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Fishing and Farming at Lake Chad: Responses to Lake-level Fluctuations

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Lake Chad lies at the southern extreme of the Sahara Desert and is well known for large fluctuations in its surface area this century. Seasonal fluctuations, however, have received much less attention. This paper presents the results of two complimentary research efforts on the south-west shore of the lake. These illustrate how important both inter and intra-annual fluctuations in the level of the lake are, both in terms of their impact on the environment and in the response of the communities living on the lake shore. The paper compares a time series of the fluctuations in the level of Lake Chad as monitored by the TOPEX/POSEIDON satellite with findings from participatory research with the communities of the south-west lake shore. It shows how the communities of the lake have responded to lake-level fluctuations with their livelihood choices. These results are used to show that although vastly different in scope, a high degree of complimentarity exists between remotely-sensed information and community-based research and that they are of potentially great value to development initiatives on the shores of Lake Chad.

KEY WORDS: Africa, Lake Chad, lake-level fluctuations, remote sensing, participatory research, agricultural development, rural development, flood warnings

The fluctuations of Lake Chad have concerned European geographers since the beginning of the twentieth century, notably the French geographer, Tilho whose expeditions to the lake basin from 1910–14 caused him to speculate that the lake was in the process of permanent contraction (Tilho, 1910; 1928). Despite contraction and expansion throughout the twentieth century, since 1973 the lake has diminished considerably (Thambyapillay, 1983; Lemoalle, 1991). This paper concerns how the villagers making a living on the south-west shore have responded to fluctuations in the level of the lake. The application of two relatively novel research techniques i.e. community-based research and radar altimetry, on this shore during the 1990s has enabled a detailed understanding of how these residents have responded to fluctuations in the level of the lake. Their responses have been examined within a sustainable rural livelihoods (SRL) framework which considers the range of natural and social, macro and micro-level factors which determine the vulnerability of the poor (Scoones, 1998; Carney, 1998; Sarch, 1999).

> A sustainable livelihood is one that can cope with stress and shocks and displays resilience when faced with adverse events
> Ellis, 2000: 137

The SRL framework has been designed to enhance understanding of how sustainable livelihoods may be achieved through development initiatives which aim for more than simply increasing incomes.

Background

The Lake Chad basin covers a large part of central Africa (see Fig. 1). The lake itself lies at the south-east extreme of the Sahara Desert and traverses the Saharan, Sahel and Sudan-Savanna agro-climatic zones. Since 1932, annual rainfall across the lake has varied from 565 millimetres in 1954 to only 94 millimetres in 1984 (Olivry *et al.*, 1996). Local rainfall, however, has little impact on the volume of the lake as rivers represent almost all of its inflow. The lake's catchment area extends into the humid zones further south where mean annual rainfall reaches 1600 millimetres. The Chari/Logone river system,

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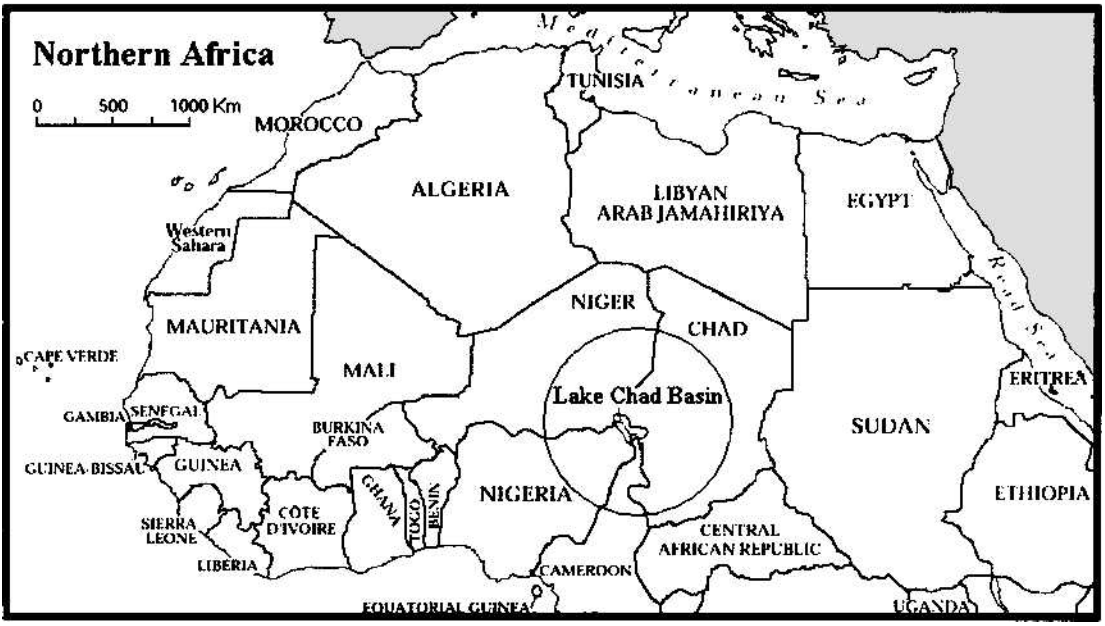

Figure 1 Location of the Lake Chad Basin

which drains into the lake from the Central African Republic and the Adamawa Highlands to the south, is the lake's major affluent. This river system currently represents almost all of the inflow to Lake Chad, most of which is lost through evaporation and some (between 10 and 21%) through ground seepage (Grove, 1964; Lemoalle, 1991; Ishiorho *et al.*, 1996; Olivry *et al.*, 1996). The balance between evaporation and seepage losses, and river and rain inflow, determines the size of the lake which is

> an accumulator of positive departures from the mean Chari/Logone discharge, rising in response to runs of wet years, falling with successive years of drought
>
> Grove, 1985a: 146

Water from the Chari/Logone rivers flows into the lake at its southern extreme and flows northwards and outwards encouraged by the lake's gradient and prevailing winds (Fig. 2). This inflow peaks in October/November following the end of the rains in the southern catchment area and reaches a minimum in May/June at the start of the next year's rains. The flood waters take between one and two months to reach the study region on the south-west shore where water levels peak in January and reach their minimum in July (Olivry *et al.*, 1996).

In the past 25 years, annual rainfall in much of the catchment area has been reduced and the surface area of the lake in most years has been reduced. In 1993, Grove estimated the surface area of the lake to be 2500 square kilometres, one-tenth of its area in 1960 (Grove, 1996). Lemoalle (1991) has described the lake post-1973 as *Petit Tchad* or Lesser Chad and distinguishes it from the period of *Tchad Normal* described by Tilho (1928), when water levels exceeded 280 metres above sea level (asl) and the lake behaved as a single water body (Lemoalle, 1991: 54–5). The average altitude of the lake in the twentieth century was considered to be 282 metres (asl) which corresponds to a surface area of approximately 20 000 square kilometres (Grove, 1985). The shore of the lake was at this level in 1972 and is used as the lake outline in Figures 1 to 3.

The lake is currently bisected into a northern and southern basin by the 'Grand Barrier', a rise in the lake bed which runs roughly east–west across the lake (see Fig. 2). Three main ecological zones of the lake remain:

1. the areas of open water which have persisted in the southern basin, frequently only in the vicinity of the inflowing River Chari;
2. the archipelago zones where water surrounds the dunes along north-east coast of the lake; and
3. the swamps to the west of the open water, some parts of which are seasonally inundated (Lemoalle, 1991).

Although the limits of each of these zones are determined by the lake's level, the map in Figure 2 indicates the approximate location of these zones

