

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

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## Abstract

1. Understanding ecosystem service change necessitates an understanding of the social and ecological dimensions of ecosystem services and how they contribute to the well-being 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 near-shore ecosystems like coral reefs.
2. 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), we conducted 41 semi-structured interviews with coral reef fishers from Seychelles, where reef ecosystems have been severely impacted by climate disturbance. We 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 well-being, we sought to identify whether reasons behind the importance of change connect to fishers' well-being.
3. 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, whereas

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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 well-being were implicated in why changing services matter.

4. 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 well-being.

#### KEYWORDS

climate change, coastal ecosystem services, coral bleaching, Seychelles, small-scale fisheries, social well-being, social-ecological system

## 1 | 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). The concept of ecosystem services that originated in efforts to guide policy (Costanza et al., 2017) has since developed into a broader framework for scientific enquiry (Evans, 2019), and is used as one of many approaches to investigate human-environment relationships (Flint et al., 2013). However, a lack of integrated understanding on the social and ecological dynamics of ecosystem services has resulted in uncertainties regarding how services will respond to future and ongoing environmental change (Bennett et al., 2015).

Relationships between the environment and human well-being within the ecosystem services concept are complex (Daw et al., 2016). In a systematic review of ecosystem service-well-being research, Cruz-Garcia et al. (2017) found that 71% of publications across Africa, Asia and Latin America assumed a link between ecosystem services and well-being without explicitly examining how this relationship occurred. Furthermore, findings from a systematic review by Blythe et al. (2020) on coastal well-being and ecosystem services revealed research biases towards certain well-being dimensions (e.g. employment) and geographical areas (e.g. 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 well-being contributions that emerge from ecosystem services.

A lack of inquiry on ecosystem service-well-being relationships, and integration of social and ecological research, is particularly relevant for tropical small island states which are highly dependent on near-shore environments (Watson et al., 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 (Barlow et al., 2018; Moberg & Folke, 1999; Woodhead et al., 2019). 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 well-being depends on coral reefs.

Perceptions of change and its implications can shape the adaptive capacity of human communities according to what is perceived to be, or not to be, a risk (Adger et al., 2008). Engaging with perceptions can help integrate social and ecological dimensions of change while dis-entangling different ecosystem service-well-being 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 (Lau et al., 2018; Martín-López et al., 2012; Oteros-Rozas et al., 2013). The importance ascribed to ecosystem services by different groups can give valuable insights into the social differentiation of ecosystem service contributions to well-being (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 et al., 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–well-being dynamics (Hicks & Cinner, 2014).

Building on the potential for perceptions research to both provide insights into socially differentiated ecosystem service–well-being relationships and explore social and ecological dimensions of ecosystem service change, 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 well-being of local fishers (Hicks et al., 2014; Lau et al., 2018). We interviewed coral reef fishers to (a) understand if and what ecosystem service changes have been perceived; (b) explore if fishers' social, demographic, economic and fishing characteristics relate to perceptions of change and (c) capture why ecosystem service changes matter and how this might connect to human well-being.

## 2 | METHODS

### 2.1 | 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, Wilson & Graham, 2019; Robinson et al., 2019). 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., 2018), 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, Wilson, & Graham, 2019; Robinson, Wilson, Robinson, et al., 2019). 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, Wilson, & Graham, 2019; Robinson, Wilson, Robinson, et al., 2019). 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<sup>2</sup>) and relatively shallow (0–75 m) Mahé plateau, which encompasses a diversity of habitats. This artisanal fleet is culturally important (Figure 1a) with c. 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 (Figure 1b), and who use traps as part of their gear assemblage to target reef-associated habitats and species (Figure 1c). These vessels, which have on average two crew members, tend to fish within 40 km of the three main inhabited islands (Mahé, Praslin and 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).

