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Probable Impact of Global Warming and ENSO on Lake Tanganyika *

by

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KEYWORDS. — Lake Tanganyika ; Climate Change ; Warming ; *El Niño* ; Fishing.

SUMMARY. — A warming trend is being observed in East Africa (0.7 ° to 0.9 °C in 27 years for air temperature at Lake Tanganyika) and winds have recently changed in strength. The temperature of Lake Tanganyika is rising. Moreover, the ENSO signal (*El Niño* /Southern Oscillation) is noted in the time series of climate data. This seems to have a strong impact on Lake Tanganyika mixture and its fishing activity. The fish catches of the main pelagic species (*Lates stappersi* and the clupeids : *Limnothrissa miodon* and *Stolothrissa tanganicae*) display variability which seems to be linked to climate changes. A trend in fishing has been observed for the last 30 years while the relative abundance of pelagic fish species is changing in the lake every three to seven years. The OSTC-funded CLIMLAKE project is currently investigating this thoroughly as well as the possible paleoclimatic signals in the lake sediments.

MOTS-CLES. — Lac Tanganyika ; Changements climatiques ; Réchauffement ; *El Niño* ; Pêche.

RESUME. — *Impact probable du réchauffement global et de ENSO au lac Tanganyika.* — Une tendance au réchauffement est observée en Afrique de l'Est (0,7 à 0,9 °C en 27 ans pour la température de l'air au lac Tanganyika) de même que des changements récents dans l'intensité des vents. La température de l'eau du lac Tanganyika augmente. De plus, le signal ENSO (*El Niño/Southern Oscillation*) est bien présent dans les données climatiques. Ceci peut avoir un impact important sur le mélange du lac Tanganyika et sur sa pêche. Les captures des principales espèces de poissons pélagiques (*Lates stappersi* et les clupéides : *Limnothrissa miodon* et *Stolothrissa tanganicae*) présentent des tendances et une cyclicité qui semblent liées aux changements de climat. Ainsi, une tendance dans la pêche est observée depuis une trentaine d'année tandis que l'abondance relative des espèces de poissons pélagiques change dans le lac tous les trois à sept ans. Le projet CLIMLAKE, financé par les SSTC, étudie actuellement cela de façon plus détaillée de même que les signaux paléoclimatiques pouvant être enregistrés dans les sédiments du lac.

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TREFWOORDEN. — Tanganyikameer ; Klimaatsveranderingen ; Opwarming ; *El Niño* ; Visserij.

SAMENVATTING. — *Mogelijke impact van de opwarming van de aarde en ENSO op het Tanganyikameer.* — In Oost-Afrika worden, naast een tendens tot opwarming van de aarde (0,7 °C tot 0,9 °C in 27 jaar wat de luchttemperatuur aan het Tanganyikameer betreft), de laatste tijd ook veranderingen in de windintensiteit waargenomen. De watertemperatuur van het Tanganyikameer stijgt. Bovendien is het ENSO-signaal (*El Niño / Southern Oscillation*) duidelijk aanwezig in de klimaatgegevens. Dit kan een belangrijke impact hebben op de menging van de waterkolom in het Tanganyikameer en op de visserij. De vangst van de voornaamste pelagische vissoorten (*Lates stappersi* en clupeïden : *Limnothrissa miodon* en *Stolothrissa tanganicae*) vertoont een tendens en een cycliciteit die lijken verband te houden met de klimaatsveranderingen. Zo werd in de visserij gedurende een dertigtal jaar een tendens waargenomen, terwijl de relatieve abundantie van pelagische vissoorten in het meer elke drie tot zeven jaar verandert. Het CLIMLAKE-project, gefinancierd door de DWTC, bestudeert dit op een zeer gedetailleerde wijze evenals mogelijke paleoklimatologische signalen zoals die werden opgeslagen in de sedimenten van het meer.

Introduction

Lake Tanganyika in East Africa displays outstanding morphological characteristics with a length of 650 km, mean width of 50 km, maximum depth of 1,470 m and average depth of 570 m (COULTER 1991). It is one of the world's greatest reservoir of freshwater as its volume is 18,880 km^3. Fish catches reach around 200,000 tons per year, provide work for about 40,000 fishermen and food for an estimated 1,000,000 consumers. Main targeted fishes are the perch *Lates stappersii* (Boulenger 1914) and two clupeids : *Limnothrissa miodon* (Boulenger 1906) and *Stolothrissa tanganicae* Regan, 1917. The lake is famous also for its great diversity of fishes and for his old age (10-20 million years).

