the size of the fished inshore area. At present, the data is only available for 5 time periods (1994, 2005, 2008, 2011 and 2014). Of these sites only 3 were located in high compliance no-take reserves and could be used as reference sites against which fished areas are compared:

6. The few data points through time results in low statistical power for detecting trends in the different ecological indicators over time. This makes it difficult to tease apart the lack of a trend from the inability to detect a trend. As a result, **more UVC sites need to be surveyed over a longer time period, incorporating areas with a broader range of fishing pressure. This would allow an effective, in-depth analysis of trends over time, and would increase the power of these analyses.**
7. The three reference sites used to estimate a no-take value for the different indicators were all surrounding Cousin, due to low compliance at the other UVC locations. **More sites in high compliance no-take areas need to be added as UVC locations to allow estimation of reference values that are more representative of the inner fringing reefs**. These **reference sites should cover high coral cover areas** as all sites currently surveyed at Cousin are high macroalgae sites. Furthermore, the granitic site at Cousin is partially composed of carbonate reef, therefore **a high compliance no-take area encompassing a fully granitic site needs to be added to the UVC surveys**. These additions would require either other high compliance no-take areas in Seychelles, if available, or might require additional sites in the Cousin no-take area that have granitic basis and higher coral cover.

Recommendations – Management

Species-level management

8. **Where increased data collection on high vulnerability, target species is not possible, precautionary management controls such as bag or size limits may be needed, particularly for *Aprion virescens* and *Lutjanus bohar*.**
9. **High productivity species (e.g. *Siganus sutor* and *Siganus argenteus*) may provide populations that are more resilient to high fishing effort than lower productivity species.** This resilience results from the greater growth and recruitment of productive species. However, the vulnerability analysis provides an indicator of potential vulnerability *not* realised vulnerability, therefore there is a need to be cautious about basing management decisions solely on these results.
10. Where specific management actions or controls are suggested in future management planning, **the potential effects of these management controls on the vulnerability of different species could be evaluated ahead of their implementation by varying values of attributes used to estimate vulnerability**. For example, the effect of limiting the use of beach seines could be assessed by removing this attribute and recalculating the susceptibility of each target species.

Site-level management

11. Praslin NE carbonate and patch areas, and Mahe NW patch show the smallest ratios of fish biomass compared to high compliance no-take areas, suggesting these sites may be most strongly impacted by fishing pressure. **Further study of fishing pressure at Praslin NE and Mahe NW compared with other, apparently less impacted areas with similar habitat is important to ensure declines are effectively tracked and then addressed through management controls.**
12. **Benthic habitat drives the patterns found in most of the indicators used.** These indicators are important for the fishery as they represent resource potential and ecosystem functioning. Specifically, the fewer small fish observed on macroalgal dominated reefs is driving lower overall productivity (e.g. lower growth rate, longer lifespan) at these reefs compared with the fish communities found at low macroalgae/high complexity reefs. Similarly, functional richness is greater at high complexity, coral-dominated reefs than at macro-algal reefs suggesting greater support for the functioning of reefs where coral dominates over algae. Therefore**, it is important to monitor and manage the state of the benthos and how it changes in time and space to effectively manage the in-shore fringing reef fishery.**

Setting reference points

13. The **ratio between fish biomass at fished and unfished sites presents a useful metric for monitoring fishing effects and trends over time** on Seychelles fringing reefs. Furthermore, it provides an **intuitive way of setting reference points in consultation with stakeholders**, e.g. setting 40% of unfished biomass as a limit reference point. However, care is needed in selecting reference sites to ensure habitat effects do not mask fishing effects.
14. Currently the fish biomass at the UVC sites sit predominantly within a proposed biomass based multispecies maximum sustainable yield (B_{MMSY}) identified for the western Indian Ocean. This suggests that fishing pressure, in the most part, may be

sustainable at present. However, there is a **need for ongoing monitoring of fish biomass and comparison to the proposed B_{MMSY} to ensure maintenance of these biomass levels.**

15. The comparison between fish biomass levels at sites in Seychelles with a measure of unexploited biomass indicates significant fishing pressure, such that there is a clear **need for better catch data to develop fishing pressure proxies for management of the Seychelles coastal fishery.**
16. Seychelles fish communities exhibit characteristics common to fish communities subject to considerably higher levels of fishing pressure, e.g. small size, and high growth rate. This may be beneficial for the productivity of the fishery but also means smaller fish with lower reproductive capacity are present in the community. **The life-history characteristics of the fish community need ongoing monitoring and comparison to published data from across the Indian Ocean.**
17. **The benthic habitat needs careful management to support the productivity of the fishery and the functioning of the reef.** Shifts in the reef benthos to macroalgal domination will see a loss of small fish and lower functional richness, which may have deleterious implications for the functioning of the ecosystem and the ongoing delivery of resources to fishermen.

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Introduction & Context

The fisheries sector in Seychelles is critically important for national development, constituting the second pillar of the economy, the major source of foreign exchange earnings and contributing more than 90% of exports. Industrial fisheries for tuna have grown considerably over the last three decades but artisanal fisheries are significant in terms of food security, local revenues and employment. Artisanal fisheries are multi-species and multi-gear, primarily focused on shallow bank habitats and notably the Mahé Plateau (although fishing does occur, especially by the schooners, in the Amirantes and other Seychelles locations remote from the Mahe Plateau). The plateau, which is closed to industrial fishing, supports an artisanal fleet of around 140 inboard vessels (>6 m LOA) and around 500 outboard vessels and sport/recreational fishing boats. The inboard fleet undertakes fishing trips lasting several days and employs hook-and-line gear to fish for snappers, groupers, emperors and semi-pelagic species in offshore areas of the plateau. The outboard fleet operate daily trips and generally remain inshore, close to the inner granitic islands of the Mahé Plateau. A range of gears are employed by the outboard fleet, including nets for mackerel and traps for rabbitfish, surgeonfish, parrotfish and emperors, as well as hook-and-line gear.

In recent years, Seychelles Fishing Authority (SFA), the executive body of the Government for fisheries, has focused on developing management plans for inshore and offshore artisanal fisheries. Fisheries-dependent data (catch, effort, species composition, size) are available aggregated to the island level for species that are taken by the trap fishery, but information on the spatial distribution of fishing data is lacking. Furthermore, there is no information on the size distributions of catches. The paucity of data seriously undermines fisheries management for reef associated fish species such as rabbitfish, parrotfish and surgeonfish, which as well as being important to the fishery, are key functional groups in coral reef ecosystem resilience. In the absence of fisheries-dependent data for these important reef families, SFA were seeking to determine if fisheries-independent datasets might be used to derive exploitation status and management advice.

There have been several advances in assessment tools for data-poor fisheries in recent years, although many of these tools have not been extensively tested in the context of coral reefs. Advances have also been made in understanding the ecosystem impacts of reducing coral reef fish biomass, such as effects on coral cover. Fisheries management can look to maintain multispecies reef fish biomass above thresholds that are associated with declines in ecosystem health, which in combination with species-specific targets or reference directions can support ecosystem approaches to fisheries management. We were tasked with examining available assessment tools for suitability, developing new approaches as required, and implementing the chosen tools in the context of the Seychelles inshore fishery. This evaluation led to the development of management advice for Seychelles reef fisheries.

Aim and Objectives

The aim of the consultancy was to provide scientific advice for the sustainable management of small-scale coral reef fisheries in Seychelles, primarily using existing, spatially explicit fisheries-independent data. The focus of the consultancy was on developing ecological indicators and methods for setting reference points for these indicators. The key outcomes will support the production of a management plan in combination with social and economic indicators and their corresponding reference points.

Specific objectives were:

i. Derive ecological indicators and determine population trends for reef fishes important to inshore trap and line fisheries
ii. Develop tools for assessing stock status and for applying decision control rules in small-scale reef fisheries

Outline of Assessment

We completed five steps in our assessment (Figure 1). These steps are described in more detail in the following sections. Step 1 was the development of a plan of action for the assessment, which was reviewed by a panel of experts. Steps 2 to 5 implemented the plan of action incorporating expert feedback: Step 2 involved a vulnerability analysis to provide a first screening of those species that are likely to be more vulnerable to fishing and therefore may require more in-depth monitoring. Step 3 produced a range of proxies for the relative fishing pressure at the different study sites that were temporally explicit to account for changes in exploitation over time. Step 4 focused on the selection and estimation of ecological indicators. Step 5 used the final list of indicators selected in Step 3 to produce reference directions and reference points for the different indicators.

Data Available

A range of datasets were used in this assessment. Example publications arising from these datasets are provided in Appendix 1.

i. ***UVC dataset*** - The primary source of information was a fisheries-independent dataset derived from underwater visual census (UVC) surveys undertaken by Prof. Simon Jennings (CEFAS, UK), Dr. Nicholas Graham (ARC CoE Coral Reef Studies, Australia) and Dr. Shaun Wilson (Department of Parks and Wildlife, Australia) in collaboration with SFA. The dataset included a robust statistical design spanning 21 reef sites across 7 regions in the inner granitic islands of Seychelles, which overlaps with the distribution of the outboard fleet of the inshore fishery. A range of reef types are covered and sites include reefs protected by marine reserves and those in fished areas (Figure 2). Surveys were conducted in 1994, 2005, 2008, 2011 and 2014, the data provide a powerful time-series to examine long-term trends in reef fish populations. The dataset details:
    a. Biomass, abundance and size composition of reef fish.
    b. Benthic composition, including cover of taxa such as corals and algae, and estimates of structural complexity.

Step 1: Plan of action

Production of a plan of action for the consultancy that was reviewed by expert panel. Feedback was incorporated into the plan.

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Step2: Estimation of fishing pressure at study sites

Calculation of fishing pressure proxy from fishing effort and fishers in space data

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Step 3: Vulnerability analysis

Productivity-Susceptibility Analysis to provide an indication of the potential relative vulnerability of different focal species (Table 2)

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Step 4: Indicator selection and calculation

A. Estimation of values for indicators of fishing effects
- All indicators calculated for the community as a whole and for the focal species (Table 2), except the functional indicators which will be calculated solely for the whole community

B. Refined list of indicators
- Assessed redundancy among indicators
- Assessed relative effect of fishing pressure (proxy) and other drivers (habitat variables) on indicators
- Finalized list of indicators for use in Step 5

C. Presented trends and patterns in indicators in space and time
- All indicators assessed temporally and spatially (except coefficient of variation in biomass which will only be assessed spatially)

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Step 5: Assessment of methods for setting reference directions and reference points for indicators selected in Step 4

A. Determined reference directions for indicators
B. Determined ratios for indicators inside vs. outside no-take areas in Seychelles
C. Determined 'utility thresholds' for indicators to use as reference points
D. Comparison of biomass values for Seychelles fish communities with proposed Multispecies Maximum Sustainable Yield

Figure 1: Outline of steps in assessment

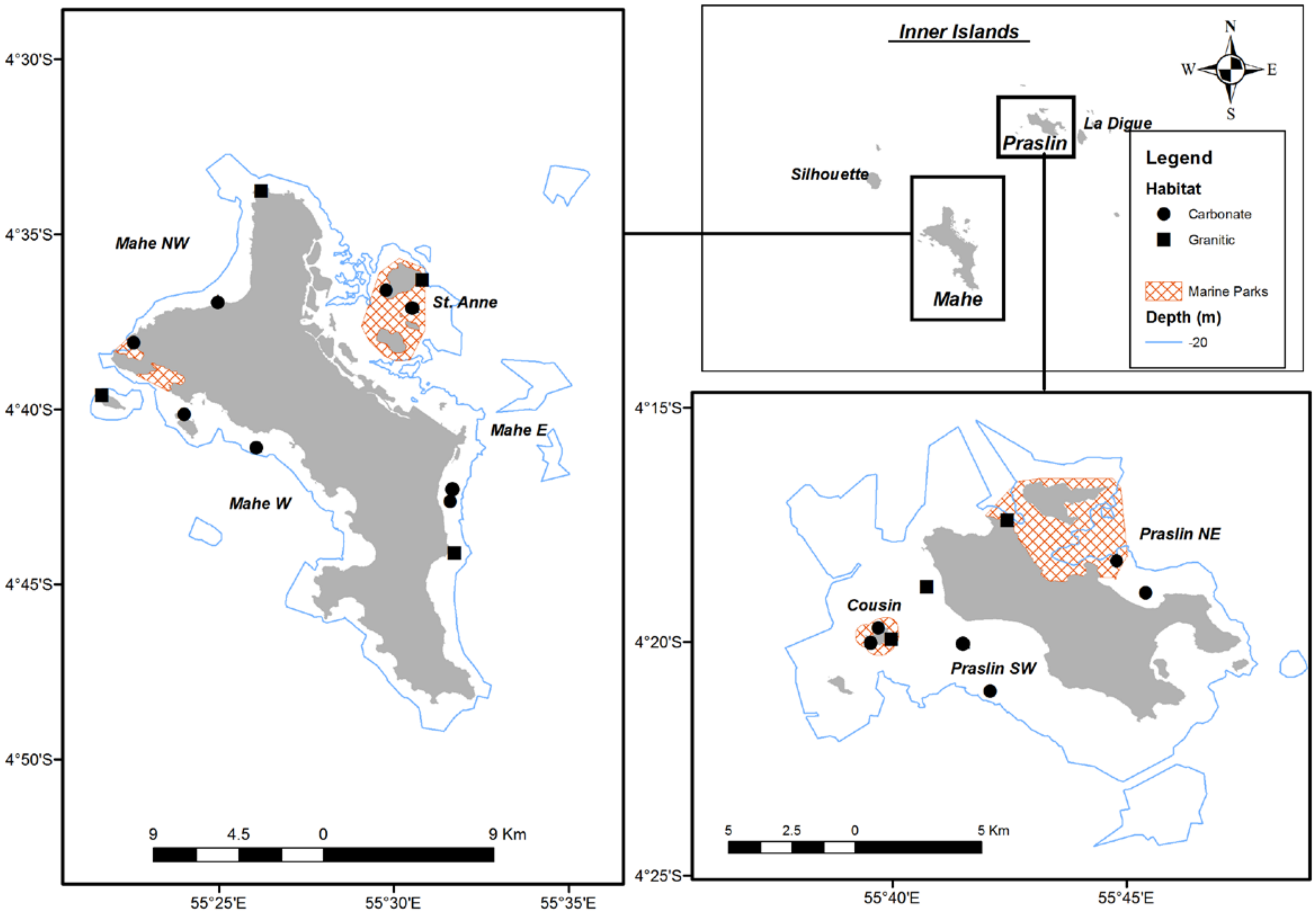


Figure 2: Map of UVC sites and their location in 7 Regions (dataset 1)

ii. ***Effort dataset*** - The second source of information was a fisheries-dependent dataset derived from catch and effort surveys undertaken by SFA. The dataset spans the inner granitic islands of Seychelles, and overlaps with those regions surveyed in the UVC data (Figure 2; Table 1). Surveys were conducted yearly from 1989 to 2013. Data included region specific annual information on the mean number of pirogues and outboard boats operating per month using different gear types (Table 2). Annual totals for the number of man hours spent fishing, and estimated catch per unit effort (CPUE, kg/man hour) for each boat type-gear combination was available at the island level (Mahe and Praslin). These data were used to calculate a proxy for fishing pressure in the different regions over time, against which indicators derived from the UVC data could be compared. Note, that although catch composition data were collected, these data have historically been classified into species groups, and therefore catch data were not available at the species level.

iii. ***Fishers in space dataset*** – The third data source was a fisheries-dependent dataset derived from 62 fishers' interviews undertaken by SFA. The dataset spans the inner granitic islands of the Seychelles, and provides an indicator of how fishing is distributed across the inner Seychelles. The data relates to outboard boats only and is limited to trap and handline fishers, therefore it doesn't cover all fishers incorporated in the effort dataset. Although the data was collected in a single year (2008), 96% of fisherman stated that they fished in the same areas over the ten year period (1998-2008) (Daw et al. 2011). The dataset provides validation that fishing within the different regions overlaps with the location of the UVC sites (Figure 3). It should be noted, from these data, that the UVC sites are predominantly located at the margins of the fishing areas identified in Figure 3, and as such the UVC data may not provide an indication of the full range of effects of fishing. This data was used to produce a proxy of fishing pressure.

iv. ***Target species dataset*** – The fourth data source was a fisheries-dependent dataset collected by Edwin Grandcourt (1999). The dataset details the species caught by inshore fishers (target and by-catch) using different gears (Appendix 2).

v. ***Focal species dataset*** – To allow population level analyses on important species, a short list of species, families and dietary groups were chosen based on their importance as fishery targets and the availability of UVC data sufficient to derive population trends and exploitation status (including biomass, abundance, size and community based metrics) (Table 3). All species of primary importance to the fishery (based on Grandcourt 1999) or where more than 70 individuals were recorded in the UVC dataset in at least 4 of the 5 sampling years were included.

Table 1: Comparison between the regions defined in the effort dataset and those in the UVC dataset. Information is provided on the habitat type and the level of protection (no-take vs. fished)

Island Group[1]	Effort Dataset Region[2]	UVC Dataset Region	UVC Site[3]	Habitat Type	No-take Area	No-take Established	No-take Compliance
Mahe	Mahe W	Mahe W	Mahe W Carbonate	Carbonate reef	No		
			Mahe W Patch	Carbonate reef	No		
			Mahe W Granite	Granite reef	No		
Mahe	Mahe NW	Mahe NW	Mahe NW Carbonate	Carbonate reef	Yes	1979	Moderate
			Mahe NW Patch	Carbonate reef	No		
			Mahe NW Granite	Granite reef	No		
Mahe	Mahe NE	Ste Anne	Ste Anne Carbonate	Carbonate reef	Yes	1973	Weak
			Ste Anne Patch	Carbonate reef	Yes	1973	Weak
			Ste Anne Granite	Granite reef	Yes	1973	Weak
Mahe	Mahe E	Mahe E	Mahe E Carbonate	Carbonate reef	No		
			Mahe E Patch	Carbonate reef	No		
			Mahe E Granite	Granite reef	No		
Praslin	Praslin SW	Cousin	Cousin Carbonate	Carbonate reef	Yes	1968	Strong
			Cousin Patch	Carbonate reef	Yes	1968	Strong
			Cousin Granite	Granite reef	Yes	1968	Strong
Praslin	Praslin SW	Praslin SW	Praslin SW Carbonate	Carbonate reef	No		
			Praslin SW Patch	Carbonate reef	No		
			Praslin SW Granite	Granite reef	No		
Praslin	Praslin NE	Praslin NE	Praslin NE Carbonate	Carbonate reef	No		
			Praslin NE Patch	Carbonate reef	Yes	1979	Weak
			Praslin NE Granite	Granite reef	Yes	1979	Weak

[1] CPUE and man hours data were available at island scale; [2] Mean number of boats per month was available at the region scale; [3] UVC and fishers in space data were available at the site scale.

Table 2: Types of boat and gears incorporated in the effort data. Pirogues wither have no outboard engine or one with ≤15hp; outboards have an outboard engine >15hp; inboards have an inboard engine and have no deck or a partial deck

Boat	Gear Code	Gear Type
Pirogue	P_LHP	Handlines
Pirogue	P_FIXS	Static Trap
Pirogue	P_FIXA	Active Trap
Pirogue	P_LHP_FIX	Handlines & Traps
Pirogue	P_GNC	Encircling Gillnets
Pirogue	P_BS	Beach Seine
Outboard	O_LHP	Handlines
Outboard	O_FIXS	Static Trap
Outboard	O_FIXA	Active Trap
Outboard	O_LHP_FIX	Handlines & Traps
Outboard	O_GNC	Encircling Gillnets
Outboard	O_GNS	Set Gillnets
Outboard	O_BS	Beach Seine
Inboard/Whaler	IB_FXS	Traps

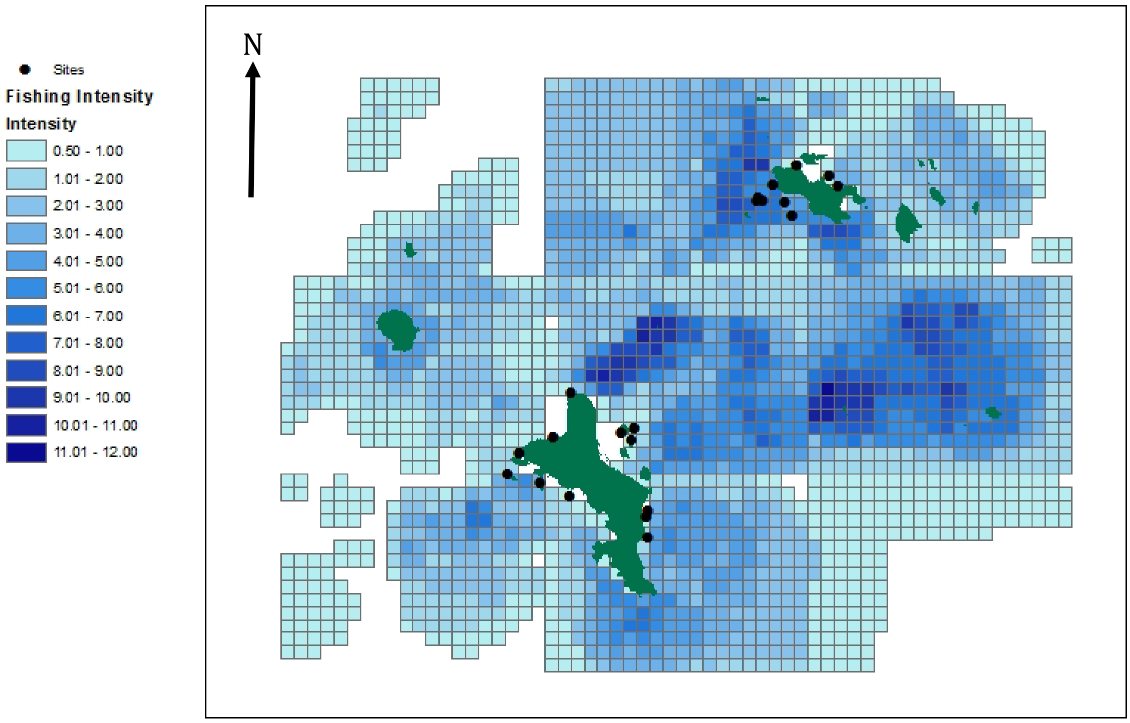


Figure 3: Distribution of fishing in space based on 62 fisher interviews (dataset 3). Black dots show UVC sites (dataset 1). Shading represents the total number of fishers that identified location as somewhere they fished. 0.5 values represent fishing in one monsoon season only.

Table 3: Focal species detailing their diet, whether they are commonly recorded in UVC dataset (greater than 70 individuals across sites in at least 4 of the 5 years of data), their relative importance as targets of the fishery, and their local name where known

Family	Species	Diet	Common	Target	Local Name
Acanthuridae	*Acanthurus leucosternon*	Herbivore	Yes	Occasional	
Acanthuridae	*Acanthurus nigrofuscus*	Herbivore	Yes	Occasional	
Acanthuridae	*Ctenochaetus striatus*	Herbivore	Yes	Important	
Labridae	*Cheilinus trilobatus*	Carnivore	Yes	Important	
Lutjanidae	*Aprion virescens*	Carnivore	No	Primary	Zob Gri
Lutjanidae	*Lutjanus bohar*	Carnivore	No	Primary	Vara Vara
Lutjanidae	*Lutjanus fulviflamma*	Carnivore	Yes	Important	Ziblo[1]
Mullidae	*Parupeneus macronema*	Carnivore	Yes	Important	
Nemipteridae	*Scolopsis frenatus*	Carnivore	Yes	Occasional	Batgren
Scaridae	*Chlorurus sordidus*	Herbivore	Yes	Primary	
Scaridae	*Hipposcarus harid*	Herbivore	Yes	Occasional	Kakatwa Brino
Scaridae	*Scarus ghobban*	Herbivore	No	Primary	Kakatawa Blan
Scaridae	*Scarus niger*	Herbivore	Yes	Important	
Scaridae	*Scarus prasiognathus*	Herbivore	Yes	Unknown	
Scaridae	*Scarus psittacus*	Herbivore	Yes	Important	
Scaridae	*Scarus rubroviolaceus*	Herbivore	Yes	Primary	Kakatawa Rouz
Serranidae	*Cephalopholis leopardus*	Carnivore	No	Primary	
Siganidae	*Siganus argenteus*	Herbivore	Yes	Important	Kordonnyen Soulfanm
Siganidae	*Siganus sutor*	Herbivore	No	Primary	Kordonnyen Blan

[1]*Lethrinus harak* is also known as Ziblo.

Step 1: Plan of Action

A plan of action detailing the proposed assessment was produced and submitted to SFA for review, then disseminated to the following panel of experts for comments and feedback:

1. Elizabeth Babcock, Assistant Professor, Department of Marine Biology and Ecology, University of Miami, USA
2. Edwin Grandcourt, Manager, Marine Assessment & Conservation Section Environment Agency Abu Dhabi, UAE
3. Simon Jennings, Lead Advisor, Centre for Environment, Fisheries and Aquaculture Science, Lowestoft, UK
4. Chris Mees, Managing Director, MRAG, London, UK

The planned assessment was modified to address the minor concerns raised.

Step 2: Calculation of Fishing Pressure Proxy

Methods

The fishing effort data overlap with the UVC data but were not collected at the same spatial scales: the UVC data were collected at multiple sites within the different regions of the inner Seychelles, whereas the data on boat numbers were collected at the regional level and the CPUE and man hours data were available at the island level (Table 1). Moreover, the regions vary in area, and fishing effort is not distributed evenly in space (Figure 3). Thus, to try and understand and quantify differences in fishing pressure over time and space we calculated three fishing pressure proxies that were then compared:

1. Proxy 1: We multiplied the total effort for each boat-gear type combination per year (measured in man hours) by the average catch per unit effort across all years (measured in kg per man hour) for each boat-gear type combination. This gave an estimate of catch in kg for each boat-gear type for each region. Values were then summed across all boat-gear type combinations. These data were collected at the region level, and thus the resulting proxy was a measure of fishing pressure for each region in each year (1989-2013).
2. Proxy 2: We estimated the mean number of fishers that stated they used the nine grid squares centred on each site (dataset 3; Figure 3); where a site was located in a marine reserve, this value was set to 0. We then rescaled these data from values of 0 to 1 (normalised the data), and multiplied proxy 1 by this value. This gave a weighted estimate of catch at each site for each year.
3. Proxy 3: Was simply the mean number of fishers that used the nine grid squares centred on each site (dataset 3; Figure 3); where a site was located in a marine reserve, this value was set to 0. These data were normalised to give a minimum value of 0 to a maximum of 1. This gave a single proxy of fishing pressure for each site (dataset 3 had no temporal component).

It should be noted that the UVC sites are predominantly located at the margins of the fishing areas identified by the fishers in space project (Figure 3), and as such there is a degree of disconnect between the spatial distributions of fishing effort and the UVC sampling. Furthermore, the regions within which fish were landed and thus recorded as part of the catch did not necessarily reflect the regions in which the fish were caught (Appendix 3). Thus, although fishermen are more likely to fish close to their landing site (J. Robinson pers. comm.), the catch and effort data available for a region, and used to calculate proxy 1 and 2 may be somewhat biased.

We assessed the degree of correspondence between the three proxies in a hierarchical manner. First, values for proxy 2 were averaged to region and the spearman rank correlation was calculated between these values and proxy 1. Then values for proxy 2 were averaged across all years and spearman rank correlations were calculated between these values and proxy 3. In this calculation, sites in no-take areas were excluded as values of both proxies had been set to 0 for these sites.

Results

The mean number of boats operating per month in each region varies considerably, but is generally highest in Mahe E (Figure 4A). There appears to be a slight increase in the number of boats in Mahe E and NE in recent years, and a decrease in boats in the two Praslin regions (NB Mahe NE in the fishing effort data equates to Ste Anne in the UVC data, as detailed in Table 1).

When accounting for relative fishing effort at the different sites (proxy 1) the patterns were similar (Figure 4B). Fishing pressure is consistently lower and even decreasing around Praslin. There are some increases in fishing pressure around Mahe since 2010, but overall exploitation appears to be declining over time at Mahe NW. When incorporating information on the distribution of fishing pressure in space (proxy 2), there appears to be similar levels of exploitation among fished sites within regions (Figure 5), with the exception of Mahe NW Patch which has been exposed to less fishing that Mahe NW Granite. There are clear differences between the patterns shown by the boat data, proxy 1 and 2 compared with proxy 3 which solely incorporates the fishers in space data and suggests that fishing pressure is greatest in Praslin SW (Table 4).

There was a strong correlation (rho = 0.82) between proxy 1 and proxy 2 averaged to region, thus of these two metrics, only proxy 2 was used in later analyses in the consultancy. There was also a strong correlation between proxy 2 and 3: rho=0.85 when incorporating all sites.

Table 4: Relative fishing pressure (proxy 3) at each site. Proxy represents the mean number of fishers identifying the nine gird squares surrounding the site as a fishing location (data from Figure 3). Fishing pressure was assumed to be zero at sites in no-take areas.

Region	Site	No-take	Proxy 3: Spatial distribution of fishing
Cousin	Cousin Carbonate	No-take	0
Cousin	Cousin Granite	No-take	0
Cousin	Cousin Patch	No-take	0
Mahe E	Mahe E Carbonate	Fished	0.30
Mahe E	Mahe E Granite	Fished	0.32
Mahe E	Mahe E Patch	Fished	0.26
Mahe NW	Mahe NW Carbonate	No-take	0
Mahe NW	Mahe NW Granite	Fished	0.32
Mahe NW	Mahe NW Patch	Fished	0.13
Mahe W	Mahe W Carbonate	Fished	0.29
Mahe W	Mahe W Granite	Fished	0.29
Mahe W	Mahe W Patch	Fished	0.15
Praslin NE	Praslin NE Carbonate	Fished	0.18
Praslin NE	Praslin NE Granite	No-take	0
Praslin NE	Praslin NE Patch	No-take	0
Praslin SW	Praslin SW Carbonate	Fished	0.43
Praslin SW	Praslin SW Granite	Fished	0.49
Praslin SW	Praslin SW Patch	Fished	0.48
Ste Anne	Ste Anne Carbonate	No-take	0
Ste Anne	Ste Anne Granite	No-take	0
Ste Anne	Ste Anne Patch	No-take	0

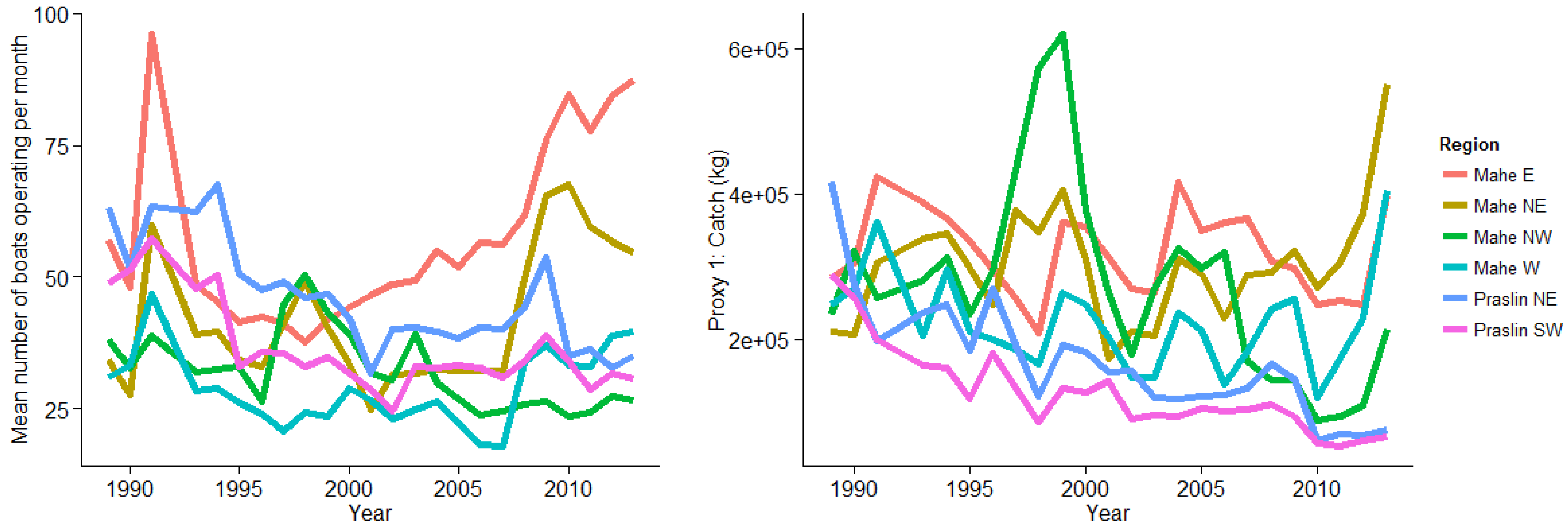


Figure 4: A) Mean number of boats operating per month in each region over time. B) Relative fishing pressure (proxy 1) in each region over time.