### 2.2 | 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



**FIGURE 1** Seychelles study site: (a) Depiction of a small-scale fisher at the 2019 Creole Festival; (b) Trap fisher repairing trap at sea and (c) Typical trap catch of reef-associated fish species (photo credit: A.J. Woodhead; permission for photo 1b to be used was given by the fisher)

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). More recent fisheries data however suggest that ca. half of registered fishing boats with an outboard engine are not actively fishing, meaning we may have captured a much larger proportion of active vessels (Rassool, 2021; unpubl. data). 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 geographical 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 (Hicks et al., 2014; Millennium Ecosystem Assessment, 2005). Habitat services are known to be valued by fishers across the western Indian Ocean region (Hicks et al., 2013; Lau et al., 2018). Reef-associated fisheries are essential for food security, economic and cultural reasons (Robinson, Wilson, Robinson, et al., 2019) while 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–well-being relationships, encompassing services that connect directly (e.g. provisioning services) and indirectly (e.g. supporting services) to well-being, 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 et al., 2013), and visually supported throughout the interview with two photo prompts per service (Table S1). Broad descriptions of ecosystem services were purposively used to capture all aspects of ecosystem service change for two reasons. First, delineating between the social and ecological dimensions of ecosystem services is both practically and conceptually challenging (Tusznió 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. Second, 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 near-shore environment for which ecological and environmental data are less readily available. Similarly, the values attached to ecosystems are not clearly delineated according to the activities being undertaken (Poe et al., 2016). Although snorkelling, free-diving 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 0–4: 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 change had first started (responses were categorised into 5-year time bins), and whether they considered this change to have been fast or gradual. Definitions of 'fast' and 'gradual' were left open to interpretation and responses were categorised based on the respondents' answers ('fast', 'gradual' or 'not answered (NA)'). Where changes were perceived to have occurred rapidly and then gradually (or vice versa), these were categorised as 'it depends'. 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 whether 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 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 changed service as important. We recorded both services and fishers' reasoning for choosing both services, which was subsequently used during qualitative data analysis. 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. Verbal consent was sought, as opposed to written consent, due to variability in how comfortable fishers were with written documents. 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 | Analysis

### 2.3.1 | 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 the number of ecosystem services perceived to have changed (FACTOMINER package; Lê et al., 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 whether fishers' characteristics explain any variation in responses as to which changing service is considered 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 were asked to identify a single changing service that was most important to them. Changes to habitat, fishery and coastal protection services were the only services included due to the small number of fishers who perceived changes in recreation services as 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 the changes he perceived were important and one fisher who reported 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).

### 2.3.2 | Qualitative data analysis

All qualitative analysis was conducted by hand in Microsoft Word and Excel (version 2016) by the lead author and cross-checked by CCH. Qualitative descriptions of perceived change and the reasons given for the importance of specific ecosystem service change were first coded inductively. Descriptions of perceived change, within each ecosystem service, were then coded in an iterative process and grouped thematically according to types of change reported (Braun & Clarke, 2006, 2019; Saldaña, 2009). The different themes capturing aspects of change in ecosystem services were agreed upon between the coders. Three themes were identified for changes in habitat services, two for fishery services, five for coastal protection services and four for recreation services (see Section 3 and Table S2 for example statements for each theme). Reasons given for the importance of specific ecosystem service change revealed emergent themes connected to three dimensions of human well-being (material, relational and subjective) which informed our subsequent analysis (see below).

Human well-being 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 well-being 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 well-being (also known as social well-being), 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).

**TABLE 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 <sup>a</sup>		Description	Population summary statistics <sup>b</sup>	Interpretation
Demographics	Age	Age of participant at the time of interview	Mean ( $\pm$ SD): 46.5 years ( $\pm$ 12.5 years) Range: 20–69 years	Age can be a predictor of fishers' perception of ecosystem services (Lau et al., 2018) and responses to change, for example, 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 <sup>c</sup>	Length of boat	Mean ( $\pm$ SD): 19.24 ft ( $\pm$ 2.69 ft); Range: 16–27.5 ft	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	Mean ( $\pm$ SD): 2 ( $\pm$ 1); Range: 1–4	
		Use of technology	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 (c. 7–12 fish)	
			Mean ( $\pm$ SD): 15 packets (per boat; $\pm$ 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 et al., 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 et al., 2010)
	Dependents	Number of people that the fisher supports financially or through the provisioning of fish <sup>d</sup>	Mean ( $\pm$ SD): 2 ( $\pm$ 2) people; Range: 0–5 people	Indicates dependency at household level on fishing for food or for income (see <i>Self-reported average catch</i> )
Household economics	Occupational multiplicity (household level)	Number of occupations per person in the household (excludes the fishers and their occupations)	Mean ( $\pm$ SD): 0.43 ( $\pm$ 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 <i>Self-reported average catch</i> )

