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Impacts of climate change for coastal fishers and implications for fisheries

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Abstract

Coastal Social–Ecological Systems (SESs) are subject to several stresses, including climate change, that challenge fisheries and natural resource management. Fishers are front-line observers of changes occurring both on the coast and in the sea and are among the first people to be affected by these changes. In this study, we perform a meta-analysis of observations and adaptations to climate change by subsistence-oriented coastal fishers extracted from a global review of peer-reviewed and grey literature. Fishers' observations compiled from across the globe indicate increased temperatures and changes in weather patterns, as well as coastal erosion, sea level rise and shifts in species range and behaviours. Coastal areas offer a wide array of resources for diversifying livelihoods, but climate change is reducing these options. Specifically, climate change could reduce the resilience of fishers' communities, limiting options for diversification or forcing fishers to abandon their houses or villages.

KEYWORDS
diversification strategies, fishery, resilience, Social–Ecological Systems (SESs), Traditional Ecological Knowledge

1 | INTRODUCTION

Marine and coastal ecosystems are interrelated with human societies in complex Social–Ecological Systems (SESs) that are rapidly shifting with climate change and other environmental stressors (Adger, Hughes, Folke, Carpenter, & Rockström, 2005; Glaeser & Glaeser, 2010; Perry, Ommer, Barange, & Werner, 2010). Impacts on these ecosystems are still understudied, but existing research suggests a number of effects from changing climate such as an increase in ocean surface temperatures, acidification, more intense storm systems and sea level rise (Hoegh-Guldberg & Bruno, 2010; Nicholls & Cazenave, 2010; Stocker *et al.*, 2013). Indirect consequences include loss of homes and cultural sites (e.g., Henry & Jeffery, 2008; O'Neill, Green, & Lui, 2012), disease epidemics—especially after floods or hurricanes (e.g., Bunce, Rosendo, & Brown, 2010), and reduced fish catches (e.g., Allison *et al.*, 2009; Bunce, Mee, Rodwell, & Gibb, 2009; Cheung, Watson, & Pauly, 2013) that threaten fishers' food security (Hollowed *et al.*, 2013; Vermeulen, Campbell, & Ingram, 2012). These changes, together with other anthropogenic impacts such as overfishing, pollution and contamination, are altering the marine and coastal ecological systems upon which coastal people rely (Hollowed *et al.*, 2013; Rice & Garcia, 2011).

Food security is of concern to subsistence-oriented fishers not only because of access to basic nutrients, but also because of its links to cultural resilience (FAO, 1996). Fish and shellfish species are often foundational to these communities, providing proteins and essential nutrients (such as vitamins and minerals) and are key components of cultural identity (FAO, 2009; Garibaldi & Turner, 2004; Golden *et al.*, 2016; Kawarazuka & Béné, 2010; Kuhnlein, Erasmus, & Spigelski, 2009; Kuhnlein *et al.*, 2006; Merino *et al.*, 2012; Rice & Garcia, 2011). However, declines in the availability of sea-based foods are forcing many subsistence-oriented fishers to change their diets (Gazeau *et al.*, 2007; Islam & Tanaka, 2004). Urgent efforts are therefore required to ensure the resilience of fishers' food systems (Marshall *et al.*, 2010).

Subsistence-oriented fishers are front line observers of climate-related changes of coastal and marine environments. For instance, because an ability to read and forecast weather is critical to fishers' survival, they are skilled at discerning local patterns of seasonal variability. They have a close relationship with and deep understanding of their environments based on long-term experiences and learning about ecological processes (Savo *et al.*, 2016). Fishers also disseminate information by sharing with community members and passing on skills to novice fishers (Deb, 2015; García-Quijano, 2009). In these communities, the accumulation of this shared knowledge over generations results in what is often referred to as Traditional Ecological Knowledge (TEK) (Nakashima, Galloway McLean, Thulstrup, Ramos Castillo, & Rubis, 2012; Savo *et al.*, 2016; Turner & Berkes, 2006). TEK underlies fishers' ability to detect and respond to local conditions resulting from complex ecological relationships. This rich knowledge base is rooted in local SESs and situates these fishers as valuable sources of information about changes in weather and climate as well as related impacts over time on physical and biological environments (e.g., Deb, 2015; Grant & Berkes, 2004). Thus, compiling observations of subsistence-oriented fishers from around the world can contribute uniquely to our understanding of climate-driven changes in coastal and marine environments.

Increasingly, researchers and resource managers are analysing the potential impacts of climate change on coastal environments to aid in the design of adaptation strategies for affected communities (e.g., Cinner *et al.*, 2012). However, these studies tend to emphasize adaptations proposed by researchers rather than locally developed solutions. Investigating and compiling the global record of strategies used by subsistence-oriented fishers to deal with climate-driven environmental changes offers a meta-view of locally developed solutions that are already being implemented by communities. This information is invaluable for climate change-related policy development, planning and management across multiple scales of governance, but particularly for community-initiated projects where examples of local responses in other areas may be highly salient (Kalikoski, Quevedo Neto, & Almudi, 2010).

In this study, we provide a global, meta-analysis of coastal subsistence-oriented fishers' observations of climatic changes, the impacts of these changes on local SESs and adaptation strategies being implemented by fishers in response to climate-induced environmental changes. We only included information reported in the literature but gathered through interviews with fishers. Focusing on observations made by fishers living in or near coastal areas, lagoons and estuaries, we synthesize fishers' observations about climate and climate-driven changes. We report fishers' adaptations to these changes and discuss the relevance of our findings to planning and management in adapting to climate change.

2 | MATERIALS AND METHODS

Our data derive from a larger study that collated observations of climate change and adaptive responses by subsistence-oriented peoples worldwide. Observations were collected from peer-reviewed research papers, books, theses, participatory videos and grey literature reports, originally written in English or with a translation in English. These sources were acquired using keyword searches with different online search engines such as Google, Google Scholar and ScienceDirect (see Savo *et al.*, 2016 for more details). We defined an "observation" as a primary observation either cited or stated in the source material by individuals and/or groups who are identified as subsistence-oriented fishers (i.e., fishers depending on the fishery for subsistence) (see also Savo *et al.*, 2016). This definition excludes observations from modern commercial fishers as well as secondary assessments from researchers (i.e., impacts assessed by researchers in fishers' communities). We then grouped all observations into four categories: changes in weather and climate, changes in the physical components of the environment, changes in the biological components of the environment and impacts on culture and well-being.

