Causes and effects of the Lake Victoria ecological revolution

Goudswaard, Pleun Cornelis

CHAPTER 3

Distribution of Nile perch (*Lates niloticus*) in southern Lake Victoria, in relation to environmental factors.

Kees (P.C.) Goudswaard[1], Egid F.B. Katunzi[2], Jan H. Wanink[1] & Frans Witte[1]

[1]Institute of Biology, University of Leiden, P.O. Box 9516,
2300 RA Leiden, The Netherlands
[2]Tanzania Fisheries Research Institute, P.O. Box 475, Mwanza, Tanzania.

Abstract

Nile perch (*Lates niloticus*) in Lake Victoria was introduced from Lake Albert and Lake Turkana where it prefers shallow waters. In Lake Victoria it is also found in deep water. As a contribution to analysing the factors determining the distribution of Nile perch in Lake Victoria, the spatial distribution of Nile perch in the southeastern part of the lake was analysed in relation to depth, temperature and dissolved oxygen (DO) concentrations. Of these factors, depth and the interaction of depth and DO-level explained the distribution of Nile perch. In offshore populations, seasonal upward movements and/or inshore migration were caused by temporary hypoxia in the bottom layers. Nile perch is found in a narrow depth range just above the oxycline, which seems a compromise between sufficient oxygen and a preference to dwell near the bottom during daytime. The seasonally hypoxic layers in the deep water of Lake Victoria might cause a threat for the Nile perch stock and the Nile perch fisheries.

Introduction

Nile perch (*Lates niloticus* L.) was introduced into Lake Victoria from Lake Albert and Lake Turkana during the 1950s and early 1960s (Amaras, 1986; Welcomme, 1988; Pringle, 2005). Landings of the piscivorous Nile perch increased slowly in the commercial catches from the 1970s onwards until the upheaval of the population of Nile perch during the 1980s (Ogutu-Ohwayo, 1990; Barel et al., 1991; Chapter 2). Subsequently, a large part of the native fish species, dominated by haplochromine cichlids (Kudhongania & Cordone, 1974), disappeared from the lake and a new fish community developed (Ogutu-Ohwayo, 1990; Wanink, 1991; Kaufman, 1992; Witte et al., 1992a,b; Chapter 6 - Goudswaard & Witte 1997, Chapter 7 - Goudswaard et al., 2002b). In the 1950s, also several tilapiine species were introduced of which Nile tilapia (*Oreochromis niloticus* L.), a detritivorous/algae feeder, gradually replaced the indigenous tilapiine species (Ogutu-Ohwayo, 1990; Chapter 8 – Goudswaard et al., 2002a). Concomitant with the decline of the haplochromines, the population of the zooplanktivorous dagaa (*Rastrineobola argentea* Pellegrin), an indigenous pelagic cyprinid, increased strongly (Ogutu-Ohwayo, 1990; Wanink, 1991, 1999). By the end of the 1980s Nile perch, Nile tilapia and dagaa had become the three commercially most important species in the lake. Nile perch fishery accounted for an estimated annual export value over 50 million US$ during 1996-2000 for Tanzania alone (Ntiba et al., 2001).

Parallel to the increase of the human population and agricultural activities during the second half of the 20th century, eutrophication and algal blooms increased in the lake (Ochumba & Kibaara, 1989; Hecky, 1993; Mugidde, 1993; Hecky et al., 1994; Scheren et al., 2000; Ntiba et al., 2001; Verschuren et al., 2002; Kishe & Machiwa, 2003). Decline of phytoplanktivorous fish after the Nile perch upsurge may have enhanced the increase of algal blooms (Goldschmidt et al., 1993; Ogutu-Ohwayo, 1999). The increased amount of decaying algae near the bottom caused a decrease of dissolved oxygen (DO) levels. Previously, thermal stratification coincided with reduced DO levels (<4 mg l^{-1}) in the 40–60 m depth zone during short periods within the rainy season (Talling, 1957, 1966). Incidentally extreme hypoxia (<0.7 mg l^{-1}) was found below 55 m deep and very infrequent anoxia (<0.1 mg l^{-1}) just off the bottom at 60 m deep. Prolonged periodic hypoxia (<2 mg l^{-1}) in the 40–60 m depth zone during the rainy season was reported for 1990 (Kaufman, 1992; Hecky et al., 1994). During 1987 and 1988 even at a 14 m deep station in the Mwanza Gulf (Fig. 3.1) severe hypoxia (< 1 mg O_2 l^{-1}) occurred for about 4 months (the second half of the rainy season) in the lower 1-3 m of the water column (Wanink et al., 2001).

