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RESEARCH ARTICLE

Climate change adaptation and adaptive efficacy in the inland fisheries of the Lake Victoria basin

Elizabeth A. Nyboer[1] | Laban Musinguzi[2] | Richard Ogutu-Ohwayo[3] | Vianny Natugonza[4] | Steven J. Cooke[5] | Nathan Young[6] | Lauren J. Chapman[7]

[1]Department of Biology, Carleton University, Ottawa, Ontario, Canada; [2]National Fisheries Resources Research Institute (NaFIRRI), Jinja, Uganda; [3]African Lakes Network (AFLANET), Jinja, Uganda; [4]Busitema University Maritime Institute, Namasagali campus, Kamuli, Uganda; [5]Department of Biology and Institute for Environment and Interdisciplinary Science, Carleton University, Ottawa, Ontario, Canada; [6]School of Sociological and Anthropological Studies, University of Ottawa, Ottawa, Ontario, Canada and [7]Department of Biology, McGill University, Montreal, Quebec, Canada

Correspondence
Elizabeth A. Nyboer
Email: b.a.nyboer@gmail.com

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Abstract

1. Inland fisheries support the livelihoods of millions of people in riparian communities worldwide but are influenced by increasing climate variability and change. Freshwater fishing societies are among the most vulnerable to climate change given their dependence on highly threatened aquatic resources. As climate change intensifies, building adaptive capacity within communities and understanding the efficacy of adaptive strategies for maintaining household stability is essential for coping with ongoing social and environmental change.
2. In this study, we examined household perceptions of climate change, livelihood impacts and responses to socio-ecological changes in fishing-dependent households in the Lake Victoria basin in Uganda, East Africa. Through a series of household surveys and focus group discussions in five fish landing sites, we assessed social adaptive capacity (SAC) based on 207 households and identified adaptive strategies that are effective for coping with climatic change.
3. We found that people in fishing households are aware of environmental change but that most households do not have adaptive strategies that are efficacious for securing long-term income and food security.
4. We also investigated household demographics that contribute to SAC, examined links between SAC and adaptive efficacy and established potential routes towards developing effective adaptive approaches in small-scale fisheries.
5. This work contributes to a growing foundation of documented community-based knowledge for building adaptive capacity in inland fisheries and the communities around the world that depend on them.

KEYWORDS

adaptation, community-based solutions, resilience, small-scale fisheries, social adaptive capacity, social-ecological systems, Uganda

1 | INTRODUCTION

Freshwater fisheries provide important sources of livelihoods and food security to riparian communities worldwide (Cooke et al., 2016; Welcomme et al., 2010). For example, the inland capture fisheries of the Mekong River supply up to 48% of animal protein to rural households in parts of its basin (Arthur & Friend, 2011), and the rich biodiversity of the Amazon River underpins the cultural, nutritional and economic livelihoods of an estimated 200,000 people living on its shores (Almieda et al., 2004; Begossi et al., 2019). In East Africa, the fisheries of the Lake Victoria basin (LVB) supply more than 3 million people with their primary source of income (LVFO, 2016), and ~22 million with >50% of their annual protein intake (FAO, 2014). Anthropogenic perturbations, including climate change, can bring about significant biophysical changes to inland aquatic ecosystems with negative impacts on fishery productivity and livelihoods (Myers et al., 2017; Ogutu-Ohwayo et al., 2016). Fishery-dependent societies must develop strategies for dealing with emerging stressors (Allison et al., 2009; Cinner et al., 2018).

The complimentary concepts of resilience and vulnerability provide key frameworks for understanding household, community and system responses to environmental stressors, including climate change (Joakim et al., 2015). In socio-ecological contexts, resilience is understood as the capacity of the system (e.g. a fishery) to respond to disturbances while maintaining essential functions (Walker et al., 2004; Folke, 2006). Resilience can be realized through reorganization, innovation and absorption of change (Armitage & Plummer, 2010; Folke, 2006; Walker et al., 2004) and manifests in long-term employment, stable incomes and productive natural resources (Coulthard, 2012). Vulnerability, on the other hand, provides insight into 'the nature and extent of the adverse effects of an environmental shock or disturbance' (Lavell et al., 2012, p. 33) to help understand processes that lead to risk (Adger, 2000; Joakim et al., 2015). In a climate change context, vulnerability is thought to reflect three interacting components: exposure (the degree to which climatic stressors are experienced), sensitivity (the degree to which households are dependent on climate-affected resources) and adaptive capacity (the ability to undertake actions that can mitigate adverse effects, take advantage of opportunities and/or cope with consequences of environmental disturbances) (Adger, 2003, 2006; Smit & Wandel, 2006). Building resilience to climate change requires bolstering adaptive capacity in vulnerable households or communities (Adger, 2003; Paul et al., 2016). Identifying the social and ecological characteristics that influence adaptive capacity is thus critical for the future stability of fishery-based social-ecological systems.

Adaptive capacity is often conceptualized as a function of access to capital assets alone (Bennett et al., 2014; Yohe & Tol, 2002). However, recent scholarship has found that adaptive capacity is shaped by a complex array of interacting social and ecological factors that must be considered for adaptive actions to be effective (Barnes et al., 2020; Cinner & Barnes, 2019; Turner et al., 2020). This broader conceptualization, referred to as social adaptive capacity (SAC), encompasses five distinct domains: (i) access to assets, (ii) flexibility in adaptive strategies, (iii) access to formal and informal modes of learning, (iv) agency to adjust livelihoods and (v) social organization (Cinner et al., 2018; see Table 1 for definitions). Each domain is itself moulded by ecological, political, cultural and environmental forces that give rise to variation in SAC across local and regional scales (Blythe et al., 2014; D'agata et al., 2020; Smit & Wandel, 2006). In small-scale fisheries, SAC can be established through familial ties and capacity to engage in groups (i.e. social organization) and strengthened by earlier experiences with climatic stress (i.e. learning) (Coulthard, 2008; Kalikoski & Allison, 2010; Turner et al., 2020). On a regional level, investment in infrastructure (e.g. schools, banks, healthcare services) can increase access to assets (Young, 2016); and environmental degradation, fisheries management practices and land tenure systems can affect agency and promote flexibility (Andrachuk et al., 2018; D'agata et al., 2020).

Despite these broad scales of influence, actual adaptive actions often take place within communities at the level of the household (Coulthard, 2008; Elrick-Barr et al., 2014). A variety of strategies have been used to reduce climatic stress within households; however, not all strategies have the desired outcome of improving long-term well-being (Berkes & Jolly, 2001; Kalikoski & Allison, 2010). Within fisheries, some strategies are short term or reactive (e.g. increasing fishing pressure) and can exacerbate negative trends in the resource base and undermine social-ecological resilience (Cinner et al., 2011). On the other hand, effective adaptive actions tend to be longer-term activities (e.g. planting drought-resistant crops) that boost system resilience by adjusting to change and stabilizing negative ecosystem trends (Cinner et al., 2011). Different historical, social and ecological contexts mean that solutions that are tenable in some contexts are unsuccessful in others (Barclay et al., 2019; Coulthard, 2008). Studies examining relationships among household characteristics and the domains of SAC have found that context-specific knowledge can illuminate adaptive options that build sustainable adaptive practices (Barnes et al., 2020; D'agata et al., 2020; Turner et al., 2020).

Adaptations do not automatically result in the improved well-being of people. Each adaptative strategy is likely to be accompanied by trade-offs with other elements of livelihoods (Coulthard, 2012). Distinguishing between effective versus less successful adaptive strategies and understanding factors that lead households to adopt one type of strategy over the other is key to understanding how to build SAC in small-scale fisheries. Studies exploring routes by which fishers respond to environmental change have provided insight into the value of various adaptive actions (Blythe et al., 2014; Coulthard, 2008; Turner et al., 2020), and others have assessed livelihood outcomes associated with adaptive actions in a variety of rural settings (Agrawal & Perrin, 2008; Osbahr et al., 2010). However, adaptive capacity in fisheries is often measured as latent adaptive potential (Bennett et al., 2016) based on household traits that could theoretically allow them to adapt (e.g. having access to financial resources) rather than measuring the efficacy of strategies that have already been or are currently being used (Mortreux et al., 2020). An important step is to connect these concepts by exploring whether adaptive strategies lead to material outcomes for people's livelihoods (Agrawal & Perrin, 2008; Blythe et al., 2014; Coulthard, 2012) and explicitly testing whether

TABLE 1 Definitions of nine continuous indices calculated from household surveys and the different survey variables (separated by semicolons) included in each index. Dark yellow boxes are the five domains of social adaptive capacity. Exposure and sensitivity represent the other two domains of vulnerability

