Capturing Change in Ecosystem Service Delivery from Coral Reefs

Thesis submitted by

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Chapter 1 – Coral reef ecosystem services in the Anthropocene

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Chapter 2 - Identifying co-production in the service providers of tropical coastal ecosystem services

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Chapter 3 - Fishers perceptions of ecosystem service change associated with climate-disturbed coral reefs

AJW, CCH, NAJG and AN conceived the ideas; AJW and CCH designed the methodology; AJW, NB, MS and M-CB collected the data; AJW analysed the data; AJW led the writing of the manuscript. All authors contributed critically to the drafts.

Chapter 4 - Wellbeing insights from coral reef fishers and the implications of changing nearshore tropical environments

AJW and CCH conceived the ideas and designed the methodology; AJW collected the data; AJW analysed the data; AJW led the writing of the manuscript. All authors contributed critically to the drafts.

Abstract

Ecosystems around the world are changing due to interacting local and global stressors. These changes are likely to affect ecosystem services - the benefits that ecosystems contribute to human wellbeing - but the complexity of social-ecological processes underpinning these services limits our understanding change. In this thesis, I examine changes in ecosystem services associated with climate-impacted tropical coral reefs and implications for the wellbeing of coastal communities. I draw on empirical data from the Seychelles, where two mass bleaching events (1998, 2016) have affected benthic and fish community composition. I first provide an overview of coral reef ecosystem services research and use empirical interview data from tourism and fishery key informants to understand the social-ecological aspects of services at the level of the service provider. This reveals the complexity of service providers underpinning locally valued services and benefits, but also the advantages of dis-aggregating service providers and their traits to understand how services are likely to respond to environmental change. Shifting from conceptualisations of change to lived experiences of change, I then explore how changes in ecosystem services are perceived by coral reef fishers. Changes have been perceived, though perceptions differ according to fishers' characteristics, and have implications for the material, relational and subjective dimensions of fishers' wellbeing. Finally, I draw on a social wellbeing approach to examine how the marine environment, and changes therein, affect fishers' understanding of and ability to live well. This reveals tensions in fishers' ability to pursue wellbeing, shaped by the social-ecological context in which changes to nearshore environments occur. These findings have implications for how changes in ecosystem services are investigated and highlight the need for multiple disciplinary perspectives to better understand the consequences of environmental change for human wellbeing.

Contributions during the PhD

Peer-reviewed publications - Thesis

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General introduction

Chapter 1

General introduction

Marine ecosystems globally are highly vulnerable to changing environmental conditions and direct human activities such as over-fishing, pollution, and physical damage (Ban, Graham & Connolly 2014). Climate change is resulting in marine heatwaves which are increasing in frequency resulting in shorter possible recovery time between heating events (Hughes *et al.* 2018a). Tropical areas, including shallow water ecosystems like coral reefs, concentrate high levels of biodiversity (Fisher *et al.* 2015) and are particularly vulnerable to these multiple and interacting stressors (Ban, Graham & Connolly 2014). Yet, these areas also underpin diverse ecosystem services that connect to the wellbeing of millions of people (Moberg & Folke 1999; Barlow *et al.* 2018; Woodhead *et al.* 2019). Questions remain as to whether the relationships between the environment and human wellbeing are sufficiently understood to address the challenges of managing for both people and ecosystems into the future (Bennett *et al.* 2015). In this thesis, I seek to examine the implications of environmental change for ecosystems and people, using ecosystem services as a conceptual frame. Drawing on different disciplinary perspectives, I explore conceptualisations and lived experiences of changing services to contribute a more nuanced understanding of the implications of environmental change for human wellbeing.

Multi-faceted environmental change, necessitating multifaceted research

How ecosystems respond to on-going anthropogenic activities is highly non-linear. Coral reefs are susceptible to multiple interacting stressors acting at local and global scales (Ban, Graham & Connolly 2014). Reef building corals are vulnerable to prolonged heating events, which can result in high levels of coral bleaching and mortality (Hughes *et al.* 2017), but the effects of these stressors vary among taxa (Yadav, Alcoverro & Arthur 2018). Vulnerability to

heat stress and recovery following these events is therefore highly variable (Hughes *et al.* 2018b). As a consequence, some areas of reef are shifting to an alternative benthic state, often dominated by macroalgae as coral species are unable to recover dominance (Nyström *et al.* 2012), whilst others remain coral dominated through the presence of more thermally tolerant coral species (van Woesik *et al.* 2011). Consequently, reef environments are degrading but also re-organising, presenting novel species assemblages (Graham *et al.* 2014). These benthic shifts are resulting in altered coral reef fish assemblages (Robinson *et al.* 2019a) and a patchier nearshore environment (Graham *et al.* 2015). Such trends are likely to continue through the Anthropocene, with predications that reefs will never recover to pre-existing states (Hughes *et al.* 2018a).

The re-organisation of reef environments and de-coupling of reef communities from 'natural' biophysical drivers (Williams *et al.* 2015) has led to calls for a re-think of coral reef research. This includes the adoption of methods and approaches that better reflect the human and biophysical determinants of reef environments (Williams *et al.* 2019). This adds to prior calls to develop a better understanding of the human dimensions of reef ecosystems, encompassing not only anthropogenic drivers of reef change but also the human-environment interactions that connect reefs to ecosystem services and human wellbeing (Kittinger *et al.* 2012). In 2016, a global mass bleaching event further awakened concerns over the future of coral reef environments (Hughes *et al.* 2017), but also highlighted that large evidence gaps remain regarding the human dimensions of reef systems (Pendleton & Edwards 2017). As such, on both an academic and practical level, there is a need to revisit current approaches to understanding change on coral reefs and to adopt methods and tools that reflect the social and ecological reality of these environments.

Three gaps in ecosystem services research

Concern over changing reef environments is acute as coral reefs globally underpin the wellbeing of ca. 400 million people through a multitude of ecosystem services (Moberg & Folke 1999; Morrison *et al.* 2019; Woodhead *et al.* 2019). Ecosystem services refer to the benefits that the environment contributes to human wellbeing (Millennium Ecosystem Assessment 2005) and are co-produced between people and nature 'for in the absence of people there are no services' (Bennett, Peterson & Gordon 2009; p.1396). The advantage of ecosystem services - as a framework for exploring human-environment relationships – is that it brings together research on both ecological complexities, for example identifying the ecological components, functions and properties that underpin services (Luck *et al.* 2009), and social complexities, for instance, the disaggregation of wellbeing contributions from the environment to different people (Daw *et al.* 2016). Despite its inter-, cross- and trans-disciplinary potential, the field remains dominated by ecological research with less disciplinary integration than might be expected (Schutter & Hicks 2020). Against a backdrop of environmental change, this poses several challenges in anticipating the likely impacts of changing ecosystems for human wellbeing. Firstly, it remains unclear how ecosystem services are co-produced between people and the environment making it difficult to know when services will or will not be resilient to change (Bennett *et al.* 2015). Secondly, perceptions of, and wellbeing contributions from, ecosystem services differ between people, yet the significance of different intermediary processes that mediate between ecological change and wellbeing are poorly tested (Andersson *et al.* 2015; Daw *et al.* 2016; Cebrián-Piqueras, Karrasch & Kleyer 2017). Thirdly, despite many different conceptualisations of ecosystem - ecosystem services - wellbeing relationships (e.g. Millennium Ecosystem Assessment 2005; Haines-Young & Potschin 2010a; Reyers *et al.* 2013; Daw *et al.* 2016) there is a lack of empirical case-studies to test and investigate the implications of changing services

for wellbeing. Further, empirical research is lacking from tropical regions and on marine and coastal ecosystem service -wellbeing relationships (Cruz-Garcia *et al.* 2017; Blythe *et al.* 2020). Below I outline the background to each of these research gaps before introducing how I address these in the thesis in the context of tropical coral reefs in the Seychelles.

Co-production of ecosystem services against a backdrop of environmental change

The co-production of ecosystem services from within social-ecological systems, refers to different social and ecological processes that combine to produce ecosystem services of value to human wellbeing. These include, for example, human inputs to, or the physical modification of, environments to enhance specific services (Palomo *et al.* 2016), which can be monitored to identify unsustainable patterns in ecosystem service use (Outeiro *et al.* 2017). Ecosystem services can also emerge through the co-construction of meanings attributed to specific services and benefits (Fischer & Eastwood 2016). This reflects a dynamic interpretation of ecosystem services as connected to the relationships between people, between people and place, and can be associated with the activities through which people engage with the environment, for example foraging (Fischer & Eastwood 2016; Poe, Donatuto & Satterfield 2016). Ecosystem services are also highly context dependent. For instance, certain parts of the ecosystem will only become important for service provision under specific 'problem contexts', such as extreme flooding events (Andersson *et al.* 2015), or according to seasonal variations in weather and resource availability (Grantham, Lau & Kleiber 2020). Perceptions of the biophysical features underpinning services can also vary according to the different types of knowledge held by ecosystem service beneficiaries (Cebrián-Piqueras, Karrasch & Kleyer 2017). Access to ecosystem services can be shaped by knowledge, as well as social and institutional mechanisms (Hicks & Cinner 2014). Finally,

differences in need and social status can shape how ecosystem services contribute to wellbeing and who's wellbeing is at risk from changes to these services (Daw *et al.* 2015).

Connecting ecosystem service co-production to environmental change is further complicated by a lack of integrative research that assesses the implications of change in the biophysical underpinning of services (Chan, Satterfield & Pascual 2020). In the context of coral reefs, indicators of ecosystem service potential are often used as a proxy for examining changes in ecosystem services following disturbances (Yee, Dittmar & Oliver 2014; Orlando & Yee 2017; Sato *et al.* 2020), but there is a similar lack of systematic engagement with the specific mechanisms through which ecosystem services emerge. As such, there is a need to develop research approaches that reflect the co-production of ecosystem services *and* which are compatible with existing knowledge of environmental and ecological change.

Perceptions and experiences of change in ecosystem services

The relative importance of different social and ecological processes underpinning ecosystem services varies according to the personal histories and circumstances of those who rely on these services. At an individual level, factors such as age, education, income, and background can affect how ecosystem services are perceived and prioritised (Martín-López *et al.* 2012; Oteros-Rozas *et al.* 2013; Lau *et al.* 2018). Identifying differences in how different groups ascribe importance to ecosystem services can provide insights on their contributions to multiple aspects of wellbeing (Lau *et al.* 2019). How people experience ecosystem services is also an important mechanism through which ecosystems connect to wellbeing. For example, fishers may value the process of fishing differently from the other benefits that they receive through fishing such as food and income (Chaigneau *et al.* 2019). In addition to these more personal factors, cross-cultural studies of ecosystem services highlight cultural differences in how ecosystem services from the same environment are perceived (Orenstein & Groner

2014), and underlying power and social structures can affect who is able to access different ecosystem services (Daw *et al.* 2015).

The combination of personal and social processes that shape the relationships between ecosystems and ecosystem services highlight the importance of understanding why ecosystem services matter from the perspective of those who benefit from them (Klain, Satterfield & Chan 2014). Engaging with perceptions of ecosystem services can also provide a tool for understanding the co-production of ecosystem services. Stakeholders in participatory assessments of ecosystem services, for example, identify both social and ecological processes as underpinning locally valued services (Tusznio *et al.* 2020), thus overcoming the artificial split created by different disciplinary approaches to how ecosystem services occur.

Perceptions of ecosystem services, and therein ecosystem service change, are also important to consider as perceptions can inform human behaviour. Fishers for example may choose to keep fishing, fish elsewhere or exit the fishery depending on the perceived decline in fishery resources (Daw *et al.* 2012), with implications for the long-term sustainability of ecosystems (Cinner *et al.* 2011). Perceptions of change thus play an important role in whether and how communities adapt to change (Adger *et al.* 2008). Complementing an understanding of ecosystem service co-production with a contextualised understanding of how changes in these processes are perceived on coral reefs can therefore provide important insights into when changes in ecosystem services are likely to have an impact on wellbeing, and how changes may interact to impact on the long term sustainability of coral reef social-ecological systems.

Connecting ecosystem services to multi-dimensional wellbeing

Human wellbeing is often conceptualised as the 'endpoint' that benefits from ecosystems flow toward (e.g. Millennium Ecosystem Assessment 2005). Changes in wellbeing can however affect the ecological structures underpinning services (Reyers *et al.* 2013) and some benefits from ecosystem services may be a pre-requisite for other services to contribute to wellbeing (what (Polishchuk & Rauschmayer 2012) refer to as conversion factors, drawing on the Capabilities Approach). Understanding the inter-dependencies between ecosystems and wellbeing is further limited by a lack of specific inquiry into these linkages. A review of ecosystem services research across Africa, Asia and Latin America shows that the relationships between ecosystem services and human wellbeing are often assumed, rather than examined (Cruz-Garcia *et al.* 2017). Indeed, part of the critique of ecosystem services research is that it does not sufficiently engage with the social complexities that shape ecosystem service -wellbeing relationships, and adopts an overly-reductionistic focus on specific ecosystems which does not reflect how people engage with and value their environment (Dawson & Martin 2015).

The importance of the ocean for many different aspects of wellbeing is increasingly recognised (Allison *et al.* 2020) but there is an urgent need to improve our empirical understanding of these relationships in the Global South and to understand how they respond to change (Blythe *et al.* 2020). Environment, and environmental change therein, are often studied as external determinants of wellbeing, rather than internal to how people define and pursue wellbeing (Schleicher *et al.* 2018). This negates an important part of the co-production of ecosystem services that identifies ecosystem services as co-constructed in the relationships between people, between people and place – including the natural environment - and through the everyday activities that shape these relationships (Fischer &

Eastwood 2016; Poe, Donatuto & Satterfield 2016). Within wellbeing research, there is a similar call to recognise wellbeing as relational, emerging from the relationships between people, societal structures, and the natural environment (White 2017). Adopting a relational approach to wellbeing, which situates coral reef ecosystems in local conceptualisations of how wellbeing is defined and pursued, could provide a better understanding of the multiple impacts of reef change on human wellbeing.

Coral reef ecosystem services

Coral reefs are commonly associated with similar types of ecosystem services regardless of geographic region (Hicks 2011; Laurans *et al.* 2013; Albert *et al.* 2015; Schuhmann & Mahon 2015; see Chapter 1 for a full review) though some ecosystem services are better researched than others (Hicks 2011). There are multiple indicators available to capture changes in ecosystem service potential (Yee, Dittmar & Oliver 2014) and evidence suggests change is already occurring following disturbances to reef environments (Orlando & Yee 2017; Sato *et al.* 2020). Data deficiency has however limited investigations into the more nuanced effects of disturbances on the ecological underpinnings of services (Carturan, Parrott & Pither 2018) but this type of information will be important to consider amidst the on-going re-organisation of reef communities (Hughes *et al.* 2018b; Robinson *et al.* 2019a). An adaptive and broader portfolio of management approaches has been put forward as vital for ensuring future ecosystem service provision (Rogers *et al.* 2015a), but there are important moral and ethical questions to consider regarding which services and ecosystems to prioritise (Vergés *et al.* 2019). Given the many uncertainties in connecting ecosystems, to services, to human wellbeing (Daw *et al.* 2016), the wider implications of changing reef systems for individual and community wellbeing (Poe, Norman & Levin 2014; Daw *et al.* 2015) necessitate further empirical investigation.

Aims and thesis outline

In my thesis, I draw on advances in ecological, social, and social-ecological approaches to ecosystem services to examine the implications of environmental change for human wellbeing. I apply this to nearshore tropical coral reefs. Reef ecosystems provide a useful example of social-ecological dynamics, as they are highly responsive to human activities yet connect to human wellbeing in numerous ways (Kittinger *et al.* 2012).

My thesis addresses three main questions relating to change in the context of coral reef associated ecosystem services (Fig. 0.1):

1. How do coral reef ecosystem services emerge from social-ecological systems? *(addressed in Chapters 1 and 2)*
2. How do these processes respond to change? *(addressed in Chapters 2 and 3)*
3. What are the implications of change for human wellbeing? *(addressed in Chapters 3 and 4)*

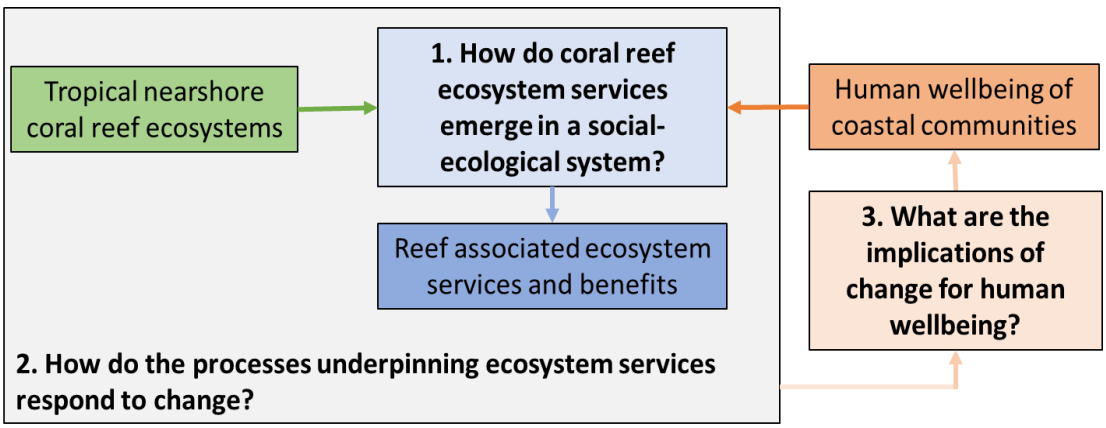

Figure 0. 1 Overview of thesis questions in relation to a simplified model of ecosystem services, as co-produced from social and ecological processes, in the context of changing nearshore tropical reef environments.

In **Chapter 1** I provide an overview of ecosystem services associated with nearshore tropical reef environments. I then draw on advances in functional ecology and social-ecological systems research to reconcile a co-production approach to ecosystem services and the need for mechanistic understandings of service provision in the Anthropocene. Beyond the mechanisms of service provision, I reflect on what this approach brings to our understanding of reef-associated services in the Anthropocene; how novelty could emerge in the context of ecosystem services; and whether coral reef research currently engages the appropriate tools for recognising different types of ecosystem service change.

Building on the approach proposed in Chapter 1, in **Chapter 2** I populate a trait-based ecosystem service framework with interview data from the Seychelles. Coral reefs around the Seychelles are known to underpin diverse ecosystem services (Hicks *et al.* 2014) but have undergone widespread ecological change (Graham *et al.* 2015; Robinson *et al.* 2019a; Wilson *et al.* 2019). Recognising that people perceive multiple benefits associated with ecosystem services (Klain, Satterfield & Chan 2014), I conducted interviews with key informants in fisheries and tourism to first identify the benefits associated with fishery and tourism services in this context. I then explore what in the marine environment is perceived to underpin each benefit, incorporating aspects of the environment that reflect preferences and values in Seychelles, as well as the species and ecological functions perceived to underpin services. Drawing on longitudinal studies of reef change in the Seychelles, I discuss the likely implications for ecosystem service provision, before reflecting on the uses and limitations of this approach for understanding ecosystem service change.

Shifting away from models of ecosystem service provision, **Chapter 3** complements Chapter 2, by seeking to understand if, and how, changes in ecosystem services have been perceived by reef-dependent fishers in Seychelles. Four services were investigated: habitat, fishery, coastal protection, and recreation services. As perceptions and wellbeing contributions of ecosystem services are socially differentiated, I also collected social, economic, demographic, and fishing information from all participants to examine if perceptions and implications of change are disaggregated within this community. Changes in services were widely perceived, and relational, subjective, and material dimensions of wellbeing were all implicated in these changes. Fishers' descriptions of changing services referenced ecological, social, and behavioural dynamics, suggesting that overly narrow indicators of change may omit wider implications for the wellbeing of reef fishers and their families.

Having worked within an ecosystem service framing in Chapters 1-3, in **Chapter 4** I reverse the linear understanding of ecosystem services flowing from ecosystems to people, and centre instead on fishers' own conceptualisations of wellbeing. Drawing on in-depth interviews with coral reef fishers, I establish what living well means in Seychelles; situate the marine and coastal environment within fishers' understanding of wellbeing; and examine the processes through which marine and coastal changes affect wellbeing. In subverting, and thereby contextualising, the framing provided by ecosystem services, this chapter contributes a much broader understanding of the implications of environmental change for the wellbeing of coral reef fishers. It highlights the tensions that emerge between different aspects of wellbeing as a consequence of environmental change within a given social-ecological context, and emphasises the need to recognise fishers as active, and not passive, recipients of changing ecosystem services.

Across these four chapters, I demonstrate the complexity needed to understand and explore the implications of changing ecosystem services. I show that working at the intersection of different disciplinary perspectives provides a more nuanced understanding of these dynamics and their implications for wellbeing. Recognising multiple understandings of change, both in how change is conceptualised and experienced, is essential if we are to meet the dual objectives of safeguarding future environments and human wellbeing.

Study region

The island nation of Seychelles is in the west Indian Ocean and consists of 115 islands spread across a vast Exclusive Economic Zone (EEZ) measuring just over 1.3 million km^2. The three main inhabited islands are Mahé, Praslin and La Digue, with the majority of the population to be found on the largest island Mahé (87%; National Bureau of Statistics 2020a). These three islands sit on the Mahé plateau, a ca. 40 000 km^2 area of relatively shallow water (max depth 50-65m) that encompasses a diversity of habitats, which underpin the two main industries in Seychelles: tourism and fisheries (Seychelles Fishing Authority 2019) (Fig. 0.2a)

Tourism in Seychelles is marine based and relies heavily on the appeal of tropical beaches and coastal environments (Mwebaze & Macleod 2013). As a sector it is growing rapidly - between 1998 and 2008, the number of international visitors nearly tripled (from 128 000 international visitors in 1998 to 362 000 in 2008; World Bank 2021). Though it is not specifically marketed as a dive destination, dive operators work across the three main islands, as well as companies offering snorkelling and glass bottom boat tours. Both fishing and dive tourism are influenced by a rough and calm season according to changes in monsoonal wind patterns across the Indian Ocean.

Fisheries in Seychelles can be divided into the offshore and inshore. The offshore fleet is made up of largely European owned tuna fishing vessels, which are of huge economic importance to Seychelles (Clifton *et al.* 2012). The inshore fleet is made up of three different fisheries: commercial (often referred to as artisanal), recreational and sport fishing. As an island nation, fishing is considered a fundamental right in Seychelles and there is very little monitoring of the recreational or sport fishery, the latter of which is predominantly geared towards international tourists (MRAG, 2017; SFA, 2019).

The commercial fishing fleet is a mixed gear, multi-species fishery that targets reef associated fish, demersal fish, and semi-pelagic species. Although economically less important than the tuna fishery, this artisanal fleet is essential for food security and local livelihoods (employing ca. 500 people; SFA, 2019; Bijoux, 2015). Fishers are predominantly male and work from landing sites across the three main islands, selling mixed species packets of fish directly to customers at the landing site or on the roadside (Fig 0.2b). Several different types of boat are used in this fishery but the most common is a small, open-decked fibre-glass boat, known as a 'mini-mahé' (ca. 4-7m in length; Bijoux 2015; MRAG 2017). These boats typically spend no more than a day at sea and are crewed by two or three people. In this thesis, I sought to work specifically with fishers who use fish traps, known as 'kazye'. Traps, which are made of metal, bamboo or wire, are used to target reef associated fish within ca. 40km of land (Bijoux 2015). Previous research in the Seychelles has established that this group of fishers value many different types of reef-associated ecosystem services for which locally relevant descriptions have been established (Hicks *et al.* 2014). This provided the baseline from which to examine changes in ecosystem services associated with coral reefs.

Changes in ecosystem services are likely to already be occurring in Seychelles. As is typical of large ocean states, Seychelles is incredibly vulnerable to changes in coastal and marine environments (Jumeau 2013) and its nearshore environment has been affected by two mass coral bleaching events in the last 20 years (Graham *et al.* 2015; Wilson *et al.* 2019). These bleaching events have resulted in an irreversible shift towards algal dominated communities in certain areas (Graham *et al.* 2015), and a re-structuring of the coral communities that remain (Wilson *et al.* 2019) accompanied with shifts in fish community composition (Robinson *et al.* 2019a) (Fig. 0.2c). The composition of catches in the artisanal fishery is also changing and becoming more un-predictable (Robinson *et al.* 2019b), though attempts to compare catch data, ecological data and fishers' knowledge indicate diverging perspectives on catch trajectories in the fishery (Daw, Robinson & Graham 2011). Coral degradation has also been associated with increased vulnerability to coastal erosion and flooding (Sheppard *et al.* 2005; World Bank and Ministry of Environment Energy and Climate Change of Seychelles 2019), which is further exacerbated by a programme of land reclamation, primarily around Mahé and Praslin. Land is a limited resource in Seychelles and recent coastal development is driven in part by the need to cater for increases in coastal tourism (World Bank and Ministry of Environment Energy and Climate Change of Seychelles 2019).

Prior research conducted in Seychelles on the ecology, ecosystem services and fisheries associated with corals reefs has provided me with a unique opportunity to examine changes in reef associated services. Many fishers and tourism operators that I spoke to were willing to be interviewed, though some expressed 'research fatigue'. Most of my data collection was conducted in partnership with the research team from the Seychelles Fishing Authority, which enabled me to interview fishers from across the three islands in Seychellois Creole, though occasionally interviews were conducted in English or French. Interviewees gave

verbal consent to be interviewed prior to the interview. All research undertaken for this thesis was done so with ethical approval from the Faculty of Science and Technology research ethics committee (Lancaster University, FST17114) and with a research permit from the Seychelles Bureau of Standards (A0157).

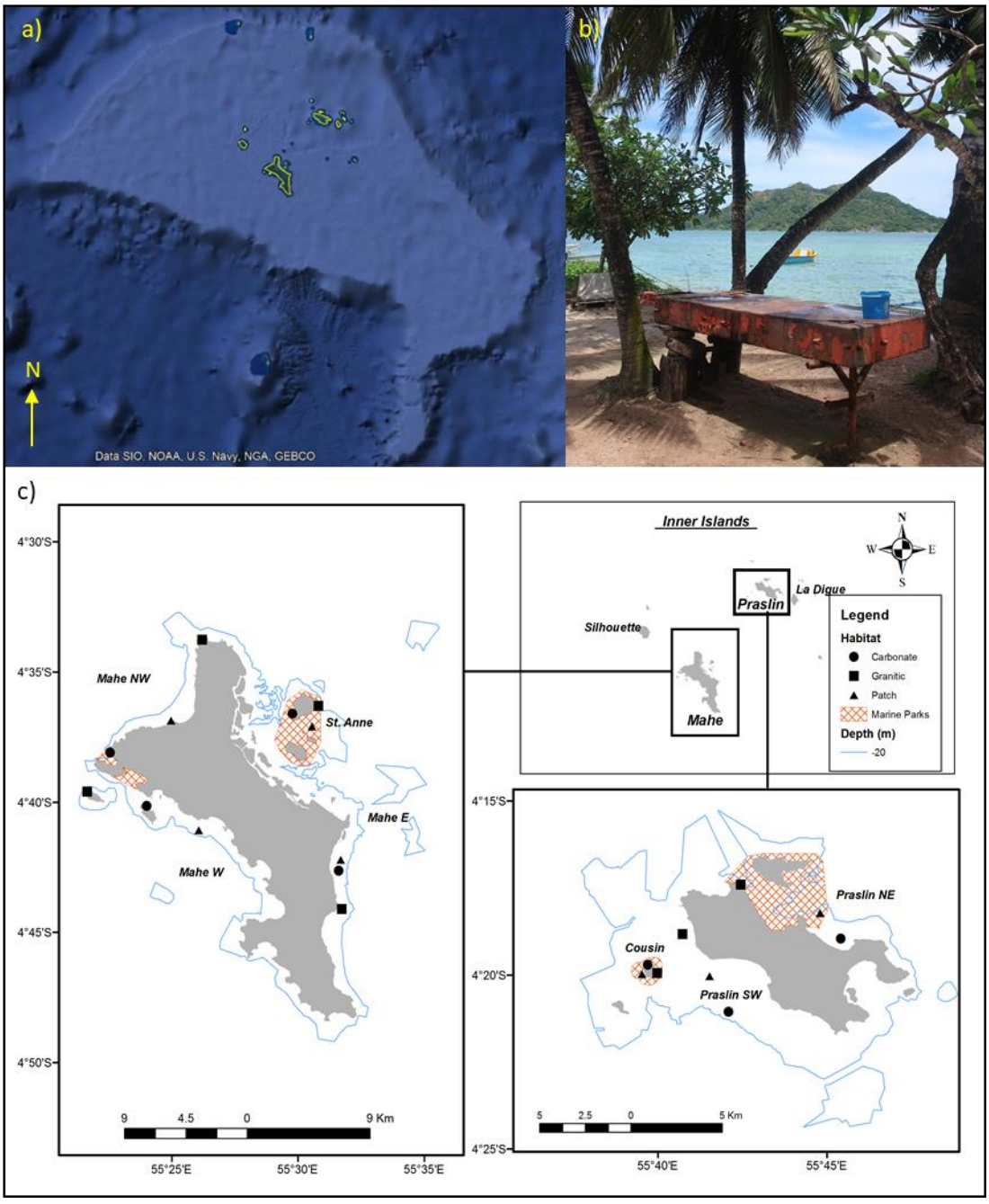

Figure 0. 2 Seychelles study site: a) The position of the inner islands on the Mahé plateau, a 40 000km area of shallow sea used by the artisanal fishery and tourism sector (image captured from Google Earth [accessed 27/01/2021]); b) A typical fish landing site and selling

place (Baie St Anne, Praslin; photo by AJ Woodhead); c) Map of ecological survey sites around Mahé and Praslin. Over 23 years of ecological data from these sites has provided information on changes in benthic and fish communities around Seychelles (image reproduced with permission from NAJ Graham)

Chapter 1 - Coral reef ecosystem services in the Anthropocene

1.1. Abstract

Coral reefs underpin a range of ecosystem goods and services that contribute to the wellbeing of millions of people. However, tropical coral reefs in the Anthropocene are likely to be functionally different from reefs in the past. In this perspective piece we ask, what does the Anthropocene mean for the provision of ecosystem services from coral reefs?

First, we provide examples of the provisioning, regulating, cultural and supporting services underpinned by coral reef ecosystems. We conclude that coral reef ecosystem service research has lagged behind multidisciplinary advances in broader ecosystem services science, such as an explicit recognition that interactions between social and ecological systems underpin ecosystem services.

Second, drawing on tools from functional ecology, we outline how these social-ecological relationships can be incorporated into a mechanistic understanding of service provision and how this might be used to anticipate future changes in coral reef ecosystem services.

Finally, we explore the emergence of novel reef ecosystem services, for example from tropicalised coastlines, or through changing technological connections to coral reefs. Indeed, when services are conceived as coming from social-ecological system dynamics, novelty in services can emerge from elements of the interactions between people and the ecosystem.

This synthesis of the coral reef ecosystem services literature suggests the field is poorly prepared to understand the changing service provision anticipated in the Anthropocene. A new research agenda is needed that better connects reef functional ecology to ecosystem service provision. This research agenda should embrace more holistic approaches to ecosystem service research, recognising them as co-produced by ecosystems and society. Importantly, the likelihood of novel ecosystem service configurations, requires further

conceptualisation and empirical assessment. As with current ecosystem services, the loss or gain of services will not affect all people equally and must be understood in the context in which they occur. With the uncertainty surrounding the future of coral reefs in the Anthropocene, research exploring how the benefits to people change will be of great importance.

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1.2. Introduction

Under the pressure of global and local stressors, it is increasingly likely that tropical coral reefs of the future will be different from those documented in the recent past (Hughes *et al.* 2017). Stressors include marine heatwaves, ocean acidification, over-fishing, pollution and physical damage, which each interact and select for different response traits within the coral assemblage (Ban, Graham & Connolly 2014; Hughes *et al.* 2018b). For example, some species of coral are more vulnerable to heat stress than others, resulting in differential mortality and recovery rates across coral taxa (Loya *et al.* 2001). In cases of severe heat stress this can lead to altered community assemblages and a decline in functional diversity (Yadav, Alcoverro & Arthur 2018). Reef-associated fish species are also differentially affected by climate change, habitat alteration and other selective pressures like fishing (Wilson *et al.* 2006). It is likely that while some coral reefs will undergo regime shifts towards a different ecological state (Norström *et al.* 2009), other reef ecosystems will continue to be dominated by calcifying organisms and will be characterised by a different set of structures and functions (Alvarez-Filip *et al.* 2013). Understanding and predicting future configurations of reef organisms and the functions they provide is highly challenging, especially as these may be increasingly decoupled from underlying natural biophysical processes (Williams *et al.* 2015).

Reef ecosystem functioning is connected to the wellbeing of millions of people who directly or indirectly benefit from tropical corals reefs (Moberg & Folke 1999). These benefits, or ecosystem services, are often grouped under provisioning (defined as the products obtained from ecosystems), regulating (the benefits resulting from the regulation of ecosystem processes), cultural (encompassing cognitive and experiential benefits), and supporting services (services that underpin the provision of other services) (Millennium Ecosystem Assessment 2005). Despite over three decades of research into ecosystem services, we

continue to have a poor understanding of how ecosystem structures and functions underpin the capacity of coral reefs to provide services. For example, declines in the structural complexity of reef habitat are often linked to changes in fish communities, with likely impacts on fishery services (Pratchett, Hoey & Wilson 2014). However, recent modelling and empirical research suggests that increases in herbivorous fish are able to maintain fishery yields under certain conditions (Rogers *et al.* 2018; Robinson *et al.* 2019b). The links between ecological change and services may therefore be more complex than originally suggested (Daw *et al.* 2016) .

The Anthropocene signifies a time in which human activities are the principal drivers of change across scales (Steffen *et al.* 2011). This presents a challenge for ecological research that must actively engage in understanding the human dimensions of coral reefs and the feedbacks between social and ecological systems (Williams *et al.* 2019). Understanding these relationships has important ramifications both for future wellbeing and future coral reef configurations. Against this backdrop, this paper asks the question: what does the Anthropocene mean for the provision of ecosystem services from coral reefs? First, we explore some of the conceptual advances in ecosystem services research outside of coral reef science. Second, we draw on approaches in functional ecology to propose a mechanistic basis for connecting between changes in reef functions and services. Finally, we reflect on whether novel reef ecosystems could also result in novel ecosystem services.

1.3. Ecosystem services from topical coral reefs

Tropical coral reefs around the world underpin a wide range of services (Table 1.1; Moberg & Folke 1999). Some of the most well-studied provisioning services include fisheries (e.g.

Grafeld *et al.* 2017), cultural services include recreation and tourism (e.g. Brander, Van Beukering & Cesar 2007), and regulating services include coastal protection (e.g. Ferrario *et al.* 2014). Other provisioning services include aquarium fish and building materials that come from reefs (e.g. Albert *et al.* 2015). Reefs also underpin a number of other important regulating services such as the generation of sand (e.g. Perry *et al.* 2015) and the processing of nutrients (e.g. Archer *et al.* 2017). Many of these service groups are inter-related, for example the presence of white sands generated by reef processes are closely linked to reef tourism (Spalding *et al.* 2017). Cultural services reflect the fact that coral reefs constitute unique spaces that are generative and supportive of human experience. As such, reefs underpin a diversity of livelihoods and associated identities (Cinner 2014) and also provide opportunities for research and education (e.g. Motuhi *et al.* 2016). Supporting services include important habitat and biodiversity services for the reef and adjoining ecosystems (e.g. Gillis *et al.* 2014; Fisher *et al.* 2015) that indirectly contribute to human wellbeing, but are challenging to capture in terms of their independent service value (Hicks 2011).

Table 1. 1 Examples of ecosystem services drawn from tropical coral reefs.

MEA category*	Ecosystem service	Definition**	Examples
Supporting (underpins the provision of all other services)	Biodiversity benefit	Describes the services and benefits gained from having a diverse reef ecosystem that underpins other services and benefits	• Tropical coral reefs are one of the most biodiverse ecosystems containing approximately 830 000 species worldwide (Fisher *et al.* 2015). • The diversity of reefs contributes to the maintenance of a genetic library (Moberg & Folke 1999).
	Habitat	Describes the services and benefits gained from having a reef ecosystem that provides key habitat	• Corals engineer the environment, interacting with and creating suitable conditions for other tropical nearshore ecosystems (Gillis *et al.* 2014). • The structural complexity of reefs provides important refugia for species (Graham & Nash 2013). • Reefs provide habitat for species at different life stages (Ortiz & Tissot 2012).
Regulating (regulates the environment)	Coastal protection	Describes the services and benefits gained from reefs providing coastal protection from waves and extreme weather events	• Coral reefs dissipate 97% of the energy that would otherwise hit shorelines. This shoreline protection benefits 197 million people who live below 10m elevation and within 50km of reefs (Ferrario *et al.* 2014). • Across reef coastlines, reefs reduce annual expected damages from storms by more than $4 billion (Beck *et al.* 2018).
	Water quality and biogeochemical cycling	Describes the services and benefits gained from the cycling of nutrients and other material on reefs	• Coral mucus acts as an energy carrier between reefs and other nearshore environments (Wild *et al.* 2004), whilst sponges play an important role in transferring energy and nutrients between trophic levels (De Goeij *et al.* 2013). • Decades of land reclamation in Seychelles has influenced water quality and coral reef fishers identify the role of biotic and abiotic processes around reefs in helping to disperse sediment loads (Hicks *et al.* 2014).

MEA category*	Ecosystem service	Definition**	Examples
Provisioning (goods and services from nature)	Fishery	Describes the services and benefits gained from fishing on reefs	• Fish provide vital nutrition to many coastal communities (Golden *et al.* 2016). From 2009 to 2013, the near-shore fishery in Hawaii provided 7.7 million meals annually (Grafeld *et al.* 2017). • Fisheries products from reef environments include a range of taxa that are used for subsistence and cash income (Albert *et al.* 2015). • Coral reef fisheries provide diverse livelihood opportunities. More than a quarter of small-scale fishers fish primarily on coral reef ecosystems (Teh, Teh & Sumaila 2013). Reef fishers get enjoyment, a sense of personal and cultural identity, prestige and a lifestyle from fishing (Cinner 2014).
	Materials	Describes the services and benefits gained from the use of materials, other than comestibles, from reefs	• In the Solomon Islands, sand and coral is harvested for use in construction, land reclamation and betel nut consumption (Albert *et al.* 2015). • 1 471 species of fish, 140 species of coral and more than 500 species of non-coral invertebrates are harvested from reefs worldwide for use in the aquarium and curio trade (Wabnitz *et al.* 2003).
Cultural (cognitive and experiential benefits)	Cultural	Describes the services and benefits gained from reefs as generative and supportive of human experience	• Coral reefs can underpin the discovery of compounds with high biotechnological potential (Motuhi *et al.* 2016). • Reef tourism is calculated to be worth *ca.* US $35.8 billion dollars globally per annum (international and domestic visitors). This includes on-reef tourism (e.g. diving, snorkelling and glass bottom-boat tours) and indirect contributions from reefs to tourism (e.g. calm waters, beaches, views, seafood and their use in advertising) (Spalding *et al.* 2017)***. • In Hawaii, the gathering and sharing of fish encompasses a range of cultural values including subsistence values (physical and cultural), activity values, knowledge values and social cohesion (Grafeld *et al.* 2017).

