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Agricultural innovation and environmental change on the floodplains of the Congo River

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Climate-driven environmental changes bring new risks but also opportunities to populations living along the world's major rivers. Based on ethnoecological fieldwork, in this paper we examine how people living in the *cuvette centrale* of the Congo basin have adopted flood-recession agriculture on islands in the Congo River, taking advantage of a secular shift since the 1980s in the hydrological regime of the Congo River. Analyses of the hydrological data reveal that this shift decreased flood risk and significantly extended the growing season on the islands, long enough to enable cultivation of fast-maturing varieties of manioc and other crops. Flood-recession farming on islands in the river is today not only an important source of food, but also a source of income for women, who are primarily responsible for seasonal cultivation of fields during the low-water season. Hydrological changes alone are insufficient to explain the adoption of the new agricultural practice; adoption also arose as a result of dynamic interactions among river fishing, trading, and broader socio-economic forces. Climate-change models project an increased frequency of extreme floods. Our results suggest that this change may limit island cultivation in the future. More generally, our findings point to the importance of looking beyond single-factor, solely environmental explanations in studies of climate-change adaptation.

KEYWORDS
adaptation, climate change, Congo Basin, ethnoecology, flood-recession farming, social-ecological system

1 | INTRODUCTION

Recognition of the challenges of climate change mitigation has led to increasing attention to how people will adapt to future environmental conditions (Kelly & Adger, 2000). A large body of literature assesses climate-related risks and the vulnerability of people in the face of climate change (McDowell et al., 2016; Wang et al., 2014). Vulnerability is often defined in negative terms as the degree to which a system becomes unable to cope with adverse effects (Adger, 2006).

Agriculture is among the sectors most impacted by climate change and many studies warn of the vulnerability of rural populations in terms of food security, mainly in developing countries (Adger et al., 2003; Eakin, 2012; Schmidhuber & Tubiello, 2007). A smaller, parallel literature addresses the capacity of people to adapt to the new climatic conditions. Scholars argue that, despite their frequent portrayal as "vulnerable" and "passive actors," communities in the developing world are in fact fundamentally proactive and creative thanks to highly dynamic local knowledge systems, and a long history of adaptation to environmental variation and risks. While recognising that climate-driven environmental change will likely have adverse effects on populations, they insist that it can also bring new opportunities, opening new windows for innovation and the emergence of latent capacities (Boillat & Berkes, 2013; Gómez-Baggethun et al., 2013; McSweeney & Coomes, 2011; Nelson et al., 2007). A recent analysis of literature (McDowell et al., 2016) shows that only 15% of climate-change studies recognise the potential positive impacts of climate change on social or ecological systems. More emphasis is thus needed on investigating opportunities that may arise with climate change and on recognising the agency of people and their ability to cope with environmental changes.

Another major challenge facing researchers working on climate change is the need to consider the multiple drivers of adaptation, beyond environmental factors. Climate change impacts and adaptations cannot be isolated from the broader social, economic, political, institutional, and technological context (Morton, 2007; Shinn, 2017). Social-economic and ecological factors interact to form a complex and dynamic system (Berkes & Folke, 2002). Despite recognition of the complexity of social-ecological systems, however, most studies on climate change vulnerability analyse only biophysical drivers (McDowell et al., 2016).

Moreover, rural producers in the developing world often practise a wide range of activities; some of these rely on natural resources (e.g., farming, fishing, hunting), whereas others do not (off-farm employment). This diversification of livelihoods allows people to benefit from the different natural resources, and to decrease the risks by spreading income sources. It also increases their flexibility and adaptive capacity in the face of change (Ellis, 2000; Thornton & Manasfi, 2010). Understanding future adaptations requires us to characterise the complexity of livelihood systems, the interactions between the different activities, and the myriad of intertwined climatic and non-climatic determinants of change.

Floodplains of major tropical rivers are good examples for addressing these challenges. These ecosystems will be heavily impacted by future climate change through altered precipitation and flow regimes, and the increased frequency of extreme flood events (Alcamo et al., 2007; Intergovernmental Panel on Climate Change [IPCC], 2014). Populations living in floodplains are considered to be especially vulnerable. Yet, these ecosystems can also offer opportunities for people to adapt (Capon et al., 2013). Periodically shifting between a terrestrial and an aquatic phase, floodplains are rich and dynamic ecosystems that particularly favour a multi-activity livelihood system, that is, one combining agriculture and fishing with pastoralism, hunting, gathering – or all of these. Such pluri-activity smooths the effects of fluctuating resource variability and reduces the risks due to flooding (Coomes et al., 2010; Duvail & Hamerlynck, 2007; Raimond et al., 2014).

In this paper, we report on a case of agricultural innovation made possible by environmental change on the floodplains in the *cuvette centrale* of the Congo River Basin. In this vast wetland, people practise a variety of livelihood activities, including farming on raised fields in the floodplain and fishing. Since the 1980s farmers have adopted flood-recession agriculture on the islands of the Congo River, a change that was enabled by a shift in the flood regime of the river in a context of broad changes in socio-economic conditions. Our study aims to investigate the drivers and processes that led to this innovation. We adopted a systemic and pluri-disciplinary approach based on ethnoecological fieldwork conducted over eight months in the city of Mossaka, in Republic of Congo, during the years 2014 and 2015. Along with participant observation, we conducted a total of 179 semi-structured interviews with 53 inhabitants of Mossaka of diverse geographic origin, duration of residence in Mossaka, age, and gender. The interviews focused on understanding the practices in subsistence activities, how and why these practices and activities have changed, and more particularly the reasons for the adoption of flood-recession agriculture. Environmental change and flooding dynamics were assessed through the analysis of historical series of data on the water level of the Congo River at Mossaka. To evaluate the agronomic advantages of flood-recession agriculture compared with raised-field farming, we analysed soil samples and measured the harvests in both agricultural systems. More information on the interviews, surveys, and analyses is provided in the Supporting Information.