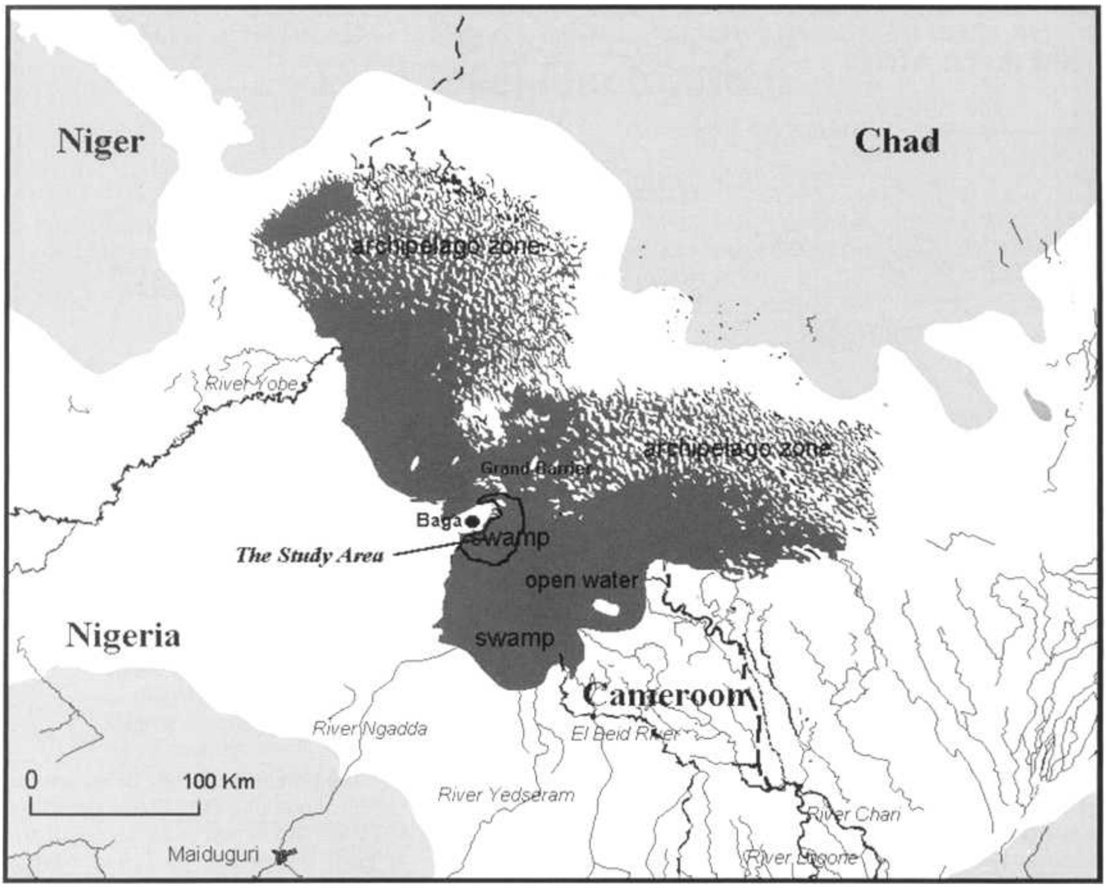

Figure 2 Map showing the ecological zones and the study area

and the study area on the western shore of the southern basin.

Soils and vegetation

As in the wider Sahel, the soils of the northern Chad Basin have been derived from Quaternary sediments deposited during the climatic shifts in the region over the last two million years (Grove, 1974). Around the lake itself, these consist of lacustrine sands and clays which overlie shales and sandstones (Adderley *et al.*, 1997; Petters, 1981; Carroll and Klinkenberg, 1972; Wright *et al.*, 1985). In pedogenic terms, the soils of the study area are young, having been revealed (most recently) following the contraction of the lake during the droughts of 1972 and 1973. Travelling eastwards across the study region, sandy soils are interspersed with dark grey muddy soils. The sandy soils are not usually cultivated, except where Neem trees have been planted to provide shade in villages which are usually sited on the slightly higher sandy areas. The sandy soils outside villages are either bare or vegetated with thorn trees (*Acacia* spp.) or the shrub *Calitropis procera* which grows on the previously cultivated areas towards the open waters of the lake. In contrast, the dark grey muddy soils are intensely cultivated. Their ability to retain soil moisture far into the dry season has been studied in other areas of the lake shore where similar soils, locally known as *firki*, have been classed as paravertisols (Beavington, 1978; Kolawole, 1991; Kirscht and Skorupinski, 1996; Sturm *et al.*, 1996).

Flora and fauna

The shallowness of Lake Chad combined with the wind action over the lake's surface ensures that the lake water is well oxygenated at all levels. This facilitates the utilization of nutrients and organic sediment of the lake bed and, combined with high temperatures, ensures the rapid development of a flora and fauna (Quensière, 1990). The result is a high level of lake biomass. Up to 179 fish species have been identified and found to be in common with species from

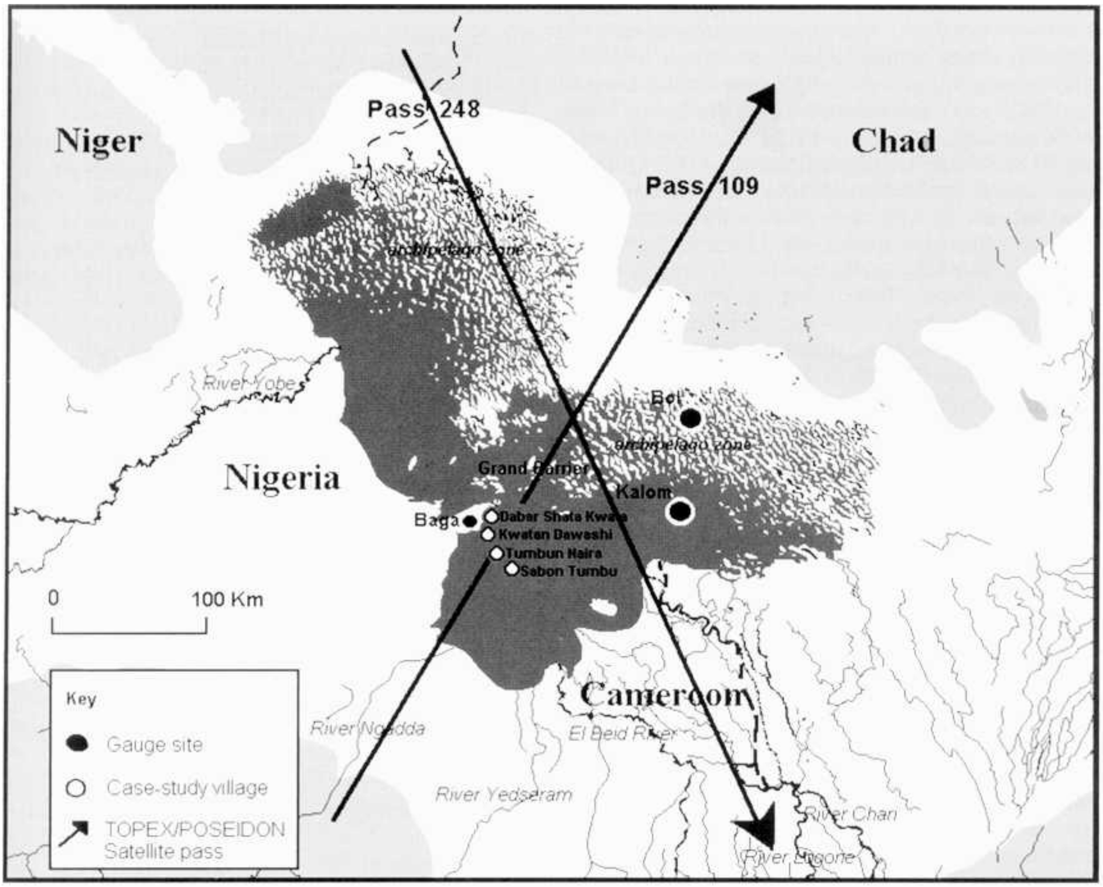

Figure 3 Map of the Lake Chad Basin showing three lake-level gauge sites, the route of the TOPEX/POSEIDON satellite passes across the lake and the four case-study villages

the Nile, Niger and/or Zaire basins (Lowe-McConnell, 1985). The fish which inhabit the swamps and seasonal floods of the study area include migratory species such as *Alestes*; and the 'sedentary' species which are adapted to life on the floodplains (e.g. *Protopterus* spp.) or in the swamps (e.g. *Clarias* spp.). Commercially, the most important species are *Alestes*, *Clarias* and *Tilapia* of which *Clarias* dominate the catch from the swamps of the study area (Sagua, 1991).

Development

The western shore of Lake Chad has been under the jurisdiction of Borno since the end of the fourteenth century. Borno State is currently one of 36 states in the Federal Republic of Nigeria. Although the administrative status of Borno itself has varied, it has been dominated by the Kanuri ethnic group for most of its existence (McEvedy, 1995). Migration during the latter part of the millennium has brought Shuwa Arabs from the east and Fulani pastoralists from the west. Recent settlers on the lake shore include Hausa families from across northern Nigeria who were attracted by fishing opportunities at the lake during the 1970s (Meeren, 1980; Neiland and Verinumbe, 1990). However, customary relationships between ethnicity and livelihood strategy are not straightforward at Lake Chad. Although certain ethnic groups have particular traditions, e.g. the fishing traditions of the Hausa, households from a variety of ethnic groups fish, farm and/or herd cattle (Harris, 1942). This paper focuses primarily on the communities which have settled on the south-west lake shore. They include mainly Kanuri and Hausa households but also smaller numbers of Fulani, Shuwa and Yedina all of whom have been documented to fish, farm and/or keep small livestock (Sikes, 1972; Meeren, 1980; Kolawole, 1986).

Following Nigerian independence in 1960, the federally-sponsored Chad Basin Rural Development Authority (CBRDA) made huge investments in irrigating areas of the lake shore. Three irrigation schemes were planned during the peak lake levels of the 1960s and implemented during the lowest levels of the century in the early 1970s (Hutchinson *et al.*, 1992). The South Chad Irrigation Project (SCIP), just south of the current study area, involved the construction of a 30-kilometre intake channel designed to pump water from the southern basin of Lake Chad to irrigate over 100 000 hectares of clay plains on the south-west shore. This irrigation was planned to enhance rain-fed rice cultivation and enable dry-season wheat cultivation (Grove, 1989). Since the implementation of SCIP in 1974, the lake level has rarely been high enough to reach the intake canal in the rainy season (June to September), and in some years has not reached the channel even during the peak flood (January). Rice cultivation has been a rarity and wheat yields have been poor (Kolawole, 1986; 1987; 1987a). Kolawole (1986) describes how the population of the clay plains have had to cope with the dual disasters of drought in 1972 and 1973 and the failure of SCIP in the following years. He explains how farmers responded by moving onto the lake floor to farm using the residual soil moisture in the lake bed.

