



# Perceptions and attitudes towards climate change in fishing communities of the Sudd Wetlands, South Sudan

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## Abstract

The Sudd in South Sudan, formed by the White Nile's Bahr al-Jabal section, is one of the largest and most important wetlands in the world. Communities in the region almost exclusively depend on fisheries for food and livelihoods. Although threatened by over-exploitation and habitat changes, fish populations are also affected by climate change. Using semi-structured questionnaires, we assessed fisherfolk's opinions of how recent variation in climate affected their livelihoods and the environment. Fisherfolk perceived that climate had changed in the past decade and were negatively impacted by this. Interviewees reported average higher temperatures, a greater frequency of floods and droughts, unpredictable timing of seasons, and erratic rainfall. Destruction of fishing villages/camps, loss and damage of fishing equipment, shifts in the fishing calendar, reduction of fish trade, and fish catch declines as well as psycho-social problems were given as the major consequences of climate change. Causes of climate change and variability were perceived to be linked to uncontrolled harvest of forest resources, anger of God and ancestors, and natural variability in climate. Most respondents expressed a desire to adopt more responsible behavior such as planting trees and establishing community nurseries, being educated on climate change risks, and sustainable fisheries management. Our results show that fisherfolk in the Sudd are troubled by climate change impacts on their livelihoods and on fish populations. In South Sudan, climate change has been reported from hydroclimatological data but concrete impacts on people remain largely unknown and of little concern because of recent wars and the poor economy. Our study provides an example of how fisherfolks' local ecological knowledge (LEK) can be used as an early warning system of the negative impacts on livelihoods and fish populations and support adaptation to the changing climate.

**Keywords** Climate change · Climate variability · Perceptions · Attitudes · Fisherfolk · Sudd wetlands

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## Introduction

The Paris Climate Agreement (PCA) has put into sharp focus the changes in climate and its variability that have already occurred during the early Anthropocene (Lewis and Maslin 2015). The PCA is a legally binding international treaty for combating global climate change, adopted by 196 Parties on 12 December 2015 in Paris at the 21st Conference of the Parties of the United Nations Climate Change Conferences (COP 21). Anthropogenic climate change (taken henceforth to include climate variability) has started to impact not only ecosystems but also human well-being and the economy. For example, decline of fishing yields in many parts of the world (Sumaila et al. 2011; Plagányi 2019) and the loss of lives during extreme weather events are consistent with changing climate (Yu et al. 2020). Evidence of the impact of recent global climatic changes on fisheries includes decreased ocean productivity, altered food web dynamics, reduced abundance of habitat-forming species, shifting species distributions, and a greater incidence of disease in marine ecosystems (Hoegh-Guldberg and Bruno 2010; Blasiak et al. 2017; Lam et al. 2020). In coastal ecosystems, interactions between climate change and local human impacts are not only decimating and destroying a variety of coastal ecosystems, but are also forcing shifts of human settlements, including the proposed relocation of the Indonesian capital (He and Silliman 2019). In freshwater ecosystems, reduced productivity has also been linked to elevated late twentieth century atmospheric temperatures, as evidenced in the declining productivity of Lake Tanganyika (O'Reilly et al. 2003; Munubi and Lamtane 2021) and Lake Malawi (Makwinja and M'balaka 2017), both in East Africa. Climate change impacts on marine and freshwater fisheries, studied in 72 national economies, are potentially likely to be substantial in two South American countries, four tropical Asian countries, and Central and Western Africa (Allison et al. 2009). Countries with the lowest adaptive capacity to climate change are found in Africa. In this continent, high vulnerability to climate change and low adaptive capacity are linked to poverty. Climate change will thus have its most severe impact on the economies of poor countries (Hope 2009). Investment in climate change adaptation will compete with resources needed to reduce poverty, the main policy driver (O'Brien et al. 2008).

Anthropogenic climate change is clearly impacting worldwide fisheries (Brander 2007; Sumaila et al. 2011; Lam et al. 2012; Allison and Bassett 2015; Plagányi 2019) and therefore the livelihoods and food security of fisherfolk that depend on this resource (Shaffril et al. 2013, 2017; Geetha et al. 2015; Sidi 2015; Muchuru and Nhamo 2018; Johnson et al. 2019; Turner et al. 2020). Loring et al. (2019) summarize "Fish is among the most eaten foods and traded commodities in the world, and small-scale fisheries provide food, jobs, and life satisfaction to billions of people worldwide."

However, food security provided by fisheries being in bad health with the median fisheries (based on 4713 fisheries worldwide, representing 78% of global reported fish catch) being overfished (Costello et al. 2016). Golden et al. (2016) estimate that 845 million people or 11% of the current global population will become zinc, iron, or vitamin A deficient if current trajectories in fish-catch declines are not reversed. Moreover, 1.4 billion people will become vulnerable to deficiencies of vitamin B12 and omega-3 long-chain polyunsaturated fatty acids. In many areas of the world, subsistence fishing provides substantial amounts of animal protein, e.g., around 50–60% in the delta regions of Bangladesh and Ghana, but modeling of future scenarios predicts reduced productivity except when impacts of climate change will be adequately mitigated by reduced overfishing and improved management (Lauria et al. 2018). Effects on fishing can also have wider implications for food security and conservation in adjacent terrestrial ecosystems as evidenced by the consumption of sea fish being inversely correlated with hunting and wild meat extraction in West Africa (Brashares 2004).

Information on local ecosystem health in fish communities is lacking in many areas. Resources are often missing to implement scientific ecosystem monitoring even in economically important, commercial fisheries (Coll et al. 2015), let alone in poor countries. About 99% of fisheries worldwide remain unassessed (Bevilacqua et al. 2016). On the other hand, fishers hold tremendous local ecological knowledge (LEK) about fish and their environments (Johannes et al. 2000). LEK is accumulated by fishers over their lifetimes by direct interactions with fish, which are the foundation of their livelihoods, and their ecosystems and by interactions with other fishers (Olsson and Folke 2001). LEK not only includes knowledge on the ecology and behavior of exploited fish species and their habitats and ecosystems, but also knowledge about changes in fish behavior and community composition over time (Rosa et al. 2014; Damasio et al. 2015; Martins et al. 2018). Bevilacqua et al. (2016) modeled the ecosystem of a small-scale fishery in Brazil using both LEK and scientific information and revealed compatible results from both approaches. Another study from Tanzania found differences in LEK among fisher groups but a strong coherence between LEK and scientific information (Berkström et al. 2019). Increasingly, scientific research and fish management utilize this information (Bender et al. 2014). TEK has been proposed to be a reservoir of knowledge that can document environmental change and aid the adaptation and mitigation strategies to cope with that change (Gómez-Baggethun et al. 2013; Kupika et al. 2019; Azzurro et al. 2019). Utilizing LEK is particularly relevant for poor and developing countries (Silvano and Begossi 2012; Berkström et al. 2019).

Understanding perceptions of those people more likely to be impacted by climate change is vital to plan and implement adaptation and mitigation strategies. Failure to respond to perceptions or misconceptions of climate-induced changes can

result in a lack of adaptation or even more harmful, in maladaptation (Grothmann and Patt 2005). However, natural variability in local climate conditions can make it hard for local people to identify climate change, its extent, and importance. For farmers, for example, social and individual factors can limit adaptation action to climate change if perceptions are not taken into account (Adger et al. 2009; Pauw 2013). In the case of fisherfolk, perceptions of climate change by this group of people have been studied in numerous locations (Nurse-Bray et al. 2012; Salim et al. 2015; Musinguzi et al. 2016; Menon et al. 2016; Hasan and Nurse-Bray 2018; Stancioff et al. 2018; Mulyasari et al. 2018; Diouf et al. 2020). Nevertheless, data are in general lacking in many other locations including South Sudan where the impact of climate change on people remains largely unknown and of little concern because of recent wars and conflicts and the poor economy.

