EFFORT DEVELOPMENT AND THE COLLAPSE OF THE FISHERIES OF LAKE MALOMBE: DOES ENVIRONMENTAL VARIABILITY MATTER?

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1. INTRODUCTION

1.1 The collapse of a fishery

Lake Malombe is sometimes considered as a foreboding of what could happen with an African fishery if the growth of fishing effort remains unchecked (Coulter, pers. com.): around 1990 an important fishery on a group of tilapiine fish species called "Chambo" collapsed as a result of overfishing (FAO, 1993; Bulirani *et al.,* 1999; Palsson, Bulirani and Banda, 1999). Annual catches of the three species that form the Chambo complex *Oreochromis lidole*, *O. squamipinnis* and *O. karongae*, dropped from 9 300 tonnes in 1982 to a mere 50 – 200 tonnes from 1993 onwards. Subsequently the *Oreochromis* fishery was almost completely replaced by a fishery on a complex of haplochromine cichlids – Kambuzi, the output of which fluctuated heavily, reached levels of around 9 500 tonnes in 1987 and 1990 but dropped to a level of around 2 800 tonnes four years later and has not recovered since[1] (Figure 1).

Presently, the exploitation of Lake Malombe is dominated by two artisanal fisheries: a gillnet fishery and a purse-seine type of fishery, locally known as Nkacha. Gillnets are used as stationary nets and as open water seines; they are on average 750 m long with varying mesh sizes. More important - and more contested as will be discussed later – are the Nkacha nets: the open water purse seines are operated from two planked boats by seven crewmembers using it in day and night shifts. The nets are around 150 m long with a mesh size of 14 mm[2]. Before the collapse of the *Oreochromis* fishery two other gear types were important as well, both beach seines. Large Chambo seines with a headline length ranging from 50 m up to 1 800 m (mean around 800 m) and a depth of 5–20 m required the labour of 10 to 30 people to operate. Kambuzi seines were nets around 200 m in length (range 50–700 m), with a depth of 2–12 m, a mesh size of 15 mm and required 6 to 20 people to operate. These expensive large seines were sometimes operated in pairs or in combination with a larger Chambo seine, where the second net was pulled around the first to catch fish escaping from it, a fishing method called Chalira. The large Chambo seines disappeared shortly after the collapse of the *Oreochromis* fishery, while most small meshed Kambuzi seines presently have been converted into purse seines. In 1993 the proportion of illegal gears used in the Malombe fishery – i.e. gears outside proscribed size and mesh size regulations – was between 40 percent and 75 percent for these four methods (FAO, 1993; Hara and Jul-Larsen, 2003).

FAO (1993) presented evidence that high fishing effort was the cause of the decline in *Oreochromis* catches since 1981 and the report warned of a possible collapse of the haplochromine fishery as well. For *Oreochromis* spp., an MSY of 6 000 tonnes per year was calculated, which was reached from 1984 until 1989, at the estimated effort levels.

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[1] Observations in 2003 indicate that a large part, possibly up to one third, of the catch of the Nkacha purse-seine fishery on Kambuzi now consists of snails (M. Banda, pers. rem.; P.A.M.van Zwieten, pers.obs).

[2] Though mesh size may be as small as 6 mm (Weyl, pers.obs).

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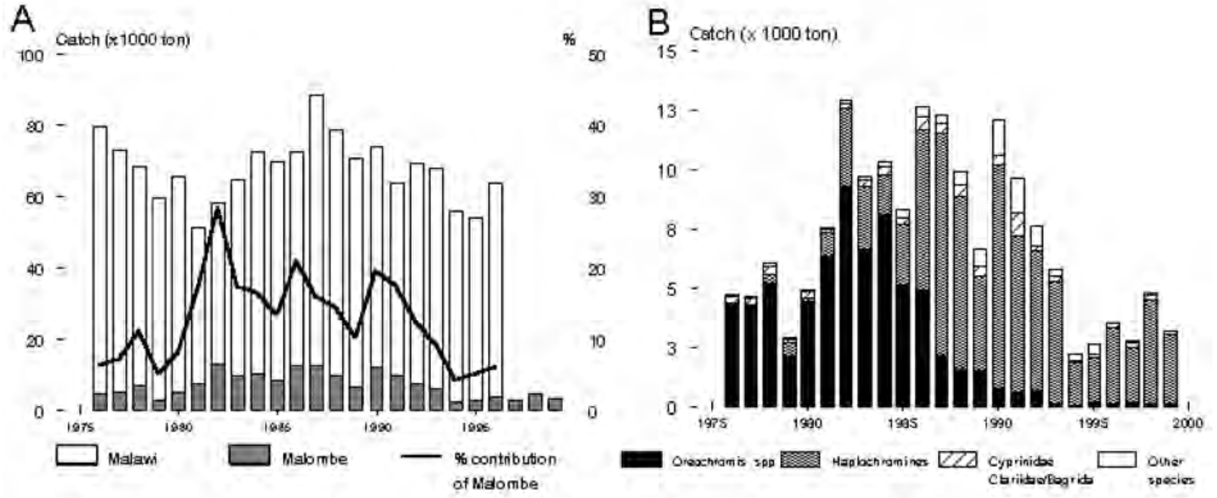

FIGURE 1 *A. Total catch from Lake Malombe as a proportion of the total catch of Malawi.* ***B.*** *Total catch of Lake Malombe broken down by species and species groups.*

Nevertheless, a sharp decline in catch occurred, with effort decreasing further in 1990 and 1991 while neither catches nor CPUE improved. The possibility of recruitment overfishing caused by excessive fishing of the parent stock, was ruled out, as effort levels exploiting the parent stock were low compared to the years between 1976 and 1983, when catch levels were maintained. FAO concluded that excessive fishing of the 0+ and 1 year juveniles by small meshed beach seines and purse seines was responsible for the collapse: 70 percent of all *Oreochromis* spp. caught were taken by these gears. Small meshed beach seines also were thought to harm *Oreochromis* spp. during breeding and brooding periods, as these seines were dragged through habitat utilized by *Oreochromis*, destroying extensive under-water weed beds (Tweddle, Alimoso, and Sodzabanja, 1994). *Oreochromis* spp. that escaped was subsequently fished further away from the shore by gillnets: fishing mortality peaked at both sizes of around 10 cm (0+ and 1+ year of age) and 25 cm and larger (3+ year of age). This is a typical case of technical interaction between different fisheries: small meshed nets, in particular Kambuzi seines and Nkacha nets exploit the juvenile stages in the inshore area, while larger meshed gillnets nets exploit the three year and older fish. In short: the *Oreochromis* stocks were thought to have collapsed by a combination both of excessive fishing of the juvenile stock followed by a high but in itself not unsustainable fishing pressure on the parent stock. The collapse possibly was accelerated by destruction of *Oreochromis* nursery habitat, though the evidence is scant.

In addition all models suggested that haplochromine – Kambuzi – stocks were overexploited by the purse-seine fishery. Nevertheless the Kambuzi fishery remained profitable. Therefore a complete collapse of the Malombe fishery was not outside the realm of the possible: the future of the Malombe fishery was bleak. Recommendations to overcome the situation included: limit access through licensing; limit numbers of gears to present levels; forbid fine meshed beach seines and stimulate conversion of them into purse seines; gear and mesh size regulations for all gears (e.g. the purse seines should have headline length of 150 m and a minimum mesh of 25 mm); no closed season. Continued monitoring was considered of the utmost importance[1]. Since then much work has gone into an attempt to regulate fishing effort through co-management arrangements (Donda, 2000).

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[1] See Banda et al. (2002) for developments on proposed management strategies from a biological point of view.

1.2 Lake Malombe: production, productivity and physical environment

Lake Malombe had a very high fishery production of between 60–320 kg/ha (average 193 kg/ha) that lead to a long-term annual average fish yield of around 7 500 metric tonnes. The fishery contributed around 15 percent to the total fish catch of Malawi during the 1980s with a peak of 22 percent in 1982, but levels dropped to between 5–10 percent in late 1990s (Figure 1). The 390 km^2 lake is shallow, twice as long as wide, and lies in the outflow of Lake Malawi through the Upper Shire River. The average depth is 5–7 m[1] with a maximum of around 17 m. Except for areas of submerged vegetation and Typha swamps found around the in and outflow of the Shire River, it is a fairly featureless open water body. Small-scale fishing only started in the 1960s after the destruction of a large crocodile population (Tarbit, 1972; Tweddle, Alimoso and Sodzabanja, 1994). Dense weed beds, reported on already in the 1940s, and lakeshore reeds were cleared in the 1970s and 1980s to facilitate seining. Currently few weed beds occur in the lake (Weyl pers. obs.). The lake is fully mixed, is fairly turbid with an average visibility of 2.4 m[2].

Rainfall and runoff are believed to contribute significantly to the productivity of the lake, which is much higher than that of the South East arm of Lake Malawi, where the Shire River originates (FAO, 1993). Average annual water levels measured in the Upper Shire at Mangochi, 6 km from its entrance into Lake Malombe have decreased by around 3.5 m over the period from 1978 to 1999 (Figure 2). During most of the decade of 1990s the area received little rainfall that resulted in a complete recession of Lake Chilwa further south in Malawi (Zwieten and Njaya, 2003). If rainfall and runoff are important for the productivity levels of Lake Malombe, then increased fishing effort and declining productivity must have at least acted in conjunction. However, possibly as a result of the overwhelming evidence for overfishing, the possibility of changing productivity of the stocks and the lake as a result of decreasing water levels, increased runoff and sedimentation due to deforestation around the lake (mentioned in discussions with older fishermen as a cause of decreased productivity of *Oreochromis*) or habitat destruction received limited attention in the discussion on the causes of fluctuations and decline in fish stocks. Habitat destruction and the effect of changes in rainfall and runoff were hinted at as causal factors, but never investigated. This is important when evaluating the success of management measures directed to limiting fishing effort: if these factors contributed to lowered productivity or even to structural changes in the pathways of biological production of the lake, expected effects of management measures may take place at a slower rate, may not be as large as expected or will not take place at all.

In this paper we will not address these issues on the level of biological processes. Here we will discuss whether fisheries authorities have the capacity to timely detect important changes and trends based on available monitoring information on catch rates, effort developments and changes in environmental drivers – those indicated by water levels: can changes and trends in fish stocks can be perceived timely and causes of change and variability in catch rates be interpreted meaningfully with the information systems available? Three questions arise:

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[1] Van den Bossche and Bernascek (1990) give an average depth of 4 m. But Figure 2 it can be inferred that average annual water levels over a 20-year period ranged over 3.5 m. A dam in the lower Shire River regulates the minimum water level.

[2] Compare with the South East-arm of Lake Malawi: visibility 7.8 m; Lake Malawi, 12.5 m (Secchi disc readings).