*this is the Millennium Ecosystem Assessment (MEA) category that the service is most often classified against, but this may vary on a case by case basis. For example, coastal protection could be considered a regulating and supporting service depending on the timescale and immediacy of impact it has on people (Millennium Ecosystem Assessment 2005);**these definitions are intended to be broad enough to capture the diversity of ways in which an ecosystem services framing can be applied to the interactions between human wellbeing and coral reef ecosystems. Specific approaches may adopt a more restricted definition;***the distinction between recreation and tourism is not often made in the literature but generally tourism refers to the activities of often stayover visitors and recreation refers to the activities of local residents (Laurans et al. 2013).

(Moberg & Folke 1999)'s paper is one of the earliest efforts to identify and categorise ecological goods and services from coral reefs, connecting coral reef science and the then growing interest in ecosystem goods and services. Their approach embodied an ecological perspective on the services provided by coral reef ecosystems and highlighted the challenges of connecting biological complexity and the provision of goods and services. Since then, our understanding of reef structures and functions in the context of environmental change has increased, whilst reef condition has continued to decline (Hughes *et al.* 2017). Despite this, the types of services identified from reefs have arguably changed very little. In contrast, the broader field of ecosystem services research has evolved, with wider engagements across disciplines and knowledge systems, and richer conceptualisations of how nature provides benefits to people (e.g. Millennium Ecosystem Assessment 2005; TEEB 2010; Díaz *et al.* 2015). For example, ecosystem service approaches have engaged more broadly with the social sciences and are adopting a more critical approach to the relationships between services and different groups of people (Chan *et al.* 2012). For instance, recent work in Spanish wetland ecosystems shows that not all stakeholders benefit equally from ecosystem services, and that variables such as formal education, gender, and rural versus urban livelihoods can be key factors influencing the access of individuals or groups to ecosystem services (Martin-Lopez *et al.* 2012; Felipe-Lucia *et al.* 2015). Furthermore, science-policy arenas such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) - and specifically its thematic assessment of pollinators, pollination and food production - are piloting approaches to bring indigenous and local knowledge into assessments (Tengö *et al.* 2017).

In parallel to wider disciplinary engagement, the form in which services are conceptualised has also developed. Many approaches assume a linear relationship, with services flowing

from ecosystems to people (e.g. Haines-Young & Potschin 2010b). These often recognise that services are inherently social and ecological but ultimately focus on one or other aspects of this relationship. However, people actively modify ecosystems to influence the delivery of services. Aquaculture, for example, is primarily adopted in marine and coastal systems to enhance food production, but can also be used to support the delivery of other services such as restoring biogenic habitat (Froehlich, Gentry & Halpern 2017). Moreover, people and cultures are shaped by ecosystems (Caillon *et al.* 2017). For instance, activities that can take place in marine and coastal environments such as shellfish harvesting, form an integral part of place attachment that is connected to personal experiences, social relationships, heritage values, ecological knowledge and local identity (Poe, Donatuto & Satterfield 2016). Recent approaches to assessing ecosystem services are now more explicitly engaging with the fact that services are the result of interactions between people and ecosystems (Fischer & Eastwood 2016), which is increasingly important in the context of a human-dominated planet. An approach that captures the interactions between social and ecological systems can be applied to understand how ecological changes are received by different people (Hamann *et al.* 2018) and how human actions, in relation to changing services, feedback onto the ecosystem (Reyers *et al.* 2013). If predicted changes in reef ecosystem functioning affect the perception of services, then an approach that recognises services as co-produced from social and ecological systems could provide analytical tools for connecting changing ecosystems, changing services, and future reef functions. Few studies to date, however, have fully explored what the co-production of services on reefs would look like.

Ecosystem services research continues to develop, with active discussion ongoing as to its future direction (e.g. Braat 2018; Diaz *et al.* 2018; Peterson *et al.* 2018). Similarly, in coral reef ecosystem services research there is no one conceptual or methodological leading edge.

Publications from 2018 encompassed work on changes in ecosystem service provision (Reguero *et al.* 2018), economic assessments of services (Robles-Zavala & Reynoso 2018), patterns and preferences across service beneficiaries (Lau *et al.* 2018) and the use of services for management prioritisation (Pittman *et al.* 2018). Drawing on the advances of wider ecosystem services science could help identify gaps and future research opportunities. Moreover, as future reef community assemblages are unlikely to be the same as those seen in recent times (Graham *et al.* 2014), the relationships between ecosystem structures, functions and services will likely change, requiring a more mechanistic understanding of these processes, and likely more anticipative management (Rogers *et al.* 2015b).

1.4. A mechanistic approach to service provision

Trait-based approaches are increasingly used to understand the mechanistic basis of ecosystem service provision (Harrison *et al.* 2014). Functional traits are broadly defined as measurable characteristics of an organism that contribute to ecosystem functioning (McGill *et al.* 2006). The presence or absence of different traits can determine differential responses to disturbances (Haddad *et al.* 2008). For example, the shape and size of corals determines their risk of dislodgement during storms (Madin & Connolly 2006). Where there is overlap between traits that contribute to specific functions and traits that respond to disturbances, it is possible to map out relationships between drivers of change and ecosystem functions (Suding *et al.* 2008). This has recently been extended to include relationships between disturbances, functions and services (Hevia *et al.* 2017b). However, few studies have explicitly connected this to coral reef services and a more systematic approach to trait identification is needed for this to be achieved (Carturan, Parrott & Pither 2018). I propose that expanding this mechanistic approach to reflect the co-production of ecosystem services

could provide a useful tool to understand the impact of on-going and future disturbances to reef ecosystem services.

If services are co-produced between ecological and social systems then the ecological units that underpin services, known as service providers, should be defined in relation to the needs, wants and aspirations of beneficiaries (Luck *et al.* 2009). Identifying service providers as distinct from wider ecosystem functioning resonates with previous findings that proxies of ecological condition and proxies of ecosystem service provision from reefs do not always overlap (Mumby *et al.* 2008). Specific characteristics (i.e. traits) of service providers determine the relationships between providers and the services that they underpin. Importantly service providers could be a population of a species, multispecies groups, functional groups, communities, and habitats (Luck *et al.* 2009). Moreover, if services are born out of interactions within coral reef social-ecological systems (Reyers *et al.* 2013), it follows that the traits of service providers can also be defined based on societal needs and preferences (Goodness *et al.* 2016). A working example of this comes from Seychelles where underwater visual census of fish biomass indicates that an increase in herbivores is sustaining fisheries yield two decades after a mass coral bleaching event. Fishery data however indicates that although catches were maintained, they became more spatially and temporally variable, linked to habitat associations when resources are patchy (Robinson *et al.* 2019b). This potentially exposes fishers and markets to greater uncertainty. By acknowledging the traits of service providers that are relevant to service beneficiaries (here the identity, biomass and predictability of the reef fish assemblage; Rogers 2019), a more holistic understanding of how disturbance impacts services may be captured.

Trait based approaches have been growing in popularity in functional ecology research as acquiring high resolution data on species' functional roles remains challenging (Bellwood *et*

al. 2019). Similarly, methods that adopt a trait-based approach can be applied to develop a mechanistic understanding of the links between disturbances and service provision. For example, tools such as a multivariate functional space could be applied to understand the mechanisms through which disturbances act on ecosystem services. A functional space is defined as "a multidimensional space, where the axes are functional traits along which species are placed according to their functional trait values" (Mouillot *et al.* 2013; p.167). A similar multidimensional space, where the axes are the traits of service providers along which ecosystem services are placed could be used to map the response of services to disturbances (Fig. 1.1). Axes may also represent synthetic traits that through ordination techniques summarise the relative contribution of multiple traits that underpin service provision.

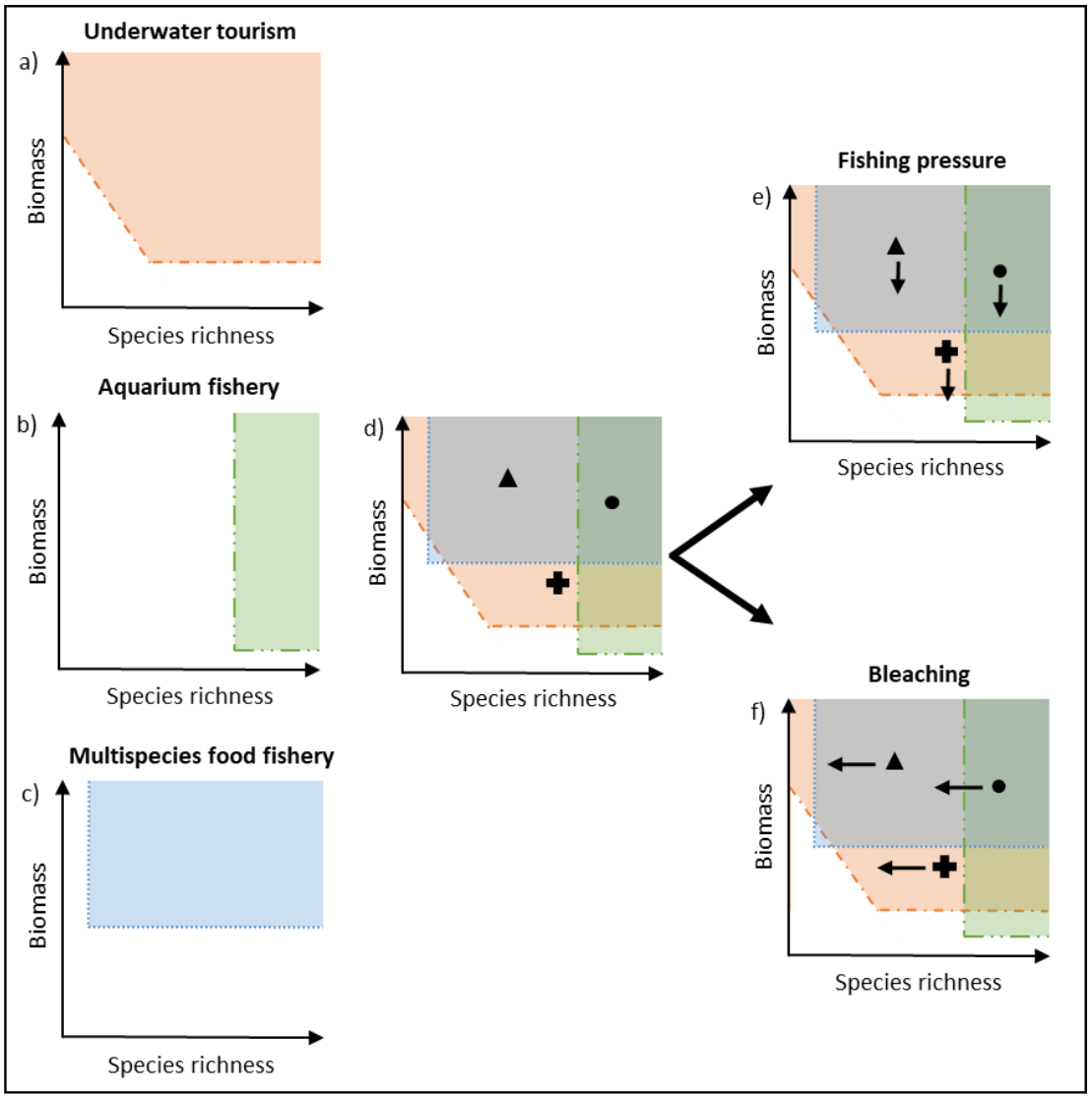

Figure 1. 1 Visualising changes in the capacity of coral reefs to underpin three ecosystem services: (a) to (f) are multidimensional spaces with axes representative of biomass and species richness (traits) of the reef-fish community (service provider) that are significant in the provisioning of three ecosystem services from coral reefs: underwater tourism, an aquarium fishery and a multispecies food fishery. Panels (a) to (c) indicate the area above which trait values are sufficient to underpin the three ecosystem services. These areas could be determined by the ecology (e.g. number of fish available to a fishery) or society (e.g. levels of fish species richness and abundance that result in aesthetically pleasing reefs for dive tourism); (d) indicates the potential of three different coral reefs to underpin services: ▲ represents a site with the potential to underpin a multispecies food fishery and underwater tourism. ✚ could underpin underwater tourism services and ● has the potential to underpin all three ecosystem services; (e) and (f) outline the possible effects of disturbances on traits underpinning service provision and the capacity of the reef sites to provide services. In (e), fishing pressure at all three sites has a negative effect on biomass and under this scenario ✚ is unable to support underwater tourism services. In (f), bleaching at all three sites has a negative effect on species richness. Under this scenario, the potential

for ● to underpin an aquarium fishery is lost. The use of multivariate spaces to visualise ecosystem service potential from reefs can show when reefs may be close to losing or gaining the ability to underpin different services.

In identifying traits of service providers that are socially and ecologically significant, it may be possible to determine relevant thresholds below which a reef's potential to provide services is lost (Fig. 1.1). For example, (Shideler & Pierce 2016) found that divers who visited Florida during *Epinephelus itajara* (Atlantic goliath grouper) spawning season had a strong preference for goliath grouper sightings and that abundance had a positive effect on divers' willingness to pay to see them. Goliath groupers are a protected species in Florida and the value of goliath grouper to dive tourism operators is likely to diminish if goliath grouper numbers decrease (Shideler & Pierce 2016). The threshold value below which this ecosystem service is no longer provided is set by the expectations of the tourists. A service could therefore be lost from an ecosystem even if the service provider, here the local population of goliath groupers, persists. Of course, population abundance is also important in the functional role of many species but defining thresholds that reflect the co-production of ecosystem services can highlight when a service may be affected by a disturbance, before or after other tangible shifts in ecosystem functioning.

Service providers can also encompass a wide range of ecological groups. For example, different taxonomic groups and processes are responsible for sand generation from reefs (Perry *et al.* 2015). The loss therefore of one calcifying species or even family may have little effect on the overall provisioning of this service. Defining a threshold at which disturbances affect the capacity of reefs to generate sand is therefore challenging. In cases like this, certain services may continue to be underpinned by even highly disturbed or degraded reefs, particularly when considering that alternate benthic states also support relevant service providers (e.g. Fulton *et al.* 2019). These examples illustrate that relationships between

ecological change and services are highly non-linear (Daw *et al.* 2016), which is significant when anticipating future changes in services and peoples' response. An example at the local reef scale might include fish feeding, used to enhance tourism services, but which can result in changes in fish behaviour and distribution (De Paula *et al.* 2018). However, it is increasingly important that changes in ecosystem services are considered within an inter-connected planet, as changes in local service provision may result in an increased reliance on service providers elsewhere, with the potential for knock-on effects (Pascual *et al.* 2017). For instance, demand for *Holothuria sp.* (sea cucumbers), largely driven by Asian luxury seafood markets, lead to dramatic changes in fisheries in Mexico with the arrival of new fishers, new livelihood opportunities, and changes in resource use and institutional power dynamics (Kaplan-Hallam, Bennett & Satterfield 2017).

Gathering evidence for traits that are socially and ecologically relevant to service provision will require a broad transdisciplinary approach. Returning to the goliath grouper example in Florida, divers have a predominantly positive interaction with this species whereas recreational fishers may have negative perceptions that groupers are over-predating other reef species (Shideler & Pierce 2016). The relationships between goliath grouper abundance and the provisioning of two recreational services could therefore be very different. Moreover, ecosystem services are highly context dependent (Andersson *et al.* 2015). Looking at the social-ecological context in which services are co-produced can help identify socially and ecologically relevant traits of service providers (Table 1.2). Lastly, it is understood that the traits of service providers may be connected in multiple ways to multiple services (Hevia *et al.* 2017a), and that there are important interactions to consider between services (Bennett, Peterson & Gordon 2009). Most ecosystem service studies focus on one or two services, but a mechanistic understanding of multiservice provision will be important for monitoring and managing future changes (De Groot, Jax & Harrison 2016).

Table 1. 2 Identifying traits of service providers and possible outcomes for coral reef ecosystem services in the Anthropocene. Identifying traits of service providers that are relevant to the social-ecological context in which services are co-produced can provide a more nuanced mechanistic understanding of how coral reef ecosystem services respond to disturbances. Examples provided on changes in coral reef ecosystem services are based on moderate (with some patches live coral cover intact) and severe levels of reef degradation (no remaining live coral cover).

Ecosystem service (MEA category)	**Examples of traits likely to underpin service provision**	**Importance of social-ecological context**	**Ecosystem service changes in the Anthropocene**
Fishery (Provisioning)	• Species composition and suitability of gear (Hicks & McClanahan 2012) • Biomass and accessibility of target species (Robinson *et al.* 2019b) • Dietary needs and preferences (Golden *et al.* 2016)	Specific traits will be highly dependent on local diversity, the capacity of local fisheries and the needs and choices of consumers. For example, the effect of changes in fish aggregating behaviour will in part be determined by fishers' access to appropriate gear and knowledge that enable them to continue fishing. Populations' needs and preferences will also determine the substitutability of different species in the fishery.	• Reefs with moderate degradation in a matrix of reef habitats may continue to contribute to food security and local livelihoods (Robinson *et al.* 2019b). Other sources of food and employment will be needed to meet the shortfall (Bell *et al.* 2013). • Reefs that cannot support reef-associated species will be unable to sustain fisheries with health implications, including the loss of a vital source of micro-nutrients (Golden *et al.* 2016), and socio-economic consequences from the loss of livelihoods and associated knowledge.
Coastal protection (Regulating)	• Structural complexity (Graham & Nash 2013) • Carbonate budgets (Januchowski-Hartley *et al.* 2017) • Reef height and depth (Ferrario *et al.* 2014)	Coastal protection services from reefs are determined by the abiotic (e.g. wave height and geomorphic setting), biotic (e.g. reef growth rate and resulting structure), and socio-cultural context in which coastal areas are used. Importance of coastal areas can be ascribed in terms of population density or built assets, or in relation to the activities that take place	• Reefs with moderate degradation may continue to provide some protection to coastal areas, though there may be changes in shoreline positioning. Reefs could be used to inspire coastal protection solutions that help address issues of reef degradation and coastal protection (Reguero *et al.* 2018). • A combination of severe weather events, sea level rise and reef degradation may result in reefs being unable to protect current shoreline configurations.

	• Socio-cultural importance of coastal areas (Hicks *et al.* 2014)	there. For example, many beaches are used as places to clean fish and socialise.	Atolls may become un-inhabitable (Storlazzi *et al.* 2018) and there may be tensions in re-locating people and activities from the coast further in land.
Underwater recreation (Cultural)	• Fish abundance, coral condition and reef colour (Uyarra, Watkinson & Cote 2009) • Accessibility of reef sites (Yee, Dittmar & Oliver 2014) • Presence and/or abundance of charismatic species (Giglio, Luiz & Schiavetti 2015).	There is large variation in the preferences and expectations of underwater tourists. Although certain general rules may apply (e.g. accessibility), the preferences of dive operators and tourists will determine the importance of different traits. For instance, less experienced divers tend to prefer charismatic species, whilst more experienced divers prefer cryptic species.	• Reefs with moderate degradation that retain some fish biomass may remain aesthetically pleasing (Uyarra, Watkinson & Cote 2009), though some species specific tourism may decline. Reefs that are in relatively better condition may attract dive tourism because of their rarity. • Reefs with high degradation may sustain low levels of tourism from inexperienced divers more interested in the excitement and experience of diving (Lucrezi, Saayman & van der Merwe 2013). Declines in water quality and sand production may affect beach aesthetics and other water-based activities.
Habitat (Supporting)	• Species richness (Duffy 2019) • Structural complexity (Graham & Nash 2013)	Different reef regimes are characterised by a variety of species assemblages and processes that co-exist at scales relevant for service provision. Identifying which reef regimes occur within a study area can help identify traits of service providers that reflect the natural variability of reef communities, that services come from a matrix of habitats, and that many reefs are already transitioning away from a dominance of hard coral cover.	• Coral reefs with moderate degradation may be able to sustain some habitat. Different reef states support different species and processes. Specific adaptations (e.g. through behavioural plasticity) may also mitigate the effects of habitat loss (Karkarey *et al.* 2017). • Reefs with no live coral cover and no structural complexity are unlikely to be able to provide habitat for reef-associated species. Herbivorous species may benefit from increases in algal growth but will be negatively affected if algal stands are too dense (Hoey & Bellwood 2011).

1.5. Novel ecosystem services

Questions remain as to whether reefs are able to sustain current ecosystem services into the future (particularly under high degradation; Table 1.2). However, as environment and society continue to change in the Anthropocene, novel ecosystem services may emerge from coral reef social-ecological systems. We propose that novel ecosystem services from coral reefs could originate from changes in social and ecological systems, as well as from changes in the interactions from which services are drawn. Novelty could therefore occur at different points in the co-production of services.

Changes in the underlying ecology of reefs will likely result in new or different configurations of service providers. For example, the tropicalisation of temperate areas is occurring in many locations, where corals and tropical fishes are establishing populations at the expense of temperate rocky reef organisms (Vergés *et al.* 2019). This could lead to the presence of novel service provider combinations that may change the services drawn from an area. In Japan, where hard corals are encroaching on temperate reefs at a rate of 14 km a year, (Nakamura *et al.* 2013) suggest tropicalisation may benefit local dive tourism and fisheries productivity (Fig. 1.2). Of course, species incursions into temperate areas will alter ecosystem functioning of temperate habitats and potentially the pre-existing services they generated (Vergés *et al.* 2019).

Reefs underpin services within a matrix of habitats (Guannel *et al.* 2016), which are also under pressure from climate change and local human activities (Unsworth *et al.* 2018). In addition, anthropogenic structural alterations are increasingly present in nearshore

environments through artificial reefs, land reclamation, aquaculture, and coastal defences. Dominance by altered benthic habitats may sustain services traditionally associated with hard coral-dominated reefs. For instance, naturally occurring areas of tropical macroalgae can support a diversity of fish and other organisms, including some of important fishery value (Fulton *et al.* 2019). Macroalgae on regime-shifted reefs can also support herbivores, which can sustain substantial fishery yields (Robinson *et al.* 2019b) (Fig. 1.2). Further work is needed to understand the longevity of interactions that produce services on altered reefs (Rogers *et al.* 2018) and to understand what services could occur from structurally and functionally different reefs interacting with modified nearshore environments.

Novelty could also emerge from circumstances that mediate the interactions between reefs and people. In the western Indian Ocean, there is evidence to suggest that rights, knowledge, economic, and social and institutional processes combine in locally specific ways to determine the bundles of services that people perceive (Hicks & Cinner 2014). Changes in any of these processes could therefore result in altered relationships in the co-production of services. Technological innovation has arguably changed how people perceive reefs, for example the use of underwater photography to document the world's reefs in 360^{o}, making it possible for people to experience reef environments virtually (XL Catlin Seaview Survey 2015) (Fig. 1.2). These changes can connect reefs to much broader audiences, who are not traditionally considered as benefitting from reef ecosystems (Gurney *et al.* 2017).

Finally, novelty could come from changes in the wellbeing of people who benefit from reef ecosystems. Ecosystems and wellbeing are both multidimensional and there is the possibility for mismatches between ecological and wellbeing outcomes (Abunge, Coulthard & Daw 2013). Though connected through ecosystem services, human wellbeing and the

environment are both influenced by a range of processes external to that relationship. Independent of reef condition therefore, changes in the circumstances of individuals can result in a change in the interactions from which services are born. For example, the importance of fish as a provisioning service may decline when other income generating activities increase (Turner *et al.* 2007). This does not mean that other services, like cultural services, attached to fish and fishing are not maintained, but the interactions through which services occur may shift, with implications for how people engage and potentially shape their environment (Turner *et al.* 2007) (Fig. 1.2).

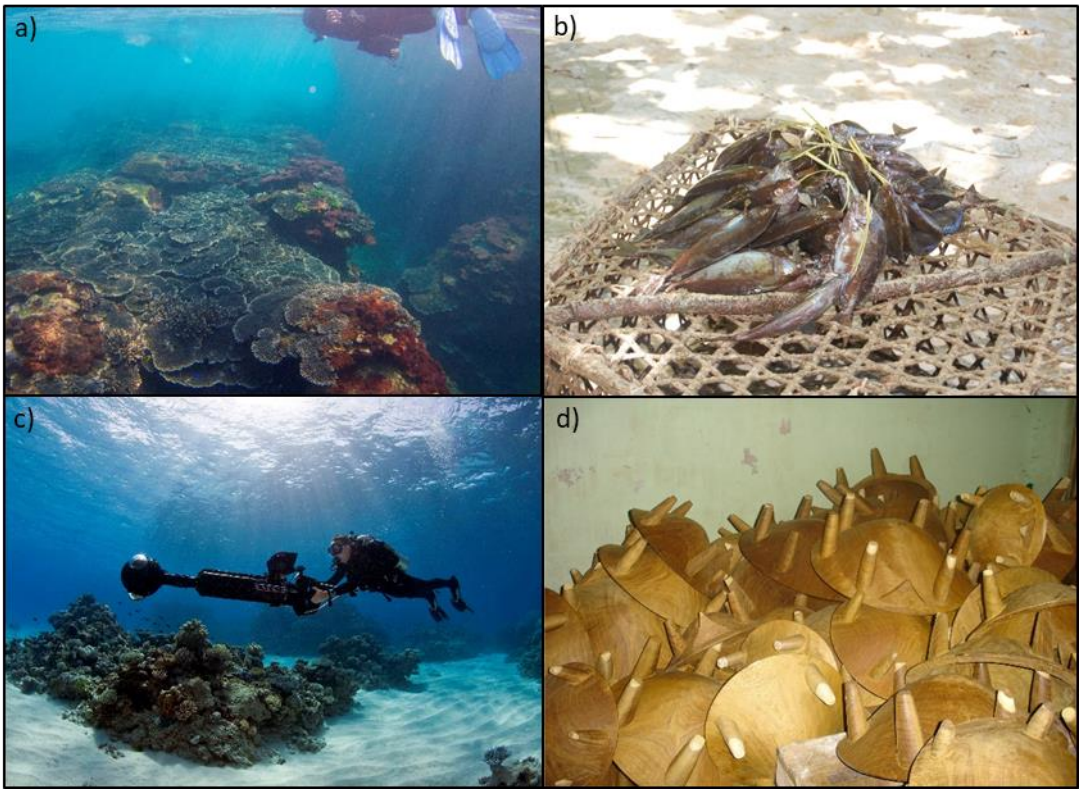

Figure 1. 2 Novel ecosystem services from coral reefs. a) Tourist diving on a tropicalized reef off Kochi, Japan. Tropicalised reefs provide a growing number of opportunities for tourism and education with local children (Nakamura, *pers. comms*.); b) A packet of *Siganus sutor*, Praslin, Seychelles. Siganids are herbivorous and can sustain fishery yields on regime-shifted reefs (Robinson *et al.* 2019c); c) XL Catlin Seaview SVII camera and diver, the Coral Sea. This camera captures 360^{o} panoramas of reefs allowing anyone to self-navigate on a virtual dive (XL Catlin Seaview Survey 2015); d) Tanoa bowls from Kabara, Southern Lau, Fiji. Tanoa bowl carving brings in a relatively high income in Kabara, which may decrease dependency on marine resources (Turner *et al.* 2007). (Photographs: a) Takuma Mezaki; b) and d) Nick Graham; c) The Ocean Agency/ XL Caitlin Seaview Survey)

1.5. Conclusion

Research approaches that can incorporate the social-ecological dynamics of reefs are increasingly seen as essential for understanding reef futures in the Anthropocene (Williams *et al.* 2019). However, explicitly engaging with the reciprocal nature of coral reef ecosystem services remains a challenge (Bennett *et al.* 2015). To address this, we draw on conceptual advances in the field of ecosystem services research and tools from functional ecology to propose an approach that recognises the co-production of services from interactions between social and ecological systems. Using this framework, we can begin to identify traits that are socially and ecologically relevant for service provision (Table 1.2), and to connect these traits to disturbances (Fig. 1.1). Reflecting more broadly on the co-production of services incentivises the need to also consider whether novelty in ecosystem services could occur (Fig. 1.2).

It is unlikely that coral reef ecosystem services in the future will be the same as they are now (Table 1.2). Evidence suggests, for example, that coral reef fisheries in some tropical Pacific countries will be unable to meet local nutritional needs in the long-term due to climate change, but in the short term due to the demand from growing human populations (Bell *et al.* 2013). Further work is needed to identify possible causal relationships between traits and perceived ecosystem services (Carturan, Parrott & Pither 2018; Bellwood *et al.* 2019), and these relationships are highly likely to be context dependent (Andersson *et al.* 2015). Filling these knowledge gaps will be useful for predicting changes in the mechanistic basis of services but will not give an indication of who is accessing services. Understanding the implications of changing and novel ecosystem services should therefore be incorporated into

wider research on who is perceiving these services (Fortnam *et al.* 2019), whilst cognisant of the fact that the relationships between people and the environment can change independent of reef condition (Turner *et al.* 2007). Nonetheless, embracing a broader understanding coral reef ecosystem services and a research agenda that links reef functional ecology to ecosystem service provision will be an important step in anticipating the challenges faced by people and reefs in the future.

Chapter 2 – Identifying co-production in the service providers of tropical coastal ecosystem services

2.1. Abstract

Ecosystem services are co-produced between people and their environment, but how social and ecological processes combine to produce services remains unclear. This limits our ability to understand the implications of on-going and future environmental change on service provision, and consequently human wellbeing. Hyperdiverse tropical ecosystems, like nearshore coral reefs, underpin ecosystem services of local and global importance but are highly vulnerable to multiple interacting stressors, most notably global heating. There is a need therefore to develop approaches that recognise the co-production of ecosystem services, and that can be assimilated with existing knowledge on the impacts of environmental change. Coral reefs around Seychelles are known to underpin diverse ecosystem services but have undergone widespread ecological change. Recognising that people perceive multiple benefits associated with ecosystem services, I conducted interviews with 16 key stakeholders in fisheries and tourism to first identify benefits associated with fishery and tourism services in Seychelles. I then identify the service providers that underpin these benefits and the traits that mediate between service providers and service provision. Traits and service providers were identified based on their importance within the local social-ecological context, reflecting their ecological functions, as perceived by key informants, as well as the preferences and needs of ecosystem service beneficiaries. Benefits associated with fishery and tourism services in Seychelles included benefits that provide material and economic components to people's lives, those that enable people to achieve wider objectives, and those that are part of Seychelles' cultural context. The service provider-trait-

benefit pathways identified by key informants are hugely varied between even closely related benefits. Combined with ecological data on reef change, these pathways reveal which services may be vulnerable to future environmental change on reefs. For example, both agency and food availability are important aspects of food security but the benefit of fisheries enabling people to exercise choice over what they eat and do, may be more at risk from future ecological change than the benefit of fisheries providing marine products for local food consumption. Redundancy between service providers may confer some resilience within ecosystem service co-production if certain traits are maintained within a system. Switching between service providers may however indicate the extent to which reefs are already degraded. These findings provide a more mechanistic approach to engaging with the social and ecological complexities of ecosystem service co-production, which will be necessary to predict the wider impacts of changing nearshore environments.

In prep - Woodhead AJ, Hicks CC, Robinson JWP, Norström AV, Williams GJ & Graham NAJ. Identifying co-production in the service providers of tropical coastal ecosystem services. *Ecosystems and People*

2.2. Introduction

Ecosystem services underpin the wellbeing of millions of people. It is widely predicted that changes in biodiversity and ecosystem functioning will affect human wellbeing through their effects on these services (Isbell *et al.* 2017). Yet, the implications of biophysical change for service provision remain understudied (Chan, Satterfield & Pascual 2020), and the relationships between environmental change, services and wellbeing are highly non-linear (Raudsepp-Hearne *et al.* 2010; Daw *et al.* 2016). The sensitivity of ecosystem services to environmental change is determined by multiple interactions between social and ecological systems (Daw *et al.* 2016). As such, ecosystem services are widely considered as co-produced between people and nature 'for in the absence of people there are no services' (Bennett *et al.* 2015; p.1396). This limits the predictive capacity of purely biophysical models to investigate how environmental change will affect future sustainable and equitable access to services (Bennett *et al.* 2015; Palomo *et al.* 2016).

Part of the challenge of engaging with ecosystem service co-production, is that ecosystem services are socially constructed. Attributing meaning to ecological structures and functions depends on how human-nature relationships are perceived (Barnaud & Antona 2014). The International Panel on Biodiversity and Ecosystem Services (IPBES) has sought to address this by recognising multiple values and knowledge systems in their approach to identifying benefits from nature (Díaz *et al.* 2015). Co-production is therefore connected to societal values and needs, which shape how individuals identify and experience benefits from the environment (Palomo *et al.* 2016). Tangible interactions between ecosystems and people also contribute to the emergence of ecosystem services (and disservices), where people have actively sought to modify ecological structures and functions to their benefit (Fischer & Eastwood 2016). Models that engage with the mechanisms of service provision must

therefore be adaptable across contexts, to reflect social differences in how ecosystem services are perceived, valued and co-produced (Spangenberg, von Haaren & Settele 2014).

Many ecosystem service frameworks recognise co-production of services, but this is not reflected in empirical inquiry. For example, the cascade model is a widely-used linear conceptualisation of ecosystem services, that separates out the ecosystem properties that produce ecosystem functions that provide an ecosystem service of benefit to people and to which a value can be attached (Haines-Young & Potschin 2010b). In reviewing the application of this model, (Boerema *et al.* 2017) show that the majority of studies adopt indicators that reflect either the ecological or social dimensions of the framework. This is despite findings from participatory research that local actors perceive co-production as integral to their understanding of how and where services occur (Tusznio *et al.* 2020). This would indicate a mismatch between how ecosystem services are conceptualised, how these conceptualisations are applied and how ecosystem services are experienced by those who rely on them. As such, there is a need to bring together conceptual advances in ecosystem services research and empirical case-studies that recognise the social and ecological dynamics of service production, and which can be incorporated into wider research on current and future environmental change. In this paper I draw on the social-ecological systems and functional ecology literatures to develop and apply an approach that recognises co-production of ecosystem services at the scale of the biophysical unit which underpins service provision. This approach can then be applied to existing knowledge of ecological change, to better interpret the implications of change for service provision and ultimately human wellbeing.

2.2.1. Identifying co-production in service provider traits

In developing this approach, I chose to distinguish between services and benefits, wherein services are "processes involving biotic features of the environment that produce benefits. Benefits are goods, conditions and experiences that are important to people" (Klain, Satterfield & Chan 2014; p.311). The relevance of making this distinction varies across frameworks and how these frameworks are used (Hattam *et al.* 2015). Here I seek to recognise that multiple benefits can emerge from an ecosystem service to better reflect how stakeholders experience and value services (Klain, Satterfield & Chan 2014) and because of the assumption that co-production may differ between benefits. This is illustrated for example in Timor-Leste, where gleaning is an important fishery service, which connects to multiple benefits including food provisioning, sharing knowledge, socialising and spending time in nature. The relative importance of these benefits varies seasonally, suggesting that different social-ecological processes underpin these different benefits (Grantham, Lau & Kleiber 2020; Fig. 2.1: A).

Having established the benefits that are of importance to people in a specific context, the next step is to identify possible mechanisms of service provision. Early work on the ecology of ecosystem services identifies service providers (SPs) as the discrete ecological unit, upon which service provision depends (Kremen 2005). These ecological units can refer to different ecological scales including populations of single species, multi-species groups, functional groups, or entire communities and landscapes (Luck *et al.* 2009). Pollination services for example are often delivered by a specific functional group combining multiple species of pollinator, whereas regulating services such as flood prevention are often dependent on landscape scale processes (Luck *et al.* 2009; Fig. 2.1: B)

The relationship between service providers and service provision is determined by key service provider characteristics, often referred to as traits (Luck et al. 2009; Fig. 2.1: B2). Trait

based approaches have widely been adopted to investigate overlaps between traits that are vulnerable to environmental disturbances, and traits that shape ecosystem service provision (de Bello *et al.* 2010; Harrison *et al.* 2014; Hevia *et al.* 2017b; Carturan, Parrott & Pither 2018). This remains a powerful tool in predicting ecosystem service responses to management or environmental change. Recognising that ecosystem services are social and ecological, (Goodness *et al.* 2016) reason that if trait based approaches are to be used in the context of ecosystem services, then the language of traits should expand to "accommodate additional characteristics that humans appreciate (or do not appreciate) in their landscape" (Goodness *et al.* 2016; p.603). (Echeverri *et al.* 2020) build on this expanded understanding of traits to identify which functional traits in avian communities also cluster with cultural ecosystem services. Knowing the overlap between traits connected to ecosystem functioning and traits that relate to service provision can then guide management decisions, identifying possible win-wins for species and services management, and also possible sources of conflict, for example where endangered species carry traits that people associate with disservices (Echeverri *et al.* 2020; Fig. 2.1:C).

In my approach (Fig. 2.1), I develop an expanded understanding of service provider traits which reflect the perceptions, preferences, and values of those who benefit from ecosystem services. This expanded understanding of traits - which reflects the social-ecological context in which services are used and valued - allows for an investigation of ecosystem service co-production at the scale of the service provider. Service providers, as a unit of analysis coming from ecological research, can be more easily integrated with existing models of environmental change.