Research around the lake was for the first time coordinated amongst all the riparine countries (Congo, Burundi, Tanzania and Zambia) during the FAO/FINNIDA project ("Research for the Management of the Fisheries of Lake Tanganyika") that started in 1992 (LINDQUIST *et al.* 1999). In the frame of the FAO/FINNIDA project and in the subsequent Belgian-funded (OSCT) projects "Recent ENSO and paleo-ENSO of the last 1,000 years in Lake Tanganyika" and ongoing "Climate variability as recorded in Lake Tanganyika" (CLIMLAKE), some aspects of the climate and fisheries variability were studied.

Methods

The air temperature data are from Mbala at the south of Lake Tanganyika. The location of this meteorological station at Mbala airport is 8.85 °S, 31.33° E. The time series were complete until 1971 and less so afterward. The running average over a 24-month period is presented for periods when at least 75 % of the observations are available. The meteorological station has not been changed over the period presented.

The Southern Oscillation Index (SOI) is an indice of *El Niño*. It is based on the standardized sea level pressure difference between Tahiti (French Polynesia) and Darwin (Australia) (PHILANDER 1990).

Fishing statistics data are for the industrial fishing since the quality of the data is better in this sector. They were collected by the Zambian Department of Fisheries (pers. com.). The catches per unit of effort are defined as the catches made by one industrial boat using a purse-seine net and fishing during one night. The running average of 12 months' data is presented.

Limnological Environment

An important limnological characteristic of the lake is the permanent density stratification of the water as the lake is meromictic. This stratification is mainly dependent on temperature differences. The surface water temperatures vary during the year between ~24.0 °C and ~28.5 °C in the south and ~26.0 °C and ~27.4 °C in the north. The temperature of the bottom waters is close to 23.4 °C. This thermal gradient is linked to a strong gradient of nutrients (Hecky *et al.* in COULTER 1991, PLISNIER *et al.* 1999).

Mixing does occur through several hydrodynamic processes such as the southern upwelling in the dry season during the south-east trade winds' seasons (from May to September). Turbulence is also an important aspect of the lake that was well observed from the formation of vortices and eddies during 24-hour cycles of measurements from the surface to 300 m from 1993 to 1995 (Plisnier *et al.,* in prep.). Internal waves occur during the whole year as a result of thermocline tilting by the winds and monsoon changes (NAITHANI *et al.* 2002, 2003). The impact of internal waves raising regularly (*i.e.* every three weeks) deep nutrient-rich water toward the surface of the lake is linked to a probable pulsed primary production in the lake (PLISNIER & COENEN 2001).

Secondary upwelling at the north of the lake was noted such as in October 1993. The changes in conductivity and pH were very indicative of water movements after main wind direction shifts particularly. The secondary upwelling is probably proportional to the intensity of the main upwelling in the south since both phenomena are related to wind intensity. However, the secondary upwelling is weaker than the southern upwelling as thermal stratification remains in the north (PLISNIER *et al.* 1996, 1999). Phytoplankton blooms had previously been detected at this time of the year in the north (SYMOENS 1955a,b ; DUBOIS 1958), which suggests the yearly occurrence of the secondary upwelling.

Climate Changes

Lake Tanganyika is very much sensitive to the climate. For example, a decrease (even small) in air temperature weakens the thermal gradient and the stability of the lake. Because of the temperature-density relationships, changes in stability of tropical lakes are proportionally much more important in tropical lakes as in temperate lakes (LEWIS 1987). Winds have a major importance on the hydrodynamic state of the lake allowing the mixing of nutrient-rich water toward the surface where light and temperature are not limitative for the primary production during the whole year.

For the 1960s, an increase in air temperature has been noted at Lake Tanganyika (PLISNIER 2000). At Mbala airport, the mean increase, based on the linear regression of monthly data between 1963 and 2000, was 1.4 °C (fig. 1).