As *L. niloticus* is the more inshore dwelling species of *Lates* in the lakes of origin (Gee, 1968), it was supposed to occupy the littoral habitats of Lake Victoria as well. This was supported by the observation that *L. niloticus* is sensitive to low oxygen concentrations (Fish, 1956; Schofield & Chapman, 2000; Wanink et al., 2001; Chapman et al., 2002). Getabu et al. (2003) suggested that in addition to an impact of DO levels, also water temperature might determine spatial distribution in Lake Victoria. High fish densities were observed in the warmer water, i.e. in the coastal shallows of the lake.

In contrast to the foregoing expectations, Nile perch appeared to have a wide distribution in Lake Victoria and was even caught at depths of 50-60 meter (Goudswaard & Witte, 1985; Goudswaard & Ligtvoet, 1988; Chapter 2). For fisheries, factors determining the distribution of Nile perch in Lake Victoria are important. Therefore, we analysed the distribution of Nile perch in the southeastern part of Lake Victoria over the period 1984-1990 in relation to depth, temperature and DO concentrations.

Material and Methods

Fish sampling

The MV Kiboko is a 105 hp bottom trawler, supplied with a net with a head rope of 18 m and a 20 mm full codend mesh. Trawl shots lasted 30 minutes and fished the lower 1.5 m of the water column. Usually, 4 trawl shots were made per sampling day. The total weight (kg) of Nile perch in each haul was recorded.

Data were collected at six sampling stations with a soft mud bottom, in the Mwanza Gulf and the open lake (Fig. 3.1), respectively 1-2 m, 2-4 m, 12-16 m, 20-25 m, 30-35 m and 57 m, deep. Each station was fished monthly from October1984 to

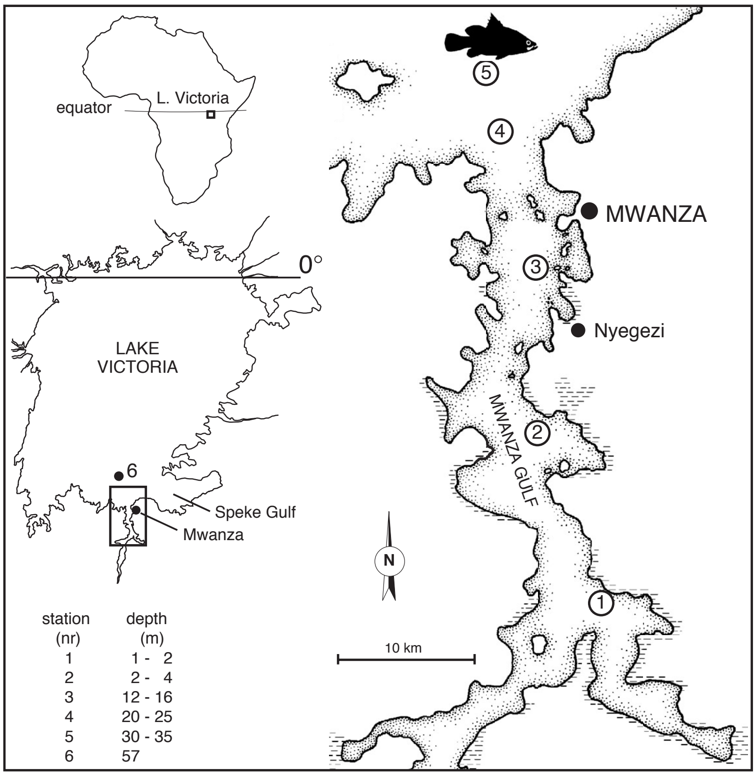

Fig. 3.1. *Map of the area of investigation in the southern part of Lake Victoria*

July 1990, except for the deepest station, which was fished only until 1986. MV Kiboko appeared unsuitable for fishing at this station due to the commonly rough weather conditions in open water. At the other stations, sampling was interrupted only occasionally.