Founded in 2011, South Sudan was identified as highly vulnerable to climate change among evaluated African countries (Allison et al. 2009). It is not only a country with widespread poverty (The World Bank 2021; UNDP 2021), but armed conflicts and political unrest in the recent past have severely limited its climate adaptive capacity due to weak governance following war and civil unrest and poverty. Climate change is therefore low in the list of local and national political priorities (Allison et al. 2009). South Sudan's score of the Human Capital Index, which measures the productivity of the next generation of the workforce weighed against a benchmark of complete education and full health, is the lowest among 157 countries with data, highlighting the level of poverty in the country (De Silva et al. 2020). On the one hand, the United Nations Millennium Development Goals have given poverty alleviation high priority on the international development agenda. On the other hand, high vulnerability and low adaptive capacity to climate change are linked to poverty. There is growing consensus that climate change will negatively affect poor countries more than rich countries because of the high direct dependence of poor people on natural resources for survival (Hope 2009). Thus, it is imperative to detect impacts of climate change on food security and economic activities as early as possible to give an early start to develop mitigation strategies.

South Sudan's biodiversity is threatened by a number of factors including fires, overexploitation of wildlife, and livestock and agricultural land expansion, as well as weak environmental regulation, poor development planning, and instability and security caused by political and armed conflict (Government of South Sudan 2018). Climate change has enabled substantially warmer and drier weather, as well as an increased incidence of droughts and flooding. Since the 1960s, floods have become more severe and take longer to recede but past permanent rivers have become seasonal in the last two decades. These changes have severely affected people in the country resulting

in crop and livestock losses and displacement. In the future, climate change is likely to cause further desertification and delayed and shorter rainy seasons and increase the frequencies of floods and droughts (Government of South Sudan 2018). As perceived by fisherfolk in South Sudan, there is little doubt that climate change has already severely impacted their livelihoods and fish populations. However, the status of the country's fisheries has not been properly quantified because of war, theft, and displacement of people along the banks of the Nile. Fishers in the Lol River, for example, have reported that five of the 15 known fish species had disappeared from their catches as well as the average size of their fish catch also decreasing (Government of South Sudan 2018).

Even from the limited information available, climate change adaptation and improved management of fish stocks in South Sudan are urgently required. So far, South Sudanese fisheries have not fulfilled their potential productivity despite these being the most important contributor to improving people's well-being and livelihoods (Government of South Sudan 2018). Small-scale fisheries, if properly maintained, can then contribute to improve food security and reduce poverty in pursuance of Sustainable Development Goal 2 (SDG 2) which aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture by 2030.

In this paper, we utilize fisherfolk's LEK and capacity to detect changes in fish community structure and ecosystem dynamics over time. We report the perceptions of local fisherfolk on climate change and how it is understood to affect their livelihoods in the southern Sudd Wetlands in South Sudan. Our results contribute new knowledge and improve our understanding of important fisheries and the impact of climate change in a highly biodiverse African country.

## Materials and methods

### Study area

South Sudan (633,906 km<sup>2</sup> (in 2018; FAO 2021)) is a tropical landlocked country in Central/East Africa situated within the Nile River Basin in East-Central Africa (NBI 2016). It has a population of about 11 million, of which around 2.5 million live in urban areas (FAO 2021). Poverty is widespread, at least 80% of the population live on less than US \$1 per day (The World Bank 2021; UNDP 2021). Food insecurity is also widespread with more than one-third of the population lacking secure access to food (UNDP 2021). Almost 80% of the population depends on smallholder agriculture, farming, and fishing. Although overall, fish only contributes 4% of the country's food consumption; about 14% of South Sudanese households rely on income from fisheries (Government of South Sudan 2018). Fish is important for both food security and livelihoods of communities living in and around the Sudd Wetlands.

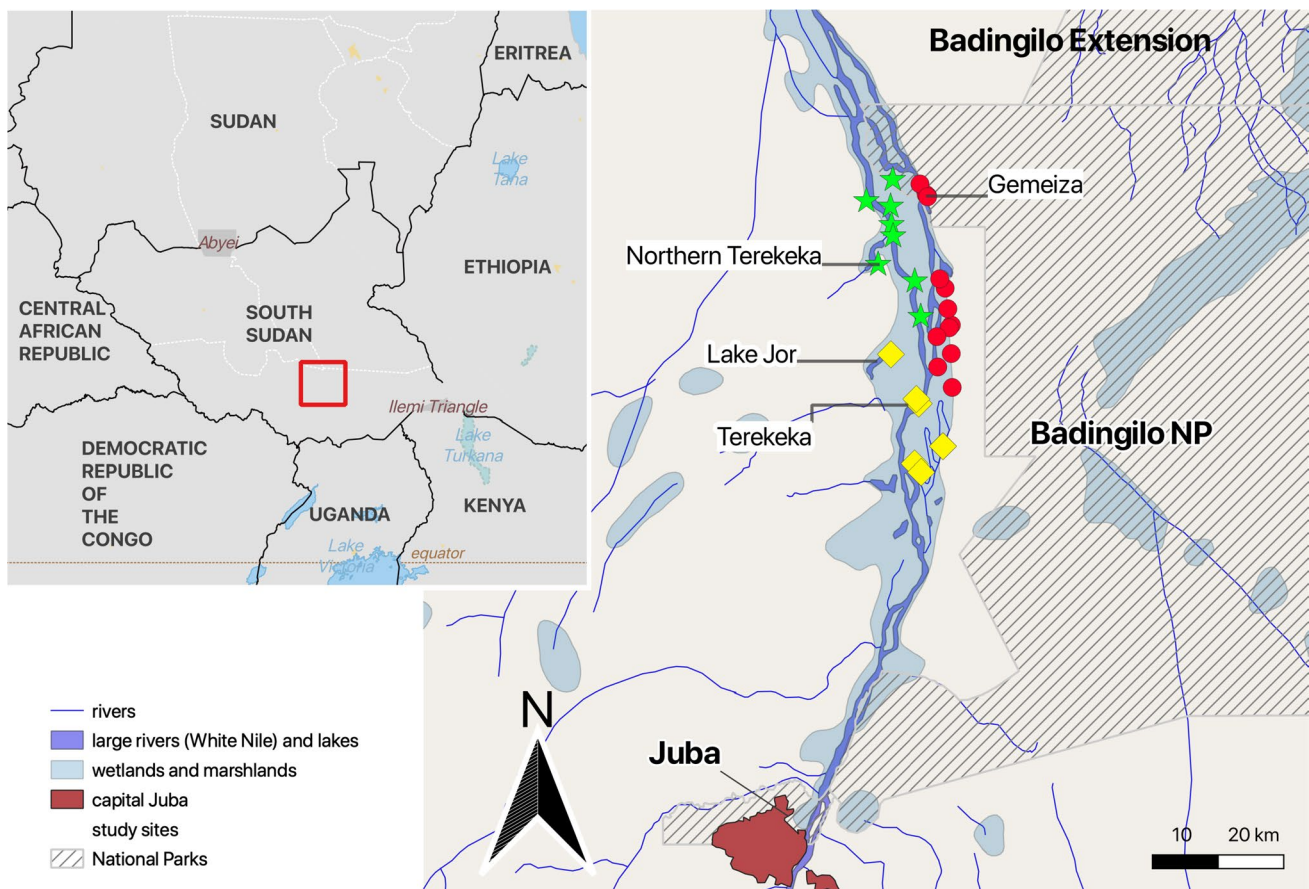
The largest river, the White Nile, traverses South Sudan from South to North. In the South of the country, the Sudd Wetlands or Sudd (approx. 100,000 km<sup>2</sup>, around 15% of the national territory), along the Nile River, is found from just North of the capital, Juba, (Fig. 1) to the Sudan border in the North. Since 2006, these wetlands are a Ramsar site. The Sudd comprises lakes, marshes, and extensive floodplains and is one of the most important and species-rich wetlands in the world (Government of South Sudan 2018). The area's biodiverse aquatic habitats offer ideal spawning, rearing, growing, feeding, and survival grounds for fish. These habitats appear “largely intact and largely unaffected by industrial development” (South Sudan Ministry of Culture, Youth and Sports 2017). These wetlands are also crucial for many people's livelihoods, ecosystem services, and water resources although information on the area's hydrology, ecology, and conservation is deficient (e.g., Mohamed and Savenije 2014; Sosnowski et al. 2016).