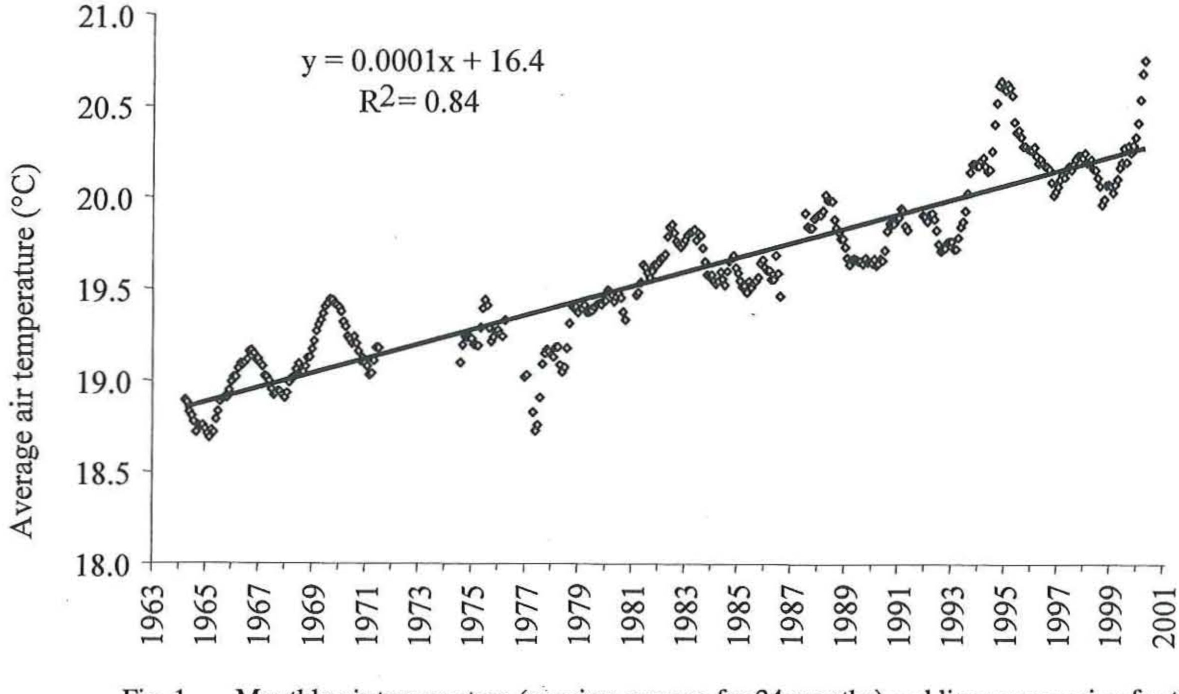

Fig. 1. — Monthly air temperature (running average for 24 months) and linear regression for the period from 1963 to 2000 in Mbala at the South of Lake Tanganyika (Zambian Meterological Dep., pers. com.).

In the 1970s, the winds decreased in Lake Tanganyika area. Preliminary data show that winds in Bujumbura (north of Lake Tanganyika) were fluctuating between 1.4 and 2.5 m/s on average from 1964 up to the end of the 1970s. Between 1986 and 1990, the wind fluctuations were between 0.5 and 1.5 m/s. In Mbala, wind speed has decreased from the end of the 1970s (PLISNIER 1997, 2000 ; O'REILLY *et al.* 2003).

Every three to seven years, *El Niño* events are observed in the Pacific Ocean and many oceanographic and atmospheric-related changes are observed in the intertropical area. In East Africa, teleconnections with ENSO (*El Niño*/Southern Oscillation) are observed with rainfall data (NICHOLSON & ENTEKHABI 1986, OGALLO 1987, FARMER 1988). During warm ENSO events, wetter conditions are observed near the equator while drier conditions are observed in southern Africa (RASMUSSON & ARKIN 1985, ROPELEWSKI & HALPERT 1987).

During warm ENSO events, air temperature is higher in most of the tropics (DIAZ & KILADIS 1992). This is well observed at Lake Tanganyika where temperatures rose on average 0.31 °C (T_{max}), 0.28 °C (T_{avg}) and 0.26 °C (T_{min}) during warm ENSO events during the period 1981-1994 (PLISNIER *et al.* 2000).

Limnological Changes

Several observations since 1916 (Marquardsen in VAN MEEL 1987) indicate that Lake Tanganyika has warmed (PLISNIER 1997, 2000 ; O'REILLY *et al.* 2003). Recent results still confirm this warming (fig. 2).