(Continues)

TABLE 1 (Continued)

Fishers' characteristics <sup>a</sup>	Description	Population summary statistics <sup>b</sup>	Interpretation	
Household income	Income per month (includes fisher)	Median: 10,000–15,000 SCR/month; Range: Less than 3,000 to more than 30,000 SCR/month. 12% fishers interviewed were from households below or near to the Seychelles poverty line (4,673 SCR/month, National Bureau of Statistics Seychelles, 2019)	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	
Other ways of engaging with the marine environment	Participation in underwater activities	Percentage of fishers who free-dive, scuba dive or snorkel while 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 its impacts are perceived (Poe et al., 2014)

<sup>a</sup>All information is self-reported.

<sup>b</sup>Missing data were 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).

<sup>c</sup>Six fishers owned multiple boats. Data collected here focus only on vessels used for trap fishing or if two vessels were used for trap fishing, data on the largest vessel were recorded.

<sup>d</sup>Can differ from household number as some fishers provided fish for people outside the household.

We therefore applied a secondary coding framework based on a three-dimensional approach to well-being (Coulthard, 2012; White, 2010) to explore if and how reasons given for change being important were connected to well-being. This approach captures well-being as emerging from three inter-related dimensions that encompass the subjective, material and relational aspects of people's lives (White, 2010). Drawn from Coulthard (2012), 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 well-being (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 | RESULTS

#### 3.1 | Ranking and perceptions of ecosystem service change

##### 3.1.1 | 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 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.

##### 3.1.2 | 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 2; Figure 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 2; further supporting quotations from interviews are found in Table S7: 1–6). Some descriptions of change captured the view that changes were spatially and temporally patchy and, in some places, reversing (Table S7: 7–8). 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

**TABLE 2** Fishers' perceptions of change in four coral reef ecosystem services (see Table S1 for picture prompts)

	Habitat services	Fishery services	Coastal protection services	Recreation services
Description of ecosystem services (drawing on Hicks et al., 2013) <sup>a</sup>	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 <sup>b</sup> )	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]
<b>Perceptions of when changes in ecosystem services started (percentage of respondents who said yes to seeing a change in each ecosystem service)</b>				
Years before 2018	n = 34	n = 33	n = 32	n = 26
0-4	15%	27%	28%	27%
5-9	18%	18%	13%	19%
10-14	29%	21%	28%	19%
15-19	6%	6%	6%	15%
Over 20	18%	12%	13%	12%
Depends	0%	12%	0%	0%
NA	15%	3%	13%	8%
<b>Speed of perceived change (percentage of respondents who said yes to seeing a change in each ecosystem service)</b>				
	n = 34	n = 33	n = 32	n = 26
Gradual	67%	68%	42%	59%
Fast	30%	29%	46%	34%

(Continues)

TABLE 2 (Continued)

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
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 <sup>c</sup> )	49%	27%	12%	2%

<sup>a</sup>See limitations section for discussion on the caveats associated these definitions.

<sup>b</sup>Two fishers (5% of the 41 fishers) attributed equal importance to all services and chose not to rank them.

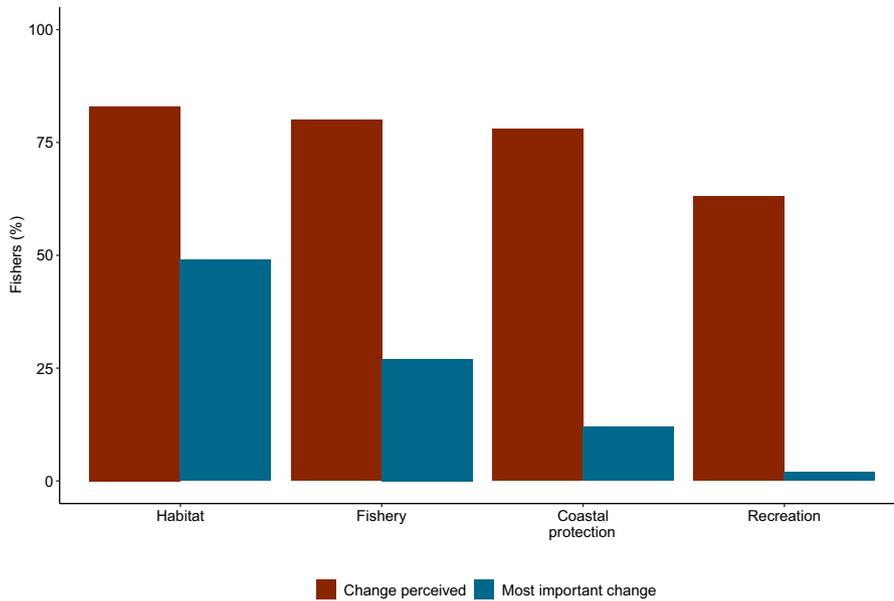
<sup>c</sup>In addition to the percentages reported, three fishers (7% of the 41 fishers) identified two changing services as jointly important (habitat and fishery services [ $n = 2$ ] and habitat and coastal protection services [ $n = 1$ ]). One fisher (2% of the 41) had observed changes in ecosystem services but did not think they were important.