2 | THE SOCIAL-ECOLOGICAL CHARACTERISTICS OF MOSSAKA AND THE *CUVETTE CENTRALE*

The Congo River Basin, covering some 3.7 million km^2, is the world's second largest river basin after the Amazon. The *cuvette centrale*, situated in the centre of the Congo Basin, consists of a vast wetland extending over almost 200,000 km^2, shared by the Republic of Congo and the Democratic Republic of Congo (DRC) (Campbell, 2005). The *cuvette* is characterised by low elevation and by a dense hydrographic network. It is covered by a mosaic of seasonally inundated forest and

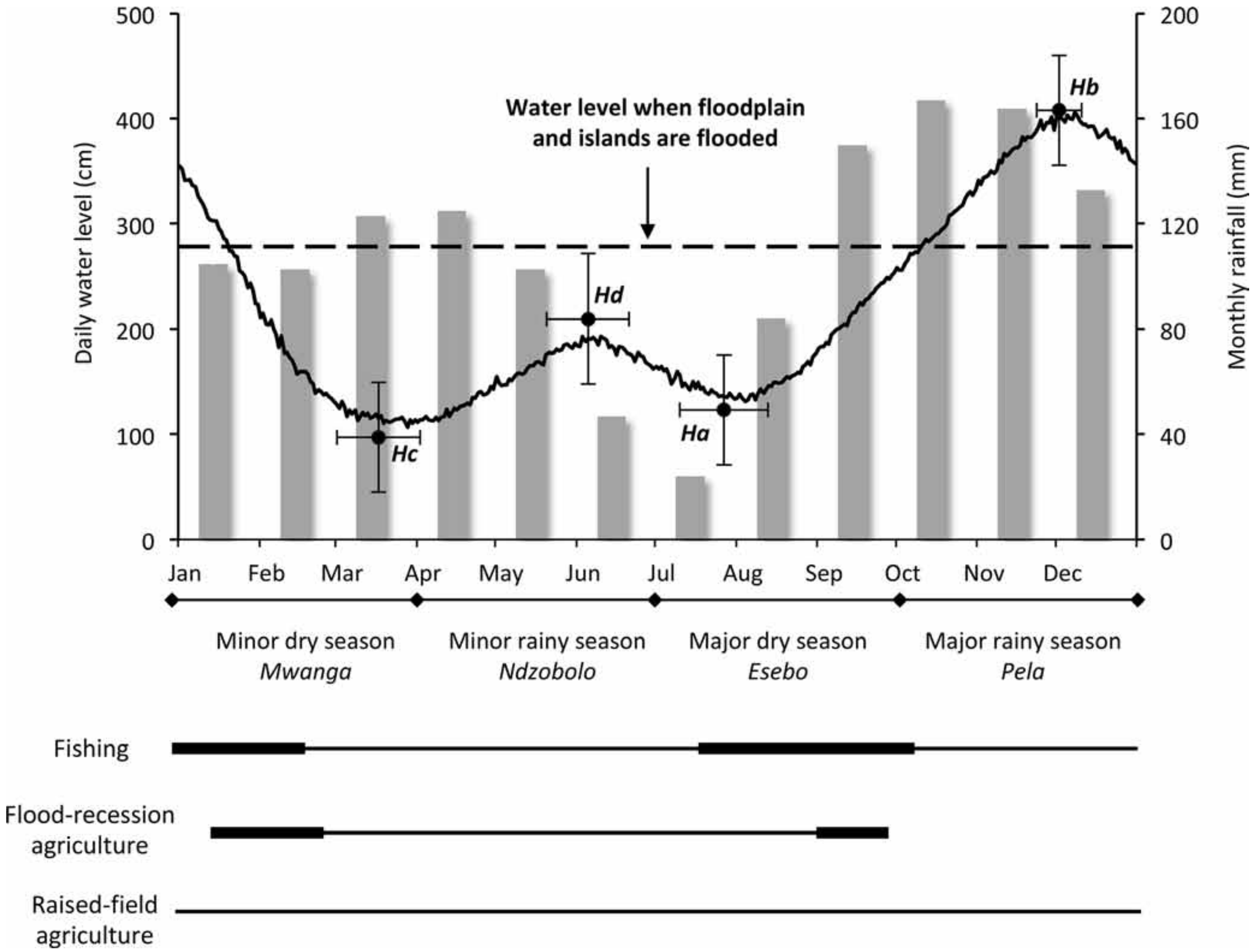

FIGURE 1 Seasonal flood cycle (1952–2015) and livelihood activities in Mossaka. Solid black line denotes the mean daily water level of the Congo River at the hydrological station of Mossaka from 1952 to 2015 (left *y*-axis). Grey bars indicate the mean monthly rainfall at the hydrological station of Mossaka from 1944 to 2001 (right *y*-axis). Filled circles and error bars show means and standard deviations of seasonal key indicators of water level: the lowest water level during the major dry season (*Ha*), the highest water level during the major rainy season (*Hb*), the lowest water level during the minor dry season (*Hc*), and the highest water level during the minor rainy season (*Hd*). In each case, the vertical error bar indicates inter-annual variation in water level and the horizontal bar depicts when the highest/lowest level was reached in the year. Lines in the lower part of the graph show the time periods for three main activities in Mossaka, with thicker lines indicating periods of especially high labour requirements.
Data sources: Data on daily water level were obtained from the Institut National de Recherche en Sciences Exactes et Naturelles (IRSEN), Brazzaville, and the ports of Mossaka and Brazzaville. Data for monthly rainfall were obtained from the Agence Nationale de l'Aviation Civile at Brazzaville

grassland. In this region, the Congo is a complex river with many islands that divide the main channel into multiple anastomosing branches. Islands can measure up to 3 km wide and several dozen kilometres long. The climate is marked by four seasons, defined by water level and by rainfall (Figure 1). During the major rainy season, locally called *pela* (October–December), river waters rise and submerge the floodplains around Mossaka as well as the numerous islands of the Congo River. In the minor dry season *mwanga* (January–March), floodwaters progressively recede from the plains and islands. During the minor rainy season *ndzobolo* (April–May), waters rise again but usually do not reach a level that floods the plains and islands. Finally, from June to September, during the major dry season *esebo*, water level again falls and water is restricted to the river beds and to ponds and lakes in the floodplain.

The Congo is one of the world's most regular rivers, showing weak variation in water flow both seasonally and across years, compared with other large tropical rivers such as the Ganges, the Orinoco, the Mekong, or even the Amazon (Latrubesse et al., 2005). This regularity is explained by the fact that the drainage basin extends both north and south of the equator in such a way that peak flows from tributaries in the two hemispheres occur in opposite seasons. Despite such