Despite several initiatives, fisheries development has achieved little lasting change at Lake Chad. Internationally, the FAO sponsored the Lake Chad Fisheries Development Project during the 1970s. This explored ways to improve fish-handling and processing and the marketing of the lake's fish from the Nigerian shore (Azeza, 1977; Meeren, 1980). More recently, from 1993 to 1996, the British Government sponsored the Traditional Management of Artisanal Fisheries research project (TMAF) which investigated the possibility of designing more appropriate management systems for Lake Chad (Neiland and Sarch, 1993).

Although linked to the Nigerian economy through the market for their produce, the households making their living on the Nigerian shores of Lake Chad are remote, both geographically and politically, from Nigerian policy-makers. The villages in which this study was based have hardly been acknowledged by the Federal Government. They have received negligible public investment in their welfare:

- most wells are hand dug;
- education is restricted to Koranic schooling for boys;
- medical facilities are only available in the large towns; and
- the security services usually monitor only transport nodes.

The villages are reached either on unmarked tracks on the lake bed, or via channels in the swamp vegetation.

Research on the shore of Lake Chad

Fishing and farming livelihoods have been anlaysed using household survey data collected in 1993 and the findings of participatory research in four villages on the lake shore in 1995 (Sarch, 1999). These exercises were undertaken as part of the British Government fisheries research project and the research techniques used are outlined below (Neiland and Sarch, 1993). The subsequent livelihood analysis examined these data in the wider context of environmental change and development described above.

The 1993 household survey aimed to gauge the relative importance of different sources of income to the communities living on the lake shore. A 1.8 per cent sample of the heads of an estimated population of 25 000 sedentary households living on the south-west shore were interviewed in 1993. Previous analyses of the survey findings revealed that many of these households were small, young and had arrived at their current location recently (Sarch, 1996; 1997). The majority (59%) earned three-quarters of their income from farming, a significant proportion (36%) earned income from a combination of fishing and farming and few (5%) households relied entirely on fishing income. Households which both fished and farmed produced more agricultural output than mainly farming households (Sarch, 1996). Further analysis of this survey data is presented here.

Participatory research to investigate links between livelihood strategies and the natural resource base was conducted with the communities of four case study villages in 1995 (see Fig. 3). Analysis of these findings is presented here for the first time. The livelihood responses to lake-level fluctuations focuses on the results of three specific participatory research techniques used in each village. These are:

1. 'time-lines' of important village events;
2. seasonal calendars of fishing and farming activities; and
3. market-chain diagrams.

Ground-based and remote sensing data

To compare livelihood decisions with the lake's inundation status, either ground-based or remote sensing data is required. Such data falls into two categories:

1. areal extent of inundation either in diagrammatic or quantitative (i.e. in km^2) form; and
2. surface water level.

Lemoalle (1991) used METEOSAT imagery to estimate the areal extent of the lake from 1972 to 1990 and Olivry *et al.* (1996) combined this with gauge data to derive a categorization of annual flooding from 1972 to 1995. Although there are a number of gauges within the catchment region which potentially record variations of water level, not all data are complete, and some sets contain erroneous values owing to gauge or reference datum changes (Lemoalle, pers. comm. June 1993). For example, a good data set has been collected at Bol, but Kalom's data is incomplete and there are probably no data from Baga, the site of this study region (see Fig. 3). It has, however, been possible to utilize the relatively new satellite remote-sensing technique, radar altimetry, to provide such water level information for the 1990s study period at Lake Chad.

The altimetric technique has been applied to lakes, rivers and wetlands in several case study regions (see Birkett, 1995 and 1998 for details). As Rapley (1990) gives full details of the altimetric technique, a brief description is given here. A satellite radar altimeter operates at microwave frequencies, effectively transmitting and receiving echoes continuously as it transverses over the Earth's surface. A number of physical parameters are deduced from the echoes, including the height of the terrain. It is not an imaging device, however, and the instrument's field of view is restricted to a relatively narrow footprint. As the technique relies on pulse-limited, rather than beam-limited altimetry, the diameter of the footprint depends on the duration of the emitted pulse and the roughness of the surface. For lakes, the presence of strong winds could effectively broaden the footprint by several kilometres. For rivers and wetlands, the footprint could potentially be a few hundred metres over these more sheltered, specular-echo surfaces.

With nadir-viewing operation, the instrument is extremely sensitive to the presence of water whose signal in the returned echo essentially masks any influence from tree or vegetation canopy. Theoretically, a single pool of water, several metres square in surface area, could be detected above the 'background noise' of the surrounding terrain. However, the presence of multiple small pools, or many small pools at differing elevations, may bias the overall average height value thus leading to larger errors at minimum inundation periods. With limited technique-derived parameters, it is thus difficult to determine the exact transition point between water, puddles, wet mud and dry river or lake bed. Based on observation of wetland and desert surfaces, Birkett (1998) utilized the radar backscatter coefficient as a first-order data filter to identify potential transition periods.

Regarding temporal resolution and height accuracy, altimetry is poor in comparison with standard gauge data, which is often measured daily to centimetre accuracy. Temporal resolution is set primarily by the repeat orbit of the satellite (e.g. 10 to 35 days). The best retrieved height accuracies have been observed to be 3–4 cm root mean square (rms) for lakes (Birkett, 1995) and 10–15 cm rms for wetlands (Birkett, 1998), the value being dependent on the echo shape, the number of echoes across the target and precise knowledge of the satellite orbit. First-order accuracies can be estimated theoretically, but final values are usually determined via validation exercises, in which the altimeter results are correlated with ground-based gauge data on a daily basis. Considering hydrological variations, gauges closest to the altimeter ground track (within a few kilometres) are usually preferred, and for large lakes, several gauge data sets are often averaged together to eliminate the local effects of strong wind events.

Aims of this paper

Government policy goals for Nigerian agriculture, including the fisheries 'sub-sector', during the 1990s included:

- the attainment of national self-sufficiency in basic food commodities;
- increased production of industrial and export crops;
- increased rural employment; and
- improved living standards in rural areas (World Bank, 1989).

Nevertheless since the efforts of the CBRDA, government investment in the lake shore has been sparse. A proposal to invest 17 million Euro in the agriculture of the study area was postponed by the European Union following the political upheavals in 1995 (CEC, 1994). The 'Borno State Anti-Poverty Programme' planned to alleviate poverty through investment in farming inputs, extension advice and credit for farmers' groups of the lake shore. It is anticipated that, following the cessation of European Union sanctions in June 1999, the research reported here will be of value to future initiatives on the lake shore (N. Costello, personal communication, November 1999).

This paper, then, considers a crucial part of the analysis of fishing and farming livelihoods at Lake Chad: how the villagers settled on the south-west shore have responded to fluctuations in the level of the lake since 1973. A combination of data sets are used to examine inter and intra-annual variability in the level of the lake and the livelihood choices made in response to it. The findings of the paper are important for two main reasons. Past development initiatives have:

1. under-estimated the variability in the level of the lake; and
2. assumed that the stability of lake shore is desirable (Hutchinson *et al.*, 1992).

Kolawole (1986; 1987a) describes how villagers coped with the 'environmental hazard' brought about by the contraction of the lake during the 1980s. The paper presents the results of two research techniques, radar altimetry and participatory research, which demonstrate how the variability of the lake level can now be monitored remotely and how the communities of the lake shore exploit this variability.

Fishing and farming livelihoods

Fishing and farming livelihoods on the shore of Lake Chad were examined within a livelihoods framework (Sarch, 1999). This involved analysis of the 1995 participatory research and further analysis of the 1993 survey data within the wider context of the secondary information reviewed above. Responses to lake-level fluctuations are examined here in two stages. Firstly, responses to inter-annual variations in the level of the lake are examined using the findings from the 1995 time-lines in the context of longer-term hydrological information. The 'time-lines' of important village events were drawn during group discussions of their community histories. The group discussions of community history provided a forum for both the villagers and the research team to cross-check and double-check dates and sequences during the discussion.

The second stage examines the responses of farmers and fishers to intra-annual or seasonal lake-level variation. This utilizes the findings of the 1995 seasonal calendars and market-chain diagrams, further analysis of the 1993 survey data and the level-change time series as monitored by the TOPEX/POSEIDON satellite. The seasonal calendars of fishing and farming activities which were compiled from discussions with, and diagrams drawn by, groups of farmers and fishers in each village. The timing and sequence of the activities portrayed in the seasonal calendars were confirmed during several discussions of the seasonal calendar with different groups within each village, for example, young and old men's groups and women's groups. The market-chain diagrams were drawn by traders and cross-checked by farmers and fishers in each village.

Responses to inter-annual lake-level fluctuations

Variation in the inflow to the lake from the River Chari has been monitored with ground gauges. Olivry *et al.* (1996) have combined this information with images from METEOSAT in order to compare the distribution of floodwater across the lake bed on an annual basis from 1972 to 1995. This work illustrates the overall contraction of the lake since 1972 (and the occasional year, e.g. 1989, where the peak flood has reached a similar extent to that in 1972). These data sets have been synthesized to derive a categorization of flooding in the study area over the past quarter-century. Table 1 presents this, alongside a summary of the responses which village communities of the lake shore made to lake-level fluctuations during this time period. Their responses have been derived from the 'time lines' discussed among different groups during the 1995 participatory research.

