Global Environmental Change 23 (2013) 252–263

Contents lists available at SciVerse ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Floods and livelihoods: The impact of changing water resources on wetland agro-ecological production systems in the Tana River Delta, Kenya

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ARTICLE INFO

Article history:
Received 26 November 2011
Received in revised form 20 September 2012
Accepted 28 September 2012
Available online 2 November 2012

Keywords:
River water depletion
Food production
Wetland
Human well-being
Sustainability
Sub-Saharan Africa

ABSTRACT

Wetlands are highly dynamic and productive systems that have been under increased pressure from changes in land use and water management strategies. In Eastern Africa, wetlands provide resources at multiple spatial and temporal levels through farming, fishing, livestock ownership and a host of other ecosystem services that sustain the local economy and individual livelihoods. As part of a broader effort to describe future development scenarios for East African coastal wetlands, this qualitative study focuses on understanding the processes by which river water depletion has affected local food production systems in Kenya's Tana River Delta over the past 50 years, and how this situation has impacted residents' livelihoods and well-being. Interviews performed in six villages among various ethnic groups, geographical locations and resource profiles indicated that the agro-ecological production systems formerly in place were adapted to the river's dynamic flooding patterns. As these flooding patterns changed, the local population diversified and abandoned or adopted various farming, fishing and livestock-rearing techniques. Despite these efforts, the decrease in water availability affected each subcomponent of the production systems under study, which led to their collapse in the 1990s. Water depletion negatively impacted local human well-being through the loss of food security. The current study provides a detailed account of the dynamics of agro-ecological production systems facing the effects of river water depletion in a wetland-associated environment in Sub-Saharan Africa.

1. Introduction

Wetlands have long been recognised as valuable ecosystems for human beings because they provide a wide array of ecosystem services (Costanza et al., 1997; Daily, 1997; Millenium Ecosystem Assessment (MA), 2005; Maltby and Acreman, 2011). In particular, wetlands and their natural resources have been used for small-scale farming, fishing and livestock-rearing. Despite these benefits, wetlands have been continuously degrading over the past 50 years (MA, 2005). Abundant water resources and generally fertile soils lead many policymakers to dream of converting these supposedly empty zones into large-scale intensive agricultural schemes that could improve a region's food security. However, such schemes require numerous inputs (capital, fertiliser, water, infrastructure, etc.), are often detrimental to the ecosystem's other services and, in particular, are not applicable worldwide (Horlings and Marsden, 2011). The construction of dams that modify the flood pulses of river systems is also of concern (Junk et al., 1989). Although hydraulic infrastructure has contributed to economic development, there is growing recognition of the fact that dams have also had many adverse effects (World Commission on Dams, 2000) because they alter key hydrological factors, such as the timing, extent and frequency of floods; the sediment flow associated with these floods; the quality, temperature and chemistry of water (Olden and Naiman, 2010) and the morphology of river channels

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http://dx.doi.org/10.1016/j.gloenvcha.2012.09.003

(Petts and Gurnell, 2005). In a cascading effect, these issues then affect the integrity of adjacent ecosystems (such as riparian forests Hughes, 1984, 1990; Shafroth et al., 2010), floodplains, mangroves and coral systems (MA, 2005) and finally local communities by depriving them of vital water resources. Numerous studies have stated that water depletion impacts local farming, fishing and livestock-rearing in Sub-Saharan wetlands (e.g., Bader, 1998; Emerton, 2003; Loth, 2004; Schuyt, 2005; Kgathi et al., 2006) but few have explicitly explored the precise mechanisms by which these changes occur from a historical perspective (Verhoeven and Setter, 2010; Vilardy et al., 2011).

The objective of this study was to document the use of river water resources and the impact of their decrease on small-scale, subsistence-oriented, agro-ecological production systems in wetland-associated ecosystems in Sub-Saharan Africa. We hypothesised that a decrease in river-water resources modified local cropping systems (e.g., crop type, cropping season and crop location), changed the pastoralist system (e.g., transhumance and herd resistance to drought) and decreased fishing activities. To test these hypotheses, we explored the temporal dynamics of change in agro-ecological production systems as water resources diminished and analysed how water was used and whether its usage had changed over time. We then examined local adaptive strategies and evaluated whether and how water changes had impacted the population's food production systems. Finally, we explored how these changes had affected various components of human well-being. Our study focused on the farming, fishing and livestock components of the Pokomo and Orma communities' production systems in Kenya's Tana River Delta (TRD) and on the changes that had occurred in the past 50 years.

2. Conceptual framework

2.1. Ecosystem services, livelihoods and human well-being

Ecosystem services, livelihoods and human well-being are closely related. The term "livelihood" was initially defined by Chambers and Conway (1991), then by Scoones (1998) as comprising "the capabilities, assets (including both material and social resources) and activities required for a means of living". The concept, later broadened to include other assets (Blaikie et al., 1994), is closely connected to the notions of human rights, capabilities and sustainability (Bohle, 2009). The terms "ecosystem services" and "human well-being" (Holdren and Ehrlich, 1974; Westman, 1977; Daily, 1997) have become popular through the MA, which states that human well-being is composed of five dimensions (basic materials for a good life, health, security, good social relations, and freedom of choice and action), all of which are linked to the supporting, provisioning, regulating, and cultural services rendered by ecosystems. The link between ecosystem services and human well-being is readily apparent, but this sole provision is insufficient: other determinants (Butler and Oluoch-Kosura, 2006; Carpenter et al., 2009), such as social position, a sense of participation or belonging, context and others, also play a role in shaping how people perceive their lives.

A key question in on-going research is how to "assess, project and manage flows of ecosystem services and effects on human well-being" (Carpenter et al., 2009) and make these concepts more efficient through their integration into policy and decision-making.

Different valuation methods linking livelihoods, ecosystem services and human well-being have been developed to answer this question (Costanza et al., 2011). The method we chose for our research is a qualitative approach based on the understanding of historical events, links and processes (Enfors and Gordon, 2007; Liu et al., 2008) because they have legacy effects on current conditions (Liu et al., 2007).

2.2. Adaptive strategies, resilience and thresholds

The impact of changing environmental, political and societal conditions on ecosystem services, livelihoods and human well-being is not a linear process, and the concept of resilience (Holling, 1973; Holling and Gunderson, 2002; Folke et al., 2004; Folke, 2006) has helped researchers gain insight into this domain. Living systems, taken very broadly as individuals, communities, ecosystems or complex socio-ecosystems, are robust in the face of change: they are capable of absorbing shocks to maintain their major functions and services. Another property of living systems is their adaptive capacity, which can make disturbances an opportunity for development and for new trajectories to emerge. Previous studies have documented the erosion of ecosystem resilience and the insufficient adaptive capacities of many socio-ecosystems (such as Enfors and Gordon, 2007). In such cases, systems can undergo abrupt changes, transitioning from a productive to a degraded state from which it can be difficult to emerge (e.g., Folke et al., 2004; Steneck, 2009; Cinner, 2011). Current research has focused on the mechanisms through which these traps appear, the thresholds involved, the consequences on human well-being and how to make such systems more or less resilient.

This study applied these concepts to river water resources and small-scale, subsistence-oriented, agro-ecological production systems. Because our objective was to identify the major mechanisms by which river water depletion has affected the production systems, we restricted our study to the provisioning services of water and its link to food security.

