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Full Length Research Paper

Influence of Flooding Variation on Molapo Farming Field Size in the Okavango Delta, Botswana

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In the Okavango Delta of Botswana, flood recession farming (*molapo* farming) contributes substantially to rural livelihoods by providing better yields than rain-fed dry land farming. However, *molapo* farming communities experience challenges associated with the unpredictability and unreliability of flooding that are paradoxically part of the dynamism essential for the farming practice. This makes it difficult for farmers to decide on when to plough and plant. These challenges might have contributed to a reduction in the number of farmers practicing *molapo* farming. It is not clear if there is corresponding change in the spatial extent of the practice and if such a change may be related to variation in annual flood extent. We investigated the association between maximum inundated area and the size of *molapo* fields in three rural communities – Tubu, Shorobe and Xobe. Three time-steps representing different hydro-climatic phases (medium phase 1989-1991, dry phase 2000-2003, wet phase 2008-2011) constituted the study period. We used a geographic information system (GIS) and remote sensing approach to show flooding variability and changes in area under *molapo* farming over time under different flooding conditions in the Okavango Delta. *Molapo* fields were mapped using GIS and a global positioning system (GPS). The area under *molapo* farming for the time-steps 1989-1991 and 2000-2003 were calculated from aerial photographs. For the base time-step 2010, corners of the fenced fields were marked with a GPS receiver, from which polygons were generated. Using Landsat imagery we determined maximum flood extent by working with a combination of Tasseled Cap Analyses and spectral band thresholds to create wet-dry classifications. In each of the study sites, there was considerable variation over time in the location, size and distribution of *molapo* fields, as well as in the total area occupied. Importantly, the response was different for each of the three study sites. Shorobe showed the most dramatic decrease in the 2010/11 time-step, which represents a high water phase, while Tubu had a decrease in 2002/3 (low water phase) with strong resurgence in the area farmed in the subsequent high water phase (2010/11). Because Xobe's fields are restricted by steep banks there was less variation in area farmed, but otherwise this community's farming patterns appear to reflect those of Shorobe. The main reason for the decrease in hectarage in Shorobe and Xobe during the high flood phase is that much of the potential farming areas remained inundated for the entire farming season due to heavy and extended floods. Thus, the decline in *molapo* farming in the short term may in fact be attributed to the changing hydrology of the Delta.

Keywords: flood recession farming, geographic information system, hydro-climatic factors, Okavango Delta, remote sensing

INTRODUCTION

The climate of the Okavango Delta makes flood recession farming much more lucrative than dry land farming because rainfall in the area is relatively low (an annual average of 500 mm) in addition, the distribution of annual rainfall across the season is erratic, making it hard for farmers in the surrounding dry land savannah areas to decide whether or not to plant (Oosterbaan, Kortenhorst, and Sprey, 1986). There is frequently not enough moisture from rainfall to last the whole cropping season, and the sandy soils are generally low in nutrients. These factors make it difficult to attain high crop yields through dry land agriculture. In the Okavango Delta, however, there are exceptionally good soils due to annual deposition of alluviums. The higher levels of soil nutrients, combined with flood-induced higher soil-moisture, make higher crop yields possible with minimal use of expensive inputs.

Maize is the main crop grown in *molapo* farms however other crops such as water melons, sorghum and beans are planted in *molapo* farms (Bendsen, 2002). Although still somewhat low, yields from *molapo* farms are much more than those obtained from rain fed farms. On average 1800 kg ha^{-1} to 2900 kg ha^{-1} of sorghum are obtainable from *molapo* farms compared to 500 kg ha^{-1} of sorghum from rain fed farms (Arntzen, 2005; Bendsen, 2002). *Molapo* farm yields support household subsistence particularly in years with low rainfall, when rain fed agriculture cannot be practiced (Saarnak, 2003).

Despite the importance of flood recession farming to these communities, this farming system is faced with many challenges, such as lack of draught power, shortage of labour and unfavourable policy environment. Hydrological conditions also pose a challenge in particular flooding variability, which is the most important factor in determining the extent to which *molapo* farming is practiced. The duration of flooding is as variable as each flood (see

Figure 1), and while there is a broad range of flooding conditions that the *molapo* farming practice can tolerate, too little water leaves the fields too dry to grow crops, while too much can leave the fields inundated for the entire growing season. A reduction in the use of *molapo* areas reduces the potential of food production by communities living around the Delta (Magole and Kebonyemodisa, 2005)

Recent studies (Kgathi, Mmopelwa, and Mosepele, 2005) showed that the proportion of households practicing molapo farming in Ngamiland were 27% and 16% for 1997 and 1998 respectively suggesting a decline in the farming practice. These studies used socio-economic indicators and secondary data sources such as the Arable land surveys carried out by the ministry of Agriculture. The study suggested abandonment due to a desiccation trend.

More recent research now show that in fact the Okavango river system cycles through long-term wet and dry phases (Mazvimavi and Wolski, 2006). This has been borne out by the recent return to a high water phase (See

Figure 1 below). We therefore seek to understand the relationship between these different flood phases and extent and distribution of *molapo* fields in space and time. We seek to explore whether in fact farmers are responding to these broader changes in flooding conditions, and whether the perceived abandonment was in fact only temporary. Understanding the flooding dynamics and how they affect the farming system will enable communities to be better prepared for future scenarios. The aim of this paper is to investigate the association between maximum inundated area, and the total hectarage of *molapo* fields in each of 3 time-steps representing the different hydro-climatic phases (medium phase1989-1991, dry phase 2000-2003, and wet phase 2008-2011) in three different parts of the Okavango floodplain system.