Figure 5: Relative fishing pressure (proxy 2) at each site, grouped by region, over time. Proxy 2 data represent proxy 1 information weighted by the number of fishers identifying the site or its immediate vicinity as a fishing spot. Sites in no-take areas, where fishing pressure is assumed to be zero, are not shown.

Recommendations: Fishing pressure proxies

1. Need to assign landings to region caught not region landed – Fishers in Space data shows that fish landed in Mahe E may be caught around Praslin, thus information on number of boats used and fishing effort from Praslin underestimates the current level of fishing in the waters surrounding the island.
2. Currently, there is a spatial and scale disconnect between the UVC data and the fishing data. Specifically, the UVC sites are located at the edges of the fishing areas (spatial disconnect) and the UVC data is collected as the site level, whereas the fishing data is collected at the region or island level (scale disconnect). Greater spatial and scale overlap is needed to strengthen the use of UVC data to inform inshore fisheries management in Seychelles.
3. Need catch data available at the species level for those species that are of importance to the fishery or are functionally important in relation to reef health. This will allow a more refined ecosystem-level understanding of the effects of fishing pressure in space.

Step 3: Vulnerability Analysis

Productivity-Susceptibility Analysis uses a risk-based framework to assess the relative vulnerability of different species to fishing. Vulnerability is estimated from species productivity, and their susceptibility to different fishing activities present in the region. If a species is particularly productive (r-selected life history strategy) and not susceptible to fishing (e.g. not often caught by gears employed), then it will be considered less vulnerable. In contrast, a species that is not as productive (K-selected life history strategy) and particularly susceptible to fishing (e.g. often caught by gears employed), will be considered more vulnerable (Figure 5). Thus, we would expect to see a greater change in abundance and biomass across a fishing gradient for the more vulnerable species compared to the less vulnerable species.

To date, there have not been many peer-reviewed examples of PSAs for coral reef fisheries (but see Fujita et al. 2014, Robinson et al. 2014). However, the different traits on the productivity axis have been shown to be affected by fishing pressure on coral reefs (McClanahan and Humphries 2012). Furthermore, due to the multi-species, data-limited nature of coral reef fisheries, this tool presents a useful method for screening potentially vulnerable species.

Relevant Management Issue[1]

Overfishing of key species; local depletion of demersal fish populations; species at high risk; declining catch rate; shifts in size structure of catch; spatial shifts in catch and effort; changes in catch composition.

Aim

To provide an indication of the relative vulnerability of different reef fish species to fishing:

1. Identify species that may act as ‘early warning’ species, i.e. those that are likely to be particularly vulnerable and thus show signs of overfishing most rapidly.
2. Identify species that are highly productive and thus able to withstand higher levels of fishing pressure, i.e. may be more suitable target species as they will show less impact in response to fishing.

Methods

This analysis concentrated on those species outlined as focal species for the consultancy (Dataset 5; Table 2). A productivity value was calculated for each species using 7 life history attributes: maximum body length, growth rate (von Bertalanffy K parameter), natural mortality, life span, age at maturity, length at maturity, and trophic level. Values of these traits for each species was sourced from the literature (Froese and Pauly 2012).

[1] In steps 2 and 3 the methods we used are presented with relevant management themes. These represent themes identified in the Mahe Plateau draft management plan (supplied by SFA) and thus methods/indicators were chosen and developed to fit within these themes.

A susceptibility value was calculated for each species from 7 attributes: spawning behaviour (sourced from De Mitcheson et al. 2008, Russell 2001, SCRFA 2013), whether the species are targeted (sourced from dataset 4 Grandcourt 1999), and the selectivity of 5 different gear types used in the Seychelles inshore fishery (sourced from dataset 4 Grandcourt 1999).

Each attribute for the two axes was scored on a 3 point scale (1 is low risk, 3 is high risk; Table 5) for each species following category thresholds provide by Robinson et al. (2014) and Patrick et al. (2010). The life-history scores were averaged to produce a single productivity value for each species. As many species are caught by multiple gear types (Appendix 2) and are thus potentially exposed to compound levels of exploitation, we produced an aggregated value for the gear selectivity variables for each species as detailed and recommended by Micheli et al. (2014a). The susceptibility value for each species was then estimated as the average value of the aggregated selectivity and the remaining two susceptibility attributes (spawning and preference as target). Equal weightings were given to each attribute. This could be revised if certain attributes are considered of particular importance.

Table 5: Threshold values for categorising species under the different productivity and susceptibility attributes.

		Category Thresholds		
Axis	**Attribute**	**1**	**2**	**3**
Productivity	Max body length	<60cm	60-150cm	>150cm
	Growth rate	>0.25	0.15-0.25	<0.15
	Natural mortality	>0.4	0.2-0.4	<0.2
	Life span	<10yrs	10-30yrs	>30yrs
	Age at maturity	<2yrs	2-4yrs	>4yrs
	Length at maturity	<30cm	30-50cm	>50cm
	Trophic Level	<2.5	2.5-3.5	>3.5
Susceptibility	Aggregate to spawn	No	Some evidence	Confirmed
	Target	Occasional	Important	Primary
	Casier Dormi Trap	Occasional	Important	Primary
	Casier Pesser Trap	Occasional	Important	Primary
	Casier La Vole Trap	Occasional	Important	Primary
	Handline	Occasional	Important	Primary
	Beach Seine	Occasional	Important	Primary

Species' productivity (x-axis) and susceptibility (y-axis) scores were plotted and the vulnerability score was calculated as the Euclidean distance from the origin of the plot to the coordinates of each species. This gave a single measure of vulnerability for each species across the inner Seychelles giving an indication of the likely response of different species to fishing. Vulnerability was coded as high (>3.18; red), moderate (2.64-3.18; yellow) and low (<2.64; green) such that if all attribute scores on both axes are equally probable, then the vulnerability scores should be equally spread across these three quantitative groupings (Hobday et al. 2007)

Results

The focal species are distributed throughout the vulnerability space, with most species sitting in the low vulnerability (green) zone (Figure 6; Appendix 4). However, with the exception of *Cephalopholis leopardus* all the species listed as primary targets by Grandcourt (1999) exhibit moderate (yellow) to high (red) vulnerability to fishing. *Aprion virescens* and *Lutjanus bohar* are of particular concern, with both having low productivity and high susceptibility to fishing. Neither of these species are commonly recorded within the UVC dataset (Table 3), therefore further investigation of trends in these species over time is not possible at this stage. *Scarus rubroviolaceus* also has high potential vulnerability to fishing, but is found relatively often in the UVC dataset, allowing more in-depth analysis of actual trends in biomass and size over time in the indicators section. Although *Siganus sutor*, *Siganus argenteus*, *Ctenochaetus striatus* and *Chlorurus sordidus* exhibit moderate vulnerability to fishing, this is primarily driven by their susceptibility to being caught. These species are all highly productive and thus may be more able to cope with high levels of fishing pressure than those species that are moderately vulnerable but show lower productivity, e.g. *Scarus ghobban* and *Cheilinus trilobatus*.

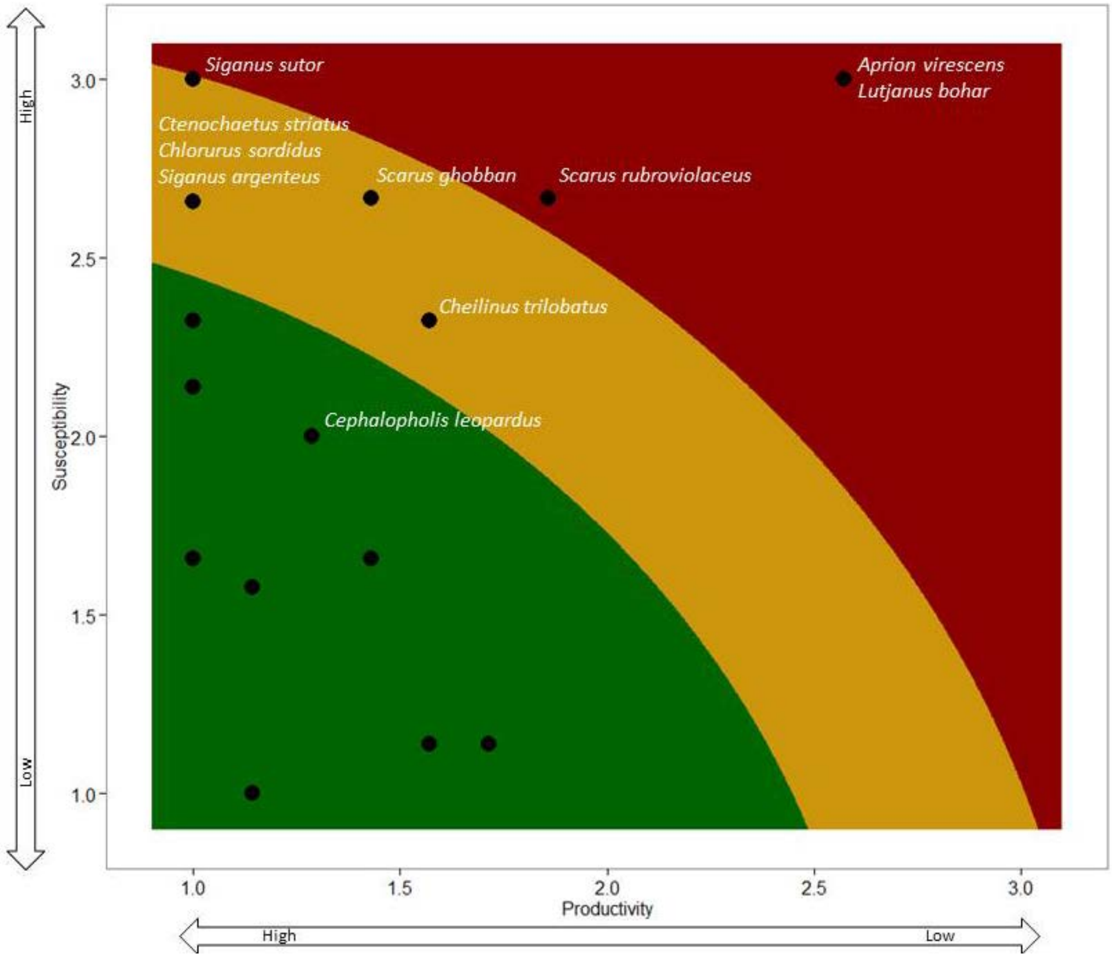


Figure 6: PSA of focal species (see Table 3 for species list). Identified species are classified as moderately (yellow) to highly (red) vulnerable to fishing. *Cephalopholis leopardus* is also identified as this is the only primary target species classified as possessing low (green) vulnerability to fishing. *Scarus prasiognathus* is not incorporated into the PSA as susceptibility information was not available for this species.

Recommendations: Vulnerability analysis

1. More data needs to be collected on *Aprion virescens, Lutjanus bohar* and *Siganus sutor* as these species show high potential vulnerability to fishing but are not adequately surveyed by the UVC methods. Where such data collection is not possible, precautionary management controls such as bag or size limits may be needed, particularly for *Aprion virescens* and *Lutjanus bohar*.
2. High productivity species (e.g. *Siganus sutor* and *Siganus argenteus*) may provide populations that are more resilient to high fishing effort than lower productivity species. This resilience results from the greater growth and recruitment of productive species. However, the PSA provides an indicator of potential vulnerability not realised vulnerability, therefore there is a need to be cautious about basing management decisions solely on these results.
3. The PSA should be revisited and revised as more information becomes available. For example, information on the spatial overlap between the distribution of populations and fishing effort of different gears could be incorporated into the PSA to increase its relevance as a predictor of species vulnerability in Seychelles. Similarly, if information becomes available on data quality for each attribute for each species, this would allow interpretation of the relative reliance we can place on the vulnerability measures for each species (Patrick et al. 2010).
4. Where specific management actions or controls are suggested in future management planning, the potential effects of these controls on the vulnerability of different species can be assessed by varying values of attributes used to make up the susceptibility axis (Micheli et al. 2014a). E.g. The effect of limiting the use of beach seines could be assessed by removing this attribute and recalculating the susceptibility of each target species.

Step 4: Selection and Estimation of Indicators

Ecological indicators provide measurable representations or proxies for the state of different ecosystem attributes and how these attributes may be changing over time (Caddy 2004). A broad range of ecological indicators such as the slope of fish community size spectra or herbivore biomass may be useful to assess the impact of fishing pressure and the state of fishery resources where traditional stock modelling is not possible due to data limitations (Rochet and Trenkel 2003). To assess changes in the fish community and the broader fringing reef ecosystem over time, along with the potential impacts of fishing on these communities, we selected a short list of ecological indicators, assessing their trends over time and space and comparing them with patterns of exploitation (fishing pressure proxies). These indicators were selected to fit within management themes identified in the Mahe Plateau draft management plan (supplied by SFA), their measurability based on the available UVC data, their complementarity and ease of communication to stakeholders within the Seychelles. Indicators were excluded where our review of the literature suggested there was unlikely to be a clear link to fishing impacts.

A range of multi-species indicators were estimated, grouped into different types:

- Size-based indicators
- Density-based indicators
- Functional indicators
- Life-history indicators

The UVC data (dataset 1) were used to calculate these indicators at the site level for each year of data (1994, 2005, 2008, 2011, and 2014). It should be noted that the UVC method under-samples cryptic species, and therefore the indicator estimates will not account for changes in these species over time or space. This needs to be considered when drawing conclusions from the indicators.

4-1 Types of indicator

Size-based indicators

Fishers tend to preferentially target larger individual fish due to increased returns generated from large individuals (Dulvy et al. 2004a, Link 2005), although this depends on the size selectivity of the specific gear used (Hicks and McClanahan 2012). Furthermore, large species are often more vulnerable to a given level of fishing pressure due to the low rate of population increase associated with low productivity and a k-selected life history strategy (Jennings et al. 1998). In addition to these direct fishing impacts on the size structure, exploitation may indirectly affect fish communities through predation release, whereby lower levels of predation by large individuals results in increases in the populations of smaller species (Dulvy et al. 2004b). These impacts may result in shifts in the relative abundances of different sized fish (Gislason and Rice 1998). Longer-term consequences of removing large individuals may be evolutionary shifts in the traits exhibited by targeted species, for example reduction in size and age at maturity (Shin et al. 2005).

On coral reefs there is evidence of a shift to smaller sized individuals (e.g. Guillemot et al. 2014) and changes in trait attributes such as length at sex change (e.g. Taylor 2014) in response to fishing. Similarly, there is evidence that the slopes of fish community size spectra respond predictably to fishing pressure (Figure 5; Graham N.A.J. et al. 2005). However, evidence of predator release resulting in an increase in prey numbers is equivocal (e.g. Jennings et al. 1995). In the Seychelles the mesh size of traps is large enough to allow escape of individuals <6cm in body depth. The influence of this on the lengths of different fish species depends on depth:length ratios, but the majority of fish caught are >15cm in length (Graham N. A. J. et al. 2007).

Relevant Management Issue[2]

Overfishing of key species; local depletion of demersal populations; declining catch rate; shifts in size structure; ecosystem impacts.

Aim

To understand how fishing is affecting size structure within the reef fish community.

Methods

1. *Mean length - to assess the relative abundances of small vs. large individuals*

Mean length was calculated by averaging length across all individuals within the sample. Mean length was calculated for the community as a whole, and for each focal species. For the community estimation, individual length was not averaged to species level first, so that the mean length estimate is dominated by more abundant species.

2. *Proportion of large fish – to assess the loss of large individuals*

The proportion of individuals greater than 30cm in length was calculated for each sample as a whole, and for the individual focal species. For the community estimation, individual length was not averaged to species level first, so that the proportion of large fish estimate is dominated by more abundant species. The reference level of 30cm was used as it lies midway between reference levels used in other coral reef studies (Guillemot et al. 2014). Other reference lengths may be used.

3. *Ratio of mean length: maximum length – to assess the loss of large individuals*

The ratio of the mean observed species length to the species' maximum length recorded in the literature was estimated for each species. The ratios were averaged across all species in the sample to produce a community-level estimate (e.g. Froese and Pauly 2012). Estimations of this ratio for each of the focal species were also calculated.

4. *Ratio of mean length: length at maturity – to assess whether fish are being caught before they mature and have the potential to reproduce*

The ratio of the mean observed species length to the species' length at maturity recorded in the literature was estimated for each species. The ratios were averaged

[2] In steps 2 and 3 the methods we used are presented with relevant management themes. These represent themes identified in the Mahe Plateau draft management plan (supplied by SFA) and thus methods/indicators were chosen and developed to fit within these themes.

across all species in the sample to produce a community-level estimate (e.g. Froese and Pauly 2012). Estimations of this ratio for each of the focal species were also calculated.

5. *Slope of size spectra - to assess the relative loss of large individuals and potential increases in small individuals*

The slope of the size spectra for each site and time period were estimated. Individual fish were assigned to 5cm size classes. Slopes of the linear regression between log (abundance) and log (mid-point of body length size classes) were calculated. Size classes were centred to remove correlation between intercept and slope values for the size spectra. This metric was only calculated at the community-level, it was not estimated for the focal species individually.

Density-based indicators

Fishery exploitation removes individuals, particularly targeting larger fish, resulting in a decline in abundance and biomass of target species (Jennings and Kaiser 1998). A constant density over time may reflect the sustainability of the fishery, and suggests some form of compensatory mechanism counteracting removals, such as increased growth and recruitment (Gonzalez and Loreau 2009, Thorson et al. 2012). However, declines in biomass/abundance may be compensated for through predation release and resultant growth and recruitment of non-target species (Jennings and Kaiser 1998). Studies of changes in abundance and biomass of fish communities on coral reefs, in response to fishing pressure, provide evidence of overall declines in the biomass of the whole community and target species. These evaluations have primarily been made comparing extremes of fishing pressure i.e. no-take vs. fished areas (e.g. Lindfield et al. 2014, Roberts 1995) rather than along a fishing gradient (but see Guillemot et al. 2014).

Relevant Management Issue[3]

Overfishing of prey species; local depletion of demersal populations; shifts in size structure; ecosystem impacts

Aim

To understand how fishing is affecting the abundance of reef fish.

Methods

1. *Biomass per unit area – to assess the total biomass of fish*

Fish lengths were transformed to weight estimates using published length:weight relationships (e.g. Froese and Pauly 2012). Then mean biomass of fish per unit area was calculated for all individuals within each sample, and for each focal species.

2. *Proportion of biomass – to assess the proportion of total biomass contributed by focal species*

The proportion of total fish biomass represented by each focal species was calculated.

[3] In steps 2 and 3 methods introduced in concert with relevant management themes, these represent themes identified in the Mahe Plateau draft management plan (supplied by SFA) and thus indicators were chosen and developed to fit within these themes.

Functional indicators

Fishing generally targets particular species, primarily those composed of larger individuals (Link 2005). In targeting individuals with particular traits, fishing has the potential to remove certain functional groups or reduce redundancy within those functional groups (Micheli et al. 2014b). Modelling of species loss suggests that fishing has a greater potential to reduce functional richness and diversity than a random loss of individuals would produce (Martins et al. 2012). Studies of trends in functional richness and redundancy on coral reefs suggest that fishing pressure may indeed result in a decline in both richness and redundancy, with resultant implications for fishery yields (Micheli et al. 2014b). Furthermore, there is evidence of fishery driven declines in some reef fish functional groups (Friedlander and DeMartini 2002), for example herbivores, which are critical for mediating competition between coral and macroalgae on coral reefs (Edwards et al. 2014).

Relevant Management Issue[4]

Overfishing of key species; local depletion of demersal fish populations; ecosystem impacts.

Aim

To understand how fishing is affecting the functioning of fish communities.

Methods

All these indicators were estimated for the community (sample) as a whole. No metrics were estimated at the focal species level as these indicators are not applicable at the species level.

1. Functional richness – to assess the change in the number of different functional groups

Species were classified into different dietary functions based on the literature e.g. browsing herbivore, grazer, planktivore or piscivore (Froese and Pauly 2012, Green and Bellwood 2009). Functional richness was estimated as a simple count of the different functions within the sample.

2. Functional redundancy – to assess the change in functional diversity

Species were classified into different functions based on the literature (Froese and Pauly 2012, Green and Bellwood 2009). Functional redundancy was estimated using the Shannon-Wiener diversity index. The Shannon-Wiener index was calculated using the number of species in each function, giving a measure of redundancy (Micheli et al. 2014b).

3. Biomass (density) of piscivorous fishes – to assess the change in biomass of piscivorous fishes

For all piscivorous fishes, body lengths were transformed to weight estimates using published length:weight relationships (e.g. Froese and Pauly 2012). Then mean

[4] In steps 2 and 3 methods introduced in concert with relevant management themes, these represent themes identified in the Mahe Plateau draft management plan (supplied by SFA) and thus indicators were chosen and developed to fit within these themes.

biomass of piscivores per unit area was calculated for all individuals within each sample.

4. *Biomass (density) of herbivorous fishes – to assess the change in biomass of herbivorous fishes.*

For all nominally herbivorous fishes, body lengths were transformed to weight estimates using published length:weight relationships (e.g. Froese and Pauly 2012). Then mean biomass of herbivores per unit area was calculated for all individuals within each sample.

5. *Ratio of piscivorous biomass : total piscivore and herbivore biomass – to assess the relative dominance of piscivores and herbivores*

If both herbivore and piscivore biomass are changing in the same direction in response to increased fishing, this ratio may help tease apart how these two functional groups are changing in relation to each other. Piscivore biomass per unit area was divided by the total biomass of both herbivores and piscivores for each sample.

Life-history indicators

Fishers tend to preferentially target larger, slow growing individuals (Link 2005). Furthermore, large species are often more vulnerable to a given level of fishing pressure due to low rate of population increase associated with low productivity and a k-selected life history strategy (Jennings et al. 1998). Longer-term consequences of removing large, slow growing individuals may be evolutionary shifts in the traits exhibited by targeted species, for example reduction in size and age at maturity (Shin et al. 2005). Thus varying levels of fishing pressure may be expected to drive differences in the life history composition of fish communities (Winemiller 2005). It is expected that fast growing, rapidly maturing species will be found in heavily fished areas, whereas slow growing, late maturing species will be more prevalent in lightly fished, or unexploited areas (King and McFarlane 2003, Winemiller 2005).

Work evaluating the impact of fishing on life history traits in coral reef fish communities has been gathering momentum in recent years (e.g. Taylor 2014, Vallès and Oxenford 2014). Studies looking at vulnerability of certain traits with respect to fishing have highlighted a narrow range of primarily, size-based traits as the most useful indicators of vulnerability (Taylor et al. 2014). In contrast, research looking at the relationship between fishing protection and shifts in life history traits over time suggest a wide range of traits are good indicators of fishing effects (McClanahan and Humphries 2012). Currently more work is needed in this area across a broader range of traits, coral reef locations and fisheries.

Relevant Management Issue[5]

Overfishing of key species; species at high risk; changes in catch composition; overexploitation of juveniles of most reef fish species.

[5] In steps 2 and 3 methods introduced in concert with relevant management themes, these represent themes identified in the Mahe Plateau draft management plan (supplied by SFA) and thus indicators were chosen and developed to fit within these themes.

Aim

To understand how fishing is affecting the life history structure of fish communities.

Methods

All life history indicators were estimated for the community (sample) as a whole. No metrics were estimated at the focal species level as these indicators are not applicable at the species level. For each of the following traits, the mean trait value was estimated: maximum body length, growth rate (K parameter from von Bertalanffy growth curve), natural mortality, life span, generation time, age at maturity, length to achieve optimum yield. For each species, values for these traits were sourced from the literature (e.g. Froese and Pauly 2012). We used fixed trait values for each species over time, and thus the analysis was focused on how changing relative species' abundances within the community affects mean trait values, as opposed to how trait values for each species is changing over time. This latter approach would require observational data on trait values, data that are unavailable for Seychelles fringing reef fish communities at this time.

4-2 Temporal trends in indicators

Methods: Community-level indicators

The indicators were estimated for each site in each year. Then we assessed the presence of positive or negative temporal trends (1994-2014) in indicator values at each site using spearman rank correlations (following Blanchard et al. 2005). We evaluated these relationships at the site and region level. To assess whether the lack of a trend over time was reflective of no signal or the inability to detect a signal, the power of each test was estimated (p value =0.05, n=5; pwr package in R).

Methods: Focal-species indicators

The size and biomass indicators were estimated for the different focal species in each site in each year. Many of the species were not recorded in each year at each site, giving fewer than 4 data points; therefore it was not possible to calculate spearman rank correlations between indicator values and year for each site. Here we provide the regional trends for three primary or important target species that were observed fairly regularly within the UVC dataset (see table 3 for more information): *Chlorurus sordidus*, *Scarus rubroviolaceus* (Kakatawa Rouz) and the grouped species *Siganus argenteus* (Kordonnyen Soulfanm) and *Siganus sutor* (Kordonnyen Blan). Only biomass trends are provided for *S. rubroviolaceus* and *S. argenteus/S. sutor* as there were insufficient data to calculate size indicator trends over time.

Results: Community-level indicators

At both the site and regional level, there is considerable variation in the trends found for the different indicators (Figure 7-14). These trends are summarized at the site level in Figure 15; the majority of trends were negative over time for the size-based indicators but were positive for the functional indicators and biomass. The life-history indicators were highly variable. Similar patterns were seen at the region level (Figure 16). A number of trends are worth examining more closely: i) mean size of the community generally declines over time at most of the sites (Figure 7) and regions (Figure 11), with important exceptions at sites/regions designated as no-take areas (Cousin and Ste

Anne; Figure 11). ii) The mean size to maximum size ratio and mean size to size at maturity ratio show consistent declines; this pattern is seen most clearly in the regional trends (Figure 11). iii) Herbivore biomass consistently increases over time across all regions (Figure 13).

Few trends were found to be significant (summarized in Figures 15 and 16), but importantly, this is likely due to insufficient power to detect a trend rather than due to the lack of a trend, with few of the power analyses showing a power of 0.8 or greater (Appendix 5-6). The influence of power can be seen most clearly by comparing significance values in Figure 16 with power values in Appendix 6: relationships for those indicators and regions with good power invariably showed significant trends. At both the site and the regional level the life-history indicators showed the lowest power. The remaining three groups of indicators (size, biomass and function) performed slightly better with greater power to detect correlations. These results suggest that over the time-scale of the UVC data, the life-history indicators may be the least useful in highlighting trends in the fish community. Nonetheless, interpretation of trends in the indicators is currently constrained by this lack of power across all indicators.

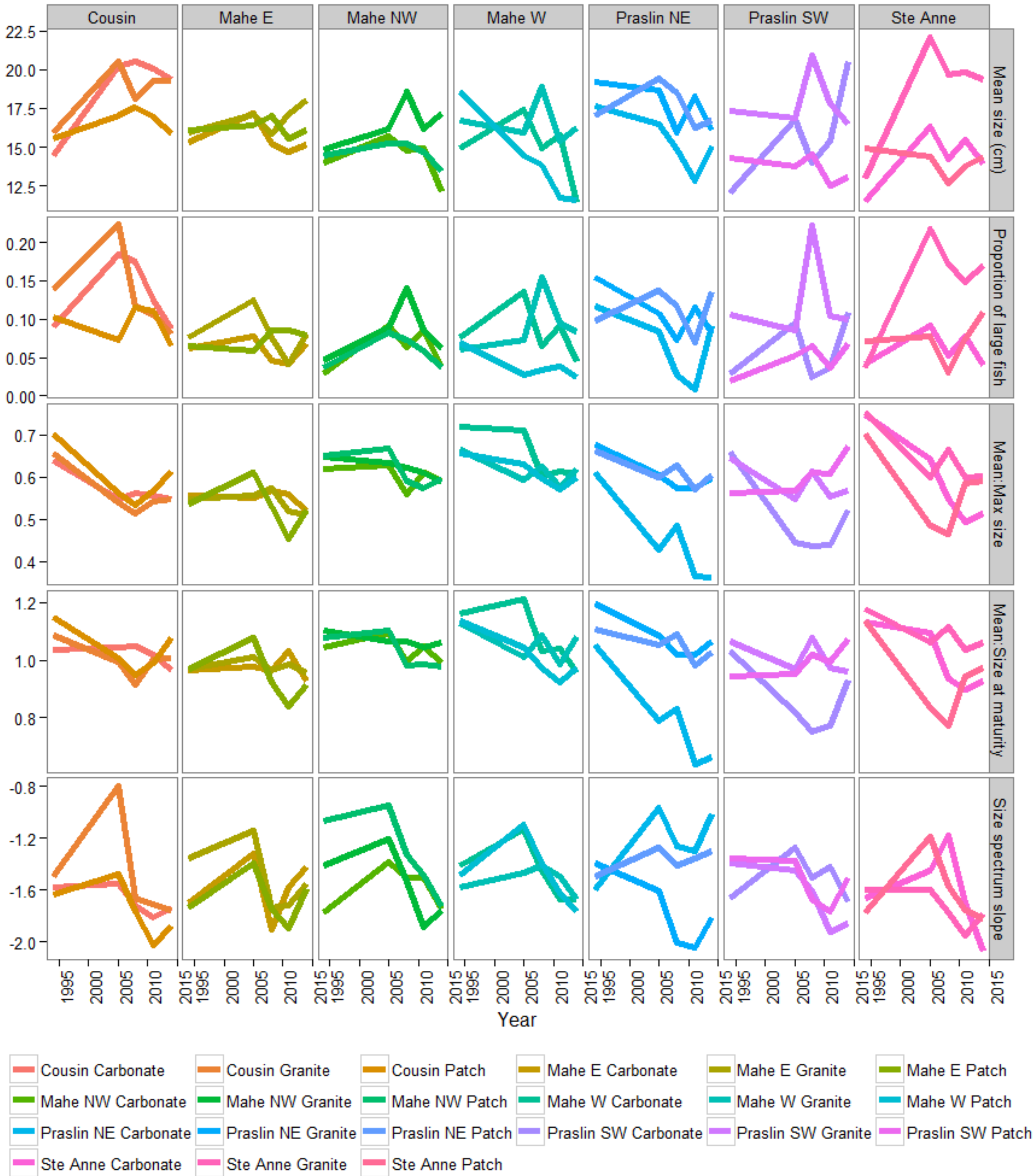


Figure 7: Trends in size-based indicators over time at each site, grouped into region. Region-level means are presented in Figure 11.