had come around gradually (67%) but that opinions as to when the change in habitat services started were varied (Table 2). Nearly a third (29%) believed that the change had started 10–14 years before the survey period (2018).

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 while 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 2; Table S7: 9–13). 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 5–9 years and 21% said 10–14 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 2; Table S7: 14–19). 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 4 years before the survey period (28%) and 10–14 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 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 2; Table S7: 20–28). Of the fishers who perceived a change in recreation services, the greatest proportion thought that these changes had started recently (in the last 4 years; 27% of fishers) and more than half (59%) considered these changes to be gradual (Table 2).



**FIGURE 2** Ecosystem services that were perceived to have changed and the changing service 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)

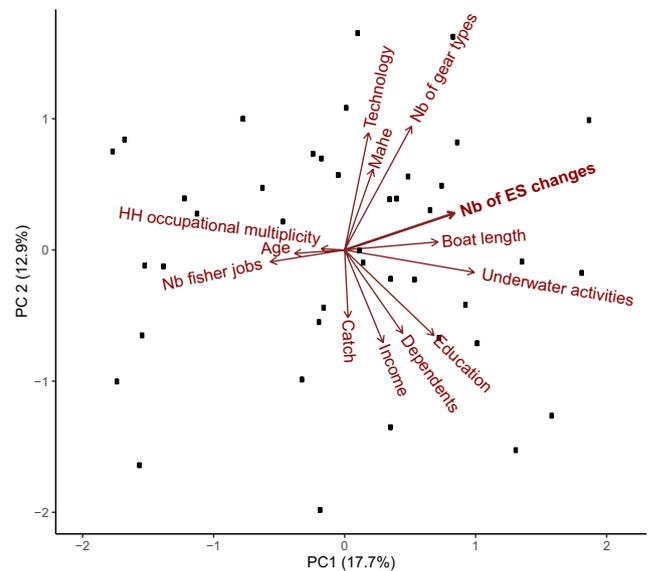
## 3.2 | Exploring differences between fishers

### 3.2.1 | 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. 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 ( $\cos^2 < 0.3$ ; Oteros-Rozas et al., 2013; Table S3; Figure 3).

### 3.2.2 | Differences in which perceived change is most important for fishers

Of the perceived changes, more than half of fishers (56%) identified changes in habitat services as most important to them. Twenty-nine percent identified changes in fishery services and 15% coastal protection services. A small number of fishers identified changes in recreation services as most important ( $n = 1$ ), could not distinguish between services ( $n = 3$ ) or did not consider the changes they perceived to be important ( $n = 1$ ; Figure 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 ( $F_{1,12} = 1.49$ ;



**FIGURE 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 S4; 'Nb of ES changes': Number of ecosystem services perceived to have changed; 'Nb of gear types': Number of gear types)

$p = 0.1$  from 999 permutations; Table S5). 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 (Figure 4; Table S6).