Environmental factors

Dissolved oxygen was recorded with a Yellow Springs Instrument (YSI model 57) to the nearest 0.1 mg l^{-1} at every 0.5 m in the water column. Temperature was measured to the nearest 0.1°C with the same instrument. Measuring was done from a moored canoe. During 1985-1987 records were made synchronised with bottom trawling. In 1988, 1989 and 1990 temperature and oxygen recording and trawling were done on different days. As the building up of a deoxygenated bottom layer of water may take several days, all records made within 6 days before a trawling date were used. Although stratification can break down due to storm within a short period, all records taken within 6 days after fishing were also used, as we never recorded a storm during these days. DO levels and temperature were only measured at stations 1-5, and only concomitant with a restricted number of trawl shots (Fig. 3.2). For seasonal variation in wind speed we used the average of monthly average speeds measured at 06.00 a.m. and at 12.00 a.m. over a 20 year period and published by the East African Meteorological Department in 1975. We used an average of the morning and midday wind. The amount of rain was measured daily with a rain gauge at Mwanza (Capri Point) from January 1985 to July 1990 and summarised to monthly averages.

Hydro acoustics

A Lowrange Mach 1 echo-sounder, using a frequency of 192 Khz and a 1192 transducer (8º), fitted under MV Kiboko at 1.2 m below the surface, could detect all objects > 8 mm in the water column.

Statistical analysis

In the current study two data sets were analysed. The total data set including all average monthly catches (N=329) at stations 1-6 over a period of six years, and a subset of catches (N=84) made during periods from which oxygen and temperature measurements were available from station 1-5. The latter data were analysed with a General Linear Model (GLM) using station as factor and oxygen and temperature as covariate. Before performing the GLM, data were log transformed. Residuals were tested for normality with a Kolmogorov-Smirnov test. Pearson correlations were calculated between rainfall, wind speed, DO-levels and temperature, in order to reveal seasonal patterns.

Based on the subset of data it was determined during which months DO-levels were generally low. Thus, the catch rates in the total data set could be tested against periods with high and low DO-levels. As these data were not normally distributed, the Kruskal-Wallis and Jonkheere-Terpstra test were used to test for differences between catch rates. To test for differences between catches in periods of hypoxia and normoxia per station, a Mann-Whitney U test was applied. Results were Bonferroni corrected.