Index	Description	
Assets	Definition	Total value of household structures and possessions, access to credit through formal or informal means; access to services and infrastructure (Cinner & Barnes, 2019)
	Survey variables (13)	Number assets owned (not including fishing gear); asset values; total annual income; number of facilities; distance to school, market, bank, health center, water; housing type; transportation mode (bike, motorcycle, vehicle)
Flexibility	Definition	The capacity for households to deal with change by switching between livelihood strategies; reflects people's ability and willingness to engage in alternatives (Cinner & Barnes, 2019)
	Survey variables (8)	Number of fishing activities; fishing gears; crops and livestock; trade and service activities; non-fishing natural resource-based activities; capacity change activities during droughts and floods (y/n); number of options during droughts; number of options during floods
Agency	Definition	The ability of individuals to have free choice in responding to environmental change and people's belief in their ability to manage prospective situations and events; empowerment, cognition, motivation (Cinner et al., 2018)
	Survey variables (6)	Leadership role in community group (y/n); leadership role in the village (y/n); do they provide advice to peers (y/n); do they control household income (y/n); has household well-being improved over the last 10 years (y/n); do they take proactive measures to protect their household (y/n)
Learning	Definition	Formal and informal forums of learning that enable people to frame or reframe problems by recognizing change; attributing this change to its causes and assessing potential responses (Cinner et al., 2018)
	Survey variables (5)	Years of education; diversification training or outreach programs (groups); previous experiences with droughts and floods and other environmental changes (number of changes mentioned); experience with human-caused changes; changes in fish stocks
Social organization	Definition	Societal organization that enables cooperation, collective action, access to resources and knowledge sharing including formal and informal relationships between individuals, communities and organizations (Cinner et al., 2018)
	Survey variables (8)	Number of community groups; level of involvement with community groups; partake in communal tasks in the village; sense of social cohesion (y/n); access to help and support from the community (y/n); aid from government/external organizations (y/n)
Exposure	Definition	The frequency and severity of environmental shocks experienced by communities; perceptions of changes in frequencies of extreme weather events, alterations to timing of seasonal shifts and impacts of droughts and floods on income, employment and food security (Bennett et al., 2016)
	Survey variables (13)	Perceptions of effects of droughts and floods on fish abundances (Nile perch, Nile tilapia and Silver cyprinid); effects of droughts and floods on income; changes in seasonal timing; changes in intensity of seasons; changes in the frequency and severity of unpredictable weather events; other impacts
Sensitivity	Definition	Degree of reliance on fish for income and food, and how environmental shocks (i.e. droughts and floods) affect the number of fish consumed within a household (Bennett et al., 2016)
	Survey variables (4)	Proportion of income earned from fishing; proportion of employment from fishing; effect of floods on household fish consumption; effect of drought on household fish consumption
Efficacy of adaptive actions	Definition	Degree to which adaptive actions lead to positive outcomes for food security, income and employment
	Survey variables (4)	Results of adaptation actions on food security, income and employment within fisheries during past droughts and floods; outside of fisheries during past droughts and floods; results of actions taken for survival (coping); results of actions taken for protection of households (planning)

households with high latent adaptive potential are more likely to use adaptive actions that do in fact improve long-term livelihood stability in terms of food security and income.

Here, we examine climate change vulnerability (exposure, sensitivity and latent SAC) in five inland fishing communities in the LVB in Uganda. Our objectives were to: (1) establish a baseline understanding of perceptions of climatic change (exposure) and livelihood impacts (sensitivity); (2) determine the latent SAC of households by assessing indicators of assets, flexibility, agency, learning and social organization; (3) develop a catalogue of actions that have been used within these communities to respond to climatic stressors and document effects on food security and income to determine the efficacy of current adaptive actions; and (4) examine the relationship between household characteristics, latent SAC and adaptive efficacy to identify socio-economic characteristics of households that are the most important for adaptive actions that can promote resilience. Finally, we provide recommendations for routes by which Ugandan fishing communities in the LVB may be able to prepare for and respond to climate change. This work contributes to a growing base of community knowledge and experience to build adaptive capacity in Ugandan fishing communities and inland fisheries generally.

1.1 | Research context: History and social-ecological changes in the Lake Victoria basin

The LVB is a region in equatorial East Africa composed of a network of lakes and rivers, many of which host economically important inland fisheries. Lake Victoria is the largest tropical lake in the world and supports ~200,000 fishers among the three countries that share its waters: Uganda (43%), Kenya (6%) and Tanzania (51%) (LVFO, 2016). For many decades, Lake Victoria supported a productive multi-species fishery, but the 20th century brought massive social and ecological changes to the region as human populations increased and demands for aquatic resources intensified. During this period, species introductions and increased eutrophication altered the trophic structure of the lakes, changing species composition and reducing catches of several native species (Chapman et al., 2008).

The most dramatic ecological change occurred in the mid-20th century with the introduction of a large predatory fish, Nile perch *Lates niloticus*, to several lakes in the LVB, primarily to boost declining native fisheries (Pringle, 2005). A dramatic increase in Nile perch abundance in the 1980s coincided with the decline or disappearance of many native fish species (Marshall, 2017; Taabu-Munyaho et al., 2014) and ultimately shifted the fishery from a multi-species system to one dominated by three species: the introduced Nile perch and Nile tilapia *Oreochromis niloticus*, and the native silver cyprinid, *Rastrineobola argentea*, locally known in Uganda as mukene (Marshall, 2017). The highly productive Nile perch fishery fueled development of a lucrative export industry through the 1990s (Balirwa, 2007; Balirwa et al., 2003), bringing about an economic boost for fishing communities. These ecological and social shifts spurred changes in fishing practices and management policies (Barratt et al., 2015; Ogutu-Ohwayo, 1993), and the extremely valuable open-access fishery drew great numbers of fishers to the lake.

Over the last two decades, continuous intense fishing and other changes in the LVB have led to an apparent reduction in exploitable Nile perch biomass in Lake Victoria (Hecky et al., 2010; Matsuishi et al., 2006), and the fishery continues to be exploited at ever-increasing rates (Musinguzi et al., 2020; Taabu-Munyaho et al., 2016). Dwindling stocks have motivated illegal fishing practices that have further reduced stocks (Mbabazi et al., 2016; Timmers, 2012) and contributed to widespread poverty among fishing communities. Over the last 20 years, efforts in the three riparian countries were made to shift authority away from central governments towards fishing communities through locally regulated beach management units (BMUs). These co-management structures were established as mechanisms to increase community participation in management, improve compliance and foster responsible fisheries (Nunan, 2006; Obiero et al., 2015). Although initially successful at enhancing adaptation and curbing some aspects of illegal fishing (Downing et al., 2014; Lawrence, 2013), BMUs have not been wholly effective (Barratt et al., 2015; Nunan et al., 2015) partly because of inconsistent leadership, inadequate power transfer and insufficient funding (Lawrence, 2013; Nunan et al., 2018). In Uganda, BMUs were completely dissolved in 2015 and replaced by a military outfit (the Fisheries Protection Unit) attached to the Uganda People's Defence Forces (UPDF), which started operations in 2017 (Kantel, 2019). This change represented a paradigm shift back to a top-down approach with implications on fishers' abilities to adapt to stressors such as climate change (Mpomwenda et al., 2021).

Ecologically, the LVB is extremely sensitive to climatic variation (Nyboer et al., 2019; Ogutu-Ohwayo et al., 2016), and several international assessments rank Uganda as one of the world's most vulnerable countries to climate change based on its dependence on natural resources (Allison et al., 2009; Liu et al., 2008). Over the past 60 years, numerous drought and flood events have caused fluctuations in lake levels (Goulden et al., 2013; Musinguzi et al., 2015), which have affected ecosystem function through changes in species distributions and habitat degradation (Ogutu-Ohwayo et al., 2016). In Uganda, freshwater fisheries provide a substantial contribution to the national economy and food security as the main source of livelihoods for >1.2 million people (Timmers, 2012). Vulnerability to climate change in Ugandan inland fisheries is thus predicted to be high (Allison et al., 2009). However, little directed local-scale analysis has examined the consequences of changing fishery ecosystems on human communities in Uganda, creating barriers to coping with risks posed by global warming.

2 | METHODS

2.1 | Site selection

Data were collected during two field excursions: February–April 2016 and September–December 2016 from lakes Victoria and Nabugabo (a small satellite lake of Victoria) in the Masaka District of Uganda

(Figure 1a). We selected five villages or landing sites for this study: three on Lake Victoria (Lambu, Ggolo and Nakiga) and two on Lake Nabugabo (Luwafu and Kaziru; Figure 1). Sites were chosen to represent a range of population size, wealth status and fishing capacity. Luwafu and Kaziru on Lake Nabugabo have ~20–30 actively operating fishers each (Table 2) and have limited access to electricity and few public services. Fishers use paddle-propelled boats and hand-operated gear, yet fishing pressure on Lake Nabugabo has been intense with both harvestable size and catch rates of Nile perch declining (Paterson & Chapman, 2009; Vaccaro et al., 2013). The Nakiga landing site on Lake Victoria (~50 active fishers; Table 2) also has few amenities, no electricity and no permanent roads. Fishers in this site target mainly Nile tilapia, but also catch Nile perch, mukene and Marbled lungfish *Protopterus aethiopicus*. The Ggolo and Lambu landings sites (~500–1000 active fishers) have the highest fishing capacity. At these sites, 2–8 fishers work together in large (7–10 m) outboard engine-powered wooden boats. Mukene is an important part of the catch at these sites and is fished by teams operating boat seines with floating lanterns at night. Long lines and gill nets are used to target Nile perch and Nile tilapia. Fishers at Ggolo and Lambu have benefitted from government investment in infrastructure to promote the Nile perch export market, including access to electricity and well-maintained roads. Our focus on Ugandan fishing communities means the generalizability of these data to the entire LVB is limited; however, our diverse selection of fishing sites provides insight into factors that influence SAC among households and communities in Uganda.

