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Interactions between Climate Change and Infrastructure Projects in Changing Water Resources: An Ethnobiological Perspective from the Daasanach, Kenya

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Abstract. The fast and widespread environmental changes that have intensified in the last decades are bringing disproportionate impacts to Indigenous Peoples and Local Communities. Changes that affect water resources are particularly relevant for subsistence-based peoples, many of whom already suffer from constraints regarding reliable access to safe water. Particularly in areas where water is scarce, climate change is expected to amplify existing stresses in water availability, which are also exacerbated by multiple socioeconomic drivers. In this paper, we look into the local perceptions of environmental change expressed by the Daasanach people of northern Kenya, where the impacts of climate change overlap with those brought by large infrastructure projects recently established in the Omo River. We show that the Daasanach have rich and detailed understanding of changes in their environment, especially in relation to water resources. Daasanach understand observations of change in different elements of the social-ecological system as an outcome of complex interactions between climatic and non-climatic drivers of change. Our findings highlight the perceived synergistic effects of climate change and infrastructure projects in water resources, driving multiple and cascading impacts on biophysical elements and local livelihoods. Our results also demonstrate the potential of Local Ecological Knowledge in enhancing the understanding of complex social-ecological issues, such as the impacts of environmental change in local communities. To minimize and mitigate the social-ecological impacts of development projects, it is essential to consider potential synergies between climatic and socioeconomic factors and to ensure inclusive governance rooted in local understandings of environmental change.

Keywords: dams, environmental change, water grabbing, Local Ecological Knowledge, Omo-Turkana basin

Introduction

Environmental changes are driven by the interaction between multiple biophysical, ecological, and socioeconomic factors operating at different scales. When overlapping spatially and temporally, these interactions may have antagonistic—but most often synergistic—effects, with significant impacts on ecological processes and human health and wellbeing (Díaz et

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al. 2019). Indigenous Peoples and Local Communities (IPLC) across the world are largely dependent on natural resources for subsistence (FPP 2020). Thus, the fast and widespread environmental changes that have intensified in the last decades disproportionately impact their livelihoods, wellbeing, and social-ecological resilience (Ford et al. 2020; Savo et al. 2016).

Changes related to water are driven by complex interactions of socioeconomic and ecological factors, notably climate change and direct human interventions (Droogers et al. 2012; Graham et al. 2020; Haddeland et al. 2014). Changing rainfall patterns, for example, result from alterations in the global climatic system but also from land-use changes, with impacts on water evaporation, infiltration, and discharge (Gerten et al. 2008; Sterling et al. 2013). In some coastal areas, water quality is being compromised by increased salinity, driven by sea-level rise and intensive farming (Vineis et al. 2011). Beyond the direct impacts, these changes in hydrological patterns and processes may also lead to shifts in multiple biotic components of ecosystems, such as in species distribution or phenology (e.g., Comte et al. 2013).

Changes in water and associated impacts are particularly relevant for IPLC, many of whom already suffer from constraints regarding water security and sovereignty (e.g., Rosinger et al. 2020; Wilson 2014), and especially for those who inhabit regions where water is scarce and/or whose livelihoods are largely dependent on aquatic resources (Alessa et al. 2008; Dow et al. 2007). These changes may also negatively impact IPLC's multifunctional and holistic systems of water management, sometimes referred to as "Indigenous water cultures" (McLean 2017). Many ethnobiological studies have taken water as a starting point to explore the complex inter-connections between people and their biological worlds (e.g., Reyes-García et al. 2011; Singh 2006). Ethnobiologists have long examined the historical interactions between people and waterscapes (Prestes-Carneiro et al. 2021) and how water defines our food systems (Young et al. 2021). Not surprisingly, the study of Indigenous and local knowledge around water is gaining prominence in the discipline (e.g., Goodall 2008; McLean 2017).

Changes in water driven by direct human interventions, like those brought by large-scale infrastructure projects that drastically impact water quality, availability, and dynamics, can be, however, severe and immediate (e.g., Veldkamp et al. 2017). The challenges of a rapidly changing global environment further compound, and are aggravated by, colonial settlement, land dispossession, resource extraction, and the imposition of large-scale infrastructures, all of which continue to deny IPLC access to a safe and clean environment, including water (Armstrong and Brown 2019; Estes and Dhillon 2019). These interlinked changes endanger IPLC livelihoods and the very foundations of their ways of life (e.g., Gebreyes et al. 2020; Wolverton et al. 2014).