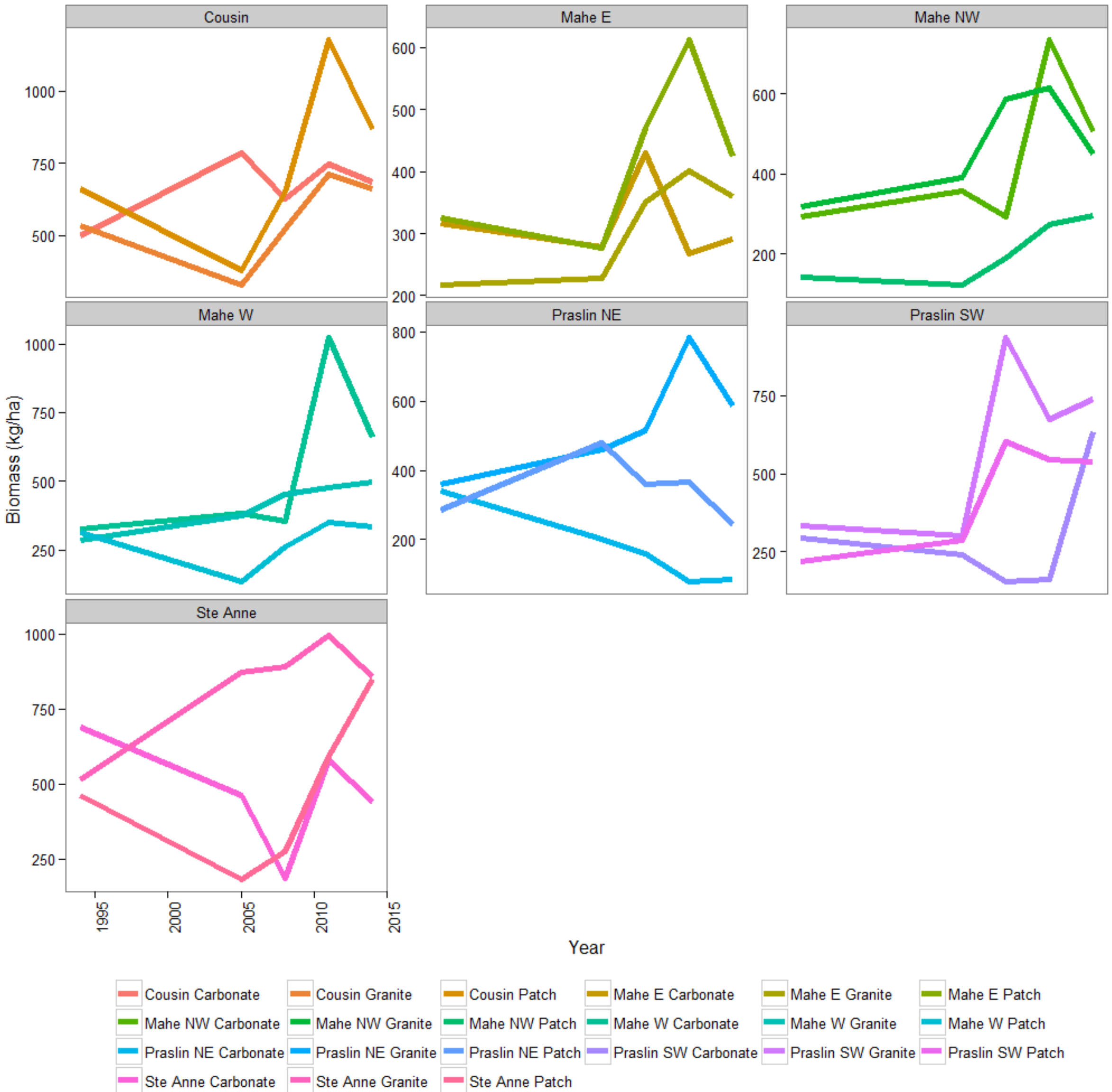


Figure 8: Trends in biomass indicator over time at each site, grouped into region. Region-level means are presented in Figure 12.

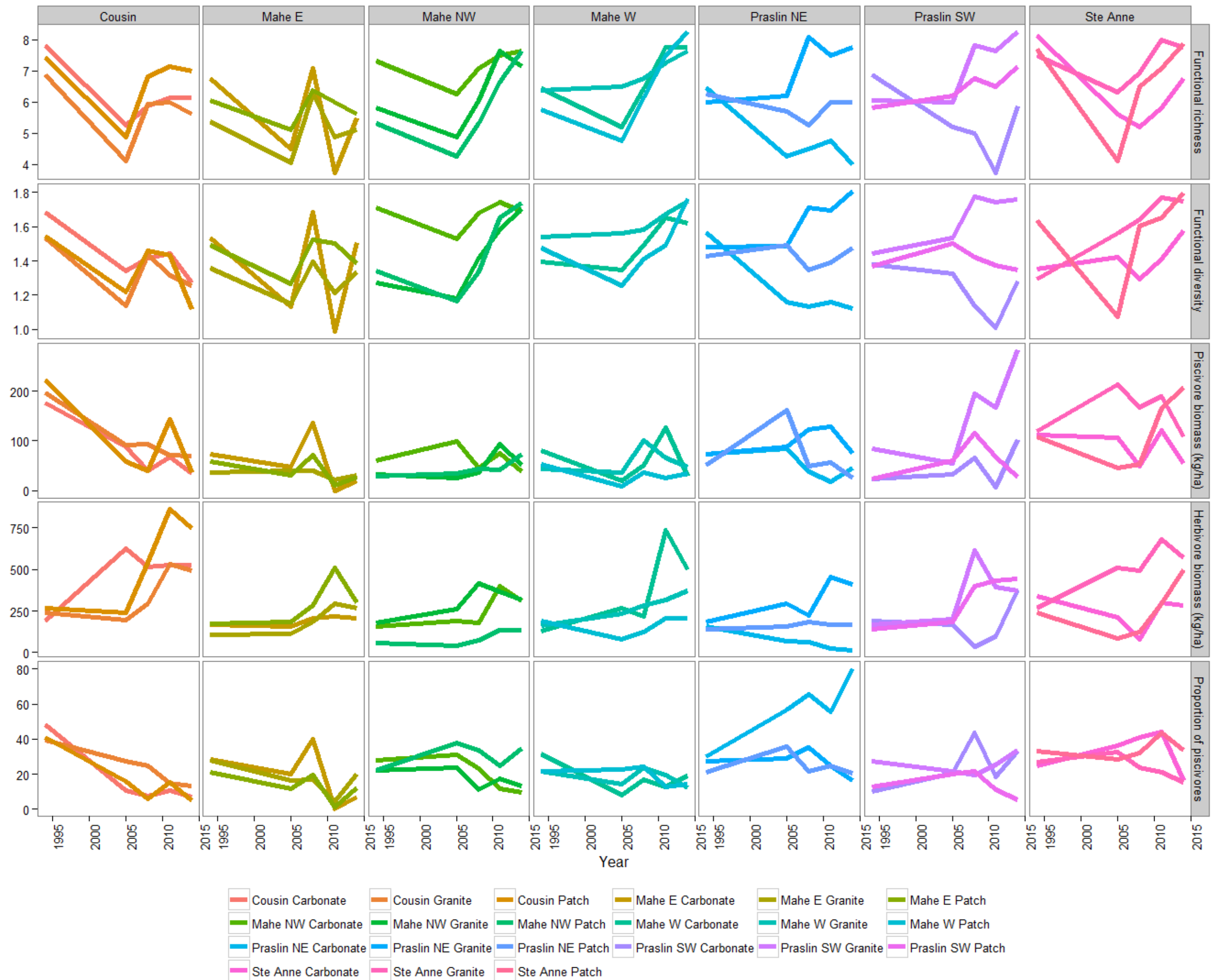


Figure 9: Trends in functional indicators over time at each site, grouped into region. Region-level means are presented in Figure 13.

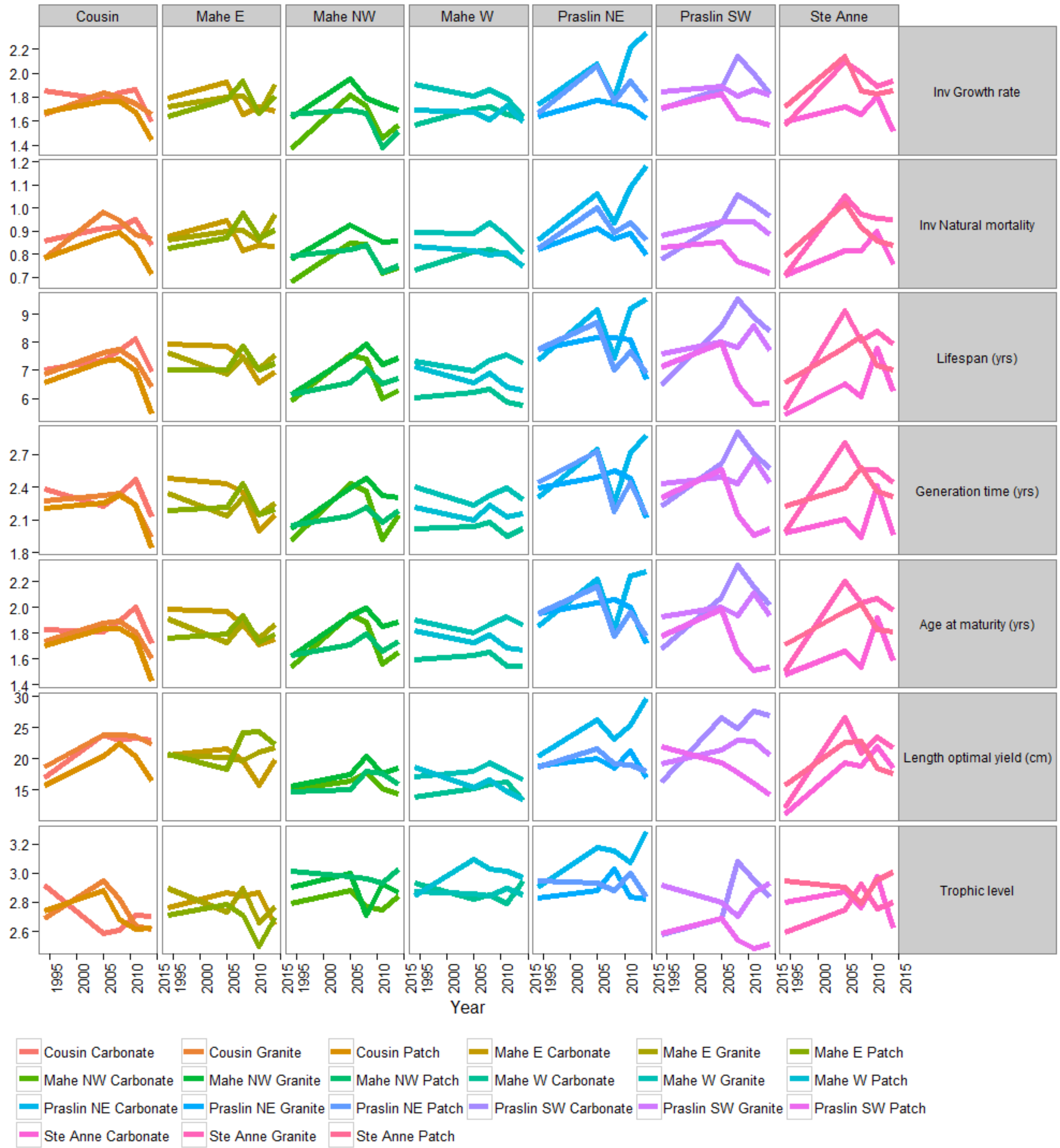


Figure 10: Trends in life-history indicators over time at each site, grouped into region. Growth rate and natural mortality are presented as inverse metrics to standardise the expected effect of fishing – all indicators are expected to decline in response to fishing pressure. Region-level means are presented in Figure 14.

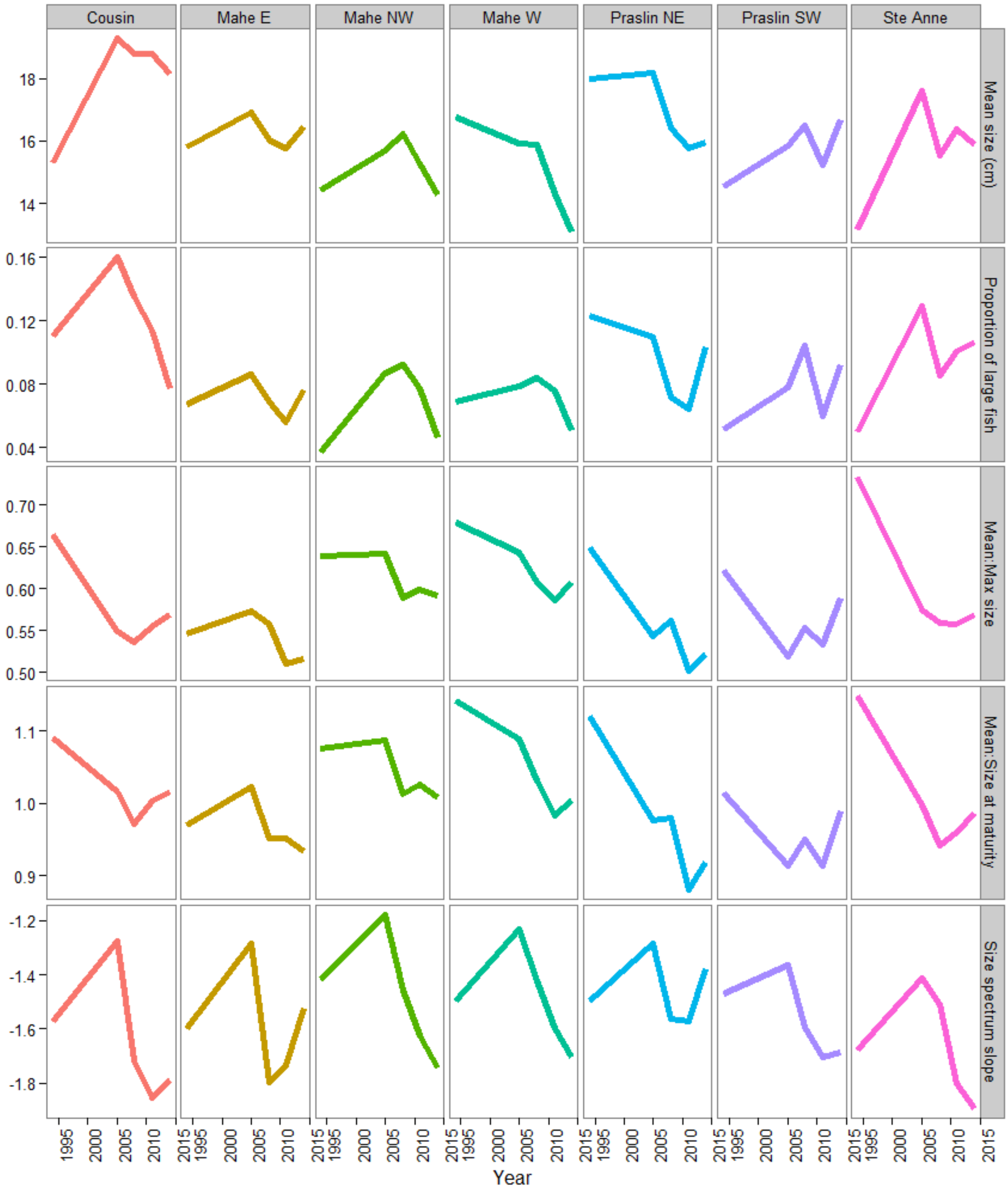


Figure 11: Trends in size-based indicators over time in each region.

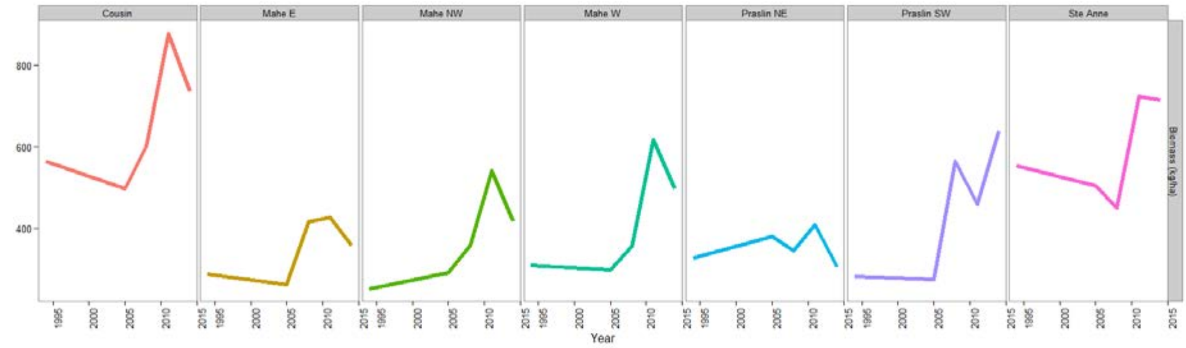


Figure 12: Trends in biomass indicator over time in each region.

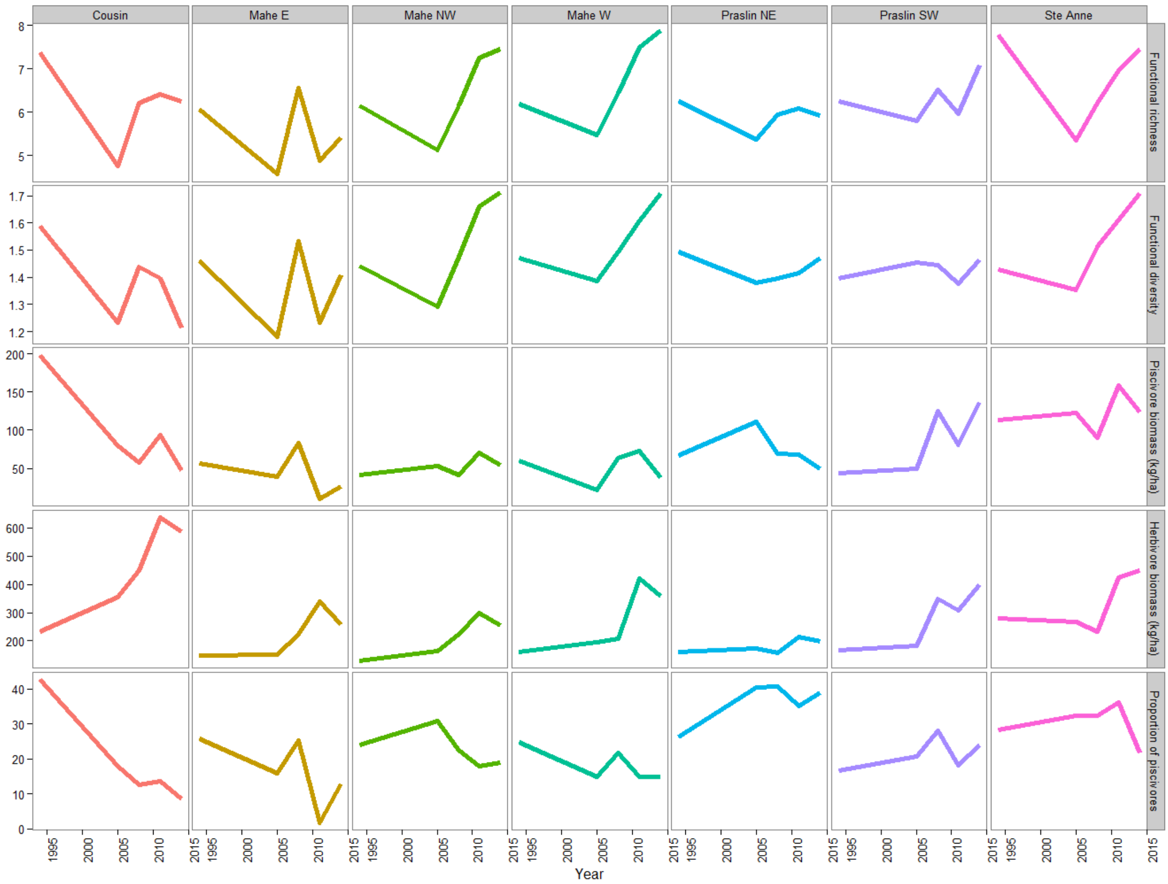


Figure 13: Trends in functional indicators over time in each region.

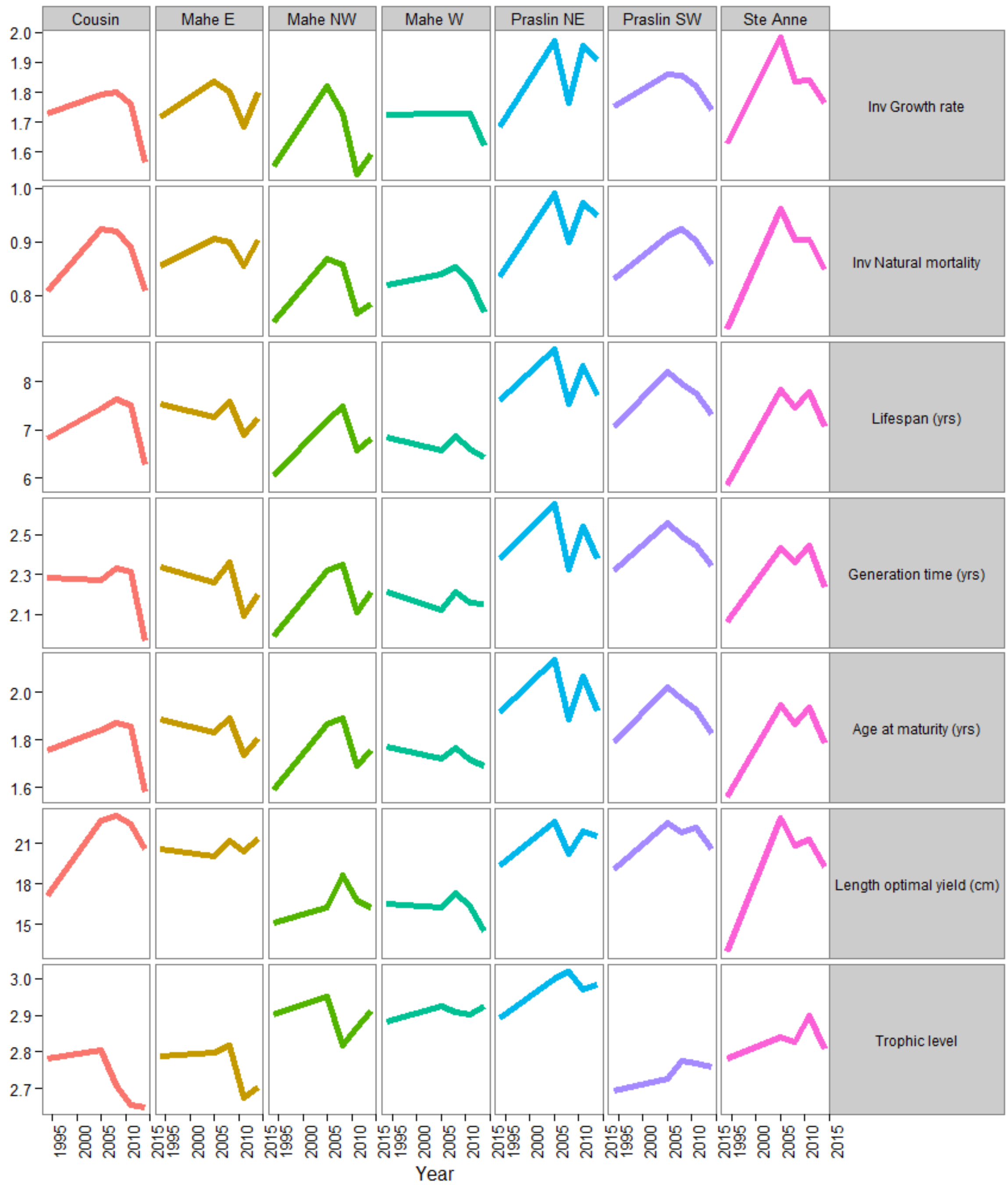


Figure 14: Trends in life-history indicators over time in each region. Growth rate and natural mortality are presented as inverse metrics to standardise the expected effect of fishing – all indicators are expected to decline in response to fishing pressure.

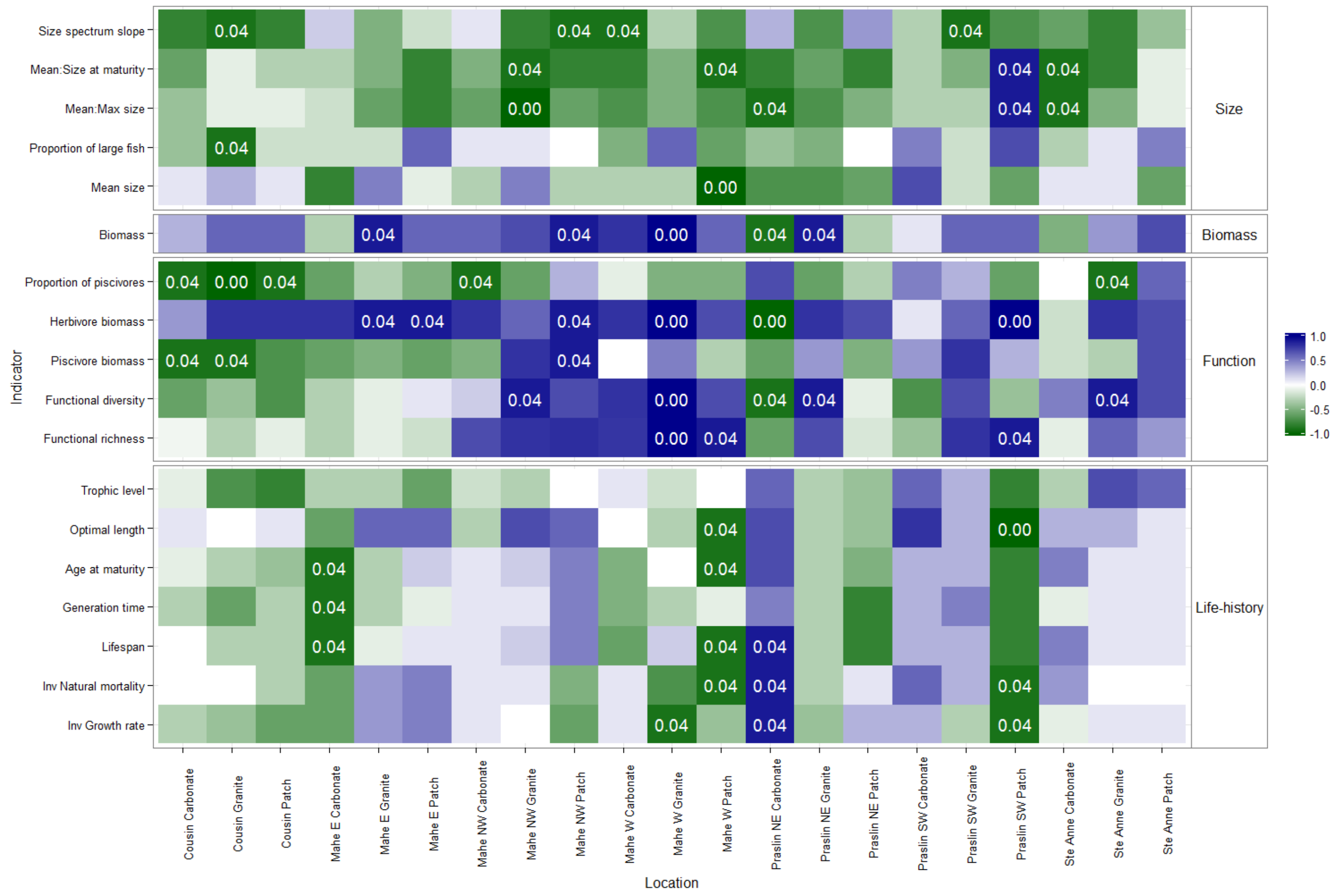


Figure 15: Correlations between time and the different indicators at the site level. Colours indicate correlation coefficients. Significant correlations (<0.05) are indicated in text. Growth rate and natural mortality are presented as inverse metrics to standardise the expected effect of fishing – all indicators are expected to decline in response to fishing pressure. Optimal length is the length to achieve optimum yield.

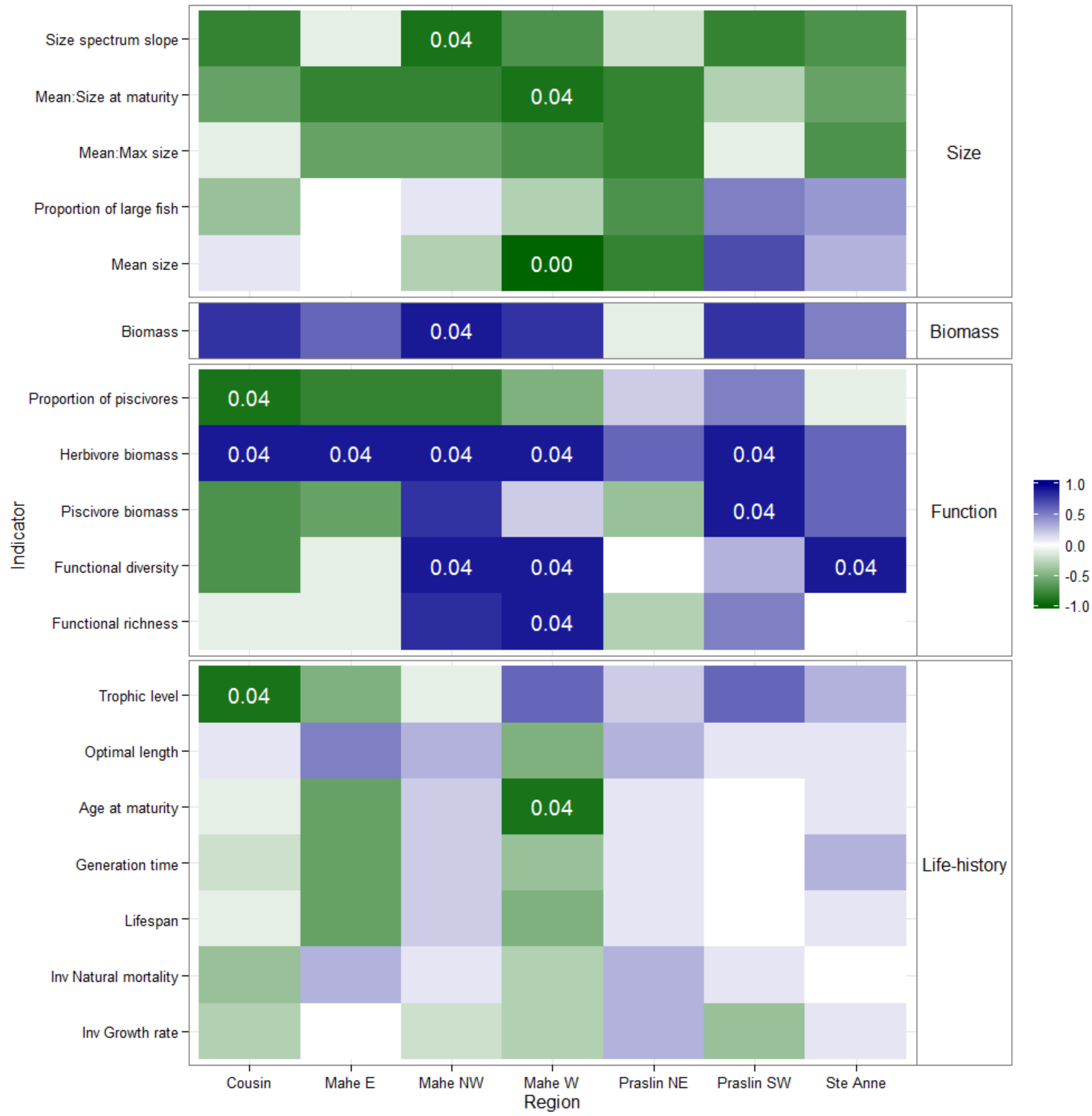


Figure 16: Correlations between time and the different indicators at the region level. Colours indicate correlation coefficients. Significant correlations (<0.05) are indicated in text. Growth rate and natural mortality are presented as inverse metrics to standardise the expected effect of fishing – all indicators are expected to decline in response to fishing pressure. Optimal length is the length to achieve optimum yield.

