II. The main types of communities and their evolution during a drought period

5. The aquatic vegetation of Lake Chad

André Iltis and Jacques Lemoalle

The phanerogamic vegetation of the lake was studied by Leonard (1969, 1974) during two surveys carried out in December 1964 and January–February 1968. The species composition and the location of the populations were determined and some observations on the aquatic vegetation of the then reduced lake area were made by Chouret and Lemoalle (1974), Fotius (1974), Fotius and Lemoalle (1976). These observations follow the changes in the lake basin which are related to the continuing slow recession of water since 1968. Due to travelling difficulties in the marshy or recently dried zones, the last surveys were made only in the south basin, while only some aerial surveys of the north basin could be made.

The existence, composition and population density are influenced by different ecological factors of which the principal ones are:

— the variations in water level which determine total or partial dryness during the period of lake contraction and determine the height and the duration or submersion at the time of high water;
— the nature and the slope of the substrate;
— the exposure to wind and its force; wave action determining the presence or absence of certain floating species highly sensitive to the disturbance of water;
— the physico-chemical composition of the water which is progressively loaded with salt with increasing distance from the Shari delta.

During the stage 'Normal Chad' until the end of 1972, the aquatic vegetation could be considered to be highly developed in comparison to that existing in the shallow European or African lakes. However the vegetation cover was limited to the deltaic zones; to the borders of the archipelago islands and to the floating islands which detach from it; to the shallower areas of the eastern part of the lake; and to the shallows. After this period, the stage 'Lesser Chad' can be distinguished, when this vegetation cover extended over approximately 50% of the normal lake basin. The drying up of vast areas situated below the former shore line and the appearance of extensive marshy zones with some temporary drying up gave rise to the development of considerable aquatic vegetation relatively poor in species.

J.-P. Carmouze et al. (eds.) Lake Chad

ISBN 90 6193 106 1. Printed in the Netherlands

Photo 7 Aerial photograph of an island showing the fringe of aquatic macrophytes.

5.1 'Normal Chad' stage

5.1.1 *Main species associations*

— *Potamogeton* spp. and *Vallisneria* sp. association
Found in aquatic vegetation in weak currents, it is well represented east of the Shari delta and scattered through the lake. It also often includes two genera, *Najas* sp. and *Ceratophyllum demersum*. Several different groups can be distinguished which are characterized by the dominance, sometimes exclusive, of each constituent of this association.

— *Nymphaea* spp and *Utricularia* spp. (Nymphaeïdae association)
This is found in the sheltered bays, the leeward shores and the ponds.

— *Pistia stratiotes* and *Lemna perpusilla* association
This is an association of floating plants, characteristic of sheltered zones and more particularly of sheltered and open bays with semi-aquatic vegetation. It includes some *Spirodela polyrhiza*, *Azolla africana* (on the surface) and often *Ceratophyllum demersum*. It is found almost everywhere in the lake but especially in the south, and in the El Beïd and Yobé deltas. It is absent from the Shari delta.

Photo 8 Palm tree ('doum').

— *Ludwigia adscendens* subsp. *diffusa* association
This semi-aquatic vegetation, spread over the water's edge, is found in the sheltered bays and in the fringes of the aquatic meadows and reed beds. It includes some *Ipomoea aquatica* and *Neptunia oleracea* and dynamically follows the *Pistia stratiotes* and *Lemna perpusilla* association. It is widely spread throughout the lake especially in the south and particularly well represented in the deltas of the El Beïd and the Yobé.
— *Cyperus laevigatus* association
This association is characteristic of the fringes of the salt ponds of the Sahel zone and is frequently found around the Kanem lakes, a region bordering northern Lake Chad. It also appears very sporadically in the extreme north of the lake, where the waters have the highest dissolved salt concentration.
— Aquatic meadows of *Vossia cuspidata*
This is a semi-aquatic, well-spread grassy plant which is dominant in the Shari and El Beïd deltas. The series often includes the reed fringes in some other parts of the lake. Though abundant in the south and the east, the *Vossia* meadows are progressively scarce close to the 'Great Barrier', north of which the papyrus become yellowish and less developed. They progressively disappear and are almost absent from the northern border of the lake.

— *Phragmites australis* subsp. *altissimus* (Phragmitidae) association
The established populations form reed belts with a dense surface root mat and some tropical creepers. It is a very frequent association throughout the lake and is present in the south (Shari and El Beïd deltas), well developed in the east and the center ('Great Barrier') and clearly dominant in the northern part.

— *Typha australis* (Typhidae) association
The established population forms reed belts but without floating root mats and thus only very rarely with tropical creepers. This association, which forms some scattered groups, is absent in the south, fairly well represented in the east and the center and well developed in the north.

— *Aeschynomene elaphroxylon* (local name 'ambatch') group
This bush can reach five to six meters high and is scattered throughout the zone of the reed islands and on the border of the islands of the archipelago but appears to be absent in the south of the lake.

— Vegetation of the archipelago
Two different zones can be distinguished: (a) the zones of flat islands with long submerged aquatic meadows of *Leersia hexandra* and *Echinochloa* sp., or with long dried meadows of *Panicum repens* and *Sporobolus spicatus*, or with a belt of *Hyphaene thebaïca* ('doum' palm) in the high waters. These flat islands are especially abundant in the Northeastern Archipelago; (b) the

Photo 9 Fishermen camp on a reed island.

zones of islands which have prominent relief and so are never submerged, with a vegetation of Sahelian trees: *Acacia* sp., *Calotropis procera*, *Leptadenia* sp. and a belt of *Hyphaene thebaïca*. These islands constitute the major part of the Southeastern and Eastern Archipelago.