Our study was conducted in the southern part of the Sudd within the state of Central Equatoria where the national capital Juba is located (Fig. 1). The climate of the region is

tropical, with a wet season in April–October (with an average of 100 mm rainfall per month) and a dry season between November and March (5–35 mm per month). Temperatures are relatively constant throughout the year with average day-time temperatures of 30 to 33 °C during the dry season and 26 to 28 °C in the rainy season (Mohamed et al. 2005).

This study was carried out in the Terekeka County on the bank of the River Nile, on the western border of the Badingilo National Park (UNEP-WCMC and IUCN 2021). Within the Terekeka County, we focused on three main districts—Northern Terekeka (total inhabitants = 17,835; males = 8463, females = 9372), Terekeka (total = 20,770, males = 10,564, females = 10,206), and Gemeiza (total: 7796, males = 4313, females = 3478) (South Sudan National Bureau of Statistics (SSNBS) 2018). According to a census taken by Taege et al. (2009), a total of 72 fishing camps/villages were counted in Terekeka County.

The Sudd is affected by (a) multiple hazards and is considered a climate-sensitive area (Benansio, unpublished data, 2020); (b) frequent occurrence of natural disasters and floods (Benansio, unpublished data, 2020); (c) the shrinking



**Fig. 1** Study area showing the White Nile river course and the study villages in Gemeiza (red circles), Terekeka (yellow diamonds), and Northern Terekeka (green stars). The map was created using QGIS version 3.20.2-Odense ([qgis.org](https://qgis.org)) from public domain map datasets

from Open Street Map ([www.openstreetmap.org](https://www.openstreetmap.org)), diva-gis ([diva-gis.org](https://diva-gis.org)), Humanitarian Data Exchange, HDX ([data.humdata.org](https://data.humdata.org)), and UNEP-WCMC and IUCN (2021) for the boundaries of the Badingilo National Park

of River Nile and river bank erosion (Benansio, unpublished data, 2018); and (d) the desiccation of natural lakes such as Lake Jor, resulting in the migration of fisher communities to new fishing grounds. The key livelihood activities in our study communities include small-scale agriculture (maize, sorghum, and groundnuts) cultivated close to homesteads in the village/fishing settlements. Fishing, livestock farming (small ruminants), illegal wildlife hunting, charcoal production, collection of reeds and other building materials, fuel production, and crafts are all important aspects of the rural economy, including around the peripheral sectors of the protected areas (unpublished data). All communities are strongly affected by various natural forces including flooding and drought.

## Sampling methods

Out of the 72 known fisher villages, we randomly chose a total of 28 to survey. In each study settlement, we randomly selected fishers and agro-pastoralists (who also fished) to interview. We selected potential respondents by approaching persons in the street, at their workplace, or at home.

According to Taege et al. (2009), as many as 1553 (1142 men and 411 women) fisherfolk lived in the 72 fisher villages in the Terekeka County. Sample size of respondents needed to adequately cover the target population of fishers in Terekeka County (95% CI, 10% margin of error) which was calculated to be 91 (SurveyMonkey 2021), or a 5.9% coverage.

Before developing the questionnaire to apply in the interviews, we conducted focus groups within each study settlement to better understand peoples' perceptions of changing climate and how they would cope with these changes. We organized five separate focus group meetings in each of the study settlements. These were attended by 6–8 persons. Based on the perceptions voiced during the focus group discussions, we formulated the questions for the semi-structured questionnaire. For example, comments confirmed that interviewees were unaware of the overwhelming evidence for anthropogenic causation of climate change or international efforts to stop escalation such as the Paris Climate Agreement. Thus, we did not include questions about fisherfolk's knowledge or perceptions of the anthropogenic causation of climate change. Although we aimed to formulate the questions as neutral as possible, we like to acknowledge that any questionnaire on any topic is limited as the way questions are formulated might impact respondents' answers however subtle (Hess et al. 2013). The final questionnaire contained 24 questions, divided into different sections (Supplement). We first noted gender, age, education, and migration status of the interviewee. We then addressed five main themes: (1) access to information on weather (radio, television, newspapers, etc.); (2) consequence of climate change on different aspects of the fishers' livelihoods over the last 10 years (decline of fish catch, disappearance of economic important fish

species, including causing psycho-social problems<sup>1</sup>); (3) fishers' experience of climate change over the last 10 years (unpredictable timing for rainy and dry season, erratic rainfall, etc.); (4) fishers' beliefs on the causes of observed climate change; and (5) fishers' interest to personally adapt to climate change. All questions were probed by several statements (i.e., Likert items) about specific aspects (shown in the figures). These were selected based on the issues raised by fisherfolk during the above-described focus group discussions. Answers were either scored according to the Likert response format scale as "strongly agree," "agree," "neutral," "disagree," or "strongly disagree" (questions two, four, and five) or as "yes," "no," or "I don't know" (questions one and three). Interviewees could reject answering specific questions. Scores and comments were noted and later transcribed into spreadsheets.

All surveys were undertaken during May–November 2020 by a team of three researchers, each conducting interviews independently. After informing potential respondents of the voluntary nature of the interviews, we applied the questionnaire in the interviewee's own language, either in local Arabic or Bari. At the end of an interview, the person was asked if they wanted to give their name (optional) and a reference number was assigned to each to avoid replication.

Because of the COVID-19 pandemic, the research team employed safety measures recommended by the World Health Organization and Ministry of Health of South Sudan when conducting face-to-face interviews, including social distance measures and the use of face masks throughout the research study period.

All work was undertaken under a research permit from the Ministry of Internal Affairs, National Government, Juba.

## Statistical analysis

Demographic data were described and differences between study sites were evaluated by  $\chi^2$  test of contingency tables in R (R Foundation for Statistical Computing 2021). Likert response format scale answers were visualized using the R package "likert" (Bryer and Speersneider 2016). Differences between study sites were statistically evaluated using

<sup>1</sup> We broadly define psycho-social problems as any manifestation of anxiety resulting from deteriorating living conditions. During our interviews, we were made aware that fishers' state of mind was affected by erosion of livelihoods because of climate change. Worry and insecurity were caused primarily by increased floods forcing fishers to migrate due to the closure of fishing camps (the research team observed that at least 17 camps were closed due to flooding) and the consequent loss of income and jobs. The few fishers that remained in the camps had to adapt to the new conditions by building new houses on higher ground or erecting raised platforms to sleep on. Fishers also stated that access to selling fish during flood was another main obstacle. This is because fish traders cannot reach their respective fishing grounds to buy fish.