For this study, we extracted a subset of observations from coastal, lagoon and estuarine areas. We eliminated sources dealing with non-maritime countries and freshwater fisheries, but included those dealing with lagoon and estuarine communities if fishers were likely to be active in both ocean and rivers. Communities with mixed livelihood strategies (e.g., farming and fishing) were also included.

We treated each observation as a separate record and linked it to its geographical location, major descriptive features of the study such as dominant vegetation and climate, the bibliographic source and community attributes (e.g., cultural group, livelihoods). We analysed the data consistent with the tenets of grounded theory so as to detect and clarify emergent patterns rather than rely on prior assumptions (Glaser & Strauss, 2012). Also, consistent with subjective contextual analysis of texts (Titscher, Myer, Wodak, & Vetter, 2000), we further classified the observations of the first three main categories into 42 subcategories as described in Savo *et al.* (2016). We subclassified the category "impacts on culture and well-being" (category four) into five subcategories based on reported impacts of climate change on humans (see also Table S1). Each separate record was geo-referenced using the name of the locality and the open source Geonames geographical database (http://www.geonames.org). If the settlement name was not listed in this database, we used the centroid of the higher administrative division (e.g., county, district) or the closest village/locality. We graphically represented the observational records and analysed the spatial data using the WGS 1984 geographic coordinate system in ArcGIS 10.2. We reported results for categories 1–3 as proportions both by latitude in 5-degree bins and by subcategory. For category four (impacts on culture and well-being), there were few observational records in coastal localities so we reported these results qualitatively (Section 3.1.4). Refer to Savo *et al.* (2016) for additional details about the organization and classification of data.

We used the same methodology to collect information about coastal fishers' adaptations to climate change, which we organized in a separate database. Similar to the initial database, we treated each adaptation entry as a separate record linked to the dominant vegetation and climate, bibliographic source, community attributes and included one additional attribute—the specific problem being addressed by the adaptation strategy. We classified the strategies into one or more of twelve categories. The first nine categories integrate adaptation strategy classifications suggested by Agrawal (2008) and

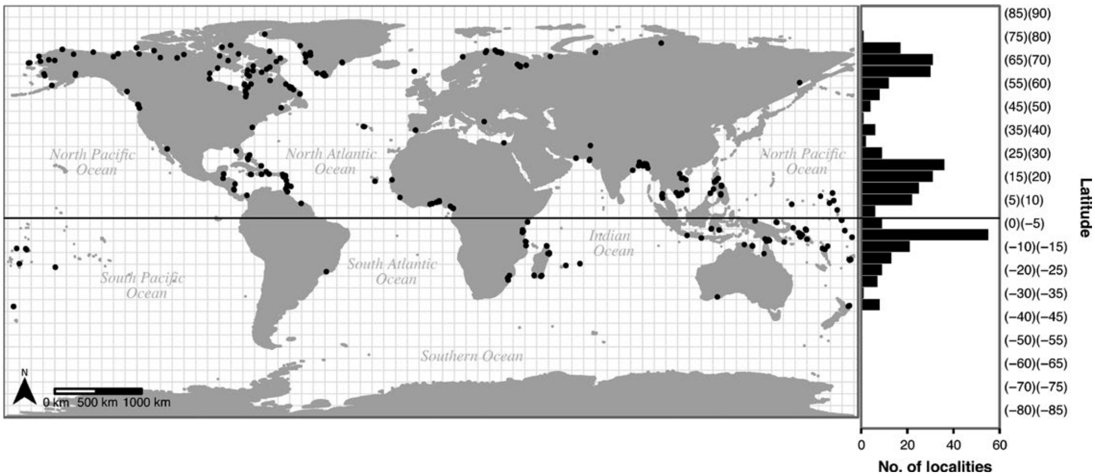

FIGURE 1 Geographical and latitudinal distribution of localities with available data. Note the concentration of fishers' communities in the intertropical zone (20°N to 20°S). Also, the Northern Hemisphere has more data than the Southern hemisphere

Gómez-Baggethun, Reyes-García, Olsson, and Montes (2012) and include diversification, exchange, forecasting, mobility, pooling, rationing, selection and storage. To better reflect our data, we added four additional categories: conservation/protection, knowledge, labour re-organization and rituals. Descriptions of these categories are available in Table S2.

3 | RESULTS

Our review of subsistence-oriented fishers' observations of and adaptations to climate change led to a selection of 249 sources covering 64 countries, representing 367 communities ("localities") (Figure 1). The countries with the most available data are small island states (e.g., Caribbean islands, Pacific islands). A high concentration of fishers' communities is represented in the intertropical zone (between approximately −25° and 25° latitude; Figure 1), which supports the notion of a "tropical majority" of small-scale fishers (Badjeck, Allison, Halls, & Dulvy, 2010). Many communities are also based in the Northern Arctic and sub-Arctic latitudes (between 55° and 75°; Figure 1), where subsistence is closely tied to marine food resources such as fish and sea mammals. No data were available for countries without a stable population (e.g., Antarctica) or for city states (e.g., Monaco). Very few observations are from South America where climate change is projected to have high economic impact (Brander, 2007; FAO, 2006) or from Europe, but these gaps are likely due to the limited pool of available sources (Savo *et al.*, 2016) rather than low numbers of subsistence-oriented fishers (see, e.g., MacKenzie, 2001) or our selection criteria (i.e., there are only few papers reporting observations by commercial fishers).