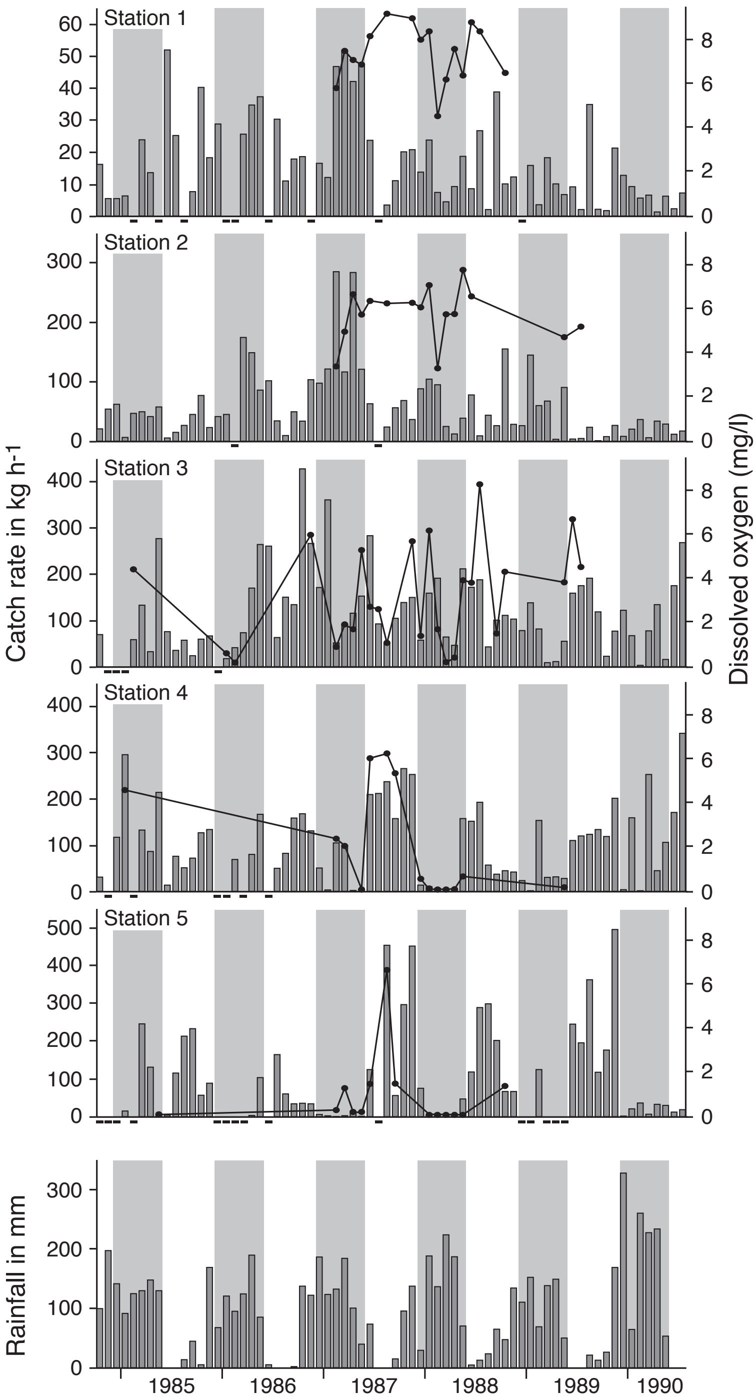

Fig. 3.2. *Mean catch (kg h^{-1}) of Nile perch in trawl shots of MV Kiboko at 5 stations in the Mwanza Gulf of Lake Victoria. The lowest panel shows the accumulated rainfall each month at Mwanza. The grey bars in the graphs show the periods (December – May), when DO levels were usually low at the deep stations number 4 and 5.*
The black dots indicate the amount of dissolved oxygen in the water 1 meter above the bottom. Black stripes at the bottom indicate months without catch records.

Results

Bottom trawling in the shallow areas (<20 m) always yielded some Nile perch (Fig. 3.2, station 1-3), while in deeper waters (station 4 and 5; 20-35 m) occasionally not a single Nile perch was caught in successive trawl shots (Fig. 3.2). A GLM of the subset of Nile perch catches at station 1-5 from periods of which oxygen and temperature data were available, revealed that catch sizes were explained by an interaction between station and DO-level (GLM adjusted R^2 = 0.559; P = 0.000), whereas temperature had no significant effect. When the two shallow stations, where catch rates were in general relatively low (Fig. 3.2), were excluded, the catch sizes were explained by DO-level and by the interaction between station and DO-level (GLM adjusted R^2 = 0.567; P DO-level = 0.037; P station **-** DO-level = 0.000). Nile perch catches at these stations were significantly lower at low DO-levels, but the impact of DO differed per station. Further comparison of the Nile perch catch rates in this subset revealed that catches declined when thickness of the hypoxic layer above the bottom increased (Fig. 3.3).

