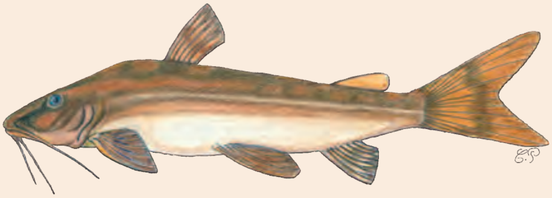
Variability of climate and hydrological systems

CHRISTIAN LÉVÊQUE



The role of hydrology in the structuring of aquatic ecology has long been well-acknowledged (Statzner & Highler, 1986; Junk *et al.*, 1989; Lowe McConnell, 1987). Of equal importance is the understanding of the history of aquatic environments in order to accurately understand the present composition and structure of communities (Lévêque, 1997a). Ichthyologists therefore have granted much attention to the hydrological conditions of environments inhabited by fish. Hydrological variability resulting from the seasonal distribution of rains or inter-annual variations in precipitation has substantial consequences for the biology and dynamics of fish communities.

Rainfall is distributed very unevenly in Africa (figure 2.1). In parts of the west coast, for example, annual rainfall averages more than 1,250 centimetres. In contrast, more than half of Africa receives less than 50 centimetres) of rainfall yearly. The Sahara and the Namib Desert receive an average of less than 10-25 centimetres a year. In parts of the deserts, rain may not fall for six or seven years in a row. The annual rainfall is normally higher at the equator and diminishes towards the tropics, but nevertheless with local variations that can be linked to relief or to other geomorphologic factors.

The existence and the range of aquatic environments depend mainly on climatic conditions, particularly the link between gains and losses in water during seasonal cycles or in long-term changes at geological time scales. This results in a highly contrasted distribution of aquatic environments, with vast zones (40 to 50% of the continent) in which permanent hydrographical systems are extremely reduced or absent (figure 2.2; see also box “From Mega to Marshy Chad” and chapter *The diversity of aquatic environments*).

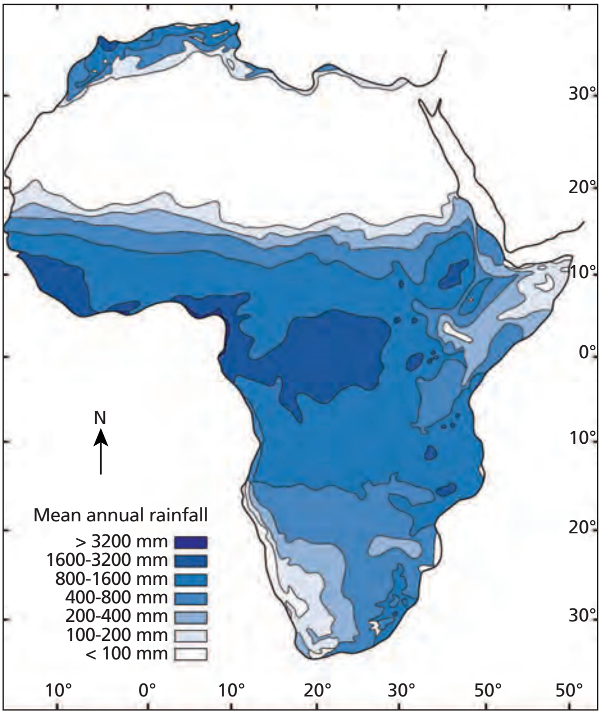


FIGURE 2.1.
Distribution of mean annual rainfall (from Balek, 1977).

FIGURE 2.2.
Comparison between the current geographical distribution of river and lacustrine systems (right) with that of the theoretical maxima that these systems attained during wetter periods (left) (from Dürr, 2003).

Seasonal climatic variations and river discharge

Climatic conditions depend on the circulation of air currents driven by the energy budget of the earth-atmosphere system. The equator is a zone of updraft in which air currents cool during their rise and then descend at the subtropical anticyclone level. These in turn re-converge around the equator forming trade winds. The meteorological equator, or convergence zone of the trade winds, does not coincide with the exact position of the geographical equator, and is situated about 5°N during the boreal winter and about 10°N during the boreal summer.

During the year, the distribution of rainfall at different latitudes is uneven. At the equator it rains throughout the year with two maxima, one in April, and the other in November. North and to the south of the equator, rain distribution patterns become more seasonal, leading towards a single rain season. In the tropics, the rain season becomes comparatively short, with a peak in July-August in the northern hemisphere, and January-February in the southern hemisphere. The relative humidity of the air diminishes while evaporation increases considerably with distance from the equator.