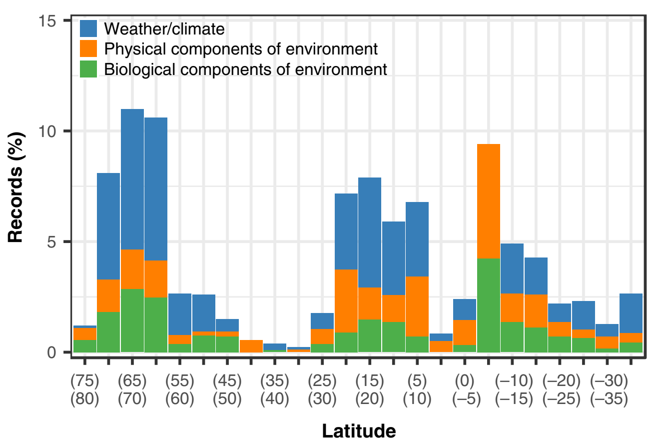

FIGURE 2 Latitudinal distribution of observations for main thematic categories*.
*Category four ("impacts on culture and well-being") is not included because of small sample sizes. [Colour figure can be viewed at wileyonlinelibrary.com]

3.1 | Observations

Combining all records of fishers' observations, the total number of entries sums to 1898. About half of all these entries (~50%) are about observations of changes in weather and climate, ~24% are of changes in the physical components of the environment, and ~22% are of changes in the biological components of the environment (Figure 2; the category "impacts on culture and well-being" [~4% of entries] is not included). The subsections below discuss results for each of the four main categories.

3.1.1 | Changes in weather and climate

Nine hundred and forty-three records of observations of changes in climate and weather occur in 89% of the 367 localities. The majority of observations occur in the northern latitudes and the intertropical zone (Figure 3). Increased air temperature (47% of localities), changes in weather patterns/seasonality (47% of localities) and increased extreme weather events (41% of localities) are the most frequently reported (19%, 18% and 16% of records of the climate/weather observations, respectively; Figure 3). All three of these subcategories are reported more frequently in the intertropical zone, but changes in weather patterns/seasonality are also often observed in the northern latitudes.

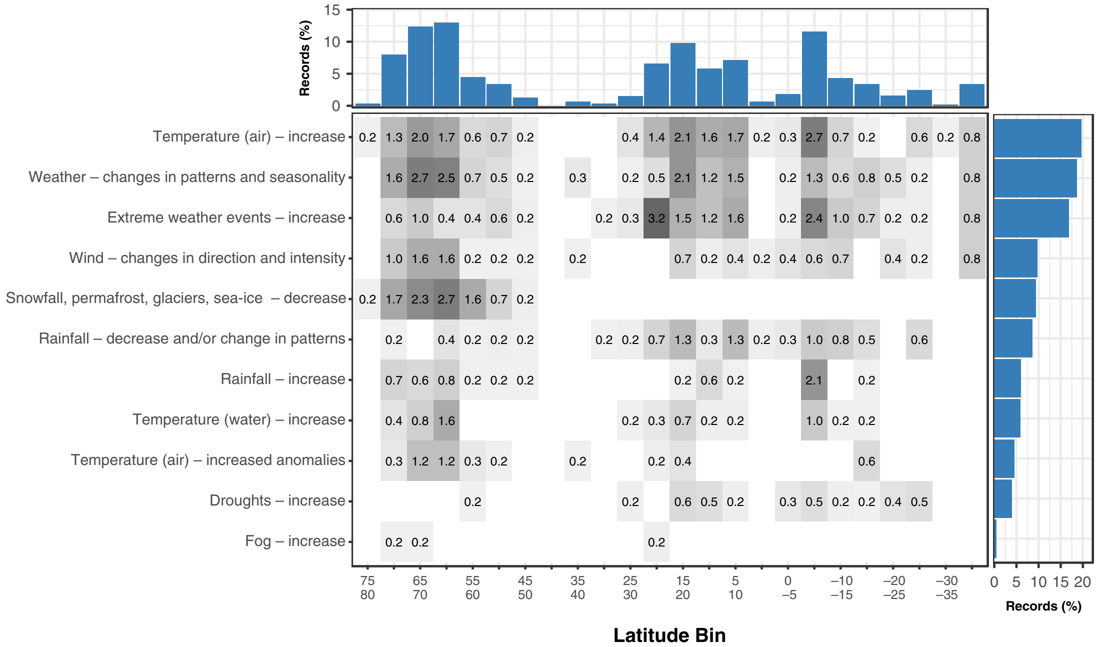

FIGURE 3 Observations by fishers of changes in weather and climate by latitude and category*.
*Shading in the table is a gradient from the highest (dark grey) to lowest (light grey) proportion of all 943 records of the observations in the weather and climate category. Bar charts indicate the total proportion of records by latitude (top) and subcategory (right). [Colour figure can be viewed at wileyonlinelibrary.com]

Other studies suggest the changes included in these three subcategories can have a variety of adverse effects on the coastal environment (Harley *et al.*, 2006), local economy (Allison *et al.*, 2009; Strobl, 2011), society and culture (Adger, Barnett, Brown, Marshall, & O'Brien, 2013; Adger *et al.*, 2005). Cyclones or hurricanes, for example, can devastate terrestrial resources and ecosystems. Understanding and reading weather is crucially important for fishers' safety and is of particular concern in the Arctic where weather conditions can already be extreme (e.g., Ford, Pearce, Gilligan, Smit, & Oakes, 2008; Prno *et al.*, 2011). More unpredictable storms endanger fishers at sea and force changes in seasonal fishing schedules (e.g., Fisher, 2011; Turunen *et al.*, 2011), which may, in turn, affect catch availability and the local economy.

In 36% of localities, fishers also report decreases, increases and/or changes in the duration and timing of rainfall (14% of records of the climate/weather observations). These results should be considered alongside Savo *et al.* (2016), where changes in rainfall are the most commonly reported type of observation by subsistence-based communities globally. While fishers appear to observe such changes less commonly, their reports do suggest some coastal environments are experiencing shifts in rainfall that may affect fish populations. Research suggests such shifts are important to monitor because many fishes and shellfish depend on seasonal fluxes of precipitation (e.g., monsoons, snowmelt) that can generate major nutrient transport from freshwater rivers to marine and estuarine environments (e.g., Doney *et al.*, 2012; Salen-Picard, Darnaude, Arlhac, & Harmelin-Vivien, 2002).