Kruskal-Wallis tests. We evaluated the impact of demographic variables on the replies of each question by Kruskal-Wallis tests. Because each main question was statistically evaluated by one or several tests for several Likert items, the Benjamini and Yekutieli (2001) correction for false discovery rates was applied to calculate a corrected  $p$  value,  $p'$ , for multiple tests of the same main questions using the function  $p.adjust$  in R.

## Results

A total of 294 fishers ( $n = 201$ ; 68.4%) and agro-pastoralists ( $n = 93$ ; 31.6%), who also fished, participated in our study: Terekeka (fishers: 65, agro-pastoralists: 25, total: 90), Gemeiza (68, 37, 105), and Northern Terekeka (68, 31, 99). The 201 full-time fishers constitute 13% of the 1553 fishers counted in Terekeka county, corresponding to a 6.5% margin of error for the survey with a 95% confidence level. Table 1 presents the main characteristics of all interviewees. Across villages, 20 women (6.8%) agreed to be interviewed. Most interviewees were 30–49 years old (57 to 73%). Education levels were highest in Terekeka, where 17% held a secondary or university degree, followed by Gemeiza, where some interviewees had secondary but no university degrees, and Northern Terekeka, where the highest level was primary education. The number of migrants was highest in Terekeka with almost a quarter of interviewees originating from another area, whereas less than

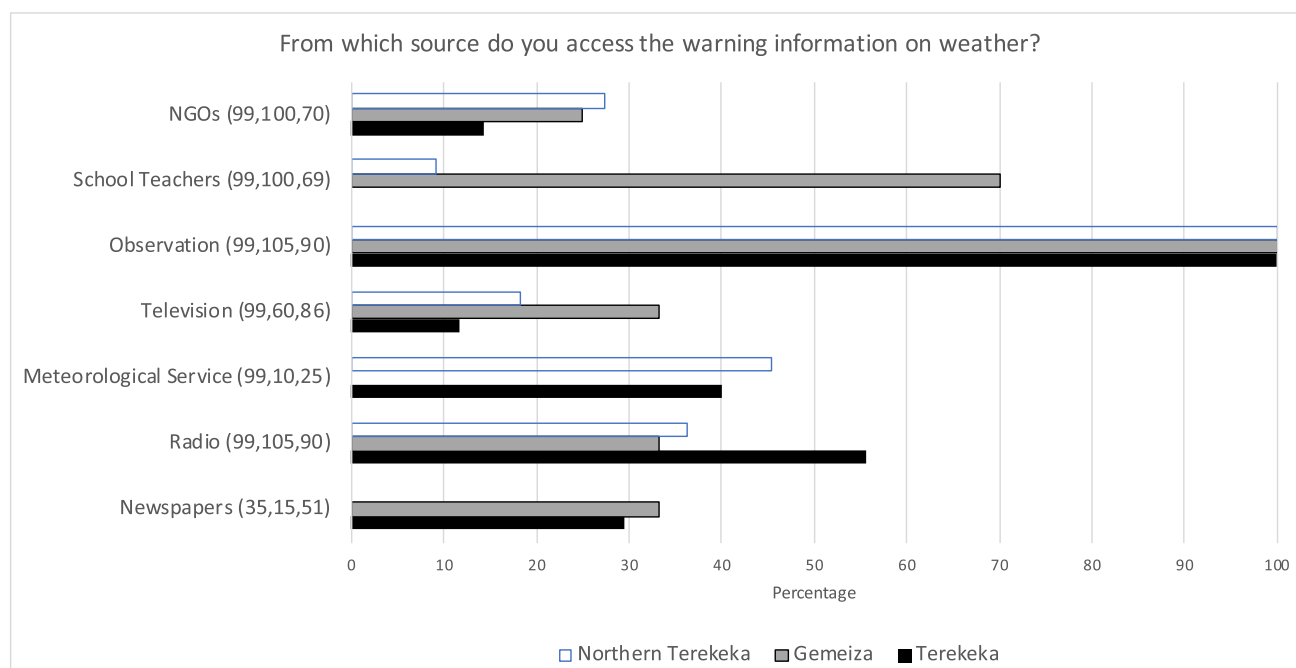
10% of interviewees were migrants in the other two study sites. Although the demographic characteristics appear similar in the three study sites, the  $\chi^2$  tests revealed significant differences for all demographic parameters (Table 1).

All interviewees reported they gained information on the weather from their own observations (Fig. 2). The most popular external source of weather knowledge was from radio (44 to 67% in the three study sites), followed by NGOs (24 to 33%). All other information sources were less used: television (16% across the three study sites), newspapers, meteorological services, and schools and teachers (each 7%). A higher percentage of interviewees in Terekeka used newspapers, radio, meteorological services, and NGOs, where the highest education levels were observed. After the Benjamini and Yekutieli (2001) correction for false discovery rates (30  $p$  values across seven statements), only information gained from school teachers was significantly different ( $\chi^2 = 127.15$ ,  $DF = 2$ ,  $p' < 0.001$ ) between the study sites. None of the demographic variables was correlated with the answer frequencies of the different study sites (all with  $p' > 0.05$ ).

Climate change was described to have impacts on all aspects of fishers' livelihoods (Fig. 3). Across the three study sites, more than 90% of interviewees agreed or strongly agreed with the statements on decline of fish catch (98%), disappearance of economic important fish species (92%), decline in quantity of fish landing (98%), destruction of houses in fishing villages (100%), changes in fishing calendar

**Table 1** Demographic characteristics of 294 interviewees in three study sites

		Terekeka	Gemeiza	Northern Terekeka	$\Sigma$
All samples	Camps/villages ( $N$ )	9	11	8	28
	Interviewees ( $N$ )	90	105	99	294
Sex	Male	88.9%	90.5%	100%	93.2%
	Female	11.1%	9.5%	0%	6.8%
	$n$	90	105	99	294
Age	$\chi^2$ test	$\chi^2 = 11.1$ , $DF = 2$ , $p = 0.004$			
	18–29	16.7%	39.6%	0%	19.5%
	30–49	66.7%	55.4%	70.3%	63.8%
	50–69	16.7%	5%	29.7%	16.7%
	$n$	90	101	91	282
Education	$\chi^2$ test	$\chi^2 = 58.4$ , $DF = 4$ , $p < 0.001$			
	No formal education	50%	81%	72.7%	68.7%
	Primary	34.4%	14.3%	27.3%	24.8%
	Secondary	4.4%	4.8%	0%	3.1%
	University	11.1%	0%	0%	3.4%
Residence status	$n$	90	105	99	294
	$\chi^2$ test	$\chi^2 = 42.6$ , $DF = 6$ , $p < 0.001$			
	Permanent	77.8%	95.2%	90.9%	88.4%
	Migrant	22.2%	4.8%	9.1%	11.6%
	$n$	90	105	99	294
	$\chi^2$ test	$\chi^2 = 15.3$ , $DF = 2$ , $p < 0.001$			



**Fig. 2** Access to information on weather patterns. Numbers in brackets refer to the number of interviewees in Northern Terekeka, Gemeiza, and Terekeka

(92%), reduced fish trading activities (98%), equipment damages and lost (98%), and damaged landing areas in fishing villages (100%). Support was less strong for loss and degradation of breeding grounds (50%), reduced fish size (37%), reduced fishing efforts (27%), and psycho-social problems (77%). Only for two probed statements, loss of lives and new fish species, disagreement was more widespread (standard/strong agreement versus standard/strong disagreement: 35% versus 33% and 40% versus 15%, respectively). For both statements, there were strong effects of the study sites. After the Benjamini and Yekutieli (2001) correction, significant ( $p' < 0.05$ ) differences between study sites were observed for 10 of the 14 probed statements (except loss and degradation of breeding grounds, changes in fishing calendar, reduced fish trading activities, and damaged landing areas in fishing villages) and for the two demographic variables age class ( $p' = 0.03$ ) and education ( $p' = 0.003$ ) on agreement to psycho-social problems (jointly 18  $p$ -values evaluated).