The complexity of changes in water and their consequences represents a challenge for ethnobiologists aspiring to understand the myriad of impacts upon biophysical systems and IPLC livelihoods. In this sense, addressing the interwoven nature of drivers of environmental changes through Local Ecological Knowledge (LEK) has been gaining traction in ethnobiology and other related fields (e.g., Pyhälä et al. 2016; Reyes-García et al. 2016). Changes in water affecting IPLC are expressed and observed locally, but driven by intricate political and socioeconomic pressures that happen simultaneously at local, regional, and global scales (see Gómez-Baggethun et al. 2013). Although some IPLC might not always be fully aware of socioeconomic or political changes at regional or global scales, they deal with the expressions of these changes in their daily activities and their surrounding environments (Fernández-Llamazares et al. 2015; Savo et al. 2016). Also, through their long-term and intimate empirical interactions with nature (Eira et al. 2018; Orlove et al. 2010), IPLC have developed holistic understandings and rationales about observed changes and their interconnections and drivers, on which they base their decisions and adjust their livelihoods (e.g., Mustonen and Huusari 2020; Reid et al. 2014). Understanding IPLC perceptions of environmental change, therefore, offers a window of opportunity to bring into focus the complex interrelations between climatic and other drivers of change.

In this paper, we study local perceptions of environmental change among the Daasanach people, an agropastoralist society inhabiting one of the driest regions of Kenya, where access to clean water is limited and unreliable (Bethancourt et al. 2020). Besides being affected by climate change (Kogo et al. 2020; Niang et al. 2014; Ouma et al. 2018), the region is also witnessing a surge of large-scale infrastructure projects, such as dams and irrigation projects (Carr 2017; Hodbod et al. 2019), which are bringing substantial hydrological, biological, and socio-ecological changes. By tapping into the Daasanach perceptions of change, the goals of this study are (1) to identify the changes that the Daasanach perceive in the climatic and biophysical environment, their drivers and interconnections, focusing on water-related changes; (2) to assess the salience of water-related changes within the Daasanach's perceptions of environmental change; and (3) to evaluate locally reported interactions between climate change and infrastructure projects in driving water-related changes.

The Daasanach People and Their Environment

Biophysical CHairacteristics

Our study site is located at the northeastern shore of Lake Turkana, in northern Kenya, bordering with Ethiopia (Figure 1A). The region's environment is cHairacterized by a semi-desert with an arid climate, with mean annual temperatures around 32 °C (Mbaluka and Brown 2016). Mean annual rainfall is around 150 mm distributed along two rainy seasons: from March to May and from October to December (Mbaluka and Brown 2016). The rainy and dry seasons are modulated by the El Niño Southern Oscillation and the Indian Ocean Dipole, which sometimes lead to the occurrence of pronounced rains and floods (Owiti et al. 2008). Historical climatic data for the region indicates a warming trend since the early or mid-twentieth century (Niang et al. 2014; Ouma et al. 2018). Total annual precipitation has shown no clear trends (Niang et al. 2014; Ouma et al. 2018), but the distribution of rainfall throughout the year has been changing, with the first rainy season becoming drier and the second becoming wetter (Liebmann et al. 2014).

A fundamental component of the landscape is Lake Turkana, which covers about 7560 km^2, known as the world's largest permanent desert lake and the largest alkaline water body (Ojwang et al. 2016). The lake hosts a rich aquatic ecosystem that provides food to several local Indigenous communities (e.g., Turkana, Daasanach, El Molo) and sustains small commercial fisheries (Gownaris et al. 2017). The level and chemical cHairacteristics of the lake water are highly variable and largely dependent on the Omo River, which contributes 90% of the water inflow (Avery 2010). River and lake levels fluctuate naturally on an annual basis, flooding extensive areas along the margins of Lake Turkana and the Omo Delta (Avery 2012; Gownaris et al. 2017; Ojwang et al. 2016).

The landscape is dominated by dwarf shrubland and grassland vegetation, with some riparian forests along ephemeral streams that carry underground water (Mbaluka and Brown 2016). The region contains unique flora and fauna and hosts a world-renowned

Figure 1. Location of the study area and illustration of the Daasanach interactions with water. (A) Map of the region around Lake Turkana and the Omo Delta. Names of the ethnic groups (in italics) indicate their approximate geographic distribution (according to Carr 2017). The Daasanach currently occupy the region at the northeastern part of Lake Turkana. The region depicted in the main figure is indicated with outlined rectangles in the inset maps. The specific study area is indicated with a square in the main figure, and the location of the Gibe III Dam in the Omo River is indicated in the inset map. (B) A Daasanach herder bringing his cattle to graze and drink in the shores of Lake Turkana. (C) A Daasanach fetching water from a hole dug in a dry riverbed. (D) Daasanach fishermen in Lake Turkana. Photos by Daniel Burgas.

paleontological record of human evolution (e.g., Leakey et al. 2012), all of which contributed to the establishment of Sibiloi National Park in 1973, declared as a UNESCO World Heritage site in 1993 (IUCN 2020; Mbaluka and Brown 2016; NMK and KWS 2019). The region has suffered a process of large-scale defaunation, attributed to overhunting and livestock overgrazing associated with a rapidly growing population of Daasanach pastoralists (Cabeza et al. 2016; NMK and KWS 2019; Torrents-Ticó et al. 2021). These threats, together with those brought about by large-scale infrastructure projects, led to the Sibiloi National Park being inscribed in 2018 in the UNESCO List of World Heritage in Danger (UNESCO 2018).