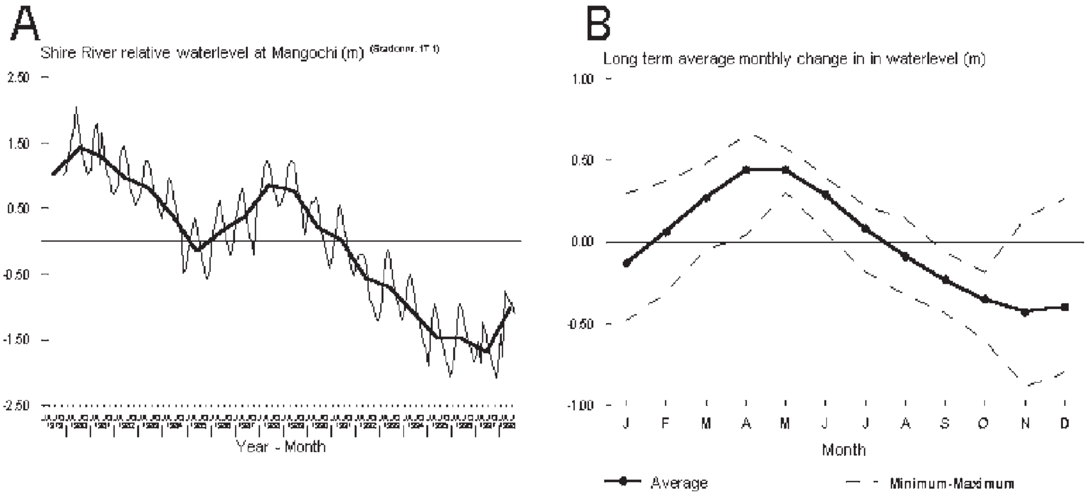

FIGURE 2. ***A***. *Annual average (thick line) and mean monthly (thin line) water levels in the Upper Shire River at Mangochi* ***B.*** *Long term average monthly water levels and highest and lowest recorded monthly water levels.*

- is there evidence for possible changes in productivity of Lake Malombe as a result of environmentally driven factors?
- is it possible to detect the combined effects of productivity changes and increased effort through the existing catch and effort and water level monitoring systems in Malawi?
- what consequences do the answers to these questions have for the resource management of Lake Malombe?

2. RESEARCH STRATEGY: DATA, INFORMATION AND EVALUATION

2.1 Data- poor yes, but not data-less

Many African fresh water fisheries can be considered as data-poor (Mahon, 1997; Johannes, 1998): management decisions have to be made based on little information on drivers of, pressures on and states of fish stocks. Nevertheless, often long-term series of catch and effort monitoring are available, obtained through Catch and Effort Data Recording Systems (CEDRS) mostly developed in the seventies and eighties. The maintenance of a CEDRS is difficult due to the high costs involved, both in the data collections themselves as well as in maintaining the institutional set-up and the knowledge base. As a result, data collected are often considered too poor to be utilized in formal stock-assessments, while the information from assessment results is often qutance, the value of single figure estimates of long-term sustainable yields (e.g. MSY) based on steady state assumptions of environmental stability is questionable when large changes in productivity of fish resources occur, as a result of environmental drivers such as seasonal, annual and longer-term fluctuations in water level. This has as a number of consequences:

- It becomes difficult to unequivocally attribute changes in the state of fish stocks to fishing effort.
- Choosing a fixed optimum level of fishing effort in order to maximize efficiency becomes at best an approximation for a range of acceptable effort levels around a range of long term yield estimates. Banda *et al.* (2002) take this approach.
- Evaluating the effectiveness of measures regulating fishing effort will be problematical as effects of fishing and environment are confounded. This complicates any effort to establish causation.

The perceived inaccuracies of monitoring data collected, as well as frustrations over the applicability of standard fishery science, have lead to a severe under utilization of the quantitative and qualitative information present in the catch and effort time series collected. Despite that, data continue to be collected and in quite a number of cases it is now possible to re-construct sometimes long time series of catch and effort (e.g. Zwieten *et al.*, 2002). Much can be gained from maximising the use of existing information and knowledge on the performance of a fishery by evaluating trends and variability in catch and effort time series.

In addition effects of naturally changing or fluctuating environments on fish production should be taken into account to assess the effect of changing fishing effort. In floodplain environments the evidence of environmentally driven fish production is overwhelming (e.g. Lae, 1995; Junk, 1996; Hoggarth *et al.*, 1999a), but in recent accounts attention is drawn to the regulation of fish stocks in small and medium sized lakes by changes in productivity through fluctuating water levels (Kariba: Karenge and Kolding, 1995; Turkana, Kolding, 1992; Chilwa Kalk, McLachlan and Howard-Williams, 1979; Zwieten and Njaya, 2003 and other lakes Lévêque and Quensière, 1988; Talling and Lemoalle, 1998) or even in large lakes as Lake Tanganyika through other, not yet fully understood long-term environmentally driven processes (e.g. Spigel and Coulter, 1996; Zwieten and Njaya, 2003; Sarvala *et al.*, 1999). Changes and fluctuations in environmental drivers as water levels can be important indicators for changes in stocks in an adaptive management context, as water levels are easily measurable, with often long times-series of data present.

Compared to surrounding countries, the Malawian information base for fisheries management is well established. Past monitoring of stocks and of some environmental parameters has yielded useful information that is available. Also specialized studies on all important fisheries in Malawi has provided biological information on a species level useful for stock-assessments (e.g. Kalk, McLachlan and Howard-Williams, 1979; FAO, 1993; Tweddle, 1995; Palsson, Bulirani and Banda, 1999, Jambo and Hecht, 2001, Banda *et al.*, 2002).

2.2 Evaluation of effectiveness of fisheries resource management in highly fluctuating environments

The evaluation of the effectiveness of fisheries resource management is largely dependent on the possibility to perceive changes in indicators for stock abundance and relate these to measures taken. Time trends in fish stocks as reflected in time series of catch rates are the basis for such evaluations. The possibility of measuring success of resource management actions within the appropriate time window depends both on the strength of effect over time and the variance around it (Peterman, 1990; Pet Soede *et al.*, 1999; Densen, 2001; Zwieten *et al.*, 2002). In this paper we will:

- *Examine trends and variability (inter-annual and seasonal variability by gear-species combinations) in the catch rates of Lake Malombe*
  to obtain an idea of the magnitude and sources of the variability in the monthly catch rates by species (group) and gear and the consequences this has for the capacity of fisheries authorities to detect changes and trends in fisheries outcomes.
  Examine changes in water levels and relate these to changes in catch rates
- to obtain information on the relative effect of fluctuating water levels on catch rates;
  Finally, examine trends in fishing effort and relate them to trends in catch rates taking into account the effect of changes in water level.

In statistical terms, the capacity to detect a trend is determined by the statistical power of the information examined, which in turn depends entirely on the variance of the data, given the number of observations and statistical decision levels. The time series of estimated monthly catch rates from CEDRS surveys of Malombe by major stratum (i.e. East and West Malombe) represent the lowest level of data aggregation for this lake that are used in reports on the status of the fishery. The capacity to detect trends and evaluate the effects of resource management with the aid of these time series is therefore dependent on the variability within these series, given the present sampling and data handling methods in use.

A justification of the research strategy followed in this study and the methodology of analysis of catch, catch rate, effort and water level data (analysis of variance, trend analysis, trend-to-noise analysis, multiple regression analysis) is outlined in Zwieten and Njaya, 2003. A description of the data sets as well as a justification of the aggregation into species groups can be found in Appendix 1. Appendix 2 describes the method of reconstruction of effort data. In Appendix 3 we give an analysis of the error structure of the data, with particular attention to the causes and effects of administrative errors on trend evaluation.

3. RESULTS

We start with an assessment of the information value of the monthly catch rates by gear and species group of Lake Malombe as taken from the CEDRS of Malawi, through an analysis of variance and trends, summarized in Table 1 and Figures 3–7. We analyse the size and sources of variability: gear selection of species, co-variation of species in the catch (see section 3.1 of this paper) and seasonal variability (3.2), inter-annual variability (3.3) and patterns trends (3.4) in catch rates (as a proxy for fish biomass). Seasonal variation is predictable while (long-term) trend is the information of interest: other sources of variation obscure the perception of trends. The variability in the data remaining after removing variability caused by trends and seasonality is called basic-uncertainty, and we will show that this is very high on the aggregated level of monthly catch rate data in the Malawian CEDRS (3.5), increasing the trend-to-noise ratio and with that decreasing the administrative capacity to detect trends (3.6). Its causes are discussed in Appendix 3. Next we will turn our attention to two potential causal factors. We use a statistical correlative approach of the trends and inter-annual variation in catch rates assuming changes in water level as driving factor of, and fishing effort as main pressure on, fish stock levels. After describing the developments in water level since 1915 (3.7), we examine the effect of annual change in water levels on the annual change in catch rates i.e. irrespective of trends in both variables (3.8). Then we describe developments in fishing effort by number of fishermen (3.9) and gears and gear activity (3.10). Lastly we examine the combined effect of increased effort and changing water levels on the development of catch- rates (3.11).

Gears are species selective

In multispecies fishery different gears, their spatial allocation and mode of operation – together forming a fishing pattern – target different sections of the fish community. A low variability[1] in catch rates of a particular species, or group of species, compared to others caught by the same gear indicates an important target of a particular fishing pattern. Changes in stock-sizes are more easily detected by analysing catch rates of these gears. The lowest variability is found in the species-gear combinations *Oreochromis* in Chambo seines (F=4.8) and *Haplochromis* in Kambuzi seines (F=8.9) and Nkacha nets (F = 2.7). The lowest variability in gillnets are Cyprinid catch rates (F=6): though *Oreochromis* is known to be a target species for this fishery a large amount of variability is induced by the declining trend as a result of the collapse of Chambo (see further). For most other species-gear combinations the variability is around a factor F=10 or higher (Table 1; Figure 3).

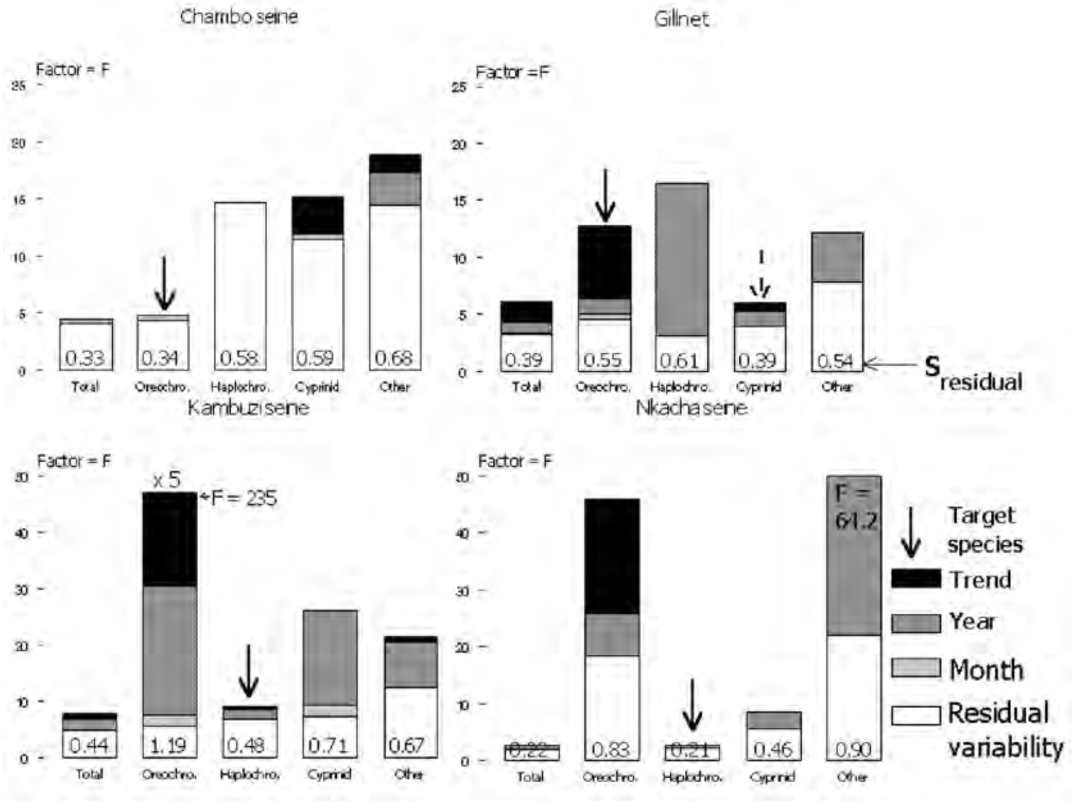

FIGURE 3. *The size of variability expressed as factor (F) around the geometric mean explained by trends (as linear regression), interannual, monthly and residual variability. The residual variability is also expressed as standard deviation (S) at the bottom of each column. The arrow indicates the target species of a gear. Basic uncertainty (see text) is the variability remaining when trend (black area) and seasonality (light grey area) are removed from the total variability.*

Aggregation of species into a total catch rate of a gear only leads to a slight reduction in total variability in all cases, and even in a slight increase in case of Nkacha seines. This indicates that though the gears are relatively specific in their target species, co-variation of the other

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[1] Variability is described in this paper by a factor F around the geometric mean catch rate. A factor of F = 2.8 means that 95% of the data fall within the range of 2.8 times the Geometric Mean (GM) and the GM divided by 2.8. The Geometric Mean is the back transformed logarithmic mean of the data (=10 log10(M)) (see: Zwieten and Njaya, 2003).

species in the catch may be high leading to a lower reduction in CV of catch rates (Oostenbrugge *et al.*, 2002). The variability in total catch rates was lowest in Nkacha nets with a factor F= 2.8 followed by Chambo seines (F = 4.5), gillnets (F = 6.1) and Kambuzi seines (F = 7.2). Kambuzi seines exhibit a surprisingly high variability, compared to the other seines, which may be due to large differences in net sizes that were not taken into account in the correction of daily catch rate samples for effort, while before 1986 Nkacha and Kambuzi seines were not separated in the data collection.