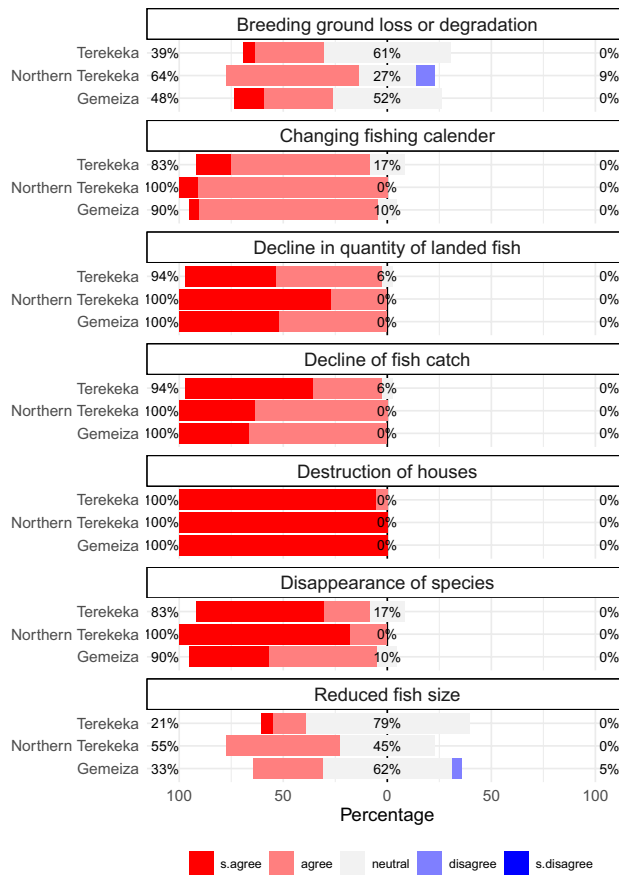
Fishers were aware of changes of climate hazards over the last 10 years (Fig. 4). From the five different changes inquired by the interviewers, all were affirmed by the majority in all three areas (unpredictable timing of seasons: 88%, erratic rainfall: 75%, incidence of high temperature: 100%, serious floods: 81%, and serious droughts: 95%). Study sites differed from each other in their combination of climatic parameters but no systematic deviation for any of the communities was observed, e.g., no differences were observed for the incidence of high temperature whereas Northern Terekeka showed a higher unpredictability

of the timing of seasons and a lower incidence of serious floods compared to the other communities. Differences in experiences between study sites were significant after Benjamini and Yekutieli (2001) correction for erratic rainfall, serious floods, and serious droughts (jointly 4  $p$ -values evaluated; the statement on incidence of high temperature was not tested as 100% of interviewees strongly agreed in all three areas).

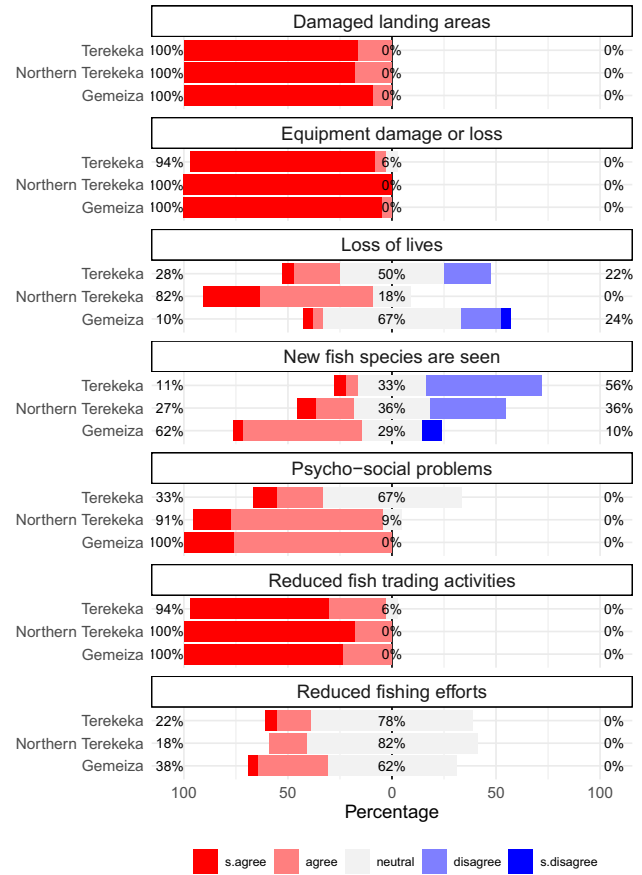
Fishers agreed or strongly agreed on the anger of God (85% across study sites), on the ancestors punishing for people's wrong doings (59%), uncontrolled harvest of forest resources (97%), and natural variability in the climate (82%) on the causes for climate change (Fig. 5). Only human population growth was disagreed with more often (21%) than agreed with (11%). Although the three study sites agreed or disagreed in similar proportions for all statements, there were significant differences in the strength of agreements between them after Benjamini and Yekutieli (2001) correction ( $p' < 0.05$ ; jointly 25  $p$ -values evaluated). The only significant demographic parameter impacting answer frequencies was gender for the opinion on uncontrolled harvest of forest resources ( $p' = 0.04$ ), which was more strongly supported by women.

Interviewees in the three study sites agreed to all but one aspect of lifestyle changes, with almost no disagreement on lifestyle changes to mitigate climate change (Fig. 6). All agreed to establish community forests and to accept training in climate change risk education and training in sustainable fisheries management. Almost all agreed to diversify

## Consequences on lives and livelihoods of fishing communities



## Consequences on lives and livelihoods of fishing communities



**Fig. 3** Consequence of climate change on different aspects of fishers' livelihoods. Interviewees had a choice of opinion (strongly agree, agree, neutral, disagree, strongly disagree) to each of the aspects. Percentages are for agreement (left), neutrality (center), and disagreement (right). Results are shown as a diverging stacked bar chart (Robbins and Heiberger 2011). The percentages of respondents who agree with the statement are shown as bars to the left of the zero line (red);