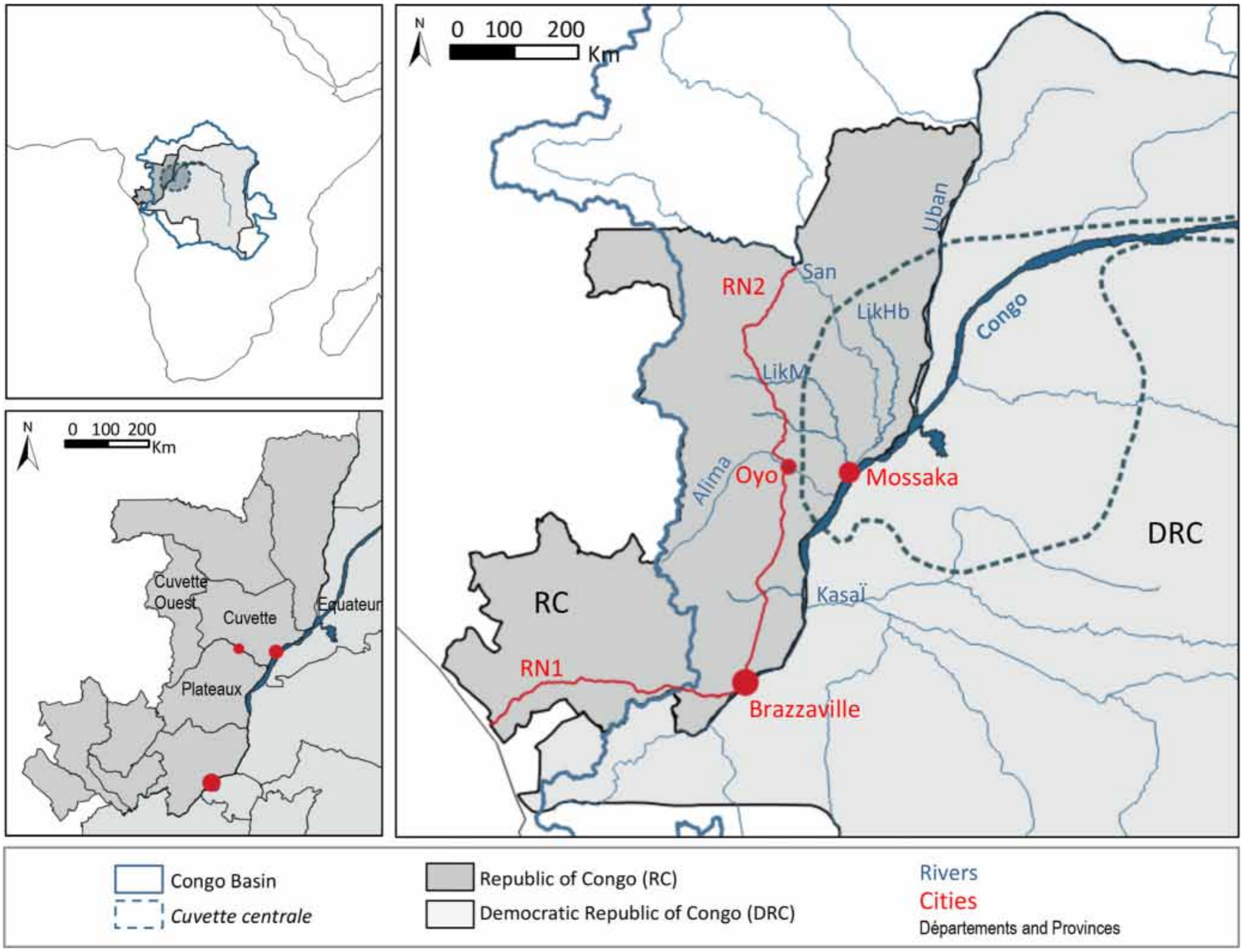

FIGURE 2 Overview map of the Congo River Basin close to the city of Mossaka, Republic of Congo, showing the extent of the *cuvette centrale*. Red lines depict the two national roads (RN1, RN2) and solid blue lines the main rivers, including the Likouala Mossaka (LikM), Likouala-aux-Herbes (LikHb), Sangha (San), and Ubangui (Uban).

regularity, long-term studies of discharge over the 20th century, measured at the Brazzaville hydrological station, demonstrate that the Congo River has experienced several successive phases of flow instability since 1960. Specifically, during the decade 1960–1970, river flows were particularly high, then diminished in the 1970s. During the 1980s, flow became lower than those observed during the first half of the 20th century (Laraque et al., 2001).

The city of Mossaka (1°13′27.32″S, 16°47′37.84″E) (Figure 2) is located on the right bank of the Congo River, in the Republic of Congo. Being at the lowest point of the *cuvette centrale*, it is surrounded by an extensive grassland floodplain. Mossaka grew considerably during the 20th century. In the first half of the century, the French colonial administration and company firms forced the relocation to Mossaka of people not only from surrounding villages but also from regions further away (in the Département de la Cuvette-Ouest, and the Département des Plateaux) (Sautter, 1962) (Figure 2). Following independence in 1960, Mossaka continued to grow. The city became the hub through which the fish caught in the *cuvette centrale* transited to the markets of Brazzaville, the country's growing capital city. This status of "fish capital," as well as the amenities offered by this new urban centre (middle school, hospital, power generator, access to markets, etc.) in an otherwise sparsely populated area[1] attracted fishers and others. From 800 inhabitants in 1900, the population rose to 6,000 inhabitants in 1981 and Mossaka counts today more than 15,000 inhabitants belonging to several ethnic groups (Centre National de la Statistique et des Etudes Economiques [CNSEE], 2007; Ndinga Mbo, 2006). Yet, Mossaka is still relatively isolated. The city is only accessible by river transport, requiring two days' travel from the capital Brazzaville, and more than 10 hours by motorised canoe from Oyo (14,295 inhabitants), the closest city.

3 | PLURALIST LIVELIHOODS OF THE CONGO RIVER, ITS ISLANDS, AND FLOODPLAIN

The people of Mossaka rely heavily upon the river, its islands, and its floodplain for their livelihoods. The mosaic of habitats favours a great diversity of activities and ways of using natural resources, which are synchronised with the seasonal flood cycle. Fishing, agriculture, and trade are the most important activities (Figures 1 and 3).

3.1 | Fishing

Fish are the most important protein source in Mossaka and, for many households, fishing is the main economic activity. Sautter (1962), who visited the region in the 1950s, described a wide range of fishing gear. Our observations and interviews also show that fishers combine a large variety of fishing techniques, allowing them to exploit the diversity of habitats and to capture a large number of fish species (Comptour, 2017; Comptour et al., 2016). Fishing is done both in the floodplain and in the Congo River and its tributaries. It is most productive during the arrival and recession of flood waters and at the end of the major dry season, but the use of different techniques allows year-round fishing. Both men and women fish, but men are engaged primarily in commercial fishing and fish both in the floodplain and in rivers, whereas women fish more for household consumption and essentially in the floodplain. However, an increasing number of women sell part of their catch:

> Women really started to fish in the 1960s, and they started to sell the fish at that time […] Before it was just to have fish for the family. (man, 40–50 years)

This change in fishing reflects an overall shift in gender dynamics throughout the country, where women have progressively achieved greater economic and social autonomy and emancipation since the 1960s:

> Before, women were subordinates, they could not have money, they could not go to school … (man, 40–50 years)

3.2 | Raised-field agriculture in the floodplain

To complement fish consumption, inhabitants of Mossaka cultivate manioc (*Manihot esculenta* Crantz; also called cassava) on the grassland floodplain that is periodically flooded during the major rainy season. They build large earthen structures