5.1.2 *Morphology of the vegetation*

The lake vegetation can be grouped according to species composition and the zone in which it is developed. Thus several major types of communities can be distinguished.

5.1.2.1 *Aquatic meadows*. Found especially in the deltaic zones, the aquatic meadows cover a triangular zone about 15 to 20 km at the outlet of the Shari. The river waters flow through it by some well-defined channels during recession and by filtering through the vegetation during high waters. *Vossia cuspidata*, which occurs in one to three meters of water is the most widespread species.

On the borders of the lake, the *Vossia cuspidata* meadows are replaced by meadows of *Cyperus papyrus* or *Phragmites australis*. The co-existing species are identical in the three areas.

Photo 10 Papyrus float used by local people to cross channels between islands.

The surveys made in the Shari delta showed the following species[a]:

	Vossia cuspidata meadow		*Cyperus papyrus* meadow	*Phragmites australis* meadow
	1st survey	2nd survey		
Vossia cuspidata	5.5	5.5	1.1	1.1
Ludwigia adscendens subsp. *diffusa*	+0.1	1.2	+0.1	
Cyperus papyrus subsp. *miliaceus*	+0.1	+0.2	5.5	
Phragmites australis	+0.1			5.5
Oxystelma bornouense		+0.2		2.1
Luffa cylindrica		1.3	2.2	
Cayratia sp.		+0.2	1.2	1.1
Thelypteris totta			+0.2	
Ipomoea rubens			1.2	1.1
Ipomoea aquatica			1.2	
Vigna sp.			+0.2	
Cyperus sp.			+0.1	

[a]Abundance and dominance notation (Braun-Blanquet):
+ = rare or very rare individuals, covering very low percentage of the area
1 = fairly abundant individuals but covering low percentage of the area
2 = very abundant individuals or found in 1/20 of the area
3 = individuals covering from $\frac{1}{4}$ to $\frac{1}{2}$ of the area
4 = individuals covering from $\frac{1}{2}$ to $\frac{3}{4}$ of the area
5 = individuals covering from more than $\frac{3}{4}$ of the area
Arrangement of the individuals of the same species in comparison to each other: 1. isolated individuals; 2. in group; 3. in set; 4. in small colonies; 5. in populations.

5.1.2.2 *Reed islands.* These are the vegetation islands established on the shallows and associated with *Cyperus papyrus* and *Phragmites* as well as other less abundant species. The latter develop on a compost of rhizoïdes and roots forming a thick mat of one to two meters under the water surface. The islands are anchored in the shallows whose form and size determines that of the reed island. These vegetation formations which can be several hundred meters long often include some clear gaps and some small closed ponds where some associations characteristic of sheltered waters develop. The reed islands occupy all the eastern part of the lake and are abundant in the region of the 'Great Barrier'. They also form a large border up a few kilometers between the open waters and the archipelago.

The group of the Tarara reed islands, situated a few kilometers northeast of

the Shari delta are composed of the following species:

Central zone, about 50 to 100 m wide		
	Phragmites australis	5.5
	Cayratia sp.	1.1
Circular zone about 30 m wide		
	Cyperus papyrus ssp. *miliaceus*	5.5
	Ipomoea rubens	1.2
	Melothria sp.	+0.2
	Luffa cylindrica	1.2
	Vigna sp.	1.2
Circular zone about 5 to 10 m wide		
	Vossia cuspidata	5.5
	Cayratia sp.	1.1
	Ipomoea rubens	+0.1
	Polygonum sp.	+0.2
	Ludwigia adscendens subsp. *diffusa*	+0.2
	Cyperus imbricatus	+0.1
	Alternanthera sessilis	+0.2
	Cyperus papyrus subsp. *miliaceus*	1.1
Floating layer on the surface, about 2 m wide, sometimes absent		
	Pycreus mundtii	4.4
	Ludwigia stolonifera	1.1
	Cyperus nudicaulis	2.2
	Ipomoea aquatica	+0.1
	Neptunia oleracea	+0.1

In the north basin of the lake, the numbers of species on the reed islands decreases and *Vossia cuspidata* and *Cyperus papyrus* disappear towards the northern coast.

5.1.2.3 *Floating islands*. Some floating islands detach from the reed islands or from the vegetation borders of the islands and archipelago peninsulas and float away as they are pushed by the wind. Consisting most often of *Cyperus papyrus* and more rarely of *Phragmites* or *Vossia*, these islands are usually circular and are locally called 'kirtas'. Their size varies from a few meters to several hundred meters. At the time of the reversal of the dominant winds, during June and October and generally in the rainy season when the wind shifts are frequent during tornadoes, these islands move back and forth, modifying the aspect of the reed islands and closing the channels of the archipelagoes. The composition of the vegetation on these islands is similar to that seen on the reed islands.

The 'kirtas' were very numerous especially in the archipelago of the south

basin until 1967 and the boats en route to Bol were often blocked for several days by the floating papyrus. These islands disappeared fairly quickly when the average level of the lake decreased below 282 m.