Changes in wind direction and intensity (24% of localities; 9% of records of the climate/weather observations) can reduce weather predictability. Different wind directions are generally associated with specific weather patterns (e.g., rain, storms) that are well known to subsistence fishers based on their long-term knowledge of particular areas (i.e., TEK) (e.g., Bunce *et al.*, 2010; King, Skipper, & Tawhai, 2008). Unpredictable winds can hinder fishers' ability to read signs of incoming storms, which critically affects ocean navigation and safety, particularly given the small vessels typically used by subsistence fishers (Glaeser & Glaeser, 2010; Grant & Berkes, 2004).

Fishers in several locations also note increases in seawater temperature (13% of localities; 5% of records of the climate/weather observations). Sixty-five per cent (31 of 48) of these localities are located within global marine hotspots for increases in sea-surface temperatures (Hobday & Pecl, 2014). The rise in sea-surface temperatures is especially relevant for fishers because of the expected changes in fish distribution and abundance (Cheung *et al.*, 2013; Perry, 2011; Weatherdon, Ota, Jones, Close, & Cheung, 2016). Fishers' awareness of these changes may also indicate these localities are ideal locations to study adaptation strategies already being implemented.

3.1.2 | Changes in the physical components of the environment

Fishers' observations of changes in the physical components of the environment (*N* of records = 456) occur in 64% of the 367 localities (Figure 4). Much of the data collected in these regions are from island states in the intertropical zone. Although less frequent, observations outside subtropical and equatorial regions suggest changes are also occurring across other latitudes.

Fishers most often report three linked phenomena in the physical environment category: coastal erosion (26% of localities, 21% of records of the physical environment observations), sea level rise (25% of

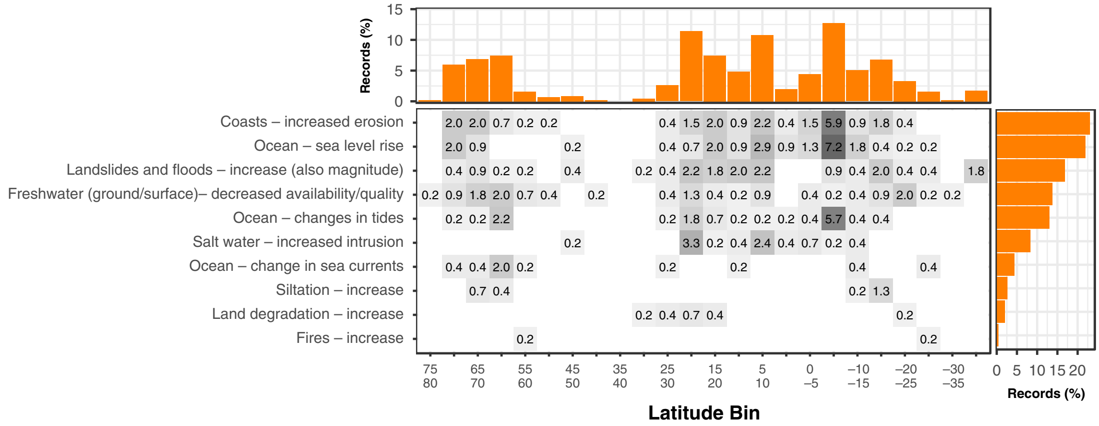

FIGURE 4 Observations by fishers of changes in the physical components of the environment by latitude and category*. *Shading in the table is a gradient from the highest (dark grey) to lowest (light grey) proportion of all 456 records of the observations in the physical environment category. Bar charts indicate the total proportion of records by latitude (top) and subcategory (right). [Colour figure can be viewed at wileyonlinelibrary.com]

localities, 20% of records of the physical environment observations) and a rising frequency and magnitude of floods/landslides (20% of localities, 16% of records of the physical environment observations). Fishers relate coastal erosion to sea level rise and floods, but also to concurrent phenomena such as higher tides, more frequent storm surges and melting sea-ice and permafrost (in the Arctic). Fishers understand that floods are exacerbated by changing local weather patterns that produce more frequent heavy rainfall events, increased river siltation and more rapid snowmelt (e.g., Logavatu, 2011; Mataki, Koshy, & Nair, 2006; Vlassova, 2006). Physical changes can make fishing more challenging if, for example, natural features useful for navigation disappear with eroding coastlines. Physical changes can also lead to loss of land/property (which can be extreme in low-lying atolls), loss of coastal vegetation (palms, mangroves) and reduced access to freshwater (see, e.g., Barnett & Adger, 2003; Kuruppu & Liverman, 2011; Rudiak-Gould, 2012). Indeed, a reduction in fresh water availability was observed in 15% of localities (12% of records of the physical environment observations), often combined with saltwater intrusion into local groundwater sources (10% of localities; 8% of records of the physical environment observations).

3.1.3 | Changes in the biological components of the environment

Fishers' observations of changes in the biological components of the environment (*N* of records = 415) occur in 57% of the 367 localities. These observations are concentrated in the Northern Arctic and sub-Arctic (Figure 5). Most records of observations are of decreased quantity and quality of crops (21% of localities; 19% of records of the biological environment observations); changes in fish and animal behaviours such as shifting migration patterns and distributions (18% of localities; 16% of records of the biological environment observations); and decreased populations of fish, corals, mammals and birds (14% of localities; 13% of records of the biological environment observations). The inclusion of terrestrial species is not surprising as fishers often engage in secondary subsistence activities such as farming or hunting. The impacts on crops as well as increased pests are more concentrated in the intertropical zone (10% of localities; 9% of records of the biological environment observations). Changes in fish and animal behaviours and the appearance of new plant species are more frequently reported in the northern latitudes (10% of localities; 9% of records of the biological environment observations). Observations about decreases in fish and animal populations are relatively evenly distributed across regions.

A general decline of local terrestrial and aquatic biodiversity is rarely reported (6% of localities; 5% of records of the biological environment observations), but may not be commonly observed in aggregate by fishers who tend to report the other specific changes already highlighted. Observations about increased incidents of diseases in animals (5% of localities; 4% of records of the biological environment observations) and changes in plant phenology (6% of localities; 6% of records of the biological environment observations) are also relatively uncommon.