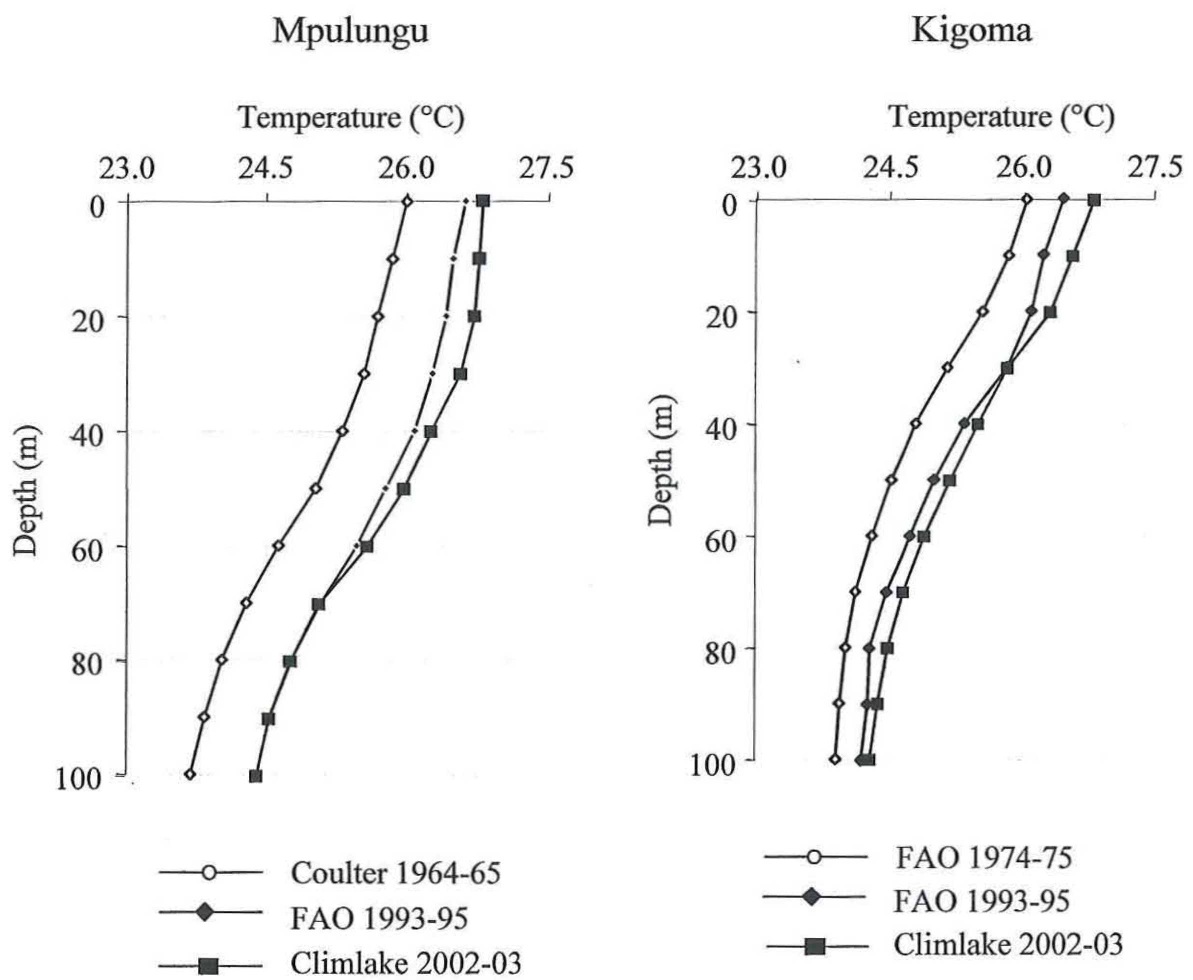

Fig. 2. — Warming of Lake Tanganyika as observed on average temperature profiles from regular measurements during complete yearly cycles in Mpulungu and Kigoma.

Warmer temperature profiles induce higher stability of the lake. Thus the work necessary to mix the lake increases. This is not favourable for the primary production as some recent results have suggested (O'REILLY *et al.* 2003). The warming linked to a decrease of winds in the region is linked to a decreased epilimnion thickness and thus a shallower thermocline.

Although a general decrease of productivity may be expected for most of the lake, in some areas, a shallower thermocline depth seems to be the cause of an increased productivity. This is the case for the northern end of the lake where a well-marked nutricline is observed. The extremities of the lake are under the strong influence of the pulses of internal waves and nutrient-rich layers reach periodically the biotic zone there with a great amplitude. Primary production values were between 1 and 4.5 gC m^{-2} d^{-1} near Bujumbura in 1995-96 (Sarvala *et al.* 1999) and estimated to be 0.8 gC m^{-2} d^{-1} from data obtained during a cruise in October-November 1975 (Hecky & Fee 1981). Water in the pelagic zone in the north of the lake was not as clear (annual average for secchi depth (SD) : 9.9 m) in 1993-96 as in 1955-57 (SD : 13.6 m) (Dubois 1958). The positive relationship between thermocline and secchi depths has been shown before (Ferro 1975, Plisnier *et al.* 1996).

The shallower thermocline is linked to a decreased oxic layer depth. Near Bujumbura, the oxygenated layer was shallower in 1993-94 (*c.* 60 m) compared to 1946-47 (80-100 m). During the dry season, anoxic conditions (< 1 mg/l DO) were measured at 100 m during the dry season in 1993-94 compared to 130 m in 1946-47 near Bujumbura (Kufferath 1952, Plisnier *et al.* 1996).