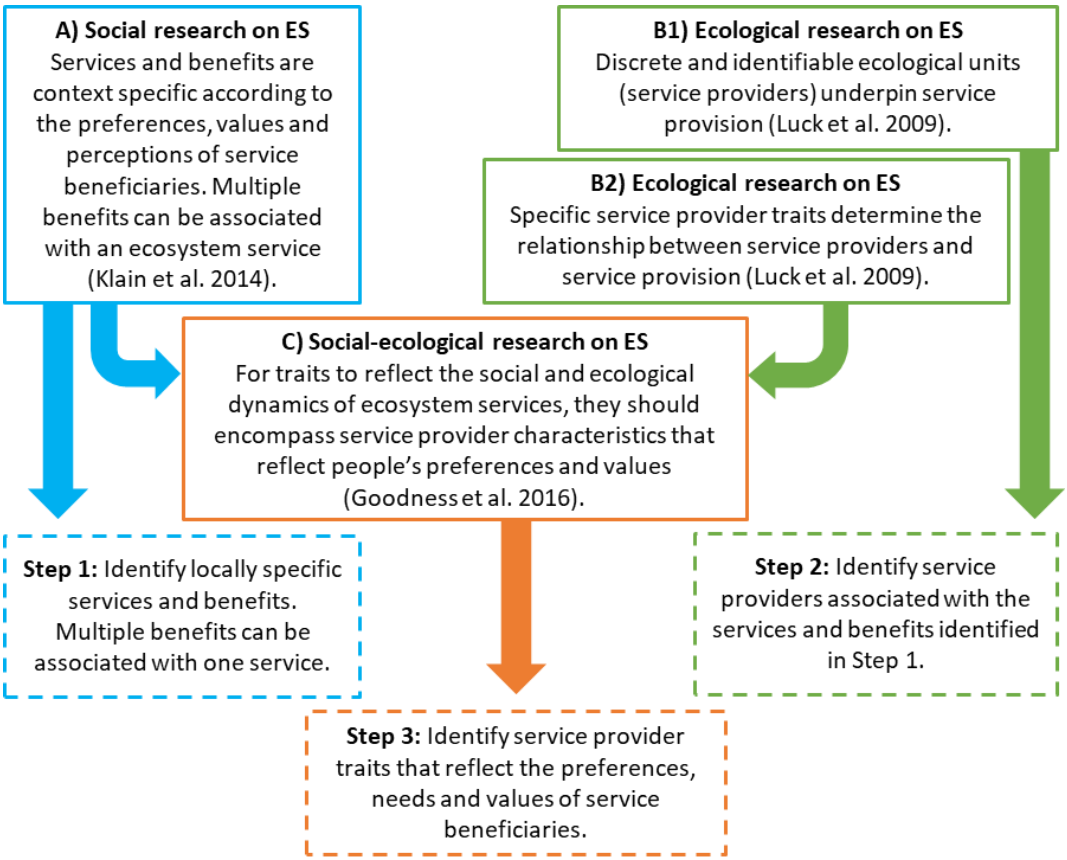

Figure 2. 1 Identifying co-production in service provider traits. Solid lined boxes denoted by A), B1), B2), C) refer to bodies of research within ecosystem services (ES). Dashed lined boxes refer to steps applied to a case-study from the Seychelles.

I applied this framework to a case-study of tropical coastal ecosystem services, with an emphasis on coral reef associated services. Tropical coral reefs underpin multiple ecosystem services, contributing to the wellbeing of millions of people (Moberg & Folke 1999; Woodhead *et al.* 2019). Over a quarter of small-scale fishers globally rely on reef environments (Teh, Teh & Sumaila 2013) and 9% of coastal tourism in coral reef countries is associated with reefs (Spalding *et al.* 2017). However, reefs and their associated services are at risk from human activities and climate change (Barlow *et al.* 2018). This has, and will, result in reef degradation but also re-organisation, as coral reef communities respond to increasing levels of disturbance (Hughes *et al.* 2018a; Robinson *et al.* 2019a) or are replaced

by alternative benthic states (Nyström *et al.* 2012). The social and ecological dimensions of reefs necessitate a broader approach to ecosystem services, which is applicable and adaptable to contemporary reef contexts, but data deficiency has limited previous attempts to examine changing reef services through trait-based methods (Carturan, Parrott & Pither 2018). Having outlined such an approach (Fig. 2.1), I apply it to fishery and tourism services in the Seychelles, with an emphasis on coral reef fisheries and dive tourism. Using an exploratory approach, I identify locally relevant benefits (Step 1; Fig. 2.1), the service providers that underpin these benefits (Step 2; Fig. 2.1), and the social-ecological traits that mediate the relationship between service providers and service provision (Step 3; Fig. 2.1). I then discuss the service providers and social-ecological traits that underpin fisheries and tourism services in the context of past and future change to reef environments, before reflecting on the advantages and limitations of my approach and its contribution to research on ecosystem service change.

2.3. Methods

2.3.1. Study area

This research took place on the three main inhabited islands of Seychelles: Mahé (where 87% of the population live; National Bureau of Statistics 2020a), Praslin and La Digue. The Exclusive Economic Zone (EEZ) of Seychelles encompasses 1 374 000 km^2 of ocean and 115 islands. The main inhabited islands sit on the Mahé Plateau, a 40 000 km^2 area of relatively shallow water (max depth 50-65m) that encompasses a diversity of habitats (Seychelles Fishing Authority 2019). This large EEZ and the diverse marine resources it incorporates sustain the two main industries of Seychelles: fisheries and tourism.

Fisheries in Seychelles are diverse and include an offshore industrial tuna fishery, predominantly fished by European flagged vessels targeting multiple species of tuna, the majority of which are processed for export (Clifton *et al.* 2012). The inshore fishery, often referred to as the artisanal fishery in Seychelles, comprises commercial fishing vessels, sport fishing vessels and recreational fishing vessels (MRAG 2017). The commercial fishing fleet is a mixed gear, multi-species fishery that targets reef associated fish, demersal fish, and semi-pelagic species. Although economically less important than the tuna fishery, this inshore artisanal fleet is essential for local livelihoods and food security (Seychelles Fishing Authority 2019). Relatively little is known of the sport fishing and recreational fisheries (MRAG 2017). Sport fishing is a small sector that takes tourists on big game fishing trips with little associated monitoring. Fishing is considered a fundamental right in Seychelles and there are currently no restrictions on access that could limit recreational fishing (Seychelles Fishing Authority 2019).

The tourism industry is centred on international tourism and has grown as a sector over the last 20 years, vying with fishing as the main industry. Between 1998 and 2008, the number of international visitors nearly tripled (from 128 000 in 1998 to 362 000 in 2008; World Bank 2021). Tourism in Seychelles is marine based and relies heavily on the appeal of tropical beaches and coastal environments. Though it is not specifically marketed as a dive destination, dive operators work across the three islands, as well as companies offering snorkelling and glass bottom boat tours (Mwebaze & Macleod 2013). Both fishing and dive tourism are influenced by a rough and calm season according to changes in monsoonal wind patterns across the Indian Ocean.

As is typical of large ocean states, Seychelles is also incredibly vulnerable to changes in coastal and marine environments (Jumeau 2013). Seychelles' nearshore environment has

been affected by two mass coral bleaching events in the last 20 years. This has led to a large-scale re-structuring of coral communities (Wilson *et al.* 2019), a shift towards algal dominated communities in some areas (Graham *et al.* 2015) and irreversible changes in fish community composition (Robinson *et al.* 2019a). Coral degradation has been associated with increased vulnerability to coastal erosion and flooding, which is further exacerbated by a programme of land reclamation, primarily around Mahé and Praslin. Land is a limited resource in Seychelles and recent coastal development is driven in part by the need to cater for increases in coastal tourism (World Bank and Ministry of Environment Energy and Climate Change of Seychelles 2019).

2.3.2. Study design, data collection and analysis

Using qualitative interview data from sixteen interviews I adopted an exploratory approach to identify a) the benefits associated with fishery and tourism services in Seychelles (Step 1; Fig. 2.1); b) the relevant service providers (Step 2; Fig. 2.1) and c) the social-ecological traits that underpin the relationship between service providers and relevant services and benefits (Step 3; Fig. 2.1).

2.3.2.1. Sampling strategy

Sixteen Interviewees were purposively sampled for their professional expertise in either fisheries or tourism, with an emphasis on artisanal fishing and dive tourism. It was hypothesised that these key informants could provide an overview of fishery and tourism services in Seychelles, as well as a more mechanistic understanding of what makes these services possible. Fishers' associations enable cooperation and represent fishers' views to national level decision makers. At the time of interviewing (June/July 2018), there were six

associations (two regional associations and one island level association on Mahé, two associations on Praslin and one on La Digue; Seychelles Fishing Authority, *pers. comms.*) and 13 registered dive operators across the three islands (eight on Mahé, four on Praslin and one on La Digue; Department of Tourism, *pers. comm.)*. I approached fishers' associations and dive centre operators from across the three islands, as well as government officials with responsibilities or experience of working with fisheries or tourism. Five representatives from different fishers' associations and seven dive centre owners or instructors from each of the islands agreed to be interviewed, in addition to a government representative from each area of expertise. Many commercial fishers in the inshore fleet do not own their own boat and work for a boat owner (Bijoux 2015), who provide onshore assistance to fishers (e.g. processing of fuel rebate claims) and take a percentage of the profits from fish sales. One boat owner from Mahé agreed to be interviewed. Although independent consultants in both fisheries and tourism were approached, only a fisheries consultant was available to be interviewed. Sixteen people agreed to be interviewed in total, eight each from the tourism and fisheries sectors (Table A2.1.; Appendices). All participants were male, bar two female participants from the tourism sector. All but one participant from the tourism sector were long term residents in Seychelles. Verbal consent to participate was given by all interviewees and all interviews were conducted in English, recorded, and transcribed for analysis. This research was undertaken with ethical approval from the Faculty of Science and Technology research ethics committee (Lancaster University, FST17114) and with a research permit from the Seychelles Bureau of Standards (A0157).

2.3.2.2. Interview design

Semi-structured interview questions were used to explore what and how different ecosystem services and benefits emerge from the marine environment around Seychelles'

(Appendix A2.2). The interview consisted of questions and prompts along five broad levels of enquiry. Interviewees were first asked to describe the marine environment around Seychelles and how it featured in their daily lives. They were then asked to list the different services and benefits that they got from that environment and what services and benefits other people in Seychelles or Seychelles as a nation may get from the sea. Drawing on previous research, I then provided interviewees with a list of locally relevant reef and coastal ecosystem services (Hicks *et al.* 2014) and asked if they wanted to add any of these other services and benefits to their list. Although key informants were specifically chosen for their knowledge of reefs and the marine inshore environment, ecosystem services are rarely delineated according to specific ecosystems (Dawson & Martin 2015). I therefore also recorded services and benefits that were identified as important, for example the importance of the offshore tuna fishery for the Seychelles economy, but that reflect a much wider use of the marine environment.

To understand why these services matter interviewees were then asked to rank the services in order of importance to them as individuals, to explain their reasoning for this ordering and to discuss how this order might change if they had to think of Seychelles as a whole. To further prompt around the meanings behind services and how they occur in Seychelles, key informants were asked about any possible connections between the sea and recreation, identity, culture or bequest to ensure that these wider connections to the marine environment were not missed. I then focused specifically on fishery services and tourism services, and their associated benefits, by asking interviewees from the fisheries sector what made services and benefits connected to fisheries possible, what would need to change for these services to no longer be possible and who they thought benefitted most and who benefitted least from fishery services and associated benefits. These same questions were posed for tourism services and associated benefits to interviewees from the tourism sector.

If coral reefs were not mentioned, then interviewees were asked if reefs featured in the provisioning of either fishery or tourism services and benefits.

2.3.2.3. Identifying benefits, service providers and traits

Audio recordings of the interviews were transcribed, and transcripts were coded in two stages (coding done in NVivo version 12). The first stage was exploratory, in which I sought to identify the different benefits specifically associated with fishery and tourism services in Seychelles and why they were important in this context (Step 1; Fig. 2.1). These benefits were used to guide the second stage of coding (coding done in Microsoft Excel 2016), in which I identified the relevant service providers for each of the services and associated benefits (Step 2; Fig. 2.1), and the social-ecological traits that shape the relationship between service providers, and services and benefits (Step 3; Fig. 2.1).

Service providers were grouped to reflect the scale at which they underpin service provision. This ranged from the environment as a whole to specific types of marine fauna (Table 2.2). Social-ecological traits had to be explicitly connected to service provision to be recorded (Luck *et al.* 2009) and to thus be distinguishable from the wider contextual processes that are also important for service provision (Andersson *et al.* 2015). As an example, in Seychelles, rabbit fish (*Siganid sp.*) are the only type of fish currently dried and salted. This comes from before other food preservation methods were available, and in response to the abundance of rabbit fish caught during seasonal spawning aggregations. Preparation, in the form of drying and salting, is therefore a characteristic that is only associated with rabbit fish and which connects rabbit fish to a specific benefit (e.g. cultural benefit linked to traditional food). Food preparation in general, although an important mediator in many ecosystem

services and benefits, was not recorded if it wasn't specifically tied to a specific service provider.

2.4. Results

2.4.1. Benefits associated with fisheries and tourism services in Seychelles (Step 1; Fig. 2.1)

2.4.1.1. Services that 'provide', 'enable' and are 'part of'

Fishery and tourism services were identified as important because they are associated with multiple benefits. Based on interviewees descriptions, these benefits were grouped thematically according why they were important to key informants. This resulted in three grouping based on what services *provide*, what they *enable* and what they are *part of*. These groupings were not disaggregated according to different types of fisheries (e.g. offshore or inshore) or tourism, apart from one benefit where dive tourism specifically connected to enabling a lifestyle (see below).

The *provide* group of benefits captures specific material and economic outputs associated with fishery and tourism services in Seychelles. This includes economic benefits significant at an individual or household level (as incomes or livelihoods) and the wider Seychelles economy (e.g. as contributions to gross domestic product, via support for other sectors of the economy). Fisheries also provide marine products associated with different benefits, including marine products for local food consumption (i.e. households), hotels or other commercial establishments, and for export (Table 2.1).

Fishery services and tourism services *enable* people to achieve wider benefits. Fisheries enable a wide suite of benefits, including building and maintaining relationships (e.g. through the gifting of fish within the community), opportunities for future development (e.g. hopes expressed around fisheries that could be developed in the future), leisure and enjoyment (expressed by both commercial and recreational fishers), self-sufficiency (at an individual and national level), and the expression of preferences and a freedom of choice over the ways that people want to fish and the food that people want to consume (e.g. being able to choose fish as a healthy and more enjoyable option to imported meat). It was felt that dive tourism specifically enabled dive tourism operators to live a lifestyle that they valued (consistent with what one interviewee described as 'island life'; Table 2.1).

Finally, fishery services and associated benefits were identified as *part of* a shared identity in Seychelles. Fisheries and their associated benefits are embedded in a shared understanding of life, which in this context included references to the ubiquitousness of fish in the Seychelles diet, seafood of symbolic importance eaten at special events, and specific ways of preparing seafood. References were also made to traditional fishing techniques, fishing areas, or the fact that fishing as a form of employment is passed through the generations (Table 2.1).

In a few cases, participants highlighted specific feedbacks between the *provide*, *enable* and *a part of* groupings of benefits. This included references to income *provided* by fisheries or tourism, which *enables* people to live a lifestyle that they value, or that the self-sufficiency *enabled* by fisheries is *part of* descriptions of a shared identity. These overlaps in benefit types are likely to be non-exhaustive as this was not the primary focus of the interview but illustrates the inter-connectedness between different types of benefits.

2.4.4.2. Perspectives of fisheries and tourism interviewees

Many of the benefits associated with both fishery and tourism services were identified by interviewees from both sectors. Though individuals were prompted on their specialist area (fisheries or tourism), four of the eight dive tourism operators revealed during the interview that they also fish recreationally. A greater number of benefits were identified in the context of fisheries than of tourism. Only interviewees from the fisheries sector identified opportunities for future development associated with fisheries. Only interviewees from the tourism sector identified the benefits associated with dive tourism which enables them to live a lifestyle that they want to live (Table 2.1).

Table 2. 1 Benefits associated with fisheries and tourism services in Seychelles as identified through key informant interviews (n=16)

	Benefit type	Sub-benefits		Description of benefit	Quote	Fisheries participants	Tourism participants
Benefits associated with fishery services	Provide	Economic benefits	As income and livelihoods to households	Fisheries provide income and livelihoods that are important at an individual and household level	'Some people tend to try and make a living out of it, like this gentleman [fisher on the beach] is doing right there. He can go fishing, get the resources he needs' (T6)	6	4
			To the economy	Fisheries provide benefits to the Seychelles economy	'For the fishermen, they are centre of our economy, fishing' (F2)	4	3
		Marine products	For local food consumption	Fisheries provide marine products for local food consumption	'Well definitely fishing is the most important […]. Because it is in access to the fish, which is the main source of our diet in Seychelles' (F1)	6	5
			For commercial establishments	Fisheries provide marine products for commercial establishments	'Even hotel owner [benefits] because they get the fish from local fishermen for their kitchen' (T2)	4	3
			For export	Fisheries provide marine products for export	'A lot of the tuna, the bourzwa*, these are exported' (F5)	3	3
	Enable	Building, maintaining relationships		Fisheries enable people to develop and maintain relationships	'I would say families benefit a lot. Families in societies. Why? I look at my, my fishermen when they come, the amount of fish sometimes that they remove for their families, you know, uncles, aunties, family members or yeah, family members or even friends that they used to know long ago to try and help out, you know.' (F8)	6	3

		Expression of choice and preferences	Fisheries enable people to express preferences or choices in their lives (e.g. in the food that they want to eat or the places that they want to work)	'Well the first thing that is important about it for us is that is provides a form of food. We eat a lot of fish here in this country and it's not because we are forced here to eat fish but because most Seychellois enjoy fish, they prefer it and people are becoming more conscious that the fish, that it is better, it's nicer, it's fresher because most of the meat is imported.' (T8)	7	6
		Future development	Fisheries seen as having the potential to be further developed	'Spanner crabs. This is one species where, my next project is when I finish on Praslin, I'm going to try to make this alive and get Praslin maybe to be a hub for the guys to come in and offload their catch purely, and create an export market for it.' (F3)	2	0
		Leisure, enjoyment	Fisheries enabling people to relax, to do something that they enjoy	'But otherwise, in the outside of job, yes I like fishing. I like going out to catch some fishes for cooking, some fresh fishes.' (T2)	4	5
		Self-sufficiency	Fishing enables individuals and/or Seychelles to be self-sufficient	'I don't have to buy octopus, which is like, now it's like 100-110 rupees per kg or something like that. I don't have to buy octopus. I don't have to buy fish.' (T5)	3	3
	Are part of	Shared identity	Fisheries, and their associated benefits, as part of a shared identity and history in Seychelles	'So, not many people in this country can afford to eat the bourzwa* anymore and that used to be something that belonged to us, that comes from our sea. It's part of what we have naturally, given to us by God let's say and we don't have it anymore, and it's so expensive. And I'm sure there will be youngsters, young families who will not eat this in their lifetime	8	6

					[…] but instead we will be eating chicken from Brazil. So that's, for me, that's really sad.' (T8)		
Benefits associated with tourism services	Provide	Economic benefits	As income and livelihoods to households	Marine and coastal tourism provides income and livelihoods that are important at an individual and household level	'Of course, we [dive operators] get a big benefit, our livelihood. We employ a staff of six currently, their families, they are dependent.' (T7)	2	7
			To the economy	Marine and coastal tourism provide benefits to the Seychelles economy	'And then, obviously it's important for the economy that, in terms of the GDP, that the money from tourism produced for this country is very important.' (T4)	1	7
	Enable	A lifestyle		Dive tourism specifically enables people to, or is consistent with, the lifestyle that they want to live	'Before I wanted to become a pilot, before diving, and when I got into the diving, the more I did it, the more experience I gained, I found that it goes well with my lifestyle. I live on an island, I like the way I dress for work, island style, I love fishing, I love spear fishing, hunting for lobsters at night. Everything that has to do with the ocean, I'm a part of it.' (T6)	0	3

*bourzwa, Seychellois Creole for emperor red snapper (*Lutjanus sebae*)

2.4.2. Service providers underpinning fishery and tourism services and associated benefits (Step 2; Fig. 2.1)

Twenty-one different groups of service providers emerged as important for fishery and tourism services and associated benefits. Service provider groups range from non-specific references to the environment down to specific types of fish or other marine organisms. Thirteen of these service provider groups were reported as underpinning both fishery services and tourism services. Three service provider groups were reported specifically in relation to fishery services (specific types of seaweed; specific type of plants (terrestrial); molluscs and other inter-tidal species); and five service provider groups in relation to tourism services (environment as a whole; coastal environment; coral community; specific types of coral; underwater granitic/ rock formations). There were however differences in the make-up of the service provider groups according to which services and benefits they underpin, for example, in the varieties of fish that were associated with each service. Island formations and underwater granitic structures were specifically identified as important for service provision and although technically abiotic features, these were also included as service providers (Table 2.2).

Service providers attributed to fishery services tended to reflect service providers that enable people to fish (e.g. specific types of seaweed that are important for bait), service providers that are caught in different fisheries (e.g. specific types of marine organism such as lobster, tuna, emperor red snapper; specific groups of fish like pelagic fish; and generic references to the fish community) and service providers that sustain the marine organisms that are caught (specific ecosystems like coral reefs and seagrass beds; specific areas of the marine environment like spawning sites; the marine environment as a whole). A greater

range of service providers, across different scales, were identified in the context of tourism services than of fishery services. These included service providers of interest to tourists (e.g. charismatic megafauna such as sharks and rays, specific types of fish and coral, underwater granitic structures, and the environment as a whole in Seychelles), areas of the marine environment that are important for tourism (e.g. coastal areas, dive sites) and the ecosystems that sustain the features of interest to tourists (e.g. coral reefs). Figure 2.2 summarises which service providers were mentioned most frequently by interviewees in relation to all fishery and tourism services and benefits (see Table A2.3 for a breakdown of service providers according to each service and benefit; Appendices).

Table 2. 2 Service providers identified by key informants (n=16) as underpinning fishery services and associated benefits, and tourism services and associated benefits in Seychelles

Service provider group	**Description of service provider group**	**Service providers: fishery services and benefits**	**Service providers: tourism services and benefits**
Scale: Environment in general, no spatial delineations			
Environment	Where service provision is underpinned by the environment (nature) in general, including terrestrial, marine, and abiotic features.	*Not referenced*	Environment; Nature
Scale: Specific areas of the marine and coastal environment that have characteristics of relevance to service provision			
Marine environment	Where service provision is underpinned by the marine environment.	Marine environment; Plateau; Seabed	Marine environment
Coastal environment	Where service provision is underpinned by the coastal environment, specifically beaches.	*Not referenced*	Beaches
Sites of specific use	Where service provision is underpinned by specific areas of the underwater environment	Spawning sites	Dive sites
Scale: Specific ecosystems, including component species and ecological processes			
Marine ecosystem	Where service provision is underpinned by a marine ecosystem including component species and ecological processes.	Coral reef; Seagrass bed	Coral reef
Scale: Non-specified marine fauna			
Marine fauna	Where service provision is underpinned by the collection of living organisms found underwater.	Marine fauna	Marine fauna
Scale: Specific groups of marine organisms			
Coral community	Where service provision is underpinned by corals (coral type not specified)	*Not referenced*	Coral

Fish community	Where service provision is underpinned by fish (fish type not specified)	Fish	Fish
Group of different types of fish	Where service provision is underpinned by a group of fish of a certain type. These groups encompass multiple species, which together or inter-changeably underpin services.	Big game fish; Demersal fish; Reef associated species; Pelagic fish	Big game fish; Coral dependent fish; Pelagic fish
*Scale: Specific types of organism, where the identity of the organism is of relevance to service provision**			
Type of coral	Where service provision is underpinned by a specific type of coral.	*Not referenced*	Acropora; Porites; Soft corals
Type of fish	Where service provision is underpinned by a specific type of fish.	Barracuda; Batfish; Bonito; Emperor red snapper; Emperors; Goatfish; Grey mullet; Groupers; Jacks; Job fish; Mackerels; Parrotfish; Rabbit fish; Sardines; Snappers; Surgeonfish; Swordfish; Trigger fish; Tuna	Angel fish; Barracudas; Bigeyes; Butterflyfish; Groupers; Humphead parrotfish; Leaf fish; Lionfish; Mackerels; Masked porcupine fish; Oriental sweetlips; Parrotfish; Puffer fish; Red mullet; Sardines; Sergeants; Snappers; Stonefish; Surgeonfish; Tuna
Type of seaweed	Where service provision is underpinned by a specific type of seaweed.	Unknown species	*Not referenced*
Type of plants (terrestrial)	Where service provision is underpinned by a specific type of plant.	Coconut; Bamboo	*Not referenced*
Lobster	Where service provision is underpinned by lobsters.	Lobster	Lobster
Octopus	Where service provision is underpinned by octopus.	Octopus	Octopus
Molluscs and other	Where service provision is underpinned by molluscs and other non-fish species specifically in inter-tidal areas.	Molluscs; Limpets; Mangrove crab	*Not referenced*

Sharks and rays	Where service provision is underpinned by different types of shark or ray.	Shark; Stingray	Manta ray; Nurse shark; Ray; Shark; Stingray Whale shark; White tip reef shark;
Turtles	Where service provision is underpinned by turtles.	Turtle	Hawksbill turtle; Green Turtle; Turtle
Other marine fauna	Where service provision is underpinned by specific non-fish species	Sea cucumber; Spanner crabs; Squids	Moray eel; Mantis shrimp; Nudibranch/ Sea slug; Shells; Shrimp
*Scale: Geological features***			
Islands	Where service provision is underpinned by the physical structure of the islands	Islands	Islands; inner islands
Underwater granitic/ rock formations	Where service provision is underpinned by the physical structure of the underwater granitic rock formations, unique to Seychelles	*Not referenced*	Underwater granitic/rock formations

* Implied within these categories is that specific and identifiable types of coral/fish/seaweed are important for service provision. These often equate to species/family but due to the challenges of relating taxonomic groups with common names in Seychellois Creole and English I refer to them as 'types' rather than 'species'; **Islands and underwater granitic/ rock formations would technically be classified as an abiotic feature, and their inclusion as a service provider is debated in the literature (see discussion)

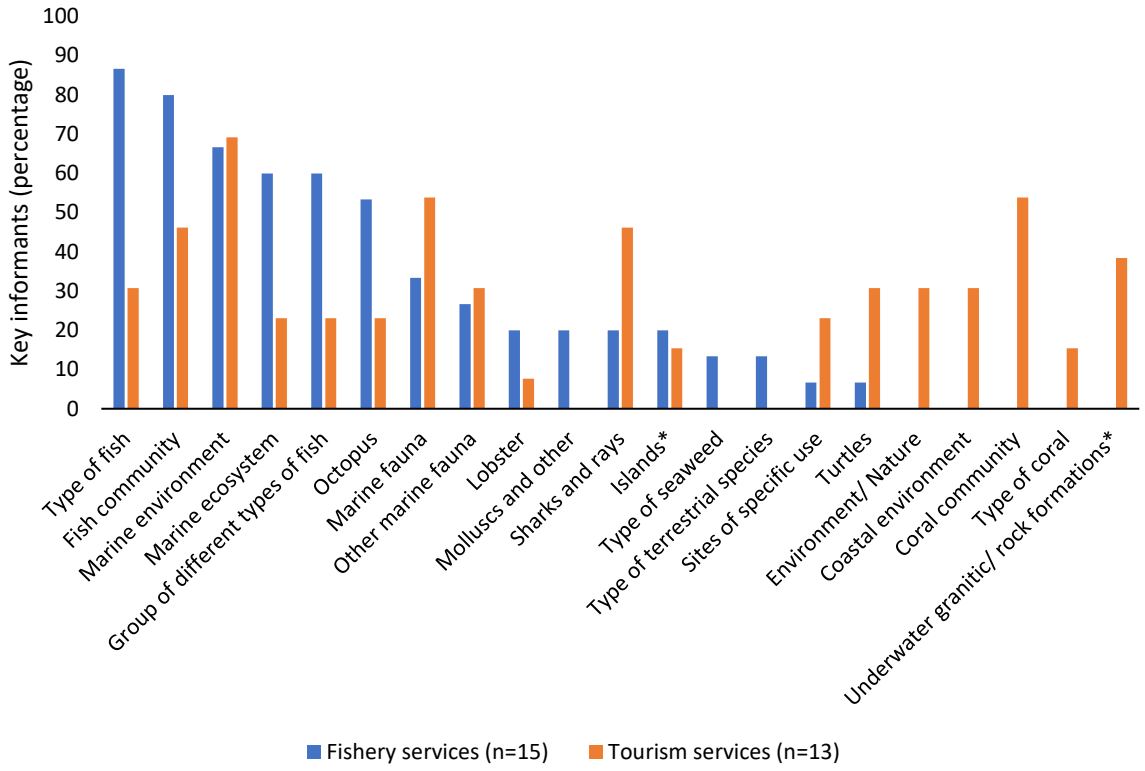

Figure 2. 2 Attribution of service providers to fishery and tourism services by key informants in the Seychelles. Percentage of key informants calculated from the total number of participants who identified the ecosystem service: Fishery services and associated benefits: n=15; Tourism services and associated benefits: n=13 (*denotes abiotic features; see discussion)

2.4.3. Service provider traits, mediating the relationship between service providers and service provision (Step 3; Fig. 2.1)

Nineteen different social-ecological traits were identified as important for mediating the relationship between service providers and service provision. All nineteen traits were identified as connected to the provision of fishery services and fifteen as connected to tourism services. These traits reflect what interviewees identify as important about service providers for the provision of different services. As such, traits reflect ecological characteristics of service providers (e.g. abundance, size, life cycle, condition, diversity), the availability and accessibility of service providers (shaped by location, seasons, restrictions),

and the characteristics that meet the needs, expectations and preferences of interviewees, both as experts in fisheries and tourism and as Seychelles' residents (e.g. aesthetics, preference, preparation, quality, substitutability) (Table 2.3).

Table 2. 3 Social-ecological traits identified by key informants (n=16) as shaping the relationship between service providers and fishery services and associated benefits, and/or tourism services and associated benefits in the Seychelles

Social-ecological trait	Description of trait	Example
Abundance	Where the abundance of the service provider shapes its relationship to a service/benefit	Historic and current abundances of rabbit fish in spawning aggregations shaped the need to dry and salt surplus fish, which is now considered a delicacy and traditional food
Accessibility	Where the accessibility of the service provider shapes its relationship to a service/benefit	Molluscs and other inter-tidal species are highly accessible for people gathering food for home consumption
Aesthetics	Where the aesthetics of the service provider shapes its relationship to a service/benefit	Related to the colour or visual appearance of service providers
Availability	Where the availability of the service provider shapes its relationship to a service/benefit.	Jacks, as opposed to many other species, are available during the rough season which maintain income and food
Behaviour	Where the behaviour of the service provider shapes its relationship to a service/benefit	Fish schooling behaviour makes for a good dive
Condition	Where the condition of the service provider shapes its relationship to a service/benefit	The condition of the reefs (often described as healthy) is important for dive tourism operators
Diversity	Where the diversity of the service provider shapes its relationship to a service/benefit	The diversity of the fish community fished by the inshore fishery enables people to exercise choice in what they eat
Growth rate/ Life cycle (NT)	Where the growth rate and/or life cycle of the service provider shapes its relationship to a service/benefit	Fast growing fish species, with short life cycles help sustain the inshore fishery
Life history (NT)	Where life history characteristics of a service provider shape its relationship to a service/benefit	The production of mucus by parrotfish makes them very hard to clean and, historically, unappealing to consumers
Preference	Where specific preferences are attributed to a service provider, which shapes the relationship between the provider and a service/benefit	Preference for a specific type of fish can be cultural (i.e. perceived as part of Seychelles culture), general (i.e. perceived generally liked or disliked by a everyone) and individual (i.e. specific to an individual or small sub-group)
Preparation (NT)	Where preparations attached to a specific service provider shapes the relationship between the provider and a service/benefit	Many species of fish are associated with their own specific type of preparation (e.g. the salting and drying of rabbit fish)

Productivity (NT)	Where productivity of a service provider shapes its relationship to a service/benefit	The productivity of reef associated species as important for sustaining the fishery
Providing habitat/ Supporting marine life	Where the ability of the service provider to provide habitat and/or support marine life shape the relationship between the provider and a service/benefit	Rock formations identified as important because they provide habitat for fish species that are of interest to tourists
Quality*	Where the quality of the service provider shapes the relationship between it and a service/benefit	The cleanliness of the environment (dirty or pristine) as important for tourism services and associated benefits. The taste (good or bad) attributed to certain types of fish as important for fishery associated services and benefits
Size	Where the size of the service provider shapes the relationship between it and a service/benefit	The size of fish can affect their saleability
Substitutable	Where the substitutability of the service provider shapes the relationship between it and the service/benefit	Coral reefs are substitutable for underwater rock formations that maintain aesthetically pleasing seascapes following mass bleaching events.
Topography/ Morphology	Where the topography/ morphology of the service provider shapes the relationship between it and a service/benefit	Island topography creates favourable conditions for fishing in different monsoon seasons
Use in fishing (NT)	Where specific traits determine a service provider's use in fishing and shape the relationship between the provider and a service/benefit	Specific types of plants (terrestrial) and seaweed attract specific target species and are used as bait
Other	Where other traits were identified that shape the relationship between service provider and a service/benefit but that were mentioned only once by interviewees	A fish's strength makes it more rewarding experience for young children when fishing recreationally

NT = not associated with tourism services; *Taken to mean: "the standard of something as measured against other things of a similar kind" (English Oxford Living Dictionary; https://www.lexico.com/definition/quality; accessed: 11/12/2020);

Social-ecological traits associated with fishery services and benefits were often described in relation to specific benefits, whereas traits associated with tourism were more often described in relation to tourism services in general and not to a specific benefit. A much greater variety of traits were identified as mediating between service providers and fishery services, of which service providers connected to the *provide* benefit group via a greater variety of traits than other benefits groups. Of these, the accessibility of service providers, preferences for specific service providers and the ability of service providers to provide habitat/support marine life were most frequently identified as important. Service providers most frequently connected to the *enable* group of fishery benefits via preferences for specific service providers, the quality of service providers and accessibility of service providers. Service providers connected most frequently to the *part of* a shared identity benefit via the quality of, preferences for, ways of preparing and accessibility of service providers. Where a benefit was not specified the accessibility, size, availability, and abundance of service providers were most frequently identified in sustaining fishery services (Fig. 2.3; see Table A2.4 for breakdown of traits according to each service and benefit; Appendices).

Service providers connected to the economic benefits *provided* by tourism services through their aesthetics, abundance, and condition. The quality of, preferences for, and diversity of service providers were identified as important for *enabling tourism* operators to live a lifestyle that they value. Where a benefit was not specified, the condition, diversity and aesthetics of service providers were most frequently identified in sustaining tourism services (Fig. 2.3; see Table A2.4. for breakdown of traits according to each service and benefit; Appendices)

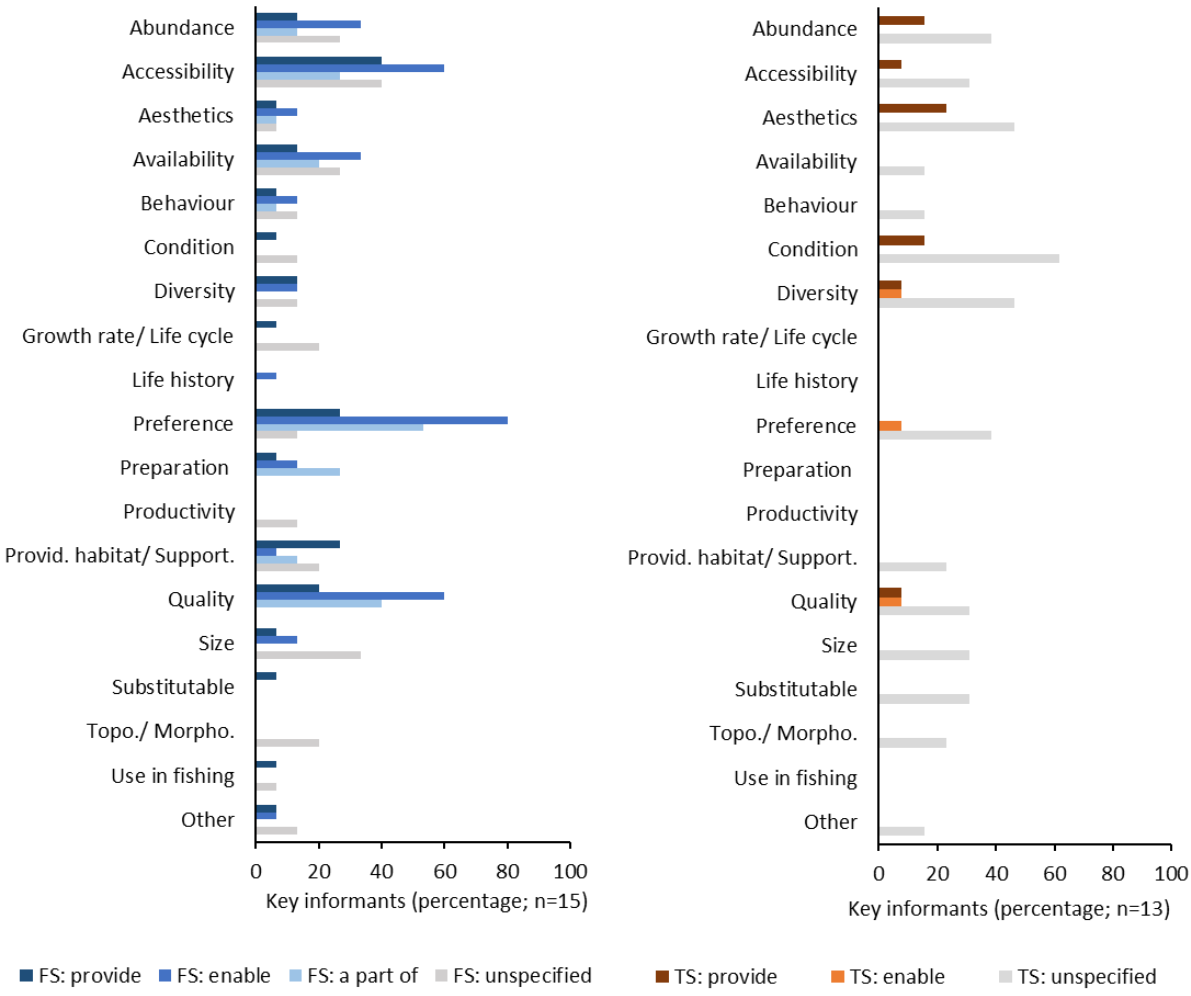

Figure 2. 3 Service provider traits identified as important in the provisioning of fishery and tourism services in Seychelles. Percentages calculated from the number of people who identified fishery services (n=15) or tourism services (n=13) as important in Seychelles (FS: Fishery services and associated benefits; TS: Tourism services and associated benefits; "Provid. habitat/ Support": Providing habitat/ Supporting marine life; "Topo./ Morphology": Topography/Morphology)

2.4.4. Visualising connections between service providers, traits, and benefits (Steps 1-3, Fig. 2.1)

Visualising the connections between service providers, traits and benefits shows the complexity in key informants' accounts of what makes different ecosystem services possible in Seychelles. I chose to illustrate two benefits that relate to fisheries and food in Seychelles to demonstrate the complexity of service provider-trait relationships underpinning even

closely related benefits: these are food availability, captured with the benefit ‘fisheries provide marine products for local consumption’ and having agency over the food you eat, captured with the benefit ‘fisheries enable people to express preferences or choices in their lives’. The provision of marine products for local food consumption was identified as important by 11 participants, who identified nine different service providers. The relationship between these providers and service provision is shaped by six different social-ecological traits. The ability of people to express preferences and exercise choice over the food that they eat, which 13 people identified as a benefit associated with fisheries, was underpinned by 23 different service providers, and mediated by 12 different social-ecological traits (Fig. 2.4).