DO-values correlated negatively with rain and positively with wind speed (Table 3.1; Pearson correlations R = -0.588, 1-tailed P = 0.022; R = 0.510, 1-tailed P = 0.045 respectively). Wind speed correlated negatively with rain (Pearson correlation; R = -0.760, 1-tailed P = 0.002). Temperature correlated possitively with rain but not significantly (R= 0.484 1-tailed P= 0.055) Low average DO-levels (<2.5 mg l^{-1}) at station 3-5 were observed during the months December to May (wind speed 7.5-8.5

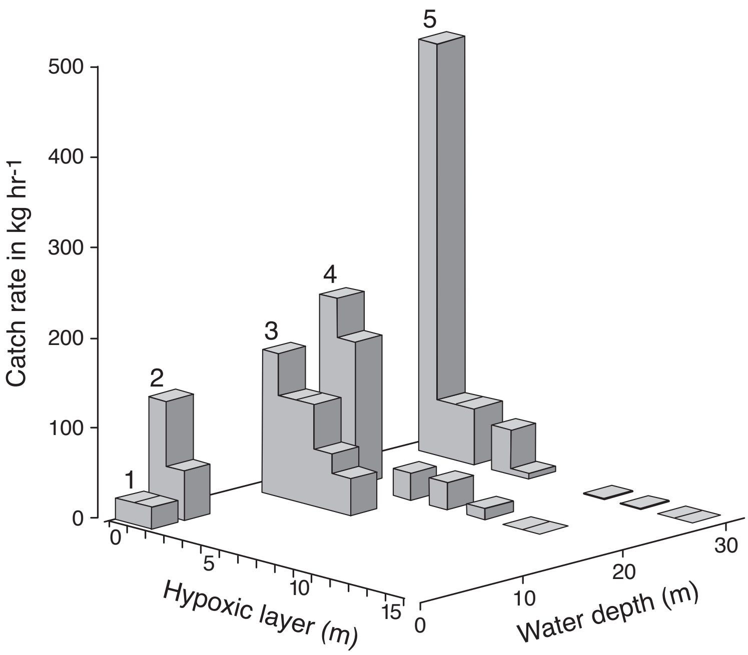

Fig. 3.3. Mean catch rate (kg h^{-1}) of Nile perch in relation to the hypoxia range. Hypoxia range measured from the bottom.

Table 3.1. *Months with hypoxic (H, Do ⩽ 2.5 ppm) and normoxic (N, Do ⩾ 2.5 ppm) water at 1 m above the bottom at stations 3-5, respectively 12-16, 20-25 and 30-35 m deep. Monthly average dissolved oxygen (DO) levels (± st.dev.) and temperature (± st.dev.) at stations 3-5. Average monthly rainfall (± st.dev.) at Mwanza town (1985-1990). Seasonal variation in wind speed at Mwanza (average of speeds at 06.00 a.m. and at 12.00 a.m.; source: East African Meteorological Department, 1975).*

Month	Oxygen level	DO ppm	Temp. C°	Rain mm month^{-1}	Wind Km h^{-1}
Jan.	H	2.3 (2.9)	23.2 (0.8)	129 (43)	7.5
Feb.	H	1.3 (1.5)	23.0 (0.6)	138 (65)	7.5
March	H	1.0 (0.9)	22.7 (0.8)	178 (46)	8
April	H	0.5 (0.7)	22.4 (1.0)	170 (45)	8
May	H	1.6 (2.1)	22.5 (1.3)	59 (33)	8.5
June	N	4.2 (2.2)	22.7 (0.3)	16 (29)	8.5
July	N	5.1 (2.9)	22.7 (0.3)	2 (4)	10
Aug.	N	4.7 (3.1)	22.0 (0.0)	9 (10)	9.5
Sept.	N	2.8 (2.3)	22.0 (0.0)	27 (26)	10.5
Oct.	N	2.9 (2.1)	21.3 (0.4)	62 (53)	10
Nov.	N	5.9 (0.2)	24.0 (1.4)	145 (53)	8.5
Dec.	H	1.0 (0.6)	23.0 (0.0)	144 (117)	8

Table 3.2. *The average yield of Nile perch per month in kg h^{-1} (± st.dev.) from 1984-1990 at periods when the water at 2 m above the bottom is hypoxic or normoxic. Hypoxic (⩽2.5 mg l^{-1}) periods usually last from December to May, normoxic (⩾2.5 mg l^{-1}) periods from June to November). P-values of 1- tailed Mann-Whitney U test under assumption that catches under normoxia are larger than under hypoxia. Significant P values (Bonferroni corrected) are given in bold.*