TABLE 2. *Results of Analysis of Variance and regression analysis on monthly catch rates of Lake Malombe by gear and species groups as contained in the CEDRS of Malawi (see text for further explanation)*

Total catches	**Chambo *seine***						***Gillnets***					
	Model	**df**	**MSE**	**Factor**	**r2**	**p**	**Model**	**df**	**MSE**	**Factor**	**r2**	**p**
Total variance		90	0.108	4.5				234	0.153	6.1		
After Year	-	-	-	-	-	ns	*Year*	215	0.066	3.3	0.60	***
After Month	*Month*	81	0.095	4.1	0.20	*	*Year + Month*	204	0.063	3.2	0.64	***
Trend	-	-	-	-	-	ns	*Linear*	233	0.099	4.3	0.36	***
							Polynomial	232	0.084	3.8	0.46	***
							(quadratic term = 21% of total explained variance)					
	Kambuzi *seine*						**Nkacha *seine***					
Total variance		194	0.196	7.7				87	0.051	2.8		
After Year	*Year*	175	0.115	4.8	0.47	***	*Year*	76	0.021	1.9	0.65	***
After Month	-	-	-	-	-	ns	-	-	-	-	-	ns
Trend	*Linear*	193	0.172	6.8	0.12	***	*Linear*	-	-	-	-	ns
	Polynomial	192	0.164	6.5	0.17	***	*Quadratic*	86	0.040	2.5	0.23	***
	(quadratic term = 27%of total explained variance)											
Oreochromis spp.	**Chambo *seine***						***Gillnets***					
Total variance		90	0.116	4.8				231	0.305	12.7		
After Year	-	-	-	-	-	ns	*Year*	212	0.124	5.0	0.63	***
After Month	*Month*	81	0.101	4.3	0.21	*	*Year + Month*	201	0.110	4.6	0.69	***
Trend	-	-	-	-	-	ns	*Linear*	230	0.161	6.4	0.47	***
							Polynomial	229	0.141	5.6	0.54	***
							(quadratic term = 12% of total explained variance)					
	Kambuzi *seine*						**Nkacha *seine***					
Total variance		117	1.405	234.9				65	0.690	45.8		
After Year	*Year*	98	0.621	37.7	0.63		***	54	0.400	18.4	0.52	***
After Month	*Year + Month*	87	0.518	27.5	0.73	***	-	-	-	-	-	ns
Trend	*Linear*	116	1.190	152.0	0.16	***	*Linear*	64	0.500	25.9	0.29	***
	Polynomial	115	0.996	99.2	0.30		***					
	(quadratic term = 47% of total explained variance)											
Haplochromis spp.	**Chambo *seine***						***Gillnets***					
Total variance		1	0.341	14.7				12	0.371	16.5		
After Year		-	-	-	-	-	*Year*	6	0.062	3.1	0.92	**
After Month		-	-	-	-	-	-	-	-	-	-	ns
Trend		-	-	-	-	ns	*Quadratic*	11	0.227	9.0	0.44	*
	Kambuzi *seine*						**Nkacha *seine***					
Total variance		179	0.226	8.9				84	0.046	2.7		
After Year	*Year*	160	0.172	6.8	0.32	***	*Year*	74	0.024	2.1	0.53	***
After Month	-	-	-	-	-	ns	-	-	-	-	-	ns
Trend	*Linear*	178	0.215	8.4	0.06	***	*Linear*	-	-	-	-	ns
	Polynomial	177	0.208	8.2	0.09	**	*Quadratic*	83	0.035	2.4	0.26	***
	(quadratic term = 38% of total explained variance)											
Cyprinid spp.	**Chambo *seine***						***Gillnets***					
Total variance		74	0.349	15.2				232	0.151	6.0		
After Year	*Year*	62	0.248	9.9	0.41	***	*Year*	213	0.090	4.0	0.45	***
Trend	*Linear*	73	0.289	11.9	0.21	***	*Linear*	231	0.131	5.3	0.13	
	Polynomial	72	0.264	10.7	0.26	**	*Polynomial*	230	0.123	5.0	0.19	***
	(quadratic term= 21% of total explained variance)						(quadratic term= 29% of total explained variance)					
	Kambuzi *seine*						**Nkacha *seine***					
Total variance		149	0.503	26.2				81	0.215	8.4		
After Year	*Year*	130	0.233	9.2	0.60	***	*Year*	71	0.143	5.7	0.41	***
After Month	*Year + Month*	119	0.186	7.3	0.70	***	-	-	-	-	-	ns
Trend	*Quadratic*	148	0.449	21.9	0.11	***	*Quadratic*	80	0.190	7.5	0.12	***
Other spp.	**Chambo *seine***						***Gillnets***					
Total variance		70	0.409	19.0				189	0.293	12.1		
After Year	*Year*	59	0.336	14.4	0.31	*	*Year*	170	0.198	7.8	0.39	***
Trend	*Linear*	69	0.384	17.4	0.07	**	*Linear*	-	-	-	-	ns
	Polynomial	68	0.354	15.5	0.16	**	*Quadratic*	188	0.251	10.0	0.15	***
	(quadratic term = 54% of total explained variance)											
	Kambuzi *seine*						**Nkacha *seine***					
Total variance		139	0.443	21.5				70	0.818	64.3		
After Year	*Year*	120	0.302	12.5	0.41	***	*Year*	60	0.452	22.1	0.53	***
Trend	*Linear*	138	0.431	20.5	0.04	*	*Linear*	-	-	-	-	ns
							Quadratic	69	0.689	45.7	0.17	***

Significance level is indicated by asterixes: * p<=0.05, ** p<=0.01, ***p<=0.001

3.2 Seasonality only detected in *Oreochromis* catch rates

Seasonality could be significantly detected in 4 out of 20 time series examined (Figure 4, Table 1) indicating that the seasonal signal in the data sets for most species-gear combinations is low. Seasonality was seen in catch rates of *Oreochromis* spp. in gillnets (F=0.4; 6 percent of the total variance explained); Kambuzi seines (F=10.2; 10 percent) and in Chambo seines (F=0.5; 21 percent). Only gillnet catch rates displayed a regularly fluctuating pattern resulting in peak catches from November to March at low and increasing water levels and a low in June/July at decreasing levels.

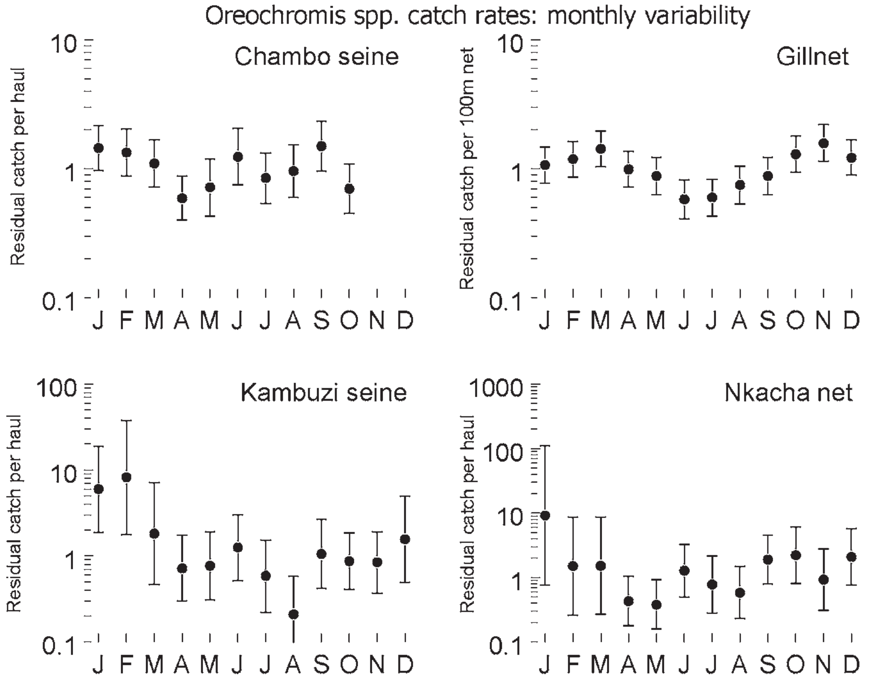

FIGURE 4. *Monthly variability in catch rates of Oreochromis spp. by gear. Vertical bars represent 95 percent confidence limits. The scale on vertical axes represents a multiplication factor of the of the ^{10}log annual mean catch rates (see Figure 5).*

Both Chambo seines and Kambuzi seines peaked in January/February at low water levels, while lower catch rates were experienced in Chambo seines during high levels in April/May and in Kambuzi seines at decreasing levels in July/August. No seasonality could be detected in Nkacha seines both in total catch rates, i.e. catch rates aggregated over species, and by species, a reflection either the low seasonality in the stock levels of the Kambuzi complex or the activity patterns of the fishery or both.

3.3 Annual variability is high and varies between different gears

Annual variability in average catch rates was high, with significant differences between years in 14 out of 20 time-series of species-gear combinations examined. Inter-annual changes, including both trends and differences between years (see also Figure 3) explained 45 – 65 percent of the total variance (Table 1). The exceptions were the total catch rates and *Oreochromis* catch rates of the Chambo seines, where no significant difference between years could be detected: average catch rates remained the same throughout the time-series. The four remaining cases were all non-target species for the various gears. Though annual averages varied much, no variability could be explained by temporal analysis: catch rate data for these series on the aggregated level of the monitoring data (month) indicated pure chance.