5.1.2.4 *Vegetation borders of the islands of the archipelago.* All the islands and peninsulas of the archipelago possess a vegetation fringe several meters wide and three to four meters high. *Cyperus papyrus*, *Vossia cuspidata* and especially *Phragmites australis* are the most abundant and largest species. At the base of the reeds, there are floating plants such as *Lemna perpusilla*, *Spirodela polyrhiza*, *Ceratophyllum demersum*, *Pistia stratiotes*. In the northern part of the lake, *Cyperus papyrus* is replaced by *Typha australis*. This vegetation barrier is interrupted in only a few places by narrow passages which allow local boats to land.

Three surveys made in three different borders showed the following species:

	1st survey	2nd survey	3rd survey
Phragmites australis	5.5	1.1	1.1
Cyperus papyrus subsp. *miliaceus*		5.5	1.2
Vossia cuspidata		1.2	5.5
Typha australis	+0.2		
Ipomoea aquatica	+0.1		+0.1
Cayratia sp.	1.1		
Oxystelma bornouense	1.1		
Ipomoea rubens	1.1	1.2	
Ludwigia adscendens subsp. *diffusa*	+0.1		
Alternanthera sessilis	+0.1	+0.1	
Polygonum sp.	+0.1	+0.1	
Pycreus mundtii	+0.2		
Lemna perpusilla	+0.1	+0.2	
Spirodela polyrhiza	+0.1		
Melothria sp.	+0.1		
Cyperus sp.	+0.1		
Oldenlandia sp.	+0.1	+0.1	
Luffa cylindrica		2.3	
Eclipta prostrata		+0.1	+0.1
Ceratophyllum demersum	2.2		

Inside this marginal fringe, a zone on the edge of the islands, 2–3 meters wide, is colonized by *Pycreus mundtii* (dominant) with *Leersia hexandra* and *Cyperus articulatus*. This is followed by a belt one to two meters wide of *Cynodon dactylon* circling a zone of doum palms (*Hyphaene thebaïca*) which marks the base of the

slope of the dunes. If the island has fairly marked relief, the summit and the slopes have bushes or trees of *Leptadenia hastata*, *Tinospora bakis*, *Salvadora persica*, *Phyllanthus reticulatus*, *Balanites aegyptiaca*, *Commiphora* sp., *Cassia occidentalis*. A grassy carpet develops during the rainy season (Fig. 1).

5.1.2.5 *Submerged vegetation banks.* These banks are very extensive in the shallow marshy zones situated to the east of the Shari delta, at the foot of the Hadjer el Hamis rock hills. In this region, the coast appears to be poorly delimited and is masked by vegetation. The wider channels are overgrown by beds of *Potamogeton schweinfurthii*, *Vallisneria* sp. and *Ceratophyllum demersum* alternating with emerged vegetation islands of *Vossia* and *Phragmites*.

Some less extensive submerged vegetation banks exist in the southern part of the lake near the El Beïd delta and especially in most of the extremities of the archipelago branches, that is in the Southeastern or Northeastern Archipelago or the channels of open water which penetrate into the vegetation border of the northeast coast.

5.1.3 *Conclusions*

The observations on the aquatic flora covering 2400 km^2 or 12% of the lake surface during the period of 'Normal Chad' (Carmouze et al. 1978) lead to the following conclusions on the distribution of species in the lake.

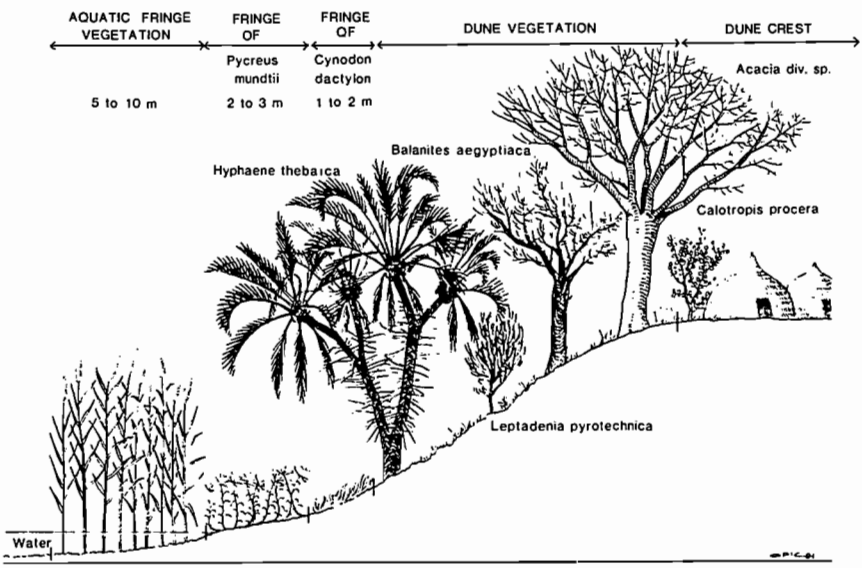

Fig. 1 Zonation of aquatic and terrestrial vegetation on a dune slope in the archipelago.