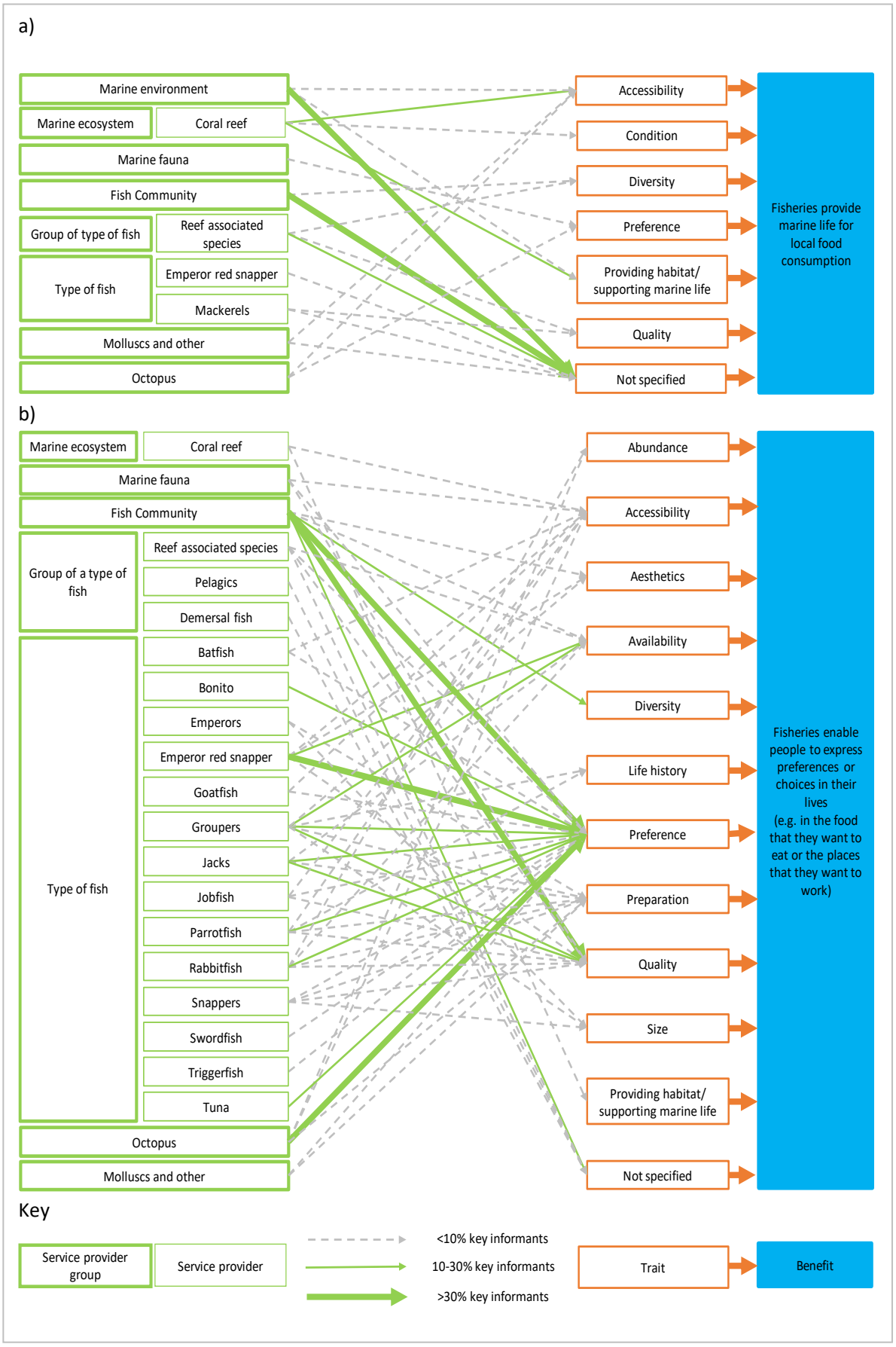
a)
Marine environment
Marine ecosystem
Coral reef
Marine fauna
Fish Community
Group of type of fish
Reef associated species
Type of fish
Emperor red snapper
Mackerels
Molluscs and other
Octopus
Accessibility
Condition
Diversity
Preference
Providing habitat/ supporting marine life
Quality
Not specified
Fisheries provide marine life for local food consumption
b)
Marine ecosystem
Coral reef
Marine fauna
Fish Community
Group of a type of fish
Reef associated species
Pelagics
Demersal fish
Type of fish
Batfish
Bonito
Emperors
Emperor red snapper
Goatfish
Groupers
Jacks
Jobfish
Parrotfish
Rabbitfish
Snappers
Swordfish
Triggerfish
Tuna
Octopus
Molluscs and other
Abundance
Accessibility
Aesthetics
Availability
Diversity
Life history
Preference
Preparation
Quality
Size
Providing habitat/ supporting marine life
Not specified
Fisheries enable people to express preferences or choices in their lives (e.g. in the food that they want to eat or the places that they want to work)
Key
Service provider group
Service provider
<10% key informants
10-30% key informants
>30% key informants
Trait
Benefit

Figure 2. 4 Visualising connections between service providers, social-ecological traits and two fishery associated benefits. a) Illustrates the nine different service providers identified by key informants that underpin fisheries providing food for local consumption. Relationships between these service providers and the benefit is mediated by six different traits, though in some cases no trait was specified; b) Illustrates the 23 different services providers identified by key informants that underpin the fisheries enabling people to express preferences and exercise choice in their lives. Relationships between these service providers and the benefit is mediated by 12 different traits, though in some cases no trait was specified. Percentages calculated based on the number of key informants who identified each benefit as important: n=11 for fisheries providing food for local food consumption; n=13 for fisheries enabling an expression of choice

2.5. Discussion

Ecosystem services, as an inter-disciplinary concept, allows for the integration of different approaches to better understand the implications of environmental change for human wellbeing. In this paper, I connect advances in functional ecology and social-ecological systems research to propose an expanded trait based-approach, incorporating traits that reflect the co-production of ecosystem services from social and ecological processes. I populate this approach with interview data from the Seychelles to identify which aspects of the marine and coastal environment contribute to the provision of locally important services and benefits. By interviewing people with expertise in both the importance and mechanisms underpinning fishery and tourism services, I demonstrate the diversity of service providers needed to sustain these services and associated benefits. Identifying social-ecological traits that reflect the context in which services are used and valued revealed many different types of traits that mediate between service providers and benefits. In the following, I discuss what my findings contribute to understanding how ecosystem services associated with nearshore tropical environments may respond to environmental change, before addressing some of the limitations of my approach and suggestions for further research in this area.

Tropical inshore areas are commonly associated with similar types of ecosystem services regardless of geographic region (Hicks 2011; Laurans *et al.* 2013; Albert *et al.* 2015; Schuhmann & Mahon 2015). My approach - which sought to identify locally relevant benefits – reveals important differences in how these different benefits emerge, which can help identify which benefits are most vulnerable to different types of environmental change (Hevia *et al.* 2017b). The fishery benefit pathways that I visualise illustrate two important aspects of food security: food availability (captured with 'fisheries that provide food for local consumption') and agency (captured with 'fisheries enable people to exercise choice and preferences') (HLPE 2020). When discussing food availability, key informants identified service providers and traits that reflect the importance of ecosystem functioning (e.g. marine environment, marine ecosystems, fish community as service providers, and accessibility and providing habitat as traits). Being able to eat the food that you want to eat was however connected to a much wider variety of marine fauna service providers (e.g. fish community, specific groups of fish, specific types of fish, specific invertebrates) and to traits that capture the preferences and needs of local consumers (that service providers are available, diverse, preferred and of a certain quality). Reflecting on these service providers in the context of previous research: fish communities in their current configurations are unlikely to persist under continued thermal stress (Robinson *et al.* 2019a), but fish landings data spanning two coral bleaching events in Seychelles indicate that total catch and mean catch rates have not changed over time, partly due to increasing abundances of herbivorous fish (Robinson *et al.* 2019b). Future disturbances may therefore not affect food availability in the short term (Rogers *et al.* 2018) but may limit people's access to the foods that they would choose to eat. Moreover, our approach identifies service providers that are preferred because of their cultural importance. Loss of these service providers and their associated traits may therefore have wide-reaching effects on community wellbeing (Poe, Norman & Levin 2014). Of note, is that both food availability and agency are perceived to be influenced by the accessibility

and/or availability of services providers. This reflects an important spatial and temporal component to assessing service providers vulnerability to environmental change (Maire *et al.* 2016; Grantham, Lau & Kleiber 2020).

Key informants' accounts of the use and importance of ecosystem services identified services that *provide*, *enable* and *are part of* Seychelles culture. Our framework adopts a linear interpretation of ecosystem services (as benefits flowing from ecosystems to people) in order to clarify on the ecological underpinnings of ecosystem services in a manner that recognises the co-production of these services (similar to Daw *et al.* 2016). This conceptualisation however does not reveal inter-dependencies between services, something that key informants were aware of. Ecosystem services function together to affect how people benefit from the environment (Polishchuk & Rauschmayer 2012) and interactions between services can result in non-linear responses to external drivers (Bennett, Peterson & Gordon 2009). Though the identification of service providers and traits is well-suited to targeted management strategies (Echeverri *et al.* 2020), the inter-dependency of different services and benefits within the same environment is also a key finding.

Service providers identified as underpinning tourism services in Seychelles span multiple scales and include a much wider range of features - including corals and different types of marine fauna - than those identified in the context of fishery services. Traits associated with tourism services also capture service provider characteristics that are most likely to shape divers' underwater experience, for example the aesthetics, abundance, diversity, and condition of service providers. This is consistent with preferences of less experienced divers in other geographic regions (Giglio, Luiz & Schiavetti 2015) and the type of diver most often found in Seychelles. Unique to Seychelles', however, is the presence of underwater granitic structures, which were also identified as a key service provider for tourism services.

Abiotic features do not depend on living processes and there is some debate as to whether these should be incorporated in ecosystem service processes or outputs (Hattam *et al.* 2015). (Haines-Young & Potschin 2010a) recommend a pragmatic approach wherein dependency on physical features should be recognised in terms of services being more or less dependent on biotic or abiotic processes. In the case of Seychelles, two mass coral bleaching events (1998, 2016) have already resulted in degradation of nearshore reef environments and regimes shifts to macroalgae (Graham *et al.* 2015; Wilson *et al.* 2019). These disturbances were perceived to negatively impact on the aesthetics of the marine environment. Key informants in the tourism sector identified coral reefs as a service provider but, in describing contemporary reef conditions, highlighted that it is the substitutability of reefs that enable tourism services to persist in a degraded reef environment. As such, dive tourism operators increasingly rely on other service providers that carry the same traits as reefs. This includes underwater granitic structures, which are aesthetically pleasing, provide habitat for marine life, and in addition to reefs meet the needs of 'thrill seeker' divers, attracted to underwater caves and tunnels.

Substitution in this context refers to the substitutability of one service provider for another service provider already present in the environment, which differs from substituting biophysical features for man-made alternatives (Moberg & Ronnback 2003). Indeed, the range of service providers identified in relation to tourism services would indicate that ecological integrity is important. Switching between service providers may be indicative of an environmental problem context, whereby the relative importance of certain service providers increases under extreme environmental conditions (e.g. during flooding events; Andersson *et al.* 2015). Implications for future service provision could be as follows. Firstly, service providers that carry similar traits may confer some resilience to on-going and future

environmental change. Service providers are however multi-functional with regards the services that they underpin and are finite (Pelenc & Ballet 2015). Increasing reliance on fewer service providers could lead to over-use and/or conflict between resource users (e.g. Shideler & Pierce 2016). Secondly, recognising that reefs are already degraded, and that the relative importance of service providers is shifting, may require additional and more adaptive management to sustain services into the future (Rogers *et al.* 2015a). Finally, substitutability also emerged in the context of fishery services, wherein local populations of a service provider (octopus, lobster) are supplemented through imports. The introduction of imports and consequent de-coupling of local social-ecological dynamics can have long-term impacts for sustainability (Dajka *et al.* 2020). Identifying critical baselines below which service providers no longer sustain ecosystem services is likely to be challenging as many service providers underpin multiple services (Pelenc & Ballet 2015; Woodhead *et al.* 2019) but could provide an early warning of where local service provider populations cannot sustain valued services (Luck *et al.* 2009).

My approach can provide a basis for incorporating ecosystem service co-production into existing methods that examine the impacts of disturbance on traits underpinning ecosystem services (Mouillot *et al.* 2013; Hevia *et al.* 2017b; Woodhead *et al.* 2019). However, the usefulness of this approach is contingent on whose preferences are reflected in the process of identifying benefits, service providers, and traits. Though key informants were identified based on their professional expertise, many had personal knowledge and experience of fishery and tourism services. I encouraged both types of knowledge in the interviews, as it elicited a wider discussion on the importance of the sea in Seychelles but acknowledge that these views may not reflect the needs and preferences of everyone. Further research adopting this approach could engage in a more deliberative process that recognises the many different contributions that ecosystem services make within a community,

acknowledging and addressing possible trade-offs in the use of ecosystem services (Daw *et al.* 2015). Finally, different non-environmental factors can mediate between ecosystems, services, and the wellbeing of different people (Andersson et al. 2015; Daw et al. 2016). Our approach explores co-production at the ecological end of service provision, but these mediating factors should also be considered when assessing the wider implications of environmental change for human wellbeing. A poignant and recent example following widespread travel restrictions during the Covid-19 pandemic is that international visitors to Seychelles dropped from 18 067 in March 2020 to 22 in April, and recovered to only 3 271 by October 2020 (National Bureau of Statistics 2020b), which would have severely impacted on tourism services.

2.6. Conclusion

Coral reefs, and many other tropical ecosystems, are highly vulnerable to environmental change, yet underpin key ecosystem services for millions of people (Barlow *et al.* 2018). Comparatively little data, however, is available to assess the implications of future environmental change on reef dependent communities (Pendleton & Edwards 2017). Understanding the co-production of ecosystem services and benefits, at the scale of biophysical unit which underpins them, can offer a more holistic and systematic approach to identifying the mechanisms of ecosystem service provision across different social-ecological contexts. Incorporating models that recognise the social-ecological dynamics of reef systems will be necessary to engage with the complexity of reefs systems into the future (Williams et al. 2019).

Chapter 3 - Fishers perceptions of ecosystem service change associated with climate-disturbed coral reefs

3.1. Abstract

Understanding ecosystem service change necessitates an understanding of the social and ecological dimensions of ecosystem services and how they contribute to the wellbeing of different people. These empirical research gaps persist across the tropics and in coastal environments, posing a challenge for small island states that depend on ecosystem services associated with nearshore ecosystems like coral reefs.

Perception-based approaches allow for a rapid appraisal of what constitutes ecosystem service change, providing insights into why these changes matter, and how experiences of change differ between individuals. To capture perceptions of change in four ecosystem services associated with coral reefs (habitat, fishery, coastal protection and recreation services), I conducted 41 semi-structured interviews with coral reef fishers from Seychelles, where reef ecosystems have been severely impacted by climate disturbance. I gathered quantitative and qualitative data to understand a) if and what changes in reef-associated ecosystem services have been perceived; b) if fishers' characteristics are associated with differences in perceived changes; and c) which changes matter most in fishers' lives. Using a three-dimensional approach to wellbeing I sought to identify whether reasons behind the importance of change connect to fishers' wellbeing.

There have been noticeable changes across all four ecosystem services investigated. Changes include social, ecological, and behavioural dynamics. Every fisher perceived at least one ecosystem service change but fishers who dive/snorkel or work from larger boats, perceived a higher number of ecosystem services to have changed. Education, age, and participation in

snorkelling/diving were associated with fishers who identified changing habitat services as most important, whilst fishers from families with fewer livelihood alternatives and from smaller islands identified changing fishery services as most important. Different aspects of the subjective, relational, and material dimensions of wellbeing were implicated in why changing services matter.

Despite known ecological shifts in reef condition, this research is one of few studies to empirically show how changes across multiple ecosystem services are being perceived. These perceived changes are complex, engage both the social and ecological dimensions of services, and connect in multiple ways to how fishers feel about their lives, their relationships and material wellbeing.

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3.2. Introduction

Human activities have resulted in degraded and functionally altered ecosystems around the world. Impacts on key ecosystem services include changes in food security, water quality, and the loss of culturally valued species and places (Isbell *et al.* 2017; IPBES 2019). Although environment-human relationships are explored by various disciplines, the concept of ecosystem services originated in efforts to guide policy by highlighting the contributions of ecosystems to human wellbeing (Costanza *et al.* 2017). It has since developed into a broader framework for scientific enquiry (Evans 2019), providing a basis to explore complex environment-wellbeing relationships. However, against a backdrop of rapid and pervasive anthropogenic pressures, such as climate change, we lack an empirical understanding of how resilient ecosystem services will be to ongoing and future change (Bennett *et al.* 2015).

Theoretical advances in the ecosystem services literature have highlighted that environment-wellbeing relationships are complex and multifaceted. For example, while many ecosystem service frameworks recognise the importance of combining social and ecological dimensions (e.g. Reyers *et al.* 2013), complexities can arise from integrating human activities and social processes into understanding how ecosystem services occur (Fischer & Eastwood 2016). Moreover, the importance of disaggregating ecosystem service-wellbeing relationships between people is increasingly apparent (Daw *et al.* 2016). The interactions between wellbeing and ecosystem services often involve trade-offs (Daw *et al.* 2015) and non-linearities (Raudsepp-Hearne *et al.* 2010), as well as being influenced by access mechanisms that determine who can benefit from which ecosystem services (Hicks & Cinner 2014). These are likely in turn to affect who is most vulnerable to ecosystem service change.

Research across the social and ecological components of ecosystem services is however fragmented (Boerema *et al.* 2017) and ecosystem service-wellbeing relationships are often

assumed but not explored. For example, in a systematic review of ecosystem service-wellbeing research, (Cruz-Garcia *et al.* 2017) found that 71% of publications across Africa, Asia and Latin America assumed a link between ecosystem services and wellbeing without explicitly examining how this relationship occurred. An empirical understanding of these relationships is necessary to understand the implications of changes in ecosystem functioning for human wellbeing (Bennett *et al.* 2015). Furthermore, findings from a systematic review by (Blythe *et al.* 2020) on the connections between coastal wellbeing and ecosystem services, show that certain wellbeing dimensions were considered more often in empirical research than others (e.g. employment was the most frequently explored and recreation the least) and that there is a geographic bias towards European case-studies. Both reviews concluded that some ecosystem services (e.g. provisioning services) are more widely studied than others and that few empirical studies disaggregate the wellbeing contributions that emerge from ecosystem services.

The lack of research on ecosystem service-wellbeing relationships, and integrating social and ecological dimensions of change, is particularly relevant for tropical small island states which are highly dependent on nearshore environments (Watson, Claar & Baum 2016). Hyperdiverse tropical areas, including coral reef ecosystems, are extremely vulnerable to climate changes, particularly heatwaves, threatening the continued provisioning of ecosystem services with both local and global importance (Moberg & Folke 1999; Barlow *et al.* 2018; Woodhead *et al.* 2019). Globally, climate stress has caused many coral reef ecosystems to shift into alternate ecological regimes, dominated by different coral assemblages or other benthic organisms such as fleshy macroalgae (Norström *et al.* 2009; Hughes *et al.* 2017). Under current climate predictions, these ecosystems are unlikely to recover to pre-industrial conditions (Hughes *et al.* 2018a). There is evidence to suggest that coral-reef-associated ecosystem services have changed in response to altered environmental

conditions (Orlando & Yee 2017; Sato *et al.* 2020), but to date few studies have sought to understand how changes in multiple ecosystem services are perceived by those whose wellbeing depends on coral reefs.

Perceptions of change play a vital role in the adaptive capacity of human communities (Adger *et al.* 2008). Engaging with perceptions can help integrate social and ecological dimensions of ecosystem service change, whilst dis-entangling different ecosystem service-wellbeing relationships within groups. For example, perceptions-based data can capture both the ecological dynamics of changing service provision, and the ways in which people feel and respond to these changes. Coral reef fishers draw on their ecological knowledge and everyday experiences to inform decision making. If perceived changes in fish catch fall within a range that is considered normal, fishers may choose to not respond (Rassweiler *et al.* 2020), but if declines are considered severe enough, fishers may choose to fish elsewhere or leave the fishery (Daw *et al.* 2012). This in turn affects what is available for local consumption and how much pressure is put on the ecosystem (Cinner *et al.* 2011). In this way perception-based research can complement scientific assessments of change to highlight which changes are meaningful within different social-ecological contexts (Quintas-Soriano *et al.* 2018; Rassweiler *et al.* 2020).

Perceptions are inherently complex. At an individual level, factors such as education, age, gender and wealth can influence how ecosystem services are perceived and prioritised, even within the same sector (Martín-López *et al.* 2012; Oteros-Rozas *et al.* 2013; Lau *et al.* 2018). Cultural background, as well as the influence of urban and rural settings can also shape how different ecosystem services are perceived from the same environment (Orenstein & Groner 2014). Understanding the importance ascribed to ecosystem services by different groups can give valuable insights into the social differentiation of ecosystem service contributions to

wellbeing (Lau *et al.* 2019). Diverging perceptions of change in ecosystem services may reflect different ecological understandings of how ecosystem services emerge (e.g. Cebrián-Piqueras, Karrasch & Kleyer 2017), but they may also result from unequal opportunities to perceive and adapt to change. Thus, perceptions of change are not immune to the underlying structures present within communities (Ensor *et al.* 2017), which also shape ecosystem service-wellbeing dynamics (Hicks & Cinner 2014). Investigating perceptions of change in ecosystem services, and how these align with other social, demographic and economic characteristics can provide important insights into how change and ecosystem service-wellbeing relationships play out within communities, allowing for a more nuanced understanding of who is most vulnerable to change (Daw *et al.* 2015).

Building on the potential for perceptions research to both explore social and ecological dimensions of ecosystem service change and provide insights into socially differentiated ecosystem service-wellbeing relationships, we conducted a study to explore small-scale fishers' perceptions of change in ecosystem services associated with coral reefs. Our study focuses on Seychelles, a small island state in the western Indian Ocean that is highly dependent on the ocean and its services. Coral reefs in Seychelles have experienced large-scale ecological change in response to climate-driven coral mortality (Graham *et al.* 2015; Wilson *et al.* 2019) and are of known importance to the wellbeing of local fishers (Hicks *et al.* 2014; Lau *et al.* 2018). We interviewed coral reef fishers to 1) understand if and what ecosystem service changes have been perceived; 2) explore if fishers' social, demographic, economic and fishing characteristics relate to perceptions of change; and 3) capture why ecosystem service changes matter and how this might connect to human wellbeing.

3.3. Methods

3.3.1. Seychelles study site

Coral reefs in Seychelles, like many in the western Indian Ocean, were affected by mass coral bleaching in the 1998 pan-tropical marine heatwave, causing >90% loss of live coral cover (Graham *et al.* 2006). As a consequence, there was a major restructuring of reef benthic habitat; some reefs recovered live corals, others transitioned to a state dominated by macroalgae (Graham *et al.* 2015), and the fish community changed into persistent novel compositions (Robinson *et al.* 2019a). In 2016, another major marine heatwave caused 70% coral mortality, particularly affecting the reefs that had recovered from the 1998 event (Wilson *et al.* 2019). As recovery time between bleaching events is likely to decrease (Hughes *et al.* 2018a), it is unlikely coral-dominated reefs will be able to recover from the cumulative impact of these events (Robinson, Wilson & Graham 2019).

Evidence suggests that since the late 1990s, ecosystem services associated with reefs in Seychelles have also been affected. Fishery landings data indicate that the inshore trap fishery, which relies on reef-associated species, has experienced an overall increase in yield and catch per unit effort, but also more unpredictable catches (Robinson *et al.* 2019b). This was associated with an increase in the dominance of schooling herbivorous fish around macroalgal reefs and the increased patchiness of the reef environment (Robinson *et al.* 2019b). Reef degradation has also led to an increase in wave energy hitting the shoreline in Seychelles (Sheppard *et al.* 2005) and greater risk of coastal flooding and erosion (World Bank and Ministry of Environment Energy and Climate Change of Seychelles 2019).

Local food security needs are met by an inshore artisanal fleet that fish on the large (41,000 km^2) and relatively shallow (0-75m) Mahé plateau, which encompasses a diversity of habitats. This artisanal fleet is culturally important (Fig. 3.1a) with ca. 500 people directly

involved in fishing across a diversity of boat types. The inshore fisheries are subsidised and largely unregulated (Bijoux 2015). In this work, we focused on fishers who fish from small boats with an outboard engine, which constitute nearly 60% of the inshore fleet (Fig. 3.1b), and who use traps as part of their gear assemblage to target reef-associated habitats and species (Fig. 3.1c). These vessels, which have on average two crew members, tend to fish within 40 km of the three main inhabited islands (Mahé, Praslin, La Digue) which are located centrally on the plateau. Artisanal fishers are predominantly male, and the average age of the population is increasing. Income and educational levels vary within this group, but they are not considered socio-economically vulnerable in Seychelles (Bijoux 2015).

Figure 3. 1 Seychelles study site: 1a) Depiction of a small-scale fisher at the 2019 Creole Festival; 1b) Trap fisher repairing trap at sea; 1c) Typical trap catch of reef associated fish species (photo credit: A.J. Woodhead)

3.3.2. Study design and data collection

Between June and July 2018, we conducted 41 semi-structured, open, and close-ended question interviews at landing sites with male fishers on Mahé (n=23), Praslin (n=16) and La Digue (n=2) in Seychelles. We sought a representative sample of the fishers who use traps from small boats with outboard engines. Working hours on these vessels vary according to local geographies, weather, fishing opportunities and personal preferences. We therefore

used a combination of non-probability sampling techniques, including convenience and snowball sampling (Bryman 2008; p. 183-185) until no new descriptions of ecosystem service change emerged and all available fishers had participated. All interviewees fished separately (on different boats) and our sample represented 38% of registered vessels that met our criteria across the three islands (Seychelles Fishing Authority 2015). Due to the proximity of Praslin and La Digue, the small sample size on the latter, and the high overlap in fishers' use of the marine environment between the islands (Bijoux 2015), we combined interviews into one geographic unit (Praslin/La Digue; n=18).

To understand fishers' perceptions of change in different types of ecosystem services, we presented respondents with four coral reef associated ecosystem services: habitat services, fishery services, coastal protection services, and recreation services. These were chosen because they represent the different established categorisations of ecosystem services - supporting (habitat), provisioning (fishery), regulating (coastal protection) and cultural (recreation) - and have previously been shown to be of importance to coral reef fishers in the Seychelles (Millennium Ecosystem Assessment 2005; Hicks *et al.* 2014). Habitat services are known to be valued by fishers across the western Indian Ocean region (Hicks, Graham & Cinner 2013; Lau *et al.* 2018). Reef-associated fisheries are essential for food security, economic and cultural reasons (Robinson *et al.* 2019b), whilst changes in coastal protection are increasingly visible across Seychelles and of growing concern (World Bank and Ministry of Environment Energy and Climate Change of Seychelles 2019). Coastal recreation is integral to Seychelles' way of life but in the wider literature, local and tourism recreation are often conflated (Laurans *et al.* 2013). We therefore defined recreation as the activities of Seychellois residents and not international tourists. This includes beach and in water recreation, which can be related to coral reef degradation, for example through increased

wave energy reaching the shore and eroding beaches (Sheppard *et al.* 2005). In sum, these services represent a range of ecosystem service-wellbeing relationships, encompassing services that connect directly (e.g. provisioning services) and indirectly (e.g. supporting services) to wellbeing, and are all at risk from well-documented environmental changes in the region.

Each ecosystem service was described verbally, using a standardised description developed from previous research (as outlined in Hicks, Graham & Cinner 2013) (Table 3.2), and visually supported throughout the interview with two photo prompts per service (Table A3.1; Appendices). Broad descriptions of ecosystem services were purposively used to capture all aspects of ecosystem service change for two reasons. Firstly, delineating between the social and ecological dimensions of ecosystem services is both practically and conceptually challenging (Tusznio *et al.* 2020), and counter-intuitive to investigating change within social-ecological systems (Reyers *et al.* 2013). We therefore sought definitions of ecosystem services that were consistent with previous research and onto which participations could reflect their own experiences of change, regardless of the nature of these changes. Secondly, ecosystem services, as they are perceived by the people who benefit from them, are rarely attributable to a single bounded ecosystem (Dawson & Martin 2015). For example, many trap fishers also use handlines to target pelagic species (e.g. jobfish and jacks) in addition to the reef-associated species caught in traps. The ecosystem services chosen in this study are known to be associated with coral reef ecosystems, but they may also depend on other parts of the nearshore environment for which ecological and environmental data is less readily available. Similarly, the values attached to ecosystems are not clearly delineated according to the activities being undertaken (Poe, Donatuto & Satterfield 2016). Whilst snorkelling, freediving, and diving on reefs are done recreationally, they are also part of fishing activities (e.g. retrieving gear, cleaning boats, diving for octopus or sea cucumber). A specific focus on

underwater recreation would have only been relevant for a handful of fishers and would not have reflected how coastal recreation is experienced in Seychelles.

To ensure a focus on perceived changes in ecosystem services, as something valued by fishers, we first asked fishers to rank the services based on their relative importance to the respondent and to provide a justification for their decisions. From this, we could also verify that participants understood the services and the differences between them. If not, service definitions were discussed, and the exercise repeated until a common understanding had been reached. For each ecosystem service in turn, fishers were then asked whether they thought the ecosystem service had changed, and if yes, to describe the change(s) that they had observed (qualitative statements). For the analysis, we created a summary variable for each fisher that captured the total number of ecosystem services they had perceived to have changed (range 0 to 4: from no perceived change to all ecosystem services perceived to have changed). To allow for a potential comparison between perceptions of ecosystem service change and ecological measures of reef change (e.g. following the mass bleaching events of 1998 and 2016) we then asked when fishers thought a perceived change had first started (responses were categorised into five-year time bins), and whether they considered this change to have been fast or slow (responses were categorised into: 'fast', 'gradual', 'it depends' or 'not answered (NA)'). The average age of artisanal fishers in Seychelles is 48 years old (Bijoux 2015) and many fishers start fishing in childhood. Known ecological changes on reefs in Seychelles are both gradual and abrupt, with potential lag effects on ecosystem services (Graham *et al.* 2007). Given that ecological records of reef condition only extend 24 years prior to data collection (Graham *et al.* 2015) we chose to not impose a time frame on when fishers might first have perceived changes as having started. This allowed for the fact that a) fishers' may have perceived changes not captured in ecological datasets and b) that perceptions of what constitutes a noteworthy change for fishers, may differ from what

constitutes a significant change for ecologists (e.g. Rassweiler *et al.* 2020) and may therefore not be captured in the ecological data.

To understand if differences in perceptions of change were associated with fishers' characteristics, we collected quantitative data on 12 different social, economic, demographic and fishing attributes, that could connect to perceptions of ecosystem services and/or awareness or ability to adapt to change (Table 3.1). Data were missing for between one and three respondents for four variables (boat length; self-reported catch; household occupational multiplicity; income), we imputed these values using the mean or median response.

To understand which of the changed ecosystem services were most important and why, we then presented participants with the descriptions and picture prompts of only the services that they perceived to have changed. This was to ensure a focus on perceived changes and to avoid confusion with the initial ranking exercise. Fishers were asked to identify which one of the perceived changes was most important to them and why (qualitative statements). Three fishers picked two instead of one service that they perceived to have changed. We recorded both services and their reasoning for qualitative data analysis (see Appendix A3.2). All qualitative statements were translated into English, in real time, and recorded to form the basis of further analysis. All data collection was conducted in partnership with the Seychelles Fishing Authority and verbal consent to participate was given by all interviewees. This research was undertaken with ethical approval from the Faculty of Science and Technology research ethics committee (Lancaster University, FST17114) and with a research permit from the Seychelles Bureau of Standards (A0157).

Table 3. 1 Trap fishers' social, economic, demographic and fishing characteristics (n=41) including a description, summary statistics and interpretation relative to perceptions of ecosystem services and/or awareness and ability to adapt to change.

Fishers' characteristics[a]		**Description**	**Population summary statistics**[b]	**Interpretation**
Demographics	Age	Age of participant at time of interview	Mean (± SD): 46.5 yrs (± 12.5 yrs) Range: 20-69 yrs	Age can be a predictor of fishers' perception of ecosystem services (Lau *et al.* 2018) and responses to change e.g. when to exit a fishery in response to declining catch rates (Daw *et al.* 2012).
	Education	Highest level of formal education achieved	7% left after primary school; 56% after secondary school; 34% had a post-secondary qualification; 2% had tertiary level education.	Formal education can be a predictor of an individual's likelihood to recognise different types of ecosystem services (Martín-López *et al.* 2012).
	Island	Location of fishers' landing site	Mahé = 23 fishers Praslin/La Digue = 16 fishers	Reef recovery following bleaching differs between the islands (Graham *et al.* 2015), with potential differential impacts on changes in services.
Fishing	Effort[c]	Length of boat	Mean (± SD): 19.24 ft (± 2.69 ft); Range: 16-27.5ft	Boat length, number of gears used and use of technology can be indicative of how much fishers have invested in fishing and can determine fishers' adaptability to change. Larger boats enable fishers to bring home a larger catch, increase their use of ice, to fish in less than ideal conditions and/or to fish further out. High gear diversity can allow fishers to target reef and non-reef associated fish, and technology (e.g. fish finders or GPS) can be used to fish more safely in unfamiliar areas offshore.
	Diversity of fishing gear	Number of gear types used	Mean (± SD): 2 (± 1); Range: 1-4	
	Use of technology	Whether fishers use technology as part of their fishing practice	32% of fishers use some form of technology when trap fishing and 68% do not.	

	Self-reported average catch	Catch reported in packets of mixed species composition (ca. 7 to 12 fish)	Mean (± SD): 15 packets (per boat) (± 9 packets); Range: 0-38 packets	Indicative of fishing success and dependence on trap fish resources. Dependency can influence awareness of ecosystem services (Cumming *et al.* 2014) and high dependency can limit fishers' ability to adapt to change in ecosystem services (Watson, Claar & Baum 2016).
Fisher economics	Number of jobs	Total number of different occupations (part or full time) undertaken by the fisher (includes fishing)	51% had one occupation; 46% had two occupations; 2% had three occupations.	Occupational multiplicity at an individual level can be interpreted as a sign of low vulnerability to change (it spreads the risk of variable success attached to resource dependent livelihoods) or of increased vulnerability to change (higher standards of living are associated with occupational specialisation) (Cinner, McClanahan & Wamukota 2010).
	Dependents	Number of people that the fisher supports financially or through the provisioning of fish[d]	Mean (± SD): 2 (± 2) people; Range: 0-5 people	Indicates dependency at household level on fishing for food or for income (*see Self-reported average catch)*.
Household economics	Occupational multiplicity (household level)	Number of occupations per person in the household (excludes the fishers and their occupations)	Mean (± SD): 0.43 (± SD) jobs per person; Range: 0-1 job per person	Low occupational multiplicity at the household level implies high dependency on fishing as fishers cannot draw on other sources of food or income from the household when catches are variable (*see Self-reported average catch).*
	Household income	Income per month (includes fisher)	Median: 10 000 to 15 000 SCR/month; Range: Less than 3000 to more than 30 000 SCR/month. 12% fishers interviewed were from households below or near to	Wealth can be a predictor in how fishers view changes in reef ecosystem services. (Lau *et al.* 2018), for example, show that fishers across wealth groups value habitat services but only wealthier fishers prioritised improvement in these services.

			the Seychelles poverty line (4 673 SCR/month, National Bureau of Statistics 2019)	
Other ways of engaging with the marine environment	Participation in underwater activities	Percentage of fishers who free-dive, scuba dive or snorkel whilst fishing, for other jobs or for recreation.	66% engage in underwater activities. 34% do not.	Ecological knowledge is embedded in the different activities that individuals partake in. How fishers engage with the environment could therefore play a role in how ecological change and it's impacts are perceived (Poe, Norman & Levin 2014).

[a]All information is self-reported; [b]Missing data was imputed using the mean or median response (applied to 'boat length', 'self-reported average catch', 'household occupational multiplicity' and 'income' for between one and three respondents); [c]Six fishers owned multiple boats. Data collected here focuses only on vessels used for trap fishing or if two vessels were used for trap fishing, data on the largest vessel was recorded; [d]Can differ from household number as some fishers provided fish for people outside the household.

3.3.2. Analysis

3.3.2.1. Quantitative data analysis

Multivariate statistics were used to explore associations between fishers' characteristics and their perceptions of ecosystem service change (e.g. Martín-López *et al.* 2012). As all inputted data were numeric, a Principle Component Analysis (PCA) was used to explore associations between fishers' characteristics, including the summary variable on number of ecosystem services perceived to have changed (FactoMineR package; Lê, Josse & Husson 2008; R version 4.0.0.; R Core R Core Team 2020). All interviewees were included in this analysis (n=41).

We applied a constrained ordination to understand if fishers' characteristics explain any variation in responses as to which perceived to be changing service is the most important (Legendre & Legendre 2012; Oksanen 2019). We used a Canonical Correspondence Analysis (CCA), which is better suited to dealing with frequencies and is commonly applied to binary data (Legendre & Legendre 2012). This was relevant as fishers who perceived changes were asked to identify a single changing service that was most important to them. Perceived changes to habitat, fishery and coastal protection services were the only services included due to the small number of fishers who said perceived changes in recreation services were the most important. This analysis was run on the responses of 36 fishers (excluding three fishers who identified two changing services as most important, one fisher who did not think any of his perceived changes were important, and one fisher who reported perceived changes in recreation services as most important to him). We used permutation tests to assess the significance of constraints (999 permutations). The analysis was run using the vegan package (version 2.5-6; Oksanen *et al.* 2019).

3.3.2.2. Qualitative data analysis

Qualitative descriptions of perceived change and the reasons given for the importance of specific ecosystem service changes were initially coded inductively. Descriptions of perceived change, within each ecosystem service, were grouped thematically according to types of change reported. Reasons for identifying one changing service as most important revealed emergent themes connected to human wellbeing and required further analysis (all qualitative analysis was done by hand in Microsoft Word and Excel 2016).