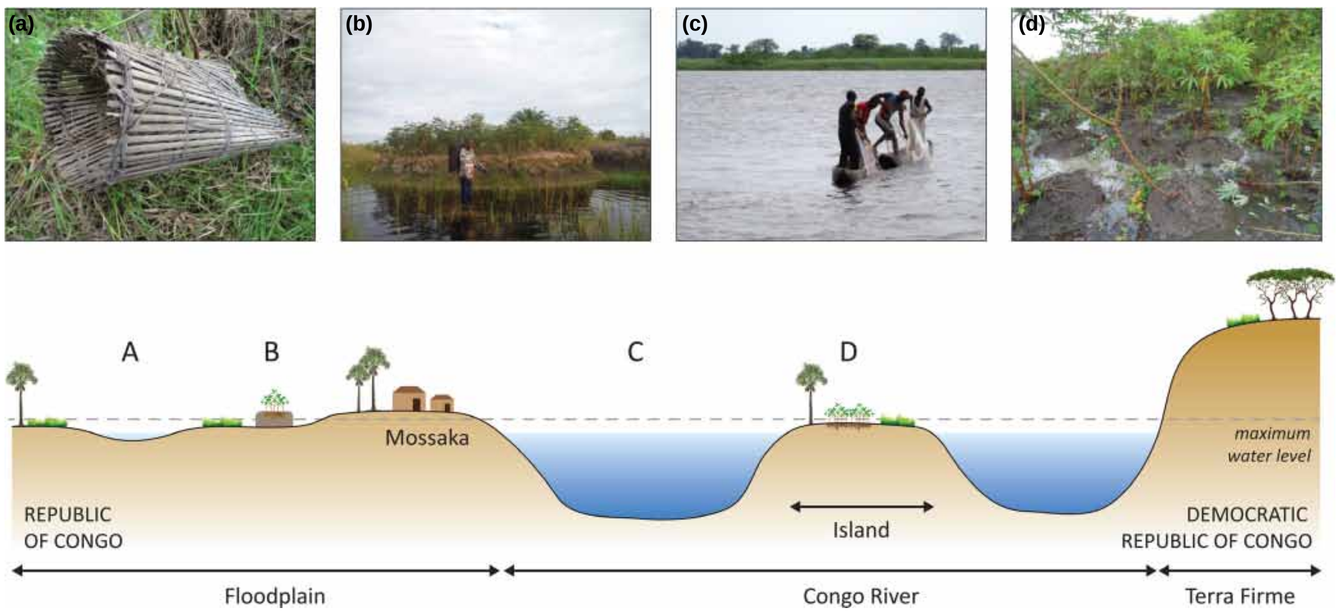

FIGURE 3 Schematic illustration of habitat diversity and the associated livelihood activities in the area surrounding Mossaka. Main activities in this area are fishing with traps in the floodplain (a), cultivation of raised fields in the floodplain (b), fishing with nets in the Congo River (c), and flood-recession agriculture on the islands of the Congo River (d). © M. Comptour.

("raised fields") that can be up to 1.5 m high, on top of which they plant their crops. During construction and maintenance of fields, farmers add grass as green manure in raised fields that increases soil fertility. Raised-field cultivation has long been practiced in this area and this technique was described by Sautter (1962). A more detailed and updated account of this farming system is provided by Comptour et al. (2018). Beyond the reach of the flood waters on the elevated surfaces of raised fields, the tuberous roots ("tubers") of manioc have time to reach their full size and can be left in the ground for up to three years. Raised fields can be harvested all year round and serve as sites for live storage of manioc. This agricultural system can easily be accommodated within the calendar of other more seasonal activities. Cultivating on raised fields is mostly women's work, but men sometimes participate.

3.3 | Trading

Agricultural production on raised fields has never been sufficient to meet all the needs of households in Mossaka and in the surrounding villages in floodplains. In contrast, fish are caught in abundance. The inhabitants of Mossaka have historically been heavily engaged in trading activities, facilitated by traffic on the dense river network, to compensate for shortfalls in agricultural production. They notably have long been involved in active trade relationships with farmers living in regions of well drained soils along the Alima River, up to more than 200 km from Mossaka (Ndinga Mbo, 2006; Sautter, 1962) (Figure 2). At the end of the 19th century, the colonial administrator Froment (1887) (as cited by Sautter, 1962) estimated that around 40 tons of manioc were transported daily by canoe from the villages situated on the banks of the Alima River to the villages in the Mossaka region, in exchange for smoked fish. Other goods were exchanged, including raw materials, commodities and luxury goods, at local scales but also over long distances (Sautter, 1962; Vansina, 1962). Today, the people of Mossaka are still heavily engaged in trade relations. Mossaka is an important market centre, a relay point between the capital and the villages and fishing camps in the *cuvette centrale*.

3.4 | Flood-recession agriculture on the islands

The inhabitants of Mossaka also farm the numerous islands in the Congo River. This flood-recession agriculture, locally termed *mitsaba*, consists of planting crops (mainly manioc) once the islands emerge from the water (January/February) and harvesting the crops seven to nine months later (September–October), before the river once again floods the islands during the major rainy season. In this agricultural system, manioc tubers are harvested before they reach their full size. Labour needs for cultivating on the islands are highly seasonal. A large labour force is required during planting (rapid planting increases the length of the growing season) and harvesting (tubers must be harvested before the floods and processed soon afterwards). This agricultural system is riskier than raised-field agriculture, because unexpected floods can inundate the fields, ruining the entire crop. As for raised-field cultivation, farming in *mitsaba* fields is essentially done by women but can involve the participation of men.

4 | WHY HAS FLOOD-RECESSION AGRICULTURE BEEN ADOPTED?

Previous studies conducted in the region do not describe the practice of flood-recession agriculture. For example, Sautter (1962) does not mention this agricultural system in Mossaka. Harms (1999), working in 1975–1976 with the Nunu people (a short distance [ca. 30 km] from Mossaka on the DRC side), also makes no mention of farming conducted on islands. We found no reference to flood-recession agriculture on islands in Miracle's (1967) book on agriculture in the Congo Basin. Based on our interviews, flood-recession agriculture on islands was adopted by the inhabitants of Mossaka in the early 1980s. As far back as local people can remember, the islands had not previously been cultivated with manioc:

> When I was born in Mossaka in 1965, my mother was not cultivating on the islands, no one was cultivating there. People were just cultivating *maanga* [raised fields]. (woman, 50–60 years)

Once adopted, flood-recession agriculture spread rapidly within Mossaka, and today, all islands around Mossaka are cultivated. Flood-recession agriculture is not restricted to Mossaka. Inspection of Google Earth images reveals that islands are farmed along the Congo River over a distance of 100 km, both upstream and downstream of Mossaka. Inogwabini and Lingopa (2013), who studied a stretch of the Congo River from 100 to 500 km upstream of Mossaka, concluded that 70% of the islands are cultivated, with field sizes ranging from 0.1 to 3 ha (mean 1.6 ha). Whether the inhabitants of Mossaka adopted this novel practice by diffusion from elsewhere in this reach of the river or by local innovation is unclear. Still, our study reveals that the adoption and spread of *mitsaba* agriculture in Mossaka were favoured by several non-mutually exclusive factors, which we consider in the following sections.