The Daasanach

The Daasanach are a semi-nomadic agropastoralist group extending between southeast of South Sudan, southern Ethiopia, and northern Kenya, occupying the northern shores of Lake Turkana, the lower stretch of the Omo River valley and its delta (Mwamidi et al. 2018; Figure 1A). They are Cushites of the Omo-Tana branch, who speak the Daasanach language (Tosco 2001). They are primarily considered an agropastoral society (Almagor 1978), mostly herding cattle, sheep, and goats (as well as donkeys and camels, to a lesser extent), and opportunistically growing maize, sorghum, and beans in flooded plains. Agriculture is practiced regularly by Daasanach living close to the Omo Delta in Ethiopia (Gebre 2012) and, more sporadically, among Kenyan Daasanach (Bethancourt et al. 2020), although some people occasionally migrate temporarily to practice cultivation in the Omo Delta. Some Daasanach have also recently started fishing in Lake Turkana, as other resources (e.g., cattle) become increasingly scarce or unavailable (Figure 1D). In this study, we focus on the Daasanach of northern Kenya, who number about 17,000 people (KNBS 2019).

The main drinking water sources for the Daasanach in northern Kenya are traditional wells, boreholes, and waterholes dug in dry riverbeds (Bethancourt et al. 2020; Figure 1C). Due to its salinity, the lake is rarely used as a source of drinking water (Bethancourt et al. 2020), but wildlife and livestock drink water directly from the lake (Kaijage and Nyagah 2009) (Figure 1B). Herding is strongly dependent on the availability of pastures, maintained by seasonal rainfall. During the dry season, conflicts over suitable grazing sites often arise with other ethnic groups (Gebre 2012) and with Kenyan authorities due to the use of pastures inside the Sibiloi National Park (IUCN 2020). Their long histories of place-based living and time-honored traditions have generated intricate and complex knowledge systems (e.g., Daasanach Community 2019; Mwamidi et al. 2018), including sophisticated sets of knowledge and practice about both climate and water management.

Infrastructure Projects along the Omo River

The Omo River and Lake Turkana are under increasing stress from hydropower development and large-scale water-intensive agricultural schemes in Ethiopia (Avery and Tebbs 2018; Tebbs et al. 2020). The construction of the 1870-megawatt Gibe III dam, one of Africa's largest hydropower projects, is predicted to recede the water flow to Lake Turkana by up to 70% (Ojwang et al. 2016; UNEP 2013), most likely opening up a Pandora's box of interrelated social and environmental problems. The dam, inaugurated in 2016, has already allowed the diversion of Omo River water for the large-scale irrigation of sugar and cotton plantations (Avery and Tebbs 2018). Such water abstractions could considerably reduce the depth of Lake Turkana, affecting its aquatic resources and fish communities (Avery 2012; Gownaris et al. 2017). Although the actual biophysical impacts of the dam are still to be thoroughly understood, some impacts, such as alterations in the seasonal water fluctuation of Lake Turkana (Spruill 2019) and decline in primary production (Tebbs et al. 2020), have already been reported.

It should be noted that the expansion of water-intensive plantations in the Omo River was not mentioned in the dam's environmental impact assessment (Asnake et al. 2009; Avery 2012), which neglected both international standards and Ethiopian domestic legislation (Schapper and Urban 2021). On the Ethiopian side, many communities were forcibly evicted from their ancestral lands (Carr 2017), and Kenyan Daasanach communities claim that they were never consulted about the project (Hathaway 2009). The absence of social, cultural, or environmental safeguards in this infrastructure project has triggered widespread condemnation in both the international media and the scholarly literature (Schapper and Urban 2021).

Methods

We conducted our study in permanent and temporary Daasanach settlements surrounding the town of Ileret (4.314° N, 36.227° E and ~380 m.a.s.l.; Figure 1A). We used qualitative methods to obtain and interpret data on Daasanach perceptions of change. Data collection took place during 2019 and 2020 and involved semi-structured interviews and a focus group discussion, following a framework to document local observations of change developed by Reyes-García et al. (2020). This research was conducted as part of a long-term participatory research project to document local knowledge and build social-ecological resilience, developed by the University of Helsinki in partnership with the Daasanach community (e.g., Cabeza et al. 2016; Daasanach Community 2019; Mwamidi et al. 2018; Torrents-Ticó et al. 2021). We employed a participatory approach, engaging two members of the Daasanach community (P. Lokono Haira and J. Guol Nasak.) in most phases of the research process and making sure that local residents adequately understood essential concepts addressed in the interviews (e.g., "change" or "environment").