Results: Focal-species indicators

Chlorurus sordidus

Biomass (kg/ha) appears to be increasing fairly consistently over time in all regions, although only one of these relationships was significant (Figure 17). The proportion of total fish biomass provided by *C. sordidus* increased (non-significantly) across most regions, but appears to be declining around Praslin. Whereas the size indicators tended to decrease (non-significantly) around Praslin and Mahe W and increase at the other sites (mostly non-significantly) Once again, the few significant relationships were due to low statistical power (Appendix 7).

Scarus rubroviolaceus

Biomass (kg/ha) appears to be increasing fairly consistently over time in all regions, although none of these relationships were significant (Figure 18). The proportion of total fish biomass provided by *S. rubroviolaceus* increased (mostly non-significantly) across most regions. Once again, the few significant relationships were due to low statistical power (Appendix 8).

Siganus argenteus & S. sutor group

Biomass (kg/ha) appears to be increasing in high compliance no-take areas but is decreasing across most other regions over time, although only the increase in the high compliance no-take area was significant (Figure 19). The proportion of total fish biomass provided by the *S. argenteus* and *S. sutor* group follows a similar pattern. Once again, the few significant relationships were due to low statistical power (Appendix 9).

Recommendations: Temporal trends in indicators

1. These findings suggest more data need to be collected, both at the fish community level and for individual target species, to allow more in-depth analysis of trends, but also to increase the power of these analyses. Currently, the low power for many of the tests means that it is difficult to tease apart the lack of a trend from the inability to detect a real trend.
2. Biomass data may show increases over time, suggesting a sustainable fishery, however size-based indicators often show that even where biomass is increasing, the size of fishes within the community or population is declining. Future analysis of changes in the fish community need to combine biomass and size-based findings to ensure a representative picture of changes in the fish community is provided.

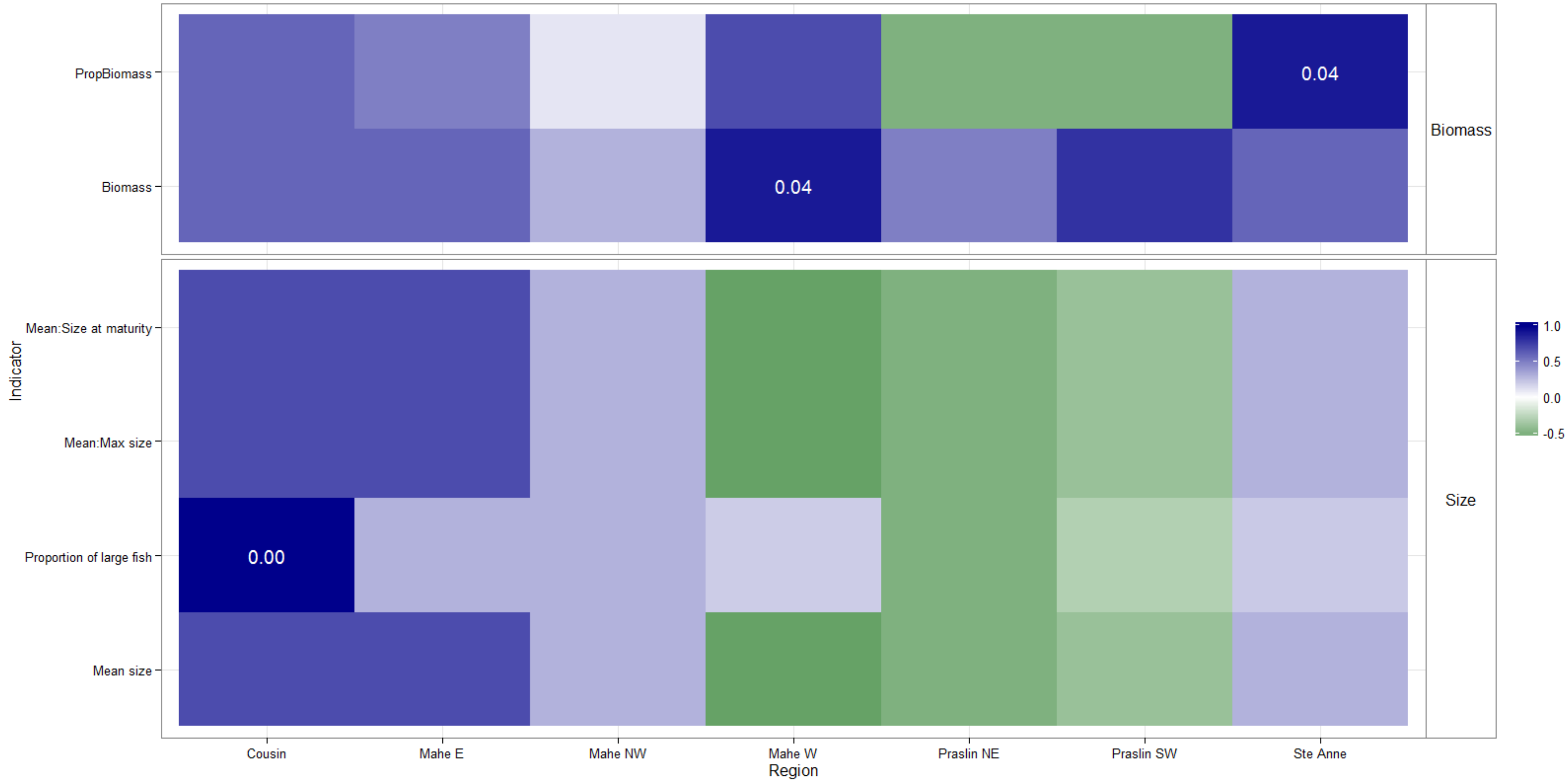


Figure 17: Correlations between time and the different indicators at the region level for *Chlorurus sordidus*. Colours indicate correlation coefficients. Significant correlations (<0.05) are indicated in text. Propbiomass represents the proportion of total fish biomass contributed by *Chlorurus sordidus*.

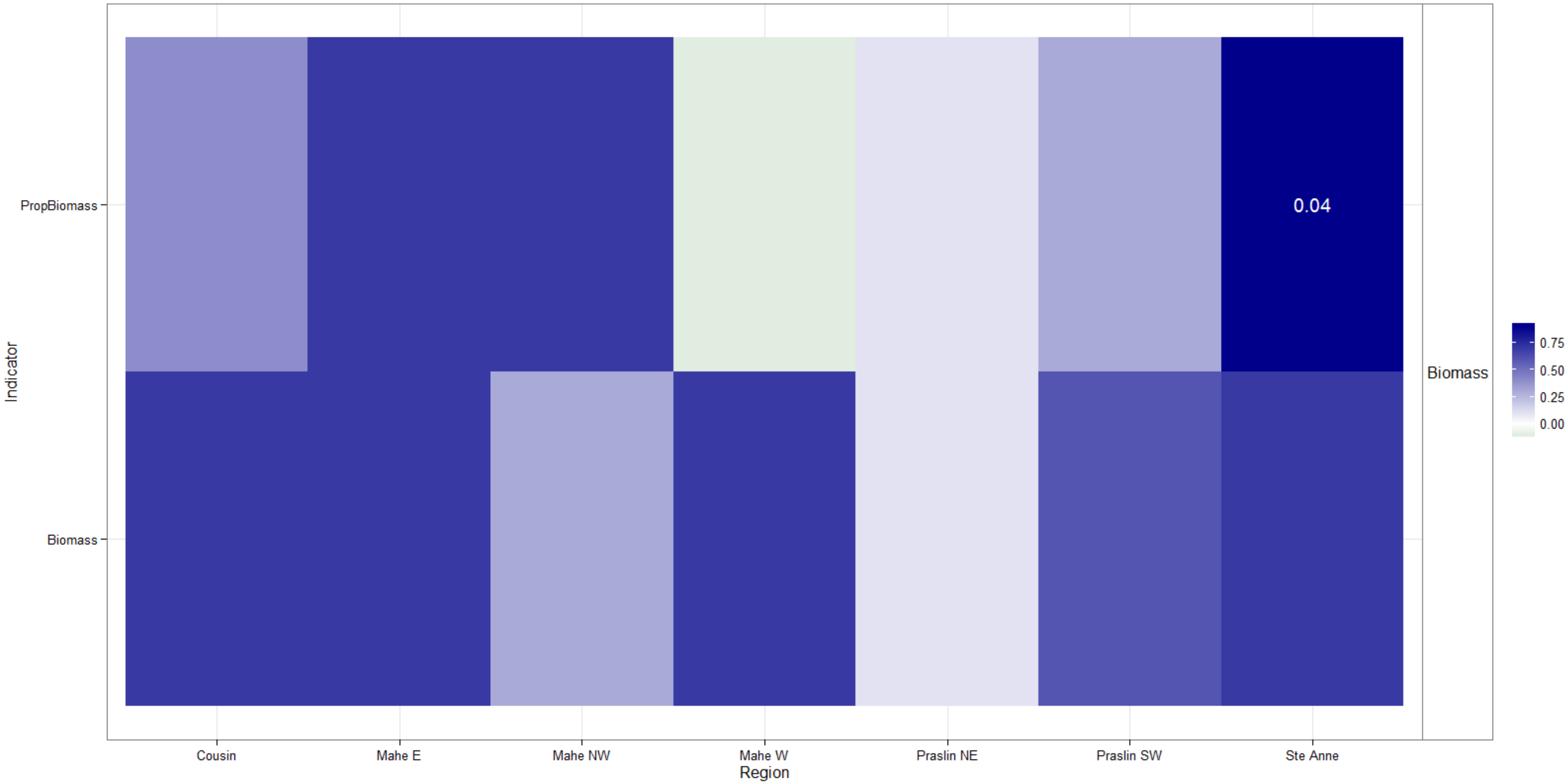


Figure 18: Correlations between time and the different indicators at the region level for *Scarus rubroviolaceus*. Colours indicate correlation coefficients. Significant correlations (<0.05) are indicated in text. Propbiomass represents the proportion of total fish biomass contributed by *Scarus rubroviolaceus*. Size indicators are not shown as there were insufficient data to estimate trends using spearman rank correlations.

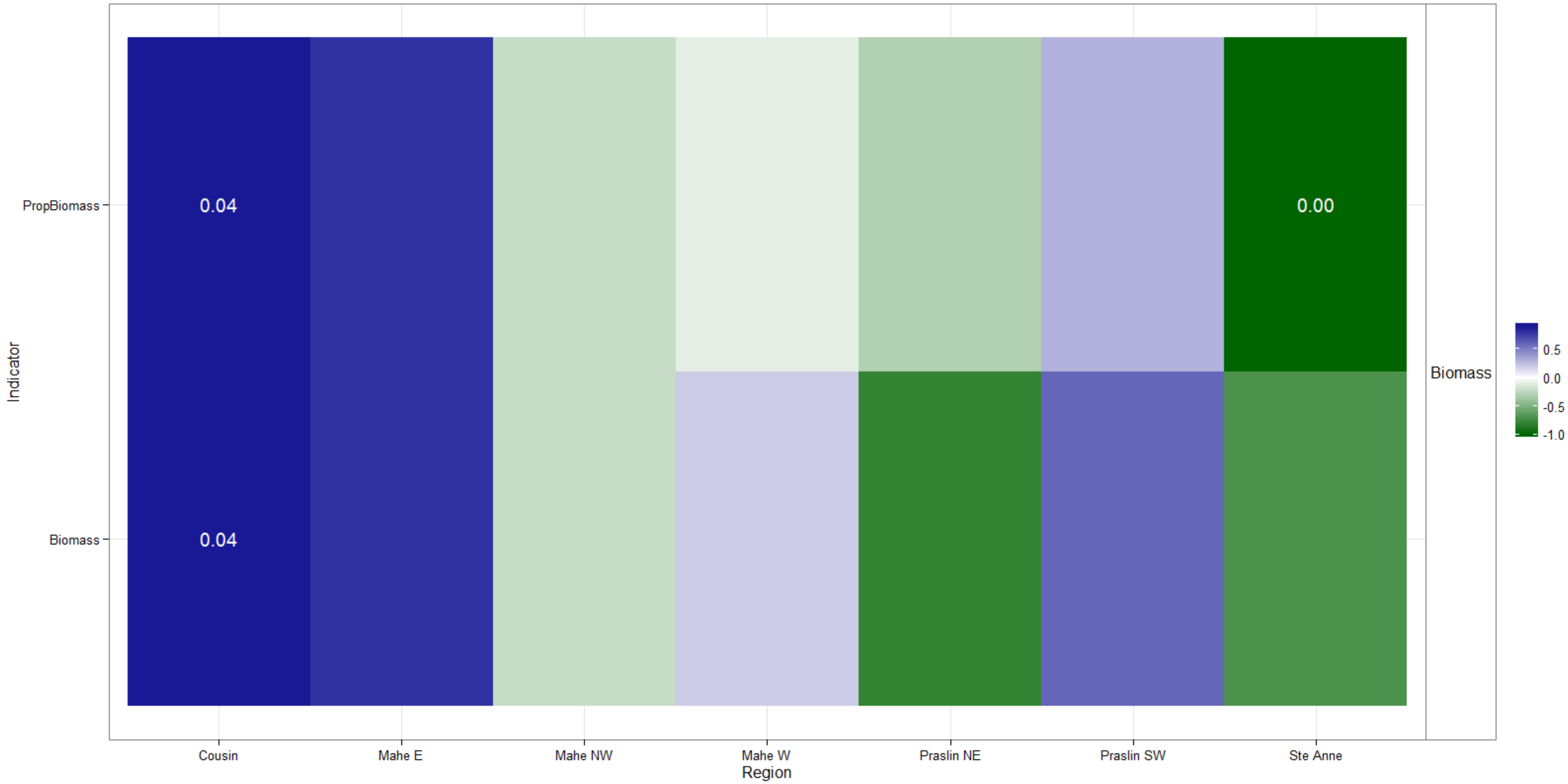


Figure 19: Correlations between time and the different indicators at the region level for the *Siganus argenteus* and *Siganus sutor* group. Colours indicate correlation coefficients. Significant correlations (<0.05) are indicated in text. Propbiomass represents the proportion of total fish biomass contributed by *Siganus argenteus* and *Siganus sutor*. Size indicators are not shown as there were insufficient data to estimate trends using spearman rank correlations.

4-3 Redundancy of indicators

Some of the indicators we estimated address similar ecosystem and fish community attributes and thus capture overlapping information. Identifying the degree of overlap among indicators can be used to highlight suites of indicators than may be represented by a single metric, reducing the costs of future data collection and analysis.

Methods

Pairwise spearman rank correlations were calculated among all the different indicators. Spearman rho values of ≥0.80 was considered to indicate a strong correlation.

Results

A number of the indicators were correlated (rho ≥ 0.80; Appendix 10). From each pair of correlated variables, we selected one indicator for future analyses: proportion of large fish, mean size: size at maturity, functional diversity, biomass, growth rate, natural mortality, generation time and age at maturity were excluded from future analyses. These indicators were chosen for exclusion as they required more information to calculate, showed more variable trends over time or could be replaced by fewer variables where multiple collinearity among variables was found.

Recommendations: redundancy of indicators

1. A number of the size-based, functional and life-history indicators were correlated and therefore not all indicators need be calculated in the future: proportion of large fish, size at maturity, functional diversity, biomass, growth rate, natural mortality, generation time and age at maturity may be excluded.

4-4 The relative influence of the benthos and fishing pressure on indicators

Methods: Community-level indicators

To assess the relative impact of fishing pressure versus benthic variables on spatial trends in our indicators, we modelled indicator values for 2014 as a function of one of our fishing pressure proxies: Proxy 2, and the benthic composition using multiple regressions.

Fishing proxy 1 was not used in the analyses as this metric was only available at the regional level, and was correlated with proxy 2 (at the regional level). Proxy 3 was collinear with proxy 2 and so was also excluded. Proxy 2 was averaged across years to give an indication of differences in fishing pressure among sites integrated across time. These data were averaged due to high variability in the fishing data over time, such that a single snapshot of catch at a particular site in a particular year did not effectively capture historical fishing pressure. As we have a small number of sites and thus data points for use in the analyses, we used a principle component analysis (PCA) to condense the benthic variables (different types of coral cover, algae cover and structural complexity) into two PCA axes variables for use in the regression analysis (Figure 20). PCA values for sites in 2014 were extracted and used to understand effects of the benthos on the dependent variables. To ensure assumptions of the models were met we log transformed PC2. Sites were located in two habitat types: granitic reefs and carbonate reefs. These habitat differences were predominantly captured by the PCA of the benthic variables, particularly PC2, therefore we did not include habitat as a separate variable in the regression. Furthermore, since the 1998 bleaching event, some sites have degraded over time, becoming dominated by macroalgae (phase-shifted), whereas other sites have recovered to being coral-dominated (recovering). The state of the reef (phase-shifted vs recovering) was collinear with PC1, and therefore reef state was not included in the regression as an additional explanatory variable.

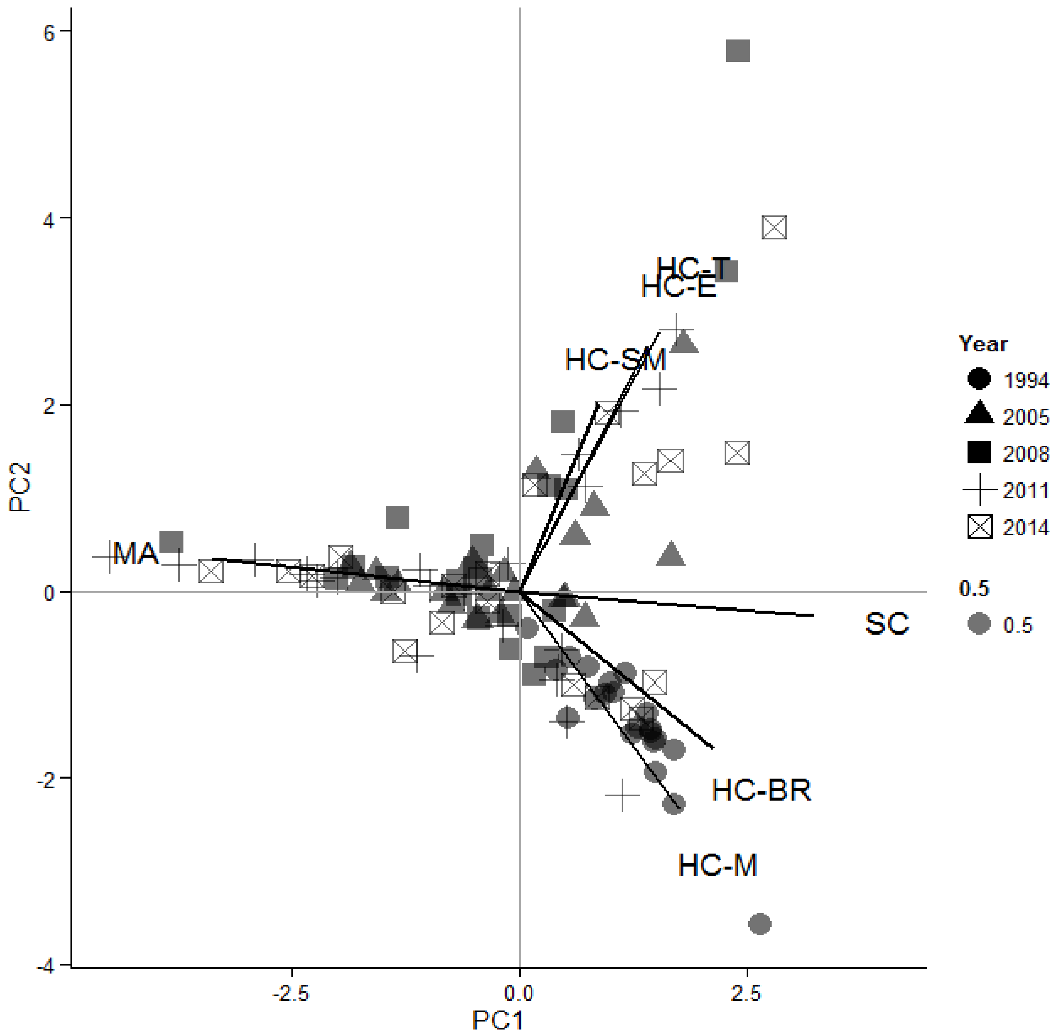


Figure 20: Principle component analysis of benthic variables. Symbols represent sites in different years. MA is macroalgae, SC is structural complexity, HC is hard coral of a specific lifeform: T is tabular, E is encrusting, SM is submassive, BR is branching and M is massive. PC1 explains 31% and PC2 explains 24% of the variation among sites.

Regressions of all possible models within the global model (~PC1+log10(PC2+1)+ Proxy2 were compared using Akaike Information Criteria adjusted for small sample sizes (AICc), for each dependent variable. Where relationships appeared to be non-linear, polynomial models were also assessed and compared to linear fits using AICc values. Model averaging of all models within 7 AICc units of the best-fit model was performed and these coefficients are presented (Burnham et al. 2011). Details of model selection including AICc values and weights are also provided.

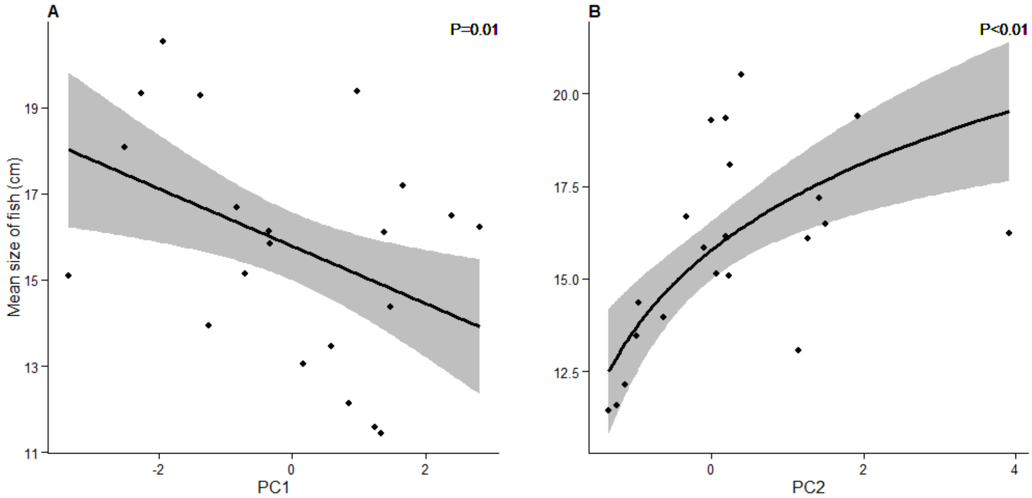
Methods: Focal-species indicators

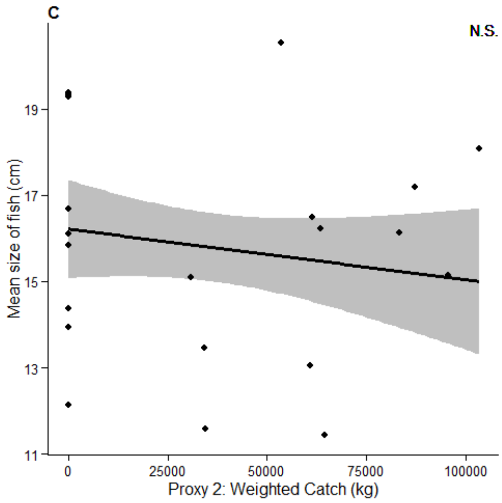
There were insufficient data to allow an analysis of the effects of fishing or the benthos on the size-based indicators for *Chlorurus sordidus* or *Scarus rubroviolaceus*. Similarly, there were insufficient data to allow analysis of the effects of fishing or the benthos on any of the indicators estimated for the *Siganus argenteus* - *Siganus sutor* group. There were strong correlations between biomass and proportion of biomass for *Chlorurus sordidus* and *Scarus rubroviolaceus*, therefore we only modelled the influence of the explanatory variables on the mean biomass (kg/ha) for these two species. Regressions were performed as per the community-level analysis.

Results: Community-level indicators

Size-based indicators – Mean size

PC1 and PC2 were in the best-fit model and were both significantly related to the mean size of fish, with mean size of fish being larger at sites with high macroalgae cover and low structural complexity and at sites with high cover of tabular, encrusting and submassive corals (Figure 21; Appendix 11). The benthic composition explained more of the variation in mean fish size than fishing pressure. As mean size was strongly, positively correlated with the proportion of large fish, the relationships between mean size and the different explanatory variables is likely to reflect their relationships with the proportion of large fish.





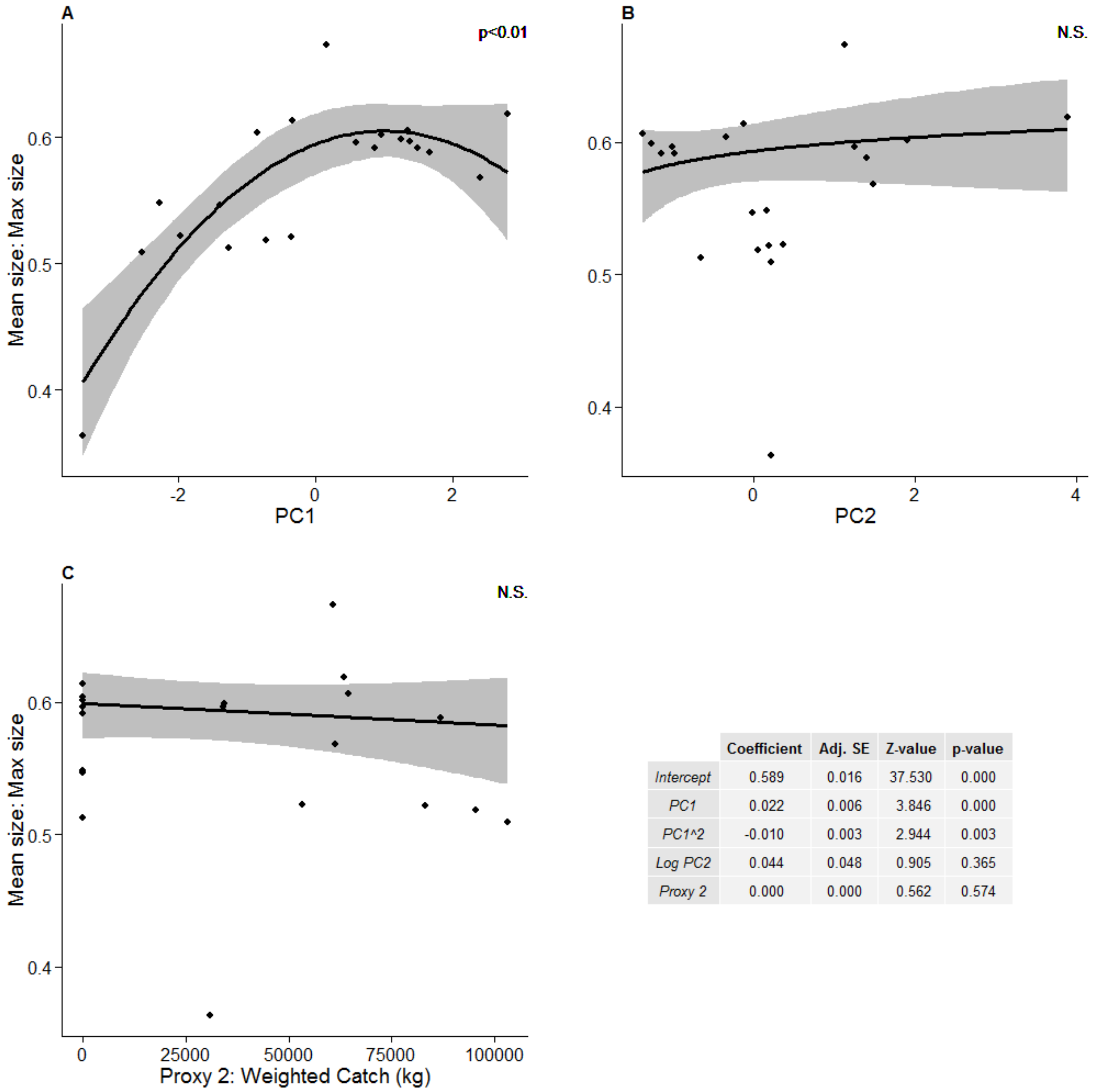
	Coefficient	Adj. SE	Z-value	p-value
Intercept	12.781	0.926	13.804	0.000
PC1	-0.671	0.260	2.579	0.010
Log PC2	8.370	2.179	3.842	0.000
Proxy 2	0.000	0.000	0.956	0.339

Figure 21: Partial effects of regressions between the mean size of fish at each site and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.52 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

We were interested in whether the decline in mean size of fish from low to high structural complexity was a function of few large fish at the high complexity sites (+PC1), or due to few small fish at the low complexity sites (-PC1). Examination of the distribution in fish body sizes across PC1 values indicates that the decline in mean size is predominantly driven by low abundance of small fish at negative PC1 values, rather than few large fish at positive PC1 values (Appendix 12). This suggests that although the mean size of fish in the community is lower at low macroalgae/high complexity sites, than at high macroalgae/low complexity sites, similar numbers of large fish are available to be caught by fishers at both ends of the benthic spectrum, and thus the potential to catch large fish isn't any greater at the macroalgal sites than at the coral sites.

Size-based indicators – Mean size: Maximum size ratio

PC1 was the only term in the best-fit model, in the form of a quadratic relationship (Appendix 11). Mean size increased in relation to maximum size, from sites with high macroalgae cover to sites with mid-high structural complexity (Figure 22). The benthic composition was a stronger driver of the mean to maximum size ratio in the fish community than fishing pressure. As the ratio between mean size and size at maturity within the community was strongly, positively correlated with mean to maximum size ratio, the ratio between mean size and size at maturity is also likely to reflect changes in the benthic composition rather than fishing pressure.