Study Area

The Okavango Delta is located in the distal end of the Okavango River basin which is shared by Angola, Namibia and Botswana (

Figure 3 below). The natural resource base of the savannas surrounding the Okavango Delta is limited in both range and quantity due to low rainfall. In contrast, the wetlands of the Okavango Delta are resource rich.

The inland Okavango Delta is fed by the Okavango River, which originates from Angola, and enters the delta at its apex. Climate in Angola is subtropical and humid. Its annual precipitation is about 1 300mm (Milzow, Kgotlhang, Bauer-Gottwein, Meier, and Kinzelbach, 2009). The flood waters from Angola accounts for two thirds of flooding in the Okavango Delta. The river carries about 10 000 million m^3 of water a year into the Delta. This large amount of water is absorbed in permanent and seasonal swamps before it slowly infiltrates and evaporates. The seasonal swamps are the *molapo* cultivation areas (Oosterbaan, et al., 1986). Depending on the floods, this inundation may last 2-4 months, or more.

Due to the large distance from the source area (

Figure 3), the annual flood wave arrives in Botswana two months after the onset of the rainy season in Angola. The area covered by water expands from its annual low of 2500-4000 km^2 in February-March to its annual high of 6000-12000 km^2 in August-September (J. G. McCarthy, 2004). The Okavango Delta is subject to inundation of varying magnitude, seasonality and inter-annual variability (

Figure 1 below). Because natural resources are scarce elsewhere, settlements are clustered around the fringes of the Delta (figure 2 below).

Tubu, Shorobe and Xobe villages were selected for the study because *molapo* farming is one of the key livelihoods for the resident communities along side other livelihood activities such as cattle rearing, fishing and collecting of veld products. Tubu is found on the western

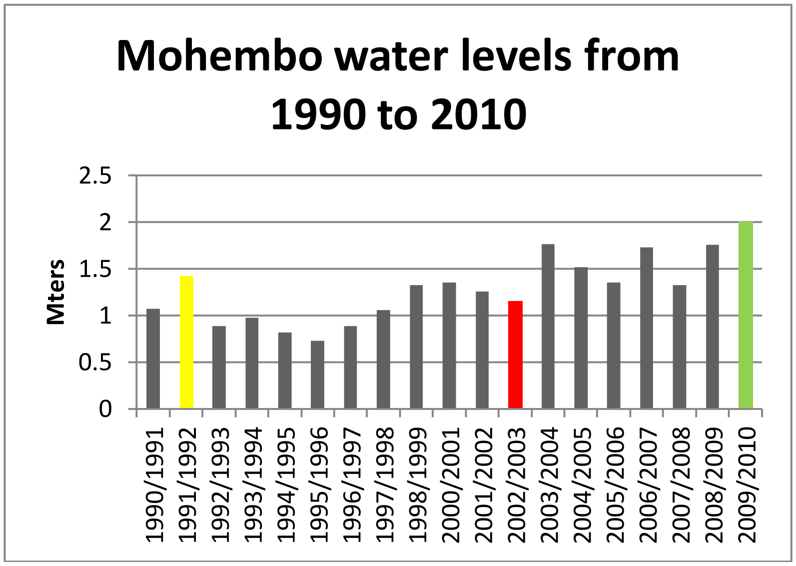

Figure 1: Mohembo water levels from 1990 to 2010, the highlighted bars represents the selected study years representing different flood levels.

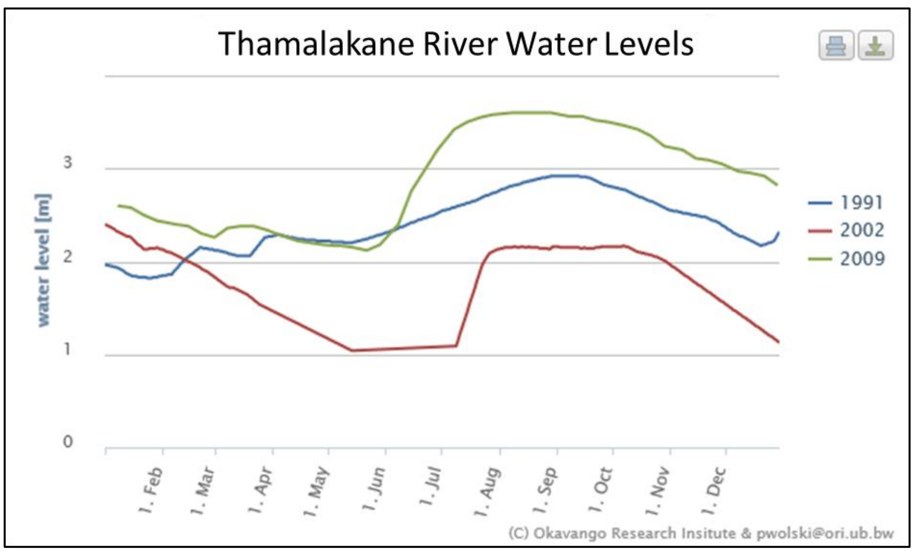

Figure 2: A graph showing water levels for the Thamalakane River which shows the variation between medium, low and high flood phases.

part representing the upper catchment part of the Delta, Shorobe and Xobe found on the eastern and south eastern part of the Delta respectively, representing the lower catchment of the Delta (
Figure 3 **below**).