	Yield in kg h^{-1} (± std)				
Station	Hypoxic	number of catches	Normoxic	number of catches	Mann-Whitney U test. P
1	18.1 (14.3)	31	16.5 (12.9)	30	0.389
2	77.2 (68.2)	35	39.7 (34.4)	33	**0.003**
3	107.4 (84.3)	33	134.2 (89.5)	33	0.078
4	77.4 (77.2)	32	134.9 (78.4)	32	**0.010**
5	36.2 (59.2)	25	175.7 (139.3)	29	**0.000**
6	3.8 (6.4)	5	24.1 (29.4)	11	0.063

kmh^{-1}) and normoxic levels during June to November (wind speed 8.5-10 km h^{-1}, Table 3.1).

Because the factor Depth and the covariate DO-level were explaining Nile perch yields in the subset of data, the total data set was only analysed for these two aspects. Catch data per station were subdivided in those made during months that are usually hypoxic and those that are usually normoxic (Table 3.1). A comparison of catch rates during normoxic and hypoxic conditions at each of the stations, showed that during hypoxic months at stations 4 and 5, catch rates were significantly lower than during normoxic months (Table 3.2). A significantly higher catch rate in the same period was found at station 2 (Table 3.2). No differences were found at station 1, 3 and 6.

There was a significant difference between average catch rates of Nile perch at different depths (stations 1-6). Differences were present, during the months with high as well as low DO-levels (Fig. 3.4; normoxic months, Kruskal-Wallis P = 0.000; hypoxic months, Kruskal-Wallis P = 0.000). In the normoxic period, catches increased significantly with depth (Fig. 3.4; Jonckheere Terpstra test P = 0.000). This also holds for the three shallowest stations during hypoxic months, but not for the three deepest stations, where a decrease with depth was observed during this period (Fig. 3.4; Jonckheere Terpstra test P = 0.000 in both cases).

A hydro-acoustic record made on 8 November 1989 at station 5 at a depth of 34 meter, during presumed oxygen stratification, showed no echo-traces that could represent fish in the lowest 2 m, while they were present in the upper half of the column (Fig. 3.5). A bottom trawl shot at this spot produced two *Clarias gariepinus* and no Nile perch. At the same day, at a depth of 32 m there were numerous traces near the bottom and in the upper half of the water column. Five bottom trawl shots of half an hour at this station produced respectively 283, 137, 278, 301 and 242 kg of Nile perch.

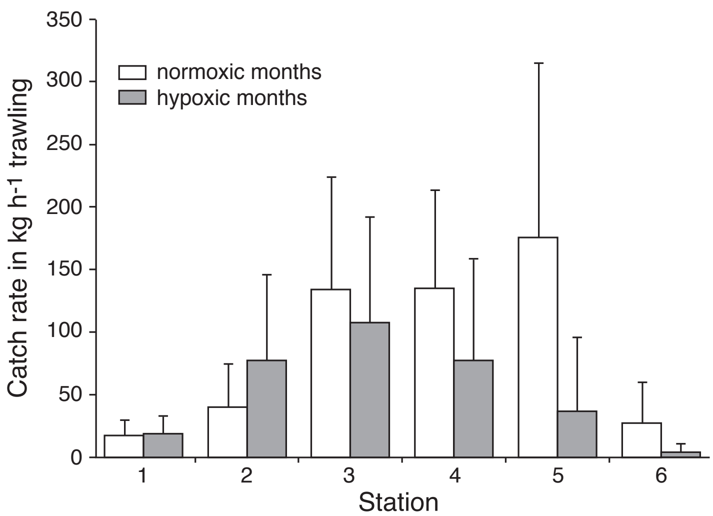

Fig. 3.4. *Mean catch rate (kg h^{-1}) and standard deviation of Nile perch at six stations in the Mwanza Gulf in the dry and the rainy season.*