— the abundance of *Vossia cuspidata* in the entire Shari delta, before its progressive disappearance and removal from this zone;
— the abundance of *Cyperus papyrus* in the south basin of the lake and the 'Great Barrier' and its progressive disappearance in the north basin after an intermediate zone of plants in poor condition;
— the scarcity of *Typha australis* in the south basin and its relative abundance in the north basin illustrated by the local boats, called 'kadeï' being made of *Papyrus* in the south basin and central part of the lake and of *Typha* in the northern part;
— the abundance of *Potamogeton schweinfurthii* as submerged vegetation in the marshy zone to the east of the Shari delta;
— the sporadic but significant appearance in the extreme north of *Cyperus laevigatus*, a species exclusive to the edges of salt ponds.

The structure of reed island vegetation belts where the following concentric zones are found in centripetal order summarizes the development of the vegetation passing from the delta towards the north of the lake:
— to the south, *Vossia cuspidata*, *Cyperus papyrus*, *Phragmites australis*;
— towards the center, *Cyperus papyrus*, *Phragmites australis*, *Typha australis*;
— to the north, *Phragmites australis*, *Typha australis*.

Towards the north, there is a progressive disappearance of several aquatic species and groups. The impoverishment of the flora is directly related to the increasing salt concentration of the water.

5.2 'Lesser Chad' stage

5.2.1 *General remarks*

The observations and descriptions of the vegetation during the period of 'Lesser Chad' appear to be more complex than for the preceding stage because of the partition of the lake into two basins, each evolving independently of each other. On the other hand, during 'Lesser Chad' the lake appears to be very unstable, the effect of the floods being much less dampened in the south basin than in the entire lake during a normal period. On the whole, two periods can be distinguished.
— a period of drought, from 1972 to mid-1975 for the north basin and until the end of 1974 for the south basin. It led to total drought of the northern part of the lake and in the southern basin to a reduction of the open water to area 1500 km^2 and to the isolation of smaller ponds subsisting in the archipelago;
— a period of 'Lesser Chad' from the end of 1974. The south basin filled up to nearly the level of 1972. The north basin remained dry or contained little more than temporary ponds, which filled during the rains or with surplus water from the Shari flood which overflowed from the south basin and emptied through the 'Great Barrier' into the north basin.

The collection of data and observations were hindered by the impossibility or the difficulty of travelling through the invading marshy zones of vegetation which prohibit access to some very extensive regions. The aerial surveys could not solve this problem effectively because the flights needed to be supported by ground surveys. In the future, the use of satellite images may provide some more complete and much more directly utilizable data.

5.2.2 *Different population types*

5.2.2.1 *South basin.* Based on the surveys made in March 1974 (Fotius 1974), successions of plant species can be seen, following the open waters towards the dry ground.

— Shari delta: *Nymphaea* sp., *Ipomoea aquatica*, *Ludwigia adscendens* subsp. *diffusa*, *Sacciolepis africana*, *Vossia cuspidata*, *Aeschynomene elaphroxylon*;
— sandy islands north of the open waters in the southern basin:
  1st survey: *Aeschynomene elaphroxylon*, *Cyperus papyrus*, *Vossia cuspidata*, *Diplachne fusca*, *Cyperus articulatus*, *C. maculatus*;
  2nd survey: *Diplachne fusca*, *Cyperus articulatus*, *C. papyrus*, *Aeschynomene elaphroxylon*;
  3rd survey: *Cyperus articulatus*, *Typha australis*, *Phragmites australis*, *Aeschynomene elaphroxylon*;
— the archipelago island towards Bol: *Cyperus papyrus*, *Typha australis*, *Aeschynomene elaphroxylon*, *C. articulatus*, *Sesbania sesban*, *C. maculatus*, *Phyla nodiflora*, *Cassia occidentalis*, *Calotropis procera*.

From the partial observations made over the first phase of the period of 'Lesser Chad', the development of the lake can be outlined by noting:

— the massive development of *Aeschynomene elaphroxylon* (Ambatch) which existed only sporadically during the period of 'Normal Chad'. These ambatch forests developed on the dried sediments in 1973 and invaded the zones in the process of drying. Some similar species like *Aeschynomene pfundii* or *A. afraspira* are observed mixed with the *A. elaphroxylon* group;
— the extension of meadows of *Vossia cuspidata*, a species whose growth was earlier limited especially in the deltaic regions and to a lesser degree to some points of the Southeastern Archipelago. This species is now very marked in nearly all the surveys of the south basin;
— the recession of the *Phragmites australis* populations. Where the decrease is not obvious the population remaining stable, the % cover has decreased with the development of areas occupied by other aquatic macrophytes;
— the relatively limited development of *Typha australis* which was observed in several points of the archipelago, but never on very large areas;
— the development on dry land of species that were less abundant earlier, such as *Cassia occidentalis*, *Cyperus maculatus*, *Sesbania sesban*, *Phyla nodiflora*

and especially *Calotropis procera*. These plants which are particularly resistant to the drought and are not consumed by the animals, multiply rapidly on the sandy or clayey substrate when they are not flooded.