Prior to data collection, we conducted a meeting with local leaders and elders from all the communities involved in this research to present the project and obtain authorization to conduct research. We obtained oral free, prior, and informed consent from each person we interviewed, as well as permission from the relevant administrative organization in the area (Ileret County Ward). After finishing data collection, we conducted a meeting with the local communities to present and discuss research results obtained. This research adheres to the Code of Ethics of the International Society of Ethnobiology (ISE 2006), and has been conducted with the permission of the National Commission for Science, Technology, and Innovation of Kenya (NACOSTI/P/18/21446/20296), and the Ethics Committee of the Universitat Autònoma de Barcelona (CEEAH 4781).

Data Collection

Semi-structured Interviews

To capture the widest possible spectrum of perceptions on changes taking place in the environment, we targeted local residents recognized as knowledgeable by members of the community (using snowball sampling), trying to cover a wide age range and diversified expertise in the local livelihood activities: livestock herding, farming, and fishing. In total, we interviewed 45 local residents (32 men and 13 women, with ages varying from 18 to ~75 years old) in eight villages and two temporary settlements. All interviews were conducted in the Daasanach language by P. Lokono Haira and J. Guol Nasak.

The semi-structured interviews had two main objectives: (1) to identify the changes that the Daasanach perceive in the climatic and biophysical environment and (2) to identify the local perceptions on the drivers of these changes and their interconnections. To do so, we asked each of the 45 interviewees about *which* changes they had noticed in their environment since they were young (i.e., approximately when they got married for the first time, usually corresponding to 13–15 years old). For every change mentioned, we also asked *why* they thought these changes were happening and *what* was causing them. Although our analyses are mostly focused on water-related changes, our interviews were designed to capture more broadly the local perceptions of environmental change. Given the wide age range of the interviewees, we were able to reconstruct changes happening in different time scales.

Focus Group Discussion

After compiling the information from the semi-structured interviews, we conducted a focus group discussion with ~20 residents (~14 men and ~6 women) from the same villages and with the same age range. About half of the participants of the focus group discussion also participated in the semi-structured interviews. The focus group discussion aimed to assess the level of group consensus regarding the changes mentioned, clarify some incomplete information, and—potentially—document new observations of change. We presented to the group every change mentioned during the semi-structured interviews, asking if they had noticed these changes, what was causing them, and what their consequences were. Therefore, all the information on the observations of change and their connections reported here are based on collectively validated information.

Data Analysis

Each individual change reported (hereafter "citation") was coded using a four-step procedure. First, we grouped similar citations into "observations of change" (hereafter OC) and calculated their frequency of citations in semi-structured interviews. Second, we coded all OC following the hierarchical classification of "Local Indicators of Climate Change Impacts" proposed by Reyes-García et al. (2019), in which changes are classified according to the "system" in which they are observed: climatic (e.g., rainfall), physical (e.g., soil), biological (e.g., plants), and human (e.g., agriculture, livestock). Although this categorization was originally designed to classify climate-related changes, we used it as a framework to classify all observations of change, irrespective of the driver. Third, we categorized the perceived drivers of change according to the Daasanach's own accounts and used three categories: "climatic" (changing climatic conditions), "sociodemographic" (changing sociodemographic conditions, e.g., growing population), and "infrastructure" (changes driven by infrastructure projects in the Omo River). A given OC may be simultaneously associated with different drivers. Lastly, we identified OC perceived to be related with water (hereafter "water-related"), categorizing them between those directly observed in hydrological processes (e.g., precipitation, river flow; "now there is less rain") and those caused by changes in hydrological processes (e.g., "now there are fewer pastures because there is less rain").

To identify the changes that the Daasanach perceive in the climatic and biophysical environment, their drivers and interconnections, we selected the most salient OC and associated drivers based on the frequency in which these were reported in the semi-structured interviews, focusing particularly on water-related changes. We then discussed these changes based on local rationales expressed during the interviews and the focus group discussion. To evaluate the perceived interactions between climate change and infrastructure projects leading to changes in water, we quantified the proportion of water-related changes that were caused by each of the three categories of drivers, and we represented these proportions using Euler diagrams (Figure 2). As part of the analysis, we illustrate the Daasanach's integrated perceptions of change using a visual representation of water-related changes, their drivers, and connections, based on the information obtained in the semi-structured interviews and collectively validated in the focus group discussion.

Results

Local Observations of Environmental Change and Their Drivers

In total, the 45 Daasanach interviewees mentioned environmental changes 194 times (citations), which were grouped in 73 observations of change (Supplementary Table 1). Most observations of change (25; 34.2 % of the total) referred to changes in the biological system, followed by changes in the human (23; 31.5 %), climatic (13; 17.8 %), and physical systems (12; 16.4 %) (Table 1; Supplementary Table 1).