Tubu is located on the western end of the Okavango Delta. The administrative boundary of Tubu is 945 km^2 in size. Flooding in Tubu begins in mid-April and the maximum inundation is reached by end of May. Normally by end of June up to mid-August the flood starts receding allowing farmers to start ploughing and planting. *Molapo* fields found in Tubu are channel type which means they are located on floodplain along main channels a pattern referred to as the channel type of *molapo* farming. Such are cultivated as soon as the flood waters start to recede. However some fields in Tubu get moisture from the rising water table (Bendsen, 2002). During the 2011 census Tubu had a population of 626 people.

Shorobe is located on the eastern end of the Okavango Delta; its administrative boundary is 1078 km^2 in area. Normally the area experiences the peak flood between August and September and by end of October the flood begins to recede. However in 2010 the flood waters started receding at the end of November resulting

Table 1: A summary table showing seasonal calendar developed by participants during Participatory Rural Appraisal workshop in the study villages in 26th-30th April, 2010.

Activity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Floods			→	→	→	→	→	→				
Land preparation						→	→	→				
Ploughing	→	→						→	→	→	→	→
Weeding	→	→							→	→	→	→
Harvesting	→	→	→	→	→							→
Grass/reeds harvesting							→	→				
Fishing							→	→	→			
Veld products	→	→	→	→	→	→	→	→	→	→	→	→
livestock	→	→	→	→	→	→	→	→	→	→	→	→

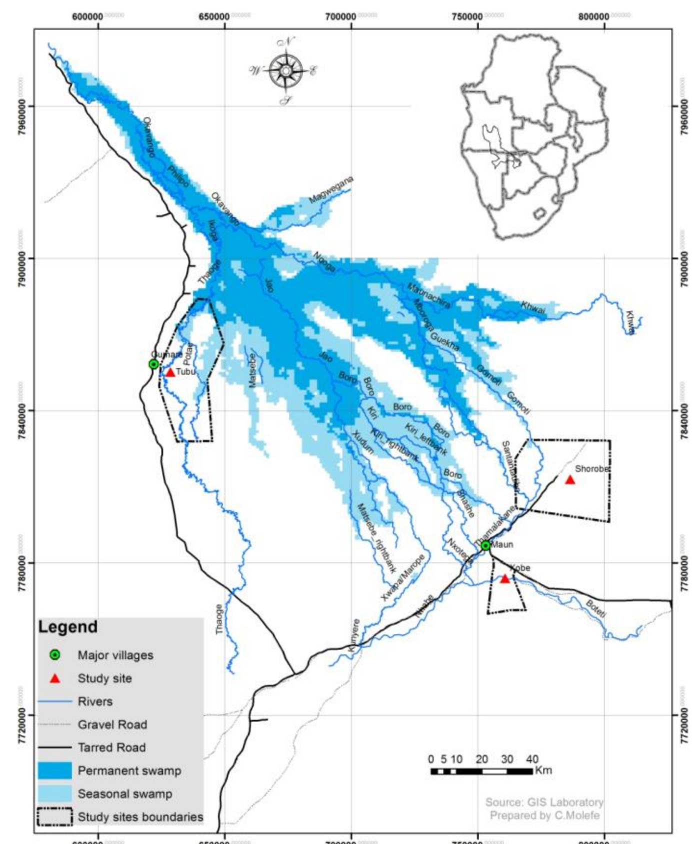

Figure 3: A Map showing the location of the Okavango Delta within the African context and the location of study sites within the Okavango Delta.

in most of the floodplain areas remaining inundated until the arrival of the 2011 floods. The *molapo* farms in Shorobe are mainly found in islands with dense riparian woodlands and their pattern is referred to as saucer-

Table 2: Total flooded area in hectares (ha) for imagery representing each of the different time-steps of interest.

Flood Phase	Year	Shorobe	Xobe	Tubu
Medium	198 9 (1 year prior to field map date)	2650.77	197.28	38974.6
Dry	2000/01 (1 year prior to field map date)	324.27	179.1	37772.6
Wet	2008*	3304.62	160.38	33142.9

* 2008 is used to represent 2010/1 because Landsat TM 5 imagery for September after that date is not available; however the flooding levels are similar enough to those years to be representative.

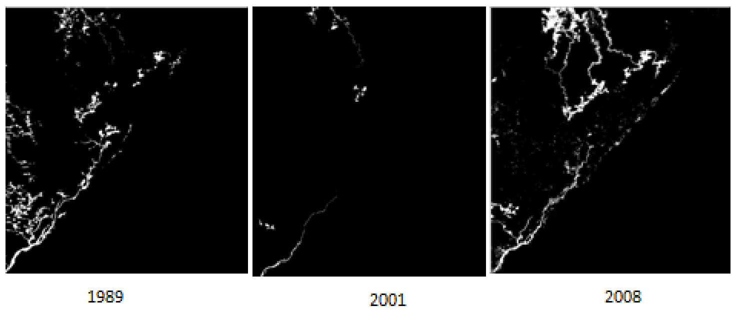

Figure 4: Flood maps of Shorobe showing the flood situation of the different time-steps

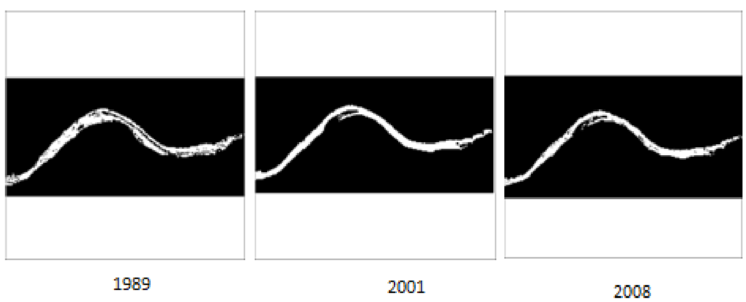

Figure 5: Flood maps of Xobe showing the flood situation of the different time-steps.