Human wellbeing can be defined as "a state of being with others and the environment, which arises when human needs are met, when individuals and communities can act meaningfully to pursue their goals, and when individuals and communities enjoy a satisfactory quality of life." (Breslow *et al.* 2016; p.251). It can thus be viewed as an outcome (i.e. a state of being) and as a dynamic process that arises from the wider social-ecological system. Different conceptualisations of wellbeing provide different analytical frameworks, complementary to ecosystem services, that capture the diversity of ways in which the environment is important to people (Schleicher *et al.* 2018). We adopt a three-dimensional approach to wellbeing (also known as social wellbeing), which has been shown to be highly applicable in small-scale fisheries (Britton & Coulthard 2013; Weeratunge *et al.* 2014) and for disentangling human-environment relationships in island contexts (Coulthard *et al.* 2017).

We therefore applied a secondary coding framework based on a three-dimensional approach to wellbeing (White 2009; Coulthard 2012b) to explore if and how reasons given for change being important were connected to wellbeing. This approach captures wellbeing as emerging from three inter-related dimensions that encompass the subjective, material and relational

aspects of people's lives (White 2009). Drawn from (Coulthard 2012b), these dimensions can be defined as:

-Subjective: "how a person thinks and feels about their life (the person's own subjective reflection on what they have and do)"

-Relational: "what a person does through social relationships that enables/or disables the pursuit of wellbeing (including relationships of care and love, relations with the state, social institutions, kinship, cultural rules and norms, forms of collective action, among others)"

-Material: "what a person has (the objective material resources that a person can draw upon to meet their needs, such as food, assets, employment, services and the natural environment)".

3.4. Results

3.4.1. Ranking and perceptions of ecosystem service change

3.4.1.1. Fishers' ranking of ecosystem services

Habitat services associated with coral reefs were most frequently ranked as the most important service to coral reef fishers (56% of fishers gave it a ranking of 1st most important), followed by fishery services (41% of fishers provided a ranking of 2nd), coastal protection services (49% of fishers provided a ranking of 3rd), and lastly recreation services (76% of fishers provided a ranking of 4th) (Table 3.2). Two fishers were unwilling to differentiate services in terms of importance. Ranking was consistent between islands, though fishers from Praslin and La Digue tended to place fishery services as the second most important and Mahé fishers were equally likely to rank fishery services as either second or third in terms of importance.

3.4.1.2. Perceptions of ecosystem service change

The majority of fishers had perceived changes in habitat, fishery and coastal protection services (83%, 80% and 78% respectively). A lower percentage, though still more than half of the respondents, had perceived changes in recreation services (64%) (Table 3.2; Fig. 3.2). When asked to describe what changes in habitat services they had experienced, fishers referred to changes in the ecology of reef habitats, for example seeing coral bleaching and increases in algae, changes in the fish and coral community, or changes in expected ecological processes. These were often framed in relation to the wider services and benefits that habitat services underpin. For instance, the loss of nursery habitat, the fact that key fishery species such as octopus are no longer found on the reef, or a perceived loss of income associated with reef degradation (Table 3.2; further supporting quotations from interviews can be found in Table A3.3: 1-6; Appendices). Some descriptions of change captured the view that changes were spatially and temporally patchy and, in some places, reversing (Table A3.3: 7-8; Appendices). This is congruent with the fact that more than half of the fishers who had observed a change in habitat services felt that these changes had come around gradually (67%) but that opinions as to when the change in habitat services started were varied (Table 3.2). Nearly a third (29%) believed that the change had started 10 to 14 years before the survey period (2018).

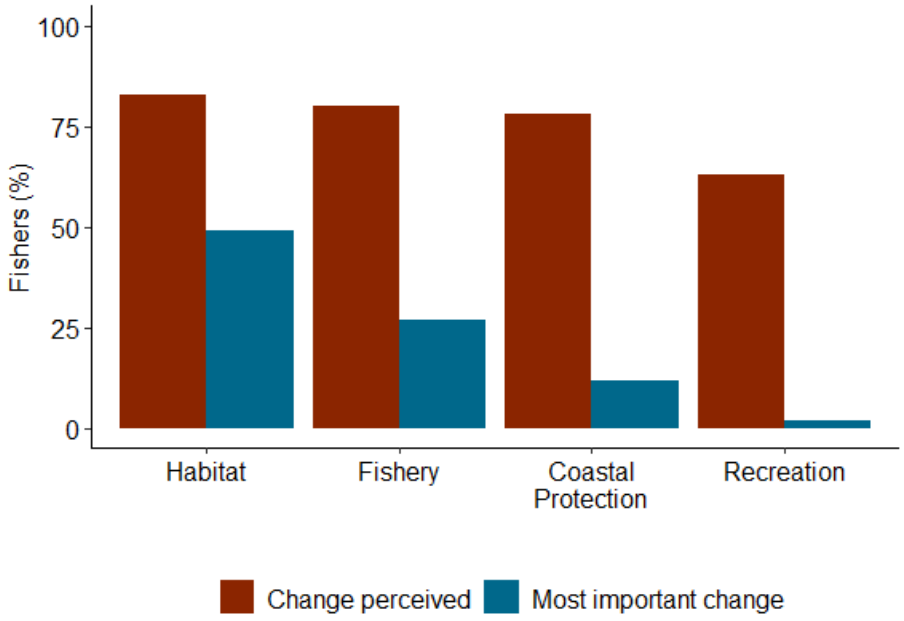

Figure 3. 2 Ecosystem services that are perceived to have changed and which of these changing services was identified as the most important to fishers (n = 41 fishers; four fishers are not represented in the 'Most important change' percentages: three who identified two changing services as most important and one fisher who had perceived changes in ecosystem services but did not think these changes were important)

In describing perceived changes in fishery services, changes in target species and/or a change in how people fished emerged as two central topics. Perceived changes in target species often referred to fish moving further offshore and/or a decline in fish populations. Changes in fishing behaviour included having to fish further out, modifying their boats or gear, changing their use of bait and increasingly relying on technology whilst fishing. Changes in fish populations were also connected to a perceived reduction in fishing opportunities because of a lack of fish inside the reef (Table 3.2; Table A3.3: 9-13; Appendices). Over a quarter of fishers who reported a change in fishery services (27%) believed that this was a recent change (starting in the last 4 years before the survey period in 2018), whereas 18% of fishers reported changes had started 5 to 9 years and 21% said 10 to 14 years before the survey. Notably, 12% of fishers felt that fishery services just depend on wider conditions and

therefore could not put a date to it. The majority of fishers (68%) felt that changes in fishery services had occurred gradually (Table 2).

Perceived changes in coastal protection included physical changes in the coastline and changes in environmental conditions connected to, for example, waves and currents. With a few exceptions, perceived changes were less directly connected to changes in coral reefs than changes in fishery and habitat services had been. However, artificial changes to the coastline, for example land reclamation and coastal defences were mentioned (Table 3.2; Table A3.3: 14-19; Appendices). Perceptions as to when changes in coastal protection services started were also varied. An equal number of fishers perceived changes in coastal protection services as having started in the four years before the survey period (28%) and 10 to 14 years before the survey (28%). Forty-six percent of fishers perceived changes in coastal protection services to have occurred rapidly but nearly the same amount reported that these changes had been gradual (42%) (Table 3.2).

Changes in recreation services were connected to changes in the physical beach environment linked to erosion or pollution. Loss of beaches and hotel development were seen as limiting access and opportunities for recreation. The beach is an important social space in Seychelles and fishers reported an increase in people using it to socialise, but that the relationships between people had changed. This was connected to the perception that lifestyles in general were different. In some cases, this connected to more personal changes, for example the need to work more to compensate for rising living costs and therefore having less time relaxing with friends and family. Although a few fishers did snorkel and swim for leisure on the reef, none of the perceived changes in recreation services reflected changes in these types of activities (Table 3.2; Table A3.3: 20-28; Appendices). Of the fishers who perceived a change in recreation services, the greatest proportion thought that these

changes had started recently (in the last four years; 27% of fishers) and more than half (59%) considered these changes to be gradual (Table 3.2).

Table 3. 2 Fishers' perceptions of change in four coral reef ecosystem services (see Table A3.1 for picture prompts; Appendices)

	Habitat services	Fishery services	Coastal protection services	Recreation services
Description of ecosystem services (drawing on Hicks, Graham & Cinner 2013)	"This picture shows a healthy coral reef. There are lots of fish and places for the fish to hide. This picture represents the benefits that we get from having healthy coral reefs in the sea."	"This picture shows fish that have been caught by fishermen and a fisherman making a packet of fish. They might sell these fish or use them to feed their families. This picture represents the benefit we get from the different fish we catch and sell."	"These pictures show waves that are breaking over a coral reef, which provides a barrier to protect the shore. It also shows a beach that has been eroded by the waves. This picture represents the benefit that we get from the reef protecting the coast."	"This picture shows some people getting ready for a birthday party with family and friends on the beach and someone swimming in the sea. This picture represents the benefits we get from being able to spend time by the sea or on the sea for fun."
Rank (mode) and percentage of fishers who gave this ranking (percentage of all respondents; n=41[a])				
	1 (59%)	2 (44%)	3 (51%)	4 (79%)
Fishers who perceived a change in the ecosystem services (percentage of all respondents; n=41)				
	83%	80%	78%	63%
Example descriptions of changes in ecosystem services (translated from Creole to English during the interview)				
	'Healthy reefs keep fish around. There's more algae on the reefs now, usually during South-East trade winds it's swept away and when it grows up, it feeds the juvenile fish, but this is no longer the case.' [MAH-0607-3]	'Changes in the quantity of fish. Have to go far to catch same fish. Three or four miles has changed to 15 miles.' [MAH-0529-3]	'Before [he] saw waves crashing on reef but now waves come up and crashing on sand. Sand moves away but also comes back.' [PRA-0613-4]	'There's a change. The people are not united together. Before groups of people do BBQ and now it's small groups of people, separated from each other.' [MAH-0607-4]
Perceptions of when changes in ecosystem services started (percentage of respondents who said yes to seeing a change in each ecosystem service)				

Years before 2018	n=34	n=33	n=32	n=26
0 to 4	15 %	27 %	28 %	27 %
5 to 9	18 %	18 %	13 %	19 %
10 to 14	29 %	21 %	28 %	19 %
15 to 19	6 %	6 %	6 %	15 %
Over 20	18 %	12 %	13 %	12 %
Depends	0 %	12 %	0 %	0 %
NA	15 %	3 %	13 %	8 %
Speed of perceived change (percentage of respondents who said yes to seeing a change in each ecosystem service)				
	n=34	n=33	n=32	n=26
Gradual	67 %	68 %	42 %	59 %
Fast	30 %	29 %	46 %	34 %
It depends	3 %	3 %	0 %	3 %
NA	0 %	0 %	12 %	3 %
Fishers perception of which is the most important of the perceived changing ecosystem services (percentage of all respondents; n=41[b])				
	49 %	27 %	12%	2%

[a] Two fishers (5% of the 41 fishers) attributed equal importance to all services and chose not to rank them; [b] In addition to the percentages reported, three fishers (7% of the 41 fishers) identified two changing services as jointly important (habitat and fishery services (n=2) and habitat and coastal protection services (n=1)). One fisher (2% of the 41) had observed changes in ecosystem services but did not think they were important.

3.4.2. Exploring differences between fishers

3.4.2.1. Differences in number of perceived ecosystem service changes

Over a third of fishers (39%) perceived that all four services had changed and another third (34%) had perceived that three of the four had changed. All fishers perceived at least one ecosystem service change. The total number of ecosystem services perceived to have changed by each fisher was best represented by principle component 1 (PC1) ($cos^2 = 0.43$), which in combination with PC2 explained 30.5% of variation between fishers (Table A3.4; Appendices). The biplot of this PCA indicates that fishers who partook in underwater activities such as free-diving, snorkelling or diving (as part of their fishing activities or at other times) and fishers working from larger boats were also likely to have reported a greater number of ecosystem services as having changed. Number of fisher jobs, age and household occupational multiplicity were not well represented on PC1 or PC2 and could not be interpreted (cos2<0.3; Oteros-Rozas *et al.* 2013; Fig. 3.3.; Table A3.5; Appendices).

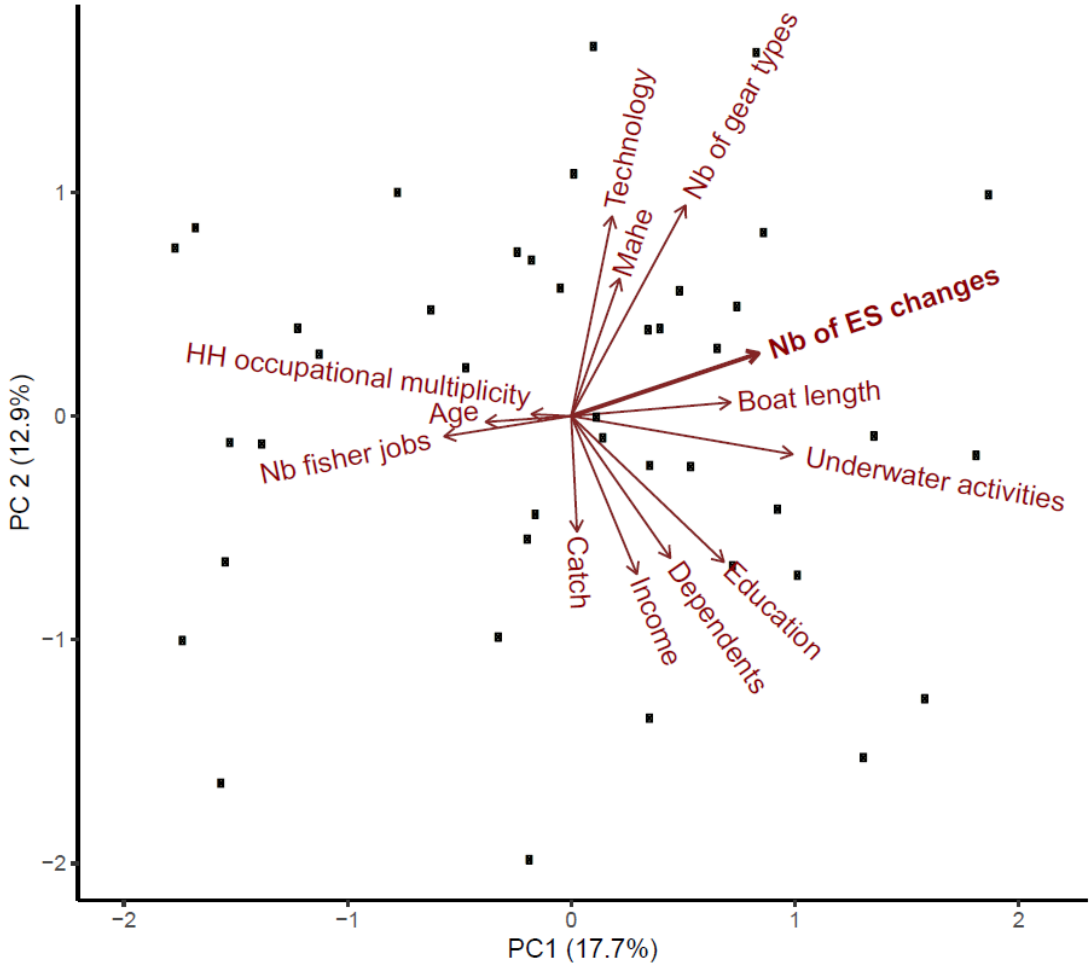

Figure 3. 3 Biplot showing Principle Component (PC) 1 and PC2 from a principle component analysis exploring the associations between coral reef fishers' characteristics and the total number of ecosystem services they perceived to have changed. PC1 and PC2 are shown because the variable "Nb of ES changes" is best represented by these two axes (Table S3) ('Nb of ES changes': Number of ecosystem services perceived to have changed; 'Nb of gear types': Number of gear types)

3.4.2.2. Differences in which perceived change is most important for fishers

Of the perceived changes, more than half of fishers (56%) identified perceived changes in habitat services as most important to them. Twenty-nine percent identified perceived changes in fishery services and 15% coastal protection services. A small number of fishers identified perceived changes in recreation services as most important (n = 1), could not distinguish between services (n = 3), or did not find consider perceived changes in services to be important (n = 1) (Fig 3.2). Fishers'

characteristics explain 44% of the variance in responses as to which changing ecosystem service was most important (R^2 = 0.44), although these characteristics were not statistically significant predictors ($F_{1, 12}$ = 1.49; p = 0.1 from 999 permutations) (Table A3.6; Appendices). Of the variation that is explained by fishers' characteristics, individuals with higher levels of education, who are younger and/or partook in underwater activities, tended to identify changing habitat services as the most important. Changing fishery services were most important for fishers with low household occupational multiplicity, and for those living and fishing in one area (Praslin/La Digue). Fishers who had few sources of income other than fishing tended to identify changing coastal protection services as important (Fig 3.4; Table A3.7; Appendices).

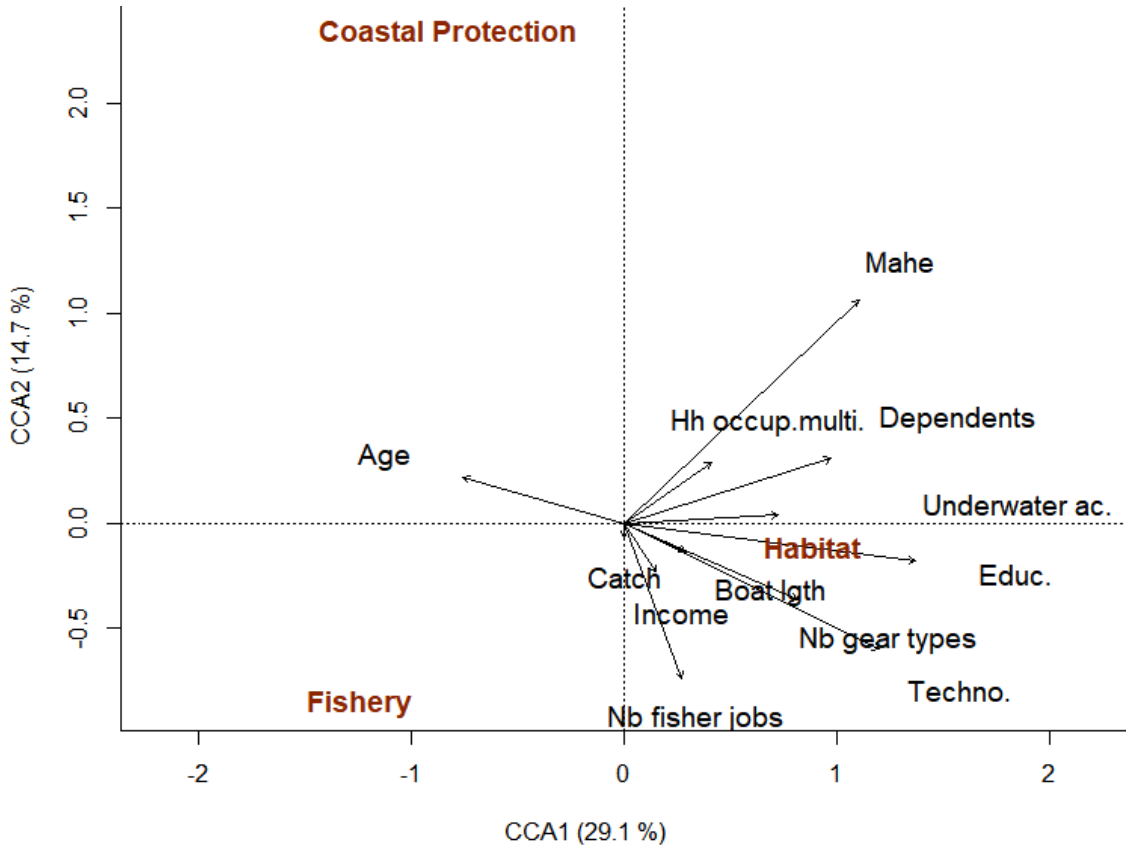

Figure 3. 4 Canonical Correspondence Analysis biplot. Of the variance that fishers' characteristics do explain (44%), this biplot shows the associations between characteristics and which perceived to have changed ecosystem service was identified as most important ('Hh occup. multi.': household occupational multiplicity; 'Underwater ac.': Underwater activities; 'Educ.': Education; 'Nb of gear types': Number of gear types; 'Boat lgth': Boat length; 'Nb fisher jobs': Number of fisher jobs)

3.4.2.3. Aspects of wellbeing that emerged in the importance of changing ecosystem services

Nineteen fishers brought up recognisable aspects of wellbeing in their reasons for identifying perceived changes as important. We grouped these aspects of wellbeing under the three dimensions of our approach, namely the subjective, relational and material dimensions of wellbeing (Table 3.3). Note that these dimensions are inter-related (White 2009; Coulthard 2012b) and many of the interview excerpts used illustratively in Table 3.3 could be placed in more than one dimension.

Some fishers expressed sadness (Table 3.3 – [1]) or concern for the perceived mismatch between reality and how they felt the reef ecosystem should be. Reflecting on his situation, one fisher saw changes in ecosystem services as important but felt unable to respond to these changes (Table 3.3 – [2]; Table A3.3: 32; Appendices).

Changes in recreational services were, for another fisher, connected to changes in personal relationships with other people (Table 3.3 – [3]). Change was also connected to how people interacted with non-human entities. For example, one fisher described that his previous interactions with rays, which he found relaxing, no longer happened (Table 3.3 – [4]). Another was concerned that future interactions with reefs would be unsustainable, connecting to stewardship values that underpin his relationship with the marine environment. Concern for the future also emerged in interviews, highlighting social relationships between current and future generations. For example, the loss of culturally important species (Table 3.3 – [5]) or the loss of knowledge between generations (Table A3.3: 33-34; Appendices).

Changes in the type and availability of ecological resources provided by the reef (Table 3.3 – [6]), potential impacts on the activity of fishing as a livelihood (Table 3.3 – [7]), and impacts on food security at a national level (Table 3.3 – [8]) also emerged as areas of concern for material wellbeing.

Table 3. 3 Aspects of wellbeing that emerge in fishers' reasoning for identifying perceived changes in ecosystem services as important. These are grouped under a three-dimensional approach to wellbeing (White 2009; Coulthard 2012b).

Dimensions of wellbeing	**Emergent aspects of wellbeing**	**Example statement and ecosystem service that it was connected to** (translated from Creole to English in the interview)
Subjective dimension	Personal perceptions of change including feelings about change (e.g. sadness and worry)	[1] 'Used to see beautiful reefs but so sad. Now they are destroyed.' [changes in habitat services; MAH-0606-3]
	Importance of change is connected to the perception that the fisher is unable to act	[2] '[It's his] living. Concerned but what can you do.' [changes in fishery services; PRA-0612-3]
Relational dimension	Importance of change connected to personal relationships between people	[3] 'Most worried because big change. Spend less time with family and friendships also. Used to be close to people but people separately going own way.' [changes in recreation services; DIG-0616-1]
	Importance of change connected to personal relationships with non-human entities like the reef	[4] 'Most worried about reef. There was something that helped [him] relax - the rays. Fish before but now there's only rocks.' [changes in habitat services; MAH-0620-2]
	Importance of change connected to social relationships, between current and future generations	[5] 'More smaller fish. Worried because then there won't be fish. Next generation won't see fish in water. Have to see it on a chart, for example red emperor snapper (bourzwa)*.' [PRA-0614-1]
Material dimension	Importance of change connected to the availability and/or type of ecological resources	[6] 'Because before there was a lot of fish on the reef and now there's not much. Used to get parrotfish and other fish. Now only get rabbitfish.' [changes in habitat services; MAH-0530-1]

	Importance of change connected to fishers' work and livelihood	[7] 'Because it [the changes] makes their work harder.' [changes in fishery and habitat services; PRA-0613-1]
	Importance of change connected to food provisioning	[8] 'Most concern: source of food. People fishing in Seychellois waters but in future may have to go to others […].' [changes in habitat services; PRA-0612-1]

* The emperor red snapper (*Lutjanus sebae*; bourzwa in Creole) is not specifically targeted by fish traps but is a reef-associated species in its juvenile stage (ReefBase 2020) and is of cultural and economic importance in Seychelles.

3.5. Discussion

Repeated ecological monitoring indicates that many reefs around Seychelles' inner islands have shifted into algal regimes following mass coral mortality (Graham *et al.* 2015). Associated with this, reef-associated fish communities have changed into novel persistent compositions (Robinson *et al.* 2019a) and wave energy hitting the coastline has increased (Sheppard *et al.* 2005). Tourism development has further modified coastal areas (Giampiccoli, Mtapuri & Nauright 2020) and a Blue Economy approach to marine management has become the dominant narrative (Schutter & Hicks 2019). In parallel with these social and ecological changes, we show that coral reef fishers have perceived a change in four major ecosystem services that are associated with reef ecosystems: habitat services, fishery services, coastal protection services and recreation services. To the best of our knowledge, this is one of few studies to explore how changes across multiple ecosystem services associated with coral reefs are perceived to have changed in a context of climatically disturbed reef environments. Every fisher reported some form of change, but interviewees' descriptions of change encompass a broad suite of topics. High levels of engagement with the marine environment through different activities such as snorkelling, freediving, or scuba diving, or through using larger boats was associated with some fishers perceiving a greater number of ecosystem services as having changed than others. Perceived changes in habitat services were of particular importance for trap fishers, though fishers from smaller, more isolated islands (Praslin/La Digue) or with fewer alternatives to

fishing available, tended to highlight perceived changes in fishery services as important. Nearly half of respondents bought up recognisable aspects of wellbeing in why changes in ecosystem services associated with reef ecosystems are important, which connected to subjective, relational and/or material dimensions of wellbeing.

3.5.1. Contextualising perceived changes in ecosystem services

Habitat services were most frequently perceived as having changed and were consistently ranked the most important service by fishers. This echoes findings that habitat services are valued by fishers in the western Indian Ocean (Lau *et al.* 2018), despite being underrepresented in regional ecosystem service assessments (Hicks 2011). The provisioning of suitable habitat, a key sub-group of supporting services, is closely linked to the structural complexity of reefs (Graham & Nash 2012), changes in which are highly observable to fishers working in shallow tropical environments. Coral bleaching is similarly visible and generally understood to be indicative of a change in coral reef conditions. These visible changes in reef condition connect to fishers' wider ecological knowledge of how reefs underpin services such as habitat provisioning. This is shown for instance in one fishers' statement: '*There used to be healthy reefs. Three-quarters of the reef is destroyed, so fish that come inside the reef as a nursery then will starve. Hard for fish to live.*' [MAH-0606-3]. However, as shown in other qualitative descriptions of change, the distinction between habitat services and other services is often fluid. For this reason, supporting services more generally are often excluded from social research because of the potential for double counting in ecosystem service assessments (Boyd & Banzhaf 2007). Understanding perceptions of change in supporting services can nonetheless provide a useful basis for management, as it confirms that fishers recognise the importance of coral reef ecosystems for other valued services, and may therefore be more likely to engage with management measures that support reef recovery (Bennett 2016; Forster *et al.* 2017).

Perceptions of change related to fishery services capture changes in target fish species (ecosystem service providers) and the practice of fishing itself (the process of deriving benefits from this service). As one fisher on Mahé commented, *'Changes in the quantity of fish. [We] have to go far to catch same fish. Three or four miles has changed to 15 miles.'* [MAH-0529-3]. Fishing further out or increasing the use of technology and bait (also shown to be occurring in this fishery by Daw, Robinson & Graham 2011), suggest fishers are responding to perceived changes in order to maintain fishery services for themselves and others through, for example, continuing to provide food. This is supported by fisheries catch data which show that total fish landings have increased due in part to the fact that fishers are fishing more (Robinson *et al.* 2019b). Fishers, and many natural resource users, play an active role in the emergence of ecosystem services (Fischer & Eastwood 2016). Whilst human behaviour has been considered in the context of ecosystem service management (Sereke *et al.* 2015), our results indicate that behavioural and other adaptive responses may also be occurring within the processes through which ecosystem services emerge. These responses can have a negative impact on the ecosystem (e.g. through the use of more intensive gear; Cinner *et al.* 2011), with implications for long-term sustainability.

The ability to adapt is, however, spread unequally within fisheries (e.g. Lau *et al.* 2020). As with much fisheries-based research, our work does not reflect the perceptions of those who have left the sector. This leads to an important consideration of agency around how fishers choose to, or are able to, respond to perceived changes in ecosystem services, and the implications of this. Wider discussions with fishers during the survey revealed that increases in the amount of time spent fishing, for example, detracts from time spent with their family. This would indicate a wellbeing trade-off for fishers who are prioritising aspects of wellbeing attached to fishery services (e.g. income, food, sense of self; Coulthard 2012b), over other aspects of wellbeing, which may be more or less directly connected to fishing (e.g. family relations). This should elicit a wider examination of

how changes in ecosystem services are defined. Changes in the density or biomass of fisheries target species on the reef are often used as proxies of ecosystem service availability, and consequently indicators of ecosystem service change (e.g. Sato *et al.* 2020). These proxies are useful for working with available ecological data (Yee, Dittmar & Oliver 2014) but should be conducted in conjunction with wider research that encompasses how people perceive and respond to ecosystem service change. If responses to change result in negative effects for overall wellbeing, then arguably this should be considered as part of ecosystem service change, even where wellbeing aspects unrelated to ecosystem services are implicated.

Coastal erosion and flooding have acute and visible effects on discrete geographic areas. This type of change is often highly memorable (Aswani *et al.* 2015) and is evident in fishers' descriptions of change, both in coastal protection services and in recreation services, where erosion has limited access to the beach environment. The connections present in perceptions-based data support the need to examine ecosystem services as inter-related, whereby perceived changes in coastal protection, which are congruent with predictions made by (Sheppard *et al.* 2005), are also perceived to affect recreational services (Bennett, Peterson & Gordon 2009).

Complex regulating services, such as coastal protection, are shaped by multiple inshore habitats (Guannel *et al.* 2016) and inhabited coastlines, such as those exemplified in Seychelles, are more likely to be shaped by human activities than by natural geomorphic processes (Hapke, Kratzmann & Himmelstoss 2013). Our findings indicate that fishers experience changes in coastal protection at a much broader scale than changes that could be incurred from reef degradation alone, but that they also report changes caused by very acute and visible human modifications of the coastline, for example the building of coastal defences. Similarly, perceived changes in recreation services tended to capture the social dimensions of coastal recreation. As one fisher explained: *'It's not the same as*

before. Life has evolved. Friendships have changed. People have moved abroad or to Mahé. Technology might also have an impact. People [are] being dispersed.' [DIG-0616-1]. This, and other descriptions of perceived ecosystem service change, indicate that changes in ecosystem services and how they relate to wellbeing can occur independently of environmental condition (Daw *et al.* 2016; Woodhead *et al.* 2019). The starting point for this work was the widespread ecological change of Seychelles' reefs (Graham *et al.* 2015; Wilson *et al.* 2019). Within the same time-frame, Seychelles has undergone substantial social, economic (Clifton *et al.* 2012; World Bank 2015) and political change (Ecott 2015) - changes that will undoubtably be compounded by the effects of Covid-19 - which may also have influenced fishers' experiences of recreation in the coastal environment. Engaging with perceptions of change, therefore underlines the diversity of approaches needed to fully understand how ecosystem services emerge, which drivers of change they may be most vulnerable to, and the multi-scalar nature of these drivers.

Limitations in capturing perceptions ecosystem service change

Many ecosystem service studies are limited in their ability to encompass the social and ecological dimensions of ecosystem services (Boerema *et al.* 2017), though many of the relevant frameworks highlight its importance (Reyers *et al.* 2013). To overcome this, we sought to use descriptions of coral reef associated ecosystem services that were relevant to Seychelles and which recognise coral reefs as social-ecological systems (Kittinger *et al.* 2012). The breadth of changes elicited is a useful indication of the complexity of coral reef ecosystem service-wellbeing relationships and is corroborated by research in terrestrial systems that show participants in ecosystem service exercises struggle to delineate between the social and ecological dimensions of services (Tusznio *et al.* 2020). Our approach however presents some challenges in connecting perceptions of change to recorded changes in reef degradation. For example, sediment production by coral reefs is largely responsible for beach formation in Seychelles (Sheppard *et al.* 2005). This occurs over long time periods unlikely

to be perceived by fishers over the timespan investigated. However, the erosion of beaches, and the recreational space that they provide, can occur over much shorter time frames and indeed, erosion of beaches in Seychelles has been linked to reef degradation allowing wave energy to pass over reef flats (Sheppard *et al.* 2005). Moving forward, a shift away from an ecosystem specific understanding of services, described as overly reductionist by (Dawson & Martin 2015), could provide a more comprehensive understanding of a) the drivers and types of change that are perceived by fishers and b) the changes that are meaningful to them. Consensus around ecological and ecosystem service change can provide a useful basis for management (Forster *et al.* 2017). However, our results also show where natural resource management may be limited in maintaining ecosystem services where drivers of change are not environmental and should therefore seek to engage in much broader multi-disciplinary approaches when managing for future ecosystem service provision.

Responses to when changes were perceived to have started were highly varied and should therefore be interpreted with caution. At a broad level, changes in supporting services were perceived to have started more than a decade prior to the interviews (10-14 years prior to 2018), changes in recreation services were perceived to be more recent (four years prior to 2018), changes in coastal protection services were perceived to be either very recent (four years prior to 2018) or more medium-term (10-14 years prior to 2018), and changes in fishery services were too variable to be conclusive. These responses are consistent with the wider context wherein recorded changes in coral reef ecology have been occurring since at least 1994 (Graham *et al.* 2015) and wider social changes that could impact on recreation services are relatively recent (Clifton *et al.* 2012; Ecott 2015; Schutter & Hicks 2019). Changes in coastal protection often result in highly localised, acute events (e.g. coastal flooding) that may indicate fine scale geographic variation in how changes are experienced. However, the variability in responses given around the timing of perceived changes also highlight some of the challenges of capturing perceptions of change through time. Perceptions of past change

are highly subjective and risk becoming less precise the further they occur from the present (Daw, Robinson & Graham 2011). Our approach may therefore be enough to establish general trends in ecosystem service change, but a more specific timeline could be captured through, for example, methods that seek to anchor perceptions to a more objectively acceptable chronology (e.g. Selgrath, Gergel & Vincent 2018).

3.5.2. Differences between fishers

Fishing from a larger boat was one of the characteristics associated with perceiving a greater number of changes in coral reef ecosystem services. Boat size can determine how far and in what weather conditions trap fishers can continue to fish, as well as the amount of ice they can carry. Boat length may be indicative of fishers spending more time at sea and a higher dependency on coral reefs, meaning fishers are more exposed to and aware of change. In the Solomon Islands, on-going, active engagement in marine activities was also a characteristic associated with observations of coastal and maritime change (Aswani *et al.* 2015).

Participating in underwater activities was an important characteristic associated with fishers who perceived a greater number of changes in ecosystem services, and in identifying changes in habitat services as the most important. Activities like snorkelling, freediving or diving may be exposing fishers to more acutely visible changes in reefs like bleaching. One fisher, in explaining why changes in habitat services were important for him, stated: *'Lot of dead coral. Coral going white. Bit alarming when [he] goes snorkelling or diving. Seeing more dead corals than before and see a sort of muddy algae growing on it.' [PRA-0614-2].* These activities were often connected to fishing (e.g. disentangling traps, cleaning or repairing boats, octopus and/or sea cucumber fishing) as well as recreation. Experiential knowledge of ecosystem services is key for understanding services and how they are valued (Klain, Satterfield & Chan 2014). Research from terrestrial and coastal systems

shows that the activities people do to interact with the environment are part of the process through which ecosystem services emerge (Fischer & Eastwood 2016), and reflecting on the importance of these activities can help sustain these services, and their connections to wellbeing, into the future (Poe, Norman & Levin 2014).

Fishers who identified perceived changes in fishery services as most important tended to be from Praslin/La Digue and/or have low household occupational multiplicity. Praslin/La Digue are smaller and more isolated than Mahé, and low household occupational multiplicity could indicate fewer alternatives to fishing, leaving fishing families more vulnerable to changes in fishery services (Cinner, McClanahan & Wamukota 2010). Fishers from these islands were also more likely to rank fishery services as the second most important, as opposed to Mahé fishers who were equally likely to rank fishery services as second or third. This is consistent with research from across the western Indian Ocean showing that poorer fishers tend to prioritise fishery services over other reef services (Lau *et al.* 2018). The trap fishery is also of greater cultural importance on Praslin/La Digue due to the presence of fish spawning aggregations (Robinson, Cinner & Graham 2014) and the practice of salting surplus fish as additional income (Chapter 2). Understanding how services are socially differentiated will be needed to ensure ecosystem service management is equitable (Daw *et al.* 2015) but inter-island variation may also be important to consider when managing for ecosystem services at a national level.

3.5.3. Wellbeing as it emerges in perceptions of change

Different aspects of wellbeing emerged in fishers' justifications for which changing services are most important to them. Some fishers expressed sadness or concern for the changes they are observing, as well as in one case feelings of powerlessness. These feelings show how the ecological context can

affect fishers' subjective wellbeing, which may not be apparent in objective measures of ecosystem service change. This echoes an example from French Polynesia that demonstrated the value of perceptions based data for contextualising experiences of change in a person's life (Rassweiler *et al.* 2020). Previous work in Seychelles had established the cultural importance of reefs for future generations and acquiring and transferring knowledge (Hicks *et al.* 2014), both of which are implicated in connection to subjective and relational dimensions of wellbeing. For example, when explaining why he was concerned about perceived changes in fishery services, one fisher stated: *'[He is] more concerned with it [fishery service changes]. Concerned if we run out of fish stock. Concerned [his] grandchildren won't be able to see the sea or learn what [he] does, for example making fish traps'* [DIG-0616-4]. Though the data was too limited to further explore relational aspects of wellbeing, it corroborates wider research that recognises connections between services, in this case the framing provided by cultural services such as knowledge generation and bequest, that shapes the importance given to perceived changes in fishery services (Fish, Church & Winter 2016).

Fishers were not asked to comment on whether change was positive or negative and many of these connections were presented as hypothetical. Concern for the material effects of changing reefs was identified by fishers but descriptions of change suggest that this is already a reality for some individuals, for example, the perceived need to fish further than before (also evidenced in Daw, Robinson & Graham 2011). Human wellbeing is connected to ecological condition but not solely, and in the short term may in fact increase despite environmental change (Raudsepp-Hearne *et al.* 2010). Multi-dimensional conceptualisations of wellbeing are not novel but can be used to re-dress the overly reductionist approaches often used in ecosystem services research (Dawson & Martin 2015). As our results show, ecosystem services are noticeably changing in ways that objective approaches to change would be unable to capture. Moreover, many of these changes originate outside the boundaries of the focal ecosystem. The changing condition of coral reef ecosystems was the starting

point of this research, but an alternative could be fishers' own conceptualisation of wellbeing, and therein, the role of coral reef associated ecosystem services (e.g. Abunge, Coulthard & Daw 2013). This approach can help unpack differences between people's ecosystem service-wellbeing relationships (Coulthard, McGregor & White 2018). The implications of ecosystem service change for different groups, particularly those that are more marginalised (Daw *et al.* 2015), remains understudied in coastal ecosystems, particularly outside of Europe (Blythe *et al.* 2020). A wellbeing focus could also provide a more nuanced understanding of how people engage with their environment, not limited to ecosystem boundaries (Dawson & Martin 2015).