3. Case study

3.1. General description

The Tana River Delta (TRD) (Fig. 1) is located in Kenya's coastal zone and extends over approximately 1300 km^2. The Tana River is the main feature of this area. By overflowing periodically into the floodplains, it supplies water and nutrients to natural and cultivated vegetation, which in turn provide food, grazing zones, building materials and other vital resources to the region's inhabitants. The Pokomo and Orma are the main residents, and live alongside the Wardei, Somali and Wata. The Pokomo define themselves culturally as farmers and fishermen; the Orma, Wardei and Somali as pastoralists; and the Wata as former hunter–gatherers. They have occupied the delta for centuries (Fitzgerald, 1898; Miller, 1981) and have been using the delta's dynamic flooding system to cultivate, fish, graze, gather and hunt. However, the region and its 100 000 inhabitants (Kenya Population and Housing Census, 2010) are poverty-stricken, and food distribution by the World Food Program is all too common. The 2009 indicators of human well-being (United Nations Development Programme, 2010) also indicate distress among the inhabitants. The Human Development Index (HDI) of the area was only 0.389, compared to the already low national average of 0.561, while the Gender-related (GDI) and Human Poverty Development Indices (HPI) were ranked among the ten worst nationwide. Human illiteracy was beyond 68% and life expectancy was less than 54 years, which was lower than the national average by nearly three years. Along with the multiple ecosystem services that the wetlands provide, the TRD forms a biodiversity hotspot and contains numerous vulnerable species (Hamerlynck et al., in press). As such, it meets all the criteria to be designated as a wetland of international importance by the Ramsar Convention (1971).

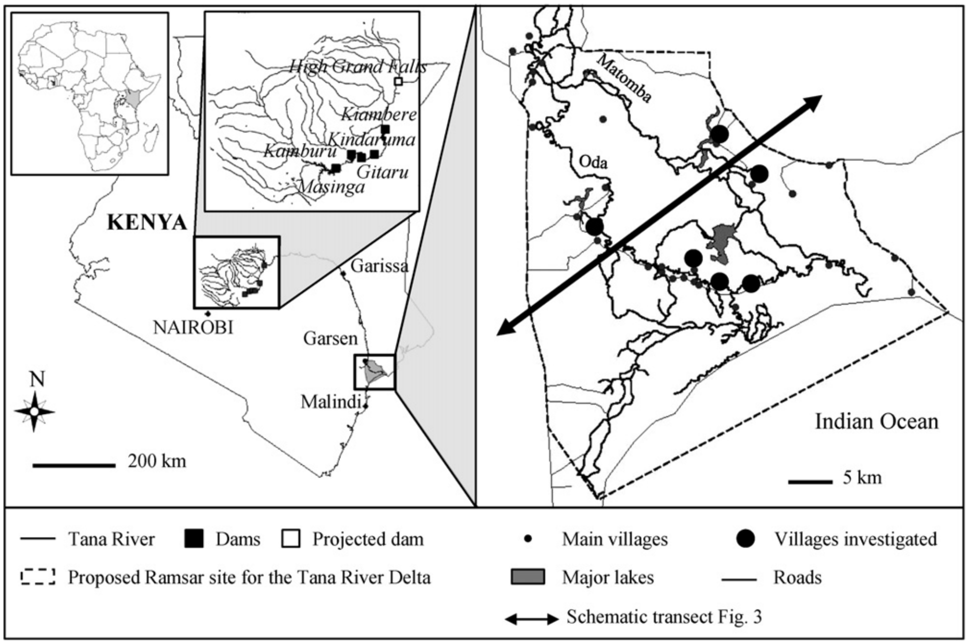

Fig. 1. Left: location of the Tana River and its dams and delta. Right: the Tana River Delta and its river, road system and main villages. The location of the six villages and the transect from Fig. 3 are also included.
Map sources: International Livestock Research Institute (2011), World Resources Institute (2011) and Hamerlynck et al. (2010), compiled by the authors.

3.2. Key water resources

Rainfall is high on the Kenyan coast, but decreases rapidly as one moves inland, from 1098 ± 306 mm in Malindi (1962–2008) to 530 ± 202 mm in Garsen (1972–1986) and 373 ± 202 mm 200 km upstream in Garissa (1962–2008, all data from the Kenya Meteorological Department, Kenya; years with more than one month of missing data have been excluded). The rainfall pattern is bi-modal, with two rainy seasons extending from April to June and from November to December (Fig. 2). The mean cumulative rainfall for each growing season is 230 mm and 124 mm in Garsen, respectively, which is not enough to grow major cereal crops such as maize. Furthermore, rainfall is highly variable, both temporally and spatially, which increases the risk of dependence on rainfall events for farming and livestock rearing.

Most water needed for productive uses is therefore derived from the Tana River. With a catchment area covering over one-sixth of the country, the river carries between 2.7 and 10.2 billion cubic metres yearly (Hamerlynck et al., 2010). Its flowing pattern is bi-modal, with peak flows occurring during the long and short rainy seasons (Fig. 2). The subsequent floods can be either productive or destructive inputs for agricultural activities depending on their predictability, timing and force. Moderate floods sustain fishing, rice cultivation and dry season grazing land. Extreme (and often early) floods cause drastic losses for farmers and livestock keepers by destroying the fields and blocking herd escape routes to higher land. The extreme flood events in East Africa are often linked to the El Niño Southern Oscillation (Bjerknes, 1966, 1969) and anomalies of the Indian Ocean's Sea Surface Temperature associated with the Indian Ocean Zonal Mode. Excessive short rainfall between October and December is closely linked to these events (Black et al., 2004). Six flood events with discharges over 1200 $m^3 s^{-1}$ have been recorded in Garissa over the last 50 years (data from the Water Resource Management Authority, Kenya), and the major catastrophic floods as perceived by the population occurred in 1961 and 1997–1998.

Five major reservoirs (Fig. 1) have been constructed in the upper basin between 1968 and 1981 to provide electricity (with a total installed capacity of just over 500 MW) to urban centres and to develop irrigation schemes. The adverse effect of this reservoir construction has been a modification of the Tana River's hydrological regime, especially since the construction of the Masinga dam in 1981. Maingi and Marsh (2002) have calculated a 20% reduction in average peak May flows. In El Niño years, heavy

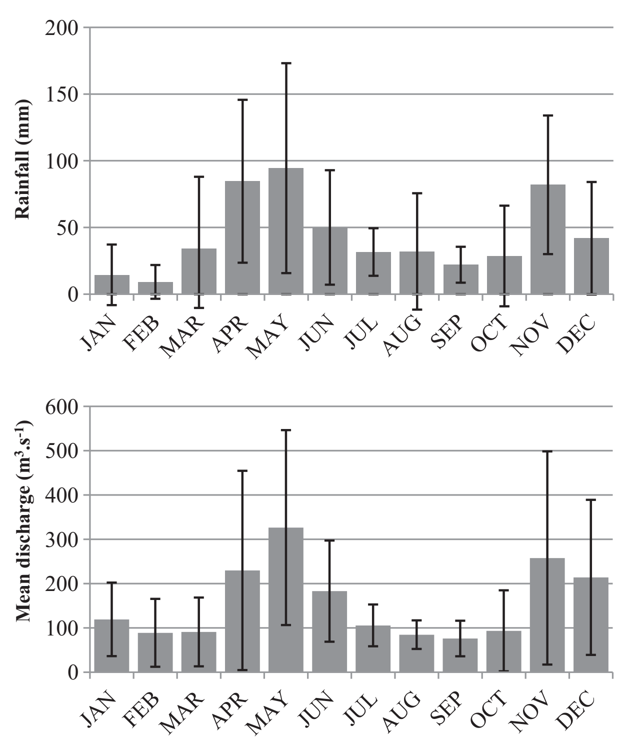

Fig. 2. Top: mean monthly rainfall and its standard deviation at Garsen (1972–1986). Bottom: mean discharge and its standard deviation of the Tana River Delta at Garissa (1941–2010).
Source: Water Resource Management Authority, compiled by the authors.