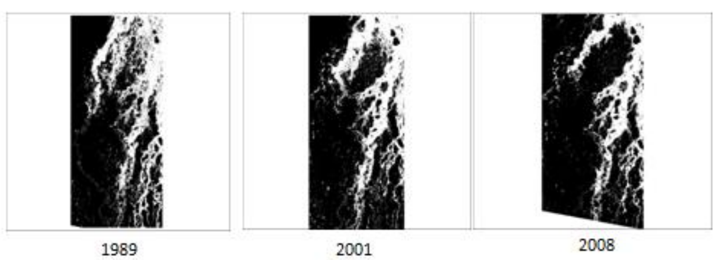

Figure 6: Flood maps of Tubu showing the flood situation of the different time-steps.

shaped because the obtain moisture from spill over or back flow water from the main river channels(Bendsen, 2002). Shorobe had a population of 2 822 people during the 2011 census (CSO, 2012)

Xobe is a small village, its administrative boundary being 204 km^2. It is located along the Boteti channel on the south eastern end of the Okavango Delta. Flood water start building end of August reaching a peak at the end of September. Normally receding of the flood begins in November, hence *molapo* farmers start cultivating their fields with the receding floods. *Molapo* fields found in Xobe can be characterised as channel type since they are located on steep banks along the Boteti channel (Bendsen, 2002).These fields are planted as the flood

Table 3: Total area in hectares (ha) occupied by *molapo* farms in each study village at each time-step

	Shorobe	Tubu	Xobe
1990/91(medium)	825.976	292.327	71.62
2002/3 (dry)	840.03	199.78	56.88
2010/11 (wet)	183.11	464.08	34.47

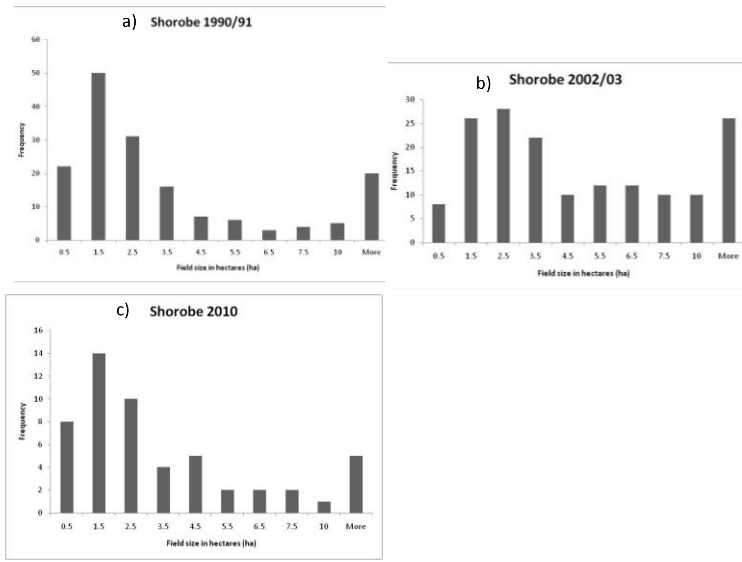

Figure 7: Histograms showing the distribution of farm sizes in Shorobe for 1990/91, 2002/03 and 2010.

waters recedes, utilising the moisture left behind by the floods.

All three villages fall on communal land. Molapo farming, as a traditional practice, has until recently been governed by customary law, with the village headman allocating use rights to village members. However, in recent years there has been a push to formalize land grants through a district-level Land Board, which is problematic since this fixes the geographic location of fields (Motsumi, Magole, and Kgathi, 2012).

Similar seasonal calendars are followed in all three villages. Although **Error! Reference source not found.** above shows the calendar year, the seasonal year typically starts in winter. The first task is to prepare the land, clearing it of bushes and fencing it then the field is ploughed and planted (table 1 above).

METHODS

To determine temporal changes in spatial extent of *molapo* farming in the context of hydro-climatic changes, we selected three time steps representing different hydro-periods: 1990/1991 represented an average flood condition, 2002/03 represented a dry phase period and 2010/11 represented a wet phase period, based on total inflow at Mohembo (Figure 1 above). Measurements of the potential area for cultivation were obtained using GIS and a global positioning system (GPS) receiver during the planting season of July 2010-February 2011. Potential area for cultivation was defined as all area fenced for purposes of *molapo* farming. Aerial photographs were obtained from the Okavango Delta Information Systems hosted by the GIS lab at the Okavango Research Institute.

GPS points of 2010/11 were plotted in ArcGIS and polygons were then created using data management tool and the area for each farm was calculated using spatial statistics. A comparison of the Xobe GPS farm data with 2009 Google Earth Imagery confirmed that measuring fields with a GPS on the field and digitizing on screen gave comparable results. The potential *molapo* cultivation area for the time-steps 1990/91 and 2002/03 were calculated from aerial photographs. The digitized *molapo* farms for each year were converted into shape files as well as raster. The shape files were overlaid for the two time steps to see how farm location and size had changed

Participatory rural appraisals (PRA) workshops were done in each village. During the PRA workshop communities assisted in establishing broader boundaries for their villages.