River discharge varies considerably following the seasonality of rainfall, and two major types of hydrological systems are recognized, reflecting strict rain patterns:

- Equatorial systems characterized by a sustained flow throughout the year and two flood periods (Congo and Ogowe, figure 2.3)

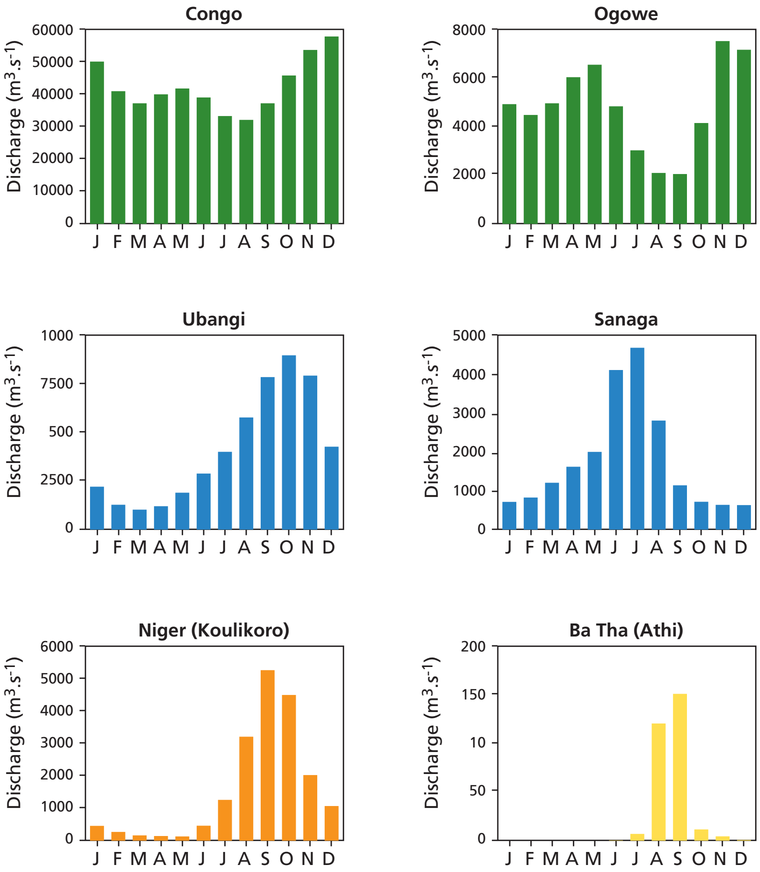


FIGURE 2.3.

Comparison of the hydrological systems of some African rivers (discharge in m^3 per second): *Sahelian type*: Ba Tha at Ati, Chad (data from Orstom) *Tropical type*: Niger at Koulikoro, Mali (data from Orstom) *Tropical transition type:* Sanaga at Edéa, Cameroon (according to Olivry, 1986) Ubangi at Bangui, RCA (data from Orstom) *Equatorial type:* Ogowe at Lambaréné, Gabon (data from Orstom) Congo at Brazzaville, Republic of the Congo *(data from Orstom).*

- Tropical systems with a single flood period more or less spread out over the year, followed by a dry period. This system may be further distinguished into:
  - – transitional tropical systems (an intermediate between tropical and equatorial system) in which the high water period is longer than the lowest water level period (for example the Ubangi in Congo and the Sanaga River in Cameroon, figure 2.3);
  - – tropical systems where the low water period is slightly more significant than the flood period (the Niger River is a good example of that, figure 2.3);
  - – Sahelian systems in which the flood period is limited to some months in the year, while the discharge is interrupted for several months (observed in the Ba Tha River at Ati in Chad, figure 2.3). The extreme situation is that of rivers in desert zones where flow is limited to flash floods after storms.

Average discharges of medium and large rivers that accumulate flows from several tributaries are relatively regular throughout the year. Meanwhile, smaller rivers are characterized by large seasonal fluctuations of water levels. These fluctuations reflect the uneven distribution of rainfalls.

In addition, certain rivers have more or less pronounced low water levels, sometimes with periods during which flow is completely interrupted. Such intermittent rivers, such as the Red Volta River in Burkina Faso or the Baoulé River in Mali, do not offer the same ecological conditions for aquatic fauna as perennial rivers would.

Climatic and hydrological variability over decades and centuries

Numerous studies had focused on the considerable inter-annual variability and irregular distribution of rains and their impact on river discharge, especially since the drought of the Sahel that started in the early 1970s. The annual peaks of precipitation in the Sudano-Guinean region showed a downward trend since as early as 1968. This rarefaction seems to have continued over a period of about twenty years. During the 1980s, the duration of drought in central Africa became more prolonged and large rivers of tropical humid and equatorial zones of Africa were in turn seriously affected by reduced flows. Even if a recent improvement were to occur, it would remain insignificant because annual precipitations are still deficient (Olivry *et al.*, 1995).

Data has been collected since the beginning of the 20th century on the discharges of some large Sahelo-Sudanian rivers such as the Senegal, Niger and the Nile (figure 2.4), as well as several decades of data from other rivers. These data indicate that the recent drought in the Sahel is not a unique phenomenon, but that similar conditions had existed during the 20th century particularly during the 1910s and 1940s. Between 1950 and 1990, the most humid period in the Sahelian region was observed between 1951 and 1970, with a maximum in 1962-1963 (Mahé, 1993; Mahé *et al.*, 1990). The driest years recorded occurred between 1980 and 1990, with a minimum in 1983.