In the course of the following period, which began in 1974 with the filling up of the southern basin up to about its 1972 level, the aquatic vegetation underwent some modifications. This was partly due to the inundation of areas which had been dry for one to two years and partly due to seasonal variations in the water level caused by the Shari flood. The following observations were made in June 1976 (Fotius and Lemoalle 1976) in different parts of the lake:

— Shari delta
  1. *Vossia cuspidata* (in the water).
  2. *Vossia cuspidata*, *Cyperus articulatus*, *Cardiospermum halicacabum* (on the edge of the bank).
  3. *Eragrostis barteri*, *Vossia cuspidata*, *Echinochloa pyramidalis*, *Phragmites australis*, *Fimbristylis cioniana*, *F. bi-umbellata*, *Cyperus* cf. *clavinus*, *C.* cf. *alopecoroïdes*, *Sphenoclea zeylanica*, *Mariscus* sp., *Rhamphicarpa fistulosa*, *Ludwigia leptocarpa*, *Ludwigia* sp. (cf. *perennis*), *Polycarpon prostratum* (level lower than the edge of the bank).

— Tarara reed island
  1. Central part with *Phragmites australis* surrounded by some groups with *Vossia cuspidata*, *Aeschynomene elaphroxylon* and *Typha australis*.
  2. In a sheltered position, *Cyperus papyrus*, *Ludwigia leptocarpa*, *L. adscendens* subsp. *diffusa*, *Cyperus* sp. (floating), *Nymphaea lotus* and *Ceratophyllum demersum*.

— Kalom reed island
  Vossia cuspidata, *Typha australis*, *Cyperus* sp. (floating), *Leersia hexandra*, *Cyperus nudicaulis*, *Ludwigia leptocarpa* and *Phragmites australis*.

— Baga Sola channel in the archipelago
  1. *Aeschynomene elaphroxylon* forest with an outer border of *Vossia cuspidata*
  2. Other species found: *Ludwigia leptocarpa*, *Cyperus nudicaulis*, *Polygonum* cf. *limbatum*, *P. senegalense*, *P. albotomentosum*, *Nymphaea lotus*, *Ipomoea rubens*, *Pistia stratiotes*, *Leersia hexandra*, *Echinochloa stagnina*, *Cyperus* sp. (floating), *Commelina* sp.

The development of the vegetation in the south basin between 1974 and 1976 can be summarized in the following way:

— almost complete disappearance of *Ipomoea aquatica*, *Aeschynomene afraspera*, *A. pfundii*, *Lemna perpusilla*, *Diplachne fusca*, *Sesbania sesban* var. *nubica*, *Ludwigia adscendens* subsp. *diffusa*, *Sacciolepis africana*;
— considerable regression of stations and/or areas occupied by *Cyperus articulatus*, *C. papyrus*, *Typha australis*, *Polygonum senegalense*;
— stabilization of *Aeschynomene elaphroxylon* populations;
— massive development of *Pistia stratiotes*, *Cyperus nudicaulis*, *Nymphaea lotus*

Photo 11 Papyrus canoe ('Kadei') used by fishermen.

and increase in area covered by *Vossia cuspidata*, *Leersia hexandra* and *Ludwigia leptocarpa*;
— thus two species make up the lacustrine vegetation carpet: *Vossia cuspidata* and *Aeschynomene elaphroxylon*.

5.2.2.2 *North basin.* The water level became lower from year to year in the northern basin until 1975 which corresponds to a complete drying up. The rapidity of the water's retreat hindered vegetation development and plant formations which existed during the period of 'Normal Chad' disappeared over the course of the recession periods. Moreover, the young shoots were heavily grazed by the herds. Around most of the islands, no aquatic vegetation existed, especially on the windward shores. *Typha australis* was only present along some leeward flat shores or the eastern part of the basin. The following survey was made from the water towards the shore near Baga Kiskra (Fotius 1974):
— water;
— open uncovered beach;
— highly grazed cover of various Cyperaceae;
— several small plants of *Aeschynomene elaphroxylon* (5 cm high), similarly grazed;

— strip of decaying *Typha australis* with numerous little shoots mixed with *Phyla nodiflora*, *Pluchea ovalis*, *Sacciolepsis africana*, *Polygonum senegalense*, *Ipomoea rubens*, *Luffa* sp., crassulescent Rubiaceae (*Oldenlandia*?);
— *Calotropis procera* developed on a cover of highly grazed grasses.

Over the course of the period which followed 1975, the depressions in the north basin filled up during the rainy season and as a result of water supplies coming through the 'Great Barrier' acted like some temporary ponds. The information on the vegetation of this period is very limited because of the difficulty of travelling through this zone. Ambatches developed towards the north starting from the 'Great Barrier' and at several points in the eastern part of the basin where this species was found near groups of *Typha australis*.

5.2.3 *Conclusions*

Two periods can be observed, that of the evolution of the macrophytic vegetation during the period of 'Lesser Chad' from 1973 until 1976 and a later one. At first, there was a very marked impoverishment of the vegetation in the north basin while the south basin was overgrown by *Aeschynomene elaphroxylon*, associated with *Vossia cuspidata* and *Ipomoea aquatica* which developed during the low waters.

In the second phase, there was a development of ambatches and to a lesser degree *Typha australis* in the north basin. In the south basin, some considerable modifications were apparent due to the reflooding. The non-perennial plants could be maintained because of the drying of the previously occupied zones while some perennial species were destroyed by submersion, the annual water level oscillations having a higher amplitude than during the period of 'Normal Chad'.

The *Aeschynomene elaphroxylon* forests had their bases drowned in the deepest zones (more than one meter) and in many places they were blown down by the wind and only a few branches continued to develop as shoots. Their populations appeared stable. It is likely that *Vossia cuspidata* and *Cyperus papyrus* became dominant in the south basin, as in several places the establishment and development of these two species was observed in some channels which were cut in the ambatch forests. The zones of open water which appeared inside the extensive group were often colonized by *Pistia stratiotes*.