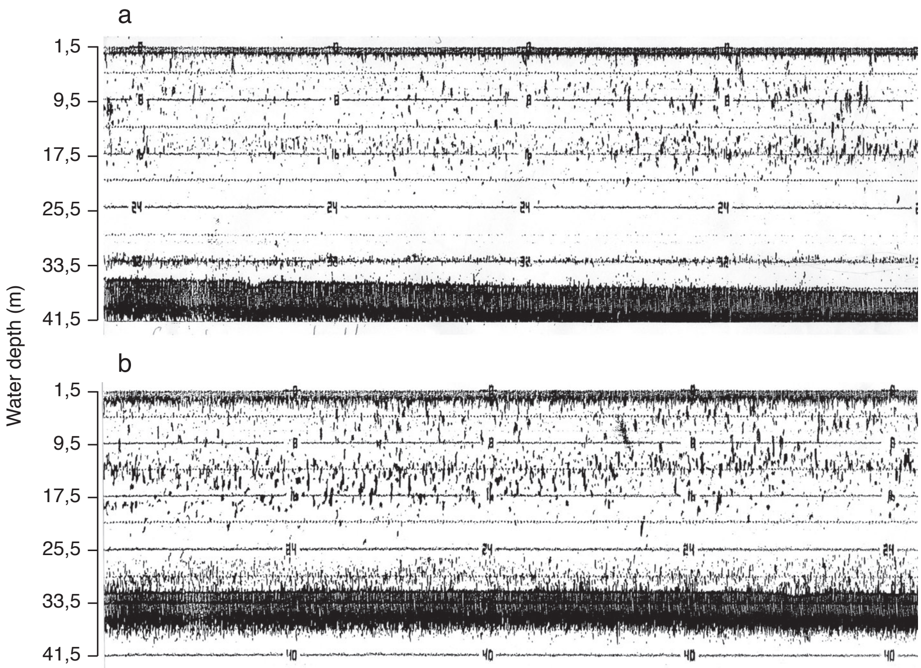

Fig.3.5. *Hydro-acoustic record made on 9 November 1989 at a 36 meter deep sampling station north of the Mwanza Gulf.*

Discussion

Our data indicate that both depth and DO-levels are the factors determining the distribution of Nile perch in Lake Victoria. In contrast to Getabu et al. (2003) who suggested that higher fish densities occurred in the warmer coastal shallows, we found no evidence for an influence of temperature on the distribution of Nile perch in the Mwanza Gulf. Nile perch appeared to occur much deeper in Lake Victoria than in its lakes of origin, viz. Lake Albert and Lake Turkana. It has been suggested that the Nile perch in Lake Victoria may not be *Lates niloticus* (Harrison, 1991). In both lakes, *Lates niloticus* co-occurs with a closely related deepwater *Lates* species, respectively *L. macrophthalmus* Worthington and *L. longispinis* Worthington (Gee, 1968). Allozyme data revealed that Nile perch in Lake Victoria were mainly *Lates niloticus* from Lake Albert, although there were indications for some genetic contribution of *L. macrophthalmus* (Hauser et al., 1998).

Already before the ecological changes took place in the 1980s, temperature and oxygen stratification occurred annually in the deeper part (>50 m) of Lake Victoria (Talling, 1957, 1966). In general, a bottom layer of slightly colder and hypoxic water was formed during the rainy season. In this period the strength of the winds was reduced (Table 3.1; Van Densen & Witte, 1995). This implicates that no or hardly any mixing of the water column occurred and that oxygen depletion in the bottom layer could occur even in water less than 15 m deep (Van Oijen et al., 1981). A single thunderstorm could cause the breakdown of these deoxygenated layers and a mixing of the whole water column within a few hours. Alternatively, in deep water areas, such a storm could cause an up-welling of deoxygenated water to the surface, resulting in low DO-levels throughout the column. In the past such up-wellings and mass fish kills used to occur only occasionally in the lake (Fish, 1956, 1957), but since the 1980s they became more common (Ochumba, 1987; 1990; Kaufman, 1992; Kaufman & Ochumba, 1993; Kudhongania & Chitamwebwa, 1995; Wanink et al., 2001). Based on oxygen measurements made during our study, a division in a hypoxic and a normoxic period was made. Hypoxic periods lasted longer and DO-levels during these periods were lower than in the past (Wanink et al., 2001). The hypoxic period (December–May) roughly corresponded with the main rainy season when wind speeds were low. The normoxic period (June-November) corresponded with the dry period and the beginning of the short rainy season, when wind speeds were relatively high.