Changes in the biological environment are strongly linked to fishers' livelihoods. Subsistence fisheries are directly affected if fish populations change and indirectly affected if changes occur throughout marine/coastal food webs. As already noted, fish and other seafood are not the only sources of sustenance for fishers—many families forage for plants, keep gardens or small orchards for home consumption, hunt and/or raise livestock. Changes in the availability of such non-primary food resources can affect fishers' food security (e.g., Aranani, Sirikolo, & Watoto, 2010; Bunce *et al.*, 2010; Waiyaki, Owiti, Angwenyi, & Muriuki, 2012). Collectively, the observations reported for this category indicate that the structure of several biological communities and ecosystems are changing in ways that could require fishers' communities to adapt.

3.1.4 | Impacts of climate change on culture and well-being of coastal fishers

Some fishers' communities feel that climate change also affects their cultural identity, well-being and the maintenance and transmission of TEK (Table S1). Examples of these consequences are not frequently

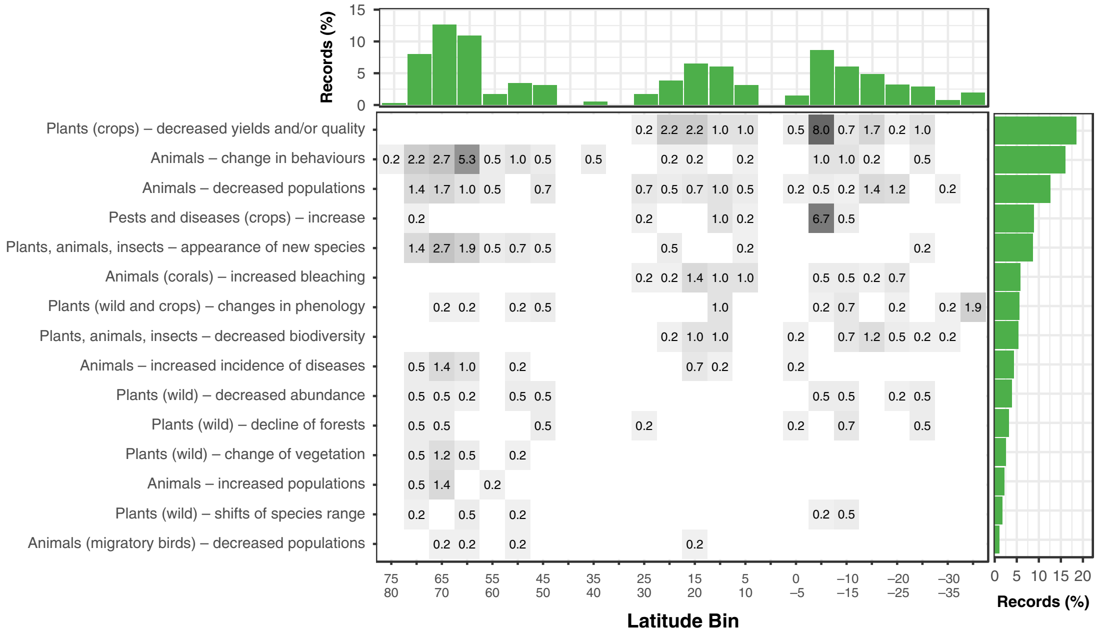

FIGURE 5 Observations by fishers of changes in the biological components of the environment by latitude and category*. *Shading in the table is a gradient from the highest (dark grey) to lowest (light grey) proportion of all 415 records of the observations in the biological environment category. Bar charts indicate the total proportion of records by latitude (top) and subcategory (right). [Colour figure can be viewed at wileyonlinelibrary.com]

reported, likely because they are under-represented in the literature. Fishers' observations about the cultural impacts of climate change include the loss of culturally important sites due to coastal erosion (e.g., Donatuto, Grossman, Konovsky, Grossman, & Campbell, 2014; Gordon *et al.*, 2008; O'Neill *et al.*, 2012), the decline and extirpation of cultural keystone species (cf. Garibaldi & Turner, 2004) and changes in weather conditions that preclude the performance of activities linked to cultural identity and the transmission of TEK (e.g., Ginsburg, 2011; Taverniers, 2010). Exclusively in the Arctic, climate-related conditions such as decreases in cold and ice affect the mental and physical well-being of fishers (e.g., Berkes & Jolly, 2001; Ford & Goldhar, 2012). Some fishers' communities (8% of localities) also observe health effects, such as skin rashes, burns and waterborne diseases, especially after extreme events such as floods and hurricanes (e.g., Furgal & Seguin, 2006; Sarker & Hossain, 2012). These observations, even if not numerous, support the research of Patz, Campbell-Lendrum, Holloway, and Foley (2005), which suggests an increase in some diseases due to climate change.

3.2 | Adaptation strategies

In general, how individuals and communities adapt to climate change depends on a multitude of social and ecological factors including cultural norms, local environmental conditions, worldview, societal values, lifestyle, age, gender, socio-economic status and processes of marginalization and inequality (e.g., Adger *et al.*, 2013; Dolan & Walker, 2006; Perry *et al.*, 2010). Like many communities elsewhere, subsistence-oriented fishers are not passively experiencing climatic changes. We found 1182 records of adaptation strategies from fishers in coastal environments (extracted from 162 studies in 49 countries). These strategies include a variety of approaches related to fisheries (e.g., selection of fishing sites) but also related to other aspects of fishers' lives with a particular emphasis on counteracting and/or repairing the effects of more frequent extreme weather events (e.g., building sea walls, rainwater harvesting). Table S2 describes strategies that are common and recurrent among subsistence-oriented fishers worldwide, and Figure 6 shows the distribution of reports for each of these strategies in our dataset.