In May 1976, in the south basin (east of a line Baga Kawa–Baga Sola), the area occupied by the macrophytes was estimated as 3270 km^2 for a total inundated area of 5960 km^2 (Lemoalle 1978) (Fig. 2). At this time, the extension of the vegetation in the north basin was of the same order of magnitude as in the south basin, or a total of 6000 to 7000 km^2.

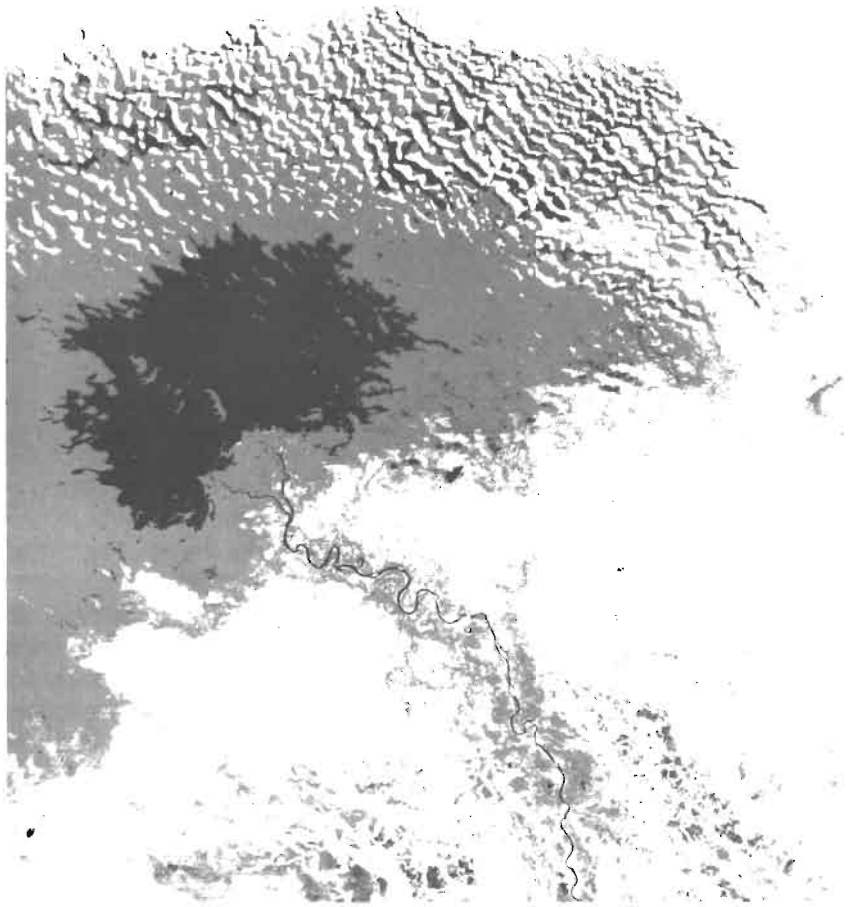

Fig. 2 Landsat image of the southern basin on 29 May, 1976. The open water areas are in black, the marshes in grey (corresponding to flooded areas). In total, the area under water is very similar to that in 1972. The marshy areas are relatively stable and are modified little between 1974 and 1979.

5.3 Mineral composition of macrophytes and its influence on water chemistry

5.3.1 *Analysis of macrophytes*

From the first study in 1970, both the biomass of emergent macrophytes in the lake and their mineral composition could be calculated corresponding to a period lower 'Normal Chad' (Carmouze et al. 1978).

Four species constituted the bulk of the biomass covering a total of 2400 km^2:

Phragmites	6355×10^3 tons d.w. covering 2000 km^2
Papyrus	674×10^3 tons d.w. covering 240 km^2
Vossia	168×10^3 tons d.w. covering 100 km^2
Typha	13×10^3 tons d.w. covering 25 km^2

The amount of salts accumulated was similarly estimated (in thousands tons):

	Na	K	Ca	Mg	SiO_2
Aerial parts	2.3	138	7.4	6.6	230
Roots	8	62.5	56	31.5	2110
Total	10.3	200.5	63.4	38.1	2340

Considering the intra-site and inter-site variability of macrophyte composition (Boyd 1969, 1971; Gaudet 1975), these results must be considered as providing an order of magnitude estimate of minerals accumulated by the emergent plants during the period of 'Normal Chad'.

A similar but detailed study was carried out during the period of 'Lesser Chad' (1974) near Bol (Southeastern Archipelago) and 12 samples were analyzed (Table 1) (Lemoalle 1979). The results on *Typha*, *Cyperus papyrus*, *Vossia* and *Phragmites* are comparable to those published by Carmouze et al. (1978).

Salt content (Table 2) shows that the importance of ions (K > Ca > Mg > Na) is generally the reverse of their average composition in the water during 'Normal Chad'. Chloride was not measured in the macrophyte samples but published data give a range from 0.3 to 3% of the dry weight. If we choose an arbitrary value of 1% (30 mé 100 g^{-1}) that is a concentration close to that of Ca, the chloride content in the water is 10 to 30 times less.