Table 1 shows that since 1972, the communities of the western lake shore have made important responses to the contraction and recent expansion of the lake. Two responses were mentioned frequently: resettlement and switching livelihood strategies. Each of the village communities involved in the participatory research explained that they had moved to their current village from a location further west. As the lake levels dropped during the 1970s and 1980s, the maximum extent which the lake reached each year receded eastwards towards the centre of the lake basin. Village elders in each village explained how they had followed the lake shore and in some cases, had moved eastwards more than once. The most easterly, and thus most remote, villages had been established most recently. Those in Hausa communities described how they had initially been attracted from north-west Nigeria to the fishing opportunities of Lake Chad in the 1970s, and had often moved again from their original settlement site on the lake shore. Kanuri communities, who have a long history of farming in the lake basin, also explained how they had resettled in village locations progressively eastwards as the lake contracted.

Further analysis of the 1993 survey data revealed that 85 per cent of households had settled in their current village within the past decade and that the mean length of residency differed little between ethnic groups. The mobility of the lake shore communities in response to lake-level fluctuations is highlighted by the community of Sabon Tumbu, the most remote village. Sabon Tumbu was established in 1985 when farmers from Tumbun Naira moved eastwards to farm the lake floor alongside the existing fishing camp; the village was evacuated after the rising lake flooded the village at the end of 1994 and, in March 1995, was being resettled as farmers and fishers moved back to farm the lake floor.

Table 1 also shows that since 1975, fishing and farming communities have not only resettled but have made significant changes to their livelihood strategies. The second response that had been made in each of the case-study villages to the contraction of the lake was to diversify from relying entirely on fishing to farming the lake floor as the flood water receded. In the years 1978, 1984 and 1985 when there was a significant, year-on-year, drop in the level of the lake, previously fishing villages responded immediately by farming the emerging lake floor. Although each of the village communities described how they had initially been set up as fishing settlements during the 1970s and early 1980s, in 1993 the majority (54%) of households relied on farming as their main source of income. Although there was an important minority (37% in 1993) who combined farming with fishing, very few households relied on fishing for more than half their income (5% in 1993). Many of the Hausa communities which had been attracted by the fishing opportunities of the 1970s explained how they had switched to farming as the lake shore contracted and

Table 1. Responses to variation in the inundation of the south-west shore of Lake Chad

Year (see note 1)	Peak flood status (see note 2)	Key events and livelihood responses (see note 3)
1975/1976	2	Temporary fishing camps set up in locations near to the current road head
1976/1977	2	
1977/1978	1	Communities of nearby fishing villages began to farm lake floor
1978/1979	2	
1979/1980		Nearby villages planted shade trees expected to mature after 10 years or more
1980/1981		Nearby village communities established permanent status with shore-based administrators
1981/1982	3	Temporary fishing camps set up in middle-distant locations.
1982/1983	2	Temporary fishing camps set up in remote locations
1983/1984	1	Drought for nearby villages, middle-distant village communities established permanent status with shore-based administrators and began farming lake floor
1984/1985	0	Remote village communities established permanent status with shore-based administrators and began farming the lake floor; clashes over access to water in middle-distant villages
1985/1986	2	Good year for farming in middle-distant villages
1986/1987	0	
1987/1988	0	
1988/1989	3	Fishermen's boats capsized in early floods
1989/1990	1	Good harvests and good catches in remote villages
1990/1991	0	
1991/1992	1	
1992/1993	1/2	Good harvests in middle-distant village
1993/1994	1	Crops flooded before harvest in villages throughout study area, remote villages evacuated
1994/1995	2	Remote villages resettled

Notes:
1 These dates refer to the flood year, i.e. from September to the following August.
2 The flood usually peaks at the end of January in the study area (see Fig. 2):
0 – no flood water reached study area;
1 – flood water inundated fringes of study area;
2 – most of study area inundated;
3 – study area submerged (Source: Olivry *et al.*, 1996)
3 Responses have been synthesized from oral histories discussed in four case-study villages in 1995. Villages have been described in terms of their location: nearby villages were within easy vehicle access (less than an hour) of the paved road and market towns; middle-distant villages were a long journey from the paved road (up to three hours); vehicle access to remote villages was only possible at certain times of year, at other times these villages were reached either on foot or by boat from middle-distant villages.

revealed the moist soils of the lake floor around their fishing settlements. There was little vegetation to clear from this 'new' land and having been submerged it had no history of farming rights associated with it. The village elders were able to start farming with a relatively small initial investment in seed and labour. Although some Kanuri households combined fishing and farming (23% in 1993), diversification from farming to fishing was much less common. Further analysis of the 1993 survey data shows that of the 80 per cent of Hausa households who had fished Lake Chad at some stage in the past, the majority (58%) now relied on farming for more than one-quarter of their annual income.

The mobility of the communities making their living on the shore of Lake Chad has been reported elsewhere as a coping mechanism (Kolawole, 1986). The mobility and livelihood flexibility of the families making their living on the shores of the lake in the 1990s has enabled them to do better than merely cope. The following subsections will show how farming and fishing communities in the study area have exploited seasonal fluctuations in the lake and produced a food surplus which has played an important role in the food balance of the region.

Responses to seasonal fluctuations

Flood retreat farming The lake and its seasonally-inundated shore are the basis of almost every household's livelihood in the study area (Sarch, 1996). Lake levels in the study area begin to rise in September and reach a peak in January (see Fig. 4). The main agricultural season starts as the flood water begins to subside at the end of January (see Fig. 5). The crops of the study area are grown almost entirely

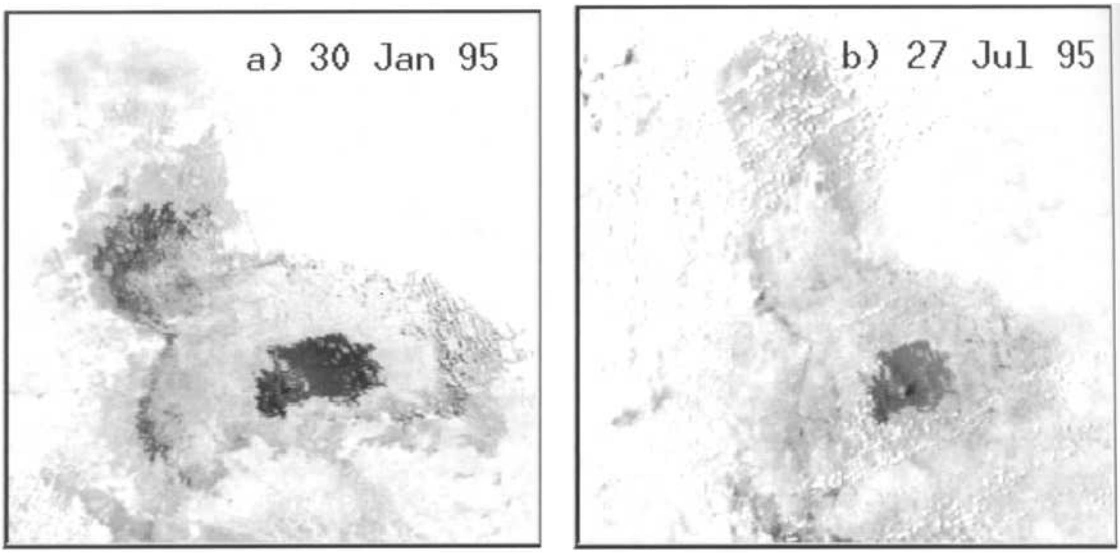

Figure 4 NOAA/AVHRR images of Lake Chad, taken at times of a) maximum inundation, and b) minimum inundation. Both images are channel 2 (near infrared), depicting open water in the perennial region and the inundated marsh as black, and vegetation and moist soil as various grey hues. Viewing geometry differs between the two images

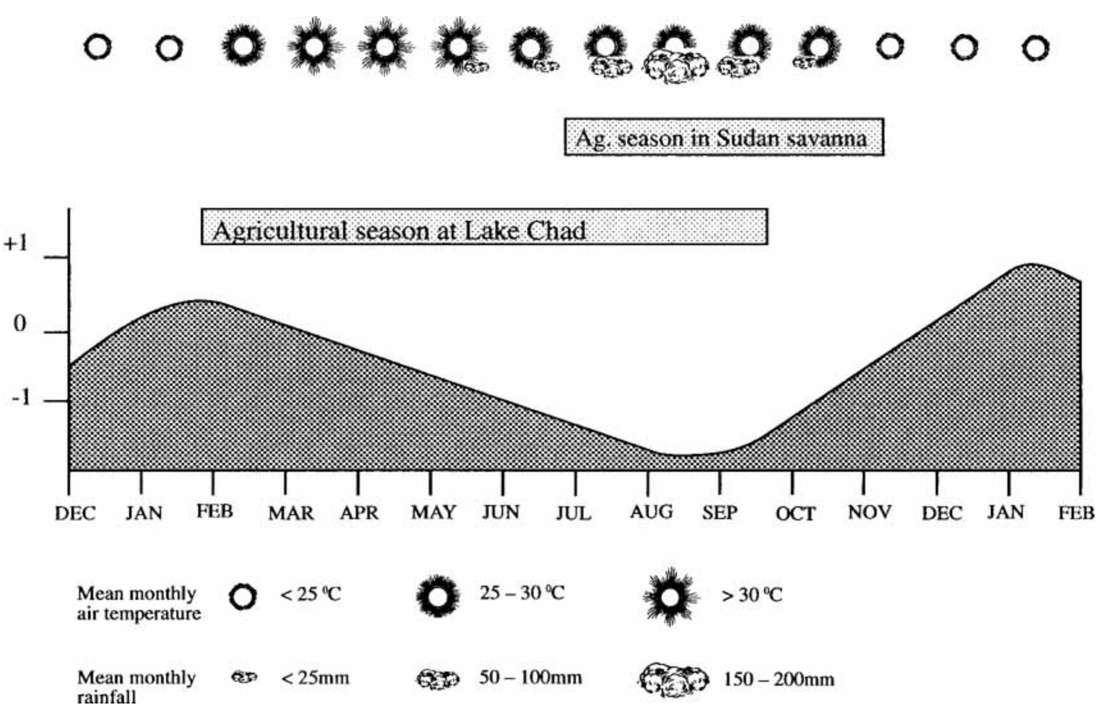

Figure 5 Agricultural calendar derived from seasonal calendars drawn by village heads and farmers, and observations on the south-west shore of the lake during 1993, 1994 and 1995. Relative changes in lake level (m) are indicated on the vertical scale. Temperature and rainfall data have been adapted from Olivry *et al.* (1996). (Graphic design for this Figure by Roz Streeten.)