4.1 | A context of population growth, scarcity of manioc, and economic crisis

Population growth in Mossaka in the 1980s led to increased demand for manioc at a time when its supply from external sources was disrupted. Villages located on well-drained soils along the Alima River, which were previously the main exporters of manioc to Mossaka, began to send most of their production to Brazzaville. This was a response to increasing demand in this booming capital city. From 128,000 inhabitants in 1962, the population of Brazzaville exceeded 585,000 in 1984, and reached more than 1,373,000 inhabitants in 2007. Brazzaville accounts for more than 40% of the country's total population (Auger, 1972; CNSEE, 2007). Intensification of trade was facilitated by the paving in the 1980s of national road RN2, which connects the capital with the northern part of the country (Figure 2). Respondents consistently reported that in the 1970s and 1980s, manioc was scarce and expensive in Mossaka.

> People from the Alima did not sell manioc to Mossaka anymore. They sent it to Brazzaville […] At that time manioc was quite rare at Mossaka. When it came you had to be the first, it was a fight. (man, 40–50 years)

Not only did the price of food rise, but all household expenses (housing, school fees, health care, etc.) increased with urban development and increased integration into the market economy. Rising expenses and living costs posed even greater difficulties for Mossaka residents because fishing productivity per individual declined during this period (see Section 4.2).

More generally, the 1980s was a period of deep recession in the Republic of Congo, largely attributable to the fall in oil prices and decreased oil production (Massengo, 2004). This economic crisis led to the adoption, under pressure from the International Monetary Fund, of successive structural adjustment programmes, beginning in 1985, that included austerity measures (World Bank, 1987). The devaluation of the CFA franc in 1994 and civil war (1993–2002) both exacerbated the deteriorating and precarious living conditions.

The combined effects of decreasing external supply of the starchy staple manioc, the rising price of manioc and the increasing cost of living, as well as a decrease in fishing productivity, pushed many households to reduce their food expenses by producing more of their own food. Many households turned to flood-recession agriculture, a change that raises several questions: Why did people start to cultivate the islands, instead of, for example, intensifying raised-field agriculture? How and when did people first start to take an interest in the islands? What advantages could *mitsaba* agriculture offer that could compensate for its more constraining calendar and its greater flood risk? What factors made farming on the islands feasible and facilitated its widespread adoption? The remainder of the paper aims to answer these questions.

4.2 | Development of fishing activities on islands

According to people we interviewed, flood-recession agriculture emerged first as a side activity when people started spending more time in camps on islands for fishing activities. Up until the 1940s, fishing in the Congo River was limited by technology; fishing was essentially done in the floodplains. The introduction of cotton and nylon gillnets in the 1940s, the increasing market demand for freshwater fish owing to population growth (in Mossaka and in Brazzaville), and the increasing need for cash led to an upswing in river fishing and to the general intensification of fishing activity in the *cuvette centrale* (Comptour, 2017).

To the fishers from Mossaka were added migrant fishers from Brazzaville and around Mossaka. In the 1950s, the colonial administration estimated that 6,000 migrant fishers came every year, for a few weeks or months, to exploit the waters near Mossaka (Sautter, 1962). Migrants particularly favoured fishing in the Congo River, because, in contrast to floodplain fisheries, which are regulated and taxed by local lineages, the Congo River was (and remains) freely accessible (Comptour et al., 2016). Fishers, often accompanied by their families, settled in camps on the shores of islands. Sautter (1962, p. 68) wrote that “the islands in the Congo River are riddled with countless camps.” As a result of increased fishing pressure, fishers experienced a decrease in their daily catch and, in a vicious cycle, increased the time they devoted to fishing. Migrant fishers, as well as fishers from Mossaka, began to stay for longer periods in fishing camps:

> Now people stay longer in fishing camps than in the 1960s, because fish are rare now. Before, if you spent one month in the camp, you would already get a lot of fish. Now, to have the same quantity, you have to spend more time. (man, 50–60 years)

While men were actively fishing, women began to cultivate small gardens near the camps. Like the waters in the main river channel, land on the islands is traditionally accessible to all: whoever first occupies land on an island can become its owner. People planted crops that developed rapidly and could be harvested between two successive floods, such as maize (*Zea mays*), roselle (*Hibiscus sabdariffa*), sweet potato (*Ipomoea batatas*), and others. Manioc was also planted but only for consumption of its leaves. Prior to the 1980s, the prevailing consensus was that "between two floods, manioc does not have sufficient time to yield." Rather rapidly soon after, however, people began to harvest manioc tubers as well:

> Before, people said that manioc could not grow on the islands. Then people saw that even though its roots are small, if they planted enough, they could still get plenty of manioc. (woman, 40–50 years)

Gardens increased in size and manioc soon became the dominant crop in these fields. Today, people who cultivate fields on the islands do not always fish nearby.

4.3 | A hydrological regime shift decreasing the risk of flooding

Cultivation of manioc on the islands has accompanied the development of fishing activities in the Congo River, but was made possible by environmental change in the 1980s. The minor rainy season, which falls in the middle of the *mitsaba* growing season, is a particularly critical period (Figure 1). If the water level rises enough during this period to flood the islands, there is high risk of losing the entire crop. *Mitsaba* farming is also constrained by variation in the timing of arrival of the floods of the major rainy season. Our interviewees reported that yields are significantly affected if the floodwaters come a few weeks too early.

Despite recent advances in remote sensing and ongoing research monitoring the hydrology of the Congo River, this river still remains one of the least studied of the world's major rivers, especially with regard to long-term flood dynamics (Lee et al., 2011; O'Loughlin et al., 2013). The few studies of the Congo to date have drawn on annual mean flow data from Brazzaville and point to a relatively dry phase in the 1980s, but do not examine flows during each season (Laraque et al., 2001). Although the hydrological regime of the Congo River shows strong correspondence between Brazzaville and Mossaka, the Kasaï River, a major tributary, joins the Congo between these two urban centres, and differentiates the flood regime between the two centres.

To assess changes in flows at Mossaka, we used data on daily water levels taken at Mossaka station, which are available only for the periods 1952–1965 and 1982–2015. We performed several treatments on the raw dataset to clean and harmonise the data and to reconstitute missing values (see the Supporting Information S2). In our analysis, we identified key indicators of the water level at Mossaka at each of the four seasons. The indicators *Ha* and *Hc* correspond to the means of the lowest water levels recorded during the major and minor dry seasons, respectively. The indicators *Hb* and *Hd* correspond to the means of the highest water levels recorded during the major and minor rainy seasons, respectively (Figure 1).