During ENSO years, it is probable that the lake is warmer. Long-time series for water temperature are lacking but the ongoing CLIMLAKE project will add supplementary information since temperature has been regularly measured for several years.

Fishery Changes

Changes in fish catches per unit of effort (CPUE) are observed in the lake. The southern catch changes are illustrated in figure 3.

The CPUE of clupeids have markedly decreased for the early 1980s in the south of the lake. The average catch by one fishing boat during one night was between 1.5 and 2.5 tons in the 1970s, between 1 and 1.5 tons in the 1980s. Every year, the main fishing period was the dry season. Since the early 1990s, the industrial fishing companies in the south have stopped operating during the dry season and target almost exclusively now *Lates stappersii* during the rain season. In the north, the catches of clupeids have also much decreased during the same period (Plisnier 1997). There has not been industrial fishing anymore in the north of the lake for more than ten years. Only the artisanal fishermen are now operating in the north of the lake near Bujumbura.

Contrary to the clupeids, for the mid-1970s, the catches per unit of effort of *Lates stappersii* in the south have shown an important increase. They represented 96 % of the total catches of industrial fisheries in 1994 (Plisnier 1995). Although there is a slight decrease in recent years, this species is thus the main target of the industrial fisheries in the south. Toward Kigoma, in the north, this

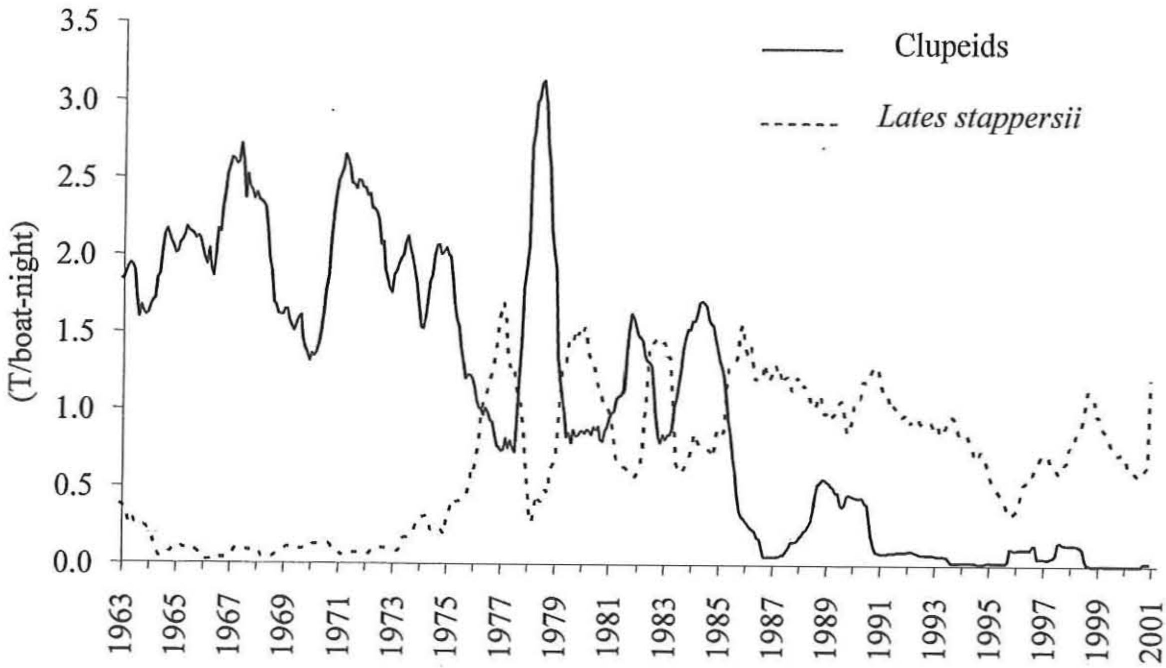

Fig. 3. — Catches per unit of effort (tons/boat-night) for the industrial fishery of clupeids and *Lates stappersii* in Mpulungu, at the south of the lake, from 1963 to 2001 (running average of 12 months).

species is alternately fished with the clupeids. While in the extreme north (Bujumbura) a decrease of *Lates stappersii* catches was observed.

The catches of clupeids in the south and the north of the lake show a positive correlation with the Southern Oscillation Index (SOI), an index of *El Niño*. For *Lates stappersii*, the inverse correlation was found (Plisnier 1997).