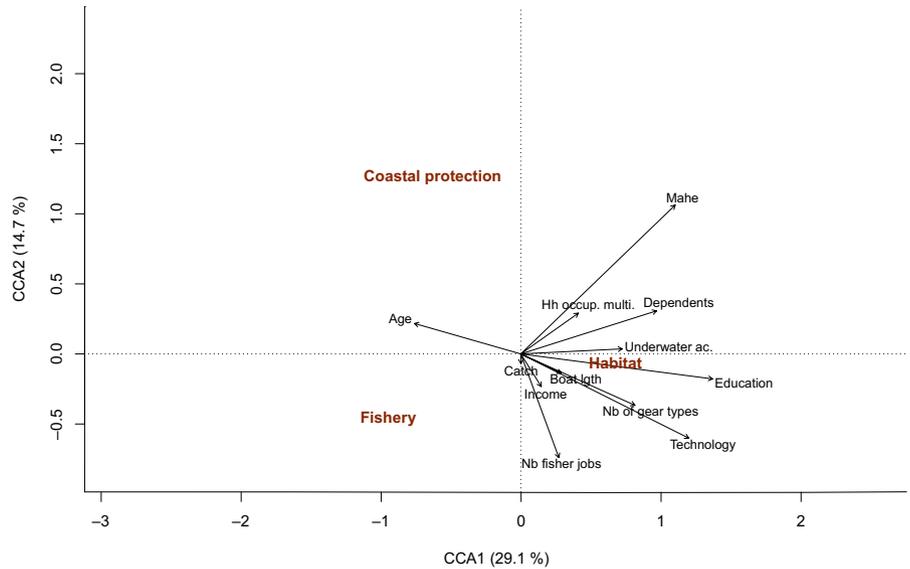
### 3.3 | Aspects of well-being that emerged in the importance of changing ecosystem services

In all, 19 fishers brought up recognisable aspects of well-being in their reasons for identifying perceived changes as important. We grouped these aspects of well-being under the three dimensions of our approach,

namely the subjective, relational and material dimensions of well-being (Table 3). Note that these dimensions are inter-related (Coulthard, 2012; White, 2010) and many of the interview excerpts used illustratively in Table 3 could be placed in more than one dimension.

Some fishers expressed sadness (Table 3–[1]) or concern for the perceived mismatch between reality and how they felt the reef

**FIGURE 4** Canonical correspondence analysis biplot. Of the variance that fishers' characteristics do explain (44%), this biplot shows the associations between characteristics and which changing 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)



**TABLE 3** Aspects of well-being that emerge in fishers' reasoning for identifying perceived changes in ecosystem services as important. These are grouped under a three-dimensional approach to well-being (Coulthard, 2012; White, 2010)

Dimensions of well-being	Emergent aspects of well-being	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 emperor red snapper (bourzwa) <sup>a</sup> '. [changes in fishery services; 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]

<sup>a</sup>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.

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–[2]; Table S7: 32).

Changes in recreational services were, for another fisher, connected to changes in personal relationships with other people (Table 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–[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–[5]) or the loss of knowledge between generations (Table S7: 33–34).

Changes in the type and availability of ecological resources provided by the reef (Table 3–[6]), potential impacts on the activity of fishing as a livelihood (Table 3–[7]), and impacts on food security at a national level (Table 3–[8]) also emerged as areas of concern for material well-being.

## 4 | 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, Wilson, & Graham, 2019; Robinson, Wilson, Jennings, et al., 2019) and wave energy hitting the coastline has increased (Sheppard et al., 2005). Tourism development has further modified coastal areas (Giampiccoli et al., 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, free-diving 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 well-being in why changes in ecosystem services associated with reef ecosystems are

important, which connected to subjective, relational and/or material dimensions of well-being.

### 4.1 | 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 fisher's 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 et al., 2011) suggests fishers are responding to perceived changes 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, Wilson, Robinson, et al., 2019). Fishers, and many natural resource users, play an active role in the emergence of ecosystem services (Fischer & Eastwood, 2016). Although 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, detract from time spent with their family. This would indicate a well-being trade-off for fishers who are prioritising aspects of well-being attached to fishery services (e.g. income, food, sense of self; Coulthard, 2012), over other aspects of well-being, 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 et al., 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 well-being, then arguably this should be considered as part of ecosystem service change, even where well-being aspects unrelated to ecosystem services are implicated.

Coastal erosion and flooding have acute and visible effects on discrete geographical 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 et al., 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 et al., 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, indicates that changes in ecosystem services and how they relate to well-being 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 changes (Ecott, 2015)—changes that will undoubtedly 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.