on the seasonally-flooded lake floor and cropping follows the receding lake, taking advantage of residual soil moisture and the high levels of sunshine during May and June when many of the crops are flowering and ripening. The lake reaches its lowest level in July by which time the rains have arrived and extend the season for some crops (see Fig. 4).

Unlike the systems described in many textbooks, the farming systems at Lake Chad are not readily assessed as 'shifting', 'semi-permanent' or 'permanent'; or extensive or intensive (Sarch, 1999). In key respects the farming techniques used are extensive. Farmers rely on 'new' land to maintain fertility levels and labour is an important constraint to production; whereas in other respects, farming systems are intensive, three or more crops are often relayed within the season and although largely unmechanized, production is commercialized, with high levels of cash inputs and crop sales. This section will explain how the farming systems in the study area have been developed in response to the seasonal flooding of the lake shore.

The soils of the lake floor are extremely fertile. They have good water retention qualities, a high organic content and have been classified as 'organic hydromorphic' (Tuley, 1972). Farmers explained that fertilizers were hardly ever used (this has also been noted by NEAZDP [1992]) and that the renewal effects of the seasonal flood were relied on to maintain fertility levels. Although an important minority of households kept livestock, this usually involved raising poultry or small ruminants within the compound, their manure was not used to fertilize land (Sarch, 1996). Some manure may have been provided by the pastoralists crossing the lake floor to water their cattle, however, given the level of conflict with farmers, farmers could not rely on this (IIED, 1999).

The seasonal calendars of farming activities constructed in each case-study village revealed that limited family labour was an important constraint on production. Although hired labour was used by the lake shore households on the majority of the crops grown, in 1993 wages from agricultural labour made only a small contribution to annual income in less than five per cent of households (Sarch, 1996). Group discussions of the seasonal calendars revealed that the hired labour utilized by farming households was provided by a large influx of migrant labourers to the study area, many of whom come from the surrounding regions in Borno State where the hot, dry season prevails during the main agricultural season at Lake Chad (see Fig. 5). Although some farmed their own crops, not all transhumant farmers were able to do this, the start of the agricultural season in their rainfall-dependent home areas, meant that many returned home before the end of season at Lake Chad (see Fig. 5).

In addition to hired labour, the main cash inputs to the farming systems of the study area were pesticides. Farmers frequently mentioned the destructive impact of flocks of Quelea birds on their crops, which they had found hard to combat without constant attention. Although insecticides were sprayed on the cowpea crop, farmers had to rely on family labour to scare away the flocks of Quelea birds which attacked the maize crop. Other than insecticides and sprayers, few labour-saving technologies were in use.

Almost all farming households (99%) grew maize and on average, 42 per cent of the maize harvest was sold (see Table 2). Many farming households also grew cowpeas in addition to maize, predominantly as a cash crop. Further analysis of the household survey data shows that in 1993, the value of farm sales represented over three-quarters (77%) of mean household farm output. This indicates the importance of crop sales in the local economy and when considered alongside the marketing channels described by farmers in 1995, it indicates that, overall at least, the households of the study area are producing a food surplus which is sold into regional markets. This was confirmed through visits to the markets of the lake shore, where container trucks from all over Nigeria could be seen transporting large quantities of various foods out of the area throughout much of the year.

The sale of farm produce is usually undertaken by the farm household. Crops are harvested and processed (for example, maize is dried, the kernels stripped off the cob and bagged; cowpeas are dried, shelled and bagged) within the farm household and transported to the weekly agricultural market in the town of Baga. During most of the agricultural season in the study area, the lake is in recession, rainfall is not expected and transport across the lake bed is easier than at other times of year, although expensive in comparison to other parts of Nigeria (see Fig. 5). Four-wheel-drive pick-up trucks are ideally suited to the sandy terrain between the road and the middle-distant villages and when dry, the flat, relatively non-vegetated lake bed is easy to navigate.

Although in theory, farmers have the option of storing their produce and selling at a later stage, in practice three key factors favour early sales:

1. the harvest from the study area is considerably earlier than that in other parts of the region as many of the crops grown on the lake bed are harvested at the end of the dry season, thus demand and prices for Lake Chad produce is high at that time of year (see Fig. 5);
2. transport across the lake bed is relatively easy at that stage, if the farming household were to delay selling, the rising flood would increase the time and cost involved in transporting produce to surfaced roads; and
3. the high degree of pest infestation of stores kept in the villages of the lake floor.

Table 2. Farm output

Crop	Proportion of farming households which grew that crop (n = 429)	Value of mean output of farming households (US$ – see note 1)	Mean proportion of output sold by farming households (see note 2)
Maize	99%	419	42%
Cowpea	80%	251	87%
Overall	–	879	77%

Source: 1993 household survey data (Sarch, 1999)

Notes:

1 Farmers were asked to estimate the number of bags which they harvested in the previous year; the number of kilograms was calculated from this using the kilogram capacity of the bag type used by the farmer. The value of agricultural output has been calculated using regional market prices converted into US$.

2 Farmers were asked to estimate the number of bags of each crop which they subsequently sold. As above, these were valued at regional market prices and the proportion of output sold was calculated as a percentage of the total number of bags harvested by the farmer.

Most farming households will sell what they do not (or cannot) keep for consumption soon after it is harvested. Long-term storage, i.e. beyond a year, is limited by both pest infestation and the risk of flooding.

Flood-based fishing As with agriculture, fishing in the study area is entirely dependent on Lake Chad. There are virtually no other natural water bodies in the study area and almost all the fishing households who had settled on the lake shore fished the lake exclusively (Sarch, 1996). In 1993, only seven per cent fished anywhere else at all. The flood plays a vital role in the renewal of the natural resource base for the lake's aquatic fauna. The annual flooding process aerates the lake water and, combined with the availability of crop residues and other vegetation, renews the aquatic ecosystem for the lake's fish. Although many of the larger fish are caught during the rising flood, the sunshine and high temperatures during the latter stages of the flood further encourage the growth of fish remaining in the residual flood water (see Fig. 6).

The strategies employed in the study area reflect important differences between fishing the rising flood and fishing the receding flood. Further analysis of the 1993 survey data demonstrated that most of the households who fish, do so within a short distance of their home village during the rising flood and only half continue to exploit the receding flood. Most of the remainder stopped fishing as the flood began to recede, many switching to farming the lake floor (see Table 3).

As expected from the sedentary focus of the study, very few fished all year round. As the lake water is within easy access of the lake-shore villages for only part of the year, in order to fish all or most of the year, some members of the household would need to travel longer distances and to lead a migratory lifestyle. The study concentrated on the livelihoods in the villages of the western shore where fishing is highly seasonal.

Table 3. Fishing strategies

Flood state	Proportion of fishing households fishing during each fishing season (n = 196)
Rising flood only	46%
Receding flood only	12%
Rising and receding flood	40%
Other times of the year	2%
Total	100%

Source: 1993 household survey data (Sarch, 1999)

Fishing throughout the lake shore was predominantly small-scale, few households owned fishing boats, although almost all owned the gear that they did use (see Table 4). Most fishing households used a range of gear types which vary in the flood state to which they are best suited. The seasonal calendars of fishing activities discussed in each case-study village revealed how certain gear was used at different stages of the flood. Although it is possible to use hooklines at any stage of the flood, fishers explained that they were preferred during the rising flood when they are used to catch fish swimming with the incoming flood. Traps, particularly the Mali trap, were used during the receding flood when they are left in channels of receding flood water to catch fish which have grown in the flood water over the hot dry season.

Despite the small scale of fishing operations, catch sales are important. This was confirmed by the high proportion of the catch which most households sold. Further analysis of the 1993 survey data shows that three-quarters of fishing households sold over three-quarters of their catch. The perishable nature of fish and their fluctuating habitat necessitate complex marketing chains from fishers to Baga, the major fish market on the Nigerian shore, at the road head (see Fig. 3).