Our data suggest, that in periods of normoxia in water of 14-30 m deep (station 3-5), Nile perch preferred to stay near the bottom. Low, or even zero, catches of Nile perch in bottom trawls at stations 4 and 5 generally coincided with the hypoxic period (December–May). The high catches at station 2 in this period could be explained by inshore migration of Nile perch towards areas where hypoxia is absent. Alternatively Nile perch may be forced to stay in the column, above the oxycline in case of anoxia or severe hypoxia in the bottom layers of the water column.

The hydro-acoustic observations at station 5 seem to corroborate that Nile perch dwell above the oxycline at periods of hypoxia. Getabu et al. (2003), who did a lake-wide acoustic survey, also reported few echoes below the oxycline when the lake was stratified. This is further supported by our observations that in cases when bottom trawling did not produce any fish, local fishermen made good Nile perch catches when their gillnets were placed in mid-water or even near the surface. When fishermen noticed that the lower part of their gillnets (1.5-2 m high) did not contain any fish, they set their gillnets higher in the water column. In this way they followed the depth distribution of their target species.

In November 1988, large quantities of freshly dead Nile perch were observed in the Western part of the lake between Kemondo Bay and Bukoba harbour (PCG, pers. obs.). In the Mwanza Gulf, we have observed also several times mass mortality. Mass mortality of bottom dwelling invertebrates e.g. the snail, *Bellamya unicolor*, was noticed as well. Thousands of dead and decaying snails were floating on the lake surface some days after a fish mass mortality (PCG, pers. obs.). Kudhongania & Chitamwebwa (1995) reported large kills of the shrimp *Caridina nilotica*. In the present study, the only fish species caught by bottom trawling during oxygen depletion near the bottom, was *Clarias gariepinus*, a fish able to survive these conditions by air-breathing at the surface via its arborescent organs.

Though Nile perch may escape areas where hypoxia is gradually building up, the sudden up-welling of hypoxic water after violent storms causes mass mortalities. During such an event in September 1984, Ochumba (1990) estimated that over 400 000 Nile perch and Nile tilapias

(*Oreochromis niloticus*) suddenly died, together weighing more than 2 400 tonnes. In this case mortality was attributed to low Ph, hypoxia and high levels of suspended material (detritus and algae), which clogged the gills.

The catchment area of Lake Victoria has a population of ca. 30 million people with a growth rate of 6% per annum in urban centres and over 3% in rural areas (Ntiba et al., 2001). Deforestation coupled with bad agricultural practices strongly increase land erosion. Rapid industrial development in the major urban centres contributes to pollution of the lake (Scheren et al., 2000; Ntiba et al., 2001; Kishe & Machiwa, 2003). Unless adequate measures are taken, eutrophication and pollution of Lake Victoria is bound to increase rapidly. If the concomitant deoxygenation of Lake Victoria intensifies and extends its range and duration, it is to be expected that the scale of massive fish mortalities will increase and become a serious threat for the Nile perch fishery and its associated industries.

Acknowledgments

HEST was sponsored by the section for Research and Technology of the Netherlands Minister of Development Cooperation and the Netherlands Foundation for the Advancement of Tropical Research (WOTRO) grants W87-129, W87-161, W87-189 and W84-488, the Leiden University Fund, the Schure-Beijerinck-Popping Fund, the Van Tienhoven foundation. The Mwanza Centre of the Tanzania Fisheries Research Institute (TAFIRI) offered hospitality during the fieldwork. Crewmembers of the research vessels are thanked for their dedication to the data collection.