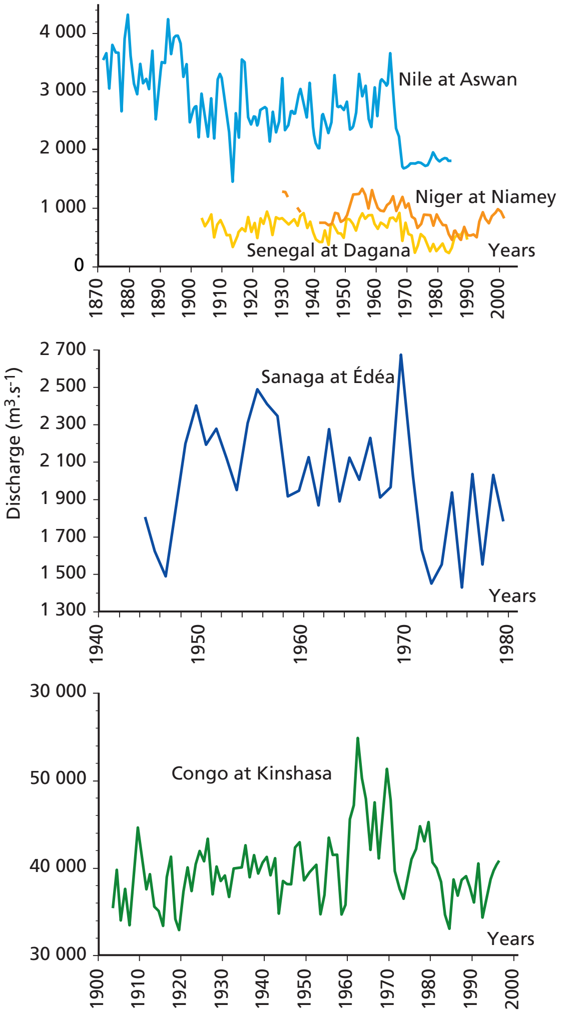


FIGURE 2.4.
Evolution of the average annual discharge of some large African rivers during the 20th century (data from Orstom).

Since 1970 the West African Sahel has experienced a significant drought which appears to correspond to abrupt change (between 1966 and 1970) in the long rainfall series collected since the end of the 19th century (L'Hôte *et al.*, 2002). A similar discontinuity (between 1969 and 1970) was also found for West and Central Africa for the series of regional rainfalls over the period 1951-1989 (Mahé & Olivry, 2001). The Sahel drought persisted into the beginning of the 21st century despite two wet phases in 1994 and 1999 which raised hopes of a remission. The decrease in precipitation observed before and after this disjunction varies between 15 and 30% depending on the zones. One of the first consequences of this decrease in precipitation was a 30 and 60% decline in flow within principal water courses of the region (Olivry *et al.*, 1998). This translates to a decrease of surface water resources which has had consequences for the vegetation cover and has accelerated desertification.

RECESSION OF THE SAHELO-SUDANIAN RIVERS

Variation of rainfall and river flows in the medium term have significant consequences for the evolution of certain continental aquatic ecosystems such as Lake Chad and, more generally, for endorheic lakes. Their hydrological budgets depend principally on supply from tributaries and loss from evaporation.

Lake Chad experienced spectacular changes of the aquatic environment between 1965-1978, with significant consequences for the biology of species and the composition of fish communities (Carmouze *et al.*, 1983; Bénech & Quensière, 1989). The area of the lake decreased from about 25,000 km² in 1965 to only 5,000 km² in the middle of the 1970s, with a decrease of the average depth to 3 m and the transformation from a predominantly lacustrine system to a marsh-type system (see box "From Mega to Marshy Chad").

A comparable situation was observed in Lake Chilwa which dried up in 1968 and then recovered normal water levels between 1969 and 1972 (Kalk *et al.*, 1979).

Lake Naivasha (Kenya) also experienced a period of low levels between 1945 and 1955 (figure 2.5).

Major changes in lacustrine levels have also been observed for other East African lakes. The depth of Lake Turkana for instance decreased by close to 15 m within a century (figure 2.5). Lake Victoria however experienced very high levels in the mid-1960s (see box "Is there a risk of Lake Victoria drying out?").

Lake Malawi, which overflows annually into the Zambezi via the Shire River, experienced an interruption of this connection between 1915 and 1935 when the rainfall fell below normal.