Our results confirm the presence of a "dry" period in the 1980s at Mossaka, with lower water level indicators both during the dry (*Ha* and *Hc*) and rainy seasons (*Hb* and *Hd*) (Figure 4). Fluctuations in *Hd* are particularly pertinent for determining the risk of flooding and the feasibility of *mitsaba* agriculture. During the minor rainy season *ndzobolo*, flood levels were significantly lower after 1980 than before. Interestingly, in 2014, during our field study, the water level reached during *ndzobolo* was so high that it submerged the *mitsaba* fields, causing extensive crop loss on the islands. Losses were such that most farmers (59% of a total of 196 farmers we specifically interviewed on this question) did not plant their fields in the following year, either because they feared another crop loss, or for economic reasons (e.g., lack of cash to buy new manioc stem cuttings). Those who still decided to cultivate planted smaller areas. According to farmers, this was the first time since the beginning of *mitsaba* cultivation that the floods during *ndzobolo* had overtopped fields. Indeed, as Figure 4 shows, the water level *Hd* attained in 2014 (285 cm) was equalled or surpassed several times in the decade of the 1960s but was never attained during the entire period 1970–2013.

Lower flood levels since 1980 decreased the risk of flooding during the minor rainy season and thereby extended the growing season, giving the tubers of manioc more time to mature. To assess the length of the growing season between two floods, we determined the number of days when the water level remained below 280 cm, as when the level exceeds

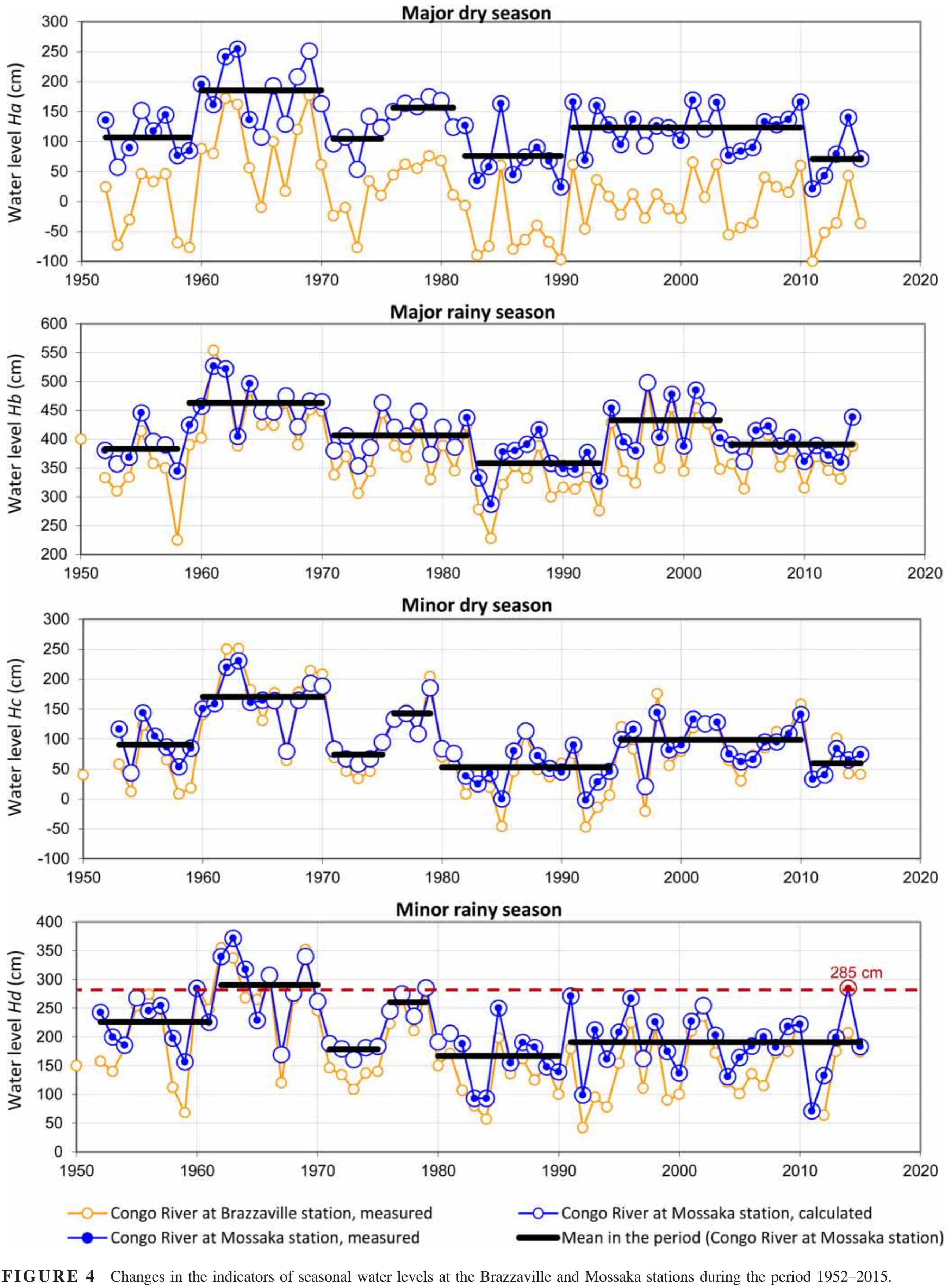

FIGURE 4 Changes in the indicators of seasonal water levels at the Brazzaville and Mossaka stations during the period 1952–2015.

285 cm, islands are inundated (as happened in 2014). We found that in the period 1982–2015, crops would have been able to grow on the islands during a mean of 268 days each year, whereas they had only 196 days to grow in the period 1955–1964. The 37% increase in the length of the growing season after 1980 is largely attributable to the absence of interruption by *ndzobolo* floods.

4.4 | Agronomic advantages

Flood-recession agriculture offers agronomic advantages compared with raised-field agriculture that may have encouraged its adoption. Whereas the floodplain near Mossaka is inundated primarily by rain water and by the "blackwater" Likouala-Mossaka River, characterised by strong acidity, high concentrations of dissolved organic matter and low concentrations of suspended sediment, the islands are flooded by the Congo River, a "clear-water river" with a somewhat higher concentration of sediments and lower acidity (Junk et al., 2011; Laraque & Olivry, 1996). The soils of islands are therefore expected to be more fertile than those of the floodplain where raised fields are built.

Analyses[2] of soil samples from the floodplain and islands show similarities in terms of low cation exchange capacity and low pH, but differences in at least three important respects (Table 1). Soils in the islands are lighter in texture, with less clay and silt, and more sand. The clay loam soils of the islands also have significantly higher levels of available phosphorus, which is vital to plant growth, than the clay soils of the floodplain. The C/N ratio in floodplain soils is significantly higher, indicating that their organic matter is more resistant to decomposition. All these properties make island soils more suitable for agriculture.