#### 4.1.1 | Limitations in capturing perceptions of 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-well-being 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 (Tusznió et al., 2020). However, given the wider context of social and ecological change in Seychelles, different definitions of services may have elucidated different types of ecosystem service change, with possible implications for how changes in services are prioritised. Our approach also presents some challenges in connecting perceptions of change to specific reef processes. This is in part due to the scale of the descriptions and fishers' own experiences relative to environmental processes on reefs, and inter-dependencies between services. 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). Fishers value both coastal protection services and recreation services that are associated with reef habitats (Hicks et al., 2013) but may have different individual interpretations on whether changes associated with reef degradation constitute a change in coastal protection services or a change in recreation services. Moving forward, a shift away from an ecosystem specific understanding of services, described as overly reductionist by Dawson and 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 (4 years prior to 2018), changes in coastal protection services were perceived to be either very recent (4 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 geographical variation in how changes are experienced. However, the variability in responses given around the timing of perceived changes also highlights 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 et al., 2011). We left the definition of ‘fast’ or ‘gradual’ change open to fishers’ interpretation. Reported speed of change is therefore also subjective. 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 et al., 2018).

## 4.2 | 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, ongoing, 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 such as snorkelling, free-diving 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 et al., 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 well-being, into the future (Poe et al., 2014).

Fishers who identified changes in fishery services as most important tended to be from Praslin/La Digue and/or have low household occupational multiplicity. Praslin and 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 et al., 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 et al., 2014) and the practice of salting surplus fish as additional income. Fishers who rely predominantly on fishing at an individual level and/or who were older also identified changes in coastal protection as most important, though the association with age was weaker. Changes in coastal protection can make fishing more physically challenging as fishers have to deal with increased waviness and coastal flooding, and may therefore affect the accessibility of fishing, with older fishers being more at risk than others. 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.

## 4.3 | Well-being as it emerges in perceptions of change

Different aspects of well-being 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 well-being, 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 well-being. 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]. Although the data were too limited to further explore relational aspects of well-being, it corroborates wider research that recognises connections between services, in this case the framing provided by cultural services such as knowledge generation and bequest, which shapes the importance given to perceived changes in fishery services (Fish et al., 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 et al., 2011). Human well-being 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 well-being 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 well-being, and therein, the role of coral-reef-associated ecosystem services (e.g. Abunge et al., 2013). This approach can help unpack differences between people's ecosystem service-well-being relationships (Coulthard et al., 2018). The implications of ecosystem service change for different groups, particularly those that are more marginalised (Daw et al., 2015), remain understudied in coastal ecosystems, particularly outside of Europe (Blythe et al., 2020). A well-being focus could also provide a more nuanced understanding of how people engage with their environment, not limited to ecosystem boundaries (Dawson & Martin, 2015).

## 5 | CONCLUSIONS

Although recognising the importance of social differentiation in environment-well-being 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., 2018). Multiple aspects of well-being were implicated in these perceived changes, including subjective well-being which is shaped by fishers' perceptions of their surroundings (White, 2010). Subjective well-being can therefore be implicated prior to or without changes in ecosystem service-material well-being relationships. Any assessment of changing ecosystem services should therefore include approaches through which changes in subjective well-being 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' well-being. Perception-based data allow 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 focusing on single ecosystems (Dawson & Martin, 2015). An alternative approach may be to centre future research on locally relevant understandings of well-being and from there investigate the implications of environmental change on ecosystem service-well-being relationships, an area which remains under-researched (Blythe et al., 2020; Cruz-Garcia et al., 2017). The prioritisation of supporting services and the understanding that fishers have of how ecosystem services relate to one another provide 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.

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## CONFLICTS OF INTEREST

On behalf of all authors, the corresponding author states that there are no conflicts of interest.

## AUTHORS' CONTRIBUTIONS

A.J.W., C.C.H., N.A.J.G. and A.V.N. conceived the ideas; A.J.W. and C.C.H. designed the methodology; A.J.W., N.B., S.M. and M.-C.B. collected the data; A.J.W. analysed the data; A.J.W. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

## DATA AVAILABILITY STATEMENT

Quantitative data from the interviews are publicly available through Lancaster University <https://doi.org/10.17635/lancaster/researchdata/464> (Woodhead et al., 2021). Fishing communities in Seychelles are close-knit so some variables (fine-scale geographical information on landing sites and age) have been removed to maintain participants' anonymity.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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