At 26% of records, diversification is the most frequently reported adaptation strategy (Figure 6). Coastal fishers rely on food sources from both marine and terrestrial ecosystems (Newell, Ommer, & Ommer, 1999; Turner, Davidson-Hunt, & O'Flaherty, 2003) because coastal areas are transition zones between these ecosystems and as such they offer relatively greater choice and flexibility in the use of resources. Fishers diversify sources of income, switch primary livelihoods, change gathering/fishing sites and replace food sources (e.g., Uy, Takeuchi, & Shaw, 2011; Waiyaki *et al.*, 2012). The diversification choices fishers make might depend on a range of factors including cultural context, economic options and environmental context (i.e., switching from fishing to farming would not be possible in the Arctic). At the most fundamental level, people select opportunities and options given their skills and the resources they can reach, afford or use.

Fishers in many localities, especially island communities, report strategies to conserve or protect their environment from climate-related changes (17% of records). These strategies are primarily of fishers planting mangroves and building seawalls to counteract erosion, or planting trees as windbreaks (e.g., Henry, Jeffery, & Pam, 2008). In a few cases, fishers are adopting management strategies oriented towards preserving fish populations impacted by climate change (e.g.,

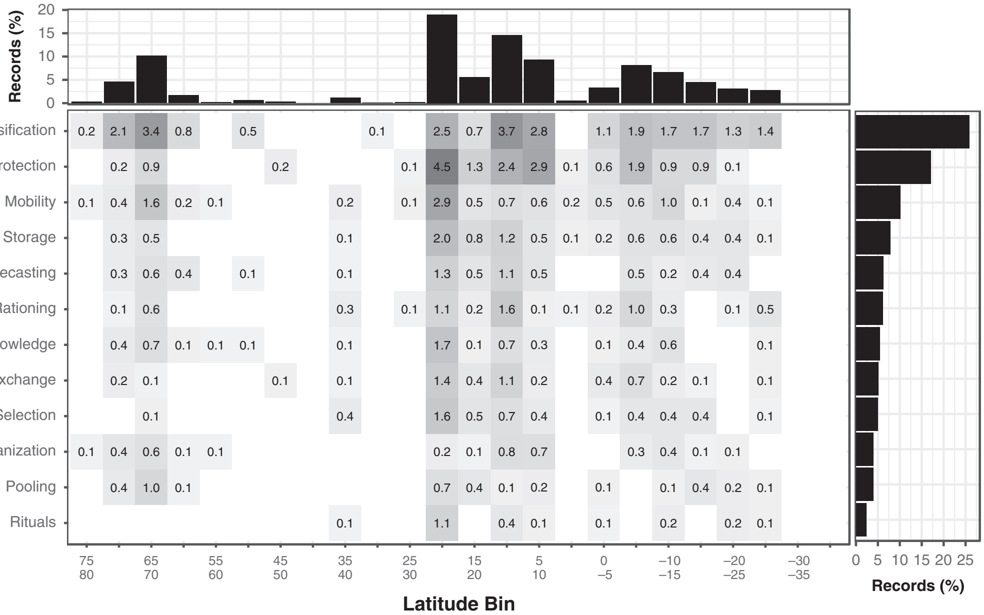

FIGURE 6 Fishers' adaptation strategies by latitude and category*.
*Shading in the table is a gradient from the highest (dark grey) to lowest (light grey) proportion of all records of the adaptation strategies. Bar charts indicate the total proportion of records by latitude (top) and subcategory (right)

Galloway McLean, 2010). Other strategies include building storm shelters and windbreaks (e.g., Resture, 2011).

Mobility is the third most frequent strategy, with 11% of reports. One option for fishers is to change their fishing or gathering areas (e.g., Khan, Ali, Asaduzzaman, & Bhuyan, 2010). However, in cases where there are no other local areas to move to, either because of access or because climate-induced changes are widespread, fishers are forced to leave their homes or villages for other regions and countries. Migration has significant consequences for the social fabric of these communities. This trend to migrate could indicate important cultural shifts among fishers given that they do not typically lead nomadic lifestyles.

Storage as an adaptation strategy is mentioned in 8% of the records. Our use of the term "storage" encompasses both physical storage and storage of information. Many fishers try to mitigate potential difficulties associated with rising frequencies of floods and droughts by physically storing emergency food and water supplies. Some fishers also report harvesting rainwater during dry periods (e.g., Karim, 2010; Kuruppu & Liverman, 2011). Physical storage strategies can have ecological implications, for example, if fishers increase fishing effort in specific seasons to augment their food supply during the rest of the year (e.g., Rasmussen *et al.*, 2009). In terms of information storage, fishers report helping future fishers cope with ongoing changes via the preservation of TEK through the transmission to younger generations.

Storage strategies can also have implications related to labour reorganization (4% of records) and rationing (6% of records) strategies. Additional labour may be required in the preparation and preservation of food for emergency consumption (e.g., Khan *et al.*, 2010). In addition, if climate change impacts make it more difficult to acquire basic or emergency supplies, fishers' traditional labour patterns may change (e.g., longer fishing trips, focusing effort on other food types and removal of children from school to assist) (e.g., Hanh, 2011). Some fishers also use rationing (i.e., reduced food intake) strategies in life-threatening situations (e.g., Mbwambo *et al.*, 2012).

In 6% of records, forecasting is reported as an adaptation strategy. As information technology becomes increasingly available and the reliability of weather forecasting continues to improve worldwide, subsistence-oriented fishers are more heavily utilizing instrument-based meteorological information such as weather reports from television, the Internet, marine satellite and weather radar services, and VHF radio (e.g., MacDonald, Harper, Willox, & Edge, 2013). These strategies are important for minimizing uncertainty and maximizing fishers' safety in the face of more unpredictable weather patterns related to climate change.

Reports about current and daily utilization of knowledge comprise 5% of reports. Some fisher communities stress the importance of TEK as a critical factor in increasing local resilience to climate change (e.g., Petheram, Zander, Campbell, High, & Stacey, 2010). For instance, the ability to understand environmental indicators of weather changes can reduce risk, even if the unpredictability of the weather is now making past experience and knowledge of fishers less reliable.