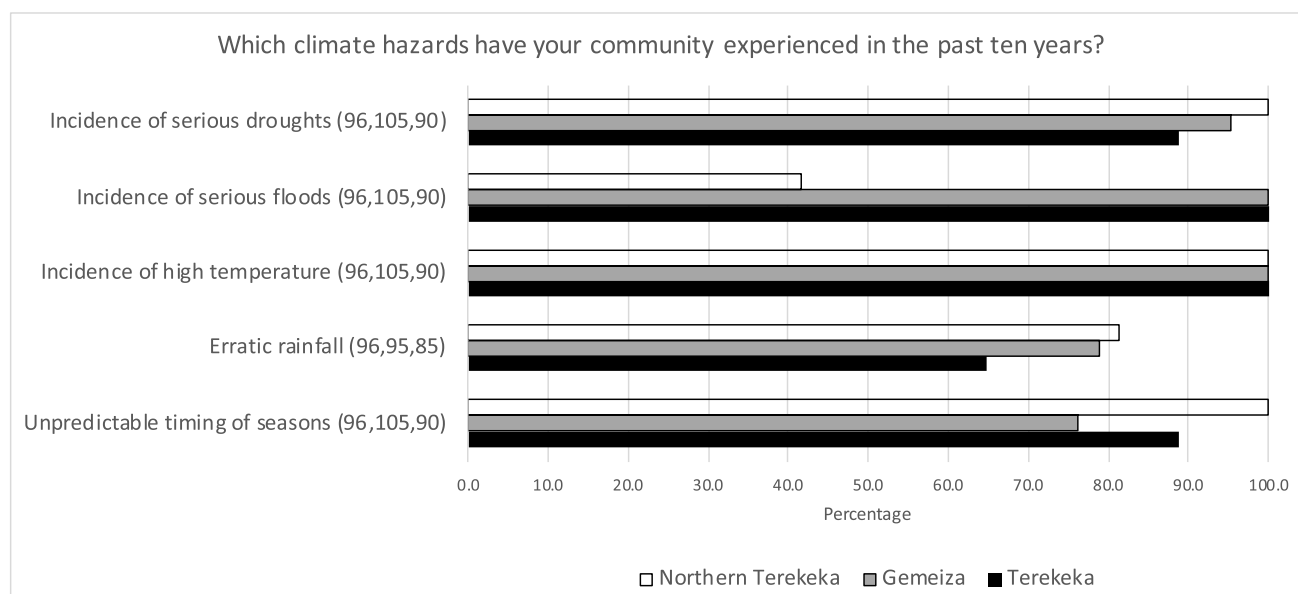
the percentages who disagree are shown as bars to the right (blue). The percentages for respondents who neither agree nor disagree are split down the middle and are shown in a neutral color (light gray). Percentages are also shown as numbers for agree plus strongly agree (left values), neutral (center values), and disagree plus strongly disagree (right)

household income activities and to receive training in agriculture for small business and training in aquaculture development. The only adaptation strategy not generally accepted was the willingness to use alternative cooking energy, where 51% were neutral, 34% supportive, and 15% rejected it. Although the three study sites agreed or disagreed in similar proportions in all aspects, there were significant differences between them regarding the strength of agreement to five statements with the exceptions of willingness to use alternative cooking energy and accepting training on climate change risk education after Benjamini and Yekutieli (2001) correction ( $p' < 0.05$ ; jointly 27  $p$ -values evaluated; the impact of demographic values on the latter two statements was not further evaluated because  $p > 0.05$  in each case). The two significant demographic parameters impacting answer frequencies were age for accepting training in aquaculture for small business ( $p' = 0.004$ ), which

was strongest supported by the youngest age class, and migration background for willingness to plant trees and establish community forest ( $p' = 0.02$ ), which was strongest supported by people without a migration background.

## Discussion

In the absence of scientific data, we used fisherfolk's LEK to understand the ecology and behavior of exploited fish species and their habitats and to monitor changes over the last decade. We quantitatively assessed fisherfolks' perceptions and sentiments about the impact and causes of climate change on their livelihoods and the environment and how they were related to different individual (demographics) and locational (geographic setting and local group identity) parameters. Interviewed fisherfolk perceived climate as having changed



**Fig. 4** Fishers' experience of changes of climatic conditions

dramatically, and they were negatively impacted by these variations. Most interviewees were strongly impacted economically, with also negative consequences on their mental health. As described for other areas, changes over time in fish behavior and community composition were reported in our study (Rosa et al. 2014; Damasio et al. 2015; Martins et al. 2018). Our findings, based on fisherfolks' LEK, can be used to forecast natural hazards and reduce disaster risk (Santha et al. 2014; Šakić Trogrlić et al. 2019). Fisher LEK may be more sensitive to changes in the environment, compared to farmers, since this information is not only important for their livelihoods, but often for their immediate survival, given that fishing is a dangerous and sometimes life-threatening enterprise with many fisher-specific occupational hazards abound (Kolawole and Bolobilwe 2019; Shrestha et al. 2021). Indicators of change in freshwater environments can be direct (frequency of droughts and floods, changes in temperature, breeding ground loss, decline in fish catch, disappearance of species and arrival of new species, change in size of landed fish, damage to houses and landing sites through floods) and indirect (changing fish calendar, reduced trading, increase of psycho-social problems). All of these indicators were probed in our study and fisherfolk reported changes in all (Figs. 3 and 4).

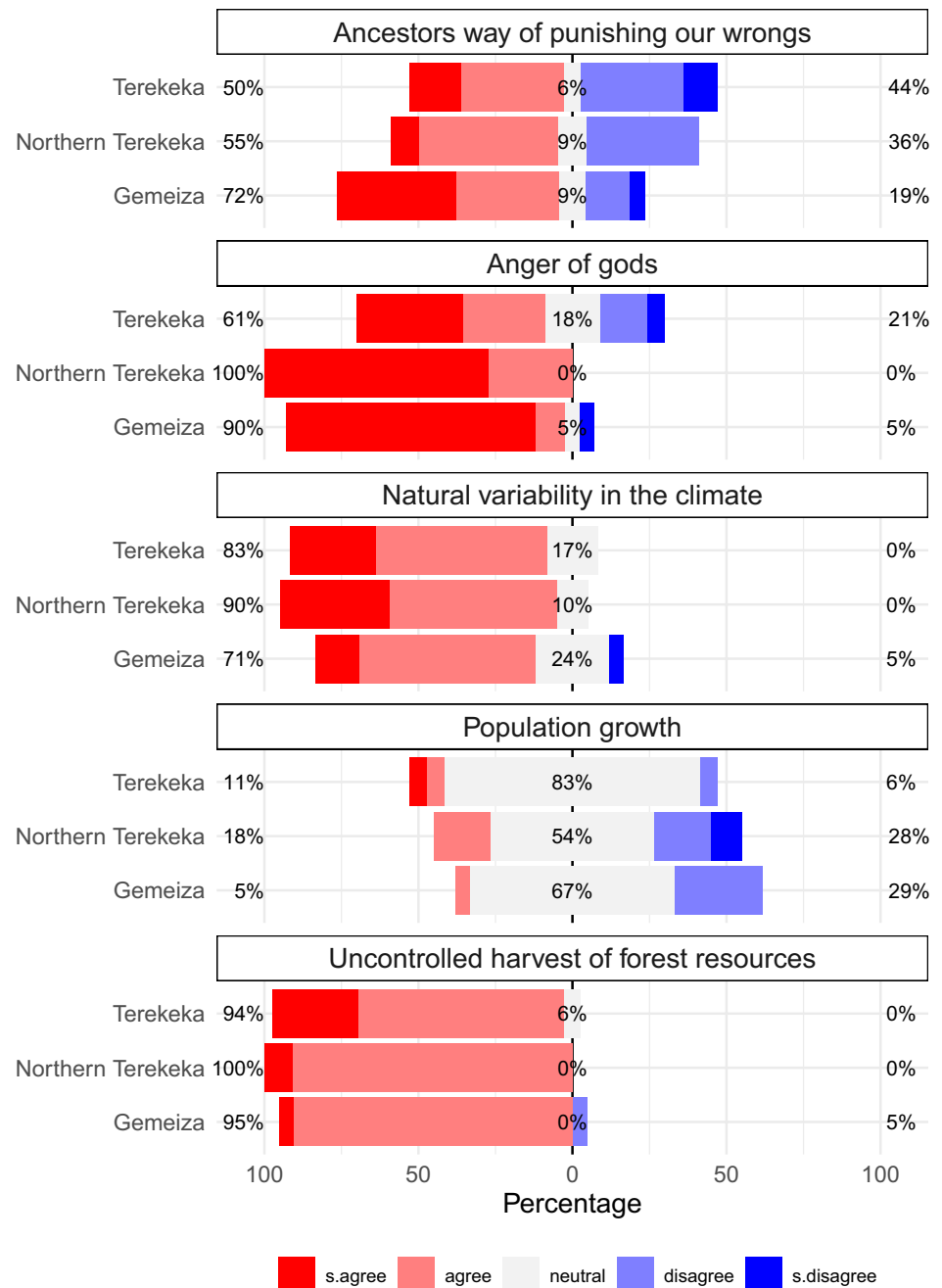
Fisherfolk can act as sentinels able to detect changes in the environment that are relevant to their livelihoods. However, because their knowledge needs to be critically assessed (Bender et al. 2014) and may vary between groups (Berkström et al. 2019), LEK should be used to complement though not replace scientific knowledge (Acharya and Prakash 2019) but can act as an early warning system. Changes in fish ecology and densities