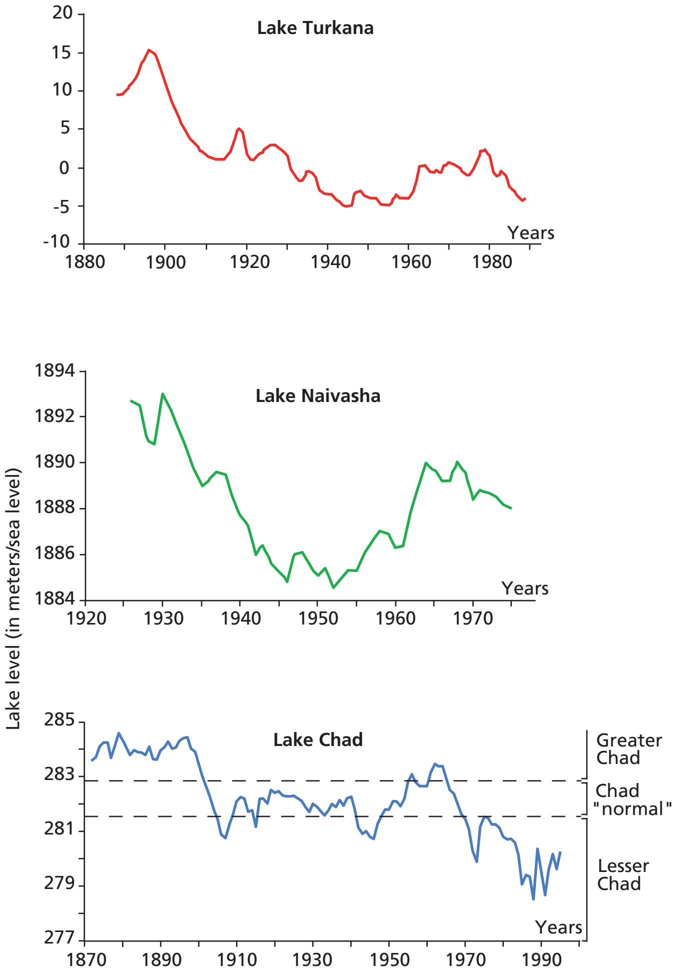


FIGURE 2.5.

Lake depth changes in Lake Turkana (Kolding, 1989), Lake Naivasha (Litterick *et al.*, 1979) and Lake Chad (Olivry *et al.*, 1996).

The Sahel drought had a counterpart in Central Africa, a region also known as "wet Africa" (Laraque *et al.*, 2001). With regards to the equatorial zone, the inter-annual mean discharge of the Congo River is 41,000 $m^3\ s^{-1}$ for a recorded period of 86 years, with extreme mean from 55,200 $m^3\ s^{-1}$ in 1962 to 33,300 $m^3\ s^{-1}$ in 1984. The river was comparatively regular over the entire period up to 1960, while for 1960-1970 exceptional floods were recorded in 1961, 1962 and 1969. The means in the 1970s were closer to normal but with a period of great deficit, centred around 1972-1973, which chronologically corresponds to the beginning of the Sahelian drought. The 1980-1990 period marked a decade of generally diminished river flows, particularly in 1984 (Olivry *et al.*, 1995).

The decrease in river flood discharges is not the only consequence of the drought. There is also a decrease in low water level discharge resulting from depleted groundwater. The reduction of the flow of certain tropical rivers, marked by longer and more frequent interruptions during the low water period, has adversely affected fish communities.

Long-term climatic and hydrological changes

Long-term change in rainfall and the extent of aquatic ecosystems can be reconstructed using various methods (study of sediments, fossil diatoms, etc.) or deduced from ancient climatic fluctuations (palaeoclimates) which are underscored by changes in terrestrial vegetation. Variations in the expansion of dense tropical rain forests which cover regions that receive at least a monthly rainfall of 100 mm, and whose average annual temperature exceeds 24°C without any period of freezing, are useful for the study of climatic changes in geological time.

Climatic changes over millennia

From around 150,000 to 130,000 years ago, Africa experienced colder and more arid periods than present conditions. About 130,000 years ago, a warm phase moister than the present began, and this lasted until about 115,000 years ago, with greater rainforest extent and the deserts almost completely covered with vegetation. A rise of sea level occurred some 140,000 years ago and reached a maximum 125,000 years ago. This phenomenon was accompanied by increased temperatures and rainfall, translating into a major humid period in the Sahara (Petit-Maire, 1994; Leroux, 1994).

Progressive change of the climate has been observed during the last 115,000 years with periods of degradation followed by regeneration of terrestrial environments varying substantially according to latitude. Little is known about the periods between 100,000 and 50,000 years before present (BP). Phases of cooling and drying of the climate led to a cold, arid maximum about 70,000 years ago, Between 50 and 40,000 years BP a dry phase occurred in

IS THERE A RISK OF LAKE VICTORIA DRYING OUT?

Lake Victoria plays a vital role in supporting the millions of people living around its shores. The basin serves as a major source of employment for some 30 million people, of which 80% are engaged in agriculture. For a long time, the lake has been subjected to a high level of eutrophication. This phenomenon is a result of human activities, mainly agricultural development because the surrounding basin is intensely cultivated.

Lake Victoria's water level remained relatively stable from the turn of the 20th century to 1960. In late 1961 and early 1962, the lake received unusual and abundant rainfall and unexpectedly rose 2.5 metres. The water level has remained above average for more than 40 years since 1963. However, *the lake's surface lowered progressively* and the lowest level since the beginning of the 1960s was recorded in 2005 (figure 2.6). The lowering of the lake had economic consequences: ports were closer to closure, and it caused some regions on the lake to institute water rationing.

The lake level became therefore a matter of concern, and a debate rose about the causes of the lake level changes: rainfall variability or human impacts?