rainfall in the upper catchment rapidly fills the successive dams, which, combined with rainfall in the mid to lower catchment area, causes excessive flooding in the delta. Water retention within the reservoir during dry and moderately wet years has prevented the river discharge from attaining the threshold at which flooding occurs. In 2010, Kenya proposed the construction of the High Grand Falls dam, which is expected to contribute an additional 700 MW of power to the national electricity grid, but the downstream impacts of this dam on ecosystems and livelihoods are still uncertain.

4. Methodology

4.1. Agrarian diagnosis

The methodology employed in this study consisted of the first two sections of an agrarian diagnosis first defined by Dumont and later refined by Mazoyer and Dufumier (Cochet et al., 2007; Cochet, 2012). An agrarian diagnosis provides a framework for the analysis of agricultural production systems. The first step determines the landscape's functional units in relation to agricultural production systems, while the second step characterises the recent transformations of agricultural production systems and explores the major factors – ecological, sociological and economic – that determine their functionality, performance and development. The third step establishes a typology of the major production systems and models their economic performances. A two-step, largely qualitative approach was used in accordance with this methodology.

1. The identification of relevant hydro-ecological landscape units in the TRD through field visits and the analysis of available maps and satellite images.
2. A sociological and agronomic analysis of the changes in the production systems over the past 50 years.

4.2. Survey methodology

Interviews were conducted with village elders and key informants from different social categories (Table 1). The interviews focused on the productive activities of individual life trajectories. The state of a production system at different times (i.e., what was cultivated, where, how, and what animals an individual owned, when, where and how an individual fished, etc.) and the major changes that had occurred between the different states were determined for each informant. When a detailed chronology of events was obtained, it was based on time relative to the informant's history (i.e., how old he was, when he married, etc.), then transposed to the appropriate dates. Each person was able to provide relatively accurate data because the focus of the interviews was on individual life histories rather than general trends.

To transition from the state and dynamics of individual production systems to a typology of the region's production systems and their dynamics, we then cross-referenced and interpolated between households of similar ethnic origins, structures and locations. In the absence of reliable historical quantitative data such as mean yields from administrative records, we asked for minimum and maximum yields, then averaged the results for each category of production system over different time periods. Finally, field observations on current and historical forms of land use were performed and compared to the oral data to correct and corroborate the latter.

The methodology was applied to six villages (Fig. 1) in the TRD between March and July 2009. These villages were chosen because of their inhabitants' various ethnic origins and the villages' locations and resource profiles. Kikomo and Chalaluma are Orma villages, while Golbanti and Shirikisho are Pokomo villages. All were considered representative of the majority of the villages within the delta because they are of medium size (approximately 150 households each), established before the 1960s and located close to the river. The main communities within the village of Moa are the Luhya, Luo and Orma, of which only the last was interviewed. Boramoyo village was chosen for its striking differences from the other villages: its inhabitants are of Somali origin and it was set up in the 1990s and is the only place within the delta where water pumps are regularly used for irrigation. Residents from all age groups and social status were interviewed, and semi-direct interviews were conducted in the local languages, Kipokomo or Kiorma, or in Swahili, and translated into English by

Table 1
Number of interviews in each village, differentiated by age, gender and tribe. The period during which the interviews took place is also specified.

Number of interviews	Village	Gender	Age	Tribe	Comment	Period
4	Shirikisho	Woman	Young-Middle aged	Pokomo		06/04/2009–11/04/2009
3	Shirikisho	Man	Young-Middle aged	Pokomo		06/04/2009–11/04/2009
2	Shirikisho	Woman	Elderly	Pokomo		06/04/2009–11/04/2009
3	Shirikisho	Man	Elderly	Pokomo		06/04/2009–11/04/2009
0	Boramoyo	Woman	Young-Middle aged	Other		13/04/2009–20/04/2009
6	Boramoyo	Man	Young-Middle aged	Other	3 Wata and 1 Orma	13/04/2009–20/04/2009
1	Boramoyo	Woman	Elderly	Other		13/04/2009–20/04/2009
3	Boramoyo	Man	Elderly	Other	1 Orma	13/04/2009–20/04/2009
0	Kikomo	Woman	Young-Middle aged	Orma		22/04/2009–05/05/2009
4	Kikomo	Man	Young-Middle aged	Orma		22/04/2009–05/05/2009
1	Kikomo	Woman	Elderly	Orma		22/04/2009–05/05/2009
2	Kikomo	Man	Elderly	Orma		22/04/2009–05/05/2009
1	Chalaluma	Woman	Young-Middle aged	Orma		15/05/2009–23/05/2009
5	Chalaluma	Man	Young-Middle aged	Orma		15/05/2009–23/05/2009
2	Chalaluma	Woman	Elderly	Orma		15/05/2009–23/05/2009
3	Chalaluma	Man	Elderly	Orma		15/05/2009–23/05/2009
1	Golbanti	Woman	Young-Middle aged	Pokomo		23/05/2009–01/06/2009
3	Golbanti	Man	Young-Middle aged	Pokomo		23/05/2009–01/06/2009
0	Golbanti	Woman	Elderly	Pokomo		23/05/2009–01/06/2009
6	Golbanti	Man	Elderly	Pokomo	1 Wata	23/05/2009–01/06/2009
0	Moa	Woman	Young-Middle aged	Orma		17/07/2009–20/07/2009
4	Moa	Man	Young-Middle aged	Orma	2 Luo and 1 Pokomo	17/07/2009–20/07/2009
0	Moa	Woman	Elderly	Orma		17/07/2009–20/07/2009
2	Moa	Man	Elderly	Orma		17/07/2009–20/07/2009

hired local guides who were fluent in these languages. In all, extensive interviews were conducted with fifty-six farmers, livestock owners and fishermen.