Discussion

Lake Tanganyika is not the only lake where a warming has been observed. A warming has been noted also for Lake Victoria (Hecky *et al.* 1994) and for Lake Malawi (Patterson & Kachinjika 1995). As the productivity of African Rift Lakes is determined to a large extent by the strength of stratification and the amount of hypolimnion water brought to the surface, this may result in a general decrease of productivity as suggested recently for Lake Tanganyika (O'Reilly *et al.* 2003).

What could be the reason for a wind decrease? Generally when temperature rises we can expect more winds as the differences of air pressure increase and air displacement tends to compensate those differences. A possible hypothesis is that the decrease in wind speed could be related to increased cloudiness linked to increased water temperature. Some elements are supporting this hypothesis : the range of mean monthly temperature at Mbala airport was much greater from the 1950s to 1970s than from the 1980s to 1990s (PLISNIER 1997). This may be the result of increased cloud cover in recent years. Cloudy skies are particularly effective in diminishing diel temperature variation by reducing solar heating by day and infrared cooling by night (KARL *et al.* 1995, HARVEY 1995). Beauchamp (1946) had noticed the strong relationship between the cloudiness, the daily range of temperature and the offshore and inshore wind speeds at Lake Tanganyika. This type of wind is particularly important during the dry season (HUTTULA 1997). Unfortunately, data on cloudiness are lacking for the Lake Tanganyika region. We note also that some observations from aviation pilots have mentioned increased cloudiness for twenty years (Blignaut, C & J., pers. com.). The use of satellite data could probably be useful to check a possible trend in cloudiness and relationships with local winds.

The reasons for fishery changes at Lake Tanganyika are still speculative. The impact of the fishing effort is one of the hypotheses but the different type of periodicities in abundance of species caught (monthly, seasonal, interannual) and the trend may not all be explained by the fishery effort changes. Also, in some areas, this effort has decreased such as for the industrial fisheries in the north.

The predator-prey relationships may explain only partially the cycles in the catches of clupeids and *Lates stappersii.* They do not explain monthly variations, seasonal cycles and long-term changes in the population. It was observed earlier that *Lates stappersii* may feed heavily on other preys than clupeids such as shrimps.

The strongest hypothesis for fishery changes links the climate change impact to the limnological changes in Lake Tanganyika. A decreased primary productivity for most of the lake is a probable consequence of the warming of waters (PLISNIER 1997). This appears to be linked to a decrease of the phytoplankton, the base of the food web (O'REILLY *et al.* 2003, VERBURG *et al.* 2003). It should influence the clupeids directly and probably other species as well.

Nevertheless, the catchability of *L. stappersii* has increased during the same period of the warming and decrease of wind speed. Since a good relationship was found between the CPUE of *L. stappersii* and the transparency of the water, it has been suggested that this species is a visual predator whose increased catches are observed when and where higher transparency is observed such as in the Mpulungu area in the south (PLISNIER 1997). An increase of transparency has been suggested for most of the lake (VERBURG *et al.* 2003).

Hypotheses to explain changes in fisheries correlated with *El Niño* have been linking "cold and windy" years to strong hydrodynamic activity and favourable conditions for the development of phytoplankton and zooplankton, the main food of clupeids. Inversely, "warm and calm" years seem to be favourable for the catches of *Lates stappersii.* The increased frequency of *El Niño* events for the 1980s has been correlated with an increased frequency of those "warm and calm" years and the trend of CPUE of the main fisheries in the south may reflect this. The impact of climate and hydrodynamic conditions and phytoplankton is dealt with in the frame of the ongoing CLIMLAKE project. The ECO-HYDRO model built during this project should help to improve the understanding of those complex relationships.

In the northern end, although a shallower epilimnion probably induces an increased primary production, an increase of clupeid catches is not observed. A likely cause, beside the possible impact of local overfishing by artisanal fishermen, is the presence of anoxic water close to the surface there. This could limit the presence and the reproduction of clupeids since their sinking eggs would undergo increased mortality before hatching when reaching faster the nearby anoxic water. Although the trend of CPUE of clupeids is decreasing in the north and the south, good catch periods may still be expected as both species of clupeids have a high resilience. It is known that with the clupeids, there may be important year class success arising from small to virtually non-existent population. There may always be enough fertilized eggs produced, no matter how small the population, to produce a good year if the conditions are right (LASKER 1985). Cold and windy years would provide those conditions.

The impact of climate change on fish catches and species relative abundance is thus likely as this may explain changes observed in different time periods (trend, ENSO, annual cycle, monthly patterns,…).