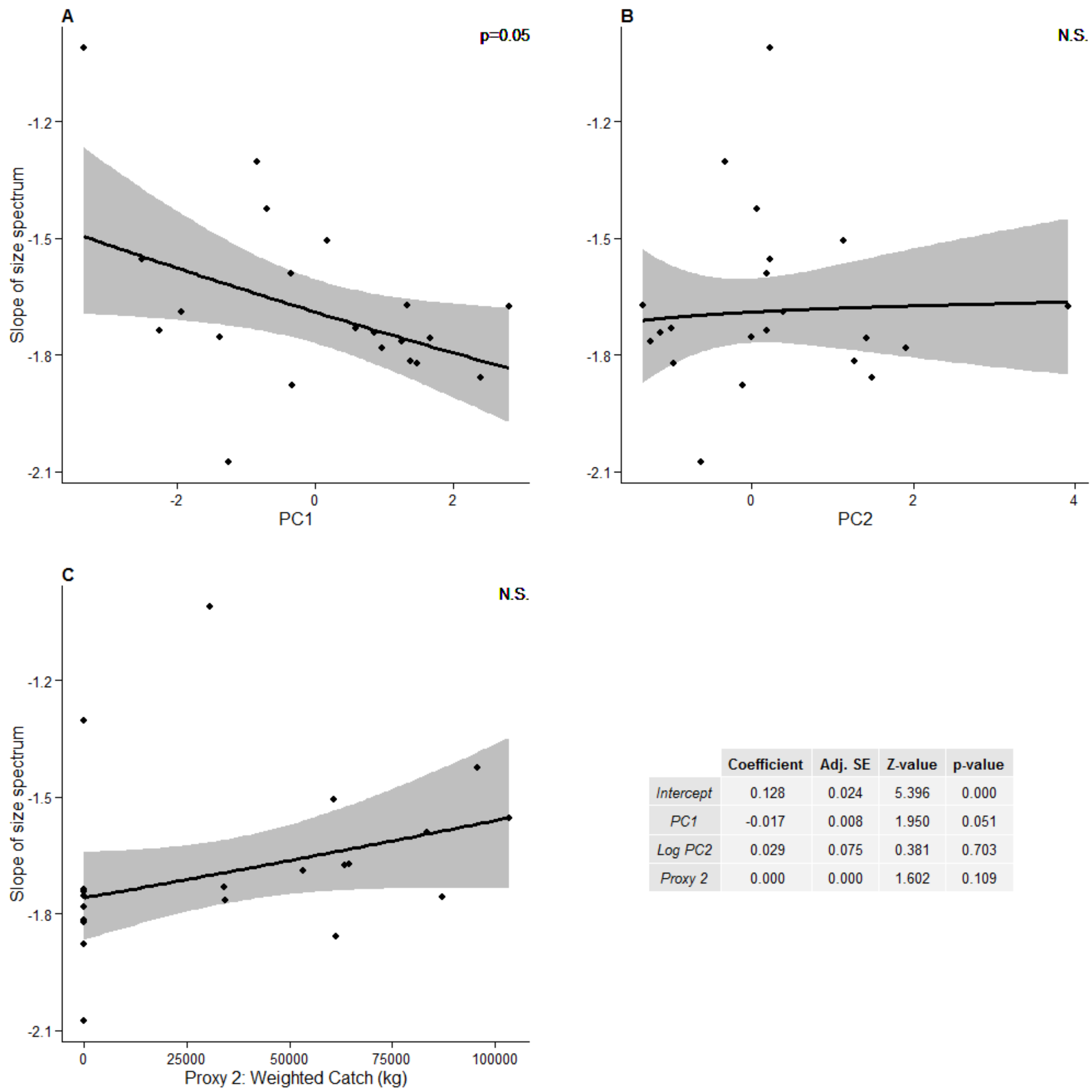


	Coefficient	Adj. SE	Z-value	p-value
Intercept	0.589	0.016	37.530	0.000
PC1	0.022	0.006	3.846	0.000
PC1^2	-0.010	0.003	2.944	0.003
Log PC2	0.044	0.048	0.905	0.365
Proxy 2	0.000	0.000	0.562	0.574

Figure 22: Partial effects of regressions between the mean size:maximum size ratio of fish at each site and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.63 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

Size-based indicators – Slope of the size spectrum

PC1 and proxy 2 were both in the best-fit model but neither term was significant, although PC1 was just not significant (0.051; Appendix 11). Thus, the slope of the size spectrum was becoming slightly more negative at sites with lower levels of macroalgae cover and higher structure complexity (Figure 23).



	Coefficient	Adj. SE	Z-value	p-value
Intercept	0.128	0.024	5.396	0.000
PC1	-0.017	0.008	1.950	0.051
Log PC2	0.029	0.075	0.381	0.703
Proxy 2	0.000	0.000	1.602	0.109

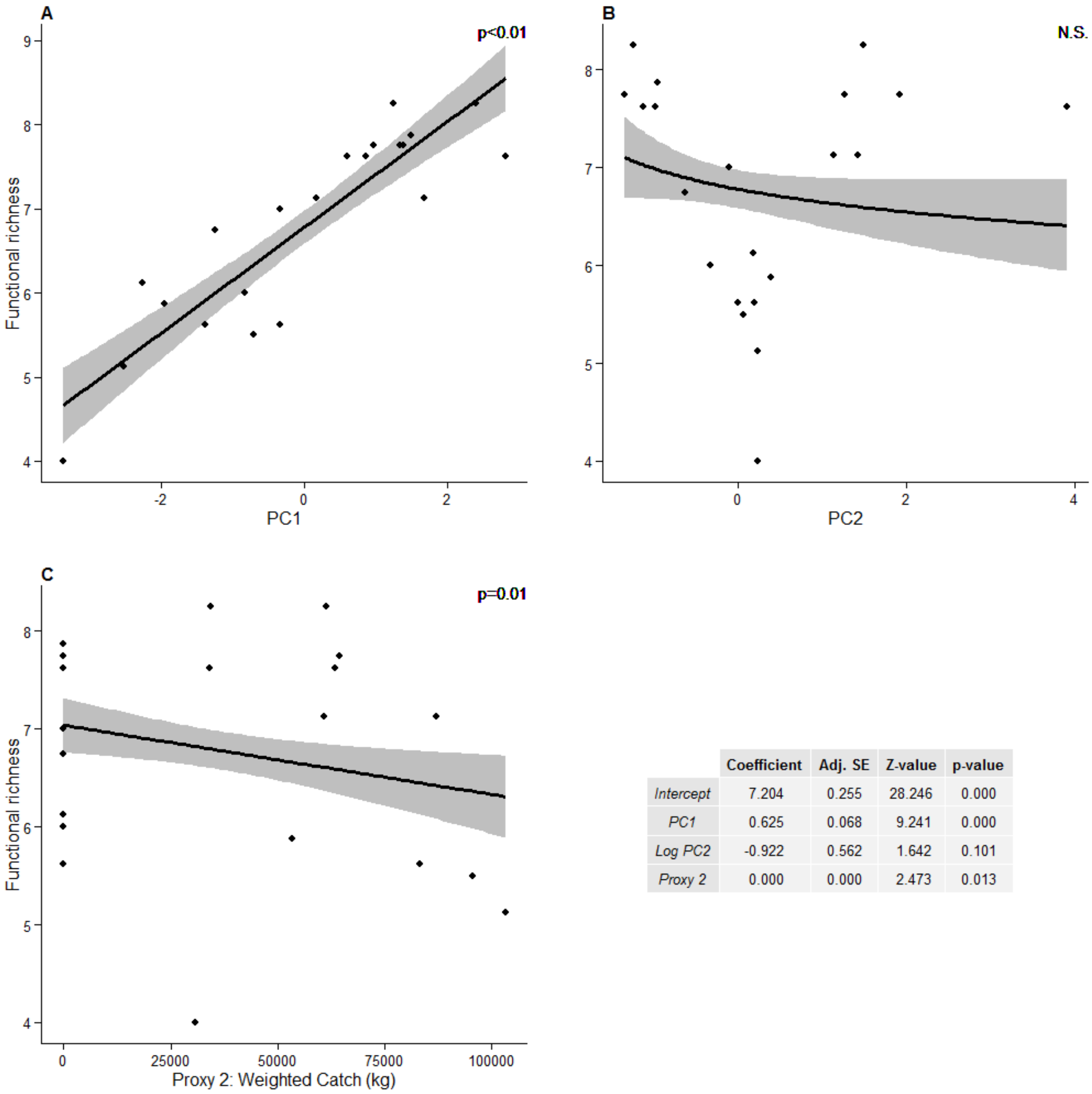
Figure 23: Partial effects of regressions between the slope of the size spectrum at each site and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.18 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

Biomass-based indicators

Biomass was strongly, positively correlated with herbivore biomass. Herbivore biomass was retained for the regression analyses and biomass of the whole fish community was not used (See section 3-3 on redundancy of indicators for more information).

Functional indicators – Functional richness

PC1 and proxy 2 were in the best-fit model and were significantly related to fish community functional richness (Appendix 11). Functional richness was higher at sites with high structural complexity and low macroalgae cover and at low fishing pressure (proxy 2) (Figure 24). Thus, both the benthos and fishing pressure affected the functional richness of the fish community. As functional diversity was strongly correlated with functional richness, functional diversity is also likely to reflect the structural complexity and algal cover of the reef, and fishing pressure proxy 2.

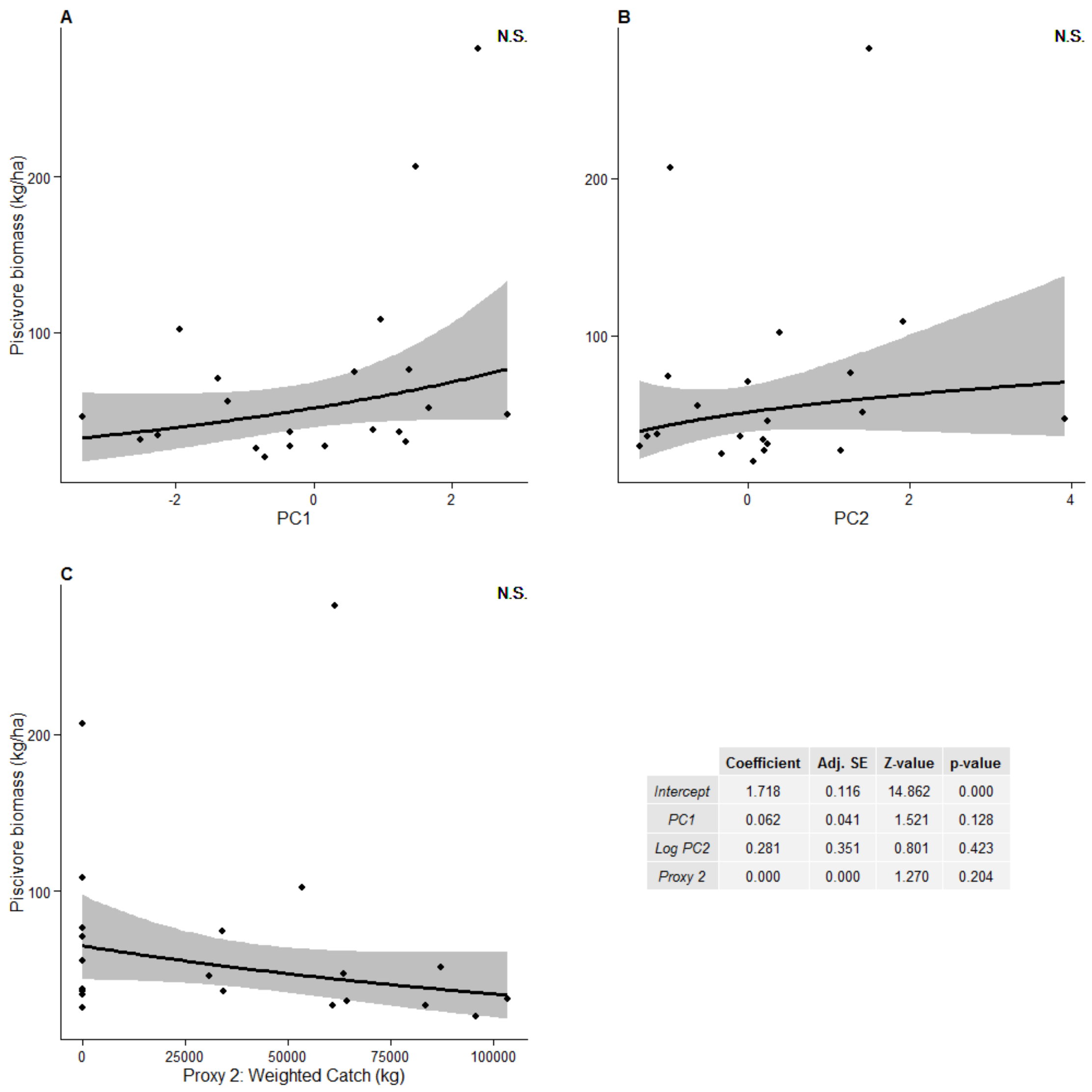


	Coefficient	Adj. SE	Z-value	p-value
Intercept	7.204	0.255	28.246	0.000
PC1	0.625	0.068	9.241	0.000
Log PC2	-0.922	0.562	1.642	0.101
Proxy 2	0.000	0.000	2.473	0.013

Figure 24: Partial effects of regressions between the functional richness of the fish community at each site and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.85 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

Functional indicators – Piscivore biomass per unit area

The optimal model was the null model with none of the variables included (Appendix 11). None of the benthic or fishing pressure variables were significantly related to piscivore biomass per unit area (kg/ha) (Figure 25).

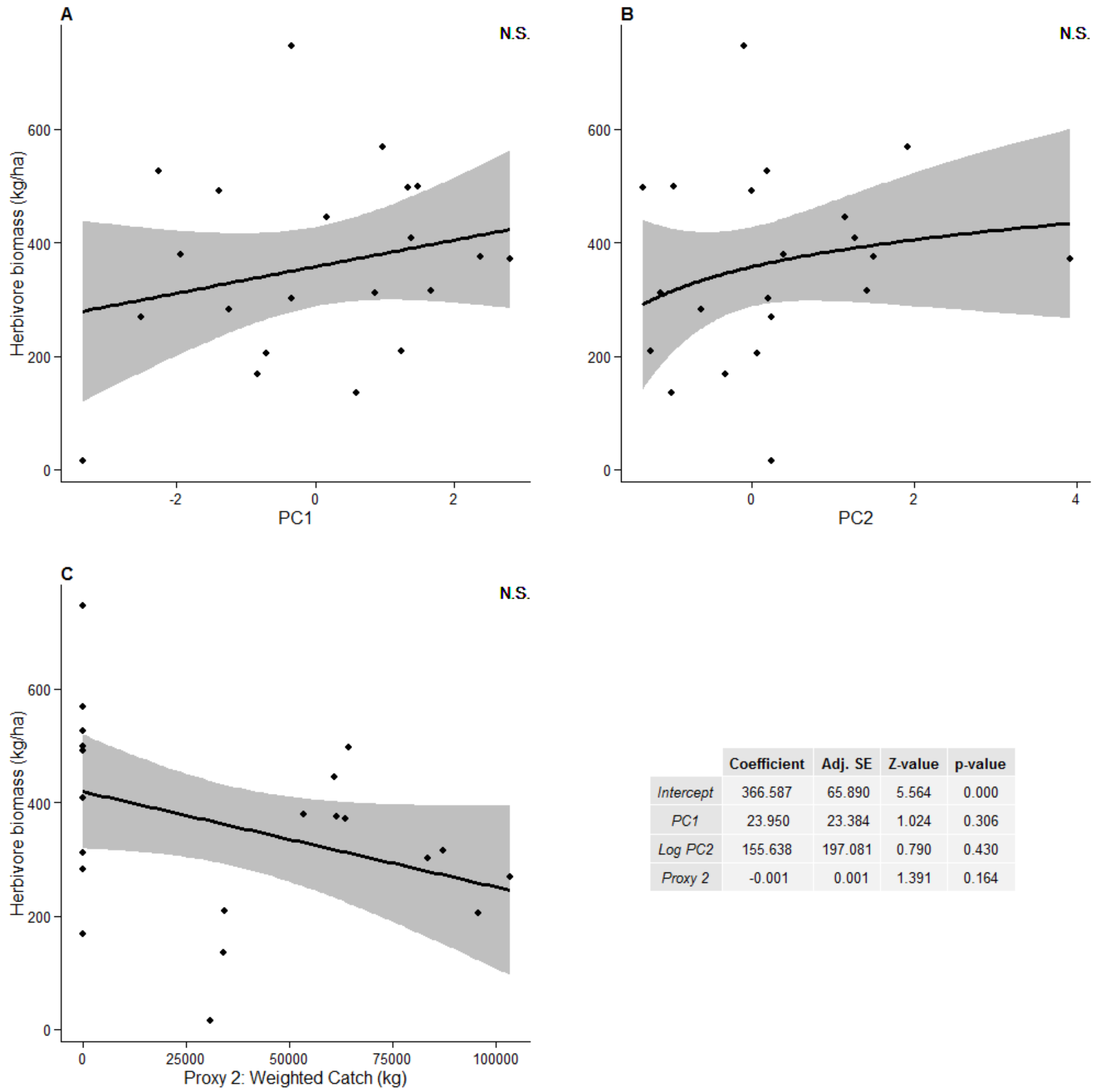


	Coefficient	Adj. SE	Z-value	p-value
Intercept	1.718	0.116	14.862	0.000
PC1	0.062	0.041	1.521	0.128
Log PC2	0.281	0.351	0.801	0.423
Proxy 2	0.000	0.000	1.270	0.204

Figure 25: Partial effects of regressions between piscivore biomass (kg/ha) at each site and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.12 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

Functional indicators – Herbivore biomass per unit area

The optimal model was the null model with none of the variables included (Appendix 11). None of the benthic or fishing pressure variables were significantly related to herbivore biomass (kg/ha) (Figure 26). Herbivore biomass was strongly, positively correlated with total fish biomass, thus total biomass is also likely to be unrelated to the benthic and fishing variables.

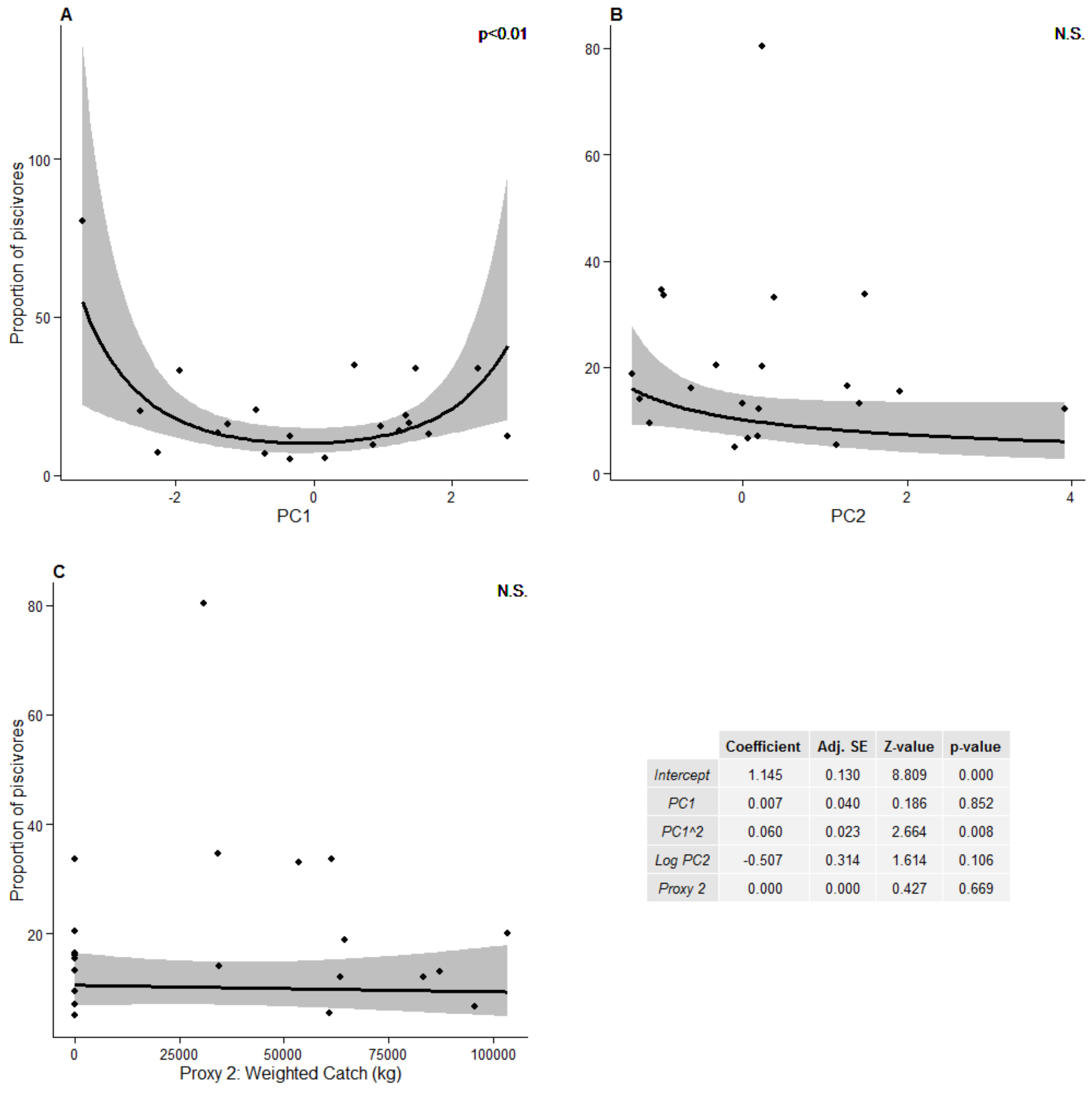


	Coefficient	Adj. SE	Z-value	p-value
Intercept	366.587	65.890	5.564	0.000
PC1	23.950	23.384	1.024	0.306
Log PC2	155.638	197.081	0.790	0.430
Proxy 2	-0.001	0.001	1.391	0.164

Figure 26: Partial effects of regressions between herbivore biomass (kg/ha) at each site and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.07 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

Functional indicators – Proportion of piscivore biomass

Piscivore biomass and herbivore biomass were not related to any of the benthic or fishing variables. However, when we examined how the proportion of piscivorous fishes (proportion in relation to total herbivore and piscivore biomass) changed in response to the different variables, clearer patterns were found. Both PC1 and PC2 were in the best model, although only PC1 was significantly related to the proportion of piscivores: a polynomial relationship was found between PC1 and proportion of piscivores (Appendix 11). At sites with either high structural complexity and low macroalgal cover, or sites with high macroalgae and low structural complexity there were greater proportions of piscivorous fishes in relation to herbivorous fishes, than at sites with moderate levels of either macroalgae or structural complexity (Figure 27).

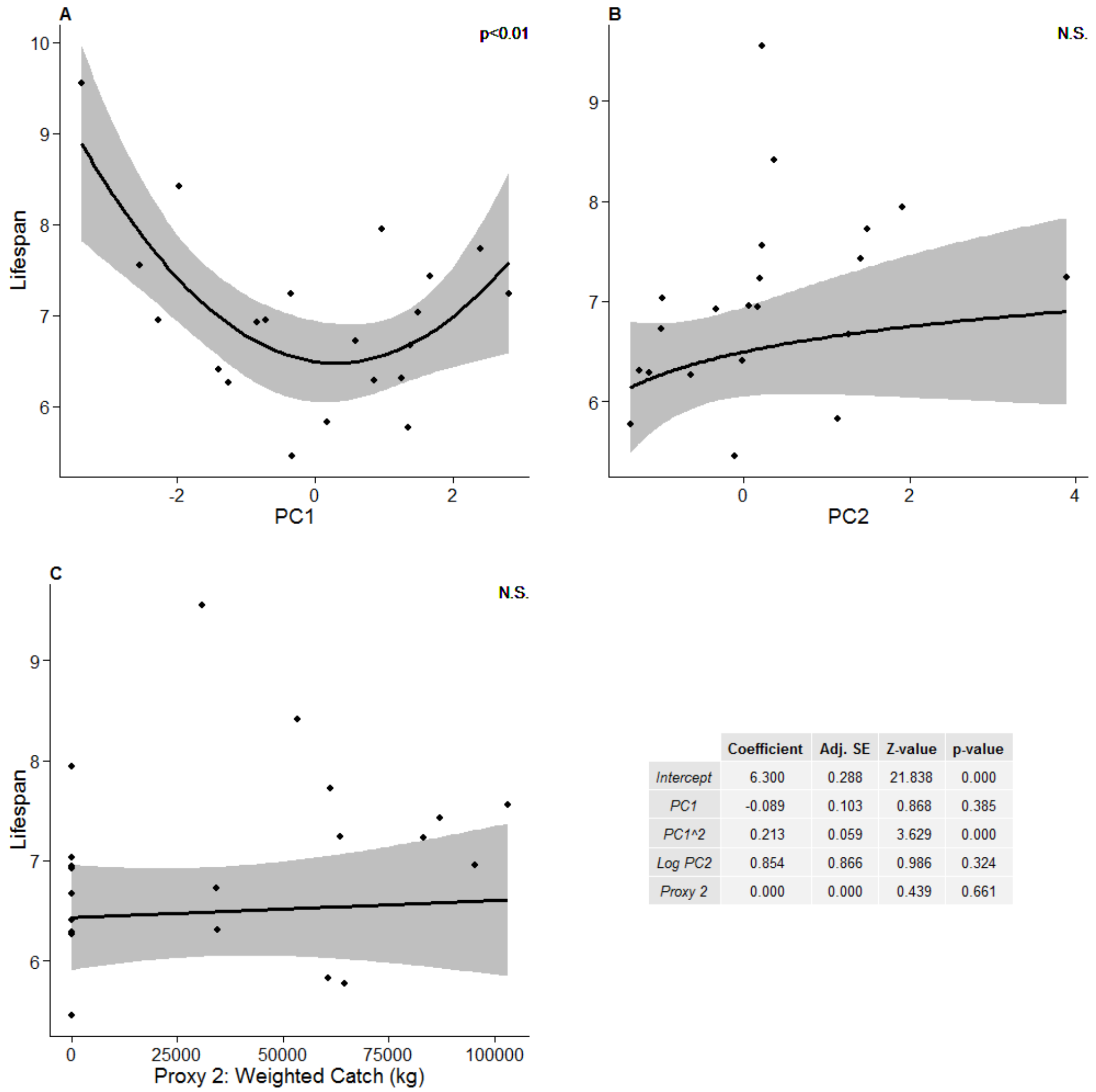


	Coefficient	Adj. SE	Z-value	p-value
Intercept	1.145	0.130	8.809	0.000
PC1	0.007	0.040	0.186	0.852
PC1^2	0.060	0.023	2.664	0.008
Log PC2	-0.507	0.314	1.614	0.106
Proxy 2	0.000	0.000	0.427	0.669

Figure 27: Partial effects of regressions between the proportion of piscivores within total herbivore and piscivore biomass at each site, and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.25 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

Life-history indicators – Lifespan

PC1 was the only variable in the best-fit model and there was a significant polynomial relationship between PC1 and mean fish lifespan (Appendix 11). Lifespan decreased from sites with high macroalgae cover and low structural complexity to sites with moderate values of both algal cover and complexity. At sites with high complexity and low macroalgal cover, lifespan increased slightly (Figure 28). Fishing pressure was not related to fish lifespan, suggesting that the benthic variables are more important in this context. As mean inverse generation time, inverse growth rate, natural mortality and age at maturity of the fish community were strongly, positively correlated with lifespan, both these variables are also likely to reflect changes in structural complexity and algal cover rather than fishing pressure.

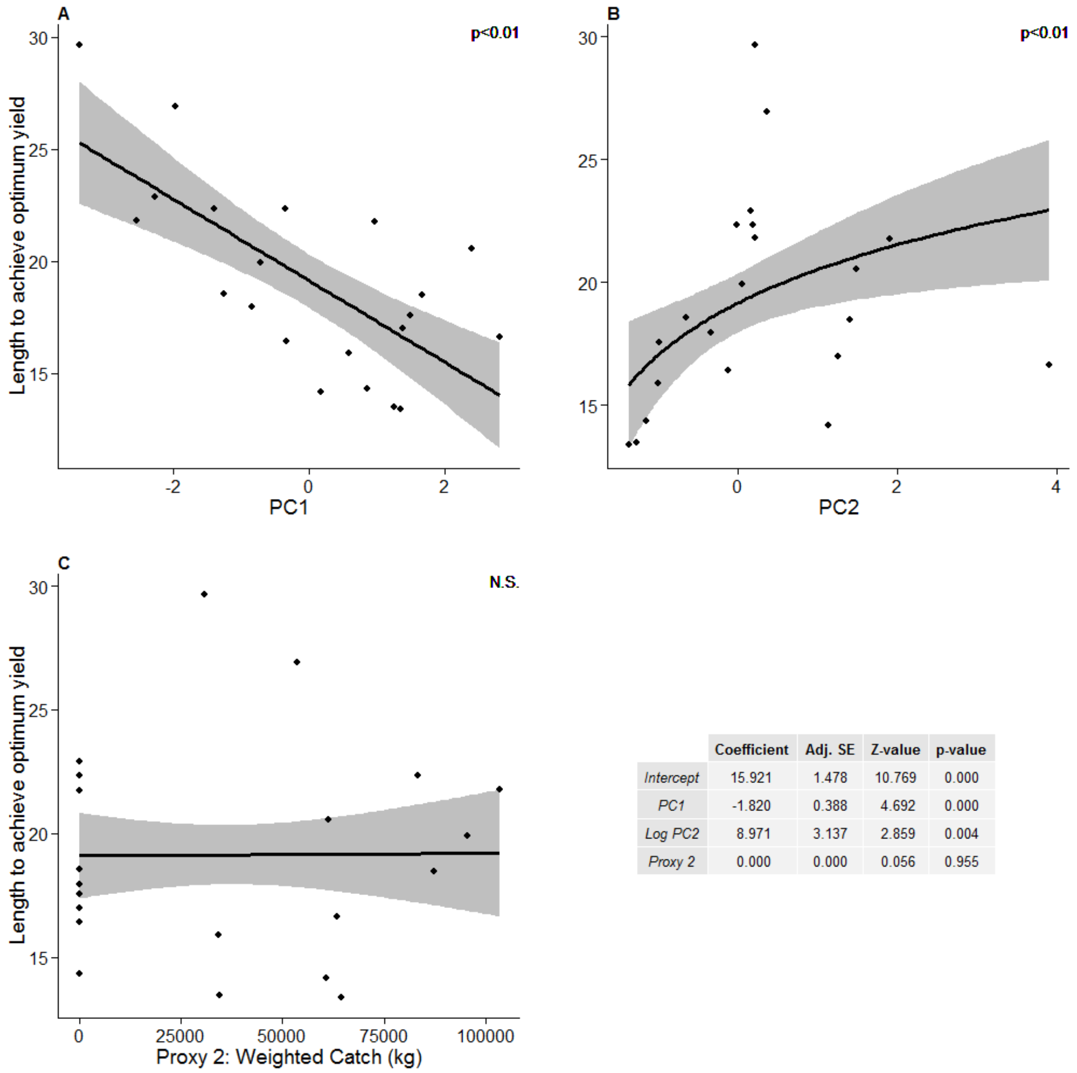


	Coefficient	Adj. SE	Z-value	p-value
Intercept	6.300	0.288	21.838	0.000
PC1	-0.089	0.103	0.868	0.385
PC1^2	0.213	0.059	3.629	0.000
Log PC2	0.854	0.866	0.986	0.324
Proxy 2	0.000	0.000	0.439	0.661

Figure 28: Partial effects of regressions between the mean lifespan of the fish community at each site, and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.45 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

Life-history indicators – Length to achieve optimal yield

PC1 and PC2 were the variables incorporated in the best-fit model (Appendix 11). Mean length to achieve optimum yield declined from sites with high macroalgal cover and low complexity to sites with high structural complexity and low macroalgal cover (Figure 29). Similarly, the mean length to achieve optimal yield was lower at sites with high levels of tabular, encrusting or submassive corals and was lower at sites with high levels of branching or massive corals. Fishing pressure was not related to length to achieve optimal yield, suggesting that the benthic variables are more important in this context.