The lake typically recharges during the "short rain" (October-December) and "long rain" (February-June) seasons. It seems that the water level of Lake Victoria is extremely sensitive to moderate changes in rainfall (at least 80% contribution to the water budget) over the lake and its catchments (UNEP, 2004b). According to Mangeni (2006) no significant influence on lake level could be deduced from changes in rainfall, evaporation and drought conditions, as these remained essentially about average at least up to 2004. Another study established an annual water balance model of Lake Victoria for the period 1925-2000 (Tate *et al.*, 2004) (figure 2.6). Climate changes scenarios were applied to the lake rainfall inflows series and evaporation data to estimate future water balances of the lake. The scenarios produced a potential fall in lake levels by the 2030s and a rise by the 2080s. On the other hand, Yousef Shahinaz & Amer (2003) pointed out a very close relationship between solar forcing and the level of Lake Victoria (and other lakes).

However, some other hypotheses accused the power stations established on the Ripon Falls, the lake's only outlet, to contribute to the depletion of the lake. In 1954, Owens Falls Dam (later renamed Nalubaale) was commissioned downstream of Ripon Falls to generate hydroelectricity along the Victoria Nile River and became Uganda's largest power station. The Nalubaale power station was recently expanded by Kiira power station located about one kilometre above. Comparison of the trend of the Jinja releases and satellite Lake Victoria height variations was carried out from 1998 to 2004 (Mangeni, 2006). The results indicated that the releases of the dams were no longer based on the agreed operational rule curve after 2001. More water than authorized was being released. Soon after, a consultant also claimed that the power stations were using more water than allowed (Kull, 2006).

The question is not yet completely solved. Independent of the dams' releases, the water levels of the lake seem to be mainly controlled by the climatic balance of the inflows (mainly rainfalls) and outflows. At the beginning of 2007 the water level of Lake Victoria had increased substantially and was still rising due to ongoing rains. This event supports the proponents of climatic variability!

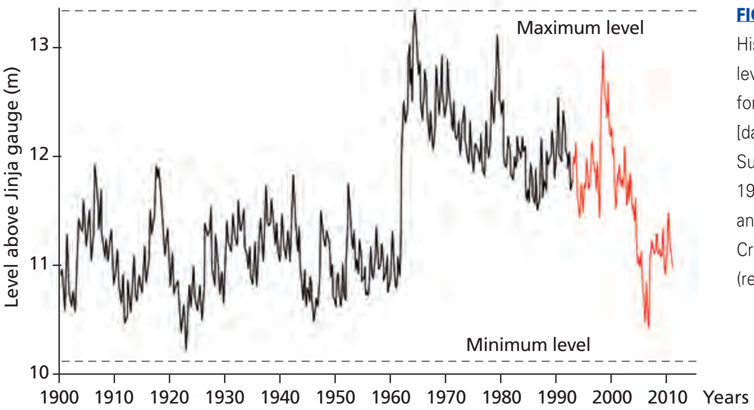


FIGURE 2.6.
Historical water level elevations for Lake Victoria [data from Sutcliffe & Parks, 1999 (black) and Legos: Crétaux *et al.*, 2011 (red).

FROM MEGA TO MARSHY CHAD

The impact of climate through changes in precipitation and enhanced evaporation could have profound effects in river discharges and lakes levels. Lakes for instance are sensitive to climate variability via pronounced changes in storage, leading, in some cases, to drying, changes in their extent, reduced outflow, etc.

Lake Chad provides a very good example of such dynamic systems which are constantly changing in size, shape, and depth. This very shallow endorheic system is particularly sensitive to fluctuations in water budget (rainfall, discharge and evaporation), which occurs both annually and over decades. A Mega Chad probably occurred some 10 000 years ago, covering at least 300 000 km^2 (almost the size of the Caspian sea) (UNEP, 2004a). More recently, many observations suggest that the level of Lake Chad fluctuated during the 19th and the beginning of the 20th century (figures 2.7 and 2.8). In the 1960s Lake Chad was, however, the sixth largest lake in the world (25,000 km^2). Since that time, the volume and area decreased rapidly as a response to the Sahelian drought. It is now no more than a small marshy area (less than 1,500 km^2) close to the Chari mouth (see figure 2.9). There is a debate on the reasons for this low water situation. Is it the consequence of climate change or does it result from human influence through water diversion and extraction for irrigation? Plainly speaking, the climate has without a doubt been the main driving factor.

So, in a few decades, the aquatic system completely changed, as well as the aquatic fauna, as the result of "non-anthropogenic" changes.

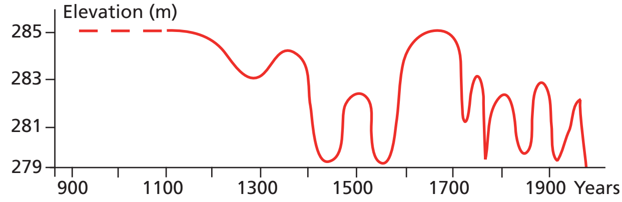


FIGURE 2.7.

Evolution of Lake Chad level over the last millennium (from Maley, 1981).