Table 4. Common fishing gear

Fishing gear	Proportion of fishing households using gear type (n = 196)	Preferred fishing season
Gillnet	78%	Any
Hookline	65%	Rising flood
Mali trap	56%	Receding flood

Source: 1993 household survey data and 1995 village case-studies (Sarch, 1999)

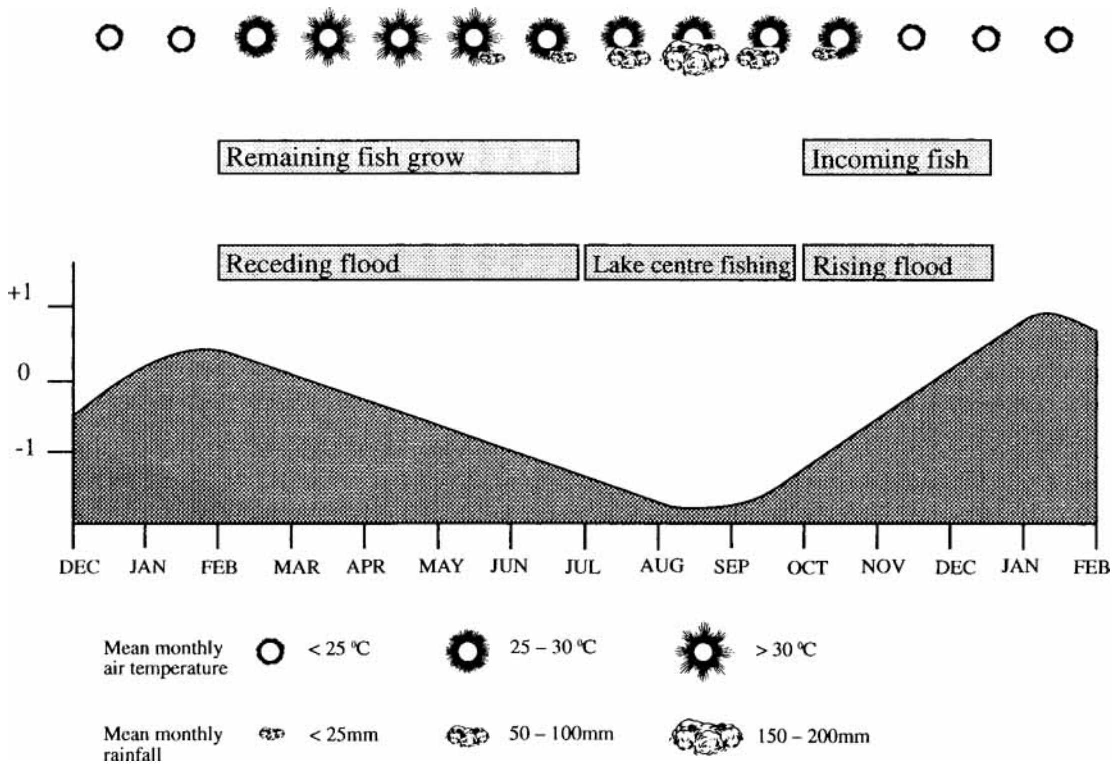

Figure 6 Fishing calendar derived from seasonal calendars drawn by village heads and master fishermen, and observations on the south-west shore of the lake during 1993, 1994 and 1995. Relative changes in lake level (m) are indicated on the vertical scale. (Graphic design for this Figure by Roz Streeten.)

During the 1995 village case studies, fish traders described how the market channels to Baga vary with season, the location of the fish *vis à vis* the market and the transport options available at different stages of the flood. Fresh fish are sold to processors/traders at landing sites which move with the fluctuating lake shore. They will usually smoke the fish, package it for transport and then, depending on the distance from the lake shore to Baga and the difficulty of travel, either sell on to another trader or take them to Baga themselves. When the lake level is low, the lake shore many miles from the market and the lake floor muddy, the processor may sell to another trader at an intermediary market. Once at the fish market in Baga, the trader will sell to further traders who supply large trucks which transport hundreds of tonnes of smoked and dried fish to sell on in the markets in the densely-populated southern belt of the country.

Estimates of fish production from the lake vary. Extrapolating from figures for the fish sold in the two key, lake-side markets, Sagua (1991) estimated an average annual production of 56 000 tons (fresh weight equivalent) between 1986 and 1989. This is a fraction of the figures calculated by Duran (1980) for the 1970–1977 period which allow a comparable estimate for average annual production of 243 000 tons. Although, the exact roles of the lake's contraction and the exploitation of fish stocks in this decline are difficult, if not impossible, to ascertain, at least part of the reduction in production over recent decades is accounted for by the contraction of the lake (Stauch, 1977).

Satellite lake-level monitoring

TOPEX/POSEIDON (T/P) is a joint NASA/Centre National d'Etudes Spatiales (CNES) radar altimeter mission. It was launched in 1992 and is still currently operational. It carries on board two radar altimeter instruments (although the NASA radar altimeter [NRA] is the primary instrument operating over Lake Chad), and is placed in an orbit having a repeat period of around ten days. During one repeat cycle, the satellite makes two passes across Lake Chad. Pass 109 ascends over the seasonally-inundated lake bed on the western shore of the lake (i.e. the region of study), whilst pass 248 descends over the lake, passing over the region of permanent water (see Fig. 3). As the satellite traverses the surface, it determines the average height of the topography found within the footprint, and such 'spot' heights are given every 580 metres along the ground track within the T/P Geophysical Data Records (GDRs).

Research by Birkett (1995) using T/P GDR data provided the first altimetrically-derived time series of water level variations within Lake Chad. These early results (September 1992 to May 1994) revealed both the seasonality of, and the phase lag between, the western and central waters. Using the same techniques, these preliminary time series are updated (September 1992 to April, 1996) and presented here, to cover the period of study with the communities of the western lake shore. Whilst Figure 7a shows the intra- and inter-annual variations of water within the swamp regions to the west (between [13.15°N, 14.02°E] and [13.50°N, 14.16°E]), Figure 7b shows the variation of levels within the permanent waters (between [12.92°N, 14.42°E] and [13.05°N, 14.37°E]). In addition, newly-acquired Bol gauge data (Y. Nelngar, personal communication August 1999) allows a first-order validation of the altimetry results (Fig. 7b). The results for the permanent waters have been arbitrarily shifted both vertically and horizontally by a constant amount, to provide a correlation with the gauge. Such an exercise only allows a qualitative validation, as a result of the large separation distance (>50 km) between target and Bol site and the known variations in amplitude and phase of the shifting waters. However, there are similarities, and based on previous validation studies Figure 7a can be accepted with some confidence. As the majority of radar echoes over both the western shore region and the permanent waters are primarily narrow-peaked as typically found over rivers and wetlands, the time series errors can be expected to be in the 10–20 cm rms range.

The radar altimeter has provided this study with unique water-level information for the western shore region (Fig. 7a). As the waters evaporate and the lake bed becomes increasingly dominant within the footprint, the echoes become more complex, leading to height biases and resulting noisy data (e.g. the 1993 minimum). However, at other times, and despite the presence of islands in this region, the retrieved echoes are relatively uniform leading to good water height retrievals. With level maxima in January and level minima in August, the two-month phase lag across the basin is evident (see Fig. 7). Common to both time series though, are the 1–2 metres seasonal oscillations and an overall rising trend in level-minima during the 1990s. Between 1993 and 1995, for example, the minimum level rose by around 40 centimetres, a significant increase considering the shallow (less than five metres in the southern basin) depth of the lake. Lake-level maxima do not follow such a trend, decreasing between the 1992/1993 and 1993/1994 seasons and increasing between the 1993/1994 and 1994/1995 seasons. This latter effect (*c.* 80 cm) in the study area was almost twice that experienced in the permanent waters to the east and compares closely with the high levels of flooding which the communities described in 1995 and which forced the evacuation of Sabon Tumbu.

The seasonal calendars of farming and fishing activities constructed in each of the case-study villages show a close consistency with intra-annual fluctuations in lake level monitored by pass 109 of the T/P satellite during the study period. In each case-study village, fishing started within the September to October period when Figure 7a shows that lake levels rose in the study area in 1993,1994 and 1995 (see Table 5). Farming in each case-study village was started just after Figure 7a shows that the lake levels began to drop in 1993, 1994 and 1995.

Discussion

Although the lake level has dropped considerably in recent decades, the lake remains a vital source of water in the region which is characterized by its aridity. Furthermore, the contraction of the lake has revealed new areas of the lake bed which have been exploited by farmers taking advantage of the fertility of 'new' land. However, the contraction does have important disadvantages. Firstly, it has been associated with considerable variation in the extent and occasionally the timing of the annual flood; farmers cannot be sure when the flood will reach the land around their village or whether it will at all. Although intra-annual fluctuation has important renewal effects for the lake's aquatic environment, inter-annual fluctuations have had a predominantly negative impact on the fishing resource base. In particular, the overall contraction of the lake during the past 25 years, has involved a reduction in the aquatic habitat of the lake's fish which has not been compensated for in other areas of the lake.