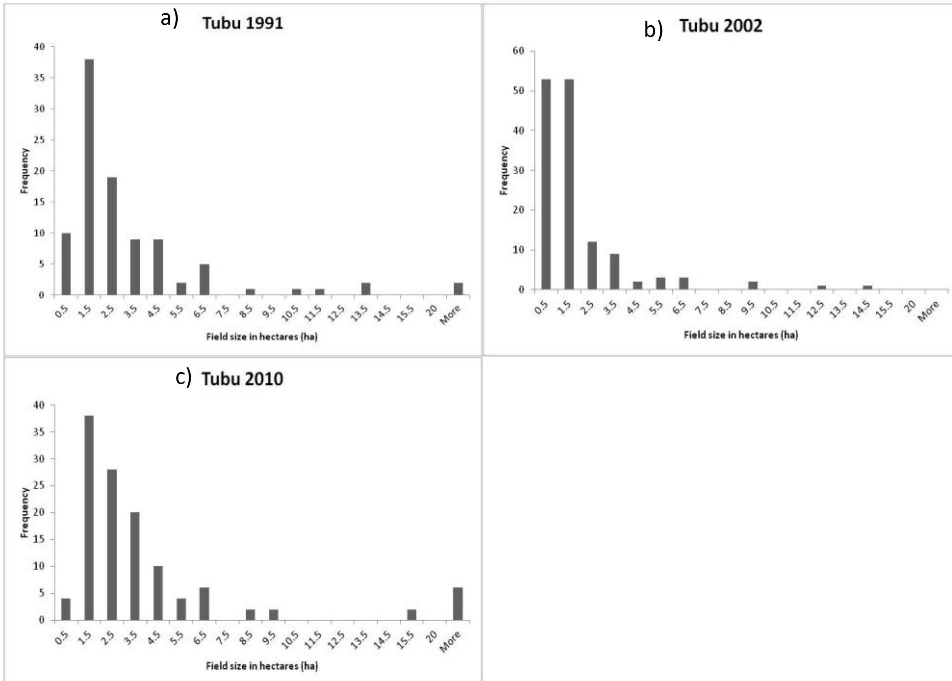

Figure 8: Histograms showing the distribution of farm sizes in Tubu for 1991, 2002/03 and 2010

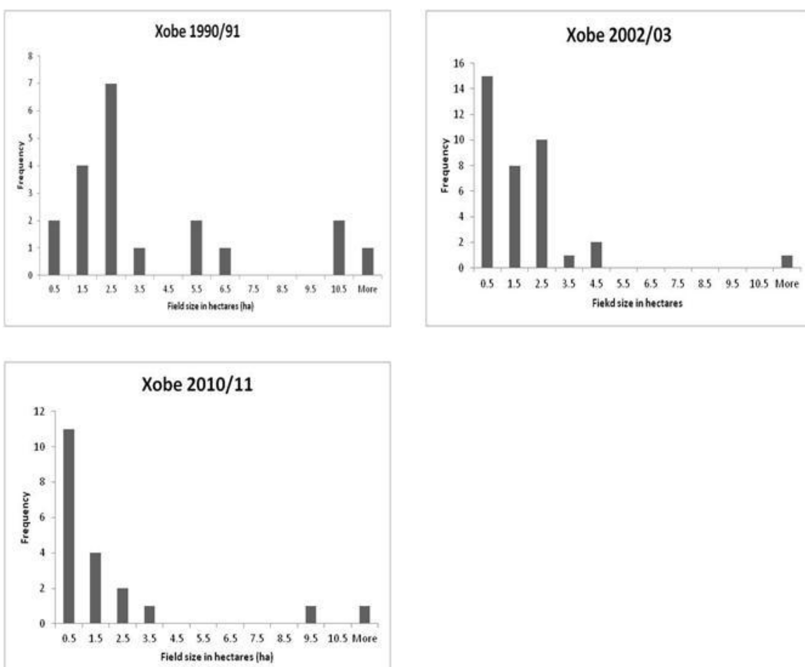

Figure 9: Histograms showing the distribution of farm sizes in Xobe for 1990/91, 2002/03 and 2010/11.

We used Landsat images to determine maximum flood extent. For Tubu village, 3 Landsat scenes (p175r073) were acquired for 1989/08/26, 2001/09/04 and 2008/08/30. Shorobe and Xobe fall on the same scene (p174r074) and dates acquired were 1989/09/04, 2001/10/15 and 2008/09/24. These images capture the year before the mapped fields because fields are ploughed depending on the previous year flood extent. Unfortunately, at the time of this study, Landsat imagery for 2009 dry season was not available, so only 2008