Most changes in the climatic system referred to increases in the frequency, duration, and intensity of drought, to an overall lower and more variable precipitation, and to increases in temperature and wind strength (Supplementary Table 1). These changes, particularly drought, were frequently mentioned as major or indirect drivers of changes in other systems. For example, several respondents mentioned

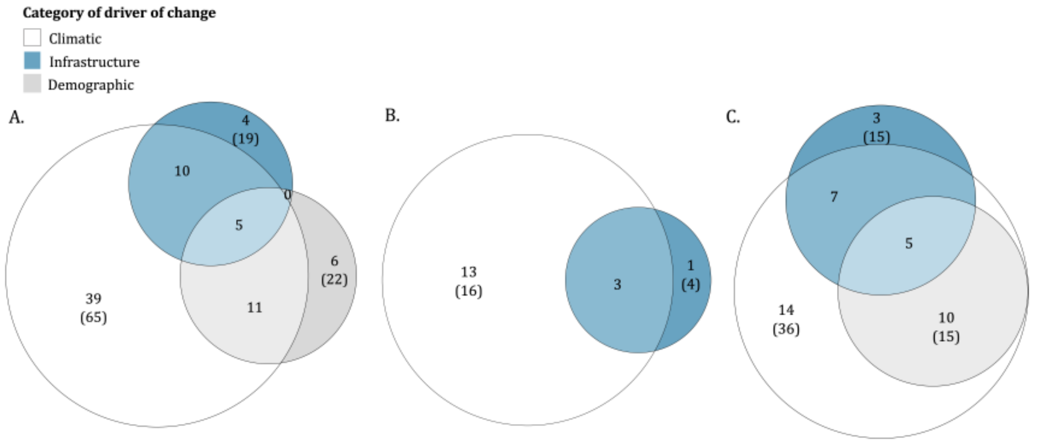

Figure 2. Euler diagrams showing the categorization of drivers of environmental changes perceived by the Daasanach. A) Drivers of all observations of change (OC); B) drivers of OC directly observed in hydrological processes (e.g., changes in precipitation); C) drivers of OC caused by changes in hydrological processes (e.g., changes caused by shifts in precipitation). Sizes of the circles are proportional to the number of OC in each driver category. Numbers indicate the number of OC affected by individual or overlapping drivers, and numbers in parenthesis indicate the total number of OC in each driver category.

that "now there is less grass for the animals because the droughts are longer." Regarding the physical system, most of the reported changes referred to changes in water quality and dynamics of Lake Turkana and to changing soil conditions (Supplementary Table 1). Respondents reported, for example, that "now the water of the lake is more salty," or that "the lake floods do not happen as before." Soils were mentioned to have become drier and less fertile, owing to drought and to the increase in wind-induced erosion (Supplementary Table 1).

Daasanach interviewees also mentioned several changes in the biological system, including changes in the abundance and species composition of freshwater animals and plants, the abundance and behavior of wild fauna, and the mortality, productivity, and phenology of terrestrial plants (Table 1; Supplementary Table 1). People said, for example, that "now there is less grass and less fish in the lake," that "drought and hunting have killed all the big animals," and that "there are fewer trees, [because] they are dying from drought and people are cutting them down." Changes in the human system were among the most frequently mentioned and largely focused on livestock and pastures (Table 1). The Daasanach agreed that there has been an increase in the amount of livestock (owing to population growth) which, together with the increased droughts, are reducing the availability and productivity of pastures. This overall reduced availability of pastures, they say, is leading to lower productivity of livestock and more livestock diseases. Changes in agriculture were less frequently reported and mostly related to the reduction of suitable cultivation areas along the Omo Delta and along small rivers (Supplementary Table 1).

Most OC (64; 87.7%) were associated with "climatic" drivers, followed by "socio-demographic" (28.8%) and "infrastructure" drivers (26%), with 35% of the changes associated with more than one driver (Figure 2A).

The Salience of Water-Related Local Observations of Change

Water-related changes are salient in local perceptions of environmental change.

Table 1. Observations of environmental change reported by the Daasanach. Each change mentioned in the interviews ("citations") was grouped into "observations of change" (OC) and categorized based on the "system" (e.g., climatic) and "subsystem" (e.g., air masses) in which they were observed. Based on the local understanding of changes and their connections, drivers of change are categorized into "climatic" ("Clim"), "demographic" ("Dem"), and "infrastructure" ("Infr"), and OC are identified as "water-related" when directly observed in hydrological processes ("Observed") or when caused by changes in hydrological processes ("Caused"). Cells show the number of citations or OC, and numbers in parentheses indicate percentages.