5. Results

5.1. Identification of land and water resources through an agro-hydrological zonation of the delta and its surroundings

The TRD landscape is a complex intertwinement of forests, wooded bush land, bush land, grasslands and lakes (vegetation maps, Kenya Soil Survey, 1984a,b), and the landscape pattern derives from soil and water conditions controlled by the Tana River. The latter is highly dynamic, with its course shifting after important flooding events or redirected by human intervention. The Oda branch, like other old river channels, has well-formed sandy levees, whereas the newly formed branches like the Matomba brook meander through the floodplains, forming braided channels with (as yet) minimal levees. A schematic agro-toposequence (Fig. 3), perpendicular to the two main types of river channels, emphasises the region's different environments and the ways in which its inhabitants use them today. Riverine forests dominated by *Ficus sycomorus* and mango plantations are located on the levees of old riverbeds. Dry grasslands cover the upper floodplains, which are no longer or very rarely flooded, while the mid floodplains, still underwater during important flood events, are cultivated. The lower floodplains, which are periodically underwater, form grasslands composed of *Echinochloa stagnina* (Retz) P. Beauv, *Vossia cuspidata* (Roxb.) Griff., *Paspalidium obtusifolium* (Delile) N.D. Simpson and various species of sedges that offer good pasture land and fishing grounds. Other low-lying areas form permanent or temporary lakes, swamps or marshes. Remnants of ancient sand dunes are covered by Acacia and palm wooded bushland, composed mainly of *Acacia zanzibarica*, *Terminalia brevipes*, *Thespesia danis*, some *Borassus aethiopium* and the invasive *Prosopis juliflora* (Hamerlynck et al., in press). These sandier zones are occasionally used as farming land. The delta itself is surrounded on both its eastern and western sides by highlands that are covered by degraded woods or wooded bush that periodically serve as pastureland. Finally, high coastal dunes give way to an extensive mangrove system at the river's mouth in the interface with the Indian Ocean (not shown in Fig. 3).

Most villages are located either on the river's levees or on the more elevated sandy zones. Land use is organised along a topographic sequence and spatially around villages. The vertical differentiation reflects the different water requirements of various crops, while the distance reflects, to a certain extent, physical and frequency efforts related to the cropping system. Farming activities are located around villages, fishing in lakes and floodplains, and grazing within the bushland and floodplains.

5.2. Dynamics of the Tana River Delta's agro-ecological production systems over the past 50 years

5.2.1. The Pokomo: strategies of farmers and fishermen

A summary of the interviews conducted for this study is reported in Table 2. The river system, land cover and production systems in the 1960s were partially reconstructed through interviews with village elders. At that time, the Tana River ran mainly through the Oda branch and overflowed into its floodplains twice a year. The lakes and floodplains located in the western part of the delta, such as Shakababo Lake, were fishing and farming grounds for the Pokomo. Their villages were located on riverbanks sheltered from floods and surrounded by riverine forests, seasonally flooded grasslands on the upper floodplain, and swamps, marshes and lakes in the lower floodplains. Rice was planted biannually at the start of each rainy season in small paddy fields located on the upper floodplains. The water height and duration of its presence within these fields were managed by simple water control structures, such as small channels, embankments and ditches. The influx of water and fertile loams and clays from the floods most likely guaranteed yields of approximately 2 T ha^{-1} per season (Table 2), typical for this type of small-scale flood recession rice farming. Banana plantations were common on the riverbanks, whereas maize was intercropped with beans, squash, sweet potatoes and cassava on slightly higher and sandier zones, and constituted an alternative, non-flood-dependent food source. Because cultivation was entirely manual, farmed surfaces were generally limited to approximately one or two acres per household. Regular fishing activities using nets, hooks and spears

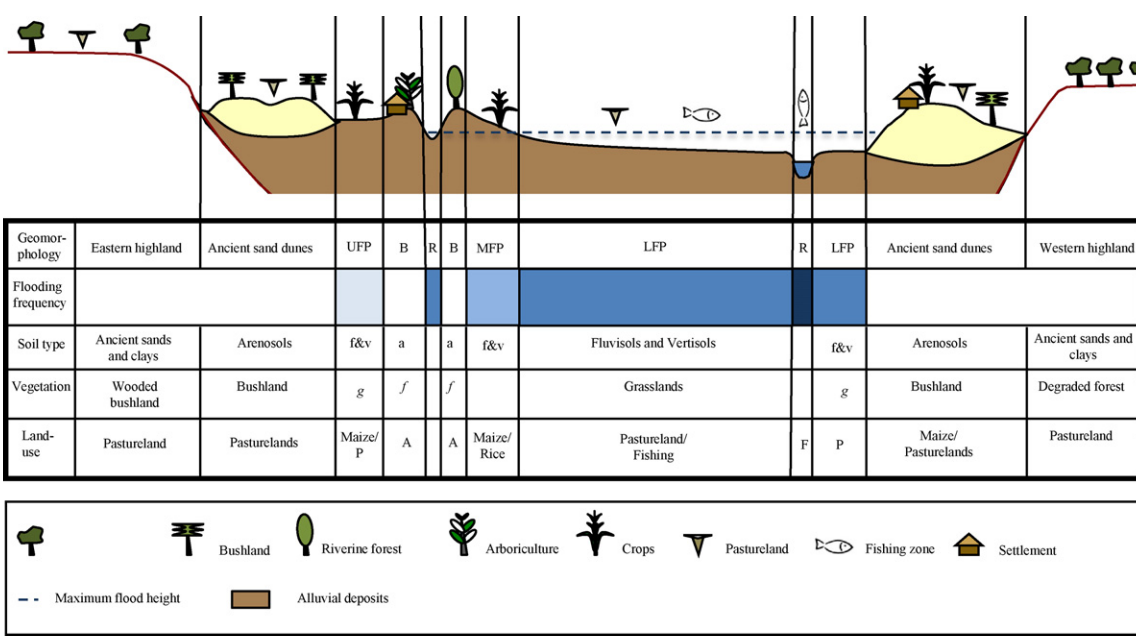

Fig. 3. Schematic transect of the delta and its different land uses. B: banks, LFP: lower floodplain, MFP: mid floodplain, R: river, UFP: upper floodplain, a: arenosols, f&v: fluvisols and arenosols, *f*: riparian forest, *g*: grassland, A: arboriculture, F: fishing, P: pastureland.

Table 2
Summary of the main responses from the interviews conducted in the Tana River Delta, differentiated according to tribal group and chronology. Common: over 50% of replies were positive, sometimes: 20–30% positive, rare: less than 10% positive.

	Pokomo			Orma	
	1960s	1970s–1980s	1990s–2000s	1960s–1980s	1990s–2000s
Livestock keeping as the main activity	No	No	No	Yes	Yes
Farming as the main activity	Yes[a]	Yes	Yes	Rare	Sometimes
Fishing as the main activity	Yes[a]	Sometimes	Rare	No	Sometimes
Farming					
Rice as major cereal crop	Yes	Yes	No	Yes	No
Maize as major cereal crop	No	No	Yes	No	Yes
Average yields per season for rice ($T_{paddy}\,ha^{-1}$)	2	2	1.3	–	–
Average yields per season for maize ($T\,ha^{-1}$)	–	–	1.3	–	–
Mango tree plantation	Rare	Sometimes	Yes	No	Rare
Number of cropping seasons	2	2	1	–	1
Additional livestock keeping activities	No	Yes	Yes	–	–
Livestock keeping					
Seasonal migrations to the highlands	No	No	No	Yes	Yes, if possible[b]
Grass height (after flood/end of rainy season) (m)	–	–	–	2/0.6	0.6/0
Additional farming activities	–	–	–	Rare	Yes
Additional fishing activities				No	Sometimes
Milk production per cow in the rainy season (L)	–	–	–	5	2–5
Fishing					
Regular fishing expeditions to the nearby floodplains	Yes	Sometimes	Rare	No	No
Fishing as a daily activity in the river	Yes	Sometimes	Rare	No	Rare
Fishing in the lakes	Yes	Sometimes	Rare	No	Sometimes
Daily fish catch compared to today	"Very high"	"Higher"	–	–	–
Total number of interviews	11	11	12	11	11

[a] In the 1960s, the Pokomo practiced both farming and fishing activities on a regular basis.
[b] The non-milked herds were brought to the hinterlands as soon as grazing there was possible.

were also carried out in the surrounding swamps and more distant lakes (Table 2).