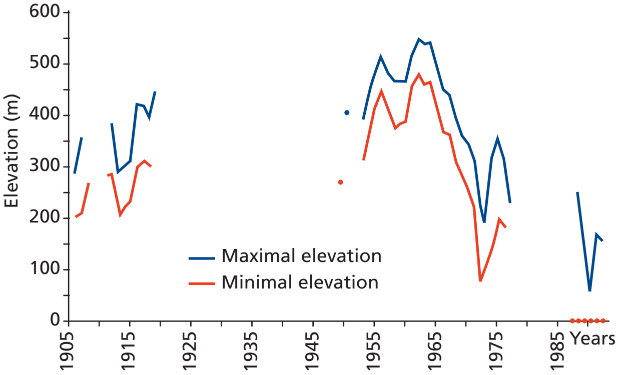


FIGURE 2.8.

Evolution of Lake Chad level over the last century (from Olivry *et al.*, 1996).

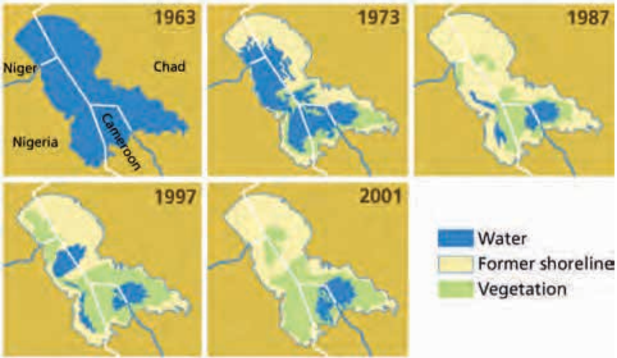


FIGURE 2.9.

Chronology of the reduction of open water affecting Lake Chad (UNEP GIWA, 2004). Maps were taken in January each year and have been sourced from satellite images provided by NASA Goddard Space Flight Center.

the Niger, followed by two humid episodes until 20,000 years BP although in general, the African continent experienced hot and humid conditions between 25,000 to 22,000 years BP with temperature and rainfall slightly above the present.

The past 20 kyears encompass extreme climatic conditions, including the last glacial maximum (LGM) around 18 kyears ago and the early Holocene (10-4.5 kyears BP) when monsoon rainfall in the northern tropics was considerably reinforced in response to orbital forcing.

Lake level records show evidence of several short-term dry periods from 13 kyears BP to present in Africa. The major ones occurred during the following intervals: 11-9.5 kyears BP, 8-7 kyears BP, 6 kyears BP, and 4-3 kyears BP (Gasse, 1998).

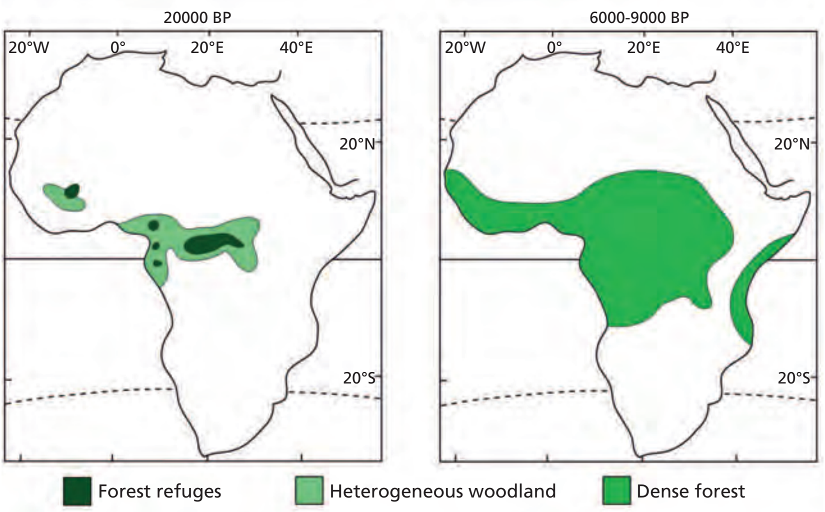
The last glacial maximum was characterized by an overall decrease of the average temperatures by approximately 8°C relative to the present for the whole of northern Africa (Frenzel *et al.*, 1992) and more accentuated cold temperatures on the borders of North and South Africa. The ocean level was 130 m below the current level. In the Sahara, the highlands of the Hoggar and Tibesti Mountain ranges received comparatively high rainfall, Meanwhile, low altitude zones and the sub-Saharan zones progressively dried out. The general decrease in rainfall resulted in a decrease in lake levels. For instance, Lake Chad disappeared around 15,000 years BP. Lake Tanganyika was at least 300 m below its present level. River systems were disrupted, an example being the Niger River whose flow was interrupted by dunes in its internal delta. Likewise, the lower valley of the Nile was also invaded by dunes after 17,000 years BP. In East Africa, Lake Tanganyika experienced a phase of regression between 17,000 to 12,500 years BP, with near-total drying of the southern basin and a decrease in depth of some 300 m relative to its current level (Tiercelin *et al.*, 1988). Lake Victoria was also totally different from present conditions some 40,000 years BP. Its lowest levels (75 m below its current level) occurred between 14,700 and 13,700 years BP (Stager *et al.*, 1986) at which time it was alkaline, endorheic, and occupied a very small area. Johnson *et al.* (1996) estimated that Lake Victoria was completely dried out 17,000 years ago, which somewhat perplexes ichthyologists interested in the hundreds of endemic Cichlid species of the lake and in their origins. If complete desiccation occurred, these numerous endemic species may have evolved during the last 12,400 years BP, dating back to the refilling of Lake Victoria which recovered its drainage to the Nile about 12,000 BP.