3.6. Conclusions

Whilst recognising the importance of social differentiation in environment-wellbeing relationships (Daw *et al.* 2015), a key finding from this research is that all fishers interviewed had perceived a change in ecosystem services associated with coral reefs. To our knowledge, this is one of few studies to have explicitly engaged with perceptions of change across multiple ecosystem services following climate-driven reef degradation, despite the fact that several pan-tropical mass coral mortality events have been documented over the last four decades (Hughes *et al.* 2018a). Multiple aspects of wellbeing were implicated in these perceived changes, including subjective wellbeing which is shaped by fishers' perceptions of their surroundings (White 2009). Subjective wellbeing can therefore be implicated prior to or without changes in ecosystem service-material wellbeing relationships. Any assessment of changing ecosystem services should therefore include approaches through which changes in subjective wellbeing are captured. Our results also provide examples of where perceived changes were associated with adaptive responses that may lead to secondary effects for ecosystems and fishers' wellbeing. Perception-based data allows for better integration of the social and ecological aspects of ecosystem service change, confirming that ecosystem services

are highly connected to processes outside of the focal ecosystem, but also highlighting the limitations of focussing on single ecosystems (Dawson & Martin 2015). An alternative approach may be to centre future research on locally relevant understandings of wellbeing and from there investigate the implications of environmental change on ecosystem service-wellbeing relationships, an area which remains under-researched (Cruz-Garcia *et al.* 2017; Blythe *et al.* 2020). The prioritisation of supporting services and the understanding that fishers have of how ecosystem services relate to one another provides a basis for management, if interventions are framed in a language that resonates with fishers' understanding. The provision of ecosystem services is shaped by many different processes, presenting challenges for natural resource managers who may need to respond to rapid ecological and social changes. Embracing multiple data types (but see Pendleton & Edwards 2017) and multi-, inter- and/or trans-disciplinary approaches will be key to develop a comprehensive understanding of changing ecosystem services into the future.

Chapter 4 - Wellbeing insights from coral reef fishers and the implications of changing nearshore tropical environments

4.1. Abstract

Millions of people around the world are dependent on ecosystem services provided by marine and coastal environments. Yet, these environments are highly vulnerable to future environmental change. Relationships between people and their environments are multi-dimensional - one ecosystem service can contribute to multiple dimensions of human wellbeing; one dimension of human wellbeing may draw on multiple ecosystem services. Ecosystem services thus provides a framing for engaging with both the social and ecological complexity of these relationships, but a better integration of these processes is still lacking. The environment can also shape what it means to live well (be an internal constituent of wellbeing) and whether people are able to achieve desired wellbeing outcomes (be an external driver of wellbeing). Yet, many wellbeing approaches have a limited approach toward engaging with these different relationships, or towards integrating ecological dynamics within understandings of wellbeing. In this chapter I seek to address both of these gaps by drawing on a social wellbeing approach to examine how the marine environment is situated within coral reef fishers' understanding of wellbeing in Seychelles, and how changes therein affect fishers' ability to live well. My findings show that the marine environment, and its inherent variability, is integral to both how fishers define and pursue wellbeing. As such, being able to adapt to change is part of fishers' personal beliefs on what it means to live well. The increasing magnitude of environmental change means that within the limits of Seychelles' social-ecological system, fishers' current adaptive responses are resulting in wellbeing trade-offs between and within the material, relational and subjective dimensions of wellbeing. This could affect fishers' future ability to respond to change. The embeddedness of the sea within fishers' conceptualisations of wellbeing, may also limit fishers in how they choose to respond. These findings have implications for understanding

fishers' ability to respond to future changes in ecosystem services, both in highlighting limits in fishers ability to adapt but also the iterative nature through which fishers navigate multiple wellbeing outcomes in the context of changing social-ecological systems.

In prep - Woodhead AJ & Hicks CC. Wellbeing insights from coral reef fishers and the implications of changing nearshore tropical environments

4.2. Introduction

Many communities across the world are highly dependent on marine ecosystems, with some of the highest levels of dependency to be found across the Pacific, Indian Ocean, and West Africa (Selig *et al.* 2018). High dependency in these areas often coincides with the presence of hyperdiverse ecosystems that span across tropical regions (Barlow *et al.* 2018). Ecological communities in these areas - such as those found on tropical coral reefs - are changing in response to multiple different local and global drivers and it is highly unlikely that reefs will return to pre-existing conditions (Hughes *et al.* 2017; Hughes *et al.* 2018a). Changes to reefs and other ecosystems have potentially important outcomes for human wellbeing as conceptualised through the ecosystem services framework. Both ecosystems services and human wellbeing are multi-dimensional such that multiple ecosystem services can contribute to the same wellbeing dimension, or a single ecosystem service can contribute to multiple dimensions of wellbeing (Pelenc & Ballet 2015). The ecosystem services framework therefore provides a basis through which to engage with the ecological and social complexities of human dependency on the environment (e.g. Luck *et al.* 2009; Daw *et al.* 2016).

Despite the promise of integration however, ecosystem services research remains dominated by the ecological sciences (Schutter & Hicks 2020) and has been critiqued for not engaging with the social complexity of social-ecological systems (Dawson & Martin 2015). These complexities include, for example, the need to recognise ecosystem services as co-produced and co-constructed from relationships between people, between people and place and through the activities that people engage in in a specific environment (Fischer & Eastwood 2016; Chapter 3). As such, ecosystem services and their connections to wellbeing should be viewed as anchored to the social, cultural, and political contexts in which they are used and valued (Klain, Satterfield & Chan 2014; Dawson & Martin 2015). Furthermore, the wellbeing contributions of ecosystems differ between people (Daw

et al. 2011) but studies on marine and coastal ecosystem services continue to aggregate wellbeing across scales (Blythe *et al.* 2020). Further clarity on the processes through which ecosystems, via ecosystem services, connect to human wellbeing must be sought to understand the implications of future and on-going environmental change (Bennett *et al.* 2015).

Similarly, however, there is limited integration of ecological complexity within wellbeing research. In a review of philosophical accounts and frameworks underpinning wellbeing research, (Schleicher *et al.* 2018) demonstrate that failing to recognise the environment as a constituent, or internal part of wellbeing, in addition to being a determinant, or an external driver of, wellbeing provides an incomplete picture of what is needed to live well. This duality of environment as both integral to, and a determinant of, wellbeing has been noted in ecosystem services research where some ecosystem services connect to wellbeing, only through the presence of other services (Polishchuk & Rauschmayer 2012). The lack of understanding of the multiple types of relationships in which the environment both shapes what it means to live well and determines people's ability to live well can lead to weak sustainability approaches that prioritise human wellbeing, without sufficient regard for the natural environment that underpins it (Helne & Hirvilammi 2015).

In the following chapter, I seek to address the dual challenge of recognising complexities in environment and wellbeing by examining how the marine and coastal environment, and changes therein, connect to the wellbeing of small-scale fishers. Although many different conceptualisations of wellbeing exist, particularly in the context of fisheries (Weeratunge *et al.* 2014), I adopt the following definition presented by (Breslow *et al.* 2016), which situates the role of the environment clearly within a multi-dimensional conceptualisation of wellbeing. They define wellbeing as: "a state of being with others and the environment, which arises when human needs are met, when individuals and communities can act meaningfully to pursue their goals, and when individuals and

communities enjoy a satisfactory quality of life." (Breslow *et al.* 2016; p.251). To examine wellbeing, I draw on a social wellbeing approach (White 2010; Coulthard 2012b), which identifies wellbeing as *a state of being* that emerges from three inter-connected dimensions of wellbeing: the material, relational and subjective. The identification of different dimensions is a useful conceptualisation as it ensures that wellbeing remains grounded in the material circumstances of individuals and communities (White 2010), embedded within existing social structures and inequalities (White 2010; White 2017), and cognisant of the role of individual's own feelings, personal history and actions in living well (e.g. Coulthard 2012b). At its core however, the social wellbeing approach seeks to emphasise the relationships that are generative of wellbeing, situated within a specific time and place (White, 2010), the latter of which includes the natural environment (White 2017).

The social wellbeing approach also complements our growing understanding of ecosystem services as co-produced in the relationships between people and their environment within a given social-ecological context (Fischer & Eastwood 2016; Palomo *et al.* 2016). For example, the Millennium Ecosystem Assessment – which is still one of the most widely used frameworks for understanding ecosystem service-wellbeing linkages (Cruz-Garcia *et al.* 2017) – asserted that "changes in cultural services have relatively weak linkages to material elements of wellbeing" (Millennium Ecosystem Assessment 2005; 51). Advances in cultural ecosystem services research has since demonstrated that cultural ecosystem services provide the framing through which changes in other ecosystem services connect to human wellbeing (Fish, Church & Winter 2016). The social wellbeing approach recognises these relationships between different parts of people's lives in asserting that the contribution of material assets to wellbeing cannot be understood as separate from the cultural context in which they occur (White 2010). This emphasis on the relationships is therefore much more open towards recognising the inter-dependencies between ecosystem services (Polishchuk & Rauschmayer 2012) as well as between different wellbeing dimensions.

In this research I draw on a social wellbeing approach to consider how wellbeing is conceptualised within the fishing community of fisher/skippers or fisher/boat owners in the Seychelles. These are the fishers who rely most heavily on coral reef environments, and who are already perceiving changes in valued ecosystem services (Chapter 3). I therefore seek to develop an understanding of how coral reef fishers perceive wellbeing (or living well, 'viv byen'), and to capture how the marine environment, and changes therein, interact with how living well is defined and pursued.

4.3. Methods

4.3.1. Study site description

Seychelles compromises 115 islands that span a vast Exclusive Economic Zone (EEZ) of nearly 1.4 million km^2 in the west Indian Ocean. Most of the population reside on the inner islands of Mahé, Praslin and La Digue, with over 87% of the population on Mahé, the biggest island (National Bureau of Statistics 2020a). Like many large ocean states, Seychelles is highly dependent on the marine environment (Fig. 4.1), but also extremely vulnerable to changes to it (Jumeau 2013). Fish is an important and preferred source of food (Chapter 2), and the beach is an important area for socialising with family and friends (Chapter 3). The right for all to access the marine environment is highly valued by coral reef fishers (Hicks *et al.* 2014) with some expressing concerns over the effects of land reclamation around Mahé and Praslin on access to the sea (World Bank and Ministry of Environment Energy and Climate Change of Seychelles 2019). Land is a limited and valuable resource which, combined with increasing costs of living, is making it difficult for young Seychellois to establish themselves independently, or to live where they would want to live.

Figure 4. 1 Seychelles' dependency on the marine environment. This mural on the wall of a guest house on La Digue summarises many of the key relationships between Seychelles and the marine environment. In the centre is a 'bourzwa' (Emperor red snapper), which is highly prized in Seychelles both culturally and because of the high quality of its meat (Chapter 2). It's supporting two cooks, highlighting the importance of fish in Creole cooking. The bottom left shows one of the large offshore tuna vessels, of economic importance to Seychelles and the bottom right shows a diver, linked to the importance of the sea for international tourism. Other species represented include the endemic Coco de Mer, a turtle, and a bat, which are all perceived to be charismatic of Seychelles. This mural is geared towards tourists and many other relationships could be represented such as the importance of coastal spaces for picnics and socialising, and the 'average' fish species in Seychellois diet such as rabbitfish (Chapter 2) (Photo by AJ Woodhead)

The nearshore environment around Seychelles is changing in response to climatic disturbances. Coral reefs around Seychelles have been affected by two large scale bleaching events (1998, 2016) with implications for benthic and fish community composition (Graham *et al.* 2015; Robinson *et al.* 2019a; Wilson *et al.* 2019). Long term catch data indicates that the composition of coral reef fishers' catch is also changing. Mean landed catch has not decreased, likely due to increases in effort, but catches are becoming more variable - bigger catches are bigger and smaller catches are smaller – which may be affecting fishers' ability to earn a stable living (Robinson *et al.* 2019b). Reef

degradation is also linked to coastal flooding and erosion (Sheppard *et al.* 2005; World Bank and Ministry of Environment Energy and Climate Change of Seychelles 2019).

Fishing is considered a fundamental right in Seychelles (Seychelles Fishing Authority 2019) and as such is relatively unregulated (Bijoux 2015). In these interviews, I chose to work with coral reef fishers working on small, open topped fibre glass boats, known as 'mini-mahés'. These range from 4-7m in length, have an outboard engine and are often crewed by two or three people (Bijoux 2015; MRAG 2017). Fishers will often go out fishing multiple times during the day but not on multi-day trips. Using traps to catch reef-associated fish often entails snorkelling and free-diving on reefs, and this type of engagement with the marine environment has been shown to correlate with perceptions of change in reef-associated ecosystem services (Chapter 3). A fisher/boat owner or fisher/skipper usually takes responsibility for a boat and it was this group of fishers who I, and my colleague from the Seychelles Fishing Authority (Rosabella Mangroo) approached to interview[5].

4.3.2. Interview participants

Rosabella and I conducted in-depth interviews with 15 coral reef fishers from across Mahé (lasting between 35 minutes to an hour) to understand what wellbeing meant in Seychelles and how the marine environment fits within fishers' understanding of living well. Fishers were either known to me, or to colleagues in the Seychelles Fishing Authority research team and therefore contacted directly or approached at the landing sites and invited to interview. A few fishers were not previously known to us but were willing to be interviewed when approached on site. We interviewed

[5] One interview was conducted with an ex-Seychelles Fishing Authority employee who was well connected with fishers at one of the landing sites and had assisted with previous qualitative interviews undertaken by researchers from the UK

fishers who use at least one fish trap, and therefore rely to some extent on reef-associated fish species.

To capture a diversity of views, interviewees were sought from across different areas of Mahé, from a range of different age groups and incomes. This was building off previous knowledge that changes to reefs around Mahé have been heterogenous (Graham *et al.* 2015) and that landing sites are often quite different depending on the number of fishers who use them and proximity to urban centres. Eight of the fishers that we interviewed fished on the east coast of Mahé and 7 from the west coast. Though artisanal fishers are not considered the most vulnerable group in Seychelles (Bijoux 2015), incomes are quite varied (Chapter 3), which could influence fishers' perspectives on living well (White 2010). The median income of interviewees was 10,000 – 15, 000 SRC per month (range: less than 3,000 to more than 30, 000 SCR per month; excluding one fisher who did not give his income). The average age of artisanal fishers in Seychelles is increasing (Bijoux 2015) and from my previous work in Seychelles (Chapter 2, Chapter 3), I was aware of concerns held by older Seychellois over the loss of experiential knowledge in younger generations. Within the fishery, this expressed itself as concerns over younger fishers reliance on technology to fish (and therefore being unable to fish if anything broke) and a perceived lack of stewardship from young fishers who were thought to be more concerned about profit than sustainability. More generally, concerns were expressed over dietary shifts away from fish towards imported meats[6], and young people being less knowledgeable of how to act safely around the sea. The median age of fishers that we interviewed was 44.7 years old (range: 29-63 years; excluding one fisher who did not give his age), which is slightly younger than the average age of artisanal fishers across Seychelles (48 years old; Bijoux 2015).

[6] This shift was encapsulated in lyrics of one Seychellois song on the radio during data collection for Chapter 3, which loosely translated as *"I'm a chicken and chips kind of girl, not a fish soup kind of girl".* Concerns were also raised over the move towards social housing (often apartment blocks), which offer a solution to some of the housing problems but provide less space for the preparation of traditional fish dishes.

4.3.3. Interviews and analysis

Interview questions were developed around five key themes designed to develop an understanding of three dimensions of wellbeing (material, relational, subjective); how wellbeing connects to the marine environment; and what the implications of environmental change may be (Appendix A4.1). The interview began with a few descriptive questions asking fishers to describe life in general in Seychelles, designed to open up the conversation. This was followed by questions and prompts aimed at understanding how wellbeing is defined by fishers in the Seychelles. The focal point of these questions was '*Ki viv byen I vedir pou ou?'*, which translates to 'What does living well mean for you?'. 'Viv byen' ('living well') was agreed upon as the closest Seychellois Creole equivalent to wellbeing defined as "*a state of being with others and the environment, which arises when human needs are met, when individuals and communities can act meaningfully to pursue their goals, and when individuals and communities enjoy a satisfactory quality of life*." (Breslow *et al.* 2016; p.251). I therefore use 'wellbeing' and 'living well' interchangeably. Fishers were first asked to discuss wellbeing in a general sense before being provided with a set of visual prompts around each of the three dimensions of the social wellbeing approach. The decision to use visual prompts was based on previous research in the region highlighting some challenges of eliciting information on multiple dimensions of wellbeing in coastal communities (Abunge, Coulthard & Daw 2013). Prompts related to material, relational and subjective dimensions of wellbeing (White 2010; Coulthard 2012b) and were developed between me, Rosabella and other colleagues at the Seychelles Fishing Authority, to capture examples that resonate in a Seychelles context. It was made explicit in the interview that these were just examples of things that could be considered important for living well and fishers were encouraged to provide others, before describing in detail how these contributed to living well (Table 4.1; Appendix A4.2).

The links between wellbeing and the sea were explicitly explored in the third theme of the interview, where fishers were asked to describe the importance and roles of the sea - and the marine plants and animals that live there - in their lives. This was followed by questions on the types of change that they had perceived as significant to them, with specific prompts on whether these changes had impacted on how they live and their feeling towards these changes. The final question on this topic was whether fishers thought that the changes in the marine environment had affected their ability to live well, as defined at the start of the interview.

At the end of the interview, fishers were asked what hopes they had for the future and to provide a Likert scale response as to how satisfied they were: with their life in general; with their ability to meet their basic needs; with the relationships they have in their life; with their ability to attain their goals in life; with the state of the marine environment. This was to complement the qualitative analysis - which focuses on how wellbeing is understood within the community of fisher/skippers and fisher/boat owners - with a subjective measure of wellbeing at the individual level. Socio-economic characteristics, including age and income, were also collected to ensure that we captured the views of fishers of different ages and incomes. Fishers were also asked to assess the extent of change that they had observed in the marine environment over the last 10 years (from “no change” to “completely changed”), to complement qualitative descriptions of change with an indication of how extensive changes are perceived to be. Following each interview, Rosabella and I discussed how the interview had gone. This discussion was structured around eight questions aiming to get at the context of the interview, tone of the interview, key findings, our thoughts, and feelings on what had emerged and, on our positionality (Appendix A4.3).

Table 4. 1 Three dimensions of the social wellbeing approach and the prompts used during interviews with coral reef fishers in the Seychelles (see Appendix A4.2 for accompanying visual prompts and descriptions)

Dimensions of social wellbeing	**Description of dimension (White, 2010; Coulthard, 2012)**	**Prompts used in interview context***
Material	Defined as what a person has (the objective material resources that a person can draw upon to meet their needs, such as food, assets, employment, services and the natural environment).	"Living well can include having enough to meet your needs. These pictures show for example: • Having enough food • Having a job like this person pulling in a fish trap • It can include having a decent house like in this picture • This last picture shows a hospital. Having enough to meet your needs can also include being taken care of when you are ill."
Relational	Defined as what a person does through social relationships that enables/or disables the pursuit of wellbeing (including relationships of care and love, relations with the state, social institutions, kinship, cultural rules and norms, forms of collective action, among others). Analytically, this can be divided into two areas of interest: the social, which captures social relations and access to public goods; and the human, which captures someone's capabilities, attitudes to life, and personal relationships.	"Living well can include having meaningful relationships with other people and with the places you are in. These pictures show for example: • Relationships with our family and friends. This is a group of family and friends who care for each other and who are relaxing together on a beach. • Relationships with people we work with. This picture shows people working together to sort a net. • Living well can also include relationships with our community. We've represented this with this picture of people attending the Independence Day parade. • It's also about relationships with the people who represent us. This picture shows the logo of a fisherman's association that works to represent the views of fishermen in that area.**"

Subjective	Defined as how a person thinks and feels about their life. Analytically, this can also be divided into two areas of interest: a person's own subjective reflection on what they have and do***, and their cultural values, ideologies, and beliefs.	"Living well can include the feelings that someone has about their life. • Our way of perceiving life can affect our ability to live well. For example, this picture shows a fisherman who is proud of the fish that he has caught. • It can also be about what a person believes and the way that beliefs help shape what we think. This is represented by a church. • Feeling that you are able to follow your goals or have opportunities in life can be part of living well"

*Delivered in Seychellois Creole; ** An association from another island (Praslin) was chosen for this visual prompt to try and ensure that the focus remained on relationships with groups who represent fishers, with the association as an example; *** Fishers' perceptions on their lives and their ability to live well were captured through questions at the end of the interview on how satisfied they were (from very dissatisfied to very satisfied): in life; in their ability to meet their basic needs; in their relationships; and in their ability to meet their goals in life

Interviews were conducted and recorded by Rosabella in Seychellois Creole, whilst I took notes. Although I understand some Creole, she would relay key aspects back to me. As fishers often speak some or fluent English, certain interviews became more conversational between the three of us. Following data collection, interviews were translated and transcribed into English for further analysis. Notes on the discussion between Rosabella and myself were also used to inform the analysis, as well as independent notes and observations taken during data collection. After an initial read through of all the interview transcripts, fishers' responses were broadly coded according to the three dimensions of the wellbeing approach. This provided a context specific understanding of wellbeing as it is manifest in fishers' descriptions of 'viv byen'. I used this as the basis to investigate the relationships between the marine environment and fishers' wellbeing. Key findings emerged according to how the marine environment, and changes therein, connect to fishers' wellbeing, which I use to structure the following results and analysis (all qualitative data analysis was conducted in NVivo; version 12).

Positionality and research ethics

As researchers, Rosabella and I were to different degrees outsiders to the fishing community. Both women in our 20s, I as a foreigner from Europe, and Rosabella had at the time, only recently joined the fishing authority. Both of us have a background in ecology and conservation. Having conducted research in the area before, some fishers were more comfortable with being interviewed by someone they know, and indeed referred to some of our previous discussions (data collected for Chapter 3). Working with and for the management authority legitimised our presence at the landing sites and in most cases, did not seem to affect fishers' responses. Where they did, Rosabella was keen to emphasise her

position within the research team at SFA (not involved in management activities) and that she, as someone new to SFA, was also learning about the everyday life of fishers.

As someone living in Seychelles, Rosabella could also empathise with many of the challenges that fishers face in their pursuit of wellbeing, which doubtless facilitated some of the conversations. Indeed, fishers were quite happy to discuss wellbeing and the environment, as it is a topic that very much emphasises their own thoughts and feelings without a 'wrong' answer, and from my previous research, I knew that there was concern within the fishing community over the state of the sea. Some fishers expressed difficulties in communicating everything they might feel about wellbeing in a relatively short space of time but were generally satisfied in the picture of wellbeing that was built up through the interview with the use of prompts. Though during previous research fishers had expressed research fatigue, the emphasis on getting a range of perspectives, rather than a representative sample, made relations more cordial at landing sites and there was always a fisher willing to be interviewed.

Research in Seychelles is often, though with notable exceptions, conducted by non-Seychellois. As I was known at the landing sites, my position as an outsider was recognised in the interview but not remarked upon. My previous research in Seychelles also informed my analysis of the data. Having established how the marine environment underpins different types of benefits (Chapter 2), and the wellbeing implications of perceived changes in specific ecosystem services (Chapter 3), I sought in this chapter to develop a more holistic understanding of marine environmental change, as situated within fishers' lives and their overall ability to live well.

Prior to any interview starting, all fishers gave verbal consent to participate and could withdraw at any time. This research was undertaken with ethical approval from the Faculty of Science and Technology research ethics committee (Lancaster University, FST17114) and with a research permit from the Seychelles Bureau of Standards (A0157).

4.4. Results and Discussion

4.4.1. Fishers' understanding of living well ('*viv byen'*) in Seychelles

Fishers' understanding of wellbeing in Seychelles was highly consistent with other indicators of multi-dimensional wellbeing in coastal communities (Breslow *et al.* 2016), but shaped by fishers strong feelings of attachment to fishing as more than an occupation but a way of life (Pollnac & Poggie 2006). Fishers valued their independence but were also cognisant of the role of other people in enabling them to make a living from fishing and emphasised the importance of unity within the community, which is consistent with how wellbeing is defined in other island contexts (Coulthard *et al.* 2017). Reflecting on these dimensions[7], that are inter-related and co-constitutive of wellbeing, showed that living well was also about what the different wellbeing components enable fishers to do. In the following, I briefly outline some of the key components of living well as manifest in fishers' descriptions of wellbeing in Seychelles, drawing specific attention to the role of the marine environment therein.

The material dimension of wellbeing manifests itself in '*viv byen*' as owning material assets (house, boat or transport), being in good health (framed as having good physical health and not suffering from poor mental health), being financially secure (having an income, being able to earn a living and being eligible for a loan) and having access to certain types of

[7] "You are able to live well when you can go to work and earn a living. When you can afford basic needs. When you have a family and don't have to steal from anyone. Living simply." (CA-1411-2)

infrastructure (information, education, healthcare) (Breslow *et al.* 2016). Being able to work was an important feature in nearly all fishers' descriptions of what it means to live well and thus explicitly tied the marine environment to everything that work enables them to do (e.g. to provide for their families)[8]. The sea's relation to income and livelihoods was qualified by two seemingly contradictory characteristics however: its inherent variability, tied to seasonal change and wider changes in the marine environment[9]; and its reliability connected to the idea that regardless of change, fishers would still be able to catch enough[10]. Fishers' also recognised the importance of the ecological integrity of the sea as a material asset for all.

Being united and having peaceful relations with others emerged as key components in the relational aspects of 'viv byen'. Island identities, and wellbeing, have previously been associated with close-knit social relationships (Schilling-Estes 2002; Coulthard *et al.* 2017). In Seychelles, fishers similarly reflected on the importance of good relationships with others, including between fishers and their community[11], which enable them to sell their fish, and within families who can support each other. Relationships with place connected to the importance of the sea in Seychelles. As an island nation, the sea is not only important but underpins the survival of everybody. Many fishers were also spiritual, identifying that it was through God's support that they were able to live well, and that the sea was valued as something created by God. However, the relational dimension of wellbeing was often

[8] "They [ocean, marine plants and animals] are good. You can get your livelihood from the ocean. You go fishing and get fish that you are able to sell and earn a living. You can help your family out. I have three children with my wife. I'm married. If we don't have the ocean then we don't have anything. If there's no fish then we can't earn a living." (AAP-1611-2)

[9] "There are times when you go out fishing and can't catch anything. The seasons changing plays a role in this. The ocean is still the same but the monsoons affect the catch. Sometimes there's less fish. Around this time in November and December, there's a lot of fish." (BV-1411-3)

[10] "As long as I'm working I can find something. If I go out today and get nothing, I will find some fish tomorrow then. As long as the sun rises tomorrow I can go out again. I don't get the same catch everyday. Some days I will catch enough to make up for the days that I didn't." (MA-1911-2)

[11] "You have to live well with others in your community in order to live well. In peace and showing respect for each other. And like I said, Seychellois people eat a lot of fish so that's also important." (AAP-1611-1)

expressed through concern over a lack of unity within Seychelles and the fishing community (e.g. a lack of trust in community members, thefts)[12]. Tensions also emerged in relation to the wider social structures that fishers engage with (e.g. a lack of government support).

The subjective components of living well were manifest in fishers' beliefs around living simply, the importance of over-coming obstacles and progressing in life[13]. Tangibly, this was often expressed through a desire to buy a bigger boat. Fishers believed strongly in being independent and in being able to adapt in life. As both are closely tied to fishing, fishers' sense of identity and self-worth were intimately bound to the marine environment[14] (Pollnac & Poggie 2006). Overall, many of the fishers interviewed reported being satisfied with the different aspects of their lives, though there was more variation in fishers views on their ability to progress (Fig. 4.2).

[12] "Things are becoming this way [lack of communication] nowadays. Seychelles is becoming like this. Even though there were thieves in the area I remember how we used to be able to leave our doors open/unlocked. We used to watch out for each other and keep an eye on our neighbour's house. Nowadays, everyone is afraid. Too many problems going on." (LR-1811-2)

[13] "You have to keep moving forward and making progress in life. I always keep moving forward." (AB-1611-4)

[14] "As a fisherman, I feel pride in what I do. When I go out fishing with my fishing trap, even though I may not get the catch that I was expecting and I may not be very happy about that, but I still feel happy because I worked for it/it's my catch." (AAP-1611-1)

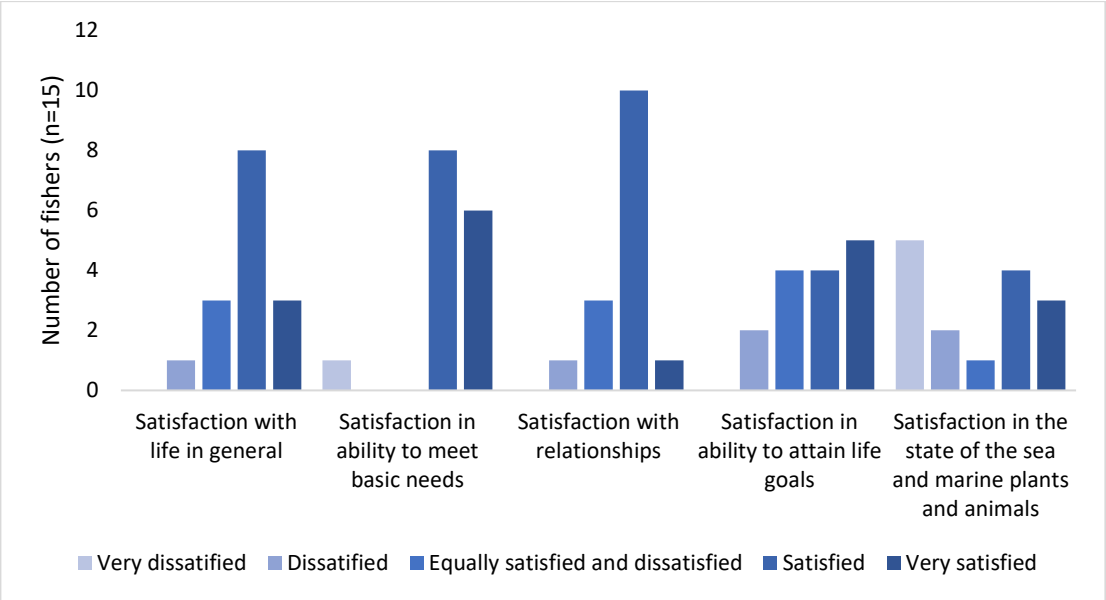

Figure 4. 2 Self-reported satisfaction with different aspects of living well in Seychelles, and the state of the marine environment (n=15)

4.4.2. Fishers' perceptions of change in the marine and coastal environment

Changes that fishers perceived in the reef and fish community are widely consistent with ecological research on coral reefs in the Seychelles. This includes observations of reef degradation but also some recovery (Graham *et al.* 2015) and changes in the composition of the fish community and catch (Robinson *et al.* 2019a; Robinson *et al.* 2019b). Both fishers and the literature attribute these changes to increases in sea surface temperature. Fishers highlighted however that fish are still found (or have moved) further out, which adds a spatial dimension to reef change with important repercussions for how and where people fish (consistent with Chapter 3 and the 'accessibility' trait in Chapter 2). Fishers also noted changes in species that are useful in fishing (e.g. declines in types of seaweed used as bait or octopus, which is caught by hand and is a valuable source of income). The environmental changes often most noticeable to fishers are therefore those that connect in a meaningful way to fishers' daily lives at sea (consistent with the approach in Chapter 2). Fishers' also

emphasised changes in environmental conditions (e.g. rising sea levels, shifts in tides and currents) and reported instances of coastal change including erosion and flooding, which has a physical impact on their ability to fish (e.g. changes in tide, affects how long they spend at sea). These concerns are consistent with policy concerns in Seychelles, as coastal margins are small and at risk from erosion following reef degradation (World Bank and Ministry of Environment Energy and Climate Change of Seychelles 2019).

Though not a question in the interview, many fishers blamed anthropogenic activities as well as feedbacks within the environment for causing these changes[15]. Many fishers reported lower levels of satisfaction with the marine environment because of the extent of changes that they have perceived (Fig. 4.2), further evidenced in fishers' quantitative responses on the extent to which change is perceived to be affecting the marine environment (Fig. 4.3)

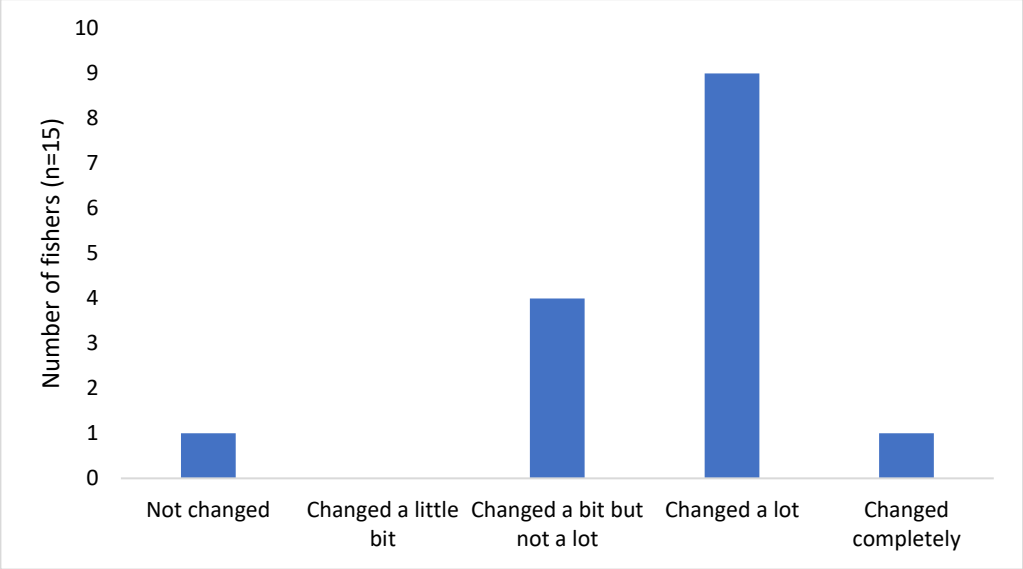

Figure 4. 3 Fishers' reporting on the extent of change that they have perceived in the marine environment over the last 10 years (n=15)

[15] "The ocean has changed. There's sea level rise. The low tide is not the same as before. Marine animals and plants are destroyed, not just directly by humans, but also by the changes with the sea itself." (AAP-1611-1)

4.4.3. Wellbeing insights on the implications of environmental change

The above illustrates that the sea both provides, enables and is a part of fishers' understanding of, and ability to, live well, but that the sea is also changing. In the following I outline two key findings from what a social wellbeing approach reveals about the implications of environmental change.

4.4.3.1. "I'm not frustrated. I have to adapt. You understand?" (BV-1411-3)

Prevalent in fishers' responses to change was acceptance of the need to adapt. This was connected to the importance that fishers attributed to being independent and that fishing is a means to other wellbeing outcomes. This acceptance was also linked to the constancy of change in their lives, most often experienced as catch variability (Robinson *et al.* 2019b). Adapting to change is therefore considered normal[16] and desirable in fishers' lives – *"Every fisherman will tell you the same thing. Fishermen need to have a plan, especially regarding money." (BV-1411-3).* Fishers' key response to change is therefore determined by their pursuit of wellbeing, shaped by subjective components on how they perceive what it means to live well and their personal experiences of working in the marine environment (Coulthard 2012b).

Tensions emerged however, in fishers' ability to balance adaptation and other aspects of wellbeing. In seeking to maintain income, support others and beliefs on what success looks like in fishing, fishers are compromising on, for example time spent with family, and harmonious relationships between fishers. Viewed through a social wellbeing approach

[16] "I'm not affected. However, it's important to understand that we used to have way more fish. Fishing is like this. Some days you catch some and can store, other times you don't catch anything or catch much less. You have to accept this. That's fishing. Some days the fishing trap is full, other days some are completely empty. You catch enough to make a living." (AB-1611-3)

(White 2010), environmental change is affecting fishers' overall wellbeing through the pressures that it places on the dynamics between these material, relational and subjective components of wellbeing. Our findings therefore contribute to (Coulthard 2012a)'s question: can someone be both resilient [to change] and able to pursue the multiple aspects of what it means to live well?

The mechanics of adapting to changes in the fish community - the key ecological change fishers were responding to – was to fish further, fish with more gear[17], fish for longer or fish with more technology. Previous research in this fishery shows that fishing further is a more recent response to perceived changes in catch, though increases in effort have been occurring for a while (Daw, Robinson & Graham 2011). Fishers however only have limited material resources within which to adapt, which is further compounded by the rising costs of living in Seychelles. On a practical level therefore, fishers are having to choose, for example, between paying to have help on the boat or buying fuel to fish further offshore. In this, fishers are mobilising both their material assets and agency to adapt to changes in the marine environment but lack any organisational support (Cinner *et al.* 2018). Changes of material inputs in the co-production of marine ecosystem services has previously been shown to increase provisioning services, but not other types of ecosystem services (Outeiro *et al.* 2017) and monitoring shifts in co-production processes is important for understanding the long-term sustainability of social-ecological systems at a national, regional and local scales (Cumming *et al.* 2014; Outeiro *et al.* 2017; Dajka *et al.* 2020).

[17] "Things are not the same because before we could easily get fish closer to shore. Now we have to go further out. [side discussion] We have to spend more on fishing traps." (RC-1111-4)

Many costs to adaptation emerged in fishers' relationships. Spending more time at sea, meant spending less time at home[18]. Differences in perceived abilities to adapt also contributed to a further break down in relationships within the fishing community. Those fishers who felt that they were still doing well at catching fish, derived some satisfaction from being successful, seeing it as validation of their knowledge as fishers, but also felt targeted by other fishers who were doing less well[19]. Thefts of traps and fish affected fishers' feelings of personal safety and exacerbated already bad relationships with the authorities, where fishers' felt unprotected and un-supported. The break down in these relationships, affects not only fishers' individual ability to live well but can erode fishers' future capacity to work together in adapting to any future change (Cinner et al. 2018).

Our findings therefore show that resilience through adaptive behaviours does not necessarily result in positive individual wellbeing outcomes for fishers (Coulthard 2012a). However, fishers' chosen strategies may equally have negative effects on both the ecology of fisheries (Cinner *et al.* 2011), and the community wellbeing (Voyer *et al.* 2017). Understanding what shapes fishers' decision making to pursue alternative adaptation options will be necessary to understand the implications of adaptation to ecosystems and for social wellbeing and particularly the trade-offs that emerge, between for example being resilient and living well (Coulthard 2012a; Coulthard 2012b). (Coulthard 2012a) and White (2010, 2017) further emphasise the importance of anchoring these decisions within fishers' existing social contexts.