Fishing activities gradually decreased throughout the 1980s (Fig. 4). The six informants who moved to Shirikisho village in the 1960s and 1970s all carried a fishing spear, indicating that fishing was a common activity. Four explicitly reported a decrease in fish yields. Overnight, one informant would catch an average of 150–170, 10–20 and 5–10 fish with 200 hooks in the 1970s, 1980s and 2009, respectively. Another reported average catches of 10–15 and 5–10 fish using hooks in 1986 and 2004, respectively. A different respondent reported daily catches of 100–200 large fish in the late 1970s and 100–200 small fish in the present day using a net. These figures appeared to depend on the fisherman's experience, equipment, location, and other factors, but all noted a decrease in their fish yields. Approximately ten out of 156 Shirikisho households regularly fished in 2009, and similar trends and figures were reported in the other villages.

The decrease in fishing activities was accompanied by increased rice and mango cultivation along the riverbanks. Most interviewed mango growers started planting mango trees (the Ngowe, Punda

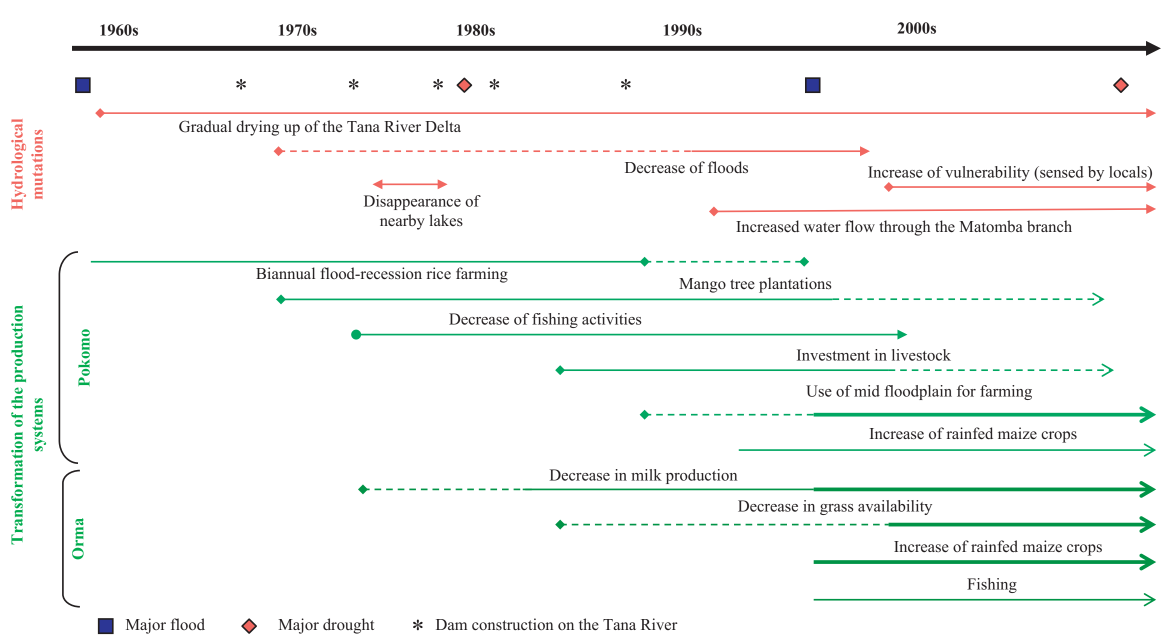

Fig. 4. Chronology of the major hydrological changes and transformations of the agro-ecological production systems from the 1960s to today.

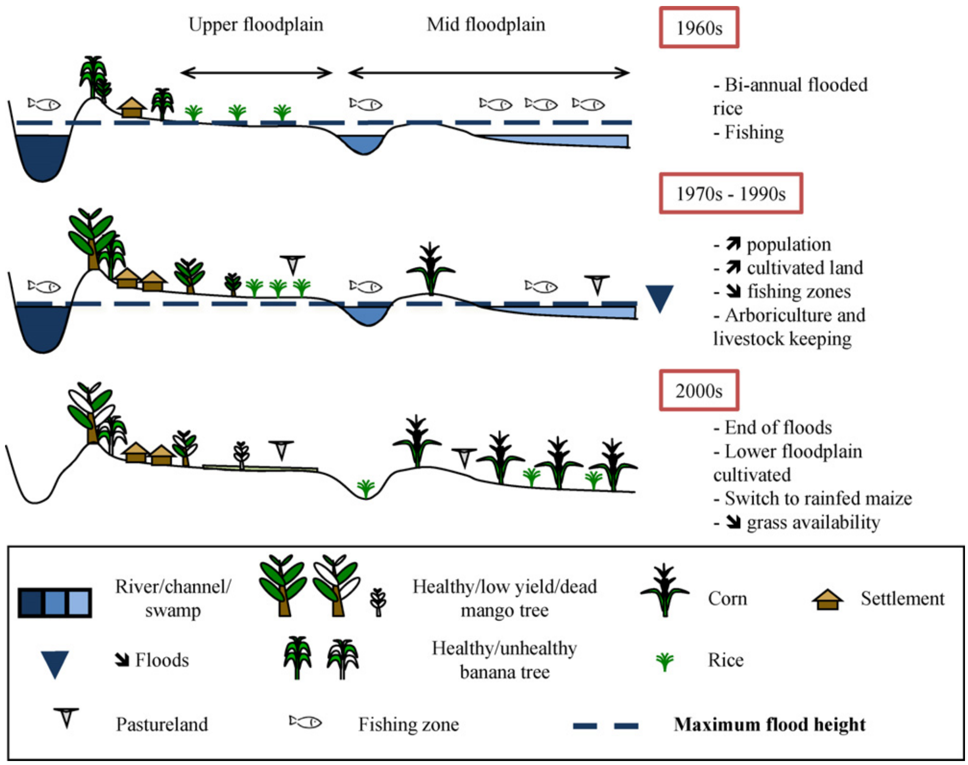

Fig. 5. Land-use changes in a Pokomo village from the 1960s to today.

and more recently Apple varieties) in the 1970s. The development of commercial arboriculture in the 1970s and 1980s, encouraged by road extensions, enabled some families to invest in livestock rearing. Larger portions of land were cultivated around the villages as a gradual decrease in rice yields became apparent. The population growth in the 1980s also favoured the increase of cultivated areas. This extension was accompanied by a transfer of fields to lower zones as flood amplitude decreased following the construction of the Masinga dam. Rice paddies were progressively transferred down the floodplain, and the mango plantations, initially located only on the riverbanks, were advantageously extended in the stead of the rice paddies (Fig. 5). Animal rearing was developed simultaneously because live capital provided higher revenues than mango and rice farming and could be rapidly transformed into cash for emergency purposes. These small herds of sheep, goats and sometimes cattle grazed around the village year-round and in the mid floodplain during the dry season.