Fishers sometimes rely on market-based exchange to cope with extreme weather events (5% of records). For example, receiving remittances from relatives, friends and community members help fishers to recover and survive after extreme climatic events (e.g., Sarker & Hossain, 2012). Other forms of exchange include purchasing of insurance and relying upon national and international aid for disaster relief (e.g., Watson, 2007). According to The World Bank (2014), these latter strategies are especially common, but not limited to, countries classified as poor.

Selection is reported as a strategy in 5% of reports. Selection means, for example, that fishers who also farm may select stress-resistant varieties of crops or animals or change crop varieties in response to drought or flooding (e.g., Adebayo *et al.*, 2011). Selection also extends to other aspects of fishers' lives such as accounting for the impacts of climate change when choosing building materials and sites for the construction of homes and other infrastructure (i.e., building stronger houses to reduce impacts of storms) (Karim, 2010).

Relatedly, fisher communities share food and pool resources (pooling = 4% of records). Pooling can occur in the form of communal use of tools and resources or in more organized forms such as the creation of fishers' cooperatives (e.g., IRG, 2008).

Some fishers report reliance on praying and/or spiritual beliefs and religious practices as coping mechanisms (Rituals = 2% of records) (e.g., Chowdhury, Hossain, Shamsuddoha, & Khan, 2012). However, data are limited for this category so it is difficult to assess; for example, if these practices are effective in improving mental/emotional well-being during crisis events.

A preliminary qualitative comparison suggests differences between some of the adaptations reported by subsistence-oriented fishers and those suggested by researchers (Table S3). Adaptation strategies implemented by those fishers are generally small-scale, specific, and do not involve regional or national administrative decisions (e.g., Cinner *et al.*, 2012). In comparison, adaptations suggested by researchers are often directed to fishers in general, are focused on environmental conservation and are often governance-oriented at broader scales. For example, local fishers might cite changes in specific fishing areas or target species, while researchers suggest broad reductions in fishing pressure as possible adaptation strategies. Other adaptations recommended by researchers include greater inclusiveness of community stakeholders (e.g., Adger *et al.*, 2005), and more integrated coastal management and urban planning implemented at multiple scales of governance. Examples of the latter include restricting development of coastal areas, resettlement to inland areas and changes in land-use and building regulations (e.g., Badjeck *et al.*, 2010; UNEP, 2000). Possibly, larger-scale commercial fisheries, which are subject to provincial or national regulations, might present different types and scales of adaptive measures. On the other hand, the local adaptations of subsistence-oriented fishers best reflect people's autonomous choices, comply with local social norms and reflect fishers' priorities.

Differences in the scale at which adaptations are recommended by researchers and reported by fishers are not surprising as researchers typically consolidate information to draw broader conclusions, whereas fishers report what they observe at the local level (St Martin, 2001). However, in consolidating information, researchers can overlook important contextual information that is specific to certain areas or fishers' communities (Daw *et al.*, 2012). If their recommendations are adopted, there is a risk of negatively impacting local SESs by ignoring critical details. This risk would be apparent, for example, in the creation of regional fishing policies that fail to account for some fishers' behaviour resulting from declining populations of certain fish species (e.g., changing fishing areas or increasing pressure on other species) (Khan *et al.*, 2010). Management policies about quotas that neglect local fishers' knowledge about behaviours and distribution of fish species can wrongfully estimate fish stock dimensions because fishers and scientists operate at different scales of observations (Mackinson, 2001; St Martin, 2001). Finally, management policies should factor in the cultural importance of certain fish species or fishing grounds for local fishers' communities (see, e.g., Gerwing & McDaniels, 2006).

4 | DISCUSSION

Our review suggests that subsistence-oriented fishers are well aware of direct and indirect effects from climate-driven changes and are experiencing decreased food security across all continents/regions (e.g., Hovelsrud, Dannevig, West, & Amundsen, 2010; Petheram *et al.*, 2010; Quiroga *et al.*, 2011). In many coastal areas, reductions in catch size associated with climate change are compounded by overfishing, pollution and deterioration of coastal habitats. Each of these factors interact and amplify one another to produce greater cumulative effects (Brander, 2007; Hughes, Bellwood, Folke, Steneck, & Wilson, 2005; Perry *et al.*, 2010). The resulting difficulty in harvesting fish and shellfish reduces protein and essential nutrient availability in fishers' diets (Kawarazuka & Béné, 2010) and increases the emotional burden on those who provide household food supplies.

The effects of shifting climate patterns, winds and storms also generate linked social–ecological feedbacks from climate change that present more immediate threats to fishers' lives (e.g., Dolan & Walker, 2006; Harley *et al.*, 2006; Hollowed *et al.*, 2013). For instance, increasingly unpredictable weather coupled with more storms increases risks (Cinner *et al.*, 2012). This is especially true because the depletion of local stocks means fishers must venture further from shore, spend more time fishing and are thus more vulnerable to storms at sea. Ocean warming further complicates this picture by altering the movement and distribution of fish (e.g., Pinsky, Worm, Fogarty, Sarmiento, & Levin, 2013), which can also require fishers to travel further from shore or to unfamiliar waters to find harvestable fish. Travelling farther afield results in a greater economic burden for fishers who must spend more on fuel and upgrades to equipment and vessels, so they can efficiently and safely follow the movements of deeper-sea fish populations. With declining catches, many fishers must also intentionally take greater risks to provide for their families by fishing in unsafe weather conditions (e.g., Sarker & Hossain, 2012).

Fishers have already begun to adapt to the various changes brought about by climate change and will need to continue to do so. Several studies speculate about adaptation options for fisheries and fishers in general, but this review helps illuminate and consolidate strategies fishers themselves implement to adapt to climate-related impacts on the ecosystems (see Table S2 and S3). We agree with Haynie and Pfeiffer (2012) that understanding fishers' harvesting behaviours in response to climate change is as important as climate models in projecting how marine SESs will change in the future. We believe this information has two main advantages: 1) it indicates which coping mechanisms are already favoured by fishers, and 2) it can assist in designing policies that fisher communities are likely to support (i.e., in co-management of resources). In particular, as our results suggest diversification strategies are already widely accepted by fishers, local policies may be more successful if they encourage adaptations aligned with diversification. For example, to compensate for the decline in protein intake associated with the reduced fish catch some fishers could diversify their food sources by raising animals that can withstand extreme events (e.g., ducks, which can swim during floods; Baumhardt, Lasage, & Suarez, 2009). Such solutions might also reduce ecological pressure on fish and shellfish populations.