As a whole, during the last glacial period, vegetation was highly degraded on the African continent with an almost-total disappearance of dense forests except in certain sheltered sites. This led to the formation of savannahs and steppes, and a considerable extension of dune structures especially in the Sahara. Around Lake Barombi Mbo (Cameroon), forest existed in the form of a small island in a semi-arid area (Giresse *et al.*, 1994). However, dense forest was generally replaced by mountain prairies at lower altitudes of 800 to 1,000 m on the Bamileke plateaus (Maley, 1987) due to temperature decreases of about 5 to 6°C. In the Congo basin the savannah expanded progressively to the detriment of the dense humid forest that now exists only in some refuges (highlands and edges of the watercourses) (Colyn, 1987). These changes in climatic conditions and terrestrial environments (figure 2.10) have certainly had an influence on aquatic systems and fish communities although precise data is unavailable at this point.

Past glacial warming was associated with monsoon reactivation. An increase in humidity recurred approximately 12,000 years ago. The Holocene climatic optimum that extended from -9,000 to -6,000 years BP was characterized by a general warming. Rain forest reappeared abruptly in Ghana about 9,000 years BP and, at the same time, there was a decline of highland forests. In Western Africa and the Congo basin the re-colonization by forest may have occurred from refuges in less than a millennium (figure 2.7). There was also an increase in rainfall and a consequent increase of lake levels. The Sahara in particular was well-watered and a multitude of shallow freshwater lakes occupied interdunal depressions; a grass cover developed and grazing herbivores migrated (Petit-Maire, 1991; Petit-Maire *et al.*, 1994). This period was also a period of intensive recharge of the aquifers in the Sahara and the Sahel. Lake Taoudeni to the north of Mali experienced a maximum around 8,000 years BP, while the Niger spread its internal delta to the north of Timbuktu. The Saharan tributaries of the Niger, Senegal and Chad had a quasi-permanent flow. Lakes Ziway, Langano, Abijatta and Shala in the Ethiopian Rift formed a single lake and Lake Abbe in the Dankali depression was 160 m above its current level (Gasse *et al.*, 1980). In southern Africa, climatic optimum is expected to have occurred between 10,000 and 8,000 years BP.

FIGURE 2.10.

Variations of the extent of tropical humid forest during the last glacial cycle (according to Leroux, 1994).



Following the humid phase, rainfall declined in the Sahara although the climate remained comparatively humid until about -4,500 years BP. This marked new climatic changes in Africa with aridification within the Sahara and decline of the hydrologic conditions. The present tendency in the evolution of the climate is seemingly towards a cold scenario with reduction of about 0.01°C per century in global temperatures.

Over the last 20,000 years, the position of the Sahara-Sahel boundary has experienced major fluctuations linked to these climatic variations (figure 2.11).

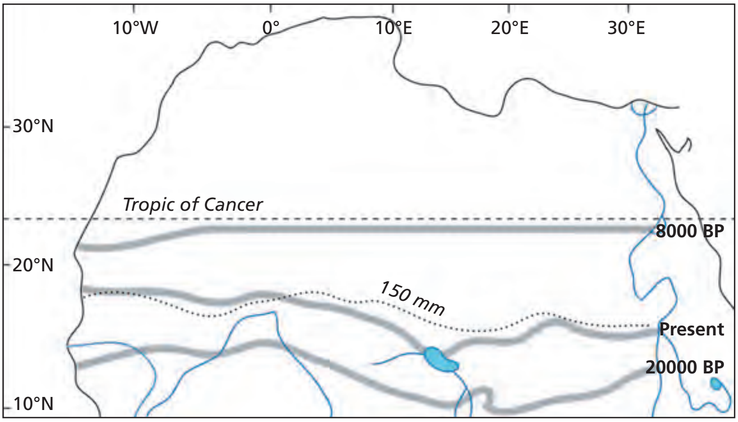


FIGURE 2.11.
The displacement of the Sahara-Sahel boundary over the last 20,000 years (from Petit-Maire, 1994).