The 1990s were marked by the 1997–1998 El Niño event that resulted in a major flood. Crop and livestock losses were accompanied by a gradual shift of the Tana River's main branch as it migrated eastwards by breaching a large hole through the riverbank. The western part of the Tana Delta floodplains now floods very rarely as a result of both this riverbed shift and the changes to the flooding patterns linked to dam construction. The farmers underwent a drastic shift from cultivating flooded rice twice a year in the upper floodplains to once-a-year rain-fed maize in the mid floodplains (Fig. 4), where enough rainwater accumulates through runoff to plant maize. Only one of the informants reported planting only rice in a field in the present day, whereas all farmers (including the Orma farmers) did in the 1960s and 1970s. The upper floodplains, no longer suitable for farming due to insufficient water and a decrease in fertility, were converted into grazing land for the village herds.

In 2009, Pokomo production systems were based mainly on cropping systems, combining maize and rice in the mid-floodplains, and mango and banana plantations on the riverbanks (Table 3). Crops were rain-fed, work was manual, and harvests were used mainly for household consumption. The total surface per household dedicated to cereal growing was generally less than 1 ha, and the mean maize and rice yields were approximately 1.3 T ha^{-1} and 1.3 T_{paddy} ha^{-1}, respectively. A lack of cash flow prevented farmers from using any type of fertiliser, herbicide or pesticide. Herd sizes varied between 0 and 100 head depending on the availability of capital for the initial investment. The sheep, goats and occasional cattle grazed in the upper floodplains around the villages and in the lower floodplains after the harvest. These herds constituted a major source of income for the interviewed farmers, although cash flow was also partially provided by the mango plantations located on the riverbanks. The respondents reported highly variable mango production, with a mean yield of 100–400 mangos per tree per season. This crop is a vital source of energy and vitamins (Litz, 1997) and can serve as a main food source during droughts. The respondents were of the opinion that fishing activities, although still present, were in decline.

5.2.2. The Orma: strategies of livestock owners

Two main phases in the production organisation of livestock owners can be distinguished that span roughly from the early 1960s to the mid-1980s and from the mid-1980s to the present day. Cattle are the social representation of wealth and status among the Orma, and most of their economic and cultural activities are centred on livestock rearing.

Sedentary and semi-nomadic groups co-existed (Ensminger and Rutten, 1991) within the delta in the 1960s. The sedentary groups had settled on the eastern side of the Oda branch of the Tana River or on the eastern highlands, close to the flooded grasslands, and the semi-nomadic groups grazed their animals in the floodplains during the dry seasons. The livestock-rearing strategy was similar in both cases: to increase the size of the herd to compensate for losses that occurred in extreme flood and

Table 3
Typology of the agro-ecological production systems encountered in the interviews. P1–P4 correspond to Pokomo production systems, O1–O5 to Orma production systems and B1–B2 to those found in the village of Boramoyo. occ: occasional, reg: regular, and reg*: regular and owner of a canoe. In places where fishing was difficult, small-scale, non-irrigated market gardening replaced fishing for monetary income. M: manual and T: tractor.

Characteristics	Agro-ecological production systems										
	P1	P2	P3	P4	O1	O2	O3	O4	O5	B1	B2
Farming component											
Mango plantation (ha)	4	2	1.3	0.3	0	0	0	0	0	2.5	2.5
Cereal crops (ha)	4	2	0.8	0.5	1.6	1.2	0.8	0.4	0.2	2	2
Market gardening (ha)	0	0	0	0	0	0	0.4	0	0	0	0.8[b]
Sugar cane (ha)	0	0	0	0	0	0	0	0	0	2	0
Irrigated banana plantation (ha)	0	0	0	0	0	0	0	0	0	2.4	0
Livestock component											
Head of cattle[a]	30 ♂	4 ♂	0	0	40 ♀, 15 ♂	20 ♀, 4 ♂	2 ♀	1 ♀	0	10 ♂	0
Head of goat and sheep♀	30	7	5	0	70	50	5	5	0	0	0
Fishing			occ	occ				reg*	reg		
Equipment	T + M	M	M	M	T + M	T + M	M	M	M	T + M	T + M
Hired workforce	+++	++	+	–	++++	+++	–	+	–	+++	+++++
Investment capacity	++	+	–	0	++++	++	0	0	0	+++++	++
% estimated population	5%	15%	20%	5%	5%	10%	20%	10%	10%	rare	rare

[a] Number of milking cows or bulls.
[b] Irrigated land.

drought years. One informant in Kikomo reported a loss of 50 out of 170 head in 1984 and 130 out of 175 in 1997. Although the herds already varied considerably in size between different families (from 4 to 5 up to 200), most people lived solely from livestock-related activities.

Livestock rearing was characterised by a high herd mobility to take advantage of the various environments in the surrounding areas. Herds would complete seasonal migrations of several hundred kilometres, back and forth from the deltaic floodplains during the dry seasons to the drier highlands during the rainy seasons. The herds were kept in the highlands as long as rainfall allowed for grass growth, thus avoiding the floods within the delta, and entered the delta only after floods, when the grasslands were productive. Small herds of milking cows were maintained permanently in sedentary villages for the household's food supply. Cows produced a maximum of 5 L of milk per day (Table 2) when grass was abundant, demonstrating the richness and quality of the deltaic pasturelands. Farming activities, similar to those of the Pokomo, were undertaken by more vulnerable village members to supplement livestock-rearing activities. This cyclical accumulation of and strategy for keeping livestock continued throughout the 1970s and 1980s. Although some livestock owners noted a slight decrease in local butter production (which was made using excess milk supplies) in the late 1970s and that herds spent less time in the highlands, there were no marked changes in the habits of the livestock owners until the mid-1980s.

The reduction in flood peaks after the construction of the Masinga dam, in conjunction with the drought of 1984, marked a turning point in the system, after which the cyclical accumulation process gradually broke down. Livestock owners noticed that grass biomass was decreasing by the end of the 1980s (Fig. 4). An elderly woman reported that the grass locally known as "Oba lesa" or "Oba kawisa", an important source of fodder (*E. stagnina* (Retz) P. Beauvoir), used to grow to over 2 m and 60 cm high in the rainy and dry seasons. Since the early 1990s, however, this grass reaches only knee height during certain rainy seasons and disappears in the dry seasons. After the 1984 drought, many livestock owners took up farming as a secondary activity. Most of them were still cultivating in the early 1990s because they had been unable to recover a sufficient number of cattle.

In the 1990s, the regular transhumance pattern from the delta's inner floodplains during the dry seasons to the highlands during the rainy seasons stopped, and the majority of the cattle lingered within the delta or the surrounding wooded bush land year-round, following the variable rainfall pattern. The El Niño event of 1997–98 had a dramatic effect on the Orma community, causing large reductions to herds. Six informants in Chalaluma and Kikomo reported 40–74% losses in their cattle herds. The loss of cattle forced the remaining population into farming activities and occasionally fishing.

Currently, the Orma mainly use the lower floodplains as grazing land and the floodplains around the villages and the ancient sand dunes for farming purposes. Although many own a low number of cattle, the informants are all adamant that livestock rearing is still the principal activity of the Orma. Income is provided by selling milk, animals, or fish. To increase their revenues, some Orma have invested either in fishing activities, if their village is located close to a lake, or small-scale market gardening. Others have succeeded in maintaining a relatively large herd and increasing their cultivated land by hiring a tractor and manual labour (Table 3). Harvests are mostly used for household consumption.