2.2 | Research approach

Primary data were collected at the household level using a mixed-methods approach, employing a series of quantitative surveys ($n = 207$ across the five villages; Table 2; Appendix A) and qualitative focus group discussions (FGDs) with members of fishing communities ($n = 16$; Table 3; Appendix B) and key informant interviews (KIIs) with community leaders ($n = 8$; Table 3; Appendix C). Mixed methods research is well suited to investigations of complex social-ecological phenomena, allowing both breadth and depth in data collection and analyses (Axinn & Pearce, 2006). Written consent to participate in the study was obtained for all participants prior to data collection activities by distributing consent forms and having participants sign the form at the start of each survey, interview or focus group session. Consent forms were written in English and Luganda and were also read aloud at the start of each session to ensure all participants fully understood the process. All personal information was kept confidential as per McGill University Research Ethics Board file number 285–1215.

2.3 | Survey methods

Household surveys captured information on household demographics, perceptions of environmental change, access to the five domains of SAC (i.e. assets, flexibility, learning, agency, social organization). Combining these five domains provided an estimate of latent SAC as access to these five domains should theoretically improve a household's adaptive capacity. For simplicity, from here forward we refer to this index as SAC (as opposed to latent SAC). Household surveys also determined the adaptative actions used during environmental shocks (e.g. droughts, floods). The efficacy of adaptive strategies was determined by asking fishers how each activity affected income and food security (increase, decrease or no change) when faced with climatic shocks.

Participants were recruited by approaching potential respondents at landing sites and arranging meeting times with the aid of community leaders. We selected participants randomly, but first conducted rapid assessments to ensure that we had roughly equal representation of age class, wealth status and involvement in the fishery (i.e. boat owners, traders, boat crew and female trader-processors). Boat owners are the proprietors of fishing craft and gears and have the highest financial investment in the fishery (Odongkara, 2006). Boat owners hire crew members to operate the gears, splitting earnings with 50% for the owner and 50% split among the crew members (Odongkara, 2006). Fish traders (male and female) meet crew members in the morning to buy fish. Male traders tend to deal in higher-priced Nile perch and Nile tilapia, which are sold to industrial processors or exporters. Female trader-processors mainly deal in *mukene* and undersized fish, processing the fish through sun-drying or smoking before selling or taking to local markets (Timmers, 2012). Sample sizes of participants at each site were roughly proportional to the number of fishers working at those sites, except for Ggolo and Lambu where surveys were administered until saturation (Baxter & Eyles, 1997). We had response rates of 96% overall with slightly higher refusal rates among female trader-processors (5%) and male traders (6%) due to time constraints. Surveys were piloted with eight community members on Lake Nabugabo (non-participants in the actual survey) and refined with fisheries scientists at the National Fisheries Resources Research Institute (NaFIRRI), Uganda. Household surveys were administered in person in the local language (Luganda) and translated immediately to English.

2.4 | Survey analysis

Households were grouped into several categories (household characteristics), including landing site (Luwafu, Kaziru, Ggolo, Lambu and Nakiga), involvement type (boat owner, trader, crew member and female trader-processor), lifestyle (migrant vs. resident), age of respondent (four categories), acres of land owned (four categories); years of fishing (four categories) and years of residence at landing site (three categories) (Table 2). Survey responses relating to perceptions of environmental change, adaptive actions and the efficacy of those responses were analysed by examining frequencies and proportions of responses.

The remaining survey responses were used to develop composite indices of sensitivity, exposure and SAC, the five domains

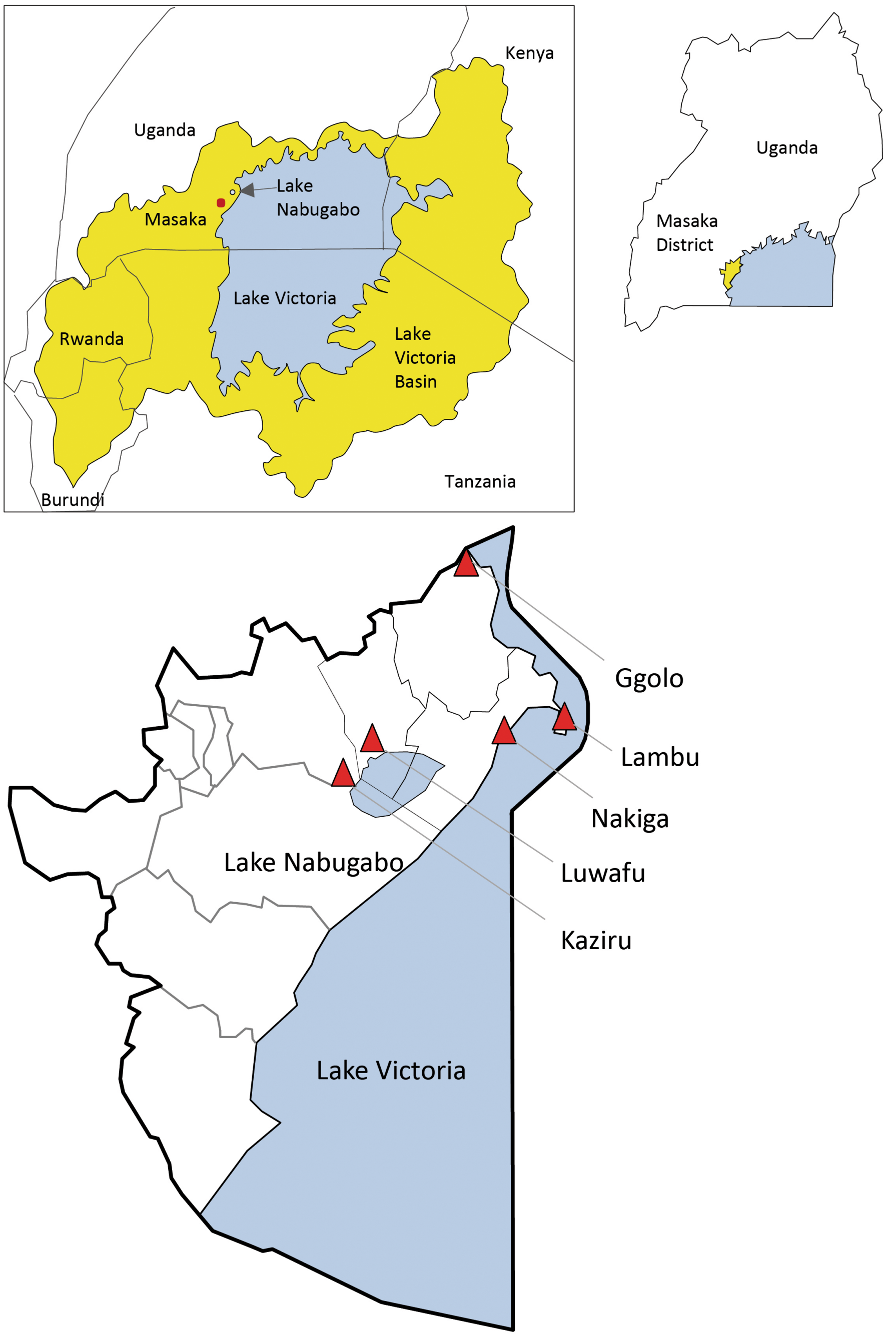

FIGURE 1 (a) Map of the Lake Victoria basin, (b) the location of the Masaka District within Uganda and (c) the location of the five study sites on Lake Victoria and Lake Nabugabo

of SAC (assets, flexibility, agency, social organization and learning), and efficacy of adaptive actions (detailed in Table 1). Each composite index was calculated from 4–13 variables from the survey (Table 1) using multi-criteria decision analysis (MDCA) and the TOPSIS method (Technique for Order Preference by Similarity to an Ideal Solution) (Hwang & Yoon, 1981), following D'agata et al. (2020). TOPSIS ranks (from zero to one) each component (in our case, households) according to their geometric distance from both the ideal and 'anti-ideal' solutions based on all criteria (in our case, survey variables) (El Amine et al., 2014; Penadés-Plà et al., 2016). Variables used as criteria in each MCDA calculation are outlined in Table 1. SAC was determined by calculating a composite index from its five domains (Cinner et al., 2018; Table 1).

An index for efficacy of adaptive strategies (or simply *efficacy*) was derived from a question that asked respondents to rate the outcomes of adaptive actions currently or already taken by their effect on household income and food security (i.e. increase, decrease or no change) (Table 1).