System / Subsystem	Total		Drivers			Water-related	
	Citations	OC	Clim	Dem	Infr	Observed	Caused
Climatic system	41 (21)	13 (18)	13 (18)			9 (12)	
Airmasses	8 (4)	3 (4)	3 (4)				
Precipitation	26 (13)	8 (11)	8 (11)			8 (11)	
Seasons	3 (2)	1 (1)	1 (1)			1 (1)	
Temperature	4 (2)	1 (1)	1 (1)				
Physical system	23 (12)	12 (16)	11 (15)		4 (5)	8 (11)	2 (3)
Freshwater	14 (7)	8 (11)	7 (10)		4 (5)	8 (11)	
Soil and Land	9 (5)	4 (5)	4 (5)				2 (3)
Biological system	64 (33)	25 (34)	20 (27)	10 (14)	11 (15)		22 (30)
Freshwater	31 (16)	11 (15)	9 (12)	4 (5)	9 (12)		10 (14)
Land cover change	1 (1)	1 (1)		1 (1)			
Terrestrial Fauna	17 (9)	7 (10)	5 (7)	4 (5)	2 (3)		6 (8)
Terrestrial Flora	15 (8)	6 (8)	6 (8)	1 (1)			6 (8)
Human system	66 (34)	23 (32)	20 (27)	11 (15)	4 (5)		15 (21)
Cultivated plants	7 (4)	3 (4)	3 (4)		1 (1)		3 (4)
Demography	4 (2)	1 (1)		1 (1)			
Human health	8 (4)	5 (7)	4 (5)	3 (4)	2 (3)		4 (5)
Livestock	23 (12)	6 (8)	5 (7)	3 (4)	1 (1)		3 (4)
Other	1 (1)	1 (1)	1 (1)				
Pastures	23 (12)	7 (10)	7 (10)	4 (5)			5 (7)
Total	194 (100)	73 (100)	64 (88)	21 (29)	19 (26)	17 (23)	39 (53)

A total of 17 OC (23.3%) referred to changes directly observed in hydrological processes (Table 1). Most of these (9 OC; 12.3%) reported changes in precipitation, namely the reduction in rain events during the dry season, changes in the temporal distribution and predictability of rains, the increase in intensity and frequency of droughts, and a prolonged dry season. The other eight OC (11%) referred to changes in water quality, availability, and dynamics, such as an increase in the salinity and changes in the flood dynamics of Lake Turkana, and the increased depth of the water table (Supplementary Table 1). Another 39 OC (53.4%) were mentioned as, directly or indirectly, resulting from changes in hydrological processes (Table 1). For example, respondents reported that "now the livestock are producing less milk because the lake water is more salty."

The Daasanach reported climate and infrastructure changes as the most important drivers of water-related changes. Within the 17 OC directly observed in hydrological processes, nearly all (16 OC; 94.1%) were attributed to climatic drivers, while four OC (23.5%) were attributed to the dam construction, and three OC (17.6%) were attributed to more than one driver (Figure 2B). Within the 39 OC understood as being caused by changes in water processes and reservoirs, most (36 OC; 92.3%) were linked with climate drivers, followed by demographic drivers (15 OC, 38.5%) and infrastructure (15 OC; 38.5%). Twenty-two OC (56.4%) were linked with more than one driver (Table 1; Figure 2C). For example, the Daasanach reported that "now the fish in the lake are smaller and scarcer," which they attribute to changes in the lake water driven by the dam construction but also to overfishing, as "now there are more people fishing." Similarly, the observation that "now there are fewer people farming, it is much more difficult to farm" is associated with changes in water fluctuations in the Omo River (reducing the floodplains in the delta, where they used to cultivate in the past) as well as with increased droughts, both of which have led to an overall decrease in seed circulation and in the availability of suitable cultivation areas.

Daasanach Holistic Understanding of Changes

The Daasanach holistic understanding of environmental change involves a complex network of interacting changes, drivers, and cascading effects. Based on the interconnections between changes mentioned during the interviews and the focus group discussion, we were able to reconstruct some of these networks, which evidence the perception that socioeconomic, demographic, and climatic changes simultaneously impact local livelihoods (Figure 3).

Given their relevance in local perceptions of environmental change, water-related changes also tend to be important elements in these networks, having cascading impacts on other elements of the biophysical and human systems. In particular, the overall lower rainfall and higher frequency and intensity of drought are directly linked with changes in water, but are also reported as major causes for changes in wild and cultivated plants, wild fauna, and the availability of pastures for livestock. Changes reported in the fluctuation of the Omo River and Lake Turkana as a result of infrastructure projects are also associated with multiple impacts in freshwater fauna and the availability of areas for cultivation (Figure 3).

Discussion

The ongoing global social-ecological crisis poses important threats and challenges to IPLC, which are likely to intensify and multiply in the near future (Reo and Parker 2013; Savo et al. 2016). Based on their LEK and close interaction with nature, IPLC are developing their own understandings of these changes and drivers. Here, we show the detailed understanding of shifts in the environment by the Daasanach in northern Kenya, with changes in water playing a central role, and where observations of change in different elements of the social-ecological system are understood as the outcome of imbricate interactions between climatic and socioeconomic drivers.