and their associated changes in ecosystem structure and function, as determined by LEK, can highlight topics requiring subsequent academic research. Here it is important to point out that LEK is a different type of knowledge from scientific information. Although the two knowledge systems cannot verify each other, jointly they can be used to better understand the impact of climate change (Tengö et al. 2014). Weaving multiple evidence from different knowledge systems such as indigenous and academic knowledge allows the generation of new, synergetic insights which are not available when using these knowledge systems separate from each other (Tengö et al. 2014).

Because of the paucity of data for this part of the world, it is impossible to scientifically validate whether the local climate such as the number of floods and droughts has significantly changed in the study sites. However, across the Nile river basin, annual rainfall significantly increased or decreased locally, maximum and minimum temperatures significantly increased across the area, and several significant increases of weather extremes have occurred (number of extreme rainfall days, cold nights, heat waves, and cold waves) since 1948 (Nashwan and Shahid 2019). The sparse available data on the hydroclimatology in the Sudd shows that the areal extent of the Sudd wetland has increased as a result of statistically significant increasing trends of water flow into the wetlands without any significant changes in precipitation over the Sudd during the last 100 years (Mohamed and Savenije 2014). Increasing trends in the daily maximum and minimum temperature in the Sudd have been recorded whereas relative humidity and solar radiation have decreased significantly (Mohamed and Savenije 2014). These changes have been correlated with large-scale climatic patterns, such as the increase of rainfall over Lake

**Fig. 5** Fishers' beliefs on the causes of observed climate change. Interviewees had a choice of agreement level (strongly agree, agree, neutral, disagree, strongly disagree) to each of the aspects (anger of God, ...). Results are shown as a diverging stacked bar chart (see Fig. 3)

### Causes for climate change and variability



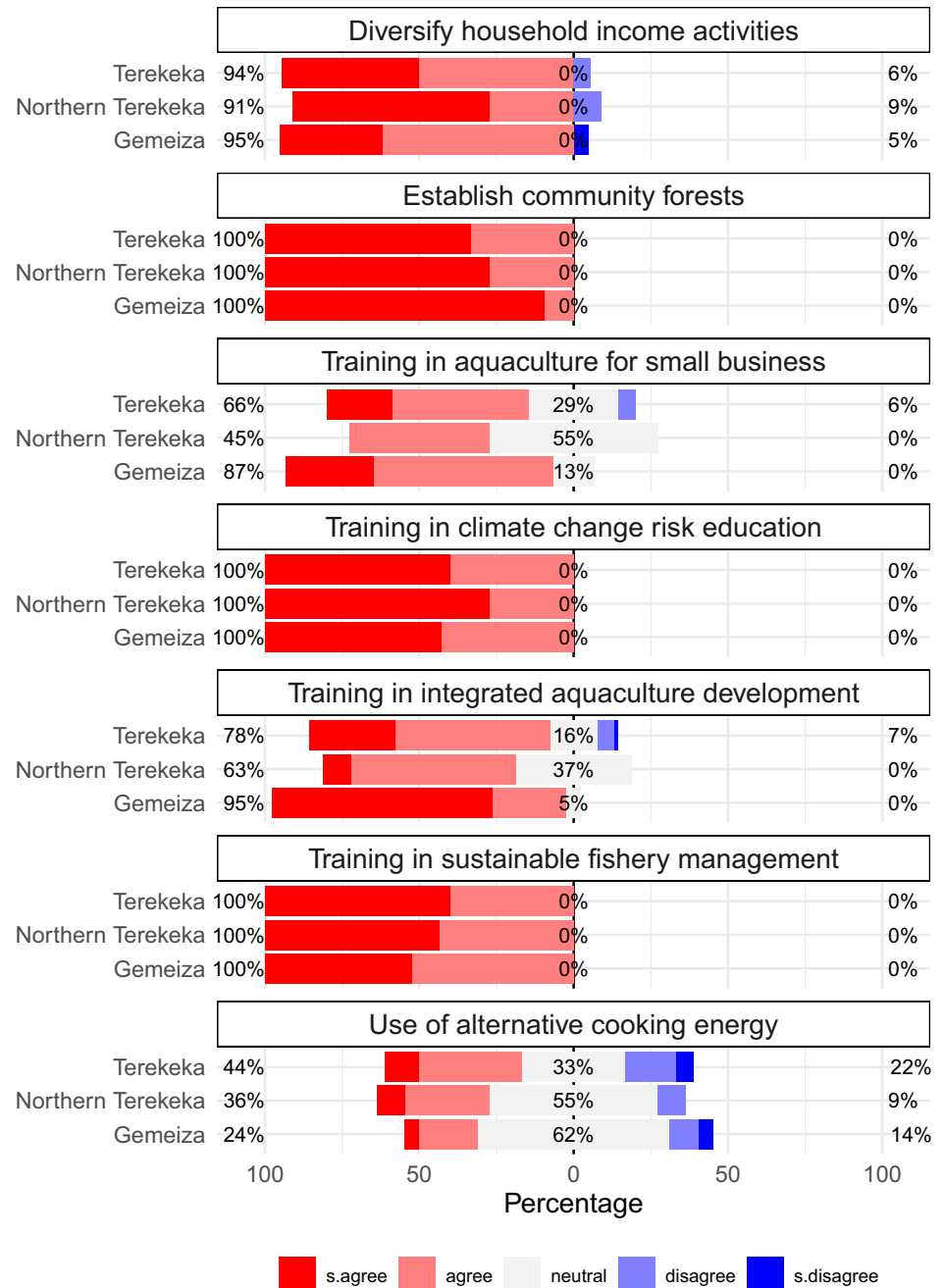
Victoria in the early 1960s (Mohamed and Savenije 2014), or local ecological changes such as changes in water flow that are related to high spatial variability in land cover which in turn is related to the spatial distribution of conflict in South Sudan (Sosnowski et al. 2016). Rural communities depending on climate sensitive resources such as fisheries generally have a high capacity to recognize changes in local climate (Howe and Leiserowitz 2013). Overall, the most parsimonious explanation for the strong level of observed changes of weather patterns and climate change is that climate has changed in reality and is

negatively affecting the fish populations of the Sudd wetlands. Of course, the data deficiency for the region does not allow us to infer whether this change is part of regional, natural changes of the hydrology or part of the global anthropologically caused climate change.