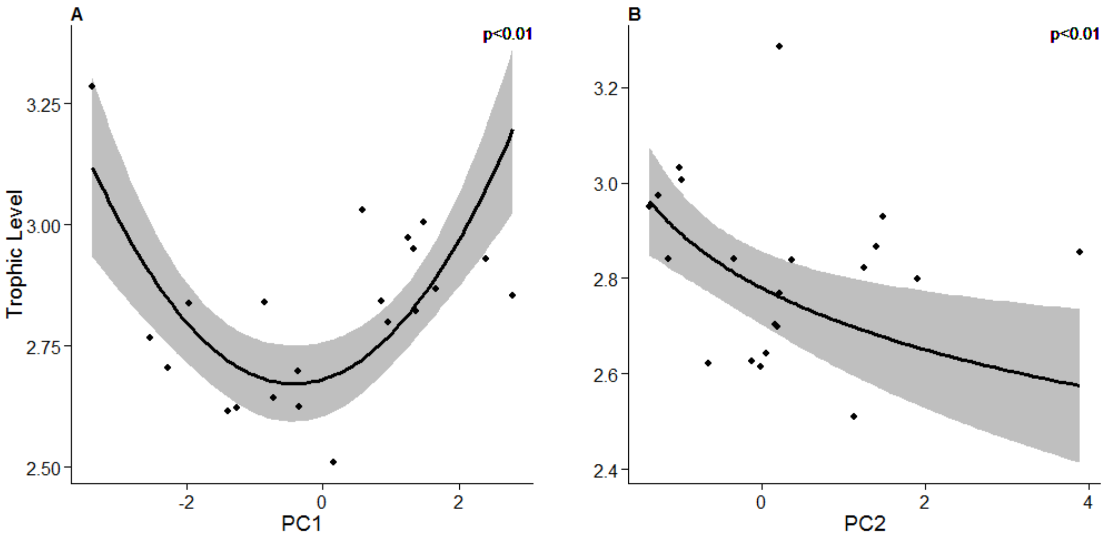


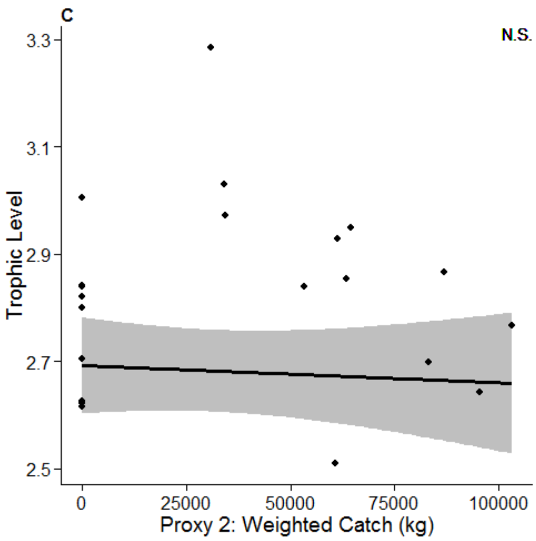
	Coefficient	Adj. SE	Z-value	p-value
Intercept	15.921	1.478	10.769	0.000
PC1	-1.820	0.388	4.692	0.000
Log PC2	8.971	3.137	2.859	0.004
Proxy 2	0.000	0.000	0.056	0.955

Figure 29: Partial effects of regressions between the mean length to achieve optimal yield of the fish community at each site, and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R2=0.58 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

Life-history indicators – Trophic level

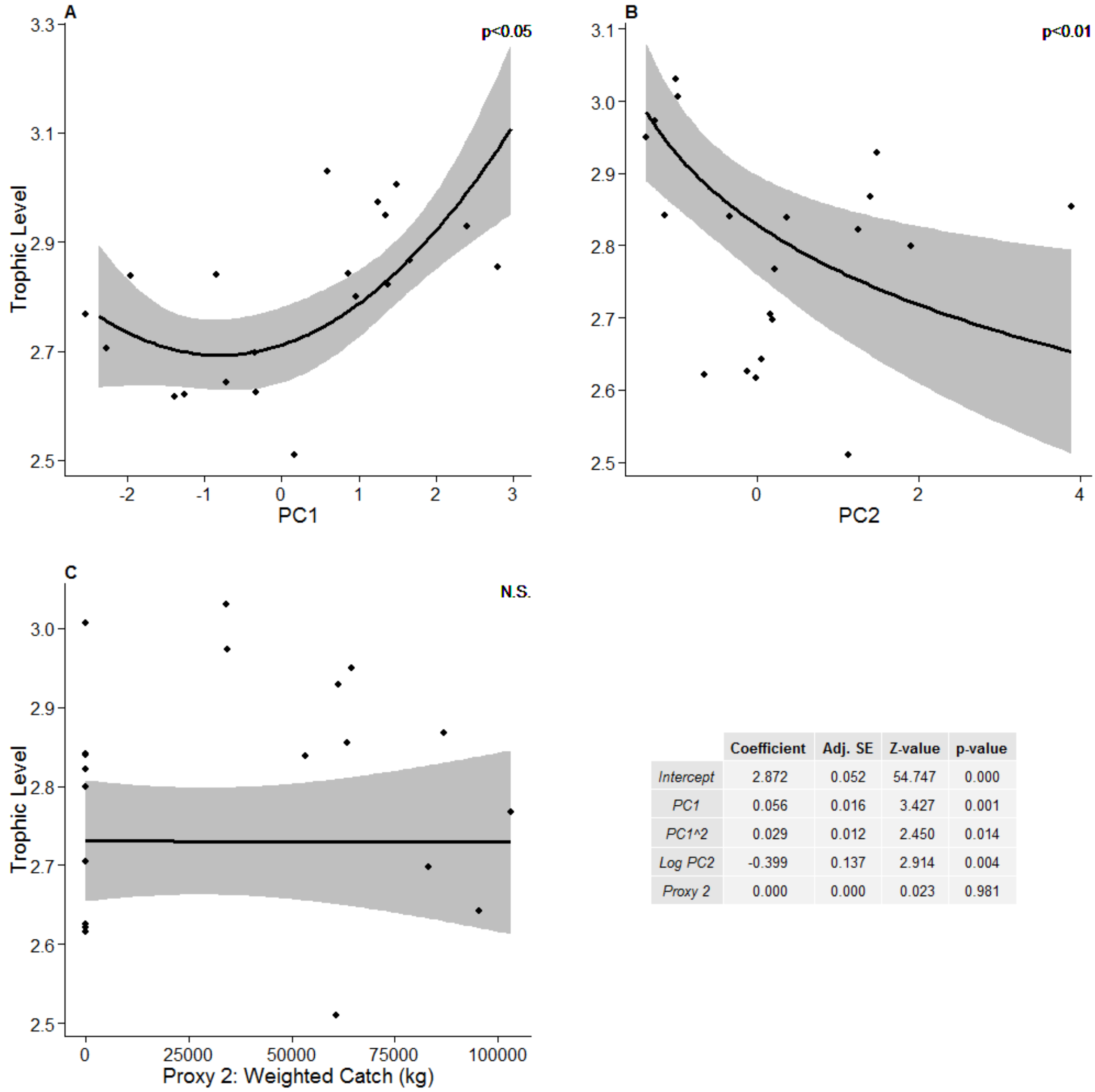
Both benthic variables were incorporated in the best model and there was a significant polynomial relationship between both PC1 and PC2, and mean trophic level (Appendix 11). At sites with either high structural complexity and low macroalgal cover, or sites with high macroalgae and low structural complexity mean trophic level was greater than at sites with moderate levels of either macroalgae or structural complexity (Figure 30). Trophic level declined from sites with high branching and massive coral cover to sites with high tabular, encrusting and submassive coral cover. Trophic level was lowest at high levels of exploitation, increased as fishing pressure declined, but decreased again in the no-take areas. Praslin NE Carbonate was an outlier (Cook's distance of 1.55). If this data point was removed from the analysis, a polynomial model was still the best model, however, the fitted relationship between trophic level and PC1 did not increase sharply at negative values of PC1 (i.e. high macroalgal cover), rather the relationship leveled off at low values of PC1 (Figure 31; Appendix 11). This means that trophic level was consistently low at sites with high to moderate levels of macroalgal cover, but increased at sites with low macroalgal cover and high structural complexity.





	Coefficient	Adj. SE	Z-value	p-value
Intercept	2.866	0.060	47.524	0.000
PC1	0.041	0.018	2.310	0.021
PC1^2	0.049	0.011	4.283	0.000
Log PC2	-0.479	0.156	3.069	0.002
Proxy 2	0.000	0.000	0.348	0.728

Figure 30: Partial effects of regressions between the mean trophic level of the fish community at each site, and the benthic and fishing pressure variables. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.54 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.



	Coefficient	Adj. SE	Z-value	p-value
Intercept	2.872	0.052	54.747	0.000
PC1	0.056	0.016	3.427	0.001
PC1^2	0.029	0.012	2.450	0.014
Log PC2	-0.399	0.137	2.914	0.004
Proxy 2	0.000	0.000	0.023	0.981

Figure 31: Partial effects of regressions between the mean trophic level of the fish community at each site, and the benthic and fishing pressure variables when outlier removed. Figures provide back-transformed relationships, whereas table provides coefficients using transformed variables. R^2=0.52 for model incorporating all terms. Grey bands represent confidence intervals around the fitted relationships.

Results: Focal-species indicators

Neither of the analyses looking at the effect of fishing pressure and benthos on the biomass of *Chlorurus sordidus* and *Scarus rubroviolaceus* showed clear effects of these drivers (*C. sordidus*: R^2=0.03; *S. rubroviolaceus*: R^2=0.06).

Recommendations: influence of fishing on indicators

1. Benthic habitat drives the patterns found in most of the indicators used. These indicators are important for the fishery as they represent resource potential and ecosystem functioning. Specifically, the fewer small fish observed on macroalgal dominated reefs is driving lower overall productivity (e.g. lower growth rate, longer lifespan) at these reefs compared with the fish communities found at low macroalgae/high complexity reefs. Similarly, functional richness is greater at high complexity, coral-dominated reefs than at macro-algal reefs suggesting greater support for the functioning of reefs where coral dominates over algae. Therefore, it is important to monitor the state of the benthos and how it changes in time and space to understand the availability of fish for the in-shore fringing reef fishery.
2. The poor performance of the fishing proxies in relation to the indicators may be due either: i) fishing pressure is relatively light and therefore there are not strong effects on the indicators; or ii) the fishing pressure differences in time and space are not adequately reflected by the proxies used. Certainly, there appears to be a low gradient in fishing pressure at the UVC sites, suggesting surveys need to be conducted over a broader range of fishing pressures, especially in areas where fishing pressure is known to be high. Nonetheless, there is a clear difference in the scale at which the fishing pressure data were collected in comparison to the UVC data. This needs to be addressed by collecting more spatially explicit fishing pressure data.
3. The UVC data are not sufficient to examine the effects of fishing on individual, target species. Fishery-dependent data may be more appropriate to study the effects of fishing on some of the target species that are poorly captured by the UVC methods. Monitoring of individual target species in the catch surveys is needed to understand how fishing is affecting these species. Expanding the number of UVC sites across the fished area may assist in making these data more amenable to studying individual level trends.

Step 5: Setting Reference Directions and Points

The overall aim of this consultancy was to guide managers and their actions in response to fishing pressure. The traditional fisheries management literature focuses on setting reference points, whether they be limits or targets, to stimulate appropriate management actions. There are currently few approaches for setting reference points for multispecies fisheries managed using an ecosystem based approach because of the difficulties associated with knowing appropriate reference points at the ecosystem level (Link et al. 2002). In order to set reference points, we need sufficient understanding of how fishing might impact indicators and their dynamics and a clear understanding of what is the desirable state and set of processes and feedbacks within the system (Shin et al. 2005). Since there is uncertainty regarding the "desired" state we used a hierarchical approach, where we started with simple reference directions indicating the direction of "preferred" states, and worked through to more targeted reference points. It should be noted that designation of reference directions, and the setting of reference points as limits or targets should occur in consultation with stakeholders, as their designation will rely on subjective decisions of "desirable" states or trends and "acceptable" risk. Here we simply explore different potential methods for producing reference points. These approaches were applied to the indicators selected and estimated in Step 3.

5-1 Reference directions

Background

In this context reference directions provide an indication of a 'less exploited' state with respect to the different indicators of ecosystem health and fish stock size. Setting these directions needs an underlying understanding of how fishing is changing indicator values, and may be determined without setting a fixed target (Shin et al. 2005). The current state of the system may be closer to the unexploited state than stakeholders are aiming for to provide optimal yields. Thus, the reference directions will provide a way for managers to track the relative state of the different regions over time (Babcock et al. 2013), and do not necessarily reflect the direction desired by stakeholders.

Aim

To provide managers with a way to assess the relative state of fishing regions over time.

Methods

The hypothesized reference directions for each of the primary indicators (Table 4) were revisited using information from the regression analyses on the strength and direction of the relationships between each indicator and the proxy for fishing pressure (proxy 2). These reference directions represent the direction of change in an indicator towards lower levels of fishing pressure.

Table 6: Hypothesised reference directions for proposed indicators used to study of effect of fishing pressure on fish communities.

Indicator	Hypothesised reference direction as fishing pressure declines	Observed reference directions as fishing pressure declines
Size-based indicators		
1. Mean length	↑	
2. Proportion of large fish	↑	
3. Length to maximum length ratio	↑	
4. Slope of size spectra	↑*	
Density-based indicators		
1. Biomass	↑	
Functional indicators		
1. Functional richness	↑	↑
2. Functional diversity	↑	↑§
3. Piscivore biomass	↑	
4. Herbivore biomass	↑^	
Life-history indicators		
1. Maximum length	↑	
2. Growth rate	↓	
3. Natural mortality	↓	
4. Lifespan	↑	
5. Generation time	↑	
6. Age at maturity	↑	
7. Length to achieve optimum yield	↑	
8. Trophic level	↑	

* Represents a shift to a shallower, less negative slope
^Effect of fishing depends on whether herbivores are fished, which they are in Seychelles
§ Reference direction finding based on strong, positive correlation with another indicator

Results

The fishing pressure proxy (Proxy 2: weighted catch in kg) was only significantly related to two of the indicators in the regression analyses (Section 4-4). Functional richness declined with fishing pressure as expected (Table 6; Figure 24). Functional diversity was strongly correlated with richness and therefore it is likely that it declines in a similar manner with increased fishing pressure.

Recommendations: reference directions

1. Currently, it is not possible to tease apart the different, potential explanations for the lack of any relationships between fishing pressure and most of the indicators: i) the gradient in fishing pressure across the UVC sites is small, meaning that there is not a clear effect of fishing on the indicators, and the fish community and ecosystem they represent; ii) habitat effects outweigh any effects of fishing pressure, effectively masking these effects; and iii) the proxies we used for fishing pressure were inadequate and did not reflect the exploitation pressures at the different sites. The next step will be to collect fishing pressure data at a similar spatial scale to the UVC data (or vice-versa), so these datasets overlap more extensively. Furthermore, there is a need to ensure that the UVC sites cover a broader range of fishing pressures. This data collection would allow a

clearer understanding of how fishing pressure if affecting the fringing reef ecosystem in Seychelles.

5-2 Ratios inside vs outside no-take areas

Background

An alternative approach to providing management advice is to use no-take areas as a potential baseline against which the effects of historic and current levels of exploitation outside the reserve can be assessed (Edwards et al. 2014, McGilliard et al. 2010). In instances where no-take areas have been implemented but are not considered sufficient to mitigate fishing pressure, e.g. if exploitation outside the reserve is such that biomass accumulation inside the reserve and spillover to neighbouring areas doesn't counteract fish loss, then there may be a need for additional management actions (McGilliard et al. 2010). Values of indicators within the reserve may then be used as a reference level representing an unfished state against which the impacts of fishing in the surrounding areas may be assessed. Work has been done looking at the potential of this approach to set control rules for fishing effort using density ratios inside and outside a reserve (Babcock and MacCall 2011, McGilliard et al. 2010). We used this approach to calculate ratios for all the proposed indicators inside and outside reserves in the Seychelles.

Aim

To provide managers with a way to assess the relative state of fished regions to unfished regions.

Methods

This approach required established no-take areas with high levels of compliance, accumulation of fish biomass within the reserve, and similar habitats inside and outside the reserve to ensure the no-take indicator value represents the unfished state (Babcock and MacCall 2011, Wilson et al. 2010). Furthermore, the method required matching sites inside and outside a no-take area for comparison. Such matches were not available for all fished sites, and compliance varies across the islands (Table 5). Thus, we averaged the values for each indicator across all the no-take areas with strong compliance (the three Cousin sites) to produce reference values. We calculated the ratio between the indicator values for each site in 2014 and the reference value in 2014. Values greater than 1 represent indicator values that are higher at the site of interest, than the reference value from high compliance no-take areas.

Results

In general, the ratios of fished/low compliance no-take areas and reference values for the size-based indicators were less than or approximately 1 (Figure 32). The ratios for the proportion of large fish were the most variable with values ranging widely around 1, whereas mean size were the most consistent with most sites having ratios of less than 1. The low compliance no-take areas around Ste. Anne were the sites with ratio values most consistently greater than 1.

The ratios of total fish biomass at a site to total fish biomass in the high compliance no-take areas, were also consistently lower than 1, with the exception of one of the low compliance no-take areas around Ste. Anne, and Praslin SW Granite (Figure 32).

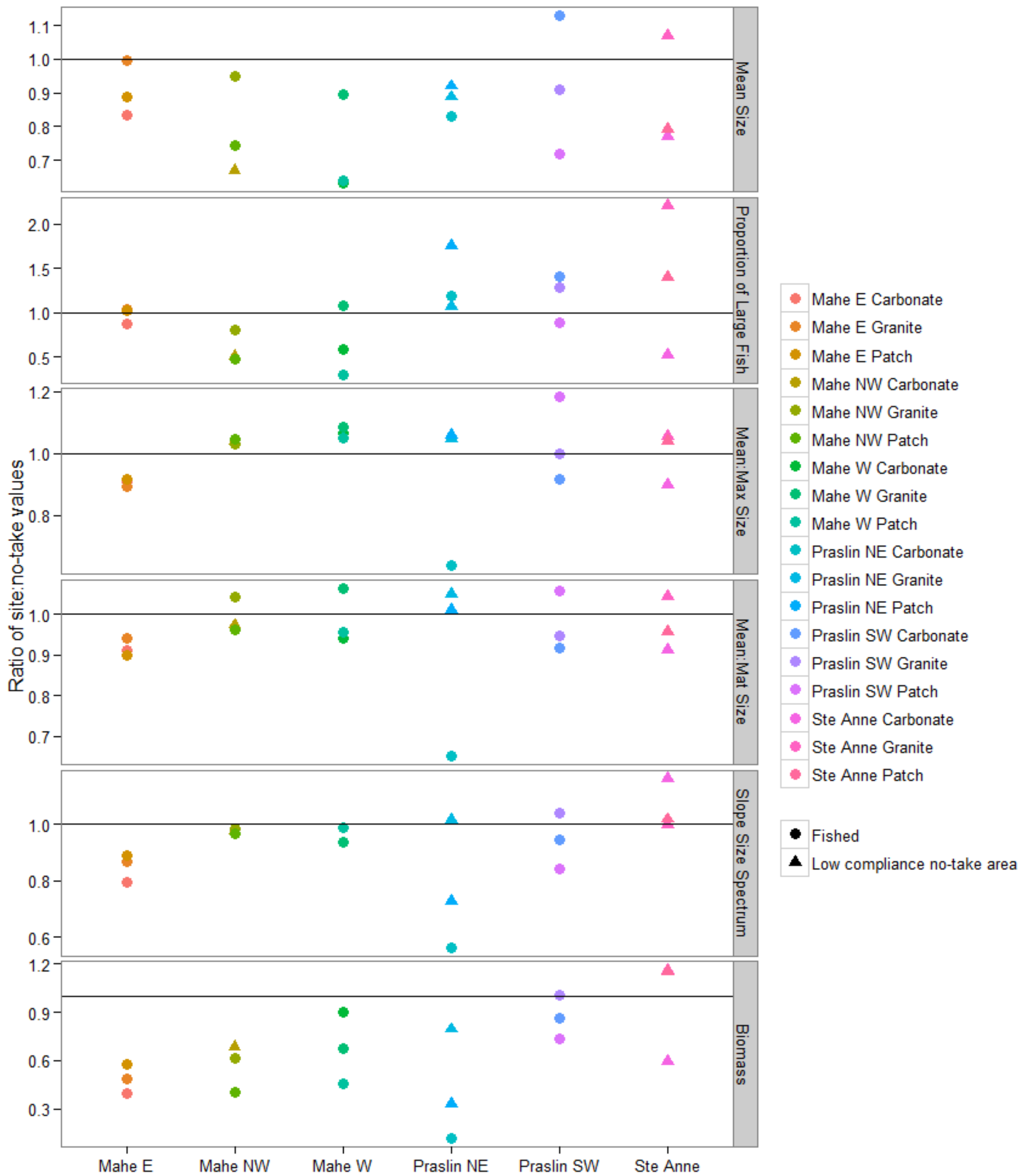


Figure 32: Ratio between size- and biomass-based indicator values at fished or low compliance no-take areas, and high compliance no-take areas in 2014. Shape of symbol represents management status. Note the different y-axis scales.

The ratios for functional diversity and richness, and proportion of piscivores were slightly greater than 1 at most sites, whereas those for herbivore biomass were less than 1 (Figure 33). The ratios for piscivore biomass were more variable across sites.

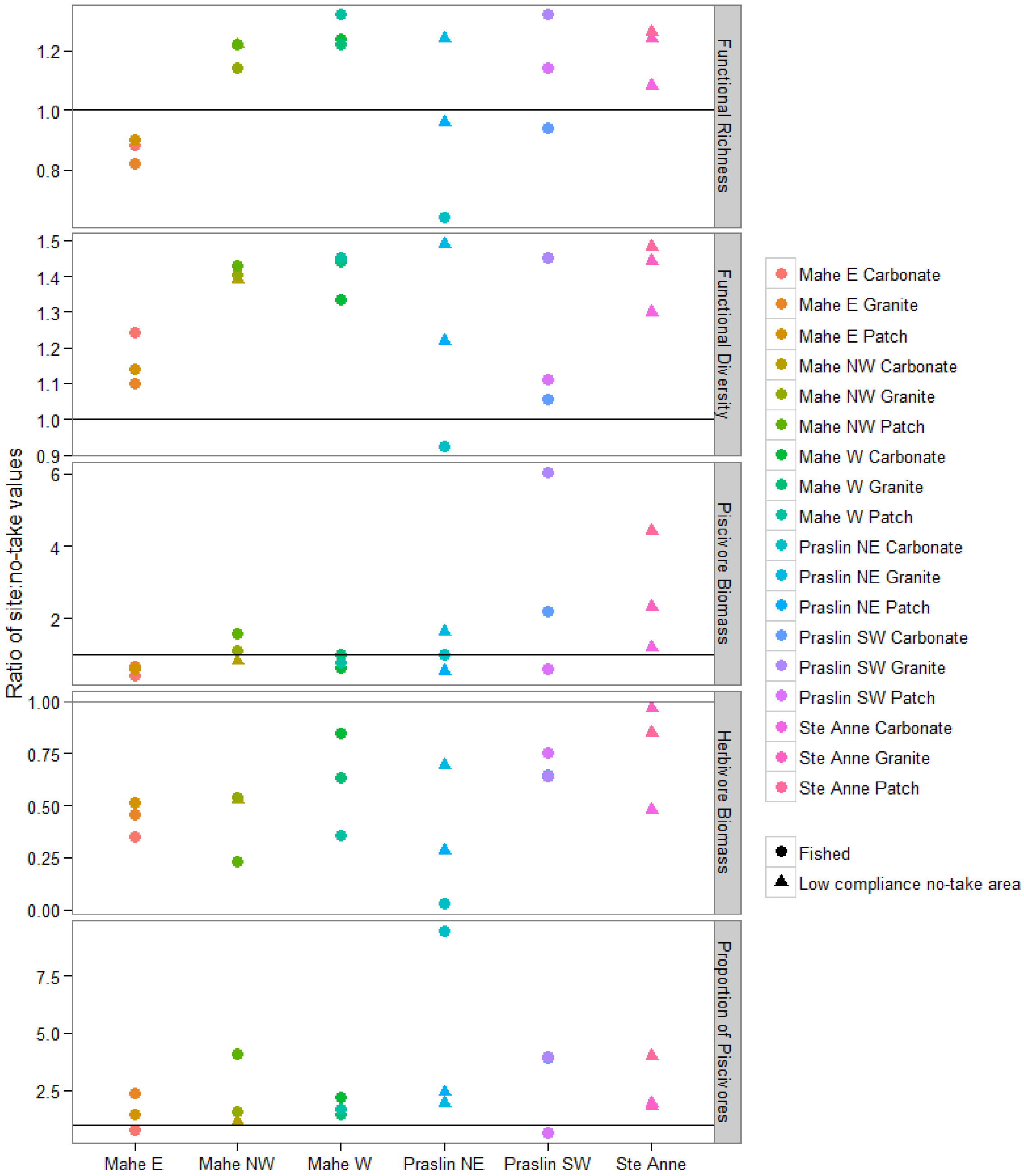


Figure 33: Ratio between function-based indicator values at fished or low compliance no-take areas and high compliance no-take areas in 2014. Shape of symbol represents management status. Note the different y-axis scales.

The ratios for the life-history indicators were quite variable across sites for natural mortality, and length to achieve optimal yield. For the remaining indicators ratios were generally greater than 1 (Figure 34).

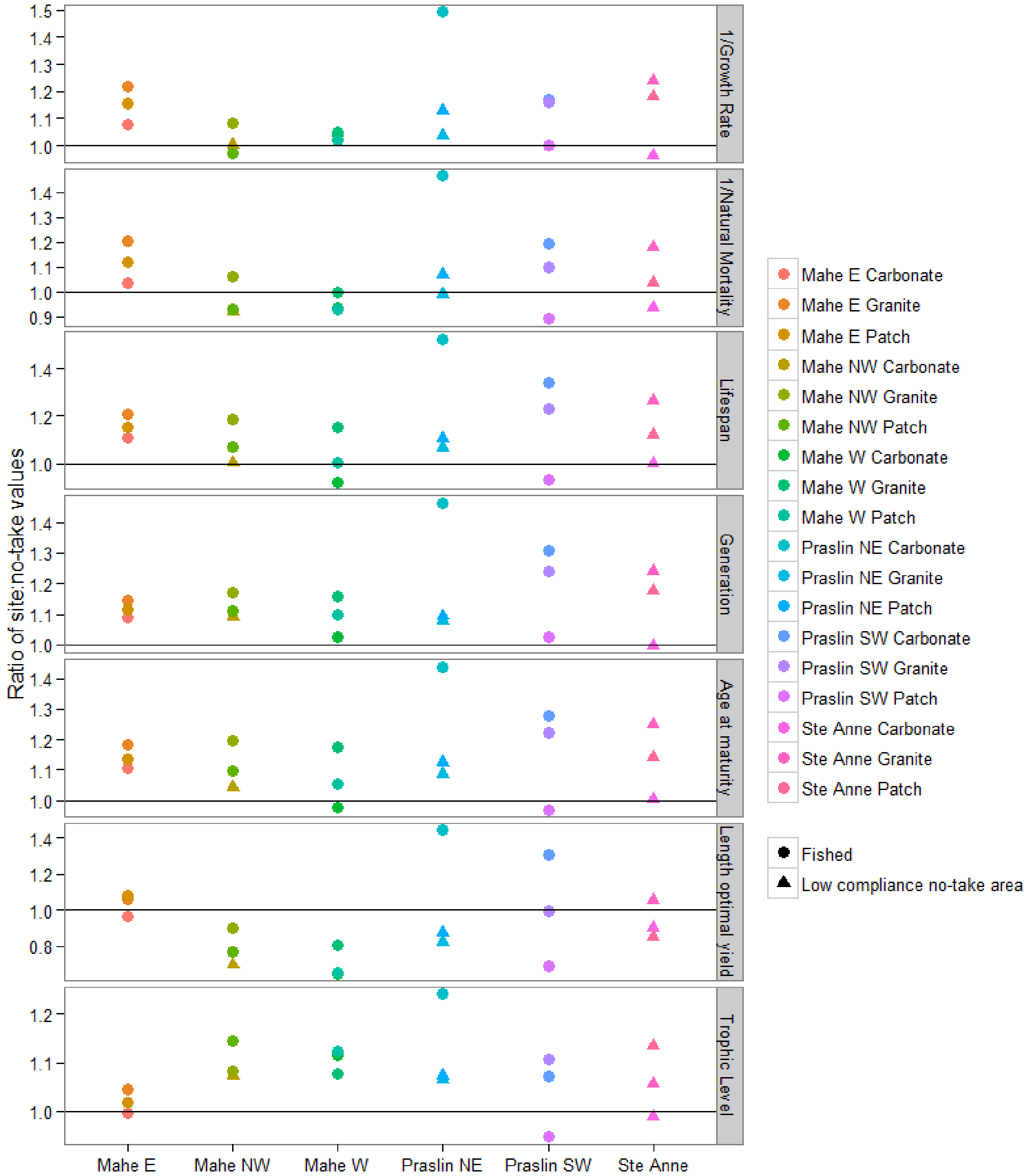


Figure 34: Ratio between life-history indicator values at fished or low compliance no-take areas and high compliance no-take areas in 2014. Growth rate and natural mortality are presented as inverse metrics to standardise the expected effect of fishing – all indicators are expected to decline in response to fishing pressure.

The consistent ratios among sites for mean size, biomass, functional richness, functional diversity, herbivore biomass and various life-history indicators, seem to suggest that for these indicators the reference values in the high compliance no-take areas might provide useful baselines. These baselines may represent an unfished state against which the impacts of fishing in the surrounding areas can be assessed. However, the regression analyses looking at the relative influence of fishing and the benthos on these indicators suggest that the benthic habitat is a strong driver of many of the indicator patterns. This in itself might not be an issue if a range of benthic conditions were found in both the fished and high compliance areas; this is not the case. While the structural complexity overlaps among fished and unfished areas, macroalgal cover is greater at the high compliance areas following the 1998 bleaching event (Figure 35), suggesting that this key benthic difference caused by an external disturbance may be influencing many of the indicator ratios in figures 32 to 34.

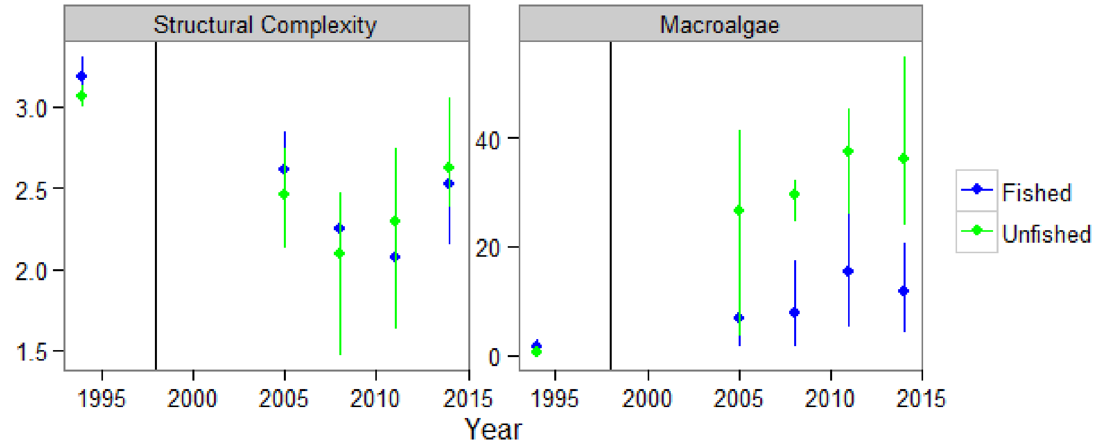


Figure 35: Mean (±CI) structural complexity and macroalgal cover at fished and high compliance no-take areas over time. Solid line represents the bleaching event in 1998 that caused 90% coral mortality on some reefs and has since results in reefs with highly variable benthic condition.