2.5 | Statistical analysis

To determine how household demographics affect SAC and efficacy, we used one-way ANOVAs with index scores as response variables and household characteristics as predictor variables. Post-hoc Tukey's tests for multiple comparisons were conducted

TABLE 2 Landing site characteristics and respondent demographics from household surveys

Landing site characteristics		Lake Nabugabo: Luwafu	Lake Nabugabo: Kaziru	Lake Victoria: Nakiga	Lake Victoria: Ggolo	Lake Victoria: Lambu	Total
Population		180	150	200	1500	12,000	
Men in fishing		35	20	50	550	750	
Women in fishing		4	5	12	200	300	
Migrant fishers		0	3	15	50	200	
Daily fish catches (kg)	Nile perch	15	15	15	60	1200	
	Tilapia	30	5	50	10	800	
	Mukene	20	0	0	500	4000	
Survey respondent demographics							
Gender	Male	22	31	29	31	45	158 (76%)
	Female	1	2	4	16	26	48 (24%)
	Total	23	33	33	47	71	207
Involvement type	Boat owner	12	21	15	18	16	82 (40%)
	Crew member	7	7	8	12	24	58 (28%)
	Trader	3	3	6	1	4	17 (8%)
	Women	1	2	4	16	27	50 (24%)
Migrant vs. resident	Migrant	0	0	9	9	39	57 (28%)
	Resident	23	33	24	38	32	150 (72%)
Age (category)	19–30	1	9	5	15	13	43 (21%)
	31–39	8	8	9	10	22	57 (28%)
	40–43	11	7	5	12	19	54 (26%)
	44+	3	9	14	10	17	53 (26%)
Acres of land (category)	0	10	17	12	26	39	104 (50%)
	0.25–3	12	14	11	16	24	73 (37%)
	3.25–7	1	2	7	3	5	18 (9%)
	8+	0	0	3	2	3	8 (4%)
Years of fishing (category)	0–4	9	8	6	16	16	55 (27%)
	5–8	10	7	5	11	21	53 (26%)
	9–15	1	12	8	10	18	47 (23%)
	16+	3	6	14	10	16	48 (24%)
Years of residence (category)	0–7	6	2	11	19	40	78 (38%)
	8–25	10	17	12	13	31	51 (25%)
	26+	7	14	10	15	0	74 (36%)

for statistically significant ANOVA$_S$ to indicate differences among groups. The effect of gender was tested under 'involvement type' since the 'female trader-processor' category was exclusively women, and all other categories were exclusively men. We conducted redundancy analyses (RDA, type 2 scaling) to investigate multivariate relationships among household characteristics and index scores (Legendre & Legendre, 2012). Because SAC is calculated from its five domains, we developed two separate RDA models to avoid collinearity issues. Model A included all household characteristics (i.e. landing site, involvement type, lifestyle, age, years of residency, years in fishing and acres of land owned) as predictor variables and vulnerability indices (i.e. SAC, sensitivity, exposure) and efficacy as response variables. Model B also included all household characteristics as predictors but had the five domains of SAC (i.e. assets, flexibility, learning, agency and social organization) as response variables. For both models, all variables had low collinearity with variance inflation factors below 2 and were thus retained in the model (Legendre & Legendre, 2012). We used stepwise (forward-backward) model selection to determine our final models, which included only the household characteristics that explained a significant amount of the variation in our response variables (Legendre & Legendre, 2012).

Finally, we used multiple linear regression to determine predictors of the efficacy of adaptive strategies. We again developed two models: the first with household characteristics and vulnerability indices as predictors and the second with the five domains of SAC as predictors. We used stepwise selection and Akaike's information

TABLE 3 Number of participants and groupings for focus group discussions (FGDs) and key informant interviews (KIIs)

	Lake Nabugabo		Lake Victoria		
	Luwafu	Kaziru	Nakiga	Ggolo	Lambu
Involvement types					
Women	8		12	14	13
Traders	10		10	11	10
Boat crew	16	23	11	13	14
Boat owners			15	10	12
KII—Role of respondent					
BMU chairperson/secretary			1	1	1
Local chairperson 1 (LC1)	1	1	1		1
Youth chairperson	1				

criterion (AIC) to determine the contribution of each predictor variable in explaining variation in efficacy (Legendre & Legendre, 2012). Variables that did not explain a significant amount of the variation were removed from the models. All analyses were conducted using R version 3.4.1 (R Core Team, 2019).

2.6 | Focus group discussion and key informant interview methods

A total of 16 FGDs were held at the landing sites and targeted the same four involvement types, and a total of eight KIIs were conducted with 1–2 purposively selected community leaders at each site (Table 3). Questions in the FGDs and KIIs were designed to explore key issues emerging from the survey data and to probe more deeply into perceptions of environmental change and adaptative strategies (Supplementary Materials Document 1–2). In Lambu, Ggolo and Nakiga, we held an FGD for each involvement type, which made up 12 of the 16 FGDs (Table 3). In Luwafu and Kaziru, there were too few male traders and women for a separate focus group at each site, so we brought individuals from the two sites together (Table 3). In addition, no strong distinction existed between boat owners and boat crew at the Lake Nabugabo sites because the boat owners typically operate their own boats with the crew members. As a result, the boat owners and crew members were combined in the FGDs (Table 3). Participants were identified with the help of community leaders and represented the three major fisheries (Nile perch, Nile tilapia and mukene), as well as a broad range of wealth statuses and age brackets. Focus groups had 10–16 participants each and included 1–2 participants who had also completed the survey. The FGDs and KIIs were conducted in Luganda or English and voice recorded. One individual on the research team led the discussions, whereas a second individual took detailed field notes.

2.7 | Focus group discussion and key informant interview analysis

Data from FGDs and KIIs were translated from Luganda to English by a single translator and transcribed in full. Qualitative analyses were conducted on the FGD and KII transcripts using NVivo software (version 12). A codebook was developed through inductive and deductive processes and refined over three rounds of coding. One initial round of coding was used to categorize and summarize the data, and two subsequent rounds were used to focus on specific themes and subthemes. The code book was organized according to specific research questions, including perceptions of changes in the environment and in the fishery, responses to environmental change and adaptation strategies. The data from the qualitative analysis is presented in the form of quotes; these quotes were carefully selected to represent a range of perspectives from the different groups and landing sites included in the study and to be representative of viewpoints expressed in the FGDs. The mixed methods approach used in this study combined with 8 years of relationship building in the Nabugabo communities (EAN), 6 months of data collection and post-data-collection visits to the research sites allowed for validation of the findings.

3 | RESULTS

3.1 | Survey results

3.1.1 | Perceptions of environmental change

People in Ugandan fishing households on Lake Victoria and Lake Nabugabo are highly exposed to and aware of the biophysical effects of climate change. Commonly perceived effects included changes in seasonal rhythms, including increased frequency of extreme events (i.e. droughts, 86%; floods, 51%) and changes in wind and storm patterns (31%) (Table 4). Most fishers stated that rainy and dry seasons were becoming more intense and less predictable (Table 4). Fishers also noted other forms of anthropogenic environmental degradation, especially destruction of wetlands (37%) and forests (56%). Many respondents mentioned rapid human population growth (22%) as an important component of environmental change (Table 4).

Environmental changes were perceived to affect availability of fish resources (Table 4). At all landing sites, fishers reported decreases in catches of Nile perch and Nile tilapia. There was general agreement that fish sizes and abundances tended to decrease during droughts and increase during floods and that fish movement patterns were tightly connected to changes in wind and precipitation. Catch reductions were also attributed to wetland and forest degradation (Table 4). Other negative impacts of droughts included crop failure, reduced incomes and high food insecurity (Figure S1, Table 4). Floods, if not severe, were associated with increased incomes and food security through better fish catches. However, excessive flooding led to crop failure, road blockages, damage to infrastructure and higher post-harvest losses (Figure S1; Table 4).

3.1.2 | Responses to environmental change and livelihood outcomes

Responses to environmental disturbances were split into four categories: adaptations within the fishery (40%); adaptations outside of the fishery (19%); planning for future disturbances (16%); and coping or emergency responses (22%) (Figure 2), with many individuals adopting more than one adaptation option within and among each category. For adaptations within the fishery, a large proportion of respondents (92%) stated that they do not have a specific strategy but continue fishing as usual (Figure 2). Others mentioned a variety of strategies intended to counteract livelihood impacts such as increasing fishing effort, migrating to new fishing grounds or changing target species (Figure 2). Although some indicated that adapting withing the fishery improved income and food security, most indicated that long-term stability stayed the same (44%) or worsened (33%) with strategies that led to more fishing instead of diversifying (Figure 2). Fishers that employed coping strategies such as borrowing capital (e.g. money, seeds, fishing gear), selling off livestock and assets, relying on support from community groups or exiting the fishery indicated that often (43% of the time) these strategies incur negative long-term impacts on livelihoods. Except for relying on social groups, most reactive or emergency response strategies decreased the long-term well-being of households (Figure 2). In terms of planning ahead for future climatic stresses, just over half of the respondents (53%) stated that they have no specific strategy. Some made efforts to improve fish processing, save money, plant fruit trees, build storage facilities for food, dig trenches to prepare for floods or invest in irrigation infrastructure (Figure 2). Planned

TABLE 4 Fishers' perceptions of climate change and livelihood impacts and the percent of survey respondents who mentioned each category. Environmental changes are categorized as climatic or anthropogenic

%	Type	Environmental change	Description and effects on fish catch and livelihoods
86%	Climatic	Increased frequency of unpredictable dry seasons or drought events	Dry seasons are longer, hotter and more intense, and are unpredictable in timing Crops fail, fish catches drastically reduce, famine and food insecurity increase. Fish processing can be easier due to good conditions for sun-drying
81%	Climatic	Increased frequency of unpredictable wet seasons or flood events	Rainy seasons are shorter, but more intense than in the past, and unpredictable in timing Sudden intense rains destroy crops, cause diseases among livestock, damage infrastructure at landing sites, cause post-harvest losses (fish rot) and block transportation routes. Floods can increase catch rates as fish tend to move with freshwater inputs
31%	Climatic	Unpredictable wind patterns	Winds travel in different directions than in the past; more sudden strong winds and storms Fish movement patterns are altered; fishers experience dangerous conditions on the water
56%	Anthropogenic	Deforestation	Large swaths of land deforested on the Ssese Islands for industrial agriculture Removal of natural forests has exacerbated drought conditions resulting in fewer fish and crop failures
37%	Anthropogenic	Wetland destruction	Wetlands have been developed for agriculture, urban development and tourism Loss of breeding ground for fishes results in recruitment failures and reductions in fish catch. Loss of natural filtration system for the lake reduces mitigation potential for pollution and eutrophication
22%	Anthropogenic	Population growth	Population has grown due to economic boom, both through higher birth rates and through influx of migrants Increased competition in the fishery leads to reduction in fisheries and higher demand for fish in lakeshore communities

strategies had long-term positive effects on food security and income 35% of the time (Figure 2). Finally, respondents suggested that diversifying outside of fishing into crops, livestock and various forms of business, trade and service had the most substantial positive impacts with 55% indicating improvements in food security and income (Figure 2).