Our results show how changes in water are central in local perceptions of change, driving multiple changes in other elements of the biocultural system. Many IPLC across the world face important constraints to their water security and sovereignty, driven by both geographic and climatic conditions, but also by socioeconomic and political arrangements (Alessa et al. 2008; Fernández-Llamazares et al. 2020; Rosinger et al. 2020). Ongoing and predicted changes in climate, such as changes in rainfall and in river fluctuation regimes (Jiménez Cisneros et al. 2014), will affect the dynamics, availability, and quality of water resources. Although the Daasanach have historically adapted to dry and markedly seasonal landscapes

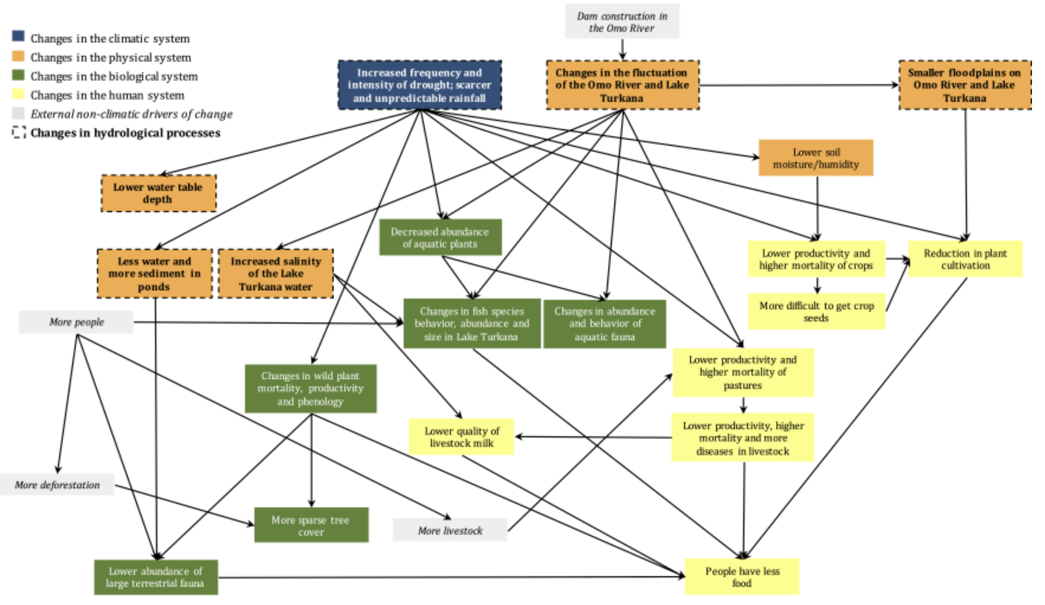

Figure 3. Representation of the network of environmental changes collectively perceived by the Daasanach, focusing on water-related changes. Blue, green, orange, and yellow boxes indicate changes reported in the climatic, physical, biological, and human systems, respectively (sensu Reyes-García et al. 2019), while the gray boxes indicate non-climatic drivers of change. Changes on water processes and reservoirs are indicated by dashed boxes. This visual representation is based on Daasanach's perceived changes and drivers, mentioned in the semi-structured interviews and the focus group discussion.

(Mwamidi et al. 2018), the perception that drought patterns and river-lake water dynamics are changing are both undisputed, and this is understood to have several cascading consequences.

Overall, the salience of changes in water amid the local perceptions of environmental change is largely due to the fact that the Daasanach's main livelihood activities are all finely tuned with seasonal fluctuations in water availability. Thus, consequences of changes in these fluctuations are perceived in many elements of local livelihoods. Hence, considering only direct impacts of environmental change on biocultural heritage or over-simplifying the richness of IPLC environmental relations can underestimate the severity of rapid social-ecological changes on IPLC cultures and livelihoods (see Lyver et al. 2019). While water-related changes affect (and are perceived by) IPLC all over the world, these can be particularly salient and harmful to subsistence-based groups, like the Daasanach, who inhabit dry or very seasonal regions, where certain livelihood activities may become untenable and water security may worsen, as societies face more extreme or unpredictable climatic conditions (see Dong et al. 2011).