Examination of the values for each indicator at fished and the high compliance no take areas over time show that there is an interaction between time and fished status for many of the indicators (Figure 36): the difference between fished and unfished sites changes sign (e.g. difference shifts from positive to negative) across the bleaching event that drove large benthic changes (Graham N.A.J. et al. 2015). Examples of this can be seen for functional diversity, richness, mean size and lifespan. Only biomass is consistently greater in unfished areas over time. This suggests that it is only the biomass reference values that might provide a useful unexploited baseline in this context where there are clear differences in habitat among the reference sites and many of the other sites.

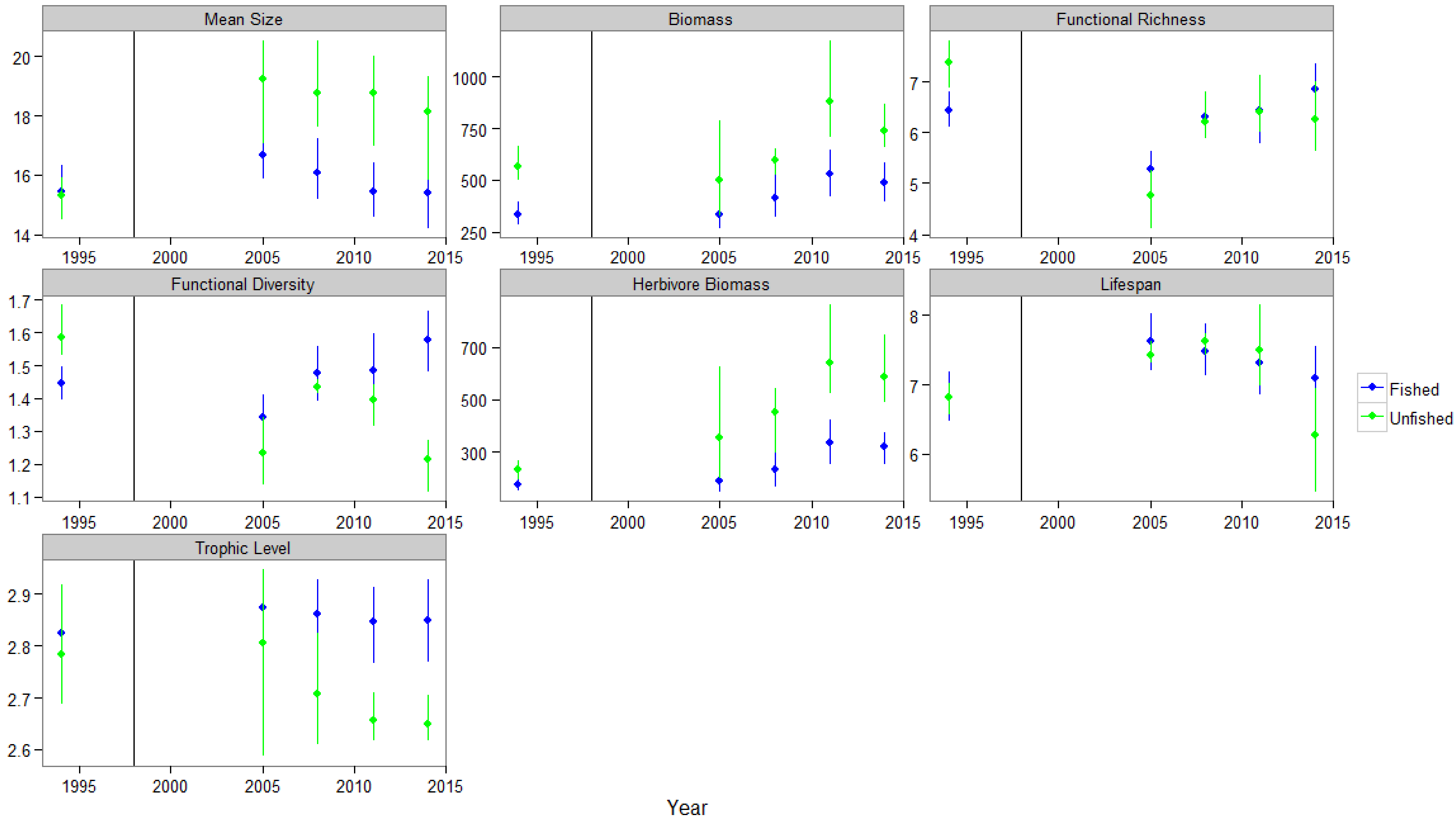


Figure 36: Mean (±CI) structural complexity and macroalgal cover at fished and high compliance no-take areas over time. Only lifespan and trophic level are presented of the life-history indicators due to high correlation among these indicators.

Based on these findings we assume that the biomass ratio between fished and high compliance no-take areas represents the effects of fishing and are not masked by habitat effects resulting from the 1998 bleaching event. Thus, it is now possible to evaluate the effects of fishing over time at the different sites and it provides potential a tool for setting reference points in consultation with stakeholders. Sites in Mahe E and Mahe W show fairly consistent biomass ratios over time (Figure 37). In contrast, Mahe W, Praslin NE, SW and Ste Anne show greater variation. Of particular note are the declining ratio values for Praslin NE carbonate and patch and the consistently low values at Mahe NW patch. The implication is that fishing may be having the largest impacts on total fish biomass in these areas, but this contrasts with our fishing proxies, and thus, once again it is difficult to pinpoint fishing effects with the current proxies.

Looking at the regional scale (Figure 38), the biomass ratio for most regions is fairly steady overtime. Praslin NE is the region of most concern, with a declining biomass ratio. The fish biomass in the Ste Anne region is most similar to the reference no-take areas, with a ratio of about 1 that is fairly consistent over time. This is despite apparent low compliance in regards to Ste Anne's no-take status.

Based on stakeholder consultation, it may be possible to set target or limit reference points using these ratios. For example in Figure 36 the green shaded area represents the unfished state (as given by the high-compliance no-take areas), the yellow shaded area might represent the desired ratio or target, whereas the change from yellow to red may represent the limit or threshold point beyond which management actions are implemented to prevent further decline. Due to differences in habitat among sites, these thresholds may need to vary among sites to acknowledge local habitat and environmental effects on fish productivity.

Recommendations: ratios inside versus outside reserves

1. Praslin NE carbonate and patch areas, and Mahe NW patch show the smallest ratios in fish biomass compared to high compliance no-take areas, suggesting these sites may be most strongly impacted by fishing pressure. This differs from the spatial picture of fishing pressure given by the proxies developed in Step 2. Further study of fishing pressure in these areas compared with other potentially less impacted sites, such as Mahe W carbonate would be beneficial at this stage.
2. The ratio between fish biomass at fished and unfished sites presents a useful metric for monitoring fishing effects and trends over time on Seychelles fringing reefs. Furthermore, it provides an intuitive way of setting reference points in consultation with stakeholders.
3. The three reference sites used to estimate a no-take value for the different indicators were all surrounding Cousin, due to low compliance at the other UVC locations. More reference sites need to be added as UVC locations to allow estimation of reference values that are more representative of the inner fringing reefs. These reference sites should cover high coral cover areas as all sites at Cousin are high macroalgae sites. Furthermore, the granitic site at Cousin is partially composed of carbonate reef, therefore a high compliance no-take area encompassing a fully granitic site needs to be added to the surveys.

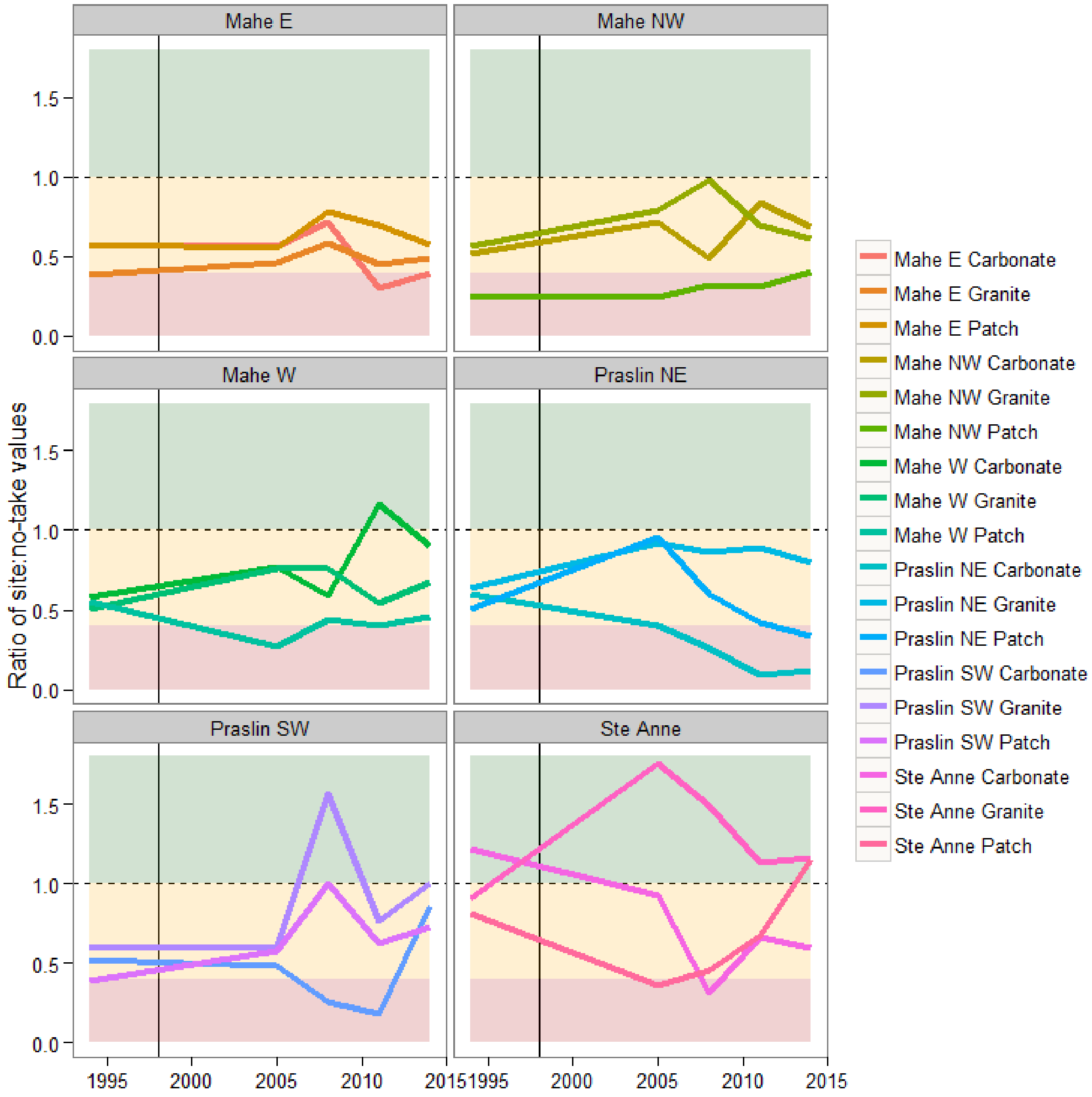


Figure 37: Ratios in total fish biomass of fished and high compliance no-take areas over time. Shaded regions represent different potential reference points or regions, e.g. the green area shows the unfished state, whereas the red area might be avoided.

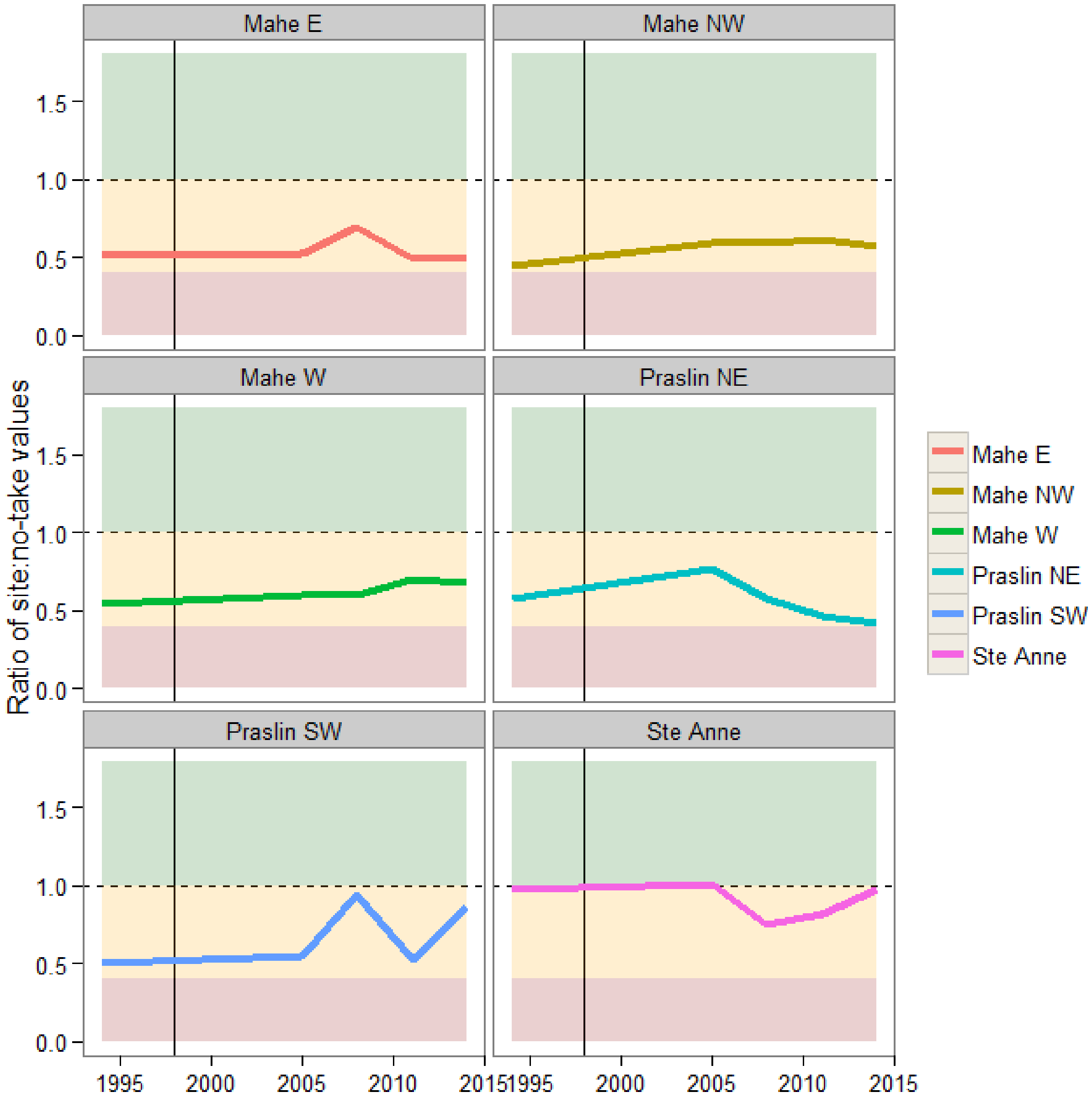


Figure 38: Ratios in total fish biomass of fished and high compliance no-take areas over time. Shaded regions represent different potential reference points or regions, e.g. the green area shows the unfished state, whereas the red area might be avoided.

5-3 Thresholds

Background

Defined reference points may be found for ecosystem-based fisheries by identifying the shape of the relationship between fishing pressure and ecosystem attributes or indicators of these attributes (Samhouri et al. 2010). Non-linearities or inflexion points in these relationships, may be used as reference points identifying the levels of fishery exploitation beyond which there is likely to be significant detrimental effects on the functioning of important ecosystem processes (McClanahan et al. 2011) or the fish community (McClanahan et al. 2015); thus, management intervention may be required before these threshold values are reached. In contrast, flat sections of the relationship curve, where indicator values change little in response to variations in fishing pressure may provide useful targets around which management actions can focus.

Thresholds have previously been determined in relation to fishing pressure on coral reefs, using total fishable biomass as a proxy for fishing pressure (McClanahan et al. 2015, McClanahan et al. 2011). Our proxies of fishing pressure were not related to the majority of our fisheries indicators, therefore instead of exploring thresholds in these relationships, we used the relationships determined by McClanahan et al. (2015, 2011) to examine the current status of the Seychelles fish and benthic communities.

In contrast, we did find strong relationships between our indicators and benthic condition. Therefore, management that supports the benthic habitat is likely to influence characteristics of the fish community important to a healthy fishery. As a result, we also examine the shape of the relationships between our fisheries indicators and the benthos to identify potential limits or targets for macroalgal cover and structural complexity.

Aim

To provide managers with identified reference points for the different indicators.

Methods

We estimated fishable biomass at each site in 2014 and then plotted the values of our fisheries indicators for these sites on the relevant relationships between these indicators and fishable biomass, identified by McClanahan et al. (2015, 2011).

We brought together the relationships between the fisheries indicators and PC1 (Figure 20; high macroalgae and low structural complexity to low macroalgal cover and high structural complexity) identified in Section 4-4. The shapes of these relationships were evaluated in relation to possible limit, threshold or target reference points. Comparisons among indicators were used to understand the relative trade-offs between different management actions.

Results

The fish biomass at each site stretches from low to moderate levels compared to data collected from across the Western Indian Ocean (Figure 39). These values are well below the unexploited biomass for coral reefs estimated by McClanahan et al. (2011)

based on unfished and long-protected areas from the Indo-Pacific region: B_0 = 1200kg/ha ±110 95%CI. This suggests that fishing pressure is significant at the UVC sites, and thus the fishing pressure proxies we used were not related to the indicators due to poor performance of the proxies and low gradients in fishing pressure rather than due to light fishing pressure. Nonetheless, most sites in 2014 have a fish biomass within or greater than the multispecies maximum sustainable yield (B_{MMSY} = 300±28 - 600±54 kg/ha) proposed by McClanahan et al. (2011), which may indicate that fishing is currently occurring at sustainable levels at most sites. Those sites falling below the B_{MMSY} window were Mahe E Carbonate, Mahe NW Patch, Praslin NE Carbonate and Praslin NE Patch. These were the sites that were also highlighted as sites of concern in the analysis in section 5-2 looking at ratios inside versus outside no-take areas (Figure 37). In contrast, most of these sites were not identified as areas of high fishing pressure using either proxy 2 (weighted catch; Figure 5) or proxy 3 (fishers in space data; Table 4). Indeed, Praslin NE Patch is located within a no-take area, albeit one with weak compliance (Table 1).

For the life-history traits, most of the sites sit either below (maximum length, lifespan, generation time and age at maturity) or above (growth rate and natural mortality) the fitted lines identified by McClanahan et al. (2015) (Figure 39). The values for the Seychelles sites correspond to values of these indicators commonly found at much lower fish biomass (greater fishing pressure), an outcome that may be considered worrying as it may indicate fishing effects that are not highlighted by biomass changes. However, these findings also suggest that the fish communities are showing higher productivity life-history traits than predicted using data from across the Indo-Pacific. Specifically, fish are growing fast, whilst exhibiting smaller maximum length, lower age at maturity and shorter lifespans and generation times. This may be beneficial for the productivity of the trap fishery but does suggest the sizes of fish caught may not be as great as in other areas in the Indo-Pacific.

The sites were distributed on either side of the fitted relationships between fish biomass and coral or macroalgal cover identified by McClanahan et al. (2011). As with the life-history traits, some sites were showing coral cover and macroalgal cover values that might be expected at much lower levels of fish biomass (fishing pressure) based on the McClanahan et al. (2011) relationships. However, this is likely due to the effects of the bleaching event in 1998 causing significant habitat changes, rather than due to fishing pressure. Interestingly, the proportion of herbivores within the fish community at most sites was higher than predicted across the full range of fish biomass incorporated in the study by McClanahan et al. (2011). Indeed this high proportion of herbivores in the community may be driving the life-history results due to the high productivity of many herbivorous species.

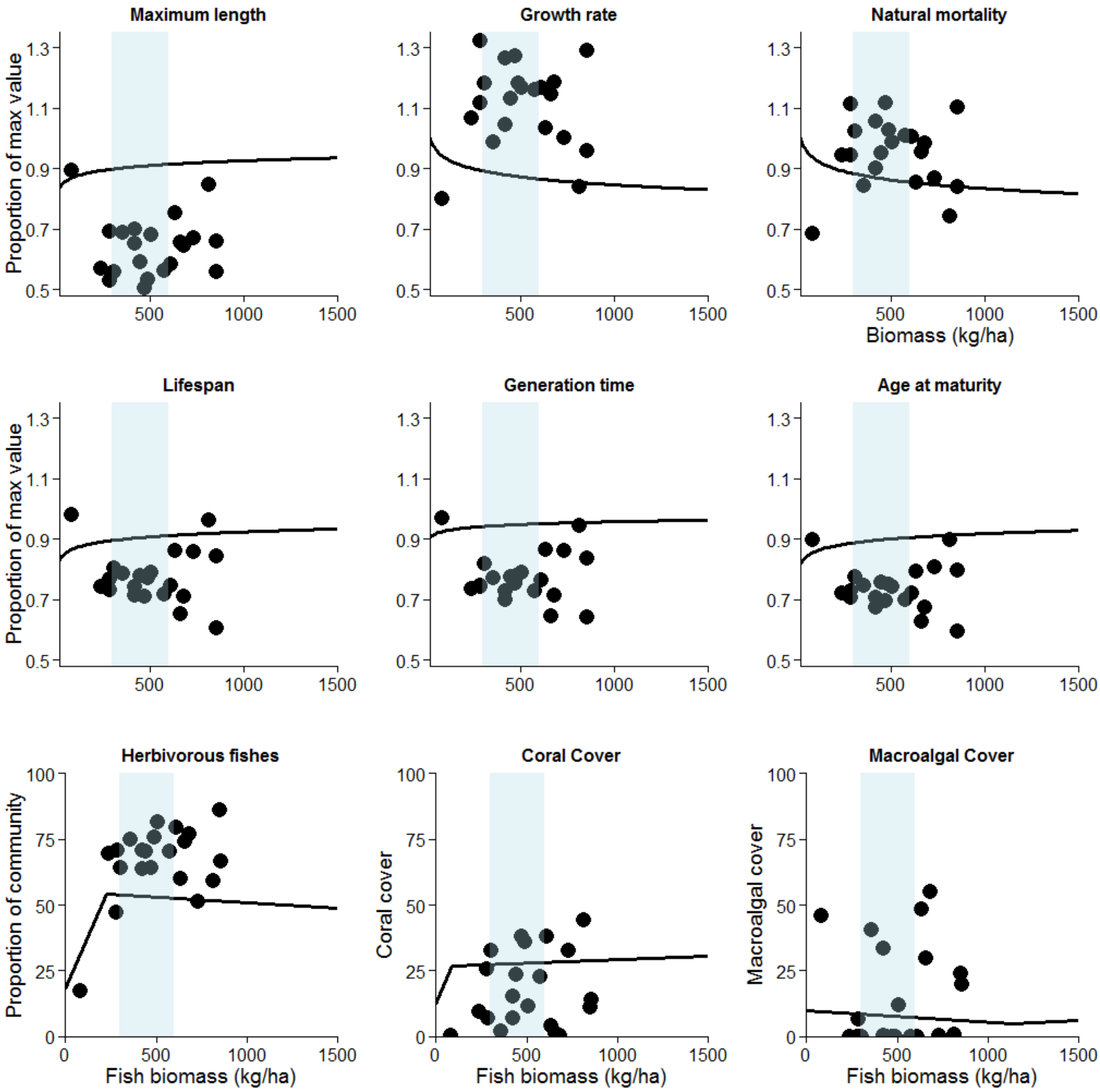


Figure 39: Relationship between fish biomass and the different indicators. Fitted lines were extracted from McClanahan et al. (2015, 2011) and represent relationships for data sourced from 9 countries across the western Indian Ocean. Symbols represent data for the 21 sites in Seychelles in 2014. Blue shaded areas represent Biomass based multispecies maximum sustainable yield calculated by McClanahan et al. (2011).

The relationships between the different indicators and the benthos show lower productivity life-histories (large size, larger length at optimal yield, longer life span and generation time, greater age at maturity and lower growth rate and natural mortality) at the macroalgal dominated reefs (Figure 40). In contrast, fish communities tend to be higher productivity (smaller mean size, shorter length at optimal yield, shorter life span and generation time, lower age at maturity, growth rate and natural mortality) at sites with low macroalgal cover and high structural complexity. Interestingly, the mean:max size ratio increases from high to low macroalgal cover and high to low complexity. Thus, fish are closer to achieving their maximum recorded size at coral-dominated, high structure reefs, rather than macro-algal dominated reefs. These results likely reflect the few small, high productivity fishes found at high macroalgal sites compared with high complexity sites, rather than the presence of more large, low productivity fish at the former sites (Appendix 9). This distinction is important as it suggests that fishers will not necessarily catch more large fish at macroalgal sites compared with coral-dominated, high complexity sites. This proposition is supported by the greater trophic level found at high complexity sites compared with high macroalgae sites. Functional richness is also higher on the high structure reefs (Figure 40). The trophic level and proportion of piscivores was lowest at moderate levels of macroalgal cover and moderate levels of structural complexity, highlighting that reefs at an intermediate stage between coral- and macroalgal-domination are inhabited by the fewest piscivores.

Recommendations: thresholds

1. Currently Seychelles fish communities at the UVC sites sit predominantly within the biomass based multispecies maximum sustainable yield identified for the western Indian Ocean. This suggests that fishing pressure, in the most part, may be sustainable at present. However, this needs ongoing monitoring to ensure maintenance of these biomass levels.
2. The comparison between fish biomass levels at sites in Seychelles with a measure of unexploited biomass indicates significant fishing pressure, such that there is a clear need for better catch data to develop fishing pressure proxies that are useful in the Seychelles coastal fishery context.
3. Seychelles fish communities exhibit characteristics common to fish communities subject to considerably higher levels of fishing pressure, e.g. small size, and high growth rate. This may be beneficial for the productivity of the fishery but also means smaller fish with lower reproductive capacity are present in the community.
4. The benthic habitat needs careful, ongoing monitoring. Importantly, shifts in the reef benthos to macroalgal domination will see a loss of small fish and lower functional richness, which may have deleterious implications for the functioning of the ecosystem and the ongoing delivery of resources to fishermen.

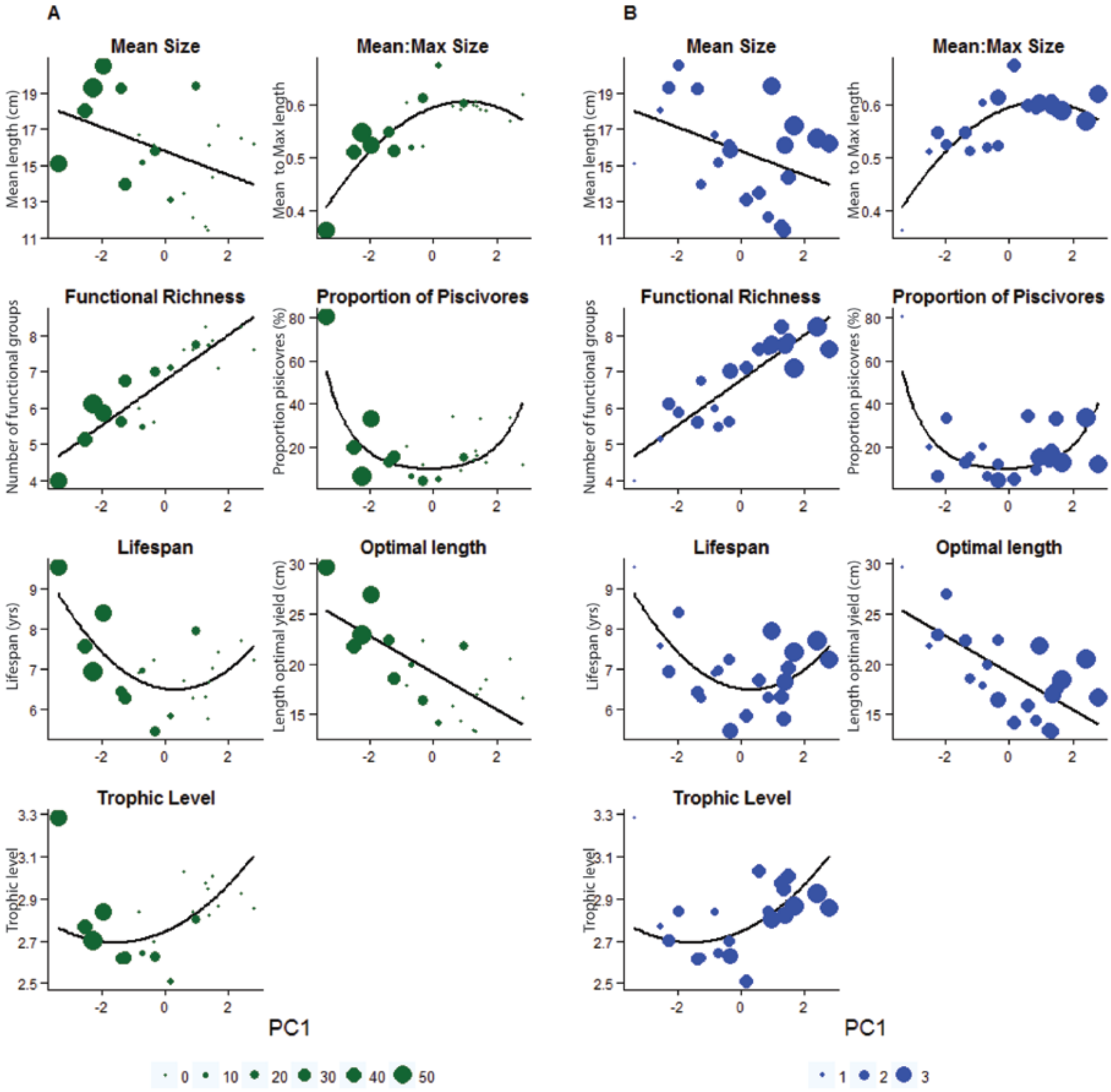


Figure 40: Relationship between benthic condition (PC1; see section 4-4) and the different indicators. Fitted lines are those estimated in regressions in section 4-4. Circles represent data for the 21 sites in Seychelles in 2014. Size of the symbols represents values for A) macroalgal cover, or B) structural complexity at the sites. Note this plot uses the fitted relationship between PC1 and trophic level where the outlier was removed (see section 4-4).

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Appendices

Appendix 1: Examples of past publications arising from datasets used in this assessment

	Dataset	Publications
1.	UVC data	• Wilson SK, Graham NAJ, Fisher R, Robinson J, Nash KL, Chong-Seng K, Polunin NVC, Aumeeruddy R, Quatre R. 2012. Effect of macroalgal expansion and marine protected areas on coral recovery following a climatic disturbance. Conservation Biology 26:995-1004. • Graham NAJ, Wilson SK, Jennings S, Polunin NVC, Robinson J, Bijoux JP, Daw TM. 2007. Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. Conservation Biology 21:1291-1300. • Jennings S, Boulle DP, Polunin NVC. 1996. Habitat correlates of the distribution and biomass of Seychelles' reef fishes. Environmental Biology of Fishes 46 (art. all):15-25. • Jennings S, Grandcourt EM, Polunin NVC. 1995. The effects of fishing on the diversity, biomass and trophic structure of Seychelles' reef fish communities. Coral Reefs 14:225-235.
2.	Effort data	• Authority SF. 2009. Seychelles artisanal fisheries statistics for 2008. Government of Seychelles, Victoria: Seychelles Fishing Authority Technical Report. Report no. • Grandcourt EM, Cesar HSJ. 2003. The bio-economic impact of mass coral mortality on the coastal reef fisheries of the Seychelles. Fisheries Research 60:539-550.
3.	Fishers in space data	• Daw TM, Maina J, Cinner J, Robinson J, Wamukota A. 2011. The spatial behaviour of artisanal fishers: implications for fisheries management and development (Fishers in Space). Western Indian Ocean Marine Science Association Report no.
4.	Target species data	• Grandcourt EM, 1999. The population biology of exploited reef fish from the Seychelles and Great Barrier Reef. Master's Thesis, School of Marine Biology and Aquaculture, James Cook University of North Queensland, Australia.