3.1.3 | Relationships among household characteristics, vulnerability indices and domains of social adaptive capacity

Our analysis revealed that SAC varied by household characteristic (Figure 3). Tukey's multiple comparisons revealed that boat owners, permanent residents (as opposed to migrants), individuals with access to land and those with longer residence time had higher scores for SAC compared with their counterparts (Figure 3b–f). Among the different domains of SAC, flexibility varied the most with residents of Luwafu and Kaziru, boat owners, permanent residents and households with access to land having the highest flexibility (Figure 3a–f). Other domains of SAC did not vary as much, but boat owners had higher access to assets, learning and social organization, and residents had higher social organization (Figure 3b,c). Sensitivity to climate change also did not vary much among households, except that individuals who owned more land and those who were longer-term residents were less sensitive to climate change than others (Figure 3d,f). Exposure did not vary among the different household characteristics, indicating that all demographics had roughly equivalent perceptions of environmental change and livelihood impacts (Figure 3a–f).

Model A of the RDA revealed that household characteristics explain a significant proportion of the variation in scores for efficacy, SAC, exposure and sensitivity (adjusted $R^2 = 0.13$, $F = 4.40$, $p = 0.001$; Figure 4a). Axis 1 was statistically significant at $p = 0.001$ and explained 13.7% of the total variance in the data. Axis 1 described a gradient from strong SAC and high efficacy on one end to high sensitivity on the other. Years of residence in a community and acres of land owned were positively correlated with SAC and efficacy of adaptive strategies. The Lake Nabugabo sites (Luwafu and Kaziru), boat owners and residents correlated positively with axis 1, whereas migrants, traders, crew members, female trader-processors and households in Nakiga and Lambu correlated positively with sensitivity (Figure 4a). Model B of the RDA revealed that household characteristics explain a significant proportion of the variation in index scores for the five domains of SAC (adjusted $R^2 = 0.14$, $F = 4.82$, $p = 0.001$; Figure 4b). Axes 1 and 2 were statistically significant at $p = 0.001$ and $p = 0.036$ and explained 12.9% and 4.1% of the total variance in the data, respectively. Axis 1 described a gradient from high to low flexibility. Years of residence was positively correlated with flexibility. Nabugabo landing sites and boat owners also scored positively on axis 1. Axis 2 described the remaining four domains with social organization being the strongest predictor (Figure 4b).

3.1.4 | Predictors of efficacy

ANOVAs revealed that efficacy of adaptive strategies varied by demographics (Figure 3a–f). Households on Lake Nabugabo had higher efficacy compared to the sites on Lake Victoria, especially Lambu, which is the largest landing site (Figure 3a). Individuals with residential lifestyles and long residence times also had higher efficacy than their migratory or recently arrived counterparts, respectively (Figure 3c,f).

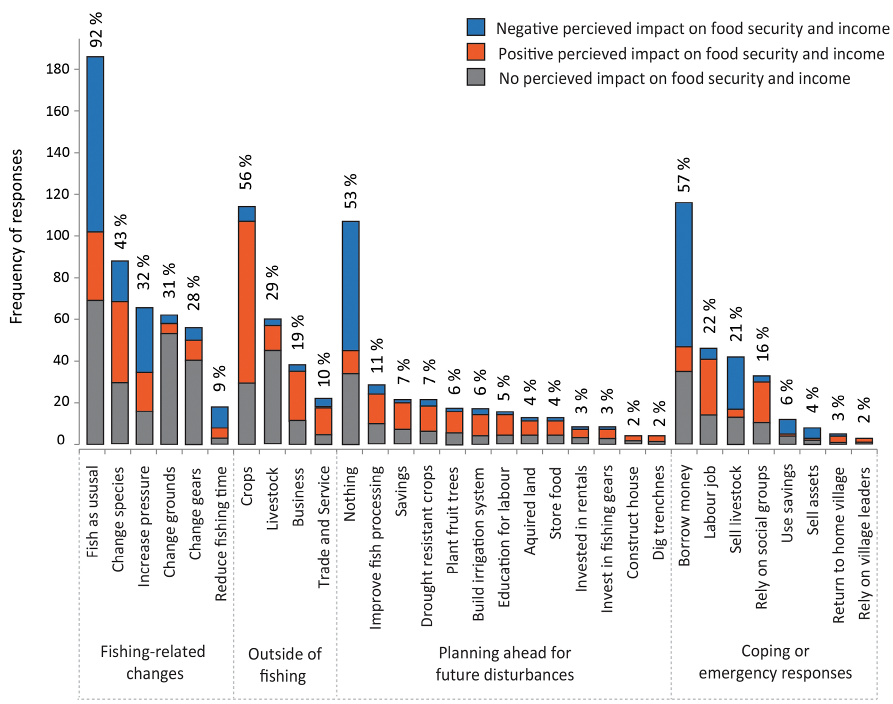

FIGURE 2 A catalogue of actions mentioned by fishers to protect households against the impacts of climatic shocks, and the perceived effect of these actions on food security and income. Proportions of survey respondents selecting each category are displayed above the bars

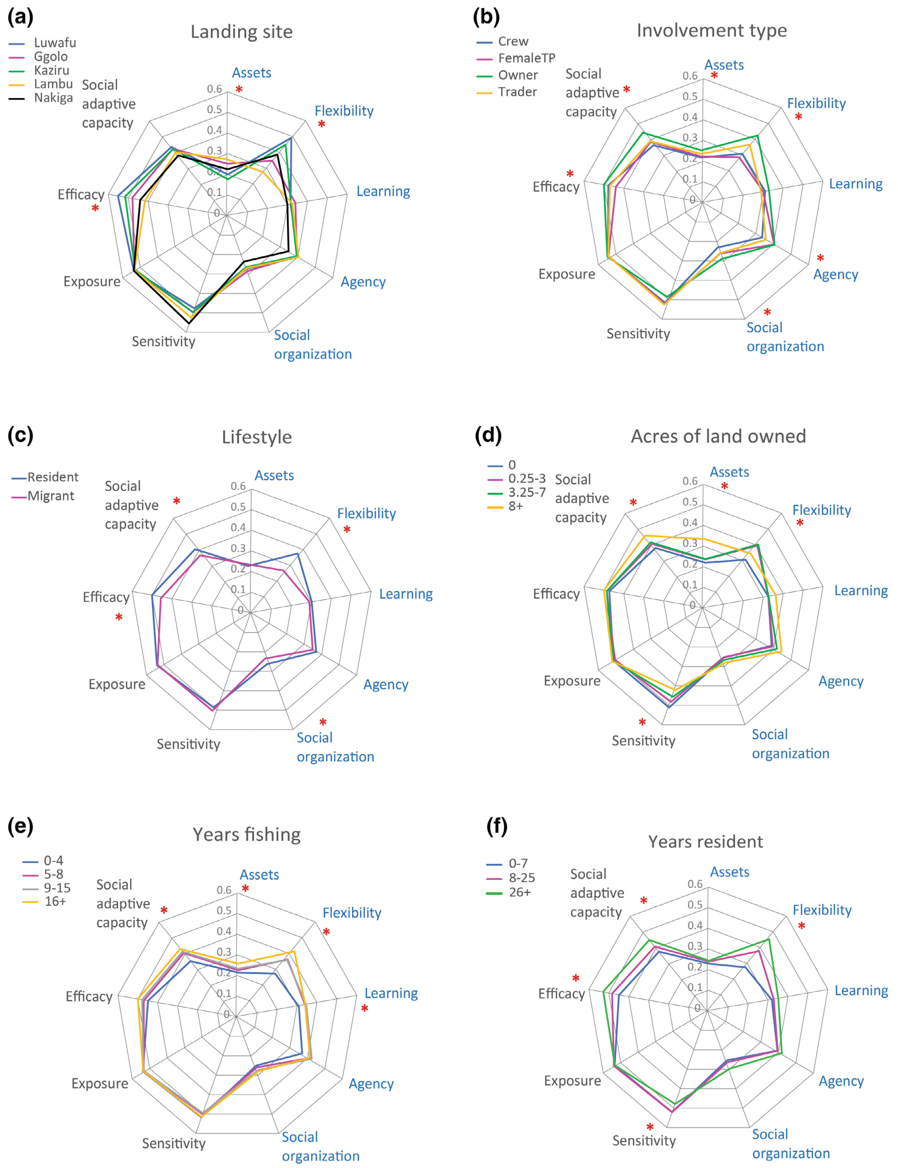

FIGURE 3 Spider plots representing the results of ANOVA to detect differences in composite indices (SAC, assets, flexibility, learning, agency, social organization, efficacy, exposure and sensitivity) among households with different characteristics (landing site, involvement type, lifestyle, land owned, years fishing and years resident). Each radial line in the spider plots represents a separate ANOVA model with the response variable indicated at the end of each line. Each colour represents a comparative group. Stars indicate the significance of the overall ANOVA model ($\alpha = 0.05$).