Table 5. Fishing and farming start dates

Village	Location *(see note 1)*	Fishing start dates *(see note 2)*	Farming Start Date
Dabar Shata Kwata	Near to road	Late October	Late January
Kwattan Dawashi	Middle-distant	Late September	Late February
Sabon Tumbu	Remote	Mid-September	Mid January
Tumbun Naira	Remote	Mid-September	Early February

Source: Seasonal calendars drawn during discussions held during 1995 village case-studies
Notes:
1 Nearby villages were within easy vehicle access (less than an hour) of the paved road and market towns to the west of the study area (see Fig. 3); middle-distant villages were a long journey from the paved road (up to three hours); vehicle access to remote villages was only possible at certain times of year, at other times these villages were reached either on foot or by boat from middle-distant villages.
2 In order to ensure their best level of recall, when constructing seasonal calendars the discussion groups in each case-study village were asked to refer to the most recent fishing or farming season and thus these start dates refer to the fishing season which started as the lake level rose in 1994 and the farming season which started as the lake levels began to drop in 1995. Approximate dates have been used here to accommodate the slight variations in start dates given by different groups in each village. Nevertheless, each discussion group considered that the calendar they had constructed was broadly representative of their fishing and farming activities over recent years.

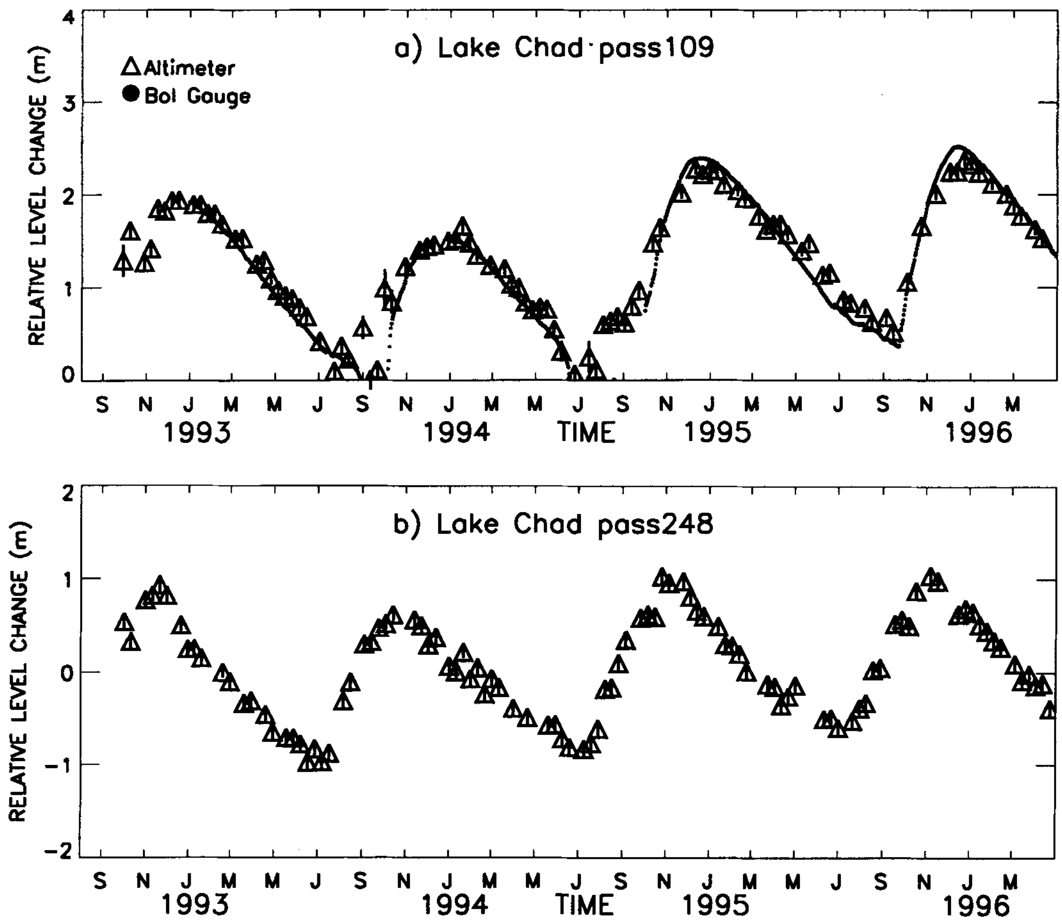

Figure 7 Altimetric lake level time series derived from the NRA altimeter, onboard the TOPEX/POSEIDON satellite. The plots denote relative level change for a) pass 109 and b) pass 248 for the time period September 1992 to April 1996. (See Fig. 3 for the route of the satellite passes.)

Despite the challenges associated with the fluctuations of Lake Chad, the communities making a living on the lake shore are surviving. Their ability to cope was observed during the low lake levels of the 1980s and the research presented here demonstrates how villagers on the western lake shore have responded to considerable variation in the extent of seasonal flooding during the 1990s. They have adapted their livelihoods to the fluctuations in the natural resources available on the lake shore. The ability to exploit the same areas of the lake basin in a range of environmental conditions, through fishing during the flood and farming after the flood has receded, provides lake shore residents with a range of options to respond to lake-level fluctuations.

Importantly, the findings of the livelihood analysis presented here show that the fishers and farmers of the lake shore are doing better than coping. Many households on the lake shore are producing a food surplus, sales of which peak during the crucial, preharvest stage of the season in the semi-arid rain-fed agricultural zones of the region. Furthermore the fishing and farming opportunities of the lake have sustained migration to the lake shore from across northern Nigeria throughout the period of *Petit Tchad*. This success is based on the flexibility of the lake shore communities in exploiting the seasonal flooding of the lake shore.

This flexibility is of crucial importance to the livelihood strategies of these households and it is important that it is recognized. Development initiatives which fail to incorporate flexibility may reduce the options available to small-scale fishing and farming households and their ability to respond to a variety of environmental fluctuations. The experience of the Chad Basin Rural Development Authority is testament to that. The assumptions of lake-level stability inherent in the CBRDA South Chad Irrigation Project (SCIP) meant that it was left 'high and dry' as the lake contracted and the SCIP farmers moved eastwards across the lake floor. There has been little point in maintaining the intake channel from the centre of the lake basin and although lake levels have begun to rise, considerable investment in rehabilitating the scheme would be necessary before the year-round farming SCIP was designed for could be achieved, let alone sustained.

The comparisons between the time series of lake-level fluctuations derived from the TOPEX/POSEIDON data set and village responses to them have important implications for development initiatives. Although extremely different in their focus, the two research efforts have been shown to provide results which are consistent and which mutually reinforce both their validity and the value of both techniques. Several applications of this consistency emerge.

While the ability to monitor lake levels at ten-day intervals cannot provide real-time warnings of fluctuations in the lake, radar altimetry can be used to show rising trends and could provide forecasts that the water level was about to rise above critical levels. Monitoring altimetry data throughout the catchment could also illuminate amplitude and phase relationships between river inflows and the lake level. Although, the communities of the case-study villages described how they had been able to respond to the fluctuations of the lake with little external or public assistance, advance warning of rising lake levels could enhance their ability to respond to them. In the case of extreme rises in lake level, this information could be invaluable to relief and rescue efforts if they were able to act at short notice. Successful flood warnings depend on three key elements:

1 flood forecasts;
2 the ability to disseminate warning information; and
3 the ability of the flood-prone to respond (Handmer, 1997).

This paper has shown how the first of these is now possible and the last is evident; the scope for disseminating flood warnings at Lake Chad warrants further investigation.

Whether or not timely flood warnings are possible in the near future, radar altimetry could provide those involved in planning the development of the lake shore with regular and frequent information on the areas of the lake floor which are likely to be flooded, and the livelihood analysis shows what adjustments are made in response to lake-level fluctuations. Rises in lake level translate into floods which are exploited by a range of fishing methods adapted to the different stages of the flood. The subsequent falls in lake level are exploited by farmers who take advantage of both residual soil moisture and the prevailing hot dry season.

The aim of this paper has been to demonstrate that development interventions should enhance the flexibility of lake-shore livelihoods rather than to reduce it by tying communities to fixed farming and/or fishing patterns with fixed inputs. The regular lake-level data which are now available from radar altimetry enable potential investors to monitor the lake level with much greater accuracy. There is no longer any reason for assumptions to be made about the stability of the lake. The challenge which now faces those, such as the European Union, who are seeking to invest in the livelihoods of the lake shore is how to enhance their flexibility. One suggestion which has emerged from the research efforts reported here is to investigate the possibilities of a warning system which, through increasing the time available for families to organize their responses, could enhance the flexibility of their livelihoods.

Conclusions

This paper has examined one part of an analysis of fishing and farming livelihoods at Lake Chad, their responses to fluctuations in the level of the lake. The sustainable rural livelihoods framework which guided the analysis placed a particular emphasis on the links between livelihood choices and the wider environment within which they are made and has been a valuable tool in examining the findings of two diverse research efforts at Lake Chad, radar altimetry and community-based research.

The paper has considered variation in the annual level of the lake over the past quarter century and has examined how the communities of the south-west shore have responded by following the fluctuating lake shore. Recently available information from the TOPEX/POSEIDON satellite has facilitated much closer monitoring of the lake level during the 1990s and this has enabled a comparison of livelihood strategies on the lake shore with the seasonal fluctuations in the lake. This demonstrated how well livelihood systems on the south-west shore of the lake have been adapted to the uncertainties of the flooding regime at Lake Chad. It is proposed that rather than coping with lake-level fluctuations, the livelihood strategies employed by the communities of the lake shore exploit them. The paper suggests the key to sustaining such livelihoods is through enhancing their flexibility to respond to lake-level fluctuations. One way in which this could be achieved is through a flood warning system and further investigation of the possibilities for such a system is recommended.