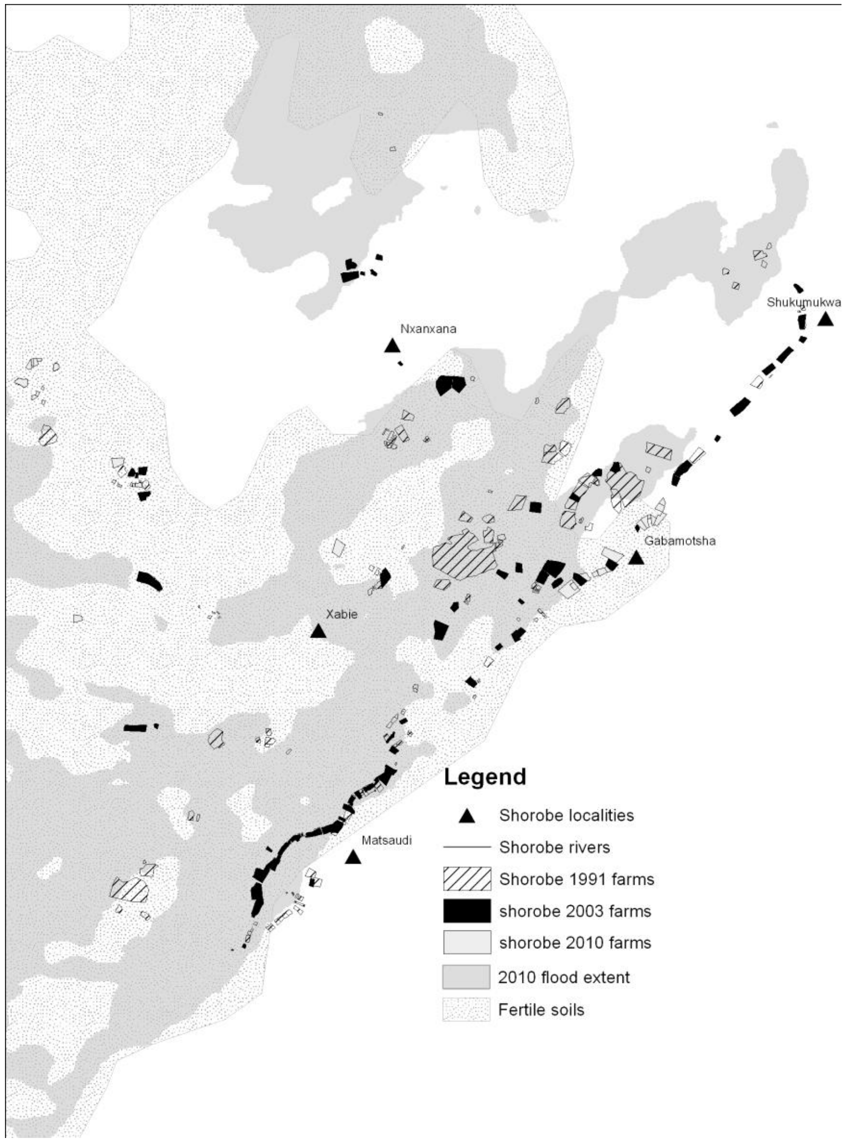

Figure 10: Shorobe *molapo* farms at the three time-steps of 1991, 2002/03 and 2010/11 ploughing seasons, shown against the 2010 peak flood extent combined with FAO fertile soil data.

was used.

Imagery was selected for dates closest to the maximum flood event in all the years for each study site. These images were subjected to radiometric and atmospheric calibration (G. Green, Schweik, and Hanson, 2000; G. M. Green, Schweik, and Randolph, 2005; Teillet and Fedosejeus, 1995).Radiometric and atmospheric calibrations for the visible bands allows features of an image to be linked to a particular land cover by converting digital number to the surface reflectance associated with a particular land cover. The images were then geometrically corrected using image to image rectification and sub-set to the three areas of interest.

We followed the approach of Wolski and Murray-Hudson (2006), combining tasseled cap analyses and spectral band thresholding to derive the flood map classifications for each study site, and then calculated the area flooded at each time-step. Firstly a tasseled cap analysis was done for each image. Tassels cap analysis, through a weighted computation, scales down the six bands of Landsat images to three bands representing: brightness, a measure of soil; greenness, a measure of vegetation and wetness, showing the interrelationship of soil moisture and canopy moisture (Jensen, 2005). The tasseled cap technique sums together the visible, near infrared bands and longer infrared bands so as to come up the degree of moisture held by vegetation or soil. After running tasseled cap analyses on all images, thresholding of band 5 and 2 ratio were done for all images. Band ratio-ing is a process that divides brightness pixels of one band by brightness pixels of

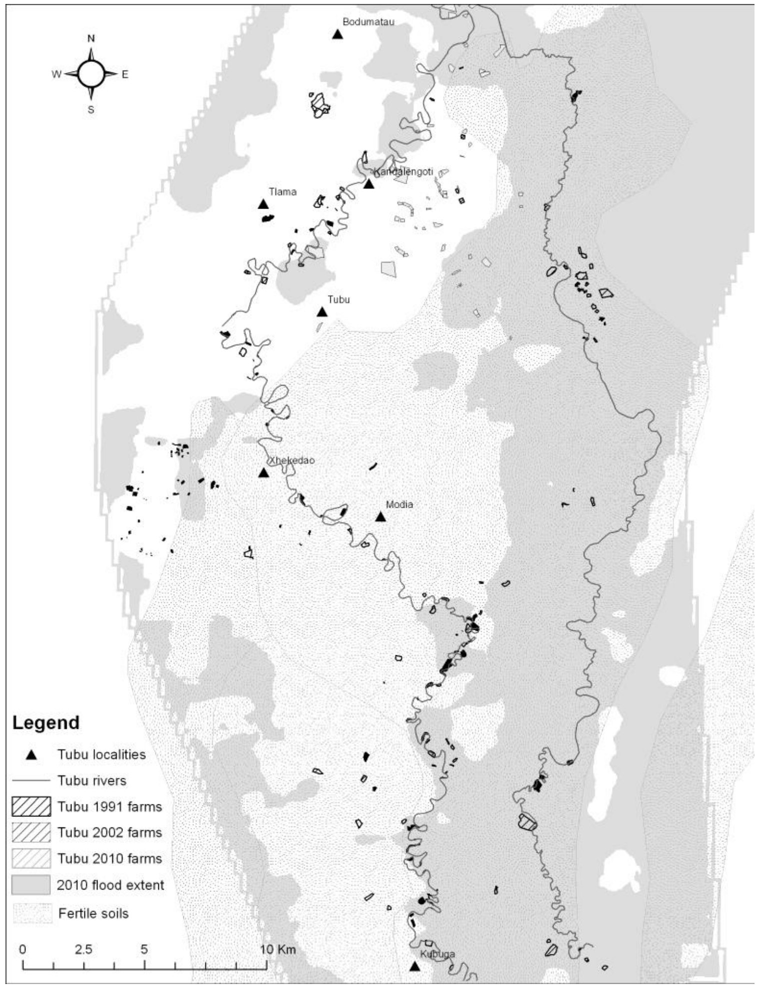

Figure 11: Tubu *molapo* farms at the three time-steps of 1991, 2002/03 and 2010/11 ploughing seasons, shown against the 2010 peak flood extent combined with FAO fertile soil data.