Conclusions

Climate change is observed in Lake Tanganyika area : the water temperature rises and weaker winds have been observed over the last twenty to thirty years. As the lake productivity is extremely sensitive to climate, the recording of this variability is likely in the laminated sediments. A better understanding of the actual climate impact on the lake is however necessary to interpret the sediments and the paleo-climate signals. This is the main objective of the CLIMLAKE project. An ECO-HYDRO model is built in the frame of this project.

The warming of the lake increases its stability. This is not favourable for the overall productivity of the lake as mixing with deep nutrient-rich water should be weaker. The decrease of some fish species such as the clupeids is probably related to this environmental change. However, the abundance of some fish species has increased in some areas of the lake. This could be expected as some niches become available. An increased transparency appears to favour visual predators such as *L. stappersii.* The long-term development of this fish stock is however unsure as the base of the food web will become less significant.

As the impact of climate is expected to drive changes in several lakes, it would be extremely interesting to study the lakes in a "multi-lake" approach in order to better quantify the anthropic impact from the climate impact.

An applied model linking the climate, the limnology and the fishery variable (ECO-FISH) could be based on a similar approach as developed by the ECO-HYDRO model. This would be useful for many fishery stakeholders to make the best use of the resources of lakes without overexploiting them ; a main concept of sustainable development.

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REFERENCES

Beauchamp, R. S. A. 1946. Lake Tanganyika. — *Nature*, **157**: 183-184.

Coulter, G. W. 1991. Lake Tanganyika and its Life. — London, Oxford University Press, 354 pp.

Diaz, H. F. & Kiladis, G. 1992. Atmospheric teleconnections associated with the extreme phases of the Southern Oscillation. — *In*: Diaz, H. F. & Markgraf, V. (Eds.), El Niño. Historical and Paleoclimatic Aspects of the Southern Oscillation. Cambridge University Press, pp. 2-28.

Dubois, J. T. 1958. Evolution de la température de l'oxygène dissous et de la transparence dans la baie nord du lac Tanganyika. — *Hydrobiologia*, **10** : 215-240.

Farmer, G. 1988. Seasonal forecasting of the Kenya coast short rains, 1901-84. — *J. of Climatology*, **8** : 489-497.

Ferro, W. 1975. Observations limnologiques dans le nord du Lac Tanganika (1972-1975). — United Nations Food and Agriculture Organisation. Report FI : DP/BD1/73/020, 29 pp.

Harvey, L. D. 1995. Warm Days, Hot Nights. — *Nature*, **377** : 15-16.

Hecky, R. E. & Fee, E. J. 1981. Primary production and rates of algal growth in Lake Tanganyika. — *Limnol. and Oceanogr.*, **26** : 532-547.

Hecky, R. E., Bugenyi, F. W. B., Ochumba, P., Talling, J. F., Mugidde, R., Gophen, M. & Kaufman, L. 1994. Deoxygenation of the deepwater of Lake Victoria, East Africa. — *Limnol. and Oceanogr.*, **39** (6) : 1476-1481.

Huttula, T. (Ed.) 1997. Flow, Thermal Regime and Sediment Transport Studies in Lake Tanganyika. — Kuopio University Publications C. Natural and Environmental Sciences 73, 174 pp.

Karl, T. R., Knight, R. W. & Plummer, N. 1995. Trends in high-frequency climate variability in the twentieth century. — *Nature*, **377** : 217-220.

Kufferath, J. 1952. Le milieu biochimique. Résultats scientifiques de l'exploration hydrobiologique du Lac Tanganika (1946-1947). — *Inst. Roy. Sc. Nat. Belg.*, **1** : 31-47.

Lasker, R. 1985. What limits Clupeoid production ? — *Can. J. Fish. Aquat. Sci.*, **42** : 31-37.

Lewis, W. M. 1987. Tropical limnology. — *Ann. Rev. Ecol. Syst.*, **18** : 159-184.

LINDQUIST, O. V., MOLSA, H., SALONEN, K. & SARVALA, J. (Eds.) 1999. From Limnology to Fisheries: Lake Tanganyika and other large lakes. — Kluwer Academic Publishers, 212 pp.

NAITHANI, E., DELEERSNIJDER, E. & PLISNIER, P.-D. 2002. Origin of intraseasonal variability in Lake Tanganyika. — *Geophys. Res. Let.*, **29** (3) : 2093-2096.

NAITHANI, E., DELEERSNIJDER, E. & PLISNIER, P.-D. 2003. Analysis of wind-induced thermocline oscillations of Lake Tanganyika. — *Environmental Fluid Mechanics*, **3** : 23-39.