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References

Adderley, P., Jenkins, D.A., Sinclair, F.L., Stevens, P.A. and Verinumbe, I. 1997 The influence of soil variability on tree establishment at an experimental agroforestry site in North East Nigeria. *Soil Use Mgmt* **13**: 1–8.

Azeza, N.I. 1977 Fish handling, processing and marketing in the Lake Chad Basin (north-west shores). In *Proc. Conf. Handling, Processing and Marketing of Tropical Fish. London 5–9 July, 1976.* London: Tropical Products Institute.

Beavington, F. 1978 Studies of some cracking clay soils in the Lake Chad Basin of North East Nigeria. *J. Soil Sci.* **29**: 575–83

Birkett, C.M. 1995 The contribution of TOPEX/POSEIDON to the global monitoring of climatically sensitive lakes. *J. Geophys. Res.* **100**(C12): 25179–204.

—, 1998 The contribution of the TOPEX (NRA) radar altimeter to the global monitoring of large rivers and wetlands. *Wat. Resourc. Res.* **34**(5): 1223–39.

Carney, D. 1998 Implementing the sustainable rural livelihoods approach. In Carney, D. (ed.) *Sustainable rural livelihoods. What contribution can we make?* London: Department for International Development: Chapter 1.

Carroll, D.M. and Klinkenberg, K. 1972 Soils. In Tuley. P. (ed.) *The land resources of North East Nigeria. Land Resources Study No 9.* London: Overseas Development Administration: 85–120

CEC, 1994 The Commission of the European Communities Directorate General for Development Operational Summary No 82 – September 1994. *The Courier* **147**: VII.

Costello, N. Personal Communication, November 1999.

Duran, J.R. 1980 Evolution des captures totales (1962–1977) et devenir des pecheries de la region du lac Tchad. *Cahiers ORSTOM séries hydrobiologie* **13**: 93–111.

Ellis, F. 2000 (forthcoming) *Rural livelihoods and diversity in developing countries: analysis, policy, methods.* Oxford: O.U.P.

Grove, A.T. 1964 Lake Chad. *Geographical Mag.* **42**(6): 432–7.

—, 1974 *The geography of Africa.* London: Longman.

—, 1985 Water characteristics of the Chari system and Lake Chad. Ch 3 in Grove, A. T. *The Niger and its neighbours: environmental history and hydrobiology, human use and health hazards of the major West African rivers.* Rotterdam: Balkema: 61–75.

—, 1989 *The changing geography of Africa.* Oxford: O.U.P.

—, 1996 African river discharges and lake levels in the twentieth century. In Johnson, T.C. and Odada, E. (eds) *The limnology, climatology and paleoclimatolgy of the East African lakes. Proceedings of the IDEAL conference, Jinja, Uganda, 1993.* Amsterdam: Gordon and Breach: 95–100.

Handmer, J.W. 1997 *Flood warnings: issues and practice in total system design.* Enfield, University of Middlesex: Flood Hazard Research Centre.

Harris, P.G. 1942 The Kebbi fishermen (Sokoto Province, Nigeria). *J. R. Anthrop. Inst. Great Britain and Ireland* **72**(1 and 2): 23–31.

Hutchinson, C.F., Warshall, P., Arnould, E.J. and Kindler, J. 1992 Lessons from Lake Chad. *Environment* **34**(6): 17–20 and 40–43.

IIED, 1999 Land tenure and resource access in West Africa: issues and opportunities for the next twenty five years. London: International Institute for Environment and Development.

Isiorho, S.A., Matisoff, G. and When, K.S. 1996 Seepage relationships between Lake Chad and the Chad aquifers. *Ground Wat.* **34**(5): 819–26.

Kirscht, H. and Skorupinski, T. 1996 Soils and peasants: geographical and ethnological investigations on soil classification and land use in the southern Chad Basin. In

Berichte des Sonderforschungsbereichs 268 Frankfurt am Main: Goethe University: 269–83.

Kolawole, A. 1986 Irrigation and drought in Borno, Nigeria. Unpublished PhD thesis, University of Cambridge.

—, 1987 Environmental change and the South Chad Irrigation Project (Nigeria). *J. Arid Environ.* **13**: 169–76.

—, 1987a Cultivation of the floor of Lake Chad: a response to environmental hazard in eastern Borno, Nigeria. *Geogrl J.* **154**(2): 243–50.

—, 1991 *Wetlands in drylands: the agroecology of savanna systems in Africa. Part 3a Economics and management of fadama in Northern Nigeria.* London: IIED.

Lowe-McConnell, R.H. 1985 The biology of the river systems with particular reference to the fishes. In Grove, A.T. *The Niger and its neighbours: environmental history and hydrobiology, human use and health hazards of the major West African rivers.* Rotterdam: Balkema: 101–42.

Lemoalle, J. 1991 Elements d'hydrologie du lac Tchad au cours d'une period de secheresse (1973–1989). In *Management strategies for inland fisheries in the Sahel.* FAO Fish. Rep. 445. Rome: FAO: annex f.

—, 1993 Personal communication, June 1993.

—, 1997 Personal communication, September 1997.

McEvedy, C. 1995 *The Penguin atlas of African history.* London: Penguin Books.

Meeren, A.G.L. van der 1980 A socio-anthropological analysis of the fisheries of Lake Chad. Mimeo report no FI: DP/NIR/74/001 prepared for FAO, Rome.

NEAZDP, 1992 *Feasibility study for the NEAZDP expansion to north and east Borno State.* Report of the North East Arid Zone Development Project (NEAZDP). Gashua, Yobe State, Nigeria: NEAZDP.

Neiland, A.E. and M.-T. Sarch 1993 The development of a survey methodology for the investigation of traditional management of artisanal fisheries, North East Nigeria. Report No. 24, Centre for Economics and Management of Aquatic Resources. Portsmouth: CEMARE.

Neiland, A.E. and Verinumbe, I 1990 Fisheries development and resource-usage conflict: A case-study of deforestation associated with the Lake Chad fishery in Nigeria. *Environ. Conserv.* **18**(2): 111–17.

Nelngar, Y. Personal communication, August 1999.

Olivry, J.-C., Chouret;, A., Vuillaume, G., Lemoalle, J. and Bricquet, J.-P. 1996 *Hydrologie du lac Tchad.* Paris: ORSTOM editions.

Petters, S.W. 1981 Stratigraphy of Chad and Illmedden basins (West Africa). *Ecologae Geolicae Helvetiae* **74**: 139–59.

Quensière, J. 1990 Les ressources halieutiques du Bassin Tchadien. Influence de la secheresse et situation actuelle. Report prepared for the Lake Chad Basin Commission, Njamena.

Rapley, C.G. 1990 Satellite radar altimeters. In Vaughan, R.A. (ed.) *Microwave remote sensing oceanographic and marine weather-forecast models.* Norwell, Mass.: Kluwer Academic: 45–63.

Sagua, V.O. 1991 The current status of the fishery resources of the Lake Chad Basin and a programme for its management and conservation. Annex E in *Management strategies for inland fisheries in the Sahel.* FAO Fish. Rep. 445. Rome: FAO: annex e.

Sarch, M.-T. 1996 Fishing and farming at Lake Chad: Overcapitalization, opportunities and fisheries management. *J. Environ. Mgmt* **48**:305–20.

—, 1997 Fishing and farming at Lake Chad: implications for fisheries development. *Dev. Policy Rev.* **15**: 1–17.

—, 1999 Fishing and farming at Lake Chad: a livelihood analysis. Unpublished PhD thesis, School of Development Studies, University of East Anglia, Norwich.

Scoones, I. 1998 Sustainable rural livelihoods: a framework for analysis. *IDS Working Paper No 72.* Brighton, UK: Institute for Development Studies.

Sikes, S.K. 1972 *Lake Chad.* London: Eyre Methuen.

Stauch, A. 1977 Fish statistics in the Lake Chad Basin during the 'drought (1969–1976). *Cahiers ORSTOM séries hydrobiologie* **X1**(3): 201–15.

Sturm, H.-J., Franke, I., Kirscht, H., Ataholo, M. and Skorupinski, T. 1996 Natural environment and land use in the Chad Basin, NE Nigeria: preliminary results of an interdisciplinary research. In *Berichte des Sonderforschungsbereichs 268.* Frankfurt am Main: Goethe Univeristy: 335–48.

Thambyapillay, G.G.R. 1983 The palaeo-hydroclimatology of Lake Chad. *Ann. Borno* **1**: 105–47.

Tilho, J. 1910 The French mission to Lake Chad. *Geogrl J.* **36**: 271–88.

—, 1928 Variations et disparition possible du Tchad. *Ann. Geographie* **37**: 238–60.

Tuley, P. (ed.) 1972 *The land resources of North East Nigeria. Land Resources Study No 9.* Land Resources Division, Overseas Development Administration, London: ODA.

World Bank, 1989 *Nigeria. Strategy for agricultural growth.* Western Africa Agriculture Operations Division Main Report No 7988-UNI. Washington DC: World Bank.

Wright, J.B., Hastings, D.A., Jones, W.B. and Williams, H.R. 1985 *Geology and mineral resources of West Africa.* London: George Allen and Unwin.