Laboratory experiments on decomposition of these macrophytes are in agreement with the *in situ* observations made elsewhere (Gaudet 1977). More than half of the inorganic elements are returned into solution after some days of flooding. For the plants of Chad, the experiments using a limited volume of water provided the following results: (Chantraine, personal communication):

— potassium represents more than half of the dissolved cations;
— the ionic ratios observed are Ca/Mg < 1 and Na/K < 0.5;
— chloride equals 5 to 15% of the concentration of cations;
— silica rapidly reaches concentrations close to saturation (amorphous silica) especially for *Cyperus papyrus* and *Vossia cuspidata*.

Table 1 Dry weight composition (%) of main plants of the Bol region (Eastern Archipelago) in 1974. The symbols Vg, Fl and Fr followed by a number (1 to 3) indicate respectively the state of the development of vegetation, flowering, and fruiting.

Samples	Dry weight composition (%)								
	N	Na	P	K	Ca	Mg	Al_2O_3	SiO_2	C
1 *Typha australis* (Vg2) stem and leaves	1.60	0.571	0.348	3.70	0.37	0.24	0.029	0.07	43.8
2 *Cyperus articulatus* (Fr3 Fl1) complete without roots	0.91	0.418	0.296	2.08	0.42	0.18	0.087	3.30	42.1
3 *Phragmites australis* stem and complete leaves	1.63	0.018	0.167	1.60	0.24	0.14	0.037	7.19	42.8
4 *Vossia cuspidata* (Vg2) aerial part and stem	1.26	0.011	0.251	1.91	0.16	0.15	0.060	8.45	40.7
5 *Ipomoea aquatica* (Fl, Fr) complete plant	1.44	0.253	0.321	2.98	0.58	0.37	0.086	0.94	43.2
6 *Ludwigia* sp. (Fl, Fr) complete plant	2.48	0.218	0.590	3.63	1.15	0.49	0.053	0.58	42.0
7 *Cyperus* sp. (flottant) (Fl1) complete plant	1.21	0.100	9.279	2.52	0.63	0.30	0.076	4.99	40.8
8 *Cyperus maculatus* (Fl, Fr) complete plant	0.95	0.172	0.219	1.00	0.39	0.15	0.051	5.52	42.9
9 *Cyperus papyrus* (Vg1) complete plant with roots	0.62	0.200	0.234	2.83	0.29	0.16	0.022	1.85	43.7
10 *Aeschynomene elaphroxylon* (branches)	1.94	0.032	0.229	1.56	1.20	0.26	0.370	2.16	44.9
11 *Aeschynomene elaphroxylon* (emerged trunk)	0.80	0.072	0.183	1.43	0.66	0.16	0.110	0.58	44.6
12 *Aeschynomene elaphroxylon* (immersed trunk)	0.86	0.164	0.249	1.99	0.50	0.12	0.197	1.05	44.2

5.3.2 *Influence of macrophytes on the hydrochemistry of the lake*

The influence of macrophytes on the water chemistry is both direct, by the transfer of salts from the water to the plant tissues and the sediments and indirect, by a modification of the physical conditions of the environment. The comparison of two periods of isolation of the Bol region in 1973 and in 1974, respectively without and with the influence of macrophytes (Lemoalle 1979), is a good illustration of that.

When the macrophytes were abundant in the period of 'Lesser Chad', the

Table 2 Salt content (mé 100 g^{-1} of dried plants).

	Na^+	K^+	Ca^{++}	Mg^{++}
1 *Typha australis*	24.8	95	18.5	20
2 *Cyperus articulatus*	18.2	53	21	15
3 *Phragmites australis*	0.8	41	12	11.7
4 *Vossia cuspidata*	0.5	49	8	12.5
5 *Ipomoea aquatica*	11.0	76	29	30
6 *Ludwigia adscendens* subsp. *diffusa*	9.5	93	57.5	40
7 *Cyperus* sp. (floating)	4.3	65	31.5	25
8 *Cyperus maculatus*	7.5	26	19.5	12.5
9 *Cyperus papyrus*	8.7	73	14.5	13.3
10 *Aeschynomene elaphroxylon*	1.4	40	60	21.7
11 *Aeschynomene elaphroxylon*	3.1	37	33	13.3
12 *Aeschynomene elaphroxylon*	7.1	31	25	10

indirect effects noted were: (1) a dampening effect of water level oscillations and a diminution in the fetch of the wind; (2) a lowering of pH and of the dissolved oxygen with an increase of the CO_2 tension. These new environmental conditions limited the neoformation of clay which participates in the salinity regulation in the lake.

One of the direct effects was the variation of ion concentrations, especially of potassium and chloride which were assimilated by plants during the growth periods in flooded environment and redissolved during submersions at the time of lacustrine floods. The phosphate concentrations (dissolved reactive phosphorus) also become greater during these periods.

It is actually difficult to estimate the balance of transfer for a longer time. The salts accumulated in the plants initially originate from dried sediments on which they have developed considerably. Later on, the macrophytes remove salts from the sediments and the water in unknown proportions. Inversely, decomposition rapidly provides a considerable amount of dissolved elements while a smaller fraction remains trapped for a time in the organic matter of the sediments.

During the period of 'Normal Chad', the influence of macrophytes is relatively weak even if the quantity of salts involved is already important. During the period of 'Lesser Chad'; the proliferation of vegetation allows a better understanding of their interactions with the physico-chemical environment.