5.2.3. The village of Boramoyo: local agro-ecological initiatives with irrigated systems

The village of Boramoyo, created in the late 1980s, is located at the southern end of the Oda river branch, where river water still partially flows by backflow from the Matomba branch. Two households (Table 3) have been using water pumps to produce crops for the local market (tomatoes, kale, onions, bananas and sugarcane) since the mid-1990s. By eliminating their dependence on rainfall, they were able to produce two (and sometimes three) harvests a year and increase their income (with a 2- to 10-fold increase over that of other production systems). This success was possible due to an initial investment in irrigation equipment and the subsequent continuous availability of river water. These irrigation techniques have not spread within the delta, despite some experienced farmers having the investment capabilities because river water is the major requirement for their success: the system is limited to zones where the river is still flowing close to potential crop land.

6. Discussion

6.1. Mechanisms of change and local adaptive strategies

Two main economic production systems coexisted within the TRD in the 1960s: the Pokomo combined rice farming, fishing and occasional hunting and gathering to secure their livelihoods, while the Orma relied on the area's rich floodplain. Although extremely different in their underlying mechanisms, both were based on the highly productive ecosystems found within the wetlands that resulted from abundant water and fertile sediments brought by the floods. As fishermen, rice cultivators or livestock owners, the Pokomo and Orma set up flexible production systems by taking advantage of diverse local agro-ecological zones and dynamic flooding patterns. Both communities perceived this period as a sort of golden age, even though it took place in a decade of nationwide instability and social battles (Kenyan independence was obtained in 1963).

The decrease in water availability led farmers to diversify their crops and integrate new subsystems. Crops were selected according to water requirements and planted along the hydrological upper floodplain-lower floodplain gradient, gradually following the water as this gradient moved downwards. Mango plantations spread out as the water table lowered and rice fields migrated down the floodplain. The increase in mango plantations is consistent with national data, which indicate an increase from 500 ha cultivated nationally in 1970 to approximately 15 000 ha in 2000 (Ministry of Agriculture, 2001, in Griesbach, 2003). 1300 ha were under cultivation along the Tana River in 2003, producing 12 000 T of mangoes yearly (FAO, 2004). Considering that 100–400 mangoes were reported per tree per season, with an average weight of 570 g per mango (Griesbach, 2003), a density of 60 trees ha^{-1} and one productive season per year, the yields in this study fell between 3.4 T ha^{-1} $year^{-1}$ and 13.6 T ha^{-1} $year^{-1}$. These yields are consistent with the FAO figures, and on the lower end compared to previous assessments (Ndungu et al., 2008). The Tana River District has a comparative advantage in mango growing within the Coast Province because its floodwaters advance the harvesting season (FAO, 2004). This situation, combined with a work calendar that is compatible with cereal crops, could explain the rapid increase in mango production in the Tana River District.

The TRD communities adopted a wide array of strategies to face the decrease in flooding duration and frequency. They changed their production systems by diversifying, abandoning or adopting various farming, fishing and livestock techniques. As people tried to adapt to their new environment, the spatial patterns of land and water use also changed. At first, the decrease in flood extent, frequency and duration was somewhat beneficial to the Pokomo because the lowering of the water table made new arable land available. However, informants reported that rice cultivation became more difficult as floods decreased. Instead of biannual rice crops, farmers switched to maize or a combination of rice and maize that were planted once a year. This technique highlighted the creativity of farmers facing serious water shortages. By doing so, they adopted a risk-spreading strategy that increased the chances of harvest because maize dominated the field in average-rainfall years and rice dominated in high-rainfall years. Despite these innovations, all informants noted a decrease in cereal yields over the past 50 years, especially since the early 1990s, with a concurrent decrease in the predictability of the harvest (Table 4).

The traditional fishing sub-component of the Pokomo's activities was also affected by the change in flood frequency and duration. Floods increased fish reproduction zones and nutrient availability (Welcomme, 1979). As the lakes near the villages dried up, fishermen migrated down the river to more distant lakes and temporary fishing grounds, but the overall productivity of their work seems to have declined. Okeyo (1991) has noted that wetland fish populations in Kenya have dwindled since the mid-1960s. Of course, upstream industrial development, the increase in human

Table 4
Changes in water resources and their consequences on production systems in the Tana River Delta. UFP: upper floodplain, MFP: mid floodplain, LFP: low floodplain.

Agriculture	Fishing	Livestock keeping
Regular floods		
Function		
Good soil fertility	Increased habitat and nursery zones	High productivity and good regeneration of grasslands
Eradication of invasive species	Fish migration and spawning	Fodder production throughout the year
Full soil water recharge		Maintains flood tolerant species and kills invasive species
Land use		
MFP: recession agriculture (rice)	Floodplains, permanent lakes, temporary lakes, channels	LFP: dry season grazing
UFP: supplementary crops (bananas, etc.)		Out of delta: rainy season grazing
Production organization		
Biannual cropping system with risk spreading strategy	Fishing all year round, in different ecozones	Seasonal migration of livestock
Productivity		
≈2 T ha^{-1} $season^{-1}$ [c]	40–60 kg fish per flooded hectare [d]	Rainy season: 60 kg DM ha^{-1} day^{-1} [e] Dry season: 5–40 kg DM ha^{-1} day^{-1} [e] Flooded: 200–250 kg DM^{-1} ha^{-1} day^{-1} [f]
Rain		
Function		
Partial recharge of soil and ground water	No spawning nor nursery zones	Dry years: limited growth
Low and medium rainfall: crops fail		Rainy years: partial growth
Low water table: low yields of tree crops		Limited regeneration of grasslands
Land use		
MFP (rain runoff zones): rainfed crops (maize)	Only in permanent lakes and channels	Floodplains: grazing all year round
UFP (sufficient water table): arboriculture		Out of delta: occasional grazing during rainy seasons
Production organization		
Cropping: April–July	Rare	Livestock follow highly variable rainfall
Increase in cultivated land		
High yield variability		
Productivity		
1.3 T ha^{-1} [a]	0	15 ± 5 kg DM ha^{-1} day^{-1} [b]

[a] Data derived from interviews.
[b] Data collected from 04/12/2010 to 20/05/2011 in the Tana River Delta
[c] Mollard and Walter (2008).
[d] Welcomme (1979).
[e] Hiernaux and Diarra (1986).
[f] François et al. (1989).

population with siltation and the use of modern fishing gear (Okeyo, 1991) have explained some of this decline, but the major factor in the TRD seems to have been a decrease in flooding. With the decrease in fish yields, the relationship between the effort required to fish and the benefits of fishing most likely changed in the 1980s, leading to a decline in fishing activities. Njuguna (1991) has indicated a fish yield of 82 T from the Shakababo and Kongolola lakes within the TRD in 1991. Because these lakes are now dry for most of the year, fish yields are close to zero. Fishing, once a defining component of the Pokomo identity, has now been relegated behind tree farming and livestock rearing.