Multiple linear regression (MLR) revealed that household demographics and vulnerability indices explained 37.2% of the variation in efficacy ($F = 12.13$, df = 11,195, $p < 0.0001$). SAC and years of residence were positive predictors of efficacy, whereas the size of the landing site (Ggolo and Lambu), age, and reliance on fishery resources (sensitivity) were all negative predictors of efficacy (Figure 5a). A second MLR revealed that the different domains of SAC explained 39.9% of the variation in efficacy ($F = 28.4$, df = 5, 201, $p < 0.0001$), with flexibility and learning both positive predictors of efficacy (Figure 5b).

3.2 | Qualitative FGD and KII results

The above analyses determined statistical relationships that might predict how households can increase adaptive capacity in the face of climate change. In the following sections we draw on the FGD and KII data to provide insight into why the above relationships exist. We use illustrative quotes from FGDs and KIIs that provide evidence for our findings (Table 5).

3.2.1 | Factors contributing to social adaptive capacity

A key finding from the quantitative analysis is that flexibility is a highly influential domain of SAC and varies substantially among households. Flexibility is closely related to livelihood diversity, but also encompasses people's ability and willingness to switch to alternative livelihoods. FGDs revealed that even when diversification options are available, a strong identity connection to fishing and/or the perception of being incapable of diversifying often prevented households from acting. This trend was especially evident among fishers on Lake Victoria who had higher financial investment in the fishery (i.e. boat owners) or people in extreme poverty (Table 5, Quotation 1).

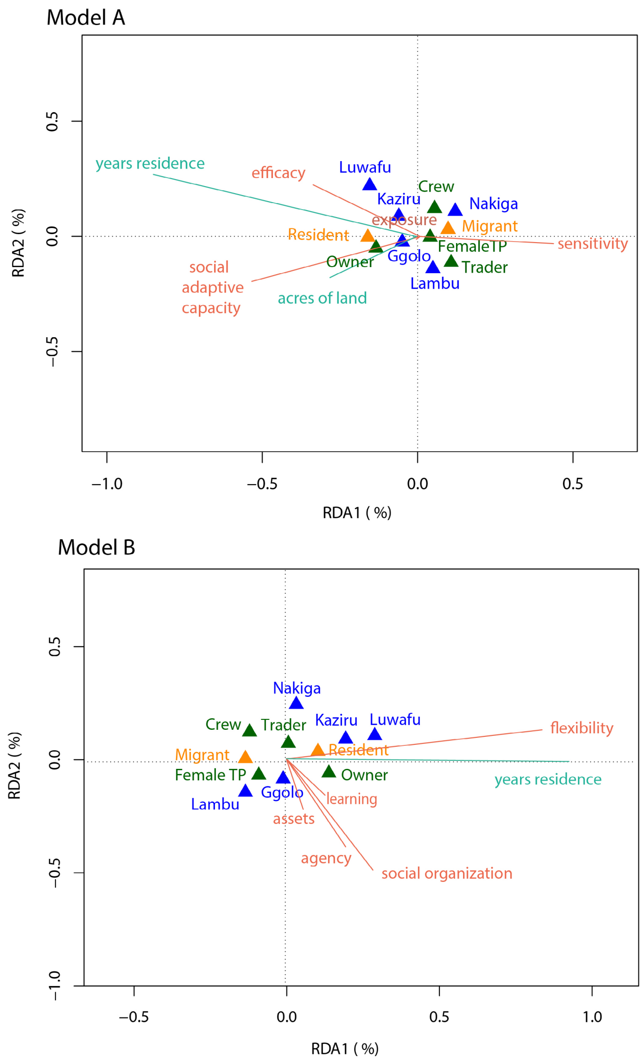

FIGURE 4 Results from the redundancy analysis of examining relationships between household characteristics with vulnerability characteristics and efficacy of adaptive strategies (model A) and household characteristics with domains of adaptive capacity (model B). Smaller angles between vectors indicate higher correlation. Symbols represent the centroids of different landing sites, involvement types and lifestyles. The mean value of centroids along the trajectories of continuous variables can be estimated by drawing a rightangle vector from the centroid to the variable line.

A second finding from the survey is that households with longer residence times and access to more acres of land tend to have higher SAC. These two characteristics are connected as most individuals with longer residence times also tend to have an established home and a plot of land in the area. Although migration to new landing sites was a popular strategy for many fishers, it is often driven by necessity over choice and frequently has the consequence of eroding trust and social cohesion within communities. By contrast, longer residence times were shown to facilitate strong social ties and improve capacity for collective action (e.g. forming groups). Although the domain of 'social organization' did not stand out prominently in the survey analysis, data from the FGDs and KIIs emphasize how crucial community cohesion is for building SAC (Table 5, Quotation 2). Likewise, the issue of not having access to land was perceived as a major barrier to diversifying (Table 5, Quotation 3).

3.2.2 | Factors contributing to efficacy of adaptive strategies

Our analysis revealed that flexibility is a key influence on the efficacy of adaptive strategies and that some forms of flexibility are more efficacious than others. Respondents indicated that increasing fishing pressure could sometimes improve food security and incomes. However, the FGDs revealed that fishing more during low-yield seasons was maladaptive, since fishers are more likely to revert to illegal practices and harvest juvenile fishes with negative long-term consequences (Table 5, Quotation 4). On the other hand, switching to activities outside the fishery or planning for future climatic disturbances had positive impacts on livelihoods. Many participants discussed how diversifying into less climate sensitive activities was desirable (Table 5, Quotation 5). Survey results demonstrated that learning is a key influence on efficacy. People learn through a variety of forums including formal education, interactions with peers and experience with environmental change (Barnes et al., 2020; Reed et al., 2010). Here, households with greater access to both formal and informal opportunities to learn were able to initiate and sustain successful adaptive strategies. For example, experience with floods impacted how fisher-farmer households prepared gardens (Table 5, Quotation 6). In addition, interactions among households through community groups improved knowledge sharing (Table 5, Quotation 7).

Surprisingly, indicators related to assets (financial wealth, possessions, access to infrastructure) were not important determinants of efficacy. Indeed, one of the landing sites with the wealthiest inhabitants and most developed infrastructure (Lambu) had the lowest efficacy of adaptive strategies. Such findings indicate that wealth does not necessarily equate to SAC or resilience. In fact, several respondents in this study noted that households with the greatest financial capacity (generally boat owners) invested in fisheries to intensify the effort of their fleets rather than investing in non-fishery-related diversification options, which can have detrimental long-term outcomes (Table 5, Quotation 8).

4 | DISCUSSION

There is growing urgency to bolster system resilience and reduce household vulnerability to climate change by fostering adaptive capacity in fisheries. The inland fishery of the LVB in Uganda is an example of a complex social-ecological system with diverse factors underlying the capacity to respond efficaciously. We examined household perceptions of climate change and livelihood impacts and investigated household demographics that contribute to SAC. In our discussion we explore routes towards developing effective adaptive approaches in Uganda's inland fisheries.

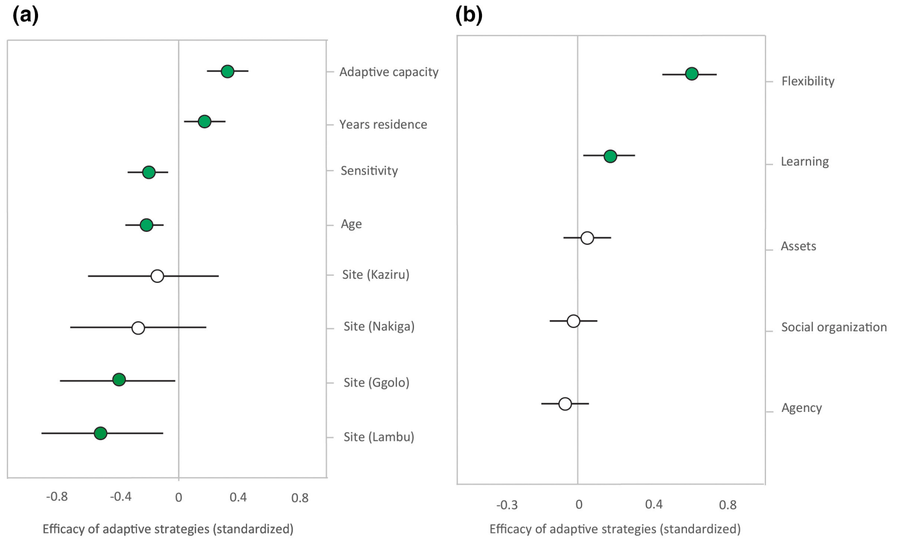

FIGURE 5 Standardized beta coefficients and 95% confidence intervals of predictors of efficacy of adaptive strategies from the multiple regression analyses with household characteristics in (a) and elements of social adaptive capacity in (b). Points to the left of the 0 line indicate negative relationships while points to the right indicate positive relationships. Significant predictors are green ($\alpha = 0.05$).