However, caution must be exercised as diversifying food resources does not always reduce ecological vulnerability (Blythe, Murray, & Flaherty, 2014). For example, when options are limited, fishers may react to declining fish stocks by increasing fishing pressure on their staple fish or alternative fish species. "Desperation strategies" (Marschke & Berkes, 2006) may be implemented, such as reducing mesh size or using illegal fishing methods that aggravate the impacts of climate change and potentially push some fishers' communities into "poverty traps" that limit future options for diversification (Cinner, Daw, & McClanahan, 2008). Introducing new food production practices may also have unexpected effects on local ecosystems and resources on which fishers rely.

Further, diversification does not necessarily create a more equitable distribution of labour (Marshall *et al.*, 2010). Although some women do fish in the ocean (e.g., Ama divers in Japan; Kato, 2006), most fishers in coastal areas are men (Davis, 1986). However, women substantially contribute to fishery and aquaculture more broadly (FAO, 1997), including repairing fish gears and processing fish or as primary gatherers of intertidal seaweeds or clams (e.g., MacKenzie, 2001; Ostraff, 2006). Women are often responsible for finding alternative sources of food when fish catches are insufficient for feeding the family. In these cases, women can play an important adaptation role in maintaining food security in coastal areas impacted by climate change (Marshall *et al.*, 2010), but they are also at risk of shouldering a greater provisioning burden.

Many of the subsistence-oriented fishers considered in this review have a profound connection with and respect for the ocean and coastal environments (e.g., Kato, 2006). Several communities already use innovative strategies aimed at preserving the resources and ecosystems on which they rely. For instance, communities in several tropical areas are planting, restoring and protecting mangrove forests as a means of combatting coastal erosion (e.g., Hogan, 2008). Other communities are building other kinds of sea walls (e.g., Gemenne & Magnan, 2010; Rasmussen *et al.*, 2009). Policymakers and managers can learn from these strategies and tailor policies such as development permits, land-use regulations and incentives (e.g., tax or income-based) to encourage their uptake within local communities and regions.

While climate change may motivate adaptation strategies, it can also limit the choices available to fishers about how to interact with their land and seascapes. For instance, if staple fish stocks decline, fishers might have limited options for diversifying their catch (i.e., if they cannot purchase the gear or licences for fishing different species). Such limitation is especially relevant when other ecological and economic factors are already reducing fishers' options. For example, when storms damage houses and public infrastructure, an economic burden is created that may increase poverty and reduce the community's future capacity to recover from similar events, effectively reducing local resilience (Badjeck *et al.*, 2010). Expansion of industrial seafood production (e.g., shrimp farms in Southeast Asia) can also reduce resilience to climate change impacts by encroaching on natural buffers such as mangroves (Adger *et al.*, 2005; Alongi, 2002).

Our results suggest options will be most restricted on low-lying islands. While several such islands will ultimately be submerged with rising sea levels (Barnett & Adger, 2003; Nicholls & Cazenave, 2010), livelihood options are already being limited by flooding and saltwater intrusion into freshwater resources on which humans, other animals and garden crops (e.g., taro) rely (e.g., Badjeck *et al.*, 2010; Bridges & McClatchey, 2009). In response, fishers are moving their villages inland or are migrating to other regions or countries. Such migration can fundamentally alter the social fabric of a community, removing people from the landscape that evokes and creates social memory (Adger *et al.*, 2005; Perry *et al.*, 2010). Resorting to migration as a strategy means that for many fishers, the social–ecological system of which they are part has already reached unmanageable thresholds.

Fishers' connection with and knowledge of their environments (TEK) can help them deal with climate change. For instance, environmental knowledge of fishing locations as well as fish population dynamics could increase fishing success (García-Quijano, 2009) and encourage sustainable practices. The sharing of this knowledge among community members could also strengthen social cohesion, especially in the management of resources and implementation of long-term adaptations that are beyond individual capacities (Blythe *et al.*, 2014; Coulthard, 2011; Ferrol-Schulte, Wolff, Ferse, & Glaser, 2013; García-Quijano, 2009; Marshall *et al.*, 2010; Thornton & Scheer, 2012). Promoting the transmission of TEK, and the pathways for sharing this knowledge, can thus be a valuable strategy to mitigate the effects of climate change. Agencies, planners and policymakers involved in adaptation planning can partner with local communities to facilitate the sharing of this knowledge and encourage its transfer to other relevant contexts.

5 | CONCLUSIONS

Our results show that fishers' observations and adaptation strategies can differ from those suggested by researchers and policymakers. This important point suggests a possible disconnect between strategies recommended by the epistemic community and on-the-ground experiences and practices of people who derive their livelihoods from coastal and marine environments. This disconnect can build on pre-existing power imbalances between those who make critical decisions on policies about adaption to climate change and those who should adhere to these policies (Adger, Paavola, Huq, & Mace, 2006). The implication of this finding is that professionals who influence policy, development, research and management in relation to climate change adaptation should not overlook the role of subsistence-based communities in developing climate change adaptations. Moreover, these professionals should factor in social and economic vulnerabilities and the unjust distribution of the impacts of climate change (Adger *et al.*, 2006).

Researchers, management and planning agents should establish a more inclusive dialogue with fishers and take into account their observations, values and existing adaptations (Chan *et al.*, 2016). Clearly, fishers' local knowledge provides useful insights into the complex and interlinked changes occurring in coastal ecosystems. Future directions in planning and management of these SESs should actively involve coastal fishers and incorporate their long-term and local knowledge. Fishers are already adjusting their lives to compensate for the effects of climate change, diversifying their livelihoods, protecting their coasts, using their knowledge of local environments and their instinct to survive. The inclusion of these stakeholders will result in policies that are more likely to succeed because they better incorporate an understanding of local social mechanisms, preferences and adaptation strategies (Barnes *et al.*, 2013; Daw *et al.*, 2012).

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