Most questions in our survey, except three, received strong support. These three questions (declining fish populations, degraded breeding grounds, reduced fish size, Fig. 3) received also a large proportion of “neutral,” i.e., undecided, answers. It is not clear whether these neutral answers indicate a lack

**Fig. 6** Fishers' interest to personally adapt to climate change. Interviewees had a choice of opinion (strongly agree, agree, neutral, disagree, strongly disagree) to each of the aspects. Results are shown as a diverging stacked bar chart (see Fig. 3)

### Lifestyle changes to mitigate climate change impacts



of own experience in these specific issues. We did not record how long interviewees fished, but 80% of interviewees were more than 30 years old, thus indicating at least a decade of fishing activities and also avoiding the problem that the results are dominated by a few recent events (Vulturius et al. 2018). LEK is being gained hands-on on the job and also handed down over generations and by peers (Olsson and Folke 2001). We did not probe how much of the LEK was gained or strengthened by school education, but it might be

low considering that only 7% of respondents across study sites received information on weather conditions from school teachers.

Willingness to learn and receive training to adapt to the changing climate was very strong. It emphasizes the opportunity for professional training, which will be the basis for future mitigation strategies such as declaration of non-harvest areas or closed fishing seasons. The only exception was the use of alternative cooking energy, which could incur extra costs, something that most people simply could not

afford. Overall, the strong willingness for learning and life style changes including the diversification of income activities gives hope that fisherfolk will adapt to the challenges if adequate support is given. A special role might come to NGOs, from which about a quarter of people have already received information on changing weather patterns. A lack of information on the anthropogenic causation of climate change is also evidenced by the reasons fisherfolk assumed having caused climate change, foremost religious beliefs (anger of God and ancestors). These beliefs emphasize that, as elsewhere (e.g., Hasan and Nursey-Bray 2018 in Bangladesh), any decisions on local and national climate change mitigation need to include not only scientific data but also wider societal considerations, such as collective and individual perceptions of risks posed by climate change. Almost all respondents also realized that the uncontrolled harvest of forest resources has had negative impacts, thus agreeing with mitigation measures of planting trees and establishing community forests. While most mitigation measures are based on individual willingness to learn and to adapt to changing conditions, other measures will have to be initiated and led by national politics. For example, public initiatives are necessary to develop some affordable insurance schemes for the sector (Diouf et al. 2020). This would allow fisherfolks to be compensated for loss of equipment and houses during adverse weather events. While the willingness of fisherfolk to adapt to climate change is a very good basis for future mitigation, the general poverty of the majority of the population (The World Bank 2021; UNDP 2021) will limit the effectiveness of individual or communal initiatives without the economic and logistic support by local and national governments, but also by the international community. Somebody needs to finance training and capacity building and other measures.

Fisherfolk reported changes in fish population structure, indicating that populations are at risk of further decrease or even collapse. This included the loss and degradation of breeding grounds, reduced fish size—likely caused by a change of age structure of captured fish towards juveniles—and the arrival of new species. Shifts in the occurrence of fish species are predicted as a result of climate change (FAO 2010) and have been observed in East African lakes, in Lake Victoria bordering Kenya, Uganda, and Tanzania; in lake Kyoga in Uganda (Ogut-Ohwayo et al. 2013); in Lake Chilwa in Malawi (Njaya et al. 2011); and in Lake Wamala in Uganda (Musinguzi et al. 2016).

Overall, the trends in reported observations and sentiments were very similar across the three investigated communities although the differences in frequencies of agreement strength were significantly different in most cases. The largest difference was loss of life, which was experienced most in Northern Terekeka, which is the northernmost study site in the Sudd wetlands, and in the observation of new fish species, which was strongest in Gemeiza. The demographic background of the interviewees showed

significant differences between areas. Education was highest in Terekeka, which is geographically nearest to the national capital Juba. Nevertheless, almost all sentiments expressed by interviewees were independent of age, gender, education, and migration status, suggesting a subtle role of local societal parameters on sentiment. Exceptions included that women blame uncontrolled harvesting of forest resources more than men (who do the harvesting), but the rationale for this difference remains unknown. Furthermore, younger people were more open to be trained in aquaculture for small business, aligning with a generally higher open-mindedness of young than older people in many societies to new developments, and migrants supported planting trees less than non-migrants, perhaps indicating that the connection to the land has an impact on how to manage the land. Although we have found only one parameter with a sex-specific difference in sentiment, we like to point out that our sample size was biased against women fisherfolk. While Taege et al.'s (2009) survey indicated that almost one-third of fisherfolk in the Terekeka County are women, they only represented a minority of interviews (128:20 men: women). The biased sample size corresponds with the cultural norm in the region. On the other hand, it is not clear from the Taege et al. (2009) survey whether women participate in the same fishing activities and own their fishing gear as men, which has been shown to be gender-specific elsewhere in East Africa (Nunan et al. 2015). Gendered behavior and norms affect climate change perception and adaptation (Ngigi et al. 2016; Pearse 2017) and require further investigations to optimally design and implement adaptation strategies among Sudd fisherfolk.

For interviewed South Sudanese, the ultimate causes of climate change and how environmental and economic policies on a national or international level can solve the climate crisis were of little relevance, especially in the face of widespread poverty (Allison et al. 2009; The World Bank 2021; UNDP 2021). While unaware of the causation of global climate change, Sudd fisherfolk already experience climate change and will suffer from its impacts despite not having contributed to it. They are, however, on the receiving end of the negative consequences especially as they heavily rely on natural resources for their own survival (Hope 2009).

The Sudd wetlands are one of the most important and biodiversity-rich wetlands in the world. The Sudd's biodiversity-rich aquatic habitats offer ideal spawning, rearing, growing, feeding, and survival grounds for fish. These habitats appear "largely intact and largely unaffected by industrial development" (South Sudan Ministry of Culture, Youth and Sports 2017), yet our results show that they are being affected by climate change. While industrial development may not have affected them, it does not mean they are not being affected. It emphasizes that many issues need to be considered when attempting to address the SDGs. The evidence raised by fisherfolk as an early warning system about negative impacts of

climate change on livelihoods and fish populations is of immediate concern for local people, emphasizing the urgent need for more research in this area. More importantly, it emphasizes the urgent need to achieve the Sustainable Development Goals (Sachs et al. 2019), especially SDG 1 (end poverty in all its forms everywhere) and SDG 13 (climate action), and applied conservation management in South Sudan.

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## Declarations

**Consent to participate** Before interviews, all potential interviewees were fully informed on the aims of the study and that any information given is anonymous. Potential interviewees could decline the interview completely or decline answers to single questions. Interviews were conducted with a research permit from the concerned authority (Ministry of Internal Affairs, National Government, Juba).

**Conflict of interest** The authors declare no competing interests.

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