4.1 | Perceptions of climate change and environmental threats

Fishing households within and among communities in our study experienced similar biophysical effects of climate change on fishery productivity regardless of socio-economic status. Observations of unpredictable seasonal patterns and associated fluctuations in fish size and catch abundance were nearly universal among respondents, and such relationships have been observed by fishers in other parts of Uganda (Goulden et al., 2013; Musinguzi et al., 2015) and in inland fisheries across sub-Saharan Africa (Kihila, 2018; Limuwa et al., 2018; Ndhlovu et al., 2018). These congruencies possibly point to one generalizable effect of climate change on inland fishery productivity in this region. The mode by which biophysical changes translate to livelihood impacts, however, did vary by demographic. Although food insecurity and reduced household income during climatic disturbances were felt by all, boat owners were most affected by damage to fishing infrastructure and loss of capital investment; boat crew were concerned with reduced fisher safety and unemployment and female trader-processors were affected by post-harvest losses (especially in the mukene fishery). Participants from landing sites where fishers are less diversified (i.e. Lake Victoria) found that ecosystem degradation (i.e. wetland destruction and deforestation) presented more extreme threats to livelihoods due to compounding effects on fish abundance, whereas climatic shifts were more detrimental to fisher-farmer communities (i.e. Lake Nabugabo), where seasonal extremes diminish multiple income sources. The various modes by which climate change affects livelihoods are important to consider when finding adaptive strategies that reflect different groups' contexts and needs (Cinner et al., 2018). However, one must recognize that this study measures community perceptions of exposure to climate change and impacts on livelihoods and the environment; it is important for future work to directly link climatic events to these outcomes and behaviours.

4.2 | Predictors of social adaptive capacity

Social demographics (i.e. gender, involvement type, residence time) influenced household access to the five domains of SAC and affected routes by which households adapted to climate change. For example, our data showed that female trader-processors have lower flexibility than boat owners and traders and face many unique challenges in the LVB fishery in Uganda (e.g. primary caregivers for children, relegated to lowest-value fish products or unpaid labour). Women tend to lack representation in co-management structures (Musinguzi et al., 2017; Nunan, 2006), so adaptation considerations are rarely tailored to their needs (FAO, 2015). Migratory fishers and boat crew also tended to be more vulnerable to climate change. Although migratory lifestyles can increase incomes and catch in the short term (Nunan, 2010), vulnerability arises due to short residence times and lack of access to land (this study). This finding is connected to differences observed between communities on Lake Nabugabo versus Lake Victoria. Lake Nabugabo communities (i.e. Luwafu and Kaziru) had higher scores for SAC despite having fewer assets and government investments in infrastructure. In Luwafu and Kaziru, most fishers are long-term residents with strong social networks, have access to land and are diversified into agricultural and other activities. At the larger landing sites on Lake Victoria with more assets and infrastructure (i.e. Lambu and Ggolo), many fishers are temporary residents whose incomes are based solely on fishing and who lack social networks or access to land. Patterns of higher adaptive capacity in communities with fewer material assets but stronger social network have been found in other systems (e.g. coastal small-scale fisheries in Mozambique; Blythe et al., 2014). Previous work has also shown that longer residence times allow fishing households to adapt via accumulation of savings, livestock and other property (Turner et al., 2020) and by accessing development projects and credit services (Nunan, 2010; Odongkara & Ntambi, 2007). These examples highlight the multi-layered nature of SAC (Cinner et al., 2018) and indicate that people from different demographics need tailored adaptive strategies.

TABLE 5 Examples of fishers' responses to environmental change in the inland fisheries of the Lake Victoria basin taken from the focus group discussions and key informant interviews

No.	Landing site	Involvement type	Quotation
1	Nakiga	Boat owner	*For me I just stay at the landing site and I cannot leave the water. I persist in fishing however much climate change affects me. I remain on the water because I am used to that kind of work.*
2	Lambu	Local chair-person	*Unlike farmers who are always at their homesteads, for fishing people—today they are here, the other day they are there. So, you start something like a development project, and when you check in, they are left with only 2–3 people, the rest have moved away to other landing sites. And that is affecting development and savings—you try to form a savings group, but you are not sure tomorrow whether the person will be around.*
3	Luwafu/Kaziru	Crew member	*Another thing is that we would join up as a group and start cultivation, but there is limited land for cultivation. We would work the land, but there is no land for us. Yet these rich people occupy bigger portions of land but cannot allow us to hire their land for cultivation.*
4	Nakiga	Crew member	*Some are changing type of gears and reverting to those techniques of tycooning and ponyoka*[a]*. And then those who had bigger sizes of mesh are now changing to 2-inch nets, but they still don't get what they want. Then after trying for up to 2 months, still you get nothing and then you are totally desperate.*
5	Ggolo	Female trader-processor	*It's not only in fishing but also in other activities like farming where we are suffering. These droughts affect you on both sides. If you fail in fishing you go to farming and* vice versa*, but these days neither one is profitable. That's why we prefer if we can be helped with a shop or a salon.*
6	Lambu	Female trader-processor	*We follow our grandmothers and prepare the land earlier to wait for the rains - we dig trenches for water not to flood the gardens. On top of the trenches, we plant cassava and that helps the water follow the channel. The cassava grows on the banks of the channel, so the channels do not get destroyed by floods.*
7	Luwafu	Youth chair-person	*The benefit from the groups is that you create positive information within the groups by education. You can learn about something new. And in our village, we have encouraged so many youths to engage in groups as the way of improving from one step to another.*
8	Lambu	Boat owner	*If you look at the situation today most people are using borrowed money from the bank. But these days when you borrow money and you invest it in the lake, for example you have bought an engine or nets, you send the workers to go and fish and they come back with nothing but still the bank will be demanding money. And you find out that all that you have invested in, the bank will take it*

[a]Tycooning and ponyoka are both methods of fishing that have been banned on Lake Victoria. Tycooning involves setting nets and then pounding the water to scare fish towards the nets. Ponyoka involves cast-netting from a boat.

4.3 | Factors contributing to adaptive efficacy

Our results suggest that households with higher latent SAC (e.g. access to the five domains of SAC that should theoretically increase adaptive capacity) were also more successful in implementing effective strategies that have material benefits to household income and food security. We identified the domains of *flexibility* and *learning* as being statistically important for effective adaptation but acknowledge that capacity in one domain is often necessary for access to the others (Cinner et al., 2018). These links provide insight into facets of people's livelihoods that, if strengthened, may positively impact resilience, and shed light on why households adopt some strategies over others.

4.3.1 | Exercising flexibility outside of fishing

Flexibility emerged as an important domain contributing to efficacy of adaptive actions. However, the type and manifestation of flexibility must be considered. Diversifying outside of fishing had long-term positive outcomes on income and food security and has been frequently highlighted as an important adaptation strategy (Cinner et al., 2018). Key areas of diversification identified in the present study included crop agriculture and livestock despite such practices being at risk from climate change (Allison et al., 2007; Musinguzi et al., 2015). Our data show that farmers who adjust planting strategies to cultivate fast-maturing or drought- and flood-resistant crops and those who planned ahead by constructing irrigation wells or trenches had positive livelihood outcomes. However, it is ultimately households that practice non-weather-dependent activities (e.g. small businesses) that achieved the greatest stability. Such strategies increase household resilience by providing flexibility in income and improving ecosystem stability by reducing fishing pressure (Musinguzi et al., 2015). Despite the desire by many fishers to diversify, socio-economic roadblocks such as poverty, lack of trust, lack of education and lack of access to land are preventative to many (Cinner et al., 2018; Sutter et al., 2019). Indeed, livelihood diversification often fails to facilitate adaptation and resilience in developing countries where poverty is an obstacle to risking new livelihood options (Cinner et al., 2009; Sievanen et al., 2005).

4.3.2 | Exercising flexibility within the fishery

A key insight from this study is that many fishers adjust by changing activities within the fishery instead of diversifying outside, even though fishing-related strategies are acknowledged to be short-term, tend to have negative outcomes on household stability and can deplete the resource base through proliferation of illegal trading and adoption of prohibited fishing practices. Fishing harder or changing fishing tactics during times of environmental stress is common in small scale fisheries (Sievanen, 2014; Limuwa et al., 2018; Turner et al., 2020). Coulthard (2008) identified such patterns in small-scale lagoon fisheries in India highlighting the complexities of adaptive decision making in dynamic and uncertain systems. Coulthard (2012) further acknowledged that each adaptive action is likely to be accompanied by trade-offs with other livelihood factors that may not be obvious to those external to the community.

In the case of Ugandan LVB fisheries, there are several interacting forces that guide the decision to remain in fishing with roots in both ecological and social dynamics. From an ecological perspective, the combined effects of climate change and environmental degradation erode flexibility in fishery social-ecological systems. In the LVB in Uganda, it is increasingly risky to rely on crops or livestock that require substantial financial and time investments and have a diminishing likelihood of success as weather patterns become less predictable. Not only does this increasing risk lead agriculturalists to the fishery (Odongkara & Ntambi, 2007), but households with fisher-farmer lifestyles and those considering diversifying to farming also abandon those plans to rely wholly on fishing instead. These strategies reduce the impact of environmental shocks in the short term but can increase long term vulnerability emphasizing the need for parallel short-term and long-term climate mitigation strategies (Jackson, 2009).