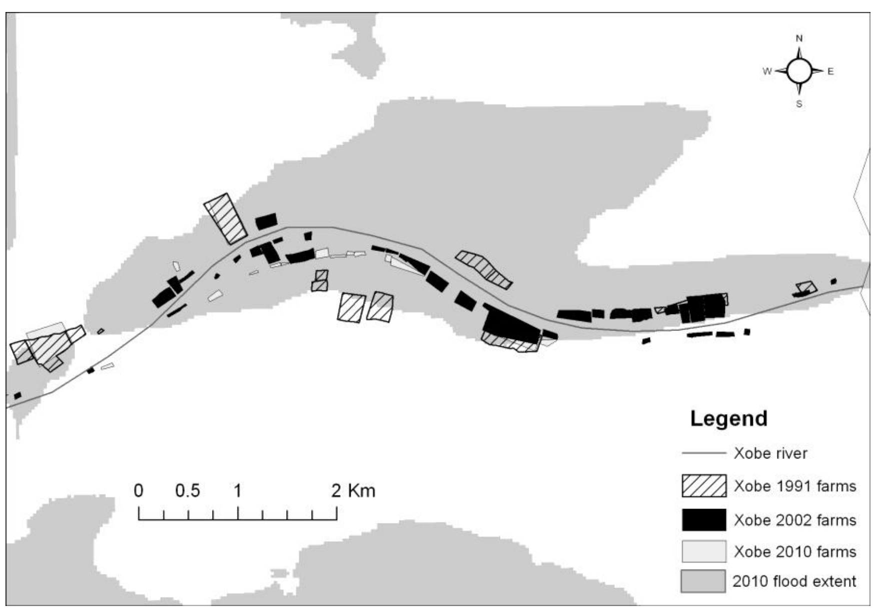

Figure 12: Xobe *molapo* farms at the three time-steps of 1991, 2002/03 and 2010/11 ploughing seasons, shown against the 2010 peak flood extent. Soil data for Xobe within the river channel is not available.

another band. Band 5 (1.55 – 1.75 um) is sensitive to the amount of water in plants. It can be used to separate between forests and plants while Band 2 (0.52- 0.60 um) is sensitive to vegetation reflectance as it cover the green reflectance peak from leaf surfaces, it also sensitive to turbidity in water bodies. The output from the ratio enabled us to distinguish vegetation reflectance from that of water bodies. Thresholding of Band 6 was done so as to mask out wet areas versus dry areas. Band 6 (10.40 – 12.50 um) is more sensitive to surface temperature of the earth's surface at that point in time. The distribution of the pixels in Band 6 seemed to suggest that areas below 25 deg C were wet areas and those above were dry so the following formulae was used to set the threshold: *EITHER 1 IF*

($n1_p174r074_19890904_tm5_calib_vir_thr_georec < 25) OR 2 OTHERWISE

RESULTS

The change in extent and distribution of floodwaters varied considerably at each site, and each site showed different responses at the three time-steps. The extent of the flooded floodplains for each study site is given in Table 2 above. There was a dramatic increase in Shorobe during the wet phase, a little decrease in Tubu during the dry flood phase and a slight increase in the high flood phase, and only some increase in Xobe during the recent return to high flood levels.

Above are maps showing flood variability of each study site for each study year (figure 4-6 above).

Furthermore, results show that in Tubu, hectarage of fields was lowest during the dry flood phase with a slight increase during the average flood phase. During the high flood phase hectarage of *molapo* fields in Tubu increased dramatically. For Xobe, the hectarage was higher in the average flood phase with a continuation of decrease through to the dry flood phase and the high flood phase. In Shorobe there was an inverse correlation between hectarage of *molapo* fields and flooding, with an increase of hectarage during the dry phase, a slight decrease during the average phase and a dramatic decrease during the wet phase (table 3, figure 7 above).

In Tubu, although farm sizes have increased, the general distribution of farm size in any one year was similar to that of Shorobe, with several small farms dominating the landscape, and only one or two large farms (

Figure **8** above).

The difference in Xobe is smaller with 71.6 hectares in 1990/91, 56.9 hectares in 2002 and 34.5 hectares in 2010. Xobe also seems to be dominated by small farms with only a few large farms. However the distribution seems to be decreasing over time (Figure 9 above).

Not only has the spatial extent of farms changed between the three time steps, but so has the distribution and location of the farms. In Shorobe, only 7 farms were located in the same places in 2010/11 as they were in 2002/3 (

Figure 10 above). Farms that were directly in the riverbed in 2002/3 no longer existed. Instead, in 2010/11, the majority of farms were located further to the northeast, and closer to the villages.

In Tubu, the change in distribution was much more than in Shorobe (

Figure 11 above). The farms from further down the floodplains to the north. Unlike Shorobe and Xobe, Tubu has extensive floodplains, but lacking major channels such as the Thamalakane (Shorobe) and Boteti (Xobe).