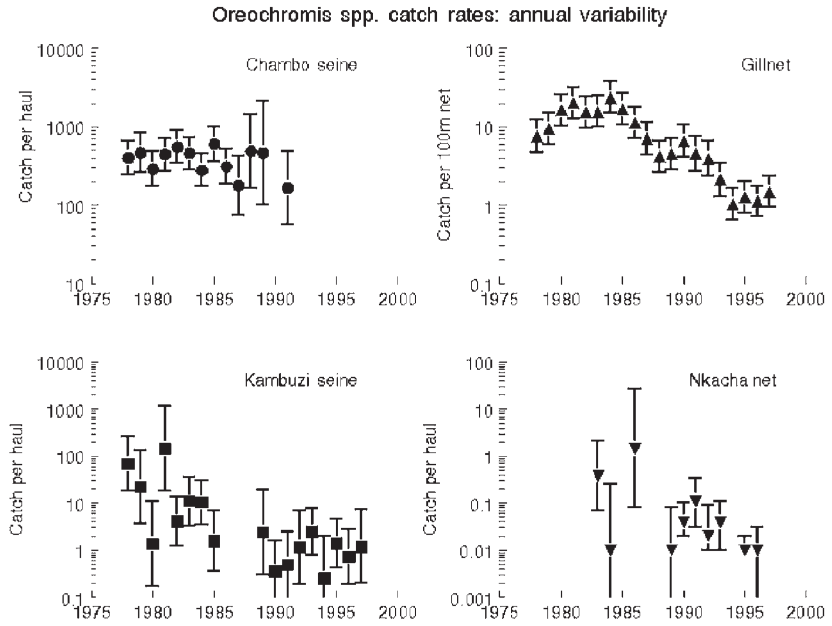

FIGURE 5. *Annual variability in total catch rates by gear. Vertical bars represent 95 percent confidence limits. Note ^{10}log scale on vertical axes. The higher confidence limits in catch rates of Chambo seines from 1987 onwards reflect the limited number of data for these years and gears respectively (see also Table 1).*

3.4 Patterns and trends in annual average catch rates

The most remarkable patterns in annual catch rates are found in Chambo seines (Figure 6 and 7): catch rates of *Oreochromis* spp. exhibited no trend with very little variability in yearly averages[1]. All other gears that catch *Oreochromis* but do not target them actively – stationary set gillnets catch the larger specimens, Kambuzi and Nkacha seines catch the juveniles as bycatch - do exhibit strong downward trends from 1984 onwards. This can only be explained if the fishing effort exerted by the Chambo seine fishery changed over this period, either by changing the gear (size), activity (more pulls per day, active hunting) or by changing the spatial coverage of the fishery. We have no information to decide on any of these possibilities, though it is known that shorelines were cleared to make the lake accessible for the beach seine fisheries. Gear activity changes are probable only if fishermen started fishing in shifts, as happened in Lake Mweru (Zwieten and Njaya, 2003) which may have occurred in Malombe as well (Weyl pers. obs.). The rapid increase in Chambo seine catch rates of Cyprinids (by a factor 28 over 15 years) and other spp. (by a factor 25 over 15 years), not repeated in any of the other gears, emphasizes that a change in effort – through gear size, gear use or spatial allocation of effort – must have taken place.

The drop in catch rates found in Kambuzi seines and gillnets shows that a comparable change in effort patterns did not take place in these gears. Annual variability for Kambuzi seines is high and highly significant: annual differences explain 47 percent of the variability. In

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[1] The data series stopped in 1991, though the fishery in the lake stopped only in 1999, but not in the Upper Shire!

particular the drop in catch rate around 1987/88 and the subsequent increase to a peak in 1993 contribute to this (Figure 6). The pattern seen in the annual average total catch rates is reflected in all species groups (Figure 7): a low is reached between 1986 and 1987 and catch rates increased and stabilized after the collapse of the Chambo seine fishery from 1989 onwards.

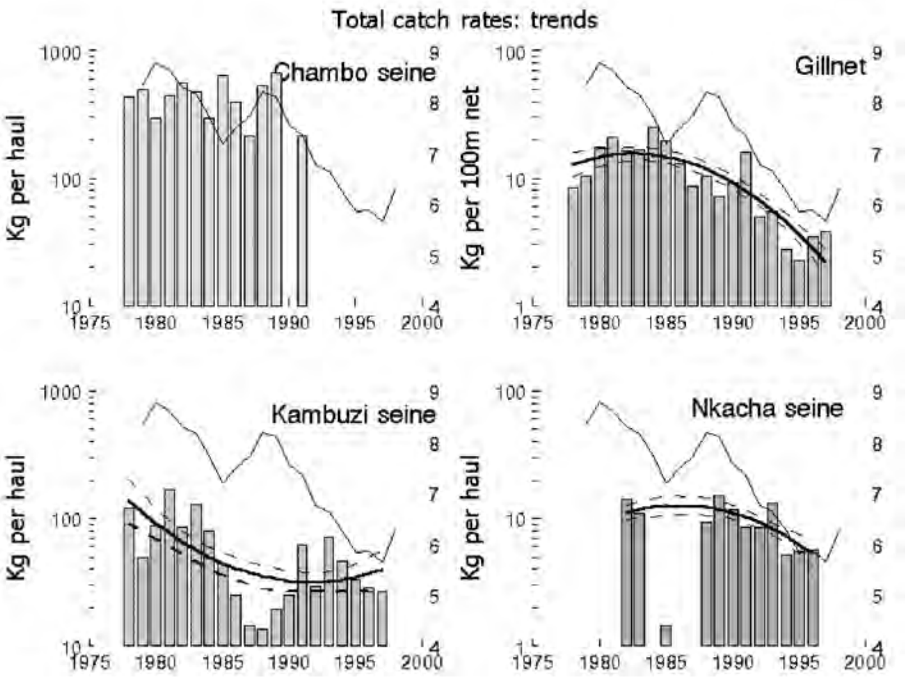

FIGURE 6. *Geometric mean annual catch rates (bars) by gear in Lake Malombe and polynomial trends (thick line). Trends are shown with 95 percent confidence limits (broken lines). The thin line is the relative mean annual water level of the lake.*

Gillnet catch rates show a less clear, but similar pattern with a drop in total (Figure 6) and *Oreochromis* catch rates (Figure 7) around 1987 followed by an increase up to 1991, after which catch rates collapsed by a factor 4-5. Gillnet total catch rates are composed of both a general decline and a shift in species dominance. The decline in total catch rates is dominated by the decline from 25 kg to 1 kg per 100 m net of *Oreochromis* catch rates from 1984 onwards. Catch rates of cyprinds increased and stabilized after 1989, while the category Other spp. remained relatively stable over the whole period peaking around 1985. The possible cause of the initial increase of catch rates of both Kambuzi seines and gillnets after 1987/88, could have been the release of pressure on fish-stocks as a result of the collapse of the Chambo seine fishery. However, as will be discussed later, this coincided with a period of increase in water level as well.

3.5 Basic uncertainty is extremely high

Basic uncertainty is defined as the variability remaining after removing the variability explained by a long-term trend and seasonality. It is the amount of variability around the long term-trend resulting from any other temporal, spatial or administrative source. When this variability is high on the aggregated level (by month) of the catch rate data analysed it indicates that trends will not be detected easily by the fisheries administration. Calculated on the level of the individual fisherman and on a daily basis it also indicates the randomness in

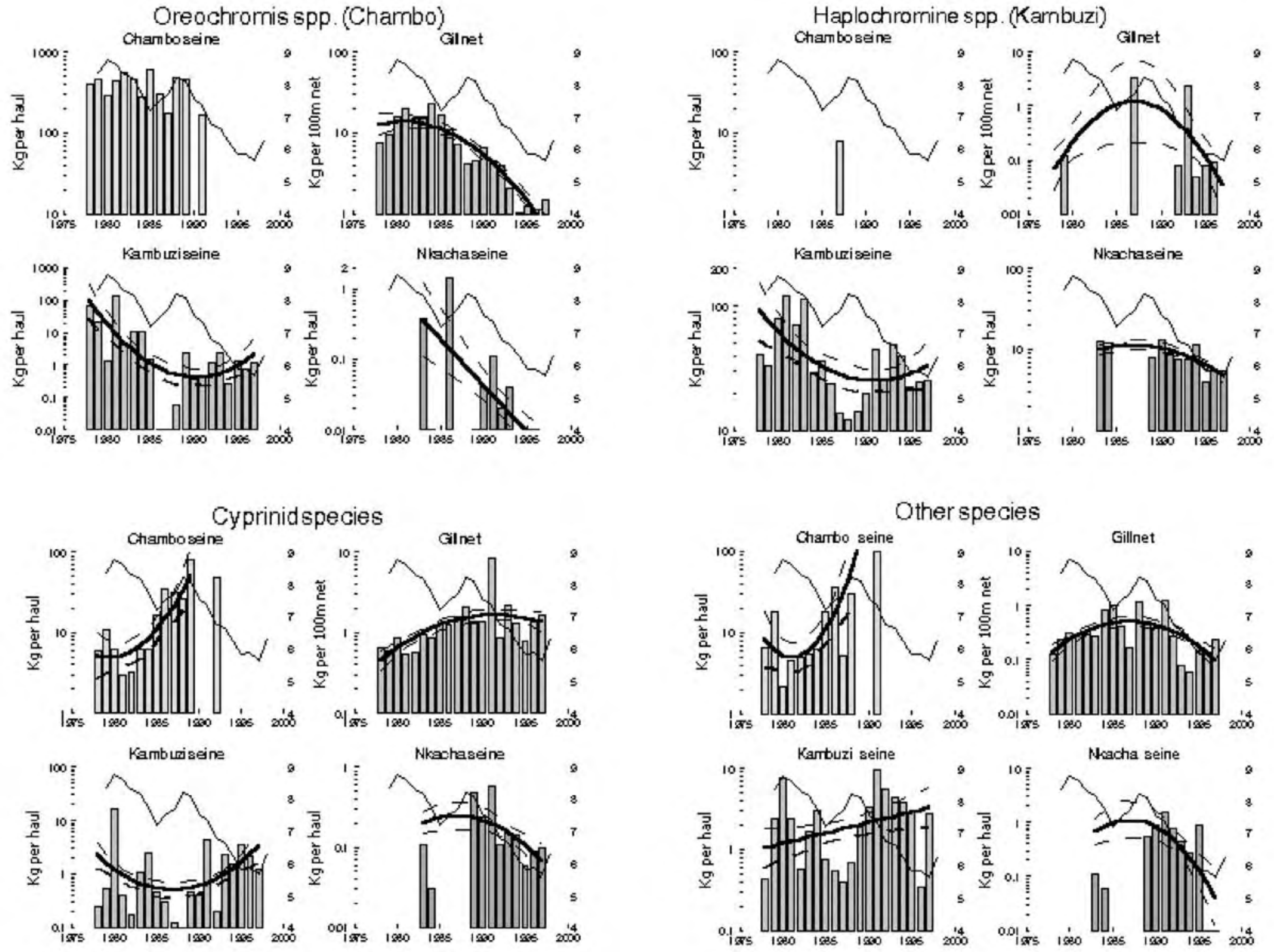

FIGURE 7. *Annual variation (bars) and polynomial trends (thick line) in geometric mean annual catch rates by species and by gear in lake Malombe. Trends are shown with 95% confidence limits (broken lines). The thin line is the relative mean annual water level of the lake.*

catches he has to deal with, i.e. variability in catches with no predictable patterns. This is an important indication of his limited capacity to observe spatial differences and temporal changes. At the same time it is an important factor to consider in the structural organization of the fishery (Oostenbrugge, *in press*).

On the aggregated administered level, basic uncertainty was high in all cases: 100 percent of the variability or a factor F = 4.5 around the mean total catch rates of Chambo seines, 55 percent for gillnets (F = 4.3), 82 percent for Kambuzi seines (F = 6.8) and 77 percent for Nkacha nets (F = 2.8). For target species of gears, basic uncertainty was sometimes lower – between 5 and 12 percent for *Oreochromis* , or was as high as or even higher than the total catch rates for haplochromines in Nkacha nets (74 percent) and in Kambuzi seines (91 percent). In other words the variability or noise around the long-term trend was high in all cases.

Basic uncertainty of Oreochromis catch rates in gillnets also became much higher after the collapse of the stocks: not only was the outcome of this fishery severely reduced, it became also much more unpredictable (Figure 8).