The above characterization of the fishery as fallback or a last resort, although true for some (Odongkara & Ntambi, 2007), is not the whole story. Our social analysis revealed that a strong identity connection to fishing and sense of belonging were important factors motivating the decision to remain in fishing, paralleling attitudes documented among fishers worldwide (Béné, 2003; Blythe et al., 2014; Coulthard, 2008; Pollnac et al., 2001; Sievanen et al., 2005). Past experiences with boom-and-bust cycles mean that fishers are accustomed to changes in productivity (Coulthard, 2009) and often opt for short term coping strategies in hopes of improved catches in the future (Coulthard, 2008; Finlayson & McCay, 1998). Exerting flexibility within fishing may therefore be the most palatable adaptation option for fishers despite temporary reductions in income and food security. Theoretical developments in the resilience literature indicate that the pursuit of well-being is critical in fishers' decision-making processes (Coulthard, 2012; Pollnac & Poggie, 2008) and warn against prescriptive approaches that push fishers to comply with adaptation measures (i.e. exiting the fishery) perceived to be valuable by external actors (Smit & Wandel, 2006). Unfortunately, as climate effects amplify, productivity cycles in the LVB are bound to lengthen and temporary economic downturns may become extended periods of poverty.

4.4 | Access to assets is not strongly related to efficacy of adaptive actions

It is important to note that not all domains of SAC will lead every household to adopt responses that boost livelihood stability. Some of the boat owners in our study with the highest access to assets (e.g. financial capital) invest solely in fishing instead of diversifying. Highly specialized boat owners may be more sensitive to climate effects on fish productivity than poorer fishers who have diversified. This decision by boat owners may be related to the identity values discussed above, but such examples demonstrate that it is not only the poorest members of society who adopt less efficacious adaptive strategies (see also Blythe et al., 2014; Coulthard, 2008). Adaptations that increase fishing pressure and dependence on fishing can undermine long-term resilience in small-scale fisheries and cement social inequalities (Berman et al., 2014; Cinner et al., 2011; Limuwa et al., 2018; Lowe et al., 2019). Despite the over-specialization that can occur, boat owners still have the highest SAC and efficacy scores. This reflects the complexities that underlie adaptation decisions and highlight that private capital for private gain does not equate to resilience or adaptation as often as collective assets and capitals that benefit whole communities (Young, 2016).

4.5 | The role of social organization and learning in bolstering adaptive capacity

Strengthening social ties and community cohesion can increase the capacity for collective action (e.g. forming groups) and promote community-centered learning (Adger, 2003; Kalikoski & Allison, 2010) to aid in adaptation processes. Informal learning via social memory and community-based knowledge are critical aspects of building resilience to climate change in fishing communities (Eckert et al., 2018; Oviedo et al., 2016). As stated by McIntosh (2000): 'Social memory refers to the long-term communal understanding of the dynamics of environmental change … it is the arena in which captured experience with change and successful adaptations, embedded in a deeper level of values, is actualized through community debate' (cited in Coulthard, 2008, p. 480). Learning from how earlier generations coped with climate change and using that knowledge to plan for future disturbances can help younger or novice fishers to adapt to environmental shocks (Kalikoski & Allison, 2010). For example, elder participants in our study told that there used to be a general exodus from fishing during the long dry season (June–August) when fish catches were naturally low, and gardens required preparation. These traditional 'no-take' months allowed resting periods that sustained fishery productivity. Similarly, traditional farming practices protect gardens from extreme events through strategic planting patterns, irrigation systems and drainage trenches. Re-adopting such practices can improve fishery and crop production and contribute to a holistic, ecosystem-based approach to adaptation.

Households are rarely able to adapt to climate change in isolation, and social organization facilitates cooperation and knowledge sharing among stakeholders (Adger, 2003; Barnes et al., 2020). Effective modes of adaptation can be adopted via participation in groups (Cinner & Barnes, 2019; Turner et al., 2020), especially for individuals who lack financial capital or formal education. In Uganda, the BMUs served as entry points for community-based development with mandates to facilitate involvement of marginalized groups (e.g. women, boat crew) (Nunan, 2006). However, breakdowns in trust (Lawrence, 2015) and lack of sustained engagement (DFR, pers. comm.) have limited their success. Outcomes from this study indicate that high fisher mobility or rapid population growth can lead to breakdowns in social cohesion, deter involvement in groups and weaken adherence to regulations (Obiero et al., 2015). This reluctance to engage in co-management or knowledge exchange can hinder fishers' ability to build strong community connections and care for the fishery (Turner et al., 2020).

4.6 | Recommendations

Our study revealed that interacting social and ecological factors shape vulnerability to climate change and that adaptive capacity is mediated by identity values, environmental degradation, socio-economic status and community networks. These findings draw attention to the unique contexts and challenges that influence adaptation within and among fishing communities. Identifying appropriate adaptive strategies will require targeted, bottom-up approaches that stem from community knowledge and experience and that are co-developed and co-implemented by communities, researchers, policy makers, fisheries officers and landing site leaders.

Strengthening social ties and trust is an important local-scale action that is likely to increase resilience to climate change in the LVB, as suggested by community members in our study and demonstrated by several previous studies (Andersson & Gabrielson, 2012; Barratt et al., 2015; Goulden et al., 2013). This suggestion is not novel; a key role of BMUs was to promote social cohesion and collective action among members, and in Uganda, BMU plans were integrative and structured to account for the diversity of interests and power imbalances among stakeholder groups (Nunan, 2006). Despite this, BMUs lost legitimacy due to corruption, inadequate power transfer from the top down and insufficient funding (Lawrence, 2013) and the goals for BMUs were not met. In Uganda BMUs were completely dissolved in 2015 and replaced by military-connected Fisheries Protection Units reinstating a top-down approach to governance. Future efforts to create social cohesion will require sustained efforts to facilitate engagement of marginalized groups and strengthen their involvement in decision making processes while consistently monitoring and evaluating development projects to ensure long-term success (Lawrence, 2015; Turner et al., 2020) and being mindful of ways in which social capital can undermine community adaptation (Paul et al., 2016).

Many community members, especially women who process and trade mukene, suggested they would benefit from innovations that aim to reduce post-harvest losses of fish. Improving fish processing has been a goal for Ugandan fisheries for over 20 years (see Bwathondi et al., 2001), yet estimates of post-harvest losses remain at 20%–40% (Gichuru et al., 2019). High losses of mukene are predicted to increase under climate change as inconsistent weather patterns disrupt sun drying processes. Many participants mentioned the desire to explore technologies like tent solar dryers, which have been shown to be effective and economically viable options to prevent post-harvest losses (Chiwaula et al., 2020). Our results indicated that improving fish processing had positive impacts on income and food security (especially for women) but that access to these technologies was rare. The Lake Victoria Fisheries Management Plan had the goal of reducing post-harvest losses to 10% by 2020. To approach this goal all fishery stakeholders must to work together to establish targeted infrastructures at landing site in much the same way as tilapia and Nile perch processing improved to meet European market standards. However, even seemingly simple solutions such as this require a great deal of mutual effort between community leaders fishers, policy makers, fisheries officers and researchers.

Another suggestion from community members was to enact protective and restorative measures to wetlands and forests in riparian areas. Again, this suggestion is not novel. Calls to identify and protect fish breeding grounds are written into BMU rules (DFR, 2003). In parts of the lake, different approaches to habitat protection were implemented with varying degrees of success (Albright et al., 2004), and recent work in Uganda has identified critical nursery areas for fish (Nkalubo et al., 2018). However, this protection must go beyond breeding grounds to include forest protection and habitat restoration. Participants in our study told of community protests that successfully prevented deforestation in their village. Others gave tours where trees had been planted to modulate temperatures at the landing site. These self-driven actions attest to the motivation that already exists within communities for protection and restoration. Community support for ecological conservation is key for building successful conservation programs (Bennett & Dearden, 2014). Such projects, thus, require transdisciplinary approaches that involve communication and collaboration across disciplinary and sectoral boundaries involving sustained and regular engagement of community members, decision makers, scientists, government and communities alike (Nyboer et al., 2022).

The insights provided here on the underlying sources of vulnerability, SAC and efficacy of adaptive strategies in the fisheries of the LVB in Uganda are key for developing policy tools to address different drivers of vulnerability. The specific innovations required to reduce sensitivity or build SAC are likely to vary across communities and households. Understanding fishers' changes to harvesting behaviour in response to climatic change is key in predicting how the fishery will fare as it highlights responses that are already chosen by the fishers and can therefore provide insight into what kinds of policies are likely to be accepted in communities. This paper provides an original contribution by focusing on what the fishers say regarding responding to environmental change; this is an important step towards incorporating fishers' voices into such policy discussions. Our results are likely to have relevance in other contexts, particularly in tropical inland fisheries around the globe which face similar climate change challenges.

AUTHORS' CONTRIBUTIONS

E.A.N., L.M., R.O.-O., V.N. and L.J.C. conceived the ideas and designed methodology; E.A.N. collected and analysed the data and led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST

The authors declare no conflict of interest in the production of this manuscript.

DATA AVAILABILITY STATEMENT

Raw survey data and calculated indices are archived and publicly available on the Open Science Framework at https://doi.org/10.17605/OSF.IO/BT4QD.

ORCID

Elizabeth A. Nyboer https://orcid.org/0000-0003-3004-009X
Laban Musinguzi https://orcid.org/0000-0001-7915-3218
Steven J. Cooke https://orcid.org/0000-0002-5407-0659
Nathan Young https://orcid.org/0000-0002-2927-7025

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