Acknowledgement

We are grateful to Mr. G. Fotius, ORSTOM botanist, who made a critical review of this chapter.

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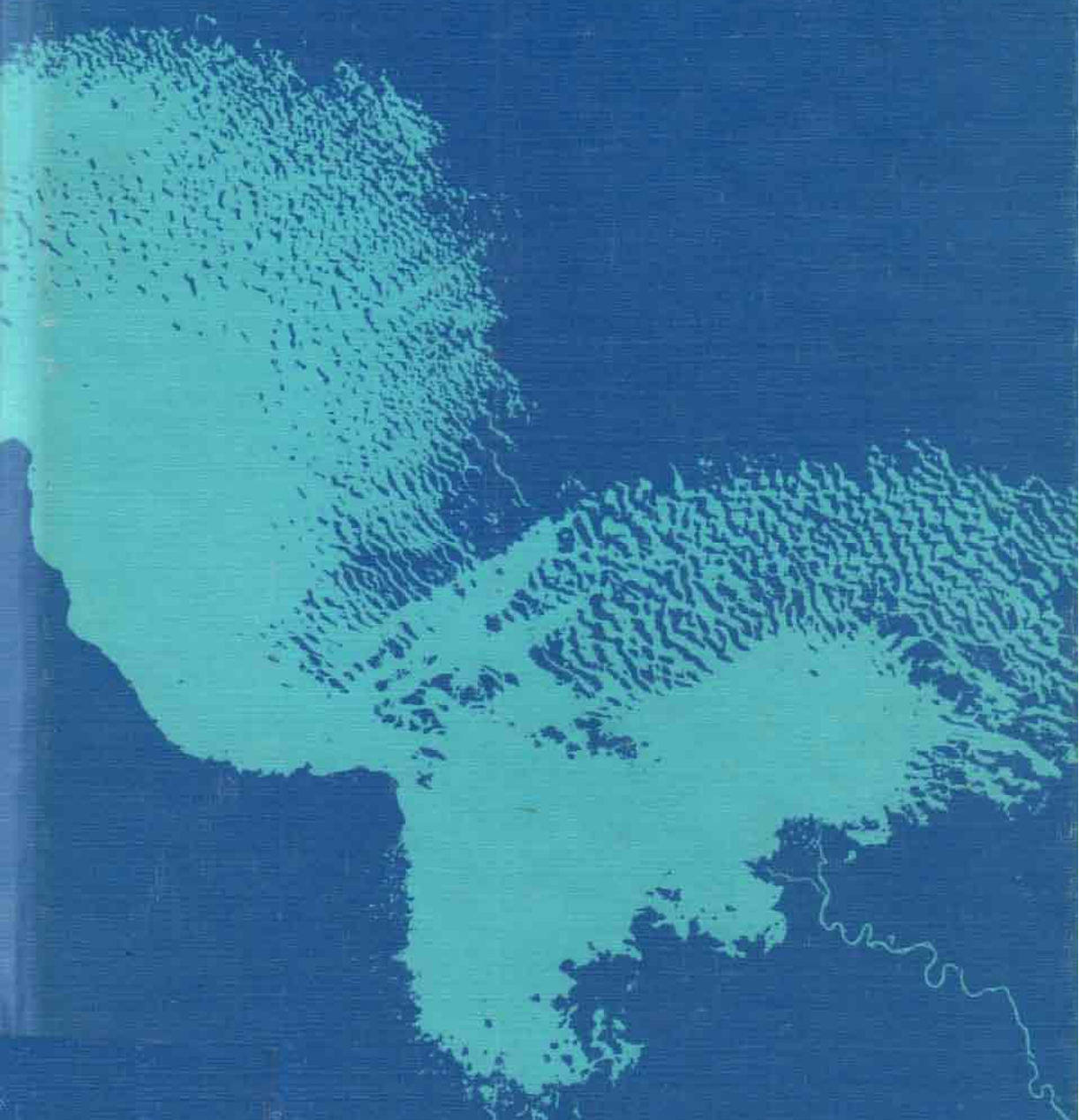

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Ecology and Productivity of a Shallow Tropical Ecosystem

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J.-P. CARMOUZE, J.-R. DURAND and C. LÉVÊQUE

1983 **Dr W. JUNK PUBLISHERS**
a member of the KLUWER ACADEMIC PUBLISHERS GROUP
THE HAGUE / BOSTON / LANCASTER

Distributors

for the United States and Canada: Kluwer Boston, Inc., 190 Old Derby Street, Hingham, MA 02043, USA
for all other countries: Kluwer Academic Publishers Group, Distribution Center, P.O.Box 322, 3300 AH Dordrecht, The Netherlands

Library of Congress Cataloging in Publication Data

Main entry under title:

Lake Chad.

(Monographiae biologicae ; v. 53)
Includes bibliographies and index.
1. Lake ecology--Chad, Lake. 2. Biological productivity--Chad, Lake. 3. Chad, Lake. I. Carmouze, Jean-Pierre. II. Durand, Jean René. III. Lévêque, C. IV. Series.
QP1.P37 vol.53 574s [574.5'26322'096743] 83-4288
[QH195.C46]
ISBN 90-6193-106-1

ISBN 90-6193-106-1 (this volume)

Cover design: Max Velthuijs

PRINTED IN THE NETHERLANDS