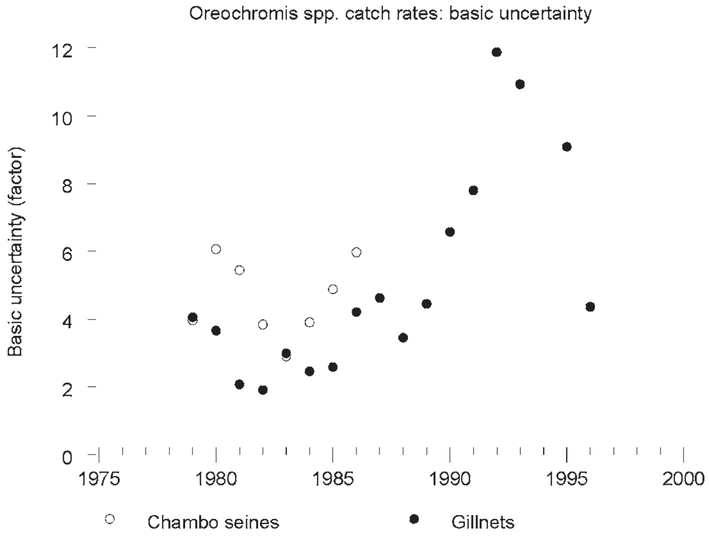

FIGURE 8. *Basic uncertainty in catch rates of Oreochromis spp. in gillnets and Chambo seines. Basic uncertainty is expressed as a factor around the geometric mean. Data points represent the factor around three year moving averages of the mean.*

3.6 Trend to noise: the administrative capacity to perceive trends

How fast can the fisheries administration decide on the direction of a long-term or short-term trend given the information at hand? Long-term linear downward trends, observed in three out of four time series of total catch rates were significant and statistically justifiable with 20 to 31 months of data (Table 3, Figure 9). Persistence, or non-random residuals that are auto-correlated at a time lag of one month, had little effect on the number of monthly data points needed, increasing by a mere one to two months (Figure 9). The trend-to-noise ratio was highest in Kambuzi seines, both in total catch rates as well as catch rates for the species groups, with 29 months of data points needed to detect a trend for Oreochromis, and between 40 and 44 months for all other species. For Nkacha seines the trend-to-noise ratio was lowest for Oreochromis and haplochromines. Thus for all time-series examined it is possible to significantly detect long and short-term trends in the various catch rate series within 1.5 to 2.5 years of monthly aggregated data. These time windows to detect a trend are not too bad, though it indicates a limit to the speed with which effects of management measures could be detected as the time lag that fish-stocks demonstrably react to measures taken needs to be taken into account as well.

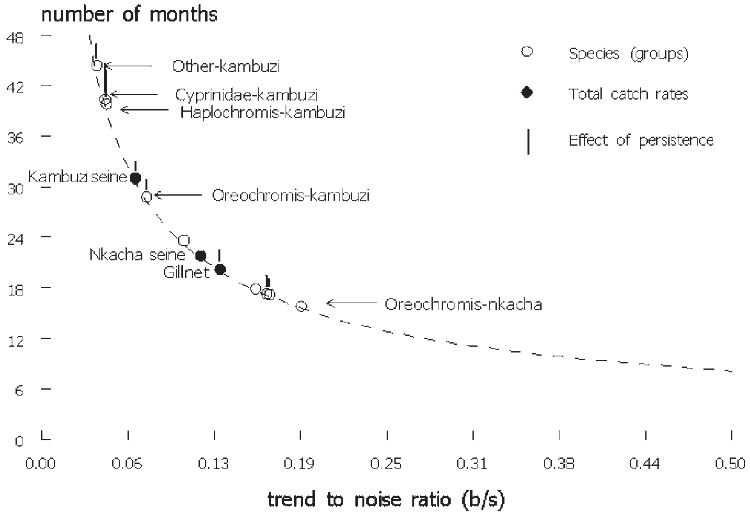

FIGURE 9. *The relation of the trend-to-noise ratio to the number of months of data needed to detect a trend in total catch rates and catch rates by species/gear combinations of including the effect of autocorrelation (persistence)*

How fast do long-term trends actually became visible in the data? For Kambuzi seines the long-term downward trend became statistically significant in 1984 and for gillnets three years later in 1987 (Figure 10a). Both remained negative from then onwards though increasingly less negative for Kambuzi seines after 1989. The long-term negative trend in Nkacha net catch rates became visible from 1993 onwards.

TABLE 3. *Trend, trend-to-noise ratio and number of months data needed to detect the observed linear trends with and without auto-correlation (persistence)*

Species	Gear	df	Trend (b)	Standard deviation (s)	Trend/noise (b/s)	N (months)	Autocorrelation coefficient (r)	N (months)
Total	Nkacha	87	-0.024	0.21	-0.12	22	0.33	23
	Kambuzi	194	-0.028	0.42	-0.07	31	0.42	33
	Gillnet	234	-0.041	0.31	-0.13	20	0.50	22
	Chambo	90	Ns				0.25	
Oreochromis	Nkacha	65	-0.133	0.71	-0.19	16	0.30	16
	Kambuzi	117	-0.083	1.09	-0.08	29	0.50	31
	Gillnet	231	-0.066	0.40	-0.16	17	0.53	19
	Chambo	90	ns				0.28	
Haplochromis	Nkacha	84	-0.030	0.19	-0.16	18	0.35	19
	Kambuzi	179	-0.021	0.46	-0.05	40	0.22	45
	Gillnet	12	ns					
	Chambo							
Cyprinidae	Nkacha	81	ns				0.45	
	Kambuzi	149	0.032	0.69	0.05	40	0.49	44
	Gillnet	232	0.025	0.36	0.07	31	0.38	33
	Chambo	74	0.087	0.53	0.16	17	0.50	19
Other	Nkacha	70	ns				0.68	
	Kambuzi	139	0.026	0.66	0.04	44	0.39	47
	Gillnet	189	ns				0.38	
	Chambo	70	0.064	0.62	0.10	24	0.17	24

However, investment or operational decisions as well as success of management measures are often to be considered in the short-term: both resource users and managers respond to short-term trends in particular. Many of the time series examined did not exhibit clear (significant) short-term – five-year – trends (Figure 10b). Catch rates in Chambo seines never exhibited upward or downward short-term trends. For gillnets this was the case in seven out of 16 five-year periods, for Kambuzi seines in five out of 16 and for Nkacha nets in one out of six. Furthermore, short-term trends in Kambuzi seines were much more erratic than those of gillnets, with much higher absolute trend-to-noise ratios. For instance trend-to-noise ratios flip-flopped from b/s= -0.67 to b/s=+0.56 between 1987 and 1991. Short-term trends are often not consistent between gears as well: for example in the five year periods before 1992 and 1993 Nkacha nets showed a downward trend, while over the same periods Kambuzi seines exhibited an upward trend while gillnets showed no trend. Some causation is hinted at in some of the short-term trends: as water-levels increased between 1985 and 1988, Kambuzi seines exhibited upward short-term trends in the five year periods before 1989 and 1993, while those in gillnet catch rates reverted from downward to upward over the same years.

In conclusion: long-term downward trends in catch rates became visible only after 1984 – 1987. The long-term pattern was confused by short-term patterns of increasing and decreasing trends, possibly as a result of environmentally favourable and unfavourable conditions, or as a result of large changes in fishing patterns. This will be discussed in the next paragraphs.

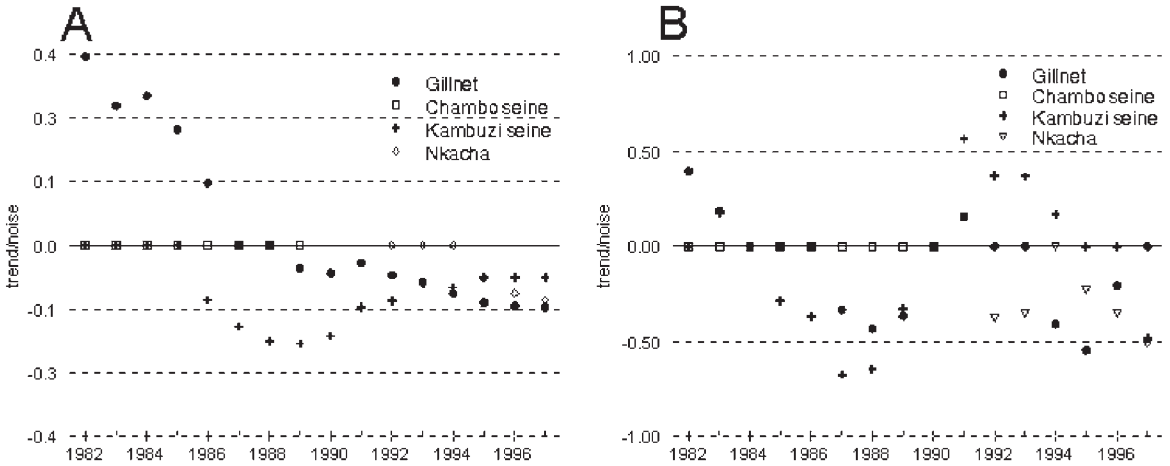

FIGURE 10A. *Long-term trends: development of the trend-to-noise ratio (b/s) in five years of catch rate data as observed in 1982 and onwards with successive addition of one year of monthly catch rate data for gillnets, Chambo, Kambuzi and Nkacha seines. 1982 is the b/s over 1977 to 1982; 1983 is b/s of 1978 – 1983 etc.* ***B****. Short-term trends: development of trend-to-noise over five year moving periods, each indicated by the last year*

3.7 Water levels were mostly decreasing from 1979 to 1998

When in 1915 Lake Malawi reached its historically lowest recorded lake level, a sand bar formed near Fort Johnston, present day Mangochi, and barred access to the Shire River. It brought to a halt its flow in all but the rainy season. By 1924, while the levels in Lake Malawi were rising, initially with no effect on the Shire River, most of Lake Malombe dried up almost entirely, “with food gardens being planted in large numbers on its bed” (McCracken, 1987).

After 1927 the water levels in Lake Malawi rose further still: in the years after 1934 the sand bar was swept away and Lake Malombe filled up again.