We also show how climatic and socio-economic/infrastructure changes interact synergistically, threatening local livelihoods through their impacts on water resources. The Daasanach unanimously report to be facing increasingly drier and unpredictable climatic conditions, perceptions that align closely with historical and predicted climatic data (Funk 2020; Liebmann et al. 2014). Current and planned large infrastructure projects in the Omo River, including dams and the establishment of sugar estates, are predicted to bring significant hydrological and social-ecological impacts to the Omo-Turkana basin (Avery and Tebbs 2018; Carr 2017; Hodbod et al. 2019). Indeed, the Daasanach refer to these infrastructure projects (particularly the construction of dams) as a major cause for changes in the hydrological dynamics in the Omo-Turkana basin, with multiple reported impacts on their livelihood activities. According to them, infrastructure projects have changed the Lake Turkana aquatic fauna and flora, including reductions in fish stocks and size, and increased water salinity. Besides the impacts on fishing, these changes also affect livestock herding, as saline water is considered to affect milk quality negatively (with potential dietary implications for the Daasanach people), and the changes in the annual flood pulse prevent the regeneration of pastures in the lake margins. Importantly, the Daasanach argue that hydrological changes brought up by the dam construction have significantly reduced the floodplains in the Omo Delta, further constraining their opportunities for practicing agriculture. While the actual infrastructure projects along the Omo River are mostly outside the territories traditionally occupied by the Daasanach, and in spite of the fact that their perceptions might be to some degree influenced by external information sources, they clearly associate these projects to several of the perceived changes in their environment.

Overall, together with changes in the Omo-Turkana system brought by large-scale infrastructure projects, climatic changes are driving important shifts in how the Daasanach are managing their biocultural landscapes and adjusting their livelihoods. Agriculture has become increasingly difficult, restricted both by the scarcer and more unpredictable rains (preventing rainfed agriculture which, although minor, was practiced along small temporary rivers) and by changes in the flood dynamics of the Omo River (preventing flood-recession agriculture in the Omo Delta). Fishing, which used to be a marginal activity associated with times of strong droughts and food shortage, is reported to have become increasingly common (in spite of the perceived diminishing stocks), owing to increased marked opportunities but also to growing challenges associated with livestock herding and plant cultivation. Besides highlighting the threats brought by environmental changes to the different livelihood activities on which the Daasanach have historically relied, understanding changes in livelihoods from the integrative perspective of the Daasanach can be used to explore viable adaptations to environmental change.

Our findings suggest that many biocultural impacts were undervalued during the planning phases of the Gibe III dam and its associated large-scale irrigation schemes (Carr 2017; Schapper and Urban 2021). Many top-down, state-sanctioned development interventions undervalue, discount, and overlook impacts on biocultural heritage (e.g., Estes and Dhillon 2019; Hinzo 2018). Although much of this relates to power dynamics and macroeconomic forces, these omissions might also stem from the difficulties in grasping the intertwined nature of many of these changes, and their cascading biocultural impacts (see also Lyver et al. 2019). Many biocultural losses continue to be largely invisible to development planners and policy-makers, particularly those that affect intangible biocultural heritage (see Turner et al. 2008). The fact that the biocultural ramifications of the dam construction were largely missing in the environmental impact assessment of the Gibe III dam (Schapper and Urban 2021) is particularly illustrative in this regard.

Finally, our results call attention to the potential of LEK in enhancing the understanding of complex social-ecological issues, such as the impacts of environmental change in local communities. A growing number of studies highlight the potential of LEK for the understanding of environmental changes (Fernández-Llamazares et al. 2017; Nabhan 2010; Postigo 2014) and the potential synergies between LEK and scientific knowledge to enhance our capacity for dealing with environmental change (Shaffer 2014; Tengö et al. 2014). By tapping into Daasanach observations of environmental change, we show that they recognize numerous indicators of change that are deeply interwoven and manifested in many different elements of their environment. We argue that ethnobiological studies around climate change should pay more attention to IPLC holistic understandings of changes, with an explicit focus on how these communities understand the drivers of changes and the myriad of interrelations between them (see Wyndham 2009). This would allow identifying impacts that may be largely overlooked by government and development agencies and foster more refined understandings of how different environmental and socioeconomic pressures interact and how they impact local biocultural systems.

Conclusions

Our findings highlight how climatic and socioeconomic/infrastructure drivers interact synergistically and lead to substantial impacts in water resources, with cascading effects in multiple components of the biocultural system and with important consequences for the livelihoods of the Daasanach people of northern Kenya. Besides jeopardizing water security, shifts in water affect all livelihood activities on which Daasanach have historically relied to manage their arid landscapes and to deal with social-ecological changes. In dry regions of Africa and elsewhere, climate change is expected to amplify existing stresses in water availability, which are also exacerbated by multiple socioeconomic drivers (Droogers et al. 2012; Niang et al. 2014). Synergistic negative effects of climate change and socioeconomic drivers on water, as illustrated here by the case of the Daasanach, are likely to occur in many other regions. It is, therefore, essential that these potential synergies are taken into account in the design of development and infrastructure projects that impact water, aiming to minimize their social-ecological impacts and to promote more equitable and ethical sharing of their benefits. We argue that inclusive governance which explicitly incorporates IPLC understanding of environmental change is a promising pathway towards achieving these goals.

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