In Xobe, while farms shifted location, they were still in the same general area and distance from the main river channel (

Figure 12 above).

The relationship between flooded area and potential area for *molapo* farms was determined by running correlations. Results showed that there is a strong negative relationship between flooded area and *molapo* farming hectarage in Tubu, at -0.845. In Xobe there is a positive relationship between *molapo* farm extent and flooding at 0.99. That is to say in Xobe as the floods increase the farming hectarage also increases. However in Shorobe there is an inverse correlation, with *molapo* fields decreasing in the high flood phase and increasing in the low flood phase, with the coefficient showed that there is a very strong negative correlation (-0.683).

DISCUSSIONS

Flooding of the Okavango Delta is cyclical (Mazvimavi and Wolski 2006; McCarthy *et al*, 2000). This translates to the extent of inundation in the various floodplains. Each site showed different responses in flooding at the three time-steps. In 1989 the flood extent in Shorobe was 2650.77 ha and between 1990 and 2002 it reduced to of 324.27 ha. The dry spell was followed by a wet spell that reached its peak in 2008 (3304.62 ha). The variation of flood extent in Xobe was less dramatic than that of Shorobe because of its channel nature. Xobe's flood extent seems to have been slightly declining over time, in 1989 it was 197.28 ha with 179.1 ha for 2001 and 160.38 ha in our high flood phase. The flood situation of Tubu is also minimal as that of Xobe over the selected study years. This is due to the fact that Tubu is located in the upper Delta where floods inundate most parts of the floodplains regardless of the flood situation of any particular year. However farmers respond to the more localised changes in the flood distribution. These

The fluctuations in water level associated with these cycles is the source of good farming conditions; during participatory rural appraisal workshops held by the Botswana Eco-Health Project, communities reported that they see the floods as bringing life to them other that being a threat to their wellbeing as often perceived. However, since flood recession farming entirely depends on the flood regime, the inter-annual variability means that in any given year, a field may be too dry or too wet. It is evident from the results that farmers respond to the flood of the previous year. For example in Shorobe, the 1991 fields were dependent upon the 1990 floods as the floods had decreased from the year prior and less fields were inundated. In the 2008 to 2010 floods most fields were submerged and hence there was less hectarage in *molapo* fields. There was a dramatic decrease of fields in that village. This showed that farmers were not fully prepared for the high floods as there were less new fenced fields compared to Tubu village.

The 2008 imagery did not reflect the high flood extent that occurred in 2009 (

Figure 1) adequately for Tubu, which is why we get a negative relationship from the correlation coefficient. The 2010 fields in Tubu increased as a result on the higher flood extent in 2009 (

Figure 1). For Shorobe the relationship between flooded area and molapo farms is inverse, that is to say, as the flood waters increase there is a decrease in the potential farming area, whilst in Xobe as the floods increase potential farmed area increases as well.

The potential area for *Molapo* cultivation has fluctuated over time in response to the variation in flooding of the Okavango Delta. This trend seems to contradict the reported decline in percentages of farmers practicing *molapo* farming over time at 27% and 16% for 1997 and 1998 respectively. Our study shows that the same area is being farmed over the long-term suggesting that abandonment has less to do with desiccation, but with variation in flooding. The Okavango Delta is also known for unstable river channels (T. S. McCarthy, Ellery, Ellery, and Rogers, 1987). The Thaoge River that feeds into Tubu began to block in the mid nineteenth century. Blockages of the Thaoge River led to a shift of flood water, making the Nqoga River on the far eastern a major distributor. However the Nqoga inevitable started blocking and water started shifting to the Jao/Boro channels (T. S. McCarthy, et al., 1987). These shifts in flooding may cause farmers to temporarily abandon their fields.

CONCLUSIONS

While our findings do not address the observed decline in number of farmers engaged in *molapo* farming (Kgathi, et al., 2005), they do suggest that the spatial extent and number of fields is not declining. Instead, they suggest that farmers are simply responding to local conditions – farming when it is appropriate, and not doing so when conditions are unfavourable. As noted earlier, the *molapo* farming in each area is different. In Tubu and Xobe, fields are primarily located adjacent to the river channels, so farmers wait for waters recede before starting to plough. However, the *molapo* fields in Shorobe are mainly found on the islands, and any excessive flood spills over and inundates the potential farming areas, which is why we have an increase of fields during the low flood phase. This is why it is difficult to infer a single response for the entire Delta. Instead, it is clear that each area responds differently depending in part on the type of *molapo* fields that exist, and in part to the different flooding conditions each area experiences. This shows that *molapo* farming in the Okavango Delta is highly variable, due to the dynamic hydrological regime within which it is practiced.

In order for farmers to maximize their benefits from *molapo* farming, they need to be able to adopt flexible and adaptable responses to variable flood conditions. Primarily, this means that they need to have access to farm land across a broad range of hydrological conditions. Consequently, support to the farming system needs to be flexible enough to respond to different flooding conditions. The Delta's rural economy requires a dynamic integrated policy support system. For example, agencies handling land allocations need to collaborate with those dealing with water and crop production. The policies themselves must be flexible if they are to support and accommodate adaptive responses. While elsewhere (such as the dry land farming areas) fixed location property rights may be preferable, in the floodplains, local-level management targeted according to geographical location and flood situation of field locations could help farmers maximize their yields. In addition, it is important to understand the multiple livelihoods activities that farmers undertake concurrently or exclusively, depending not only on the season but also on the flood regime. Further research into the overarching livelihood system, and not just the farming practices, would reveal how best to incorporate dynamic conditions and allow farmers to adapt and remain resilient to hydro-climate variability.

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