TABLE 4. *Cross-correlations between residuals of detrended annual average catch rates and detrended annual mean, minimum and maximum water levels of the Upper Shire at Mangochi. Analysis is done on total catch rates by gear and the target groups of the various gears. Regressions are done on lags with the highest significant correlation. N=number of observations,* r^2 *= proportion of explained variability, b= trend parameter. Significance is denoted by asterixes: * p<0.05, **p<0.01, ***p<0.001.*

Gear	**CATCH**	**TREND**					**Cross-correlation**						**Regression on lags with highest correlation**	
							Mean Water level		**Minimum water level**		**Maximum Water level**			
		N	**R^2**	**s**	**b**	**p**	**Lag**	**Corr.**	**Lag**	**Corr.**	**Lag**	**Corr.**	**r^2**	**p**
Gillnet	*Oreochromis*	19	0.85	0.156	-0.065	***	-4	0.43	-4	**0.48**	-4	0.38	0.26	*
	Cyprinidae	19	0.21	0.273	0.025	*	0	0.48	0	**0.54**	0	0.47	0.29	*
	Others					ns	0	**0.49**	-	-	0	0.45	0.24	*
Kambuzi	*Total*	19	0.29	0.323	-0.036	*	-2	**-0.80**	-2	-0.77	-2	-0.71	0.71	***
							-1	-0.77	-1	**-0.80**	-1	-0.68	0.64	***
	Oreochromis	19	-	-	-	ns	-2	-0.61	-2	**-0.70**	-2	-0.51	0.50	**
	Haplochromis	19	0.23	0.310	-0.029	*	-2	**-0.76**	-2	-0.74	-2	-0.67	0.64	***
							-1	-0.69	-1	**-0.74**	-1	-0.62	0.56	***
	Cyprinidae	19	-	-	-	ns	-1	-0.54	-1	**-0.58**	-1	-0.50	0.34	**
	Others	19	-	-	-	ns	-	-	-3	**-0.43**	-	-	0.37	*
Nkacha	*Total*	12	-	-	-	ns	-2	-0.79	-2	**-0.87**	-2	-0.76	0.67	**
	Cyprinidae	12	-	-	-	ns	-	-	0	0.63	-	-	0.53	*
Chambo	*Total*	12	0.64	0.281	-0.094	**	-	-	-1	**-0.54**	-	-	-	ns
	Oreochromis	12	0.66	0.296	-0.105	**	-	-	-1	**-0.54**	-	-	-	ns
	Cyprinidae	12	-	-	-	ns	-3	0.90	-3	**0.98**	-3	0.75	0.59	**
	Others	12	-	-	-	ns	-	-	-	-	-	-	-	-

Average annual water levels in the Upper Shire River near Mangochi, decreased by almost 1.5 m between 1980 and 1985, peaked in 1988 and continued to decline since then by almost 2.5 m reaching its lowest level in 1997. Over the period over which we are examining catch rates, a drop in average water levels of 3.5 m over 17 years, or 21 cm per year, took place (Figure 2A). Some contrast in the series, needed to be able to detect the effect of increased effort with changing water levels, is provided by a rise in water levels between 1985 and 1988, after which the drought of the early nineties commenced. Seasonal fluctuations vary around 90 cm per year with highest levels in April-May and lowest in November-December. Between years seasonal levels may vary between 20 and 45 cm during draw down, and much more during water level rises: in November and December minimum and maximum recorded levels could differ by up to 1m presumably depending on the onset of rains (Figure 2B).

3.8 Effect of changing water level detected in catch rates with a lag of 0–4 years

By excluding long-term trends in water-levels and catch rates and then cross-correlate or regress in steps (lags) of one year the residual variation – i.e. the variation around the long-term trends, gives an idea both of the size of the effect of changing water levels on changes in stocks and the period over which these effects become visible. The size of the effect is given by the amount of variation explained. Significant lags give an indication of the period. This can be calculated for the de-trended (=residual) time series of catch rates – indicating the speed of the reaction of stocks to changing conditions, as visible in the data. However, much more interesting is the size of such an effect of changing water levels in relation to the overall trend. Where an effect of changing water level on detrended catch rates could be detected, it explained between 3 percent and 50 percent of the residual variability in annual catch rates. For instance, approximately 26 percent of the residual catch rates of *Oreochromis* in gillnets were explained by minimum water levels with a lag of four years. But this effect amounted to the explanation of a mere three percent of the annual variability in mean catch rates: the effect is measurable but slight. In contrast, the effect in Kambuzi seines was much clearer. Highest significant regressions were found with minimum or mean levels one or two years earlier. These explained between 23 percent (*Oreochromis* – Kambuzi seines) to 71 percent (total catch rates – Kambuzi seines) of the residual variability, which amounted to a very significant 23 percent and 50 percent of the total variability in mean annual catch rates: in this case environmental effects clearly obscure the general trend, as could already be concluded from the discussion of the short-term trend-to-noise patterns. The effect in Nkacha seines was high as well, but only in total catch rates, that exhibited a negative regression with minimum water levels two years earlier, while cyprinids had a clear positive regression with this year’s minimum water level.

Remarkable is that changing water levels affect catch rates in most species group and gear combinations negatively with a lag of one to three years. Negative correlations are found in minimum and mean water levels with Kambuzi seines, Chambo seines and Nkacha nets. In other words, high minimum or mean water levels seem to have a negative effect on catch rates one or two years later and vice-versa with low levels. An explanation could be that both Kambuzi seines and Nkacha nets target small species or juveniles of *Oreochromis* more effectively at periods of higher water levels resulting in lower recruitment a few years later, though it is not clear what could be the mechanism behind this. The exceptions are *Oreochromis* spp. caught by gillnets, where high water levels have a (expected) positive effect on catch rates four years later, and Cyprinidae caught by Chambo seines, with a positive effect three years later (Table 4). Gillnets with the mesh sizes used in the lake catch three-year-old *Oreochromis* spp.: high minimum water levels give increased production three to four years later.

3.9 Effort changes are relatively small in terms of number of operators…..

Fishing effort expressed as number of gear owners increased with around two percent per year over the period examined (Figure 11). This increase was mainly due to an increase in owners on the West side of the lake (app. 4.5 percent per year), whereas numbers on the East side remained relatively stable. Except gillnets, all main gears used in Malombe require high labour input in terms of numbers of people operating the gears. Judging from the statistics obtained during frame surveys the amount of labour input has only increased slightly, while a shift in activity has taken place from the East Side of the lake to the West Side. The number of assistants counted in the frame surveys varied between 1 400 and 2 841, but taken over the whole period only a slight positive trend was seen with an increase of 0.5 percent per year. But, while on the West Side of the lake numbers of assistants increased by 4.1 percent per year, numbers of assistants decreased at the East Side by 1.4 percent per year, indicating a shift in spatial allocation of effort.

3.10 …but changes in highly effective gears are dramatic

The effort development in terms of gear size or activity is unlike that of any of the other lakes investigated in this study (Kolding, Musando and Songore, 2003; Zwieten *et al.* 2002; Zwieten and Njaya, 2003). Four gears were important in the period from 1981 to 1999, but large shifts in numbers took place between these gears, with the result that presently only two gears are important in the fishery – gillnets and Nkacha nets (Figure 12)[1].

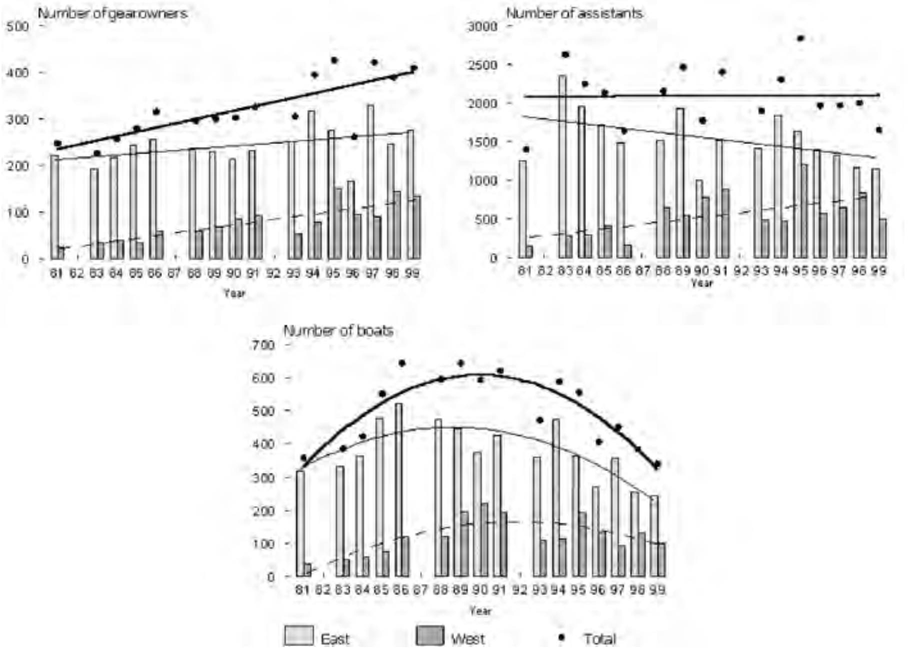

FIGURE 11. *Development in effort expressed as number of gear owners, number of assistants and number of boats in Lake Malombe. The bold line is the regression of the total numbers over time. The thin regression line refers to the numbers of eastern and the broken line is the regression of numbers of the western side of the lake.*

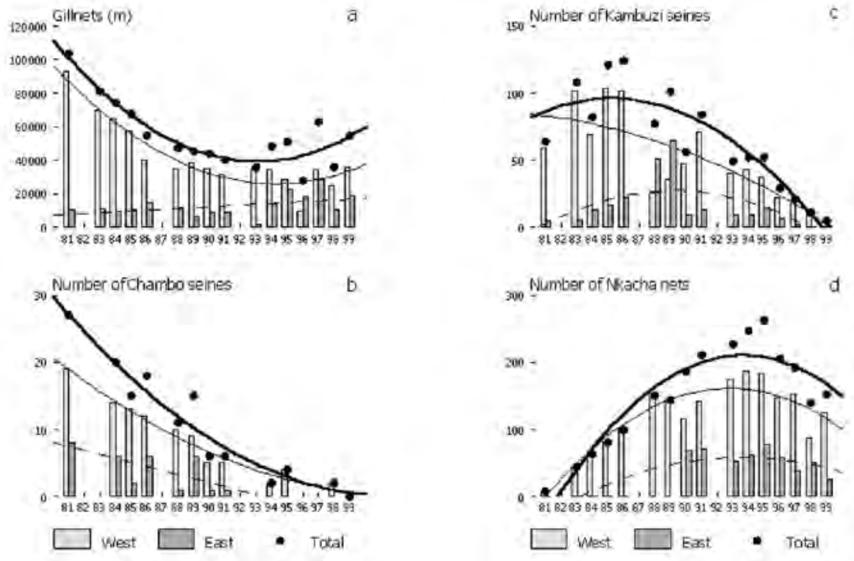

FIGURE 12. *Development in effort: number of gillnets,* Chambo *and* Kambuzi *seines, and* Nkacha *nets in Lake Malombe. The bold line is the regression of the total numbers over time; the thin regression line refers to the numbers on the eastern and the broken line to the numbers of western side of the lake. A Chambo seine net is made of approximately 750 m of gillnet. Material of one Kambuzi seine is estimated to make two Nkacha nets. Before 1989 Kambuzi seines and Nkacha nets were not recorded separately: numbers of both gears are reconstructed (see Appendix 2).*

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[1] See Hara and Jul-Larsen, 2003 for an explanation of these highly specific developments in Lake Malombe.

From 1981 onwards the number of gillnets dropped by more than 50 percent until 1991. Since then frame survey data exhibit a high variability with a slight increasing trend, particularly in West Malombe. The number of Chambo seines dropped from 27 in 1981 to 0 in 1999, with both East and West Malombe displaying a similar trend. Likewise the number of Kambuzi seines, peaking in numbers in 1986, dropped from 124 counted nets to five in 1999, with west Malombe lagging somewhat behind, as the number of seines peaked in 1989. Lastly, Nkacha nets, virtually non-existent around 1981, rapidly increased in numbers (7.5 percent per year) until 1995, when numbers dropped again. Frame survey statistics mention a number of other gears such as longlines, traps and various active gears (scoop nets, cast nets, mosquito nets and Chirimila nets).These do not seem to have much importance, though in particular traps and inexpensive active gears seem to gain some prominence in present years. This suggests that investment levels in boats and gears have decreased over time, which would be in accordance with a number of other observations that can be made based on frame survey data (Figure 13).