RELICT FAUNA IN THE SAHARA

Since the beginning of the century numerous adventurers have brought back fish captured from small water bodies in the Sahara (gueltas, wadis). About fifteen species have been identified (Lévêque, 1990), consisting of several *Barbus* (*B. apleurogramma*, *B. bynni occidentalis*, *B. deserti*, *B. macrops*, *B. pobeguini*), two species of *Labeo* (*L. niloticus* and *L. parvus*), *Raiamas senegalensis*, two species of *Clarias* (*C. anguillaris*, *C. gariepinus*), one Cyprinodontidae (*Epiplatys spilargyreius*), and three Cichlidae (*Hemichromis bimaculatus*, *Sarotherodon galilaeus*, *Coptodon zillii*). The largest number of species were collected from the Ennedi-Tibesti region, live fish were however captured in Adrar of Mauritania, Hoggar and Tassili N' Ajjer. Almost all the species, with the exception of *B. apleurogramma* and *B. deserti*, are present in the southern Nilo-Sudanian pools. It is now well established that these species are the relics of a rainy era during which the Chad and Niger basins extended much farther north (see Servant, 1973; Talbot, 1980). The current populations were isolated approximately 5 to 6,000 years ago.

B. apleurogramma is currently only known from Lake Victoria and its tributaries. It is probable that it is a relic type of an older fauna that extended more to the north and that disappeared, partly due to the numerous climatic changes that affected this region for more than 2 million years.
B. deserti on the other hand was found on the versants of Tassili and in Libya.

(see also chapter *Fish communities in small aquatic ecosystems: caves, gueltas, crater and salt lakes*.

LAKE SEDIMENTS RECORD CLIMATIC HISTORY

The study of lake sediments allows the acquisition of information relating to the characteristics of aquatic ecosystems during different historical periods, and also to deduce information on the variability of climatic conditions.

In a sediment core realized for Lake Tritrivakely in Madagascar, Gasse *et al*. (1994) and Sifeddine *et al* . (1995) demonstrated a succession of very different environments.

- 36,000 years ago, the climate was humid, the lake was filled with water and the organic sedimentation was owed principally to phytoplankton.
- between 36,000 and 20,000 years BP, progressive aridification of climatic conditions and colonization of the bottom of the lake by peat bog vegetation translate to an important decrease in water levels.
- about 20,000 years ago, during the last glacial maximum, biological production was very weak, with the near-absence of diatoms and of aquatic plants in sediments suggesting partial periods of drying up.
- conditions favourable to aquatic life were re-established at about 14,500 years BP with the presence of organic matter derived from phytoplankton in large abundance. The climate once again became humid with a maximum between 9,000 and 6,000 years.
- the period 6,000 years before present began with the existence of a peat bog, which indicates a period of drying up. This period was followed by a humid period that manifested as a lacustrine type of sedimentation, culminating in the current peat bog which appears linked to the progressive filling up of the lake.

Climatic changes over millions of years

The geographic distribution of large assemblages of vegetation that we currently observe within the African continent date back about 14 million years, *i.e.,* during the time of the positioning of the African continent in its current geographic location. Previously, Africa's location was further south, such that the Sahara was traversed by the equator. 60 million years ago, dense rain forest occupied the whole of North Africa up to the Mediterranean coast (figure 2.12).

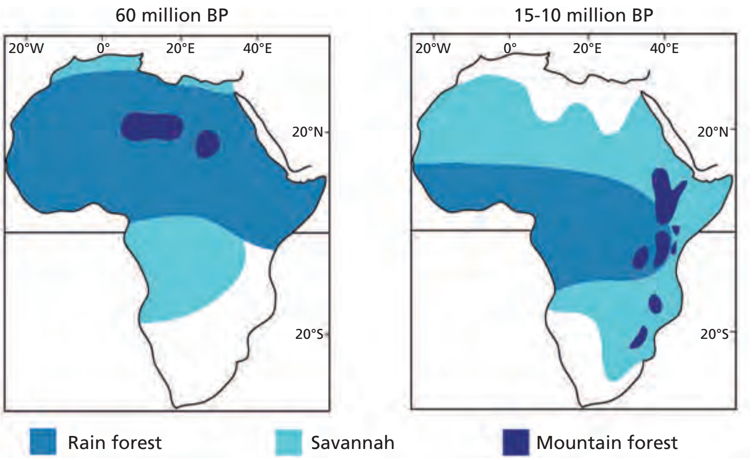


FIGURE 2.12.
Distribution of the large assemblages of vegetation during the Tertiary period (from Bonnefille, 1993).

About 6 million years ago, the Earth's climate underwent significant modifications referred to as the "Messinian salinity crisis", linked to the spread of the Antarctic glaciation. The first major arid period in Africa, marked by the extension of the savannahs, dates back 2.5 million years. During the same era, significant cooling appeared leading to the formation of ice caps in the northern hemisphere.

From this period the global climate experienced repeated glacial/interglacial cycles, with a periodicity of about 40,000 years between 2.5 and 0.7 million years ago and a periodicity of 100,000 years over the last 700,000 years. Some 20,000 years ago, the glacial period coincided with the major extension of icecaps. It has been shown that these glacial periods lasted on average ten times longer than the interglacial periods. As a result, past periods of tropical drought lasted ten times longer than wet periods.

The palaeoclimatic history over the last three million years indicates the occurrence of an alternation of dry and wet periods which allowed the restoration of permanent aquatic ecosystems (Bonnefille, 1993). The recent drought in the Sahel is thus not exceptional, and is in accordance with this climate variability, without predicting whether it is a long-term or short-term event.

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The Inland Water Fishes of Africa

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