[18] "I get home much later. I don't spend a lot of time at home. I'm working longer hours. When I wake up in the morning my children are still asleep and when I get back home at night my children are asleep. You see? He's fifteen months old. I wake up in the morning and I see him sleeping, then he goes to daycare. When I get back home around 7 or 8 p.m. he's already asleep. […] This doesn't happen everyday but often it's the case." (CA-1411-2)

[19] "Me, I get fish. But some people they don't get fish. That's why sometimes they make problem with me because [I] know [since] I grew up here in the water. I go snorkelling. I look for fish to put my net. If I don't do this, I won't get fish. I snorkel one day to look for fish and then another day I get fish. Some friends they have twelve 'kazye' (fishing traps) like me [but] they have nothing" (APA-1311-1)

In addition to marine environmental change, fishers' ability to advance in life was felt, by some individuals, to be constrained by tensions between their political views and what was at the time the ruling political party[20]. Fishers' ability to invest more in fishing is also limited by increasing living costs, which both exacerbate the material cost of adapting but also the need to adapt to maintain incomes, and fishers' future ability to adapt may be further constrained by the breakdown in relationships within fishing communities. This was expressed as concern that even if a fisher were able to buy a bigger boat to fish further offshore, where would he find the crew. These exemplify the 'stickiness' of existing social and personal relationships through which fishers are pursuing wellbeing (White 2017), but they also illustrate the subtleties of how multiple aspects of a social-ecological system combine to shape the implications of environmental change on wellbeing.

Apart from adaptation, direct effects on fisher's ability to live well most often referred to changes in the sea's contribution to material wellbeing. Examples of this include less income - which can affect fishers' ability to support other people – the loss of recreational spaces, and changes in the physical process of fishing. Notable among these is that fishing was perceived to be more dangerous and more physically exhausting. Consequently, fishers felt the need to ask for more support (for example asking for government support to establish safer fishing areas), and less able to juggle other aspects of their life which affected their mental health[21]. Although it is well recognised that fishing is a dangerous occupation, the implications of changing fisheries for mental health is under-researched globally but even more so in Africa (Woodhead *et al.* 2018). In addition, fishers in Seychelles identified having

[20] "In fact, I haven't been working that much for nearly two years because of the influence of the political system. They always find a reason to fire me/force me to quit. They find some reason to interfere with my work and dismiss me." (APA-1311-1)
[21] "I have to buy more food and be more attentive to my family, but I'm more tired nowadays, so it's more stressful." (AAP-1611-1)

enough income from fishing as important for good mental health, with the likelihood therefore that further losses of income could have wider impacts on mental health.

4.4.3.2. "The sea is still doing its best to help me earn a living." (LR-1111-4)

The sea in Seychelles was constitutive of fishers' sense of self (as fishers and Seychellois) and their ability to pursue what it means to live well. This is consistent with approaches that both frame the environment as a constituent and a determinant of wellbeing (Schleicher *et al.* 2018), and in the ecosystem services literature, as benefits arising from the environment contributing to both people's identities and what they are then able to do in life (framed as capabilities by Fischer & Eastwood 2016). A tension therefore emerges between fishers' acceptance of change as normal, and their willingness to accept changes in the sea as possibly detrimental: *"With the sea. I'm very satisfied. Even though we don't get as much fish like before, but I'm still satisfied with it. The sea is being greatly impacted from a lot of pollution and destruction. And it's still around/good*[22]*. So I'm satisfied. The sea is still doing it's best to help me earn a living." (LR-1111-4)*

The fishers that I interviewed were established fisher/skippers and fisher/boat owners, and were overall, satisfied in their general ability to live well. Where fishers were less satisfied was in their ability to achieve their goals and in the state of the marine environment (Fig 4.2), and young fishers specifically found it more difficult to progress in life. There were few indications however that fishers' beliefs and attitudes to fishing or aspirations for the future had shifted as a consequence of the changes that they had perceived. People often respond to change from within their frame of beliefs and past experiences, which can limit their

[22] In certain cases, there was no one-word equivalent for Creole into English and so two words are provided that together best convey the meaning.

ability to perceive change as significant or to be flexible in their responses to change (Cinner *et al.* 2018). Recognising social limits to adaptation (Adger *et al.* 2008) shows that diverse values, different perceptions of risks (according to individual and societal characteristics) and culture can limit an individual or community's ability to adapt to change (Evans *et al.* 2016). In addition, diverse knowledge types on what change and adaptation consist of can also shape or limit the ability of people to adapt (Adger *et al.* 2008). The need to adapt is a central tenant of being a fisher, but many other cultural connections and values connected to the marine environment limit fishers' ability to do so in a way that does not impinge on other aspects of wellbeing.

4.4.4. Wider implications

The social wellbeing approach, which reveals the drivers and limits in fishers' ability to respond to environmental change, raises questions regarding proposed adaptation services (Colloff *et al.* 2020; Lavorel *et al.* 2020) or novel ecosystem services (Woodhead *et al.* 2019; Chapter 1). Adaptation services refer to the role that ecosystems could play in enabling social adaptation to climate change (Lavorel *et al.* 2020), whilst the concept of novel ecosystem services seeks to broaden our understanding of changing services, as a consequence of novel ecological assemblages and wider shifts in how people engage with the environment (Woodhead *et al.* 2019). Whilst I show that fishers are willing to modify the co-production of ecosystem services in response to change (see also Outeiro *et al.* 2017; Chapters 2 and 3), the move to new ecosystem service configurations may depend on how they contribute to individual or community understandings of wellbeing; the existence of possible wellbeing trade-offs associated with the co-production of these new services (for individuals and between different groups in the community; Coulthard 2012a; Daw *et al.* 2015); and on the

cultural values, beliefs and perceptions that shape human-environment relationships (Poe, Norman & Levin 2014).

4.4.5. Limitations

In the above I have explored collective understandings of wellbeing and responses to environmental change, as it exists within a community of fishers. I sought to understand the patterns and processes that shape both how wellbeing is understood and where the marine environment is situated within that. I did not however interview fishers who had chosen to leave the fishery, which could provide a very different perspective on the effects of environmental change. Fishers at an individual level can also have their own narratives of change that I was unable to fully capture here. Some fishers, for example, are emotionally affected by changes in the sea according to their personal feelings and uses of the marine environment[23]. It is also easy to over-romanticise the image of a fisher as defined by their relationship to the sea. Some fishers did describe the sea as a place they could express themselves, fulfil their aspirations and relax. For others however, it is a means to an end and for one individual that we interviewed, it was an employment of last resort. These multiple and sometimes contrasting benefits of the marine environment for fishers' individual wellbeing is well summarised in the following except from an interview with a trap fisher on the east coast of Mahé: *"Dear, let me tell you something. The things that I can see/observe help me to live well. I love to observe/admire the different species of marine animals. I go snorkelling just to admire the different kinds of fish in the ocean. Even though I depend on them for a living I still love to just observe them in their habitat. It helps to relieve stress. I*

[23] "I love the ocean. That's how I feel. I love snorkelling and boat rides. Everyone can enjoy the ocean in their own way. We use the ocean to earn a living." (APP-1611-2)

forget all my worries. The sea is so beautiful and valuable, but we don't take care of it enough." (LR-1111-4)

4.5. Conclusion

This analysis was informed by two key perspectives on ecosystem services and human wellbeing. The first is that ecosystem services are co-produced in the relationships between people, between people and place, and the activities through which they engage with their environment (Fischer & Eastwood 2016). The second, that human wellbeing as a state of being, emerges from the processes connecting the material, relational and subjective dimensions of people's lives, contingent on the time and place in which these interactions unfold (White 2010). In both cases, ecosystem services and wellbeing are dynamic and contingent on relationships. Consequently, change is the norm. That is not to say that change cannot be significant. As demonstrated above, there are tangible implications of environmental change on people (e.g. fishing made more dangerous) and there are limits to how far people can adapt (Adger *et al.* 2008). My findings indicate however that the implications of environmental change for human wellbeing could best be interpreted as a constant dialogue between how people perceive and engage with their environment (also Chapter 3) and how they chose (or are able to) to pursue (their own understanding of) wellbeing. This interpretation recognises individuals and communities as having an active role in changing ecosystem services, echoing wider calls on the need to recognise knowledge of ecosystem services as co-produced between different people (Blythe *et al.* 2020).This approach is likely to be iterative but could go some way towards better understanding the relationships between ecosystems, ecosystem services, human wellbeing, and their connections with on-going environmental change.

General discussion

Marine ecosystems around the world are changing in response to human activities. Highly biodiverse coastal areas in the tropics are particularly vulnerable (Barlow *et al.* 2018), and coral reefs amongst them are unlikely to return to historic baselines (Hughes *et al.* 2018b; Robinson *et al.* 2019a). It was this context, and the knowledge that coral reefs underpin many vital ecosystem services around the world (Moberg & Folke 1999; Hicks 2011; Laurans *et al.* 2013; Albert *et al.* 2015; Schuhmann & Mahon 2015; see Chapter 1) that became the starting point for this thesis. In it, I have sought to examine changes in ecosystem services associated with coral reefs and the implications of change for human wellbeing. I focused on coral reefs in the Seychelles, which are known to have undergone widespread ecological change following two mass bleaching events affecting both benthic and fish communities (Graham *et al.* 2015; Robinson *et al.* 2019a; Wilson *et al.* 2019). Ecosystem services is however a complex, sometimes disparate and continuously growing field of research (Chan, Satterfield & Pascual 2020; Schutter & Hicks 2020). My choice of approaches has been guided by the need to reconcile both ecological and social complexity in how ecosystems services are co-produced and how they connect to changing ecological condition and ultimately to human wellbeing (Bennett *et al.* 2015). As such, my findings contribute new ways of thinking about change in the context of ecosystem services. Specifically, I highlight the need to more explicitly engage with different types of change in coral reef ecosystem services, and methods through which this can be achieved. Moving beyond change as something measured. However, I also draw attention to differences in how change is perceived within coastal communities, and the processes through which marine environmental change affects fishers' wellbeing. In addition to the findings and limitations that are specific to each chapter, the following provides an overview of what together these chapters add to our understanding of change in ecosystem services.

Coral reef ecosystem services in the Anthropocene

Early adoption of the ecosystem services concept in coral reef research identified many important goods and services attached to functioning coral reef ecosystems (Moberg & Folke 1999). In **Chapter 1**, I reviewed existing knowledge of these services, focusing specifically on the need to connect a mechanistic understanding of service provision, with the social-ecological processes underpinning services and how these might respond to the Anthropocene. Drawing on advances in functional ecology and social-ecological systems research, I propose an approach that seeks to integrate recent advances in modelling the impacts of disturbances (notably, the use of a functional space to predict the effects of change on multiple different traits; Mouillot *et al.* 2013) and how such an approach can be expanded to recognise social, as well as ecological traits, that shape the relationship between ecosystems and service provision (Goodness *et al.* 2016). The thinking behind this approach is consistent with calls for a robust review of current ecological theory as it applies to reefs (Williams *et al.* 2019). (Williams *et al.* 2019) focus specifically on the need to review the applicability of ecological theory to marine systems that are increasingly shaped by social rather than biophysical drivers (Williams *et al.* 2015; Hicks *et al.* 2016). Our findings (here and in Chapter 2) provide proof of concept that methods stemming from ecology can be expanded to reflect the value of species and ecological processes beyond their role in ecosystem functioning. Indeed, trait-based approaches that incorporate socially important, as well as ecologically significant traits have also recently been adopted in the context of cultural ecosystem services from avian communities in Central America and South Africa (Echeverri *et al.* 2020; Zoeller *et al.* 2020).

Whilst trait-based approaches to ecosystem functioning can be used to identify thresholds below which ecological functions are no longer maintained (Mouillot *et al.* 2013), (Daw *et al.*

2016) put forward the concept of elasticities between ecosystems, services, and wellbeing. This reveals many non-linearities between ecological condition and the disaggregated contribution that ecosystem services make to human wellbeing. Thus, changes in the provision of ecosystem services can originate outside of changes in reef ecological condition. The question, therefore, is whether current approaches to coral reef ecosystem services can capture change in the nature of services. Without a better understanding of the co-production of services the answer is likely to be no (Bennett *et al.* 2015). Moreover, the narrative of change need not necessarily be one of lost ecosystem services as is commonly assumed in discourses around the Anthropocene (Thomas 2020). I propose that novel ecosystem services may emerge as a consequence of social and ecological change acting on processes of ecosystem service co-production. Novelty does not necessarily imply un-precedented but can provide a rational towards recognising irreversible changes away from historical baselines (Graham *et al.* 2014). The management of changing ecosystem services in the Anthropocene therefore introduces ethical questions on managing for past or future service provision, the leading edge of this debate lying in temperate areas that are tropicalising as a consequence of rising ocean temperatures and the poleward migration of tropical coral species (Wernberg *et al.* 2016). Novel ecological communities are emerging in these areas, necessitating management decisions on whether to manage for past or future configurations of ecosystem services (Vergés *et al.* 2019).

Investigating coproduction in the service providers of tropical coastal ecosystem services

Data deficiency on the human dimensions of coral reefs is a key barrier to understanding future implications of reef change (Pendleton & Edwards 2017). In addressing this research gap, I applied the approach developed in Chapter 1 to an empirical case-study in **Chapter 2**. Drawing on interviews with key informants in the fisheries and dive tourism sectors, I

identified the service providers and their traits that underpin locally valued services and benefits. Consistent with prior research, ecosystem services connect to multiple different types of benefits (Klain, Satterfield & Chan 2014), which are inter-dependent in how they contribute to people's lives (Polishchuk & Rauschmayer 2012). Service providers that were identified as significant spanned across multiple scales, ranging from the environment as a whole to specific types of fish, seaweed or coral (Luck *et al.* 2009), and similarly the traits mediating between service providers and service provision were highly diverse.

(Spangenberg, von Haaren & Settele 2014) caution against relying on the identification of service providers in management, reasoning that the multi-functionality of ecosystems limits the use of overly specific strategies. They recommend a pre-cautionary approach to managing for service providers, and by extension their traits. My findings do indeed indicate that managing for ecological integrity is likely to maintain the greatest number of services and benefits. However, the complexity revealed in Chapter 2 could be beneficial for identifying specific services and benefits that are vulnerable to future change. This is shown through comparing service providers and traits that underpin fisheries that provide food and fisheries that enable people to exercise choice. These are both important dimensions of food security (HLPE 2020) but draw on different combinations of services providers and traits. Traits underpinning people's ability to exercise choice over what they want to eat, for example, capture a much wider set of individual, general, and cultural preferences relevant to the Seychelles context. Identifying species or areas with cultural significance may be an important step in fostering collaboration towards wider ecosystem management, whilst the loss of certain service providers may have disproportionate effects on community wellbeing (Poe, Norman & Levin 2014). Traits can also carry more meaning than the service provider themselves. Wider research on coral reef ecosystem services also draws on local knowledge

of important species (Yee, Dittmar & Oliver 2014; Sato *et al.* 2020), but it is through the identification of key traits that, for example, the substitutability of service providers may be revealed. The latter introduces an important dynamic in ecosystem service change in that people are not passive recipients of change, which is further discussed in Chapters 3 and 4.

There were certain key differences between the approach proposed in Chapter 1 and its application to an empirical case-study in Chapter 2. Firstly, focussing on locally valued services and benefits emphasised the importance of multiple marine and coastal environments needed to sustain them. This was first discussed in (Moberg & Folke 1999)'s seminal paper on reef associated ecosystem services but further supports the need for seascape level approaches to ecosystem service management. Secondly, I was also unable to identify from key informant interviews the critical baselines below which services would no longer be available (Luck *et al.* 2009). Building off the list of service providers and traits provided by key informants, a next step could be to engage with wider group of people within the community to identify critical baselines below which ecosystem service provision may be limited, recognising that this will vary according to needs of different people (Daw *et al.* 2015). Thirdly, the approach in Chapter 1 was developed with the intention of exploring ecosystem service co-production in a context of reef degradation or re-organisation. However, key informants identified the availability of service providers in specific seasons as one of the traits underpinning service provision. Recent research on the seasonality of ecosystem services associated with gleaning (Grantham et al. 2020) shows that ecosystem service provision varies significantly throughout the year. Changes in traits and service providers could also therefore be examined in a context of 'normal' seasonal change, as well as 'unusual change' related to shifting ecological conditions, to better understand how ecosystem services are co-produced in dynamic environments (see also Chapter 4)

Chapters 1 and 2 contribute towards a better understanding of how ecosystem services emerge in social-ecological systems, and how this understanding can be used to anticipate the impacts of current and future environmental change on reefs. The assumption underlying my approach is that change is objectively measurable, for example, from changes in the abundance of certain service providers, also referred to as changes in ecosystem service potential (e.g. Sato *et al.* 2020). This, however, does not capture the implications of environmental change as it is perceived and experienced by coastal communities. Combining the two approaches can elucidate where change as perceived by ecologists, differs from change as perceived by natural resource users (Rassweiler *et al.* 2020), with possible implications for management (Bennett 2016).

Contribution of perceptions-based data towards understanding ecosystem service change

In **Chapter 3**, I explored the question of changing ecosystem services from the perspective of coral reef fishers. Starting with a pre-determined list of ecosystem services, developed with fishers during a previous research project (Hicks *et al.* 2014), I sought to understand whether changes in ecosystem services had been perceived within the fishing community, what the nature of these changes were and what the implications of these changes could be. A key finding from this chapter is that changes across multiple types of ecosystem services are being perceived and that this was over time scales consistent with what is known of widespread ecological change in the coastal environment in Seychelles (Graham *et al.* 2015; Robinson *et al.* 2019b; Wilson *et al.* 2019; World Bank and Ministry of Environment Energy and Climate Change of Seychelles 2019). Moreover, perceptions over which changing service was most significant to fishers, varied according to fishers' dependency on fishing, types of

exposure to the marine environment (fishing off bigger boats, snorkelling, driving or free-diving), the island they lived on and socio-demographics (age, education). Multiple dimensions of wellbeing were also identified as being possibly implicated by the perceived changes to ecosystem services.

That change has been perceived across multiple services is an important finding in and of itself, complementing evidence of changes in ecosystem service potential following disturbances of reef ecosystems elsewhere (e.g. Orlando & Yee 2017; Sato *et al.* 2020). Perceptions of ecosystem services, however, provide a different perspective on changes in ecosystem service co-production in marine and coastal environments. Participatory ecosystem service assessments reveal that ecosystem service users often struggle to delineate between what is social and what is ecological in ecosystem services (Tusznio *et al.* 2020). This blending of the social and ecological comes across in fishers' descriptions of changing services, for example changes in fishery services involved changes in where fish were found and consequent changes to fishers' fishing practices. Identifying these types of change in co-production, for example moving from locally available service providers to ones found elsewhere, has been demonstrated as significant for the sustainability of social-ecological systems at a national or regional level (Cumming *et al.* 2014), due to the possibility of un-intended consequences or 'missing feedbacks' in the system (Dajka *et al.* 2020). My findings suggest there are also potential consequences of changes in co-production at the individual and community level as fishers seek to balance different aspects of their wellbeing whilst adapting to changes at sea and on land (Coulthard 2012a; Chapter 4). This introduces the question on how changes in ecosystem services can be delineated, or indeed managed for. Identifying where ecosystem services are likely to change is important but understanding

how these changes relate to fishers' everyday lives will be needed to safeguard future environments and human wellbeing.

Centring environmental change within fishers' understanding of living well

In the final chapter (**Chapter 4**) of this thesis, I sought explicitly to investigate how the marine and coastal environment connects to fishers' wellbeing. Wellbeing is multi-dimensional and can be conceived of as both an outcome and a process (McGregor, Coulthard & Camfield 2015), allowing for a more dynamic interpretation of wellbeing and thus its relationship to shifting environmental conditions. The marine environment manifests itself in multiple ways in fishers' understanding of living well in Seychelles, consistent with global and regional syntheses on the contributions of the sea to wellbeing (Breslow *et al.* 2016; Allison *et al.* 2020) and island communities (Coulthard *et al.* 2017). Notably, change is perceived as the norm for fishers in Seychelles - planning for and responding to change is part of everyday life and a sign of success in fishing. However, increasing levels of ecological change and the need to adapt can result in wellbeing trade-offs (Coulthard 2012a). Existing social structures and fishers' own perceptions of what it means to live well can further limit fishers' ability to balance multiple wellbeing dimensions in the face of on-going environmental change (Adger *et al.* 2008; Evans *et al.* 2016).

The findings from this chapter add a more nuanced understanding of changing ecosystem services in the context coral reef environments. With the suggestion of novel ecosystem services (Chapter 1), I sought to broaden the discussion on changes in ecosystem services as manifest through changes in the co-production of these services (e.g. Outeiro *et al.* 2017).

However, situating processes of co-production within local understandings of wellbeing shows that fishers', and other resource users', ability to adapt and maintain a 'flow' of ecosystem services (whether same or novel), has ecological and human wellbeing costs (Cinner *et al.* 2011; Coulthard 2012a). How fishers navigate these costs is likely to be shaped by the social and ecological context in which they occur (White 2017) but will also depend on where the environment is situated within fishers' understanding of living well (Schleicher *et al.* 2018).

Limitations and implications for future research

Across all chapters that incorporate empirical data from Seychelles there is a strong spatial component in the nature and implications of changing ecosystem services. This is manifest in the accessibility trait of service providers identified in Chapter 2 and the need to follow fish offshore in Chapters 3 and 4. Seychelles sits on a large shallow bank, providing habitat for coral reefs and access to other productive marine ecosystems. This differs from coral atolls, where changes in ecosystem services are having a much greater effect on coastal populations (Watson, Claar & Baum 2016). A seascape level understanding of change could also complement existing ecological data by providing information on the extent to which marine environments are re-organising in response to anthropogenic stressors. Overlap between habitats and service provision should, however, not be assumed (Mumby et al. 2014) and will likely need refining according to social-ecological contexts (Chapter 2).

Recognising that change in ecosystem services can be objectively measured and subjectively experienced necessitates the need for inter-, multi- and trans-disciplinary framings that are able to hold multiple understandings of change. These will need to reconcile possible non-

complementarities in what constitutes meaningful change but switching the focus from change as unusual to change as normal, could provide important insights into the costs associated with balancing multiple wellbeing outcomes in dynamic environments. This could help elucidate what costs and opportunities, and for whom, will emerge under future environmental conditions.

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Appendices

Appendices for Chapter 2

Appendix A2.1. Participants

Table A2.1: Interview participants from fisheries and tourism sectors in Seychelles (n=16)

Expertise	Role	Total	Mahé	Praslin	La Digue
Fisheries		**8**			
	Fishers' association representative	5	2	2	1
	Boat owner	1	1	0	0
	Government/ Management	1	1	0	0
	Consultant	1	1	0	0
Tourism		**8**			
	Dive centre owner	3	1	1	1
	Dive instructor	4	2	2	0
	Government	1	1	0	0

Appendix A2.2. Interview guide

Only data from key informant interviews from fisheries and tourism was analysed for Chapter 2. Post-it notes were used to record the ecosystem services and benefits that key informants identified as important and were moved around to facilitate in the ranking exercise. Data collected June-July 2018.

Ecosystem service providers, Seychelles 2018

Thank you for agreeing to meet with me. As discussed, I'm interested in your opinions on the benefits that people get from the sea and have approached you in your role as _____. However, I'm also interested in your views more generally as someone who lives and works in Seychelles.

The interview should take about 30 minutes and you can decide to stop it at any time; the data you give me will be brought together with others to get an overall picture of what is happening; you and your organisation won't be identifiable from it and I'll keep any personal information separate from the other data and only discuss this with my supervisors; the data may be available for other researchers to use but only in an anonymised form.

Is it ok if I record the interview? This won't be shared with anyone else and is just so I have something to refer back to.

Guide for questions

Statistics

I have a couple of questions for statistics, before proceeding with the interview but you don't have to answer them if you don't want to.

1. How long have you lived in the Seychelles?
2. Why did you move here? When did you start at your current role in_____?
3. OR What is your current occupation?
4. AND when did you start becoming a community leader, working with _____?
5. What year were you born?
6. What is the highest level of education that you have completed?

Interactions with the marine environment

This next section aims to understand how different people define the marine environment and how it features in both your professional and personal life.

1. *Defining the marine environment*
    a. Briefly, can you describe and define the marine environment?
    b. What do you see in your imagination when you think of the marine environment?

2. *Marine environment in daily life*
    a. How does the marine environment feature in your job? And in your daily life?
    b. How is being on, by the sea or knowing about the sea part of your daily life?
    c. Do you use your knowledge about the sea in you daily life?

3. *Activities in the marine environment*
    a. What are you doing when you're in this environment?
    b. What type of activities are you involved in? *(on the water, in the water, next to the water)*
    c. Which areas do you go to?
    d. Which areas do you oversee? *(use map)*
    e. Do you go with other people?
    f. How often do you go there?

Ecosystem services perceived by participant

This next section is about why the marine environment is important to people.

4. *Ecosystem services – free listing*
    a. What benefits do you get from the sea?
    b. What benefits does the sea provide to people in the Seychelles?
    c. Are there any other reasons why the sea is important to you? To the Seychelles?

5. *Ecosystem services - prompted*
    a. I have here a list of other reasons that I think the marine environment might be important, but I'm interested in your opinion on them.
        - Biodiversity
        - Habitat
        - Coastal protection
        - Water quality

- Fishery
- Materials
- Research
- Recreation
- Aesthetics
- Culture
- Existence
- Bequest
- Right to access

i. Are there any here that we can add to your list?
ii. Are there any here that you think that people benefit from in Seychelles?

Ranking ecosystem services

6. *Ranking ecosystem services – own list*
   a. I'd like you to rank your list now in terms of which benefits are the most and least important to you personally and tell me why you've put them in this order.

7. *Ranking ecosystem services - Seychelles*
   a. I'd like you to rank this list now in terms of which benefits are the most and least important to people in the Seychelles. Why?
   b. Which of these benefits are the most important to the people in Seychelles? Why?
   c. If you had to take into account the views of other people in the Seychelles, which benefits would be the most important? Why?

Features of the environment

	Ecosystem service	What is it that makes it possible for….
SPECIALITIES		
	Fisheries	…people to make a living from fishing? …people to sell fish?...people to buy fish?....people to want to buy fish?....
	Tourism	….people to make a living from tourism? …for visitors to enjoy the marine environment?....to attract people here?
	Research	…people to conduct research here?....to advance our knowledge of the sea from working here?
	Habitat/ biodiversity	….people to benefit from having coral reefs that are in a good ecological state (with lots of different species)
	Coastal protection	….people to feel protected by the sea?...to enjoy places knowing they will be the same in the long term?

	Education	…people to learn about the marine environment?...to pass skills and knowledge to other people about the sea?
	Access	….for people to have the right to access the sea?...for being to be able to access the sea?
	Materials	…for the sea to provide materials to people?...for people to be able to get materials from the sea?....for people to make a living from materials from the sea?
	Water quality	…for there to be clean water around the Seychelles?....for the sea to take away different pollution?
	Aesthetic	…for the sea to be a source of inspiration?
ALL (if not speciality)		
	Recreation	…for the sea to be a place to have fun with family and friends?...for time spent by or on the sea to be relaxing and enjoyable?
	Culture	…for the sea to play a part in Seychelles identity and culture?
	Bequest	…the sea to be appreciated by future generations?...for future generations to enjoy the benefits that we get from the sea?...for our knowledge about the sea and ways of living with it to be passed on?...for the sea to be a source of new and future benefits for future generations?
Specific case	HIGHEST IN TOP 3 IF NOT INCLUDED ABOVE	As given by them

8. *List of features*

For the next questions, I'm interested in what makes these benefits possible and what happens to them if something changes in the sea. For example, which species of fish are important for fisheries in Seychelles. *Write on post-it notes as go along.*

a. If you had to take a picture of what makes it possible to _____, what would be in that picture? *(post-its)*
b. What is it about the sea that makes it possible to _____? *(post-its)*
    i. Which species are important for being able to_____?
    ii. What habitats?
    iii. Is there anything about what's on the seafloor that's important?
    iv. Is there anything about the water or the weather that's important?
    v. What other things are important for being able to_____?

c. Are you happy with this image?

9. *Characteristics of features*
    a. What is it about these things that makes them important to _____?
        i. Does is matter how many there are?
        ii. How big they are?
        iii. How often you see them?

10. *Key elements*
    a. What would need to change in that picture for you to not be able to _____?

11. *Coral reef specific*
    a. *D*o coral reefs feature anywhere on here?
    b. What is it about reefs that makes them important for_____?

Conditions of access for service

12. For each benefit, I want to ask you:
    a. Which people or groups of people do you think benefit most from the sea in terms of _____?
    b. Who would not benefit from the sea in these ways? For whom, would it be less important to benefit from the sea in this way?

End of interview

Thank you very much for taking part. Do you have any questions for me? If you wish to withdraw your data from the study please let me know within 7 days. I will be producing a report from everyone's data. Would you like to be kept informed about what I find?

Appendix A2.3: Service providers

Table A2.3 Attribution of service providers to fishery and tourism services by key informants in the Seychelles (n=16). Numbers indicate percentage of participants who identified the benefit and who associated the service provider with that benefit

Service provider group	Fishery services												Tourism services			
	Provide					Enable					Are part of	Benefit not specified (n=11)	Provide		Enable	Benefit not specified (n=10)
	Economic benefits		Marine life										Economic benefits			
	As income and livelihoods (n=10)	To the economy (n=7)	For local food consumption (n=11)	For commercial establishments (n=7)	For export (n=6)	Building/ maintaining relationships (n=9)	Expression of choice and preferences (n=13)	Future development (n=2)	Leisure and enjoyment (n=11)	Self-sufficiency (n=6)	A shared identity (n=15)		As income and livelihoods (n=9)	To the economy (n=8)	A lifestyle (n=3)	
Environment/ Nature	0	0	0	0	0	0	0	0	0	0	0	0	22	13	0	30
Marine environment	20	29	55	0	0	0	0	0	0	17	13	44	56	50	67	70
Coastal environment	0	0	0	0	0	0	0	0	0	0	0	0	0	13	33	10
Specific sites	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	30
Marine ecosystem	10	0	36	14	0	0	8	0	0	17	7	56	22	13	0	20
Marine fauna	0	0	9	0	0	22	15	0	0	0	7	11	22	0	33	60
Coral community	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	70
Fish community	60	29	64	86	33	44	69	0	36	50	27	89	0	25	0	60
Group of different types of fish	30	0	27	14	0	0	15	0	27	17	0	33	11	0	0	20
Type of coral	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
Type of fish	40	43	18	29	83	33	85	100	18	17	47	78	0	0	0	40
Type of seaweed	10	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0
Type of terrestrial species	10	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0
Lobster	10	0	0	14	0	0	0	0	9	0	7	22	0	0	0	10
Octopus	10	0	18	29	0	11	31	0	18	33	13	56	0	0	0	30

Molluscs and other	0	0	9	0	0	0	15	0	0	17	7	0	0	0	0	0
Sharks and rays	10	0	0	0	0	0	0	0	9	0	7	0	0	0	0	60
Turtles	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	50
Other marine fauna	0	0	0	0	0	0	0	50	0	0	0	33	11	0	0	0
Islands*	0	0	0	0	0	11	0	0	0	0	0	22	0	0	0	30
Underwater granitic/ rock formations*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50

*denotes abiotic features. The inclusion of abiotic features as service providers is debated in the literature, which we reflect in the discussion.

Appendix A2.4: Service provider traits

Table A2.4: Attribution of service providers traits to services and benefits by interviewees in the Seychelles (n=16). Numbers indicate percentage of participants who identified the benefit and who associated the service provider with that benefit

Service provider traits	Fishery services and benefits												Tourism services and benefits			
	Provide					Enable					Are part of		Provide		Enable	To
	Economic		Marine products										Economic			
	As income and livelihoods (n=10)	To the economy (n=7)	For local food consumption (n=11)	For commercial establishments (n=7)	For export (n=6)	Building/ maintaining relationships (n=9)	Expression of choice and preferences (n=13)	Future development (n=2)	Leisure and enjoyment (n=11)	Self-sufficiency (n=6)	A shared identity (n=15)	Fishery services (general; n=11)	As income and livelihoods (n=9)	To the economy (n=8)	A lifestyle (n=3)	

Abundance	10	0	0	0	17	11	8	100	9	17	13	36	11	13	0	50
Accessibility	30	14	36	14	17	44	23	50	18	83	33	55	11	0	0	40
Aesthetics	0	0	0	0	0	0	15	0	0	0	7	9	33	13	0	60
Availability	10	0	0	14	0	11	31	0	9	0	13	27	0	0	0	20
Behaviour	10	0	0	0	0	11	0	0	18	0	7	18	0	0	0	20
Condition	0	0	9	0	0	0	0	0	0	0	0	18	22	0	0	70
Diversity	10	0	18	0	0	11	15	0	9	0	0	18	11	0	33	60
Growth rate/ Life cycle	0	0	0	14	0	0	0	0	0	0	0	27	0	0	0	0
Life history	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0
Preference	20	0	9	14	0	0	92	50	18	17	53	18	0	0	33	50
Preparation	10	0	0	0	0	0	15	0	0	0	27	0	0	0	0	0
Productivity	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0
Providing habitat/ Supporting marine life	0	0	27	14	0	0	8	0	0	0	13	27	0	0	0	30
Quality*	10	0	9	14	0	0	62	50	9	17	40	0	0	13	33	50
Size	10	0	0	0	0	11	8	0	9	0	0	45	0	0	0	40
Substitutable	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	40
Topography/morphology	0	0	0	0	0	0	0	0	0	0	0	27	0	0	0	30
Use in fishing	10	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0
Other	0	0	0	0	17	11	0	50	0	0	0	18	0	0	0	20

*Taken to mean: the standard of something as measured against other things of a similar kind (English Oxford Living Dictionary; https://www.lexico.com/definition/quality; accessed: 11/12/2020)

Appendices for Chapter 3

Appendix A3.1. Visual prompts accompanying interview questions

Table A3.1: Verbal and picture prompts used to describe four coral reef ecosystem services

Ecosystem service	Photo prompt[a]	Photo prompt[a]	Description (Creole)	Description (English)
Habitat services			Sa portre I montre ou en resif ki an bon leta ek bokou pwason e I osi annan bokou landwa kot bann pti pwason kapab kasyet. Sa portre I ilistre benefis ki nou ganyen letan resif labita I dan bon leta.	This picture shows a healthy coral reef. There are lots of fish and places for the fish to hide. This picture represents the benefits that we get from having healthy coral reefs in the sea.
Fishery services			Sa portre I montre pwason ki in ganny tyanbo e bann peser pe fer pake. Zot kapab servi sa bann pwason pou vann ou donn manze zot fanmir. Sa portre I ilistre bann benefis nou ganyen letan nou atranp bann diferan pwason.	This picture shows fish that have been caught by fishermen and a fisherman making a packet of fish. They might sell these fish or use them to feed their families. This picture represents the benefit we get from the different fish we catch and sell.

Coastal protection services			Sa portre I montre laroul ki ganny kraze lo resif, ki reakte koman en baraz pou protez lans. I osi montre en lans kin ganny afekte par lerozyon laroul. Sa portre I ilistre benefis nou ganyen letan nou annan resif, I protez lakot.	These pictures show waves that are breaking over a coral reef, which provides a barrier to protect the shore. It also shows a beach that has been eroded by the waves. This picture represents the benefit that we get from the reef protecting the coast.
Recreation services			Sa portre I ilistre bann dimoun pe prepar zot pou ou parti lanniverser lo lans ek zot zanmi e fanmiy. I osi montre dimoun pe naze. Sa portre I ilistre bann benefis nou ganyen letan nou kapab pas letan obor lanmer.	This picture shows some people getting ready for a birthday party with family and friends on the beach and someone swimming in the sea. This picture represents the benefits we get from being able to spend time by the sea or on the sea for fun.

[a]Photo credits: N.A.J. Graham; M.S. Schutter; A.J. Woodhead; C. C. Hicks; Eco-school via Seychelles News Agency; Roberto Schmidt/AFP via Getty Images

Appendix A3.2. Interview guide

Section 4 and 6 weren't used as part of the analysis for Chapter 3.

Semi-structured interview schedule for trap fishers, Seychelles 2018

I. Details of interview:

Name of researchers		
Date of interview		
Island	Mahé - Praslin - La Digue	
Location/landing site		
Start time		
Have they agreed to the consent form? Was this recorded?	Consent: Y/ N	Recorded: Y/N
End time of interview:		
Interviewee ID		

II. Introductory statement and consent to participate

My name is Anna Woodhead, a PhD student at Lancaster University in the UK and _____ from SFA. We're conducting interviews in the Seychelles to understand why the marine environment is important. We're interested in the opinions of trap fishers on what has changed in the sea, whether it's important and how it might have affected the benefits that the sea provides to people. This information will help us understand how future changes in the marine environment might affect coastal communities. The interview should last about 30 – 40 minutes.

- Would you like to take part? Thank you!
- Can I turn the recorder on? This is just for our notes and won't be shared with anyone.
- I have some information before we start the interview, which is also on this sheet that I can leave with you if you want
    - You can stop the interview at any point and withdraw your data up to a week after the interview has been done.
    - Anything you share with us will be confidential. I will store all your data securely until it is no longer needed. I will never keep personal information like your name with the other answers you give me.
    - The data will be available for other people to use, but it will be grouped together so no one person is identifiable.
    - I will use this data for research and for reports to give back to you and SFA but you will not be identifiable unless you choose to be.
- Do you have any questions?
- Are you still happy to continue with the interview?