According to farmers, manioc grows much more rapidly on *mitsaba* fields on the islands than in raised fields in the floodplain where "manioc grows but after a delay," "it doesn't grow well." From this, we would expect that *mitsaba* fields offer higher yields than raised fields. However, our measures of yields of manioc in the two systems[3] show that raised fields support an annual (and fallow-corrected) yield of 15.2 tons per hectare compared with an annual yield of 7.3 tons per hectare for flood-recession fields. By comparison, the mean yield of sub-Saharan African countries is 9.9 tons per hectare (Fermont et al., 2009). Although our results should be viewed with caution given the small sample size, they are consistent with farmers' reports and our observations. Manioc grows slowly in raised fields, but the addition of grasses as green manure in raised fields to increase soil fertility (Comptour et al., 2018), and the possibility of leaving manioc in the ground for enough time to mature, result in high yields. By contrast, flood-recession fields allow rapid growth of manioc tubers but are inundated for at least three months of the year and tubers must be harvested before they reach full size. This explains why annual yields are actually lower.

Still, it is likely that *mitsaba* flood-recession agriculture is more productive than raised-field agriculture in terms of yield per unit time invested. Although we did not measure directly the labour input time needed to obtain the yields, farmers agreed that *mitsaba* farming is much less labour demanding. Whereas raised-field agriculture "is difficult" and requires considerable labour investment to construct and regularly maintain the mounds, *mitsaba* farming allows cultivation of larger areas with much less time and is "easy, even children can do that." This lower labour input may have greatly contributed

TABLE 1 Comparison of soil characteristics between floodplain and island samples taken in the Congo River Basin near the city of Mossaka in 2014

Soil measurement	Floodplain ($N = 15$)	Island ($N = 9$)	*t*-Test	
			t-Value	*p*-Value
Texture (%)				
Clay (<2 μm)	46.9 ± 2.6	39.1 ± 4.8	−1.56	0.134
Silt (2–50 μm)	36.7 ± 3.2	28.2 ± 2.5	−1.83	0.081
Sand (50–2,000 μm)	18.4 ± 3.9	32.7 ± 6.6	2.00	0.059
CEC (cmol+/kg)	9.5 ± 0.7	8.9 ± 0.9	−0.55	0.586
pH	4.0 ± 0.1	3.9 ± 0.1	−0.72	0.480
Available phosphorus (mg/kg)	0.011 ± 0.001	0.034 ± 0.004	6.28	**<0.001**
C/N	14.3 ± 0.5	12.2 ± 0.4	−2.75	**0.012**
Total organic matter (g/kg)	37.6 ± 4.2	34.2 ± 5.1	−0.51	0.615

Values represent means ± 1 *SE*. Results of *t*-tests assuming equal variances are shown. Two-tailed p values of $\alpha < 0.05$ are in bold.

to the rapid adoption of *mitsaba* farming. The possibility of rapidly obtaining tubers is also often mentioned by the farmers as a major advantage compared with raised-field agriculture.

The strong interest in *mitsaba* cultivation is concomitant with flagging interest in raised-field agriculture, which is not only labour-demanding but is losing importance because one of its main functions (storage of manioc) today confers a smaller advantage, owing to the ease of access to manioc in markets (Comptour et al., 2018).

4.5 | An agricultural system that particularly benefits women and newcomers

Flood-recession agriculture offers income opportunities, particularly for women. Flood-recession agriculture is extremely seasonal and much manioc is harvested in a short period (a few weeks) when the river rises. As manioc tubers are highly perishable (within two days once harvested), women transform them into more stable products. The two favoured products in Mossaka are *foufou* (manioc flour) and *kawa okanga* (manioc dough resulting from the retting and crushing of the tubers). Still, these two forms cannot be stored for more than a few months. One strategy for women is thus to sell (in Mossaka or Brazzaville) part of the *foufou* to earn additional income. Half of the 18 women interviewed on this topic had sold a part or all of the *foufou* they produced in 2013. Women, who had long been excluded from the cash economy and were dependent economically on men, find in *mitsaba* farming a way to earn income and increase their autonomy.

Mitsaba also benefited those people who had been excluded historically from holding floodplain land for farming. In the interior floodplain where raised-field agriculture is practised, land is traditionally owned and managed by several lineages whose ancestors settled in the area long ago (Comptour, 2017). Land on the islands, however, is available for claiming by the right of the first claimant, and newcomers were quick to see the opportunity to acquire land for flood-recession agriculture. Over time, both newcomers and people who had long lived in Mossaka (who have lineage territories in the floodplain) came to occupy large areas on the islands, sometimes on different islands. At times, the area claimed was not entirely cultivated because of a lack of labour. Today, most of the islands around Mossaka are claimed and the first farmers have divided the island lands among their heirs. Landowners also lend fields to farmers who do not have fields of their own, to secure their rights over areas that they have no time to cultivate.

4.6 | Availability of manioc landraces and labour

Cultivating fields on islands between two successive floods is not possible with slow-maturing landraces[4] of manioc; that is, landraces yielding tubers only after more than one year. It was made possible by the availability of landraces of manioc that yield tubers rapidly. During our study, we identified 30 named landraces of manioc grown in Mossaka. Among them, 20 were classified by the inhabitants as short-cycle landraces, which can be harvested after a minimum of six months and which begin to deteriorate after 12–18 months in the ground. Others are medium-cycle landraces (seven), which require at least one year of development and provide maximum yield after two years of cultivation; and long-cycle landraces (two), which require at least 1.5 years of development and can be left in the ground for up to five years. The development cycle of one landrace could not be determined. All landraces are planted in raised fields but in *mitsaba* fields, no long-cycle landraces are planted and short-cycle landraces are favoured compared with medium-cycle landraces. According to farmers, of the 20 short-cycle landraces grown today in Mossaka, 12 were present before 1980 (six of them were present before 1960) (Comptour, 2017). These landraces, which were (and still are today) planted on raised fields, have allowed people to start cultivating on islands.

The development of *mitsaba* agriculture in Mossaka was then encouraged by the proximity of the DRC and by the economic, demographic, and environmental differences between the two countries. *Mitsaba* farming requires being able to marshal quickly a large quantity of stem cuttings and a large extra labour force so that fields are planted rapidly after the floodwaters recede and the growing period is thereby extended. Today, both stem cuttings and labour are supplied mainly by inhabitants of the towns and villages located on the bank of the river opposite Mossaka, in Equateur Province of the DRC (see Figure 2). In this reach of the river, the river banks on the DRC side are higher and form vast expanses of high ground that can be farmed year-round. Farmers of Equateur Province have become the principal supplier of the stem cuttings planted in the *mitsaba*. The standard of living of people in Equateur Province is much lower and the population density much higher (21 inhabitants/km^2) than in the Département de la Cuvette in Republic of Congo (3.2 inhabitants/km^2) (CNSEE, 2007; Institut National de la Statistique [INS] & Programme des Nations Unies pour le Développement [PNUD], 2015). Inhabitants of Mossaka profit from this abundant and “cheap” labour source to enlarge their fields. The DRC farmers are paid piece-rate in cash or in manufactured products.