NICHOLSON, S. E. & ENTEKHABI, D. 1986. The quasi-periodic behaviour of rainfall variability in Africa and its relationship to the Southern Oscillation. — *J. of Clim. and Appl. Met.*, **34** : 311-348.

OGALLO, L. 1987. Relationships between seasonal rainfall in East Africa and the Southern Oscillation. — *J. of Climatology*, **7** : 1-13.

O'REILLY, C. M., ALIN, S. R., PLISNIER, P.-D., COHEN, A. S. & MCKEE, B. A. 2003. Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. — *Nature*, **424** : 766-768.

PATTERSON, G. & KACHINJIKA, O. 1995. Limnology and phytoplankton ecology. — *In* : MENZ, A. (ed.), The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa. Chatham, UK, Natural Resource Institute, 67 pp.

PHILANDER, S. G. H. 1990. El Niño, La Niña, and the Southern Oscillation. — San Diego, Academic Press, 281 pp.

PLISNIER, P.-D. 1995. Catch assessment survey in Zambian waters of Lake Tanganyika in 1994. — FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/41 (En), 26 pp.

PLISNIER, P.-D. 1997. Climate, limnology and fisheries changes of Lake Tanganyika. — FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/73(En), 50 pp.

PLISNIER, P.-D. 2000. Recent climate and limnology changes in Lake Tanganyika. — *Verh. Internat. Verein. Limnol.*, **27** : 2670-2673.

PLISNIER, P.-D., LANGENBERG, V., MWAPE, L., CHITAMWEMBWA, D. & COENEN, E. 1996. Limnological sampling during an annual cycle at three stations of Lake Tanganyika (1993-1994). — FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/46 (En), 136 pp.

PLISNIER, P.-D., CHITAMWEBWA, D., MWAPE, L., TSHIBANGU, K., LANGENBERG, V. & COENEN, E. 1999. Limnological annual cycle inferred from physical-chemical fluctuations at three stations of Lake Tanganyika. — *Hydrobiologia*, **407** : 45-58.

PLISNIER, P.-D., SERNEELS, S. & LAMBIN, E. F. 2000. Impact of ENSO on East African ecosystems : a multivariate analysis based on climate and remote sensing data. — *Global Ecology and Biogeography*, **9** (6) : 481-497.

PLISNIER, P.-D. & COENEN, E. C. 2001. Pulsed and dampened annual limnological fluctuations in Lake Tanganyika. — *In* : MUNAWAR, M. & HECKY, R. (Eds.), The Great Lakes of the World (GLOW) : Food-web, health and integrity. Leiden, The Netherlands, *Ecovision World Monograph Series*, pp. 81-94.

RASMUSSON, E. M. & ARKIN, P. A. 1985. Inter-annual climate variability associated with the El Niño/Southern Oscillation. — *In* : NIHOUL, J. C. (Ed.), Coupled Ocean-Atmosphere Models. *Elsevier Oceanographic Series*, **40** : 697-725.

Ropelewski, C. F. & Halpert, M. S. 1987. Global and regional scale precipitation and temperature patterns associated with El Niño-Southern Oscillation. — *Monthly Weather Reviews*, **15** : 1606-1626.

Sarvala, J., Salonen, K., Jarvinen, M., Aro, E., Huttula, T., Kotilainen, P., Kurki, H., Langenberg, V., Mannini, P., Peltonen, A., Plisnier, P.-D., Vuorinen, I., Molsa, H. & Lindqvist, O. V. 1999. Trophic structure of Lake Tanganyika : carbon flows in the pelagic food web. — *Hydrobiologia*, **407** : 155-179.

Symoens, J.-J. 1955a. Observation d'une fleur d'eau à Cyanophycées au Lac Tanganika. — *Folia scientifica Africae centralis*, **1**(3) : 17.

Symoens, J.-J. 1955b. Sur le maximum planctonique observé en fin de saison sèche dans le bassin nord du Lac Tanganika. — *Folia scientifica Africae centralis*, **1**(4) : 12.

Van Meel, L. I. J. 1987. Contribution à la limnologie de quatre grands lacs du Zaïre oriental : Tanganyika, Kivu, Mobutu Sese Seko (ex-Albert), Idi Amin Dada (ex-Edouard). Les paramètres chimiques. Fascicule A : le lac Tanganyika. — Bruxelles, *Institut Royal des Sciences Naturelles de Belgique*, **41**, 118 pp.

Verburg, P., Hecky, R. E. & Kling, H. 2003. Ecological consequences of a century of warming in Lake Tanganyika. — *Science*, **301** : 505-507.