1. Statistics and understanding how people fish

Pou konmanse par demann ou kestyon lo ou e kimanyer ou lapes/ *I want to start with a few questions about you and how you fish.*

Questions	Answers
a. Ki lannen ou ti ne? Kote?/ *What year were you born? Where?*	
b. Kan ou ti konmans lapes?/ *When did you start fishing?*	
c. */Between now and when you started, have you ever stopped fishing? When was that?*	
d. Eski ou papa ou gran papa ti lapes?/ *Did you father or grand-father fish ?*	Yes or NO
e. Ki kalite bato ou pe servi la ?/ *What boat do you work on NOW?:* **f. If mini-mahe: Konbyen pye?**	Semi-indus Whaler Schooner Mini-Mahe (pye ?) : Pirogue Lezot spesifikasyon :
g. Eski sa bato i inboard ouswa ouboard?/ Is the engine inboard or outboard?	Inboard Outboard
h. Ki groser masin *(engine size)* i été?	
i. How much time do you spend fishing on and off the reef?	Inside the reef Outside the reef Lezot spesifikasyon :
j. Ki kalite lekipman ou servi ozordi ?/ *What gears do you use to catch the fish?* **k. If kazye :** -How many kazye do you use ? -Kazye dormi, kazye lavol, kazye peze? -How long do you leave them for ? -Do you put the kazye dan ou dehor recif ? kantite fwa ou servi kazye konpare ek lapes ?	Net (Lasenn) Longline Handline Kazye Lezot spesifikasyon : If Kazye – number: Kazye dormi, kazye lavol, kazye peze Time soaking: Dan ou dehor recif Time using kazye vs. other gear:
l. Eski ou servi lezot teknolozi letan pe lapes (e.g. GPS, fish-finder, robots)? *Do you use any other*	

technology when fishing (e.g. fish finder, GPS, robots)?	
m. Konbyen fwa par semenn ou al lapes ?/ How often do you go fishing ? How often do you use kazye compared to fishing ?	
n. When you go fishing, how long do you go for?	
o. Letan ou al lapes, eski ou al okenn lezot dimoun ?konbyen ?/ *When you fish, do you go with other people? How many?*	
p. Eski ou navigater, ou ansarz / ouswa lekipaz lo bato ? *Are you skipper, boat owner and/or crew ?*	Navigater Ansarz lekipaz
q. Lekel bann pwason komen ki ou tyanbo ?/ *What are the main species that you want to catch?*	
r. Apard ki lapes eski ou fer lezot keksoz ankor lo lanmer ?/ *Other than fishing, do you do anything else at sea ?*	Going to the beach : 1x a year, 1x month, 1x week, >1 week, never Boating/sailing/kayaking : 1x a year, 1x month, 1x week, >1 week,never Swimming/Wading : 1x a year, 1x month, 1x week, >1 week, never Diving : 1x a year, 1x month, 1x week, >1 week, never Snorkelling : 1x a year, 1x month, 1x week, >1 week, never Other-specify : 1x a year, 1x month, 1x week, >1 week, never

2. *Ranking what is important about the sea*

Sa bann I montre bann benefis ki nou ganyen ek lanmer e son resif. Mon ti ava kontan si ou rank zot, konmans sa ki pli enportan pou ou e dir mwan akoz

[DESCRIBE THE PICTURES ON THE RED CARDS– READ OUT ALL THE BULLET POINTS]

RED CARD	RANK (1=most imp; 4 = least)	Reason
Fishery		
Recreation		

Habitat		
Coastal protection		

3. Changes in what the sea provides

Mon anvi demann ou si sa bann benefis nou ganyen lo kote lanmer in sanze ek letan/ *I now want to ask about whether some of these benefits that we get from the sea have changed over time.*

[FISHERY – SHOW THE PERSON THE CARD]	Change: YES or NO
Eski in annan sanzman lo antrap pwason? Par egzanp, eski in annan sanzman dan kalite pwason ou antrape? Eski oun bezwen sanz fason antrap pwason? *[If they say yes AND THEY DON'T START describing it, ask in what way it has changed?]* **Si wi, dan ki fason in sanze?/** *For you, has there been a change in catching fish? For-example, has there been a change in the type of fish that you are catching? Have you had to change how you catch fish?*	*Description of change*
Kan ki ou ti war sa bann sanzman?/ *When did you notice the change starting?*	*Start of change*
Eski I ti komans vitman ou gadyelman?/ *Did it happen suddenly or gradually?*	*Vitman ou gadyelman*
Brefman, dir mwan akoz ou kwar sa bann sanzman in arive?/ *<u>Very briefly</u>, why do you think these changes have happened?*	*Causes:*
Oparavan oun dir mwan ki ou lapes lo en bato e servi lekipman. Ki lezot bato oun servi pou lapes lo la oparavan? Ki lannen pou sak bato e ki lekipman oun servi? Kan? E brefman, dir mon akoz oun sanz fason lapes? *You said before that you fish on a [BOAT] and use [GEARS]. What other boats have you fished on before, when was that and for each boat, what gear did you use? And briefly, explain why you changed how you fish [IF THEY FORGET TO*	*Past boat 1:* *When?* *Past gears 1:* *Past boat 2:* *When?* *Past gears 2:* *Past boat 3:*

SAY THE TYPE OF BOAT, WHEN THEY USED IT AND WHAT GEAR THEY USED THEN ASK AGAIN].	*When?* *Past gears 3:*
[COASTAL PROTECTION – SHOW THE PERSON THE CARD]	Change: YES or NO
Eski I annan en sanzman ek lefe dan larol obor lakot? *[If they say yes AND THEY DON'T START describing it, ask in what way it has changed?]* **Si wi, dan ki fason in sanze?/** *Has the effect of waves on the coastline changed over time changed?*	*Description of change*
Kan ki ou ti war sa bann sanzman?/ *When did you notice the change starting?*	*Start of change:*
Eski I ti komans vitman ou gadyelman?/ *Did it happen suddenly or gradually?*	*Vitman ou gadyelman*
Brefman, dir mwan akoz ou kwar sa bann sanzman in arive?/ *Very briefly, why do you think these changes have happened?*	Causes:
[HABITAT – SHOW THE PERSON THE CARD]	Changes: YES or NO
Eski oun war en sanzman dan resif e benefis ki nou ganyen letan nou annan en resif an bonn sante? Si wi, dan ki fason in sanze? / *Have you noticed a change in the coral reefs and the benefits that we get from having healthy coral reefs?* *[IF THE PERSON DOESN'T UNDERSTAND]* **Par egzanp, si resif I enportan pou_____,eski oun notifye sanzman? /***For-example you said that reefs were important for _____, have you noticed a change in that?*	*Description of change*
Kan ki ou ti war sa bann sanzman?/ *When did you notice the change starting?*	*Start of change:*
Eski I ti komans vitman ou gadyelman?/ *Did it happen suddenly or gradually?*	*Vitman ou gadyelman*
Brefman, dir mwan akoz ou kwar sa bann sanzman in arive?/ *Very briefly, why do you think these changes have happened?*	Causes:

[RECREATION – SHOW THE PERSON THE CARD]	YES or NO
Eski letan ou pase lo lans or obor lanmer avek zanmi ou fanmir in sanze? Eski sa ki ou fer lo lans in sanze? *[If they say yes AND THEY DON'T START describing it, ask in what way it has changed?]* **Si wi, dan ki fason in sanze?/** *Has the time you spend relaxing at the beach or in the sea with friends and family changed? For-example, has what you do at the beach or in the sea changed?*	*Description of change*
Kan ki oun notifye sa sanzman?/ *When did you notice the change starting?*	*Start of change:*
Eski I ti komans vitman ou gadyelman?/ *Did it happen suddenly or gradually?*	*Vitman ou gadyelman*
Brefman, dir mwan akoz ou kwar sa bann sanzman in arive?/ *Very briefly, why do you think these changes have happened?*	Causes:
[SHOW HIM THE CARDS THAT HAVE CHANGED]	
Which change do you feel most strongly about?	

4.. Changes in the environment

I annan bann sanzman lo bann lespes ek labita dan lanmer. Mon pou montre ou 7 kart lo keksoz dan lanmer e mon anvi konnen si annan okenn kin sanze. Kimanyer sa keksoz in sanze? Avan nou kontinyen, dir mwan kwa kin sanze? *I want to ask now about some of the species and habitats that are in the sea. I will show you 7 pictures of different things in the sea and I want to know whether any of them have changed. I will then ask about the how these things have changed but first of all, can you point out which ones have changed?*
Summary of changes:

Ecological feature	**Changed**
Groser pwason (the size of fish)	
Lakantite pwason (the amount of fish in the sea)	
Kalite pwason (the different types of fish in the sea)	
Koray (the coral)	
Gomon (the algae)	
Tanperatir delo (the water temperature)	

Groser laroul (the size of the waves)	

Yellow card		**Eski I ti komans vitman ou gadyelman?** *suddenly or gradually?*	**Kan ki ti komanse?** *When did it start?*	**Kote ki oun war sa sanzman?** **1 2 landwa kot** **Enpe landwa kot** **Partou kot** *Where have you noticed this change?*	*Have you noticed this change in the places where you fish?* WI ou NON
Groser pwason *Size of fish*	**Eski oun notifye:** Have you noticed: • **ki pwason I vin pli pti** – smaller: • **ki pwason I vin pli gran** – bigger: • **Lot sanzman? Ki sa sanzman?:** **eski sa I pou tou pwason ouswa en kalite pwason?** Which fish?	vitman ou gadyelman	*Start?*	*-1 or 2 places* *-A few places* *-Everywhere*	Place where you fish? Yes or no
Lakantite pwason *Amount of fish*	**Eski oun notifye :**Have you noticed: • **ki pwason I pli pti gin** – less: • **ki pwason I pli bokou** - more: • **En lot kalite sanzman? Ki sa sanzman?** **Eski sa I pou tou pwason ouswa en kalite pwason?** Which fish?	vitman ou gadyelman	*Start*?	*-1 or 2 places* *-A few places* *-Everywhere*	Place where you fish? Yes or no
Species of fish *Lespes pwason*	Are there: **eski I annan** • **Pti gin lespes** – fewer: • **Pli bokou lespes** – more: • **Ouswa I lot en kalite sanzman? Kwa sa sanzman? –** other:	vitman ou gadyelman	*Start?*	*-1 or 2 places* *-A few places* *-Everywhere*	Place where you fish? Yes or no

koray *Coral*	Is there: **Eski I anan** • **Pti gin koray** – less: • **Pli bokou koray** – more: • **Ouswa I lot en kalite sanzman? Kwa sa sanzman?** – other:	vitman ou gadyelman	*Start?*	*-1 or 2 places* *-A few places* *-Everywhere*	Place where you fish? Yes or no
Gomon *Algae*	Is there: **Eski I annan** • **Pti gin gomon –** less: • **Plis gomon –** more: • **Ouswa I lot en kalite sanzman? Kwa sa sanzman? –** other:	vitman ou gadyelman	*Start?*	*-1 or 2 places* *-A few places* *-Everywhere*	Place where you fish? Yes or no
Water temperature	Has the water: **eski delo** • **Vin pli so?** -warm: • **Vin pli fre? -**cold: • **Sa temparatir in varyab? – variable:** • **Ouswa I lot en kalite sanzman? Kwa sa sanzman? -**other	vitman ou gadyelman	*Start?*	*-1 or 2 places* *-A few places* *-Everywhere*	Place where you fish? Yes or no
Groser laroul *Size of the waves*	Have the waves: **eski laroul** • **Vin pli gro?** - bigger • **Vin pli pti? -**smaller • **Ouswa I lot en kalite sanzman? Kwa sa sanzman? –** other:	vitman ou gadyelman	*Start?*	*-1 or 2 places* *-A few places* *-Everywhere*	Place where you fish? Yes or no
Okenn lezot sanzman dan lanmer – *Other*	**Si wi, dan ki fason in sanze?**	vitman ou gadyelman	*Start?*	*-1 or 2 places* *-A few places* *-Everywhere*	Place where you fish? Yes or no

changes in the sea					
[AFTER GONE THROUGH ALL THE CHANGES]					
• **Lekel sa enn ki ou pli konsernen avek uswa happy? Akoz?**/ *Which ONE do you feel most strongly about? Why?*					

6. Identity as a fisher

- I am going to make some statements about fishing and fishermen's knowledge and would like you to tell me whether you; 1) strongly agree; 2) agree; 3) neither agree nor disagree; 4) disagree or 5) strongly disagree.

Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
1. I could easily stop fishing and make my living on land					
2. The best thing about being a fisher is the freedom it gives me					
3. I feel very proud to tell people that I am a fisher from [INSERT COMMUNITY OR LANDING SITE]					
4. If the fish we want to catch are there, it does not matter if other species of fish are there					
5. Fishermen have good knowledge of what is happening in the marine environment					
6. I think children should be taught about the sea from an early age in school and at home					
7. I think fishermen should use their knowledge to teach other people about the sea					
8.People should be in charge of the marine environment					

- There are lots of different places that someone could get knowledge about the sea. I want to know how much you trust these different sources? The options are 1) Don't trust at all; 2) Distrust more than trust; 3) about half and half; 4) Trust more than distrust; 5) Trust

[CHECK FIRST: DO THEY GET KNOWLEDGE ABOUT THE SEA FROM THIS PLACE? IF YES, THEN ASK HOW MUCH THEY TRUST IT]

	Trust	Trust more than distrust	About half and half	Distrust more than trust	Don't trust it all	Don't use information from here
Knowledge learnt through experience						

Knowledge from friends, family and/or other fishers						
Knowledge from official organisations						
Knowledge in the paper or on the news						
Knowledge from the internet						

- Do you get knowledge about the sea in any other ways?

8. Catch

Mon realize ki parler I annan zour ki ou lapes bokou and lezot zour ki napa bokou/ *I realize that some days you catch a lot of fish, other days you may not catch many fish*

- **Konbyen pake ou kapab ganyen dan en bon/ move/ mwayen zournen?/** *On a good day: what is you daily catch? In packets or kg?*
- Is that for the whole boat or per person?

On a good/bad/average day….	**Good day**	**Bad day**	**Average day**	**Units** (packets/ kg)	**Boat/ person?**
Daily catch					

- Have you noticed a change in how often you have good days or bad days: WI ou NON?
- Si wi: more good days or more bad days than before?

- From your catch, how much fish do you eat and how much is sold?
  a. % eaten:_____
  b. % sold:_____

9. For statistics

a. How many people live in your house? _____
b. How many adult males, adult females, male or female children?

Adult male	Adult female	Male children (< 18yrs)	Female children (< 18yrs)

c. How many people do you provide for?_____
d. Do you do any jobs other than fishing? What?
e. What jobs do other people in your house do that brings in food or money? Are they permanent or casual jobs? [OPTIONS: Fishing industry, Trading fish, Farming industry, Salaried Employment, Tourism, Other]
f. Which is the most important?

ACTIVITY	Tick if respondent	Number of People	Most important?	Perm/ casual	comments
Fishing industry					
Trading fish					
Farming industry					
Salaried Employment					
Tourism					
Other					

Total number of occupations_____ Number of different occupations_____

g. What is the highest level of education that you have completed?

1] None	☐	4] Post-secondary (non-tertiary) education	☐
2] Primary school	☐	8] Tertiary education	☐
3] Secondary school	☐	9] Prefer not to answer	☐

h. What is the gross income earned in your household **before taxes or other deductions** in SCR last month? [ASK THE PARTICIPANT TO SAY THE LETTER NEXT TO THEIR INCOME. USE THE INCOME CARD, REMIND THE PARTICIPANTS THAT WE DON'T KNOW WHAT THE LETTERS MEAN]

LETTER:
…….

VIII. End of interview

- Thank you very much for taking part! Do you have any questions for us?
- If you wish to withdraw your data from the study please let me know within 7 days.
- I will be writing a report with some of these results and holding a workshop to discuss them. Would you be willing to be contacted by myself or SFA to find out about that?

Name (OPTIONAL)_____; Contact details: _____

Appendix A3.3: Participant statements

Table A3.3: Qualitative statements from fisher interviews

Reference number for main text	Qualitative statements (translated from Creole to English during the interview)
1	'Lot of dead coral. Coral going white. Bit alarming when [he] goes snorkelling or diving. Seeing more dead corals than before and see a sort of muddy algae growing on it' [PRA-0614-2]
2	'If reefs are healthy, see lots of fish, but when don't have healthy reef, don't see fish. Corals being smothered by the reclaimed land, the sediment run-off ('blanc lespine'). Lots of dead corals and don't see the same species of coral as before. Don't see brain coral anymore." [PRA-0613-4]
3	'Healthy reefs keep fish around. There's more algae on the reefs now, usually during South-East trade winds it's swept away and when it grows up, it feeds the juvenile fish but this is no longer the case' [MAH-0607-3]
4	'There used to be healthy reefs. Three-quarters of the reef is destroyed, so fish that come inside the reef as a nursery then will starve. Hard for fish to live.' [MAH-0606-3]
5	'Before we had a reef and now we don't. Before we could find octopus and now we don't and have to go further' [MAH-0530-1]
6	'When have healthy reef, have more income and with dying reef have less income. Coral bleaching, he's noticed' [PRA-0612-2]
7	'3m down the coral is white but 5-6m down it's stayed original, stayed the same. Caused maybe by temperature. There's a decline in coral and there's no fish when there's a coral bleaching' [MAH-0604-2]
8	'Coral went away fast but gradually coming back' [PRA-0612-4]
9	'Species of fish has changed and quantity of fish. All fish changed. Less fish. Example of octopus, used to be a good population but they have nowhere to go now. Corals die'. [MAH-0606-3]
10	'Big change: used to be fish but now no fish. Can't do anything about it. Sometimes fish, sometimes not. Decline in fish stock, no fish anymore.' [PRA-0614-1]
11	'Changes in the quantity of fish. Have to go far to catch same fish. Three or four miles has changed to 15 miles' [MAH-0529-3]
12	'[He] didn't use bait in traps and now [he] has to use bait. The bait acts to attract fish back to where [he] used to fish because fish are moving out. Attract fish back into the currents. Before, could get fish on the reef easily if you couldn't get off the reef' [MAH-0607-3]
13	'Need more bait. Go further out. Use more technology these days, since climate change getting worse all the time' [PRA-0613-1]
14	'Change in sand so causes the waves to hit the coast differently. Change in that there's more of an effect of the waves on the coast.' [MAH-0528-1]
15	'Sometimes. Waves getting bigger, getting further inside' [PRA-0613-1]
16	'Sea levels are rising and there are more currents. They are stronger.' [PRA-0613-5]
17	'Before [he] saw waves crashing on reef but now waves come up and crashing on sand. Sand moves away but also comes back.' [PRA-0613-4]

18	‘Big change: before would get rough times but now it's much worse and waves cover the roads when the weather is bad. If put reclaimed land there, used to crash there but now force of waves has to go elsewhere.’ [PRA-0613-3]
19	‘Sometimes with bad weather the waves are bigger and have to put in protection. Sand eroding, which will make it worse’ [MAH-0529-1]
20	‘Bigger waves eroding the beach. Before had beautiful broad beaches and now they are narrow, rocks are showing. Doesn't stop [him] from going to the beach though’ [MAH-0606-3]
21	‘Lot of pollution and rubbish from picnic. Plastic bags. Not normal. People come on the beaches and throw plastics.’ [MAH-0608-2]
22	‘Some places are reclaimed [land]. Some erosion due to seasonal change. Some places have come back. Some places do not come back over time. Some places are unsafe for children, inappropriate for picnics’ [MAH-0706-1]
23	‘Lots of hotels on the beach. People can't gain access to the beach but now have a way to access the beach but can't play music on beach. Not everyone gets time to spend time on the beach because maybe they are working’ [MAH-0605-1]
24	‘Lot more people on the beach. Before people only used to go at the weekend and now they go during the week’ [MAH-0529-1]
25	‘It's not the same as before. Life has evolved. Friendships have changed. People have moved abroad or to Mahé. Technology might also have an impact. People being dispersed’ [DIG-0616-1]
26	‘There's a change. The people are not united together. Before groups of people do BBQ and now it's small groups of people, separated from each other’ [MAH-0607-4]
27	‘Nowadays [he] doesn't have time to spend with family. Working more often now.’ [PRA-0613-2]
28	‘Before we used to spend more time with family but now working more because cost of living is high. Before 2007, parents would work for eight hours. Now with cost of living, parents have to leave kids for longer so there comes a time, kids get more addicted to drugs, have friends that shouldn't have, teenage pregnancy, addiction so parents have to work longer and passes on to next generation. Has continued to happen gradually.’ [PRA-0613-5]
29	‘[It’s important] because there’s a lot less fish nowadays’ [PRA-0615-1]. This statement was made in relation to perceived changes in fishery services.
30	’Most worried because big change. Spend less time with family and friendships also. Used to be close to people but people separately going own way’ [DIG-0616-1]. This statement was made in relation to perceived changes in recreation services
31	‘It brings in everything’ [MAH-0706-1; statement made in response to changes in habitat services]
32	‘[He’s] concerned about the coral because today it doesn't look like how it does in the picture [photo prompt]. Supposed to be like in the picture but it isn't.’ [MAH-0604-3; statement made in response to changes in habitat services].

33	'More concerned with it [fishery services]. Concerned if [we] run out of fish stock. [He]'s concerned his grandchildren won't be able to see the sea or learn what [he] does, for example making fish traps. Young people not interested because of alcohol. Worried the next generation of people who come in to fish will have to use nets, which is worse' [DIG-0616-4; statement made in response to changes in fishery services].

Appendix A3.4 - A3.7: Multivariate analysis

Table A3.4.: Variance explained by principle components of the Principle Component Analysis (PCA) run on fishers' characteristics and a summary variable referring to the total number of changed ecosystem services perceived by each fisher

Principle components	Eigenvalue	Variance (percentage)	Cumulative variance (percentage)
Dimension 1	**2.30**	**7.67**	**17.67**
Dimension 2	**1.67**	**12.87**	**30.54**
Dimension 3	**1.59**	**12.26**	**42.80**
Dimension 4	**1.38**	**10.64**	**53.44**
Dimension 5	**1.29**	**9.91**	**63.35**
Dimension 6	**1.09**	**8.40**	**71.75**
Dimension 7	0.78	6.00	77.75
Dimension 8	0.74	5.70	83.45
Dimension 9	0.60	4.63	88.08
Dimension 10	0.49	3.78	91.86
Dimension 11	0.45	3.49	95.35
Dimension 12	0.39	3.03	98.38
Dimension 13	0.21	1.62	100.00

The first 6 dimensions have eigenvalues greater than 1, which would make them suitable to retain in the analysis. Cumulatively, they explain 71.75% of the variance.

Table A3.5: Representation of variables on the six first dimensions of the PCA. Values refer to the squared cosine of the different variables in relation to the different axes. Dark green indicates values that are >0.3 and pale green indicates values greater than 0.26 that have been rounded up to 0.3 (Oteros-Rozas et al. 2013)

	PC1	PC2	PC3	PC4	PC5	PC6
Number of ES changes	0.4	0.0	0.0	0.0	0.0	0.3
Mahe	0.0	0.2	0.1	0.0	0.3	0.1
Age	0.1	0.0	0.0	0.6	0.1	0.2
Education	0.3	0.2	0.0	0.2	0.0	0.0
Boat length	0.3	0.0	0.0	0.3	0.0	0.0
Technology	0.0	0.4	0.1	0.1	0.3	0.0
Number of gear types	0.2	0.4	0.0	0.0	0.1	0.0
Catch	0.0	0.1	0.6	0.0	0.0	0.1
Underwater activities	0.6	0.0	0.1	0.0	0.0	0.0

Dependents	0.1	0.2	0.2	0.0	0.0	0.0
Num fisher jobs	0.2	0.0	0.1	0.0	0.2	0.0
HH occupational multiplicity	0.0	0.0	0.3	0.1	0.0	0.3
Income	0.1	0.2	0.2	0.0	0.2	0.1

Table A3.6: Constrained and unconstrained inertia explained by the canonical correspondence analysis on fishers' characteristics and which changing ecosystem service is identified as most important (n=36)

	Proportion of inertia explained	Eigenvalues
Constrained axes	0.44	CCA1: 0.58
		CCA2: 0.29
Unconstrained axes	0.56	CA1: 0.71
		CA2: 0.42

Table A3.7: Canonical correspondence analysis between fishers' characteristics and which changing ecosystem service is identified as most important (n=36)

	CCA1	**CCA2**
Biplot scores of response variables		
Habitat services	0.68	-0.06
Fishery services	-0.95	-0.46
Coastal protection services	-0.63	1.27
Biplot scores of explanatory variables		
Mahe	0.40	0.54
Age	-0.27	0.11
Education	0.50	-0.09
Boat length	0.10	-0.07
Technology	0.43	-0.31
Number of gear types	0.30	-0.19
Catch	0.00	-0.04
Underwater activities	0.26	0.02
Dependents	0.35	0.16
Number of fisher jobs	0.10	-0.38
Household occupational multiplicity	0.15	0.15
Income	0.05	-0.12
Eigenvalues	0.58	0.29
Proportion explained	0.29	0.15
Cumulative proportion explained	0.29	0.44

Appendices for Chapter 4

Appendix A4.1. Interview guide

Material life of style index data was not analysed for this chapter

Semi-structured interview schedule for trap fishers, Seychelles 2019 – interviewer

I. Details of interview (recorded by note taker)

II. Introductory statement and consent to participate

My name is Rosabella Mangroo from SFA and this is Anna Woodhead, a PhD student from Lancaster University in the UK. We're doing interviews with fishers to better understand what it means to live well and how the sea, and the plants and animals that live there are important. We're interested in your opinions and experiences. This information will help us understand how future changes in the sea might affect people. The interview should last about 35 – 45 minutes.

- Would you like to take part? Thank you!
- Can I turn the recorder on? Anna doesn't speak much Kreol so this is just for our notes.
- I have some information before we start the interview, which is also on this sheet that I can leave with you if you want
    - You can stop the interview at any point and withdraw your data up to a week after the interview has been done.
    - Anything you share with us will be confidential. I will store all your data securely until it is no longer needed. I will never keep personal information like your name with the other answers you give me.
    - The data will be available for other people to use, but it will be grouped together so no one person is identifiable.
    - I will use this data for research and for reports to give back to you and SFA but you will not be identifiable unless you choose to be.
- Do you have any questions?
- Are you still happy to continue with the interview?

III. Interview questions

1. Warm-up questions:

Anna wants to learn more about Seychelles. Can you tell her a bit of what life is in Seychelles is like?

2. What is living well in Seychelles?

2.a. Fishers' description of living well

-**Eski ou war ou pe viv byen isi Mahe/ Praslin?** Do you think you are living well here on Mahe/ Praslin?

- **SI WI: Kwa ki fer ki ou pe viv byen?/** What makes it so you can live well?
- **SI NON: Lwa ki fer ki ou pe mal viv?/**What makes it so can live badly?

-**Ki viv byen I vedir pou ou?**/ What does living well mean for you?

For every different thing that they say, prompt with these questions: **-Akoz sa ki ou'n mansyonen I emportan pa viv byen?/** Why is what you mentioned important to live well? **-Kwa ki fe ki sa ki on'n mansyonen I bon pou viv byen?/** What makes what you mentioned good enough to live well?

2.b. Bringing in other examples what is important for living well

-**Nou pou montre ou enn de legzanp bann keksoz ki kapab enportan pou annan pou viv byen**/ We will show you a few examples of things that can be important to have for living well.

After going through the pictures:

-Eski I annan okenn lezot koksoz ki ou war I emportan pou ou viv byen?/ Is there anything else that is important for you to live well?

3. How does the sea, and the plants and animals that live there, feature in what it means to live well in Seychelles?

We now want to ask about the sea and why it is important for you.

3.a. What does the sea, and the plants and animals that live, there mean to fishers?

-Ki Iemportans lamer, bann plant e zanimo la maer I annan pou ou? Akoz? / What importance is the sea, and the plants and animals, for you? Why?/

-**Ki rol lamer, bann plant e zanimo la maer, I annan pou ou?** / What role does the sea play for you? How else are you using the sea? E.g. Do you spend time at the beach with the family on Sundays?

3.b. Do, or how do, changes in the marine environment connect to living well?

If multiple changes, repeat the questions

-Eski in annan okenn sanzman ek lamer, ek bann plants e zanimo lamer, ki emportan pou ou? Akoz ki I emportan pou ou?/ Have there been any changes in the sea, or to the animals and the plants in the sea, that are significant/meaningful to you?/ Why have they been important for you? [Extend question to changes in the coastline if they mention it]

-Ki manyer sa bann sanzman in sanz ou ou fason viv?/ In what way have those changes changed your way of living?

-Ki manyer ou santi ou vis a vis bann sanzman ki ou war pe arrive?/ How you do feel towards the changes you see happening?

3.c. Connecting changes and living well

-Konsidere ki nou'n koz lo kwa ki fer ou viv byen e bann sanzmann lanmer e bann plante e zanmio maren eski sa bann sanzman pe afekte ou abilite viv byen?/ Considering that we talked about what makes you live well and the changes in the sea and the marine plants and animals have gone through, have these changes affected your ability to live well? [Extend question to changes in the coastline if they mention it]

-Dekri ki manyer sa bann sanzman I oe afekte ou abilite viv byen?/ Describe how have they affected your ability to live well?

4. What hopes do fishers have for the future?

-**Ki ou swete dan le fitir?/** What hopes do you have for the future?

5. Characterising interviewees

Thank you for all your answers so far. We just have a few survey questions for statistics and then we will be done. In the next question we want to ask you how satisfied you are and to give a rating.

	Pa satisfe ditou	Pa satisfe	Egalman satisfe ek pa satisfe	Satisfe	Vreman satisfe	Pa fer diferans
[X] Ki level satisfakatsyon ou annan ek ou lavi en zeneral?						
Ki level satisfakatsyon ou annan ek ou bann relasyon dan ou lavi?						
Ki level satisfakatsyon ou annan ek ou abilite pou atenn ou bezen debaz?						
[X] Ki level satisfakatsyon ou annan ek ou abilite pou atenn ou bi dan lavie?						
[X] Ki level satisfakatsyon ou annan ek letat lo lamer ek bann plante ek zanimo maren?						

- **Dapre ou ki kantite sanzman in annan avek lanmer et bann plant e zanimo maren, sa denyer 10 an?** /As for you, how much changes has there been in the sea, and marine plants and animals in the last 10 years?
    - **Napa sanzman/** No changed
    - **In sanz en pti gin/** Changed a little bit
    - **In sanz en enpe/** Changed a bit
    - **In sanz bokou/** Changed a lot
    - **In sanz konpletman**/ Changed completely

- **Ou konfidan dan ou konesans sa bann sanzmann?/** Are you confident in your knowledge of these changes?
- **[X] Ki lannen ou ti ne? /** What year were you born?
- **[X] Ki pli O ledikasyon oun konplete?** / What is the highest level of education that you have completed? (None, Primary school, Secondary school, Post-secondary school (non-tertiary education), Tertiary education, Prefer not to answer)

- **Eski ou fer scuba, free-dive o snorkelling ? /** Do you scuba-dive, free-dive or snorkel?
    - **Si wi,/** if yes,
        - **Pou lwazir?** / for fun?
        - **Pou travay swa part-time?/** For full-time work or part time
        - **Pou lezot rezon? Pa ekzamp?**/ For other reasons? For example?
- **Kan ou ti konmans lapes? /** When did you start fishing?
- **Konbyen zour par semenn ou al atrap prodwi lanmer/** How many days a week do you get products from the sea ?
- **Konbyen fwa par seman ou kwi prodwi lanmer ki ou'n atrap ou menm?/** How many times a week do you cook products from the sea that you have caught yourself?
- **[X] Konbyen lezot provizyon ki ou fe pou ou lakour apard lapes? Pa ekzamp, resevwar pansyon, lagrikiltir, ou lezot louvraz?** How many other provisioning activities do you do for your home apart from fishing (e.g. agriculture, pension, other job?)
- **Ki provizyon ki pli enportan por ou?** / Which activity is most important for you in terms of food or money?
- **[X] Konbyen dimoun ki depan lo ou?/** How many people depend on you for food or money?
- **[X] Eski ou propriyeter ou prop bato?/** Are you a boat owner?
    - **Si wi, /** If yes:
        - **Konbyen bato?/** How many boats do you own?
        - **Ki kalite bato ? /**What type of boats? (Mini-mahe, pirogue, lekonomi, whaler, lavenir, schooner, other)
    - **Si non/** if no:
        - **Eski ou skipper o lekipaz lo bato?** Are you in charge of this boat or are you crew?
- **Ki kalite lekipman ou servi ?/** What types of gear do you use ?
    - **Lasenn** (gillnet):
    - **Laliny** (handline):
    - **Kazye** (fish trap):
    - **Tir zourit** (collecting octopus - harpoon)
    - **Lezot** (other e.g. oumar, crab):

- **Eski ou servi lezot teknolozi letan pe lapes (e.g. GPS, fish-finder, robots)? /** Do you use any technology when fishing (e.g. GPS, fish-finder, robots)?
- **Eski ou proriyeter ou prop lakaz?/** Are you the owner of your own home?
- **Konbyen dimuon I reste kot lakour?**/ How many people live in your home?
- **Konbyen lasanm iannan dan lakaz?/** How sleeping rooms does you house have?
- How many floors does your house have?

- **Dan ou lakour, eski/** In your home, is:
    - **Ater dan ou lakaz i:**
        - **Lestik**
        - **Tiles**
        - **Lezot**
    - **Ou miray i:**
        - **Bloks**
        - **Siman**
        - **Metal**
        - **Ros**
        - **An dibwa**
        - **Lezot**
    - **Ou twa i:**
        - **Tol**
        - **Roof tiles**
        - **Lezot**
  - **Eski ou annan**
    - **Elektrisite**
    - **Fan**
    - **Air-con**
    - **Mobile phone:**
        - **Simple?**
        - **Smartphone?**
    - **TV:**
        - **Konbyen?**
        - **Cable swa satellite?**
    - **Internet**
    - **Computer swa laptop swa tablet** [His or someone else's]
    - **Bus or own transport?**
        - **Konbyen?**
        - **Car, pickup, scooter, motorbike, hybrid…?**
    - In the last 5 years, have you travelled outside of Seychelles for fun? Yes/No

- **[X] Dapre sa lalis lekel ant sa bann swa ki dekrir zeneralman <u>ou</u> reveni an gro?** From the list, which of these best describes <u>your</u> gross monthly income (including everything: fishing, social security and other employment)?

VIII. End of interview

Thank you very much for taking part! Do you have any questions for us? If you wish to withdraw your data from the study please let me know within 7 days. I will be writing a report with some of these results. Would you be willing to be contacted by myself or SFA to find out about that?

Appendix A4.2. Visual prompts on the three dimensions of social wellbeing

Material dimension of wellbeing

Pou viv byen I kapab enkli ou bezwen debaz. Sa bann I montre legzamp sa bann bezwen, parey:

- -Annan ase nouritir
- -Annan en lampwa, parey sa peser kazye
- -Annan ou en lakour
- -Pou annan akse ek swen la sante

Eski I annan okenn lot keksoz enpe similar ki pou ou I fer ki ou viv byen?

For every different thing that they say, prompt with these questions:

-Akoz sa ki ou'n mansyonen I emportan pa viv byen?

-Kwoi ki fe ki sa ki on'n mansyonen I bon pou viv byen

Relational dimension of wellbeing

Viv byen I kapab enkli relasyon

-Annan bon relasyon ek fanmir ek zanmi

-Annan bon relasyon ek dimuon ki on travay avek

-Annan bon relasyon ek nou kominote

-Annan bon relasyon ek dimounn ou lorganizasyon ki reprezant ou pwendvi

-Annan landwa ki ou annan latasman personel avek

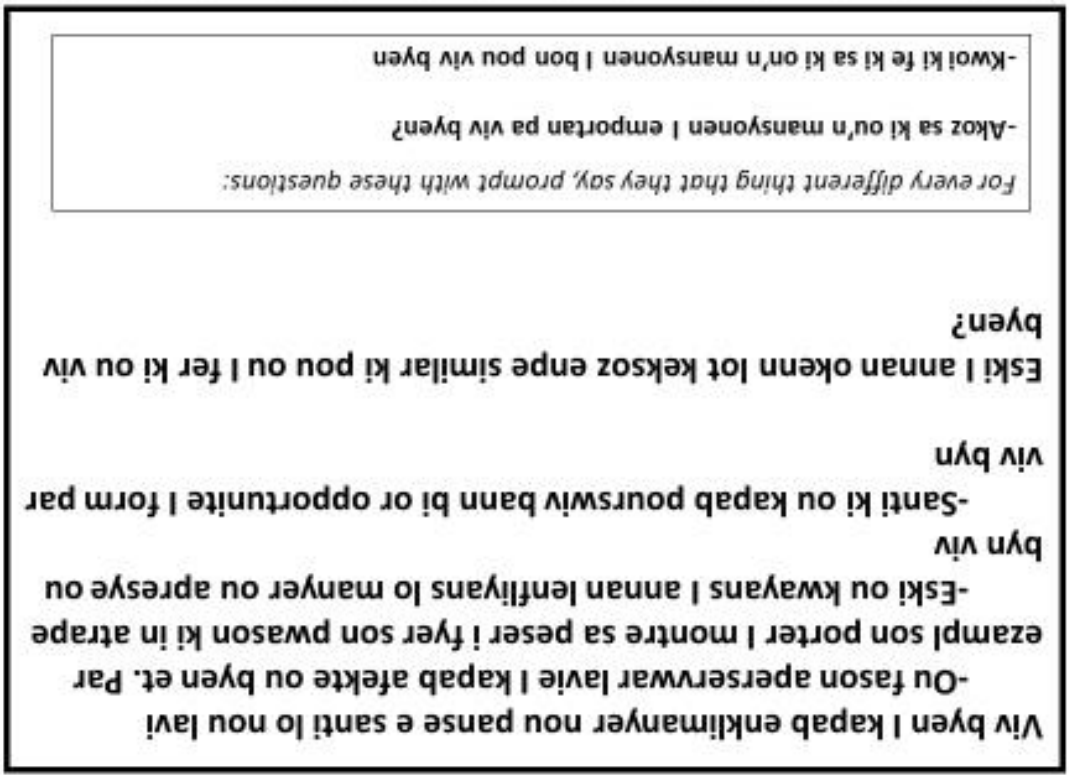
Eski I annan okenn lot keksoz enpe similar ki pou ou I fer ki ou viv byen?

For every different thing that they say, prompt with these questions:

-Akoz sa ki ou'n mansyonen I emportan pa viv byen?

-Kwoi ki fe ki sa ki on'n mansyonen I bon pou viv byen

Subjective dimension of wellbeing



Appendix A 4.3 Questions to stimulate discussion and reflection after interview between A. Woodhead and R. Mangroo

Context of interview: *What had the fisher been doing prior to the interview? Where did the interview take place? Were there many other people around? Did the fisher seem rushed? Was he comfortable having the recorder on?*
Tone of interview: *How did the interview feel? Was the participant comfortable with the questions? Did he struggle with anything? Was he really enthusiastic about anything?*
Output of the interview: *Was there anything particularly surprising from the interview?*
Summary response: 1) What does living well in Seychelles look like? *What was new or surprising in fishers' response to this question?*
Summary response: 2) What else enables living well in Seychelles? *What was new or surprising in fishers' response to this question?*
Summary response: 3) How does the sea feature in what living well looks like in Seychelles? *What was new or surprising in fishers' response to this question?*
Summary response: 4) How do changes in the sea connect to what living well looks like in Seychelles? *What was new or surprising in fishers' response to this question?*
Positionality: *What did the interview make me think of regarding the positionality of the research team? How did us being there have an effect on the area? How did the interview make us feel? What made you feel uncomfortable?*