5 | DISCUSSION AND CONCLUSION

Our study shows how people can adapt to new environmental conditions, here a climate-induced change in the hydrological regime of the Congo River, by turning the change to their advantage. Far from being passive recipients of change, residents of Mossaka seized upon the opportunity afforded by lower flood levels during the minor rainy season, which effectively extended the growing season on the nearby islands in the river channel. Adaptive change in local livelihoods was not driven, however, by one factor (i.e., climate change) but by many intertwined drivers – environmental, social, demographic, economic – acting on local and national scales. Figure 5 summarises the main drivers. Our study also reveals the importance of considering the multiple activities that constitute the livelihood system to understand the process of adaptation. In the case examined here, the adoption and spread of flood-recession agriculture on the islands can only be fully understood when considered in relation to changes in fishing, markets, and trade.

Flood-recession agriculture in the *cuvette centrale* of the Congo River Basin is likely to face at least two important challenges in the future. First, most land near Mossaka is already occupied, leading to the question of how the system will adapt to increasing demand for agricultural land. Second, climate change projections suggest that the Congo River may soon enter a period of generally higher water levels. Climate variability, both among seasons and years, is projected to increase, with rainfall increasing more than evaporation, leading to greater runoff and flooding (Beyene et al., 2013). According to Aloysius and Saiers (2017, p. 4122), annual runoff in the equatorial region of the Congo Basin is projected to increase by up to 5% by 2035 and up to 6%–7% by 2065. Further, river-level increases are projected to be greater in the minor rainy season than in the major rainy season, increasing the risk of crop loss in the middle of the period of *mitsaba* cultivation. This raises the question of whether farmers will continue to cultivate the islands. Our preliminary finding that a large number of people gave up cultivating their fields after the 2014 flood tends to answer this question in the negative. It

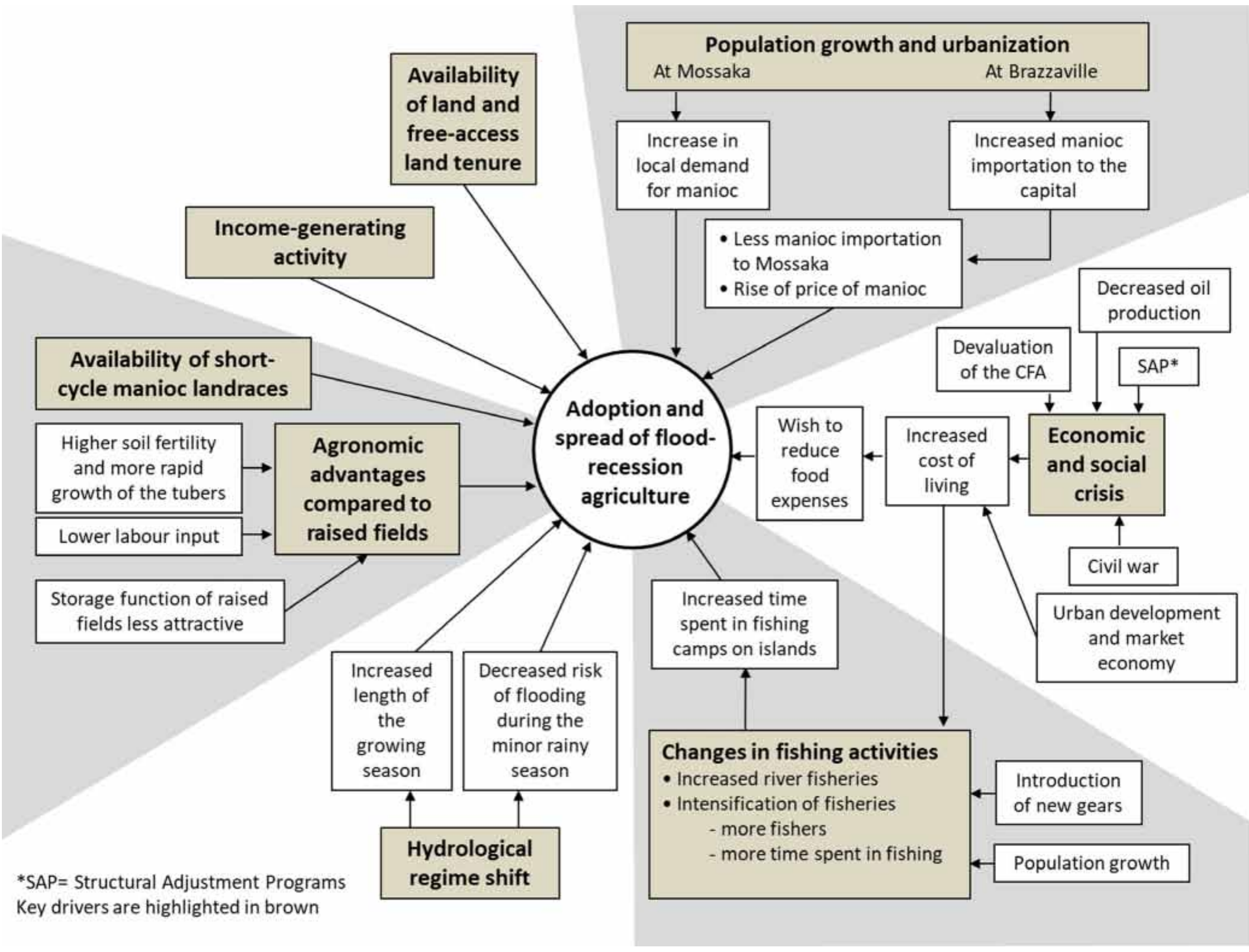

FIGURE 5 The adoption of flood-recession agriculture is due to many intertwined drivers.

is likely that people would stop cultivating islands if the risk of crop loss becomes too high. This would particularly harm women by the loss of income it represents, and newcomers, who lack other land to cultivate. Yet, the discourse following the 2014 flood revealed no desperation. People lost crops and investments, but all stated that they would rely on other activities (e.g., increase their time spent fishing, raised-field cultivation, or trading) and that they have a history without island cultivation. This again reflects the resilience of multi-activity livelihoods, which allow people to adopt or abandon activities when social-environmental conditions shift.

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ENDNOTES

[1] The Département de la Cuvette hosts a mean population density of 3.2 inhabitants/km^2, 2.9 inhabitants/km^2 if Mossaka is excluded (CNSEE, 2007).

[2] A detailed description of these analyses is provided in Supporting Information S3.

[3] We measured yields in 10 raised fields belonging to two farmers and in two flood-recession fields of two farmers. A description of the method used is provided in Supporting Information S4.

[4] The term “landrace” designates an entity that is named by farmers, who define them by a set of morphological, agronomic, or organoleptic criteria. The named landraces reflect farmers' knowledge and do not necessarily correspond to genetically defined entities. Description of the identification of landraces is provided in Supporting Information S5.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supporting information S1. Ethnoecological fieldwork: semi-structured interviews and participant observation.

Supporting information S2. Hydrological regime shift.

Supporting information S3. Collection and analysis of soil samples.

Supporting information S4. Measurements of yields of manioc.

Supporting information S5. Identification of landraces of manioc.

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