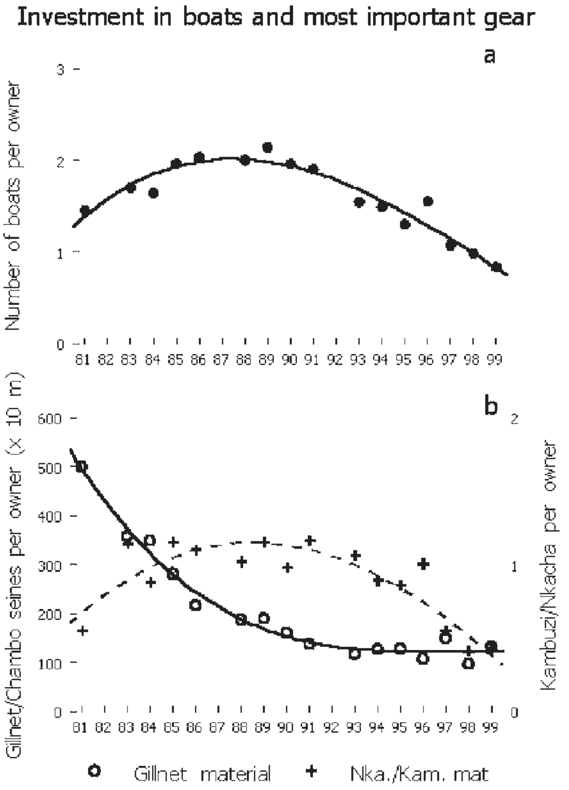

FIGURE 13. *Proportion of boats and netting material per owner as an indicator for development of investment levels in Lake Malombe*

The number of boats per owner increased from 1.5 in 1981 to 2.1 in 1989, and since has declined to less than one in 1998. Similarly, the total investment in material for Kambuzi seines and Nkacha nets increased until around 1988, and since has dropped to around the same levels as in 1981. Then, the amount of gillnets per owner dropped with a factor 5 to less then 100 m/owner in the 17 years from 1981. Lastly, the average number of assistants per owner decreases by around 30 percent over this period as well from 8.3 to 5.7, though data are highly variable due to the highly varying numbers of assistants counted (Figure 14). In other words, if these trends describe the developments in Malombe adequately, it would mean that fewer investments are done into gears for fishing activities that require a high labour input. If low investment gears indeed gain prominence, it can be concluded that the Malombe fishery has become poorer over the past 20 years (see also Hara and Jul-Larsen, 2003).

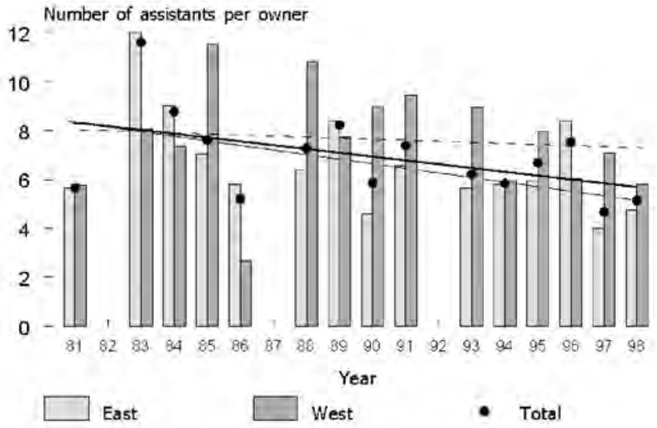

FIGURE 14. *Ratio of number of assistants and gear owners. The bold line is the regression of the total numbers over time. The thin regression line refers to the numbers of eastern and the broken line is the regression of numbers of the western side of the lake.*

3.11 Effort, water levels and catch rates

Changes in water level explained much of the annual variability in catch rates in gears targeting small species or juveniles; for those targeting older individuals – gillnets – changes explained only a small amount of the total annual variability (Table 4). The last result is rather surprising, were it not for the fact that a high technical interaction existed between gillnets and gears targeting the juveniles of *Oreochromis* spp. If a population recruits to different fisheries at different ages, the effect of year class variability induced by environmental variability will be reduced for the fishery targeting the older segment of the population.

Multiple regression explaining catch rates by the combined effect of effort, water level and its interaction was non-significant (Table 5) for any of the species groups and total catch rates examined in Nkacha seines and Chambo seines. For Nkacha seines the reason is clear: the series of annual average catch rates is short – from 1989 to 1997 – and coincided with a period of continuously declining annual average water levels: these two series were thus entirely confounded. With Chambo seines the problem is that change in the unit of effort over time renders any attempt to do this analysis impossible. For instance if the change in effort mainly was through a change in spatial coverage of the fishery, i.e. opening up new fishing grounds, an effect of annual variability caused by changing water levels, will be swamped under the effect of this change in effort. The noted increase in catch rate of non-target species in this fishery (Figure 7), with stable catch rates of the target species *Oreochromis* indicates the change in effort e.g. through larger spatial-coverage, which lead to fishing practices comparable to emptying a fishpond with seines.

Multiple regression models with number of gillnets as unit of effort and annual average catch rates of *Oreochromis* as explanatory variable either were confounded or gave counterintuitive results. Confounding means that depending on the order in which the two effects – water level and effort – enter the regression either of the two effects is significant while the other is not. Counterintuitive was the model result that indicated a positive sign to the effect of effort, implying that an increase in effort would result in an increase in catch rate. This puzzling effect can be explained if it is realized that the time series of catch rates of *Oreochromis* had a decreasing trend, while the number of gillnets was monotonously declining at the same time as well as water level – though the latter with some contrast. The decrease in catch rate was not the result of the gillnet fishery but of the Chambo fishery, though decreasing water level and associated productivity may have had an effect as well!

TABLE 5. *Proportion of variability in annual catch rates explained by the multiple regression model with water level (mean, maximum or minimum), with a lag phase of 2 – 4 years, fishing effort (number of gear) and their interaction as explanatory variables. The sign indicates the direction of the effect in the model. Analysis is done on total catch rates by gear and the main target species(groups) of the various gears. Only regressions explaining the largest amount of variability are shown. Df= degrees of freedom, SS = sum of squares, % =* r^2 *= proportion of explained variability, sign denotes the direction of the effect in the statistical model. Significance values are denoted by asterixes: * p<0.05, ** p<0.01, *** p<0.001*

Gear	Species	Model								Statistics of model				
		Water level				Gear		Interaction			Total error	Residual error	Total error explained by model	
			Lag	Sign	%	Sign	%	Sign	%	Df	SS	SS	%	
Gillnet	Oreochromis	Max	3	+	74	+	11			15	2.31	0.34	85	***
	Oreochromis	Min	4	--------- confounded ---------						14	2.10	------- confounded -------		
Kambuzi	Total	Mean	2	+	40	-	20			16	2.39	0.93	61	**
	Oreochromis	Min	2	+	32	-	21			16	22.70	10.40	54	**
	Haplochromis	Min	2	+	37	-	16			16	1.98	0.92	53	**

Only Kambuzi seine time-series behaved according to expectation: effort had a negative effect on catch rates, whereas the effect of water level was both positive and larger, i.e. explained more variation. That this result was reached with this gear should be qualified:

- In the course of the period studied Kambuzi seines both increased and decreased in numbers reaching a peak around 1986,
- The increase coincided both with a decrease and subsequent increase in water levels – the increase observed between 1985 and 1988 - and coincided with the peak in effort of Kambuzi seines which provided the contrast needed in the analysis,
- However, decreasing effort in Kambuzi seines coincided with both decreasing water level and decreasing effort of Chambo seines: a slight recovery of *Oreochromis* spp. during this last period will now be attributed to in particular this gear, as it has a similar spatial coverage as the Chambo seines.

Lastly from the analysis it can be concluded that Kambuzi seines catch species that are between one and two years of age.

3.12 No interaction between water levels and gears: no observed change in catchability

As argued by Zwieten and Njaya (2003), a significant interaction effect between gear and water level would represent a change in catchability of gears with changing water levels. Such an effect is not observed here, as the variability in water levels is much less extreme compared to Lake Chilwa, with the result that concentration of fish during receding water levels as occurs in this lake does not occur in Lake Malombe. Furthermore, two of the four gears of Malombe are used as active shore based gears. These shore-based gears are fishing in areas where concentrations of smaller fish are always present. A third gear, Nkacha nets, is an active boat based gear targeting small species and is thus are more dependent on recruitment effects than crowding effects.

4. CONCLUSION AND DISCUSSION

Does environmental variability matter? Lake Malombe presents an interesting and challenging case as it presents an example, still rare, of an African fishery that has collapsed as a result of overexploitation of its stocks. However, judging from the way fishing effort developed, it is also clear that it may represent a special case: a relatively small shallow lake has been fished with highly efficient gears that require a high investment. This is quite unlike many other similar small and medium African fisheries, where fishing effort develops more on the line of "more of the same" gears for which relatively low investment is needed. Unlike in Malombe many of these fisheries often still have under-exploited stocks. The answer therefore is no: environmental variability hardly matters where and when a complete mismatch between the scales of natural variability in fish production and human exploitation is reached through a highly efficient fishery.

But questions remains: did increased fishing effort on its own cause the collapse? Or was the collapse amplified by other factors? For instance, did habitat destruction and/or of changes in water level cause changes in productivity? Habit destruction is a side effect of the fishery itself, but has important consequences for the interpretation of our results. Sadly, not much is known about these effects as no information is available on the scale and rate of habitat destruction during the period of the collapse of *Oreochromis*. We also do not have direct evidence on changes in productivity but assume that fluctuating water levels causes them. In a small lake like Malombe the effect of surface runoff on productivity will be considerable. With highly seasonal water levels, with peaks during the rainy season, we could safely disregard the distinction between river inflow and surface, were it not that large changes in forest cover around the lake – as has occurred - not only increase the volume of surface runoff but also its sediment load, possibly bringing about structural changes in the bottom habitats of the lake.

We will now return to the two questions posed at the start of this paper and summarize our findings

- is there evidence for possible changes in productivity of Lake Malombe as a result of environmentally driven factors, such as changing water level?
- is it possible to detect the combined effects of productivity changes and increased effort through the existing monitoring of catch and effort and of water levels in Malawi?

4.1 Trend perception: The governance dilemma and the search for informative indicators

The high variability of the monthly catch rate information is, to a large extent, administratively induced (Appendix 3). After removing temporal effects (annual variability, seasonal variation) the remaining variability is about as high as in lake Chilwa (see Figure 2, Zwieten and Njaya, 2003). One of the results is that, while the high seasonal fluctuation in water level and runoff is expected to be reflected in the catch rates in particular of those gears targeting small species and juveniles, this is not the case in lake Malombe. Despite this conclusion, it is possible to detect long and short-term trends of statistical significance in the various catch rate series within 1.5 to 2.5 years of monthly aggregated data. These time windows to detect a trend are not too bad, though it indicates that there is a limit to the speed with which effects of management measures could be detected. This could be called a “governance dilemma” (Densen, 2001): the intended result of measures will take time anyway – a lag of 2–3 years – to take place (Pet, Machiels and Densen, 1996), but the number of years to detect an effect and causally attribute it to the measure taken will increase with increased natural and administratively induced variability. As the effect of a measure could be significantly detectable only after a long period – at least five years to a decade or longer, the proof of its effectiveness will be difficult to obtain, even if the necessity of the measures would be beyond doubt as in the case of Lake Malombe. Furthermore, though certainty on long-term trends could be obtained relatively fast – at least those of the magnitude discussed here, we have seen that short-term trends vary tremendously, in particular for the smaller haplochromines, which will make it difficult to decide on the causes of short run trends.

It should be noted that the analysis on trends was done on data aggregations by species. As a rule of thumb, observed variability expressed as CV will increase by $\sqrt{n}$, with n=the number of species in an aggregation, to obtain the average CV for the separate species, assuming lack of co-variation (Oostenbrugge *et al.*, 2002). With that assumption, the variability on a species level will be much higher. However, co-variation could be the rule in environmentally driven systems. In such a case species or species groups of which large amounts of information can be easily obtained could act as indicators for the state of all stocks.