The decrease in flooding within the delta also had a direct effect on the migration patterns of livestock and fodder production (Table 4). By forcing the cattle out of the floodplains, the floods contributed to the regeneration of pasturelands twice a year. As the extent and duration of floods decreased, the pastoralists were no longer forced to move their cattle to the terraces, but rather kept the herds within the delta because the latter provided better pasture than the highlands. The lack of floods was initially beneficial to the livestock owners because grazing land was made available around the villages. At the same time, however, the productivity of the floodplain grasslands dropped as water and nutrient inputs decreased. The combination of an increase in livestock due to population growth and a decline in productivity resulted in overgrazing in the late 1980s. The advantages of staying within the delta, such as shorter travelling distances, were quickly counterbalanced by losses during the dry seasons and the appearance of new diseases.

The productive systems of the TRD underwent considerable changes in the past 50 years, primarily in terms of water and land use. In the following sections, we declare the decrease in water availability the main driver of change in the TRD but also note the importance of integrating the other drivers into the analysis.

6.2. Decrease in water availability as a driver of change in wetland food production systems

The main strength of the TRD's productive systems was the existence of *multiple* sub-components that were combined under different flooding or climatic scenarios. The existence of multiple subcomponents (farming, fishing, and livestock rearing) within the production systems provided food security while maintaining the sustainable use of natural resources. The relative importance of each sub-component varied throughout the years and seasons depending on the seasonal floods. Water depletion affected not just one component but *all* of them at the same time, so that by weakening each sub-system, the resilience of the entire productive system was affected until its overall dynamic equilibrium collapsed. Enfors and Gordon (2007) have argued that smallholder agro-ecosystems in dry lands can pass from a "productive" state to a "degraded" state over short periods of time as key variables inherent to that system are modified. We found similar results transposed to a different socio-ecosystem, and this modification of the system took place because (1) water availability was the major factor influencing the productive systems and (2) the decrease in river water affected each sub-component. External incentives to build up the adaptive capacity of the local population were also most likely lacking, although this factor was not studied. Overall, the changing environmental conditions made it impossible to perpetuate or improve the food production systems. The innovative systems found in the village of Boramoyo are a striking example of how water resources, if they were available, could be used currently.

The rate at which the production systems changed was non-linear, with progressive adaptations throughout the 1960s to 1980s (e.g., a shift in and of the cropping systems and the modification of seasonal migratory movements) followed by an abrupt change from the early 1990s (e.g., the switch from two to one cropping seasons per year and the adoption of farming activities by all of the Orma). At first, the disturbance was an opportunity for innovation and development in the productive sector, such as the development of the mango sector and the combination of multiple farming and livestock-rearing systems among the Pokomo. However, the socio-ecological systems most likely experienced a phase shift from a 'desired' to a 'less desired' state in the mid-1990s, when the production systems were no longer adapted to low water supplies. This collapse had a major impact on food production. Although the mechanisms involved in this shift varied between the communities, all experienced food and water shortages.

6.3. Integrating other drivers of change

Agro-ecological production systems are complex assemblages resulting not only from strategic decisions about land and resource uses but also from various social and economic incentives, cultural influences and market and political forces. To analyse the complex systems prevalent in the TRD, we adopted a disaggregative strategy and analysed the impact of one major factor. However, it has been argued that complex socio-ecosystems are controlled by a number of key variables, often between three and five. Other factors have certainly played a major role in shaping the current agro-ecosystems of the TRD, including population growth, land rights and market incentives in particular.

The population of the TRD has increased from 47 000 in 1989 to 100 000 inhabitants in 2009 (Kenya Population and Housing Census, 2010), leading to increased strain on the region's natural resources. In particular, the population increase has encouraged settlement in remote areas where infrastructure is scarce and the environment is inappropriate for farming. Livestock numbers have also undoubtedly increased, thus requiring more pastureland. In terms of land rights, the Pokomo and Orma do not have legal titles on the central floodplain, even though they have been using it for centuries. Public and private companies have recently been acquiring this land for large-scale biofuel projects (Duvail et al., 2010, 2012), leaving little opportunity for the locals to invest in the long-term management of their resources.

Economic growth (Ensminger and Rutten, 1991), market incentives, governance issues, infrastructure development and many other factors have also shaped the development trajectories of small-scale production systems. Because these factors were not within the scope of our research, future studies will need to extend our results as part of a more holistic approach. It will also be important to combine several levels of analysis from different research fields, including economic evaluations (Barbier et al., 1991; Barbier, 1993; Barbier and Thompson, 1998; Emerton, 2003), modelling of water-demand scenarios (Duvail and Hamerlynck, 2003; Murray-Hudson et al., 2006; Singh et al., 2011) and climate change projections (Beck and Bernauer, 2011) so that a common consensus can emerge.

6.4. How changing water resources have impacted human well-being

Human well-being has several components, including basic materials for a good life (MA, 2005). The latter encompasses food supply, which is one of the essential needs for a society (Butler and Oluoch-Kosura, 2006). The decrease in water availability, accompanied by the degradation of productive capacities within the delta, deprived communities of their ability to produce their own food or secure an income to buy food and other assets. As such, the decrease clearly impacted local human well-being. However, water depletion also affected the other components of human well-being in a cascading effect. Unreliable local food production led to a stronger dependency on external food supplies. Because many families are currently unable to either produce or *buy* enough food, they receive aid through the World Food Programme. This situation, in turn, generates a sense of dependency and helplessness within the population. Boreholes dried up, obliging villagers to use river water as drinking water, which most likely affected their health. Changes in the flooding regime also hindered the economic development of the zone by blocking the implementation of small-scale irrigation systems, tree plantations and milk production that could supply the surrounding towns with local produce. Overall, opportunities through which people could increase their assets were prevented. Furthermore, water scarcity led to increased competition over natural resources: violent conflicts between the Pokomo and Orma communities broke out in 2001 and again in 2012, the underlying causes of which were the degradation of the environment and the depletion of natural resources. In turn, this type of conflict contributed to the loosening of social cohesion within and between the TRD communities.

7. Conclusion

Kenya's strategy for energy production over the last 50 years has been to construct large-scale hydroelectric reservoirs. Downstream wetlands have undergone drastic environmental changes as a consequence of these decisions, and the changes in water resource distribution have affected local food production systems, leading to a decrease in human well-being in the TRD.

The agro-ecological production systems in the TRD that were once adapted to and based on the river's dynamic flooding patterns underwent drastic changes. As the flooding time, duration and frequency diminished, the local population diversified, abandoned or adopted various farming, fishing and rearing techniques, extended land cultivation or even shifted their locations. Despite all of these changes, the decrease in water availability affected each subcomponent of the productive system, leading to its collapse in the 1990s. Water depletion led to a direct decrease in human well-being through the loss of food security, and indirectly affected well-being by restricting freedom of choice and action, and most likely by affecting the health of the communities and loosening social cohesion.

The next step in this research is to undertake a quantitative assessment of the changes in the TRD related to flow regimes. This research would provide a guideline for decision-makers and major stakeholders with which to manage the wetlands in accordance with national objectives *and* with local human and environmental requirements in mind. Because the main ecosystem services of the TRD wetlands are food-oriented, these assessments should focus first on crop, fish and fodder production and propose different flooding scenarios that would restore and improve the use of the delta's resources.

Acknowledgements

This research was done as part of the "Eaux et Territoires" project jointly implemented by the French Research Institute for Development (IRD), the National Museum of Kenya (NMK) and Kenya Wildlife Service (KWS) and funded by the French Ministry of Environment. We would like to thank the people we interviewed and the translators.

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