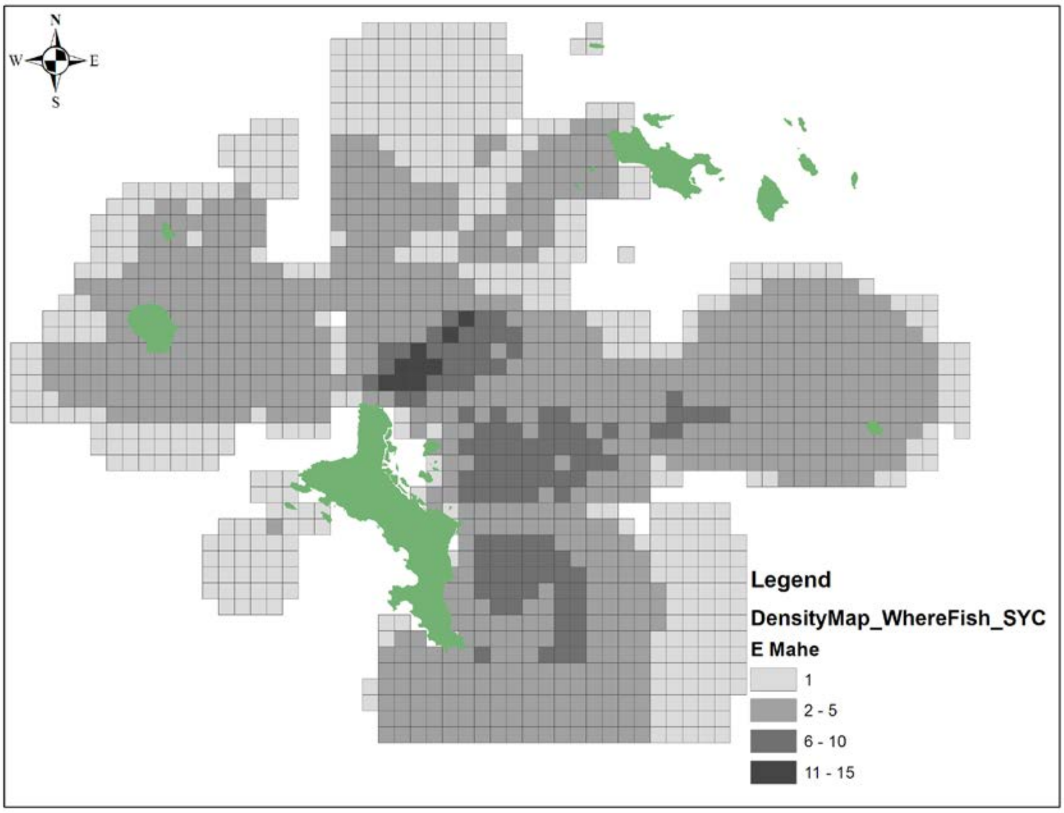
Appendix 2: Species caught by Seychelles inshore fishers (target and by-catch) using different gears. Table sourced from Grandcourt (1999). D: Casier Dormi - A static arrowhead trap of bamboo construction reinforced with wood and weighted under the corneres with rocks. The average soak time is 24 hours; C: Casier Pesser - A static arrowhead trap of bamboo construction. This trap differs from the 'casier domi' in that is set inside lagoons. The average soak time is 24 hours; L: Casier La Vole - An active arrowhead trap of bamboo construction. This trap differs from the two above in that it is of lighter construction and has a shorter soak time; N: Handline; B: Beach Seine; P: Primary target species; I: Important by-catch; O: Occasional by-catch

Family	Species		D			C			L			N			B	
		P	I	O	P	I	O	P	I	O	P	I	O	P	I	O
Acanthuridae	Acanthurus leucosternon			X						X			X			
	Acanthurus lineatus			X						X						
	Acanthurus nigrofuscus			X						X			X			
	Acanthurus triostegus															
	Acanthurus tenneti					X			X							
	Ctenochaetus binotatus						X			X						
	Ctenochaetus striatus					X			X							
	Ctenochaetus strigosus			X			X			X						
	Naso lituratus															
	Paracanthurus hepatus			X						X						
	Zebrasoma scopas															
Balistidae	Sufflamen chrysopterus			X												
Chaetodontidae	Chaetodon auriga															
	Chaetodon guttatismus															
	Chaetodon kleinii															
	Chaetodon lineolatus															
	Chaetodon madagaskarensis															
	Chaetodon melannotus															
	Chaetodon meyeri															
	Chaetodon trifascialis															
	Chaetodon xanthocephalus															
	Chaetodon zanzibarensis															
	Chaetodon lunula															
Haemulidae	Diagrama pictum		X			X			X							
	Plectorhinchus gibbosus		X				X			X						
	Plectorhinchus orientalis		X			X				X						
	Plectorhinchus schotaf		X				X			X						
Labridae	Anampses meleagrides			X						X			X			
	Bodianus axillaris			X						X			X			
	Cheilinus diagrammus		X			X			X			X				
	Cheilinus fasciatus		X			X			X			X				
	Cheilinus trilobatus		X			X			X			X				
	Cheilinus undulatus												X			
	Coris formosa			X						X						
	Epibulis insidiator			X						X			X			
	Gomphosus caeruleus												X			
	Halichoeres cosmetus															
	Halichoeres hortulans			X			X			X			X			
	Halichoeres marginatus			X			X			X						
	Halichoeres scapularis			X			X			X						
	Hemigymnus fasciatus			X			X			X			X			
	Hemigymnus melapterus			X			X			X			X			

	Labrichthys unilineatus			X		X			X				
	Labroides bicolor												
	Macropharyngodon bipartus			X		X			X			X	
	Novaculichthys taeniourus			X		X			X			X	
	Stethojulis albovittata			X		X			X			X	
Lethrinidae	Lethrinus concyliatus		X					X			X		X
	Lethrinus enigmatus		X					X			X		X
	Lethrinus harak		X					X			X		X
	Lethrinus lentjan		X					X			X		X
	Lethrinus mahsena		X					X			X		X
	Lethrinus mahsenoides		X					X			X		X
	Lethrinus nebulosus		X		X			X			X		X
	Lethrinus obsoletus		X					X			X		X
	Lethrinus olivaceus		X					X			X		X
	Lethrinus rubrioperculatus		X		X			X			X		X
	Monotaxis grandoculis		X		X			X			X		X
Lutjanidae	Aprion virescens			X					X	X			
	Lutjanus argentimaculatus			X					X		X		
	Lutjanus bohar		X					X		X			
	Lutjanus fulviflamma		X					X			X		
	Lutjanus gibbus		X					X			X		
	Lutjanus kasmira		X					X			X		
	Lutjanus monostigma		X					X			X		
	Lutjanus rivulatus		X					X			X		
	Lutjanus russelli		X					X			X		
	Lutjanus sebae	X					X			X			
	Macolor niger		X					X			X		
	Pristipomoides filamentosus									X			
Mullidae	Mulloides flavolineatus		X		X			X				X	X
	Parupeneus barberinus		X		X			X				X	X
	Parupeneus bifasciatus		X		X			X				X	X
	Parupeneus ciliatus		X		X			X				X	X
	Parupeneus cyclostomas		X		X			X				X	X
	Parupeneus rubenscens		X		X			X				X	X
	Parupeneus macronema		X		X			X				X	X
Nemipteridae	Scolopsis frenatus			X		X			X			X	
Pomacanthidae	Apolemicthys trimaculatus			X					X				
	Centropyge multispinis			X					X				
	Pomacanthus imperator			X					X				
	Pomacanthus semicirculatus			X					X				
Pomacentridae	Amblyglyphidodon leucogaster												
	Chromis antripectoralis												
	Chromis dimidiata												
	Chromis ternatensis												
	Chromis weberi												
	Dascyllus trimaculatus												
	Dascyllus aruanus												
	Dascyllus carneus												
	Neoglyphidodon melas												
	Plectroglyphidodon dickii												
	Plectroglyphidodon jonstionus												
Scaridae	Calotomus carolinus		X		X			X					
	Cetoscarus bicolor		X		X			X					

	Hipposcarus scarid			X			X			X						
	Leptoscarus vaigiensis		X			X			X							
	Scarus atriluna			X			X			X						
	Scarus caudofasciatus		X			X			X							
	Scarus falcipinnis		X			X			X							
	Scarus frenatus		X			X			X							
	Scarus ghobban	X			X				X							
	Scarus gibbus		X			X			X							
	Scarus globiceps		X			X			X							
	Scarus niger		X			X			X							
	Scarus psittacus		X			X			X							
	Scarus rubrioviolaceus	X			X				X							
	Scarus sordidus		X			X			X							
	Scarus scaber	X			X				X							
	Scarus strongylocephalus		X			X			X							
	Scarus viridifucatus		X			X			X							
	Scarus tricolor		X			X			X							
Serranidae	Aethaloperca rogaa			X						X			X			
	Anyperodon leucogrammicus		X				X		X			X				
	Cephalopholis argus		X				X		X			X				
	Cephalopholis leopardus		X				X		X		X					
	Cephalopholis miniata		X				X		X			X				
	Cephalopholis urodeta			X			X			X			X			
	Epinephelus caeruleopunctatus			X			X			X			X			
	Epinephelus chlorostigma		X				X		X			X				
	Epinephelus fasciatus		X				X		X			X				
	Epinephelus hexagonatus		X				X		X			X				
	Epinephelus merra		X				X		X				X			
	Epinephelus spiloptoceps		X				X		X			X				
	Epinephelus tukula		X						X			X				
Siganidae	Siganus argenteus		X			X			X							
	Siganus puelloides		X			X			X							
	Signaus stellatus		X			X			X							
	Siganus sutor	X			X			X								X
Zanclidae	Zanclus cornutus			X						X						

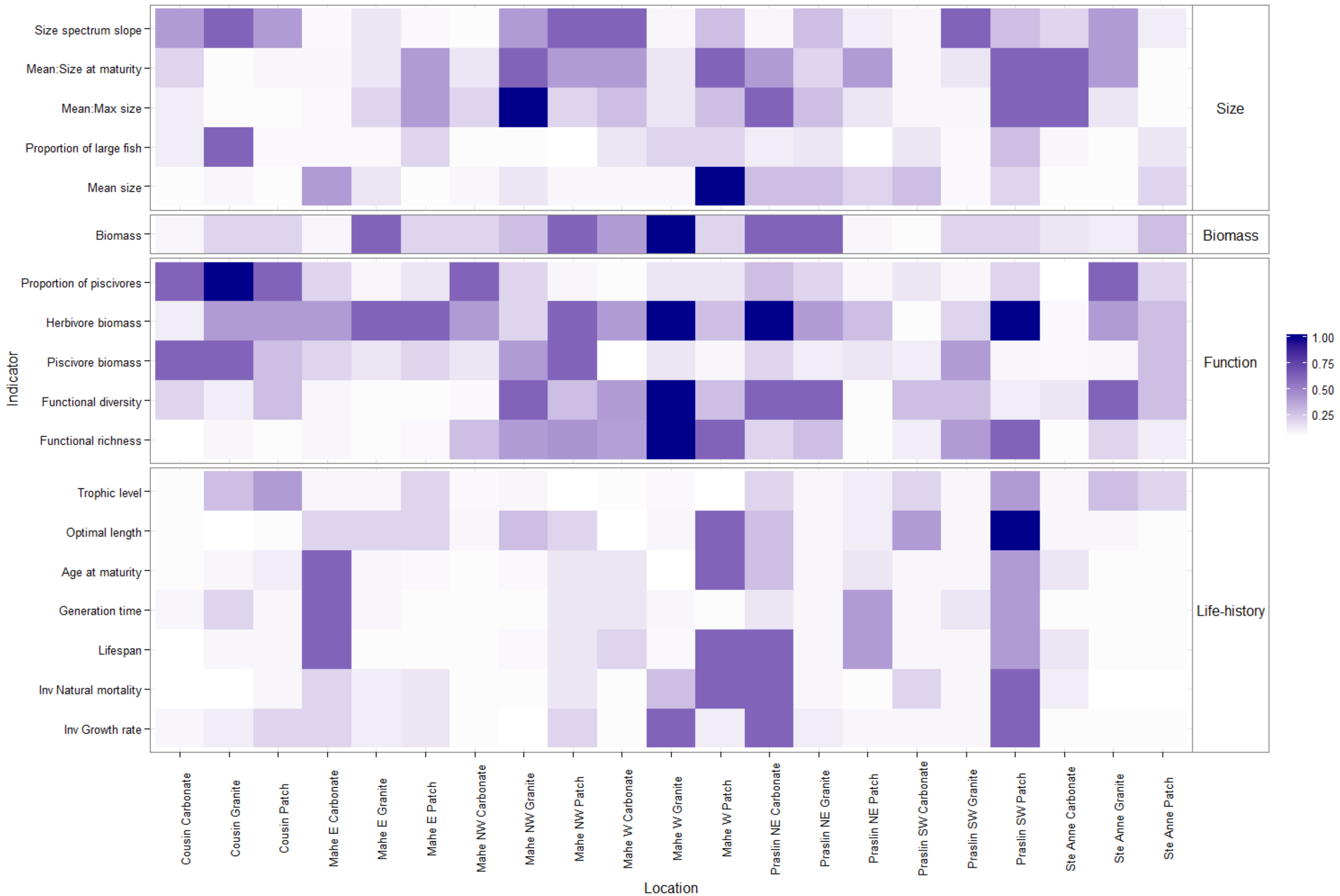
Appendix 3: Map displaying areas that fishers from Mahe East identify as fishing grounds. These data show the difference between where fish are caught (around both Mahe and Praslin) versus where they are landed (Mahe E). Grey shading represents the number of fishers identifying a grid square as a fishing location.



Appendix 4: Productivity, susceptibility and vulnerability scores for focal species estimated in PSA.

Family	Species	Productivity	Susceptibility	Vulnerability
Acanthuridae	Acanthurus leucosternon	1.57	1.14	1.94
Acanthuridae	Acanthurus nigrofuscus	1.00	2.14	2.36
Acanthuridae	Ctenochaetus striatus	1.00	2.66	2.84
Labridae	Cheilinus trilobatus	1.57	2.32	2.80
Lutjanidae	Aprion virescens	2.57	3.00	3.95
Lutjanidae	Lutjanus bohar	2.57	3.00	3.95
Lutjanidae	Lutjanus fulviflamma	1.43	1.66	2.19
Mullidae	Parupeneus macronema	1.14	1.58	1.95
Nemipteridae	Scolopsis frenatus	1.14	1.00	1.52
Scaridae	Chlorurus sordidus	1.00	2.66	2.84
Scaridae	Hipposcarus harid	1.71	1.14	2.06
Scaridae	Scarus ghobban	1.43	2.67	3.03
Scaridae	Scarus niger	1.00	2.32	2.53
Scaridae	Scarus psittacus	1.00	1.66	1.94
Scaridae	Scarus rubroviolaceus	1.86	2.67	3.25
Serranidae	Cephalopholis leopardus	1.29	2.00	2.38
Siganidae	Siganus argenteus	1.00	2.66	2.84
Siganidae	Siganus sutor	1.00	3.00	3.16

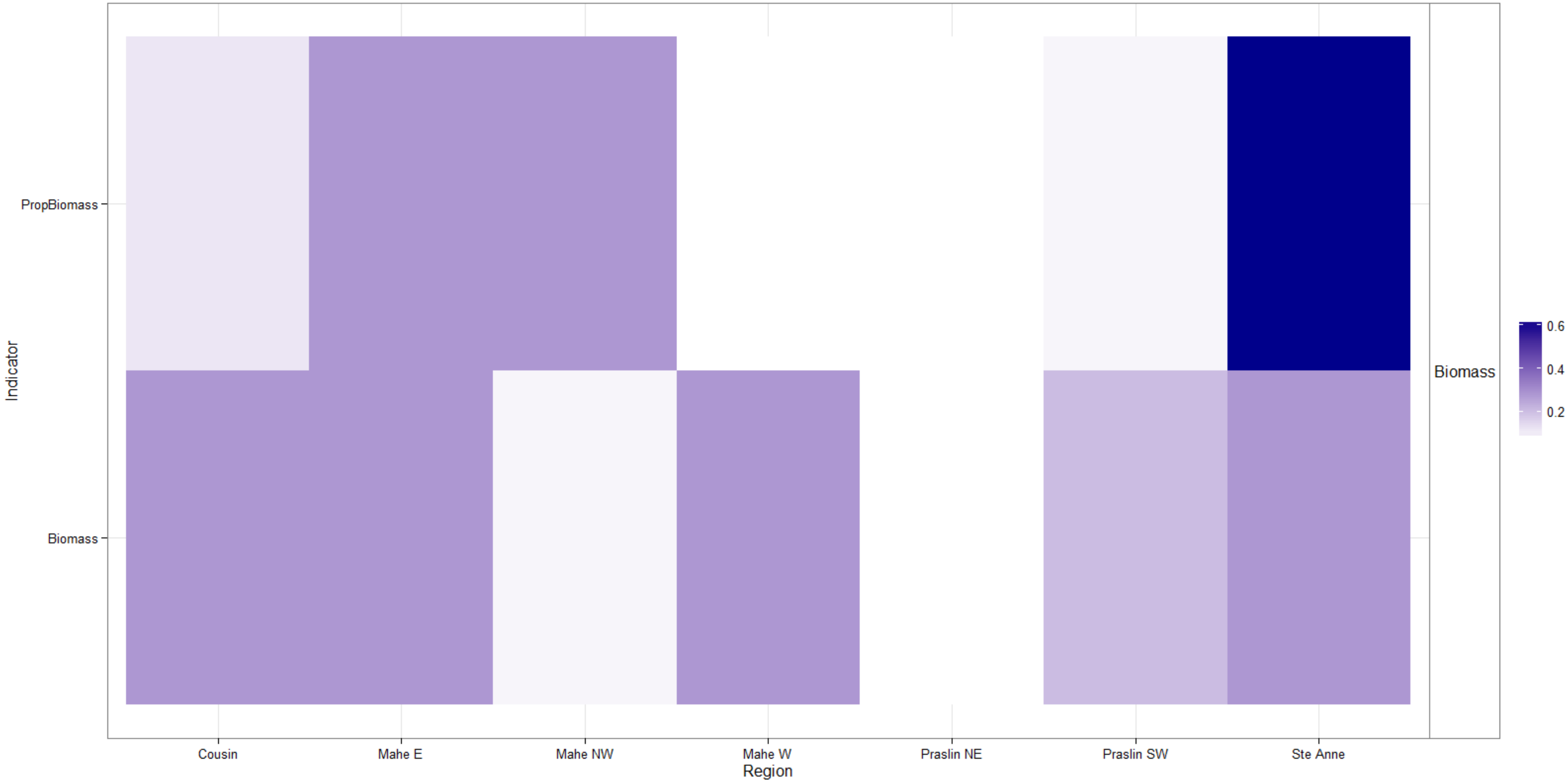
Appendix 5: Power of different indicators to show significant (p value<0.05) correlations with time for all sites. Proportion of piscivores represents the percentage of the summed piscivore and herbivore biomass that is due to piscivorous fishes. Growth rate and natural mortality are presented as inverse metrics to standardise the expected effect of fishing – all indicators are expected to decline in response to fishing pressure. Optimal length is the length to achieve optimum yield.



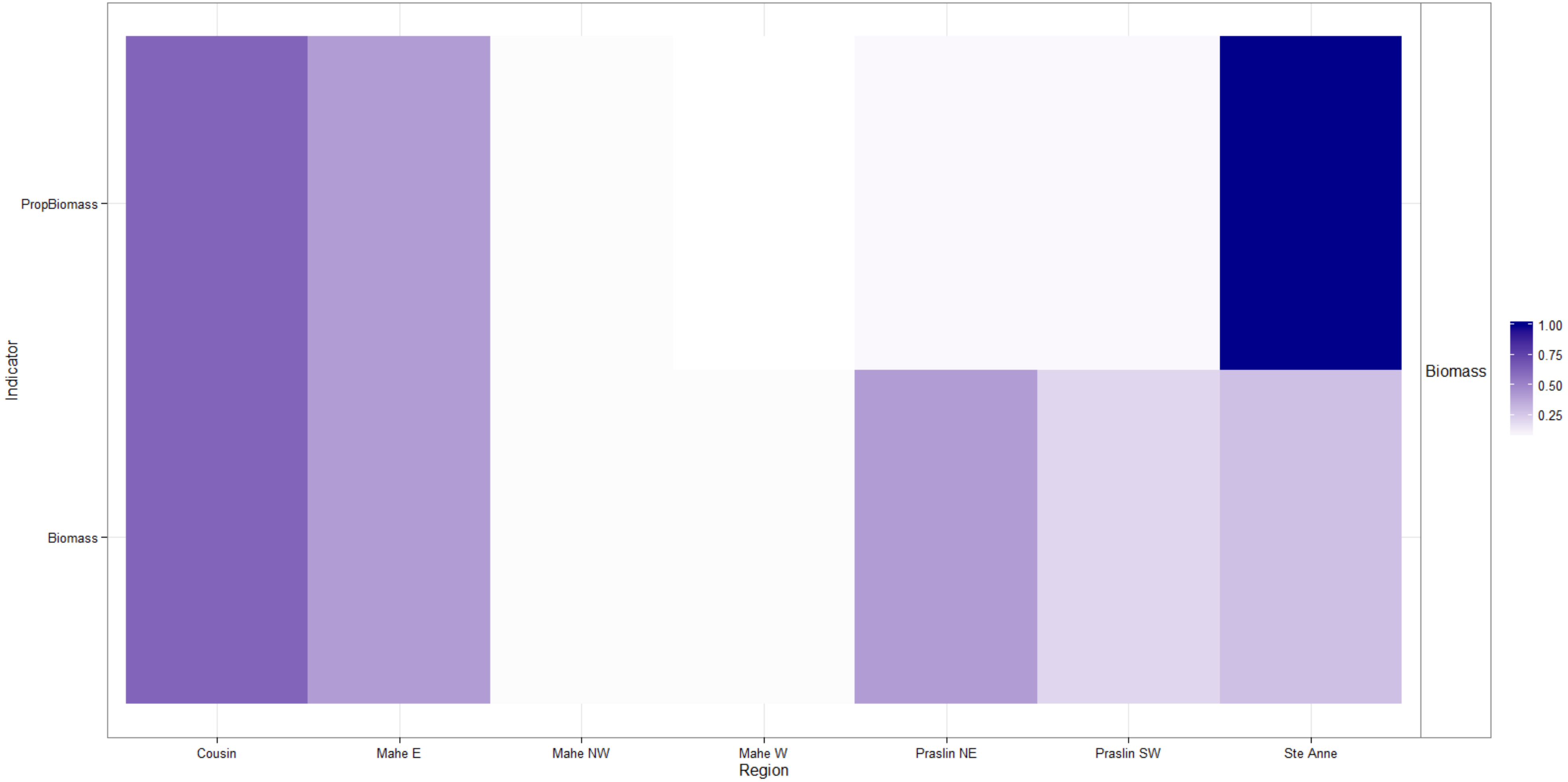
Appendix 6: Power of different indicators to show significant (p value<0.05) correlations with time for all regions. Proportion of piscivores represents the percentage of the summed piscivore and herbivore biomass that is due to piscivorous fishes. Growth rate and natural mortality are presented as inverse metrics to standardise the expected effect of fishing – all indicators are expected to decline in response to fishing pressure. Optimal length is the length to achieve optimum yield.

Appendix 7: Power of different indicators to show significant (p value<0.05) correlations with time for all regions for *Chlorurus sordidus*. Propbiomass represents the proportion of total fish biomass contributed by *Chlorurus sordidus*.

Appendix 8: Power of different indicators to show significant (p value<0.05) correlations with time for all regions for *Scarus rubroviolaceus*. Propbiomass represents the proportion of total fish biomass contributed by *Scarus rubroviolaceus*. Size indicators are not shown as there were insufficient data to estimate the power of spearman rank correlations.



Appendix 9: Power of different indicators to show significant (p value<0.05) correlations with time for all regions for *Siganus argenteus* and *Siganus sutor*. Propbiomass represents the proportion of total fish biomass contributed by *Siganus argenteus* and *Siganus sutor*. Size indicators are not shown as there were insufficient data to estimate the power of spearman rank correlations.



Appendix 10: Spearman rank correlations between indicators estimated for different sites and years. Those showing coefficients ≥ 0.8 are highlighted in yellow. Those indicators excluded from further analysis due to collinearity with other indicators are highlighted in red.

	Mean size	Proportion of large fish	Mean:Max size	Mean:Size at maturity	Size spectrum slope	Biomass	Functional richness	Functional diversity	Piscivore biomass	Herbivore biomass	Proportion of piscivores	Inv Growth rate	Inv Natural mortality	Lifespan	Generation time	Age at maturity	Optimal length	Trophic level
Mean size	1																	
Proportion of large fish	0.8	1																
Mean:Max size	-0.07	0.09	1															
Mean:Size at maturity	0.25	0.3	0.89	1														
Size spectrum slope	-0.07	-0.04	0.03	0.03	1													
Biomass	0.38	0.51	0.19	0.25	-0.7	1												
Functional richness	-0.18	0.03	0.4	0.23	-0.7	0.61	1											
Functional diversity	-0.01	0.17	0.25	0.15	-0.56	0.45	0.83	1										
Piscivore biomass	0.27	0.46	0.18	0.23	-0.39	0.57	0.5	0.49	1									
Herbivore biomass	0.37	0.44	0.09	0.18	-0.69	0.94	0.51	0.36	0.35	1								
Proportion of piscivores	-0.14	0.01	0.02	-0.06	0.24	-0.25	-0.04	0.05	0.49	-0.49	1							
Inv Growth rate	0.4	0.38	-0.37	-0.28	0.22	-0.08	-0.31	-0.12	0.15	-0.11	0.27	1						
Inv Natural mortality	0.58	0.44	-0.55	-0.37	0.16	-0.04	-0.41	-0.2	0.1	-0.04	0.17	0.91	1					
Lifespan	0.5	0.38	-0.47	-0.33	0.06	-0.05	-0.23	0	0.23	-0.09	0.31	0.81	0.86	1				
Generation time	0.38	0.35	-0.32	-0.26	0.05	-0.03	-0.08	0.11	0.3	-0.1	0.38	0.81	0.78	0.96	1			
Age at maturity	0.46	0.37	-0.39	-0.27	0.09	-0.07	-0.19	0.04	0.22	-0.12	0.33	0.82	0.84	0.99	0.97	1		
Optimal length	0.57	0.39	-0.73	-0.52	0	0.04	-0.41	-0.22	0.11	0.06	0.09	0.64	0.83	0.78	0.64	0.69	1	
Trophic level	-0.2	-0.16	0.05	-0.08	0.31	-0.4	-0.12	-0.02	0.01	-0.52	0.58	0.26	0.16	0.2	0.26	0.27	-0.14	1

Appendix 11: Model selection for multiple regressions of benthos and fishing proxy against different fishing indicators from Section 4-4

		PC1	PC1^2	Log PC2	Proxy 2	AICc	delta AICc	AICc Wt
Mean Size								
	1	-0.670		8.292		92.140	0.000	0.670
	2	-0.663		8.792	0.000	94.340	2.200	0.223
	3			7.745		96.520	4.380	0.075
	4			8.291	0.000	98.555	6.416	0.027
Mean Size								
	1	0.022	-0.009			-70.892	0.000	0.608
	2	0.021	-0.011	0.043		-68.500	2.392	0.184
	3	0.022	-0.009		0.000	-67.789	3.102	0.129
	4	0.021	-0.010	0.048	0.000	-65.209	5.683	0.035
	5	0.026				-64.392	6.500	0.024
Slope of Size Spectrum								
	1	-0.017			0.000	-52.744	0.000	0.311
	2	-0.016				-52.272	0.472	0.246
	3					-51.065	1.680	0.134
	4				0.000	-50.852	1.892	0.121
	5	-0.017		0.044		-49.690	3.055	0.068
	6	-0.017		0.018	0.000	-49.341	3.404	0.057
	7			0.031		-48.523	4.222	0.038
	8			0.006	0.000	-47.771	4.973	0.026
Functional Richness								
	1	0.620			0.000	35.668	0.000	0.451
	2	0.629		-0.862	0.000	35.798	0.131	0.423
	3	0.625		-1.163		38.994	3.326	0.086
	4	0.610				40.492	4.824	0.040
Piscivore Biomass								
	1					12.911	0.000	0.238
	2	0.062				12.968	0.057	0.232
	3	0.064			0.000	13.937	1.026	0.143
	4				0.000	14.043	1.132	0.135
	5			0.252		15.008	2.097	0.084
	6	0.059		0.204		15.581	2.671	0.063
	7			0.369	0.000	15.696	2.786	0.059
	8	0.061		0.323	0.000	16.174	3.263	0.047
Herbivore Biomass								
	1					278.291	0.000	0.294
	2				-0.001	278.941	0.651	0.213
	3	23.585				279.800	1.509	0.138
	4	25.258			-0.001	280.455	2.164	0.100
	5			126.580		280.507	2.216	0.097
	6			197.808	-0.002	280.658	2.368	0.090
	7	22.248		108.430		282.482	4.191	0.036

Proportion of Piscivores								
	1		0.066	-0.508		7.813	0.000	0.346
	2		0.053			8.197	0.383	0.286
	3		0.055		0.000	10.888	3.075	0.074
	4	0.017	0.069	-0.540		11.017	3.203	0.070
	5		0.066	-0.492	0.000	11.208	3.394	0.063
	6	0.003	0.053			11.276	3.462	0.061
	7					12.296	4.483	0.037
	8	0.006	0.056		0.000	14.360	6.546	0.013
	9	-0.021				14.738	6.924	0.011
	10			-0.163		14.765	6.951	0.011
Lifespan								
	1		0.223			49.329	0.000	0.437
	2		0.202	0.812		51.234	1.904	0.169
	3	-0.082	0.211			51.568	2.239	0.143
	4		0.218		0.000	52.140	2.811	0.107
	5	-0.108	0.181	1.011		53.221	3.892	0.062
	6		0.200	0.764	0.000	54.617	5.288	0.031
	7	-0.088	0.204		0.000	54.653	5.324	0.031
Length to Achieve Optimal Yield								
	1	-1.825		8.978		108.425	0.000	0.805
	2	-1.826		8.934	0.000	111.921	3.495	0.140
	3	-1.714				114.308	5.882	0.043
Trophic Level								
	1	0.041	0.050	-0.495		-20.741	0.000	0.679
	2		0.042	-0.419		-17.696	3.044	0.148
	3	0.042	0.051	-0.484	0.000	-16.975	3.766	0.103
	4		0.042	-0.412	0.000	-14.256	6.485	0.027
Trophic Level without outlier								
	1	0.041	0.050	-0.495		-20.741	0.000	0.679
	2		0.042	-0.419		-17.696	3.044	0.148
	3	0.042	0.051	-0.484	0.000	-16.975	3.766	0.103
	4		0.042	-0.412	0.000	-14.256	6.485	0.027

Appendix 12: The distribution of fish lengths at sites with varying levels of macroalgal cover and structural complexity. These benthic differences are represented by different values on the PC1 axis (further described in section 4-4 methods), with negative values indicative of high macroalgal cover and low structural complexity and positive values indicative of low macroalgal cover and high structural complexity.