4.2 Fluctuating water levels, effort and habitat

The effect of changing water levels on stock levels is large as it can be detected despite the high background noise in the data. Depending on the gear-target species combination the effect is detectable within 1–2 years for the small meshed seines and nets, and within 3–4 years for the larger meshed gillnets. Despite this, combined effects of fluctuating water levels and changing effort were difficult to detect, both due to problems of confounding of trends and of technical interactions between gears, in particular between gillnets and Chambo seines. The effect of Chambo seines on *Oreochromis*, exarcebated by the fishing on the juvenile part of the stock by Kambuzi seines, and in the early stages of the fishery with Nkacha nets as well, completely overshadowed possible effects of changing water level on the catch rates in gillnets. The catch rates in Kambuzi seines did show a clear combined effect of changing effort and fluctuating water level. This fishery was sensitive to short-term trends as it was fishing on the juvenile part of the *Oreochromis* stock. Both decreasing water levels and fishing effort may have caused the disappearance of submerged vegetation in the lake. If this habitat were important as nursery grounds for *Oreochromis*, it would mean that the level of the recovery of this species is dependent on the extent of restoration of this habitat.

The shift from gillnets (used in open water) and Chambo seines (used along the shore and in submerged vegetation) to Kambuzi seines (shore-based) and Nkacha nets (open water) is a shift from large species or specimens of species to smaller ones. The disappearance of *Oreochromis* from Nkacha nets indicates that the juvenile species disappeared from the open-water part of the lake – Mwakiyongo and Weyl (2001) found no change in species composition in Nkacha seines over the past ten years. The stabilization of juvenile *Oreochromis* in Kambuzi seines show that the species-group is still there and that juveniles are in in-shore areas.

Over the period examined only a limited increase in fishing effort in terms of people fishing is observed. Apart from that, two of the four gears, decrease in numbers and activity over this period, while a third - Nkacha seines – did so since 1987. The number of Nkacha nets and its activity levels has increased since the start of the series, but at present is decreasing and over the past year many operations have left Lake Malombe for the South-East arm of Lake Malawi or move between the two (Weyl, pers.obs.; Banda *et al*., 2002). Thus, the present situation of overexploitation has been caused mainly by the type of gear and their way of operation (fishing patterns), rather than demographic increase: in other words Lake Malombe does not present a case of Malthusian overfishing (Pauly, 1994), but is a case of over-investment in a fishery. With that the mode of exploitation of fish in lake Malombe seems fundamentally different from the mode of exploitation observed in the other fisheries reported on in this volume.

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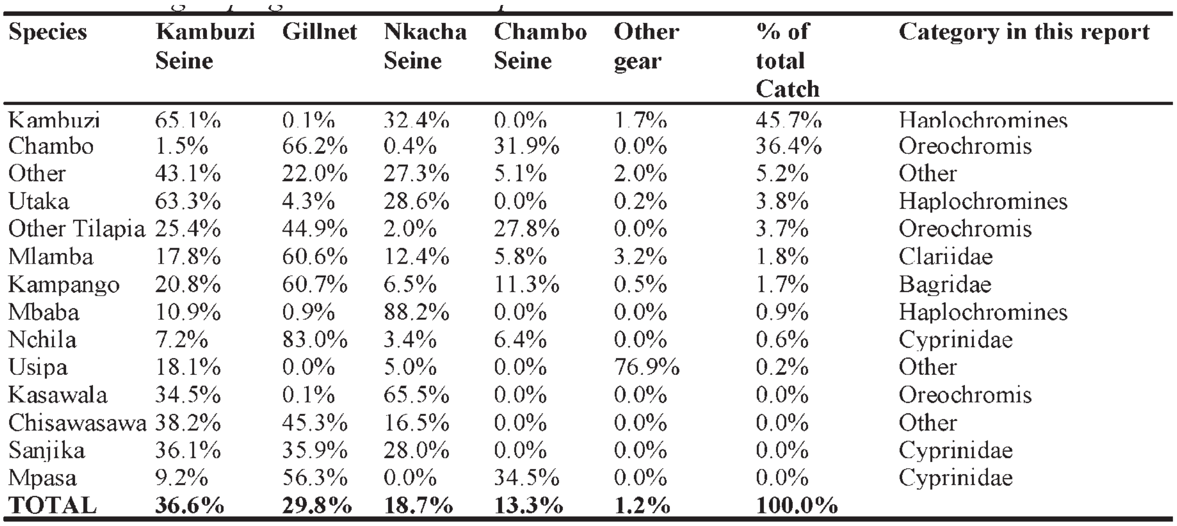
Appendix 1: Data bases used and species grouping

1.1 Data used to examine trends and variability

- Monthly average catch rates by species (or species groups) and gear from 1978 - 1997,
- Fishing effort by gear, number of fishermen, assistants and boats from 1978 – 1999,
- Daily sampled catch rate and effort data from 1994 to 1998, and
- Daily water levels from 1976 to 1998.

Monthly catch and effort data were calculated from data collected through the CEDRS of Malombe and stored at the Monkey Bay Fisheries Unit, from where we obtained them. Frame survey data were obtained from the Mangochi Fisheries Office. From 1978 to 1993 the total monthly catch estimates were done using boats as unit of effort (see description in van Zwieten and Njaya 2003). In 1993 the system changed to the Malombe Traditional Fisheries (MTF) data collection system, in which monthly catch estimates are based on units of effort using gear size (gillnets) and gear activity (other gear). Daily sampled catch rate and effort data were obtained from the data as stored in the Mangochi Fisheries Office, and compiled by Weyl (1999) and Weyl *et al*. (2001). For a description of the methods of data collection in the Malawi CEDRS we refer to Alimoso (1991), FAO (1993) and Zwieten and Njaya 2003.

TABLE 6. *Species (groups) as distinguished in the CEDRS of Lake Malombe, percentage of total catch of a species by gear and % of total catch between 1981 and 1998. The last column indicates the grouping as used in this report.*



Species	Kambuzi Seine	Gillnet	Nkacha Seine	Chambo Seine	Other gear	% of total Catch	Category in this report
Kambuzi	65.1%	0.1%	32.4%	0.0%	1.7%	45.7%	Haplochromines
Chambo	1.5%	66.2%	0.4%	31.9%	0.0%	36.4%	Oreochromis
Other	43.1%	22.0%	27.3%	5.1%	2.0%	5.2%	Other
Utaka	63.3%	4.3%	28.6%	0.0%	0.2%	3.8%	Haplochromines
Other Tilapia	25.4%	44.9%	2.0%	27.8%	0.0%	3.7%	Oreochromis
Mlamba	17.8%	60.6%	12.4%	5.8%	3.2%	1.8%	Clariidae
Kampango	20.8%	60.7%	6.5%	11.3%	0.5%	1.7%	Bagridae
Mbaba	10.9%	0.9%	88.2%	0.0%	0.0%	0.9%	Haplochromines
Nchila	7.2%	83.0%	3.4%	6.4%	0.0%	0.6%	Cyprinidae
Usipa	18.1%	0.0%	5.0%	0.0%	76.9%	0.2%	Other
Kasawala	34.5%	0.1%	65.5%	0.0%	0.0%	0.0%	Oreochromis
Chisawasawa	38.2%	45.3%	16.5%	0.0%	0.0%	0.0%	Other
Sanjika	36.1%	35.9%	28.0%	0.0%	0.0%	0.0%	Cyprinidae
Mpasa	9.2%	56.3%	0.0%	34.5%	0.0%	0.0%	Cyprinidae
TOTAL	**36.6%**	**29.8%**	**18.7%**	**13.3%**	**1.2%**	**100.0%**	

Water levels are measured twice daily at the gauge in the Shire River at Mangochi. Average daily water levels from this station were obtained through the Water Department in Lilongwe. No lake levels of Malombe itself are available.

1.2 Species groups used in the analysis

The CEDRS distinguishes 14 species and species groups (Table 6. However, most of these species take up less than four percent of the total catch and therefore were combined in four species groups. “Kambuzi” is considered as cichlids other then “Chambo” of less then 8 cm. “Mbaba” are cichlids larger than 8 cm “Kasawala” is in general juvenile “Chambo”. “Other tilapia” is in general *Oreochromis shiranus*, a species not belonging to the “Chambo” complex.

Longlines and mosquito nets caught 1.2 percent of the catch as recorded in the CEDRS and were not considered here.

Appendix 2. Reconstruction of the number of Nkacha nets and Kambuzi seines

Before 1989 Kambuzi seines and Nkacha nets were not counted separately. To investigate the effects of changes in effort on the stocks, an estimate of the number in two types of gear was made, based on the assumption that from 1981 until 1989 both gears increased linearly in number over the years (Figure 15). Trend analysis of numbers of Kambuzi seines until 1991 where they were counted separately from Nkacha nets, of Nkacha nets after 1989, and of both gears combined before 1989 yielded three linear regressions. Adding up the estimated numbers from the regressions of Nkacha nets and Kambuzi seines yielded reconstructed numbers of both gears combined that were close to the actual numbers of both gears combined. By subtracting the estimated number of Nkacha seines from these numbers of combined gears an estimate for the number of Kambuzi seines before 1988 was obtained.

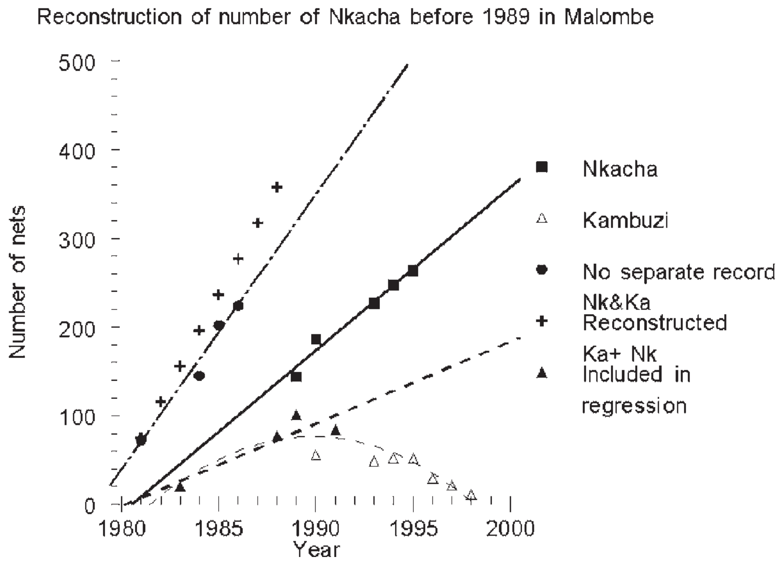


FIGURE 15. *Reconstruction of the number of* Nkacha *nets and* Kambuzi *seines between 1981 and 1989. See text for explanation*

Appendix 3: Analysis of variability in catch rates: effect of administrative error and aggregation

The total variability in the monthly mean catch rates series from 1978 to 1997 was high. For instance, the variance in catch rates of gillnets was 0.15 (=^{10}log s^2, see Table 1, main text), corresponding with a coefficient of variability (CV = standard deviation*100/mean) of 110 percent, estimated through CV = 100*√($10^{2.303\text{*variance}}$-1). This represents the variability of data aggregated over strata, fishermen, month and species. Aggregation in principle reduces variability: dis-aggregation over month and fishermen to daily catch rates of the estimated variability of CV= 110 percent would result in a CV that is outside the experience of any gillnet fishery. In general gillnet fisheries show variability in basic uncertainty of daily catches ranging between 50 percent and 80 percent (Densen, 2001). Daily catches as experienced by gillnet fishermen with a CV of for instance 80 percent would translate in an aggregated monthly CV of around 15 percent. Three sources of variability can account for this: (1) inter-annual variability – including trends (2) seasonal variability and (3) errors in data collection and handling or in other words “administratively induced” variability. Removing inter-annual and seasonal variability reduces the variance to 0.063 (Table 2), which calculates to a CV = 63 percent. This basic uncertainty at the aggregated level thus is still too high and can only be administratively induced. We will examine the causes of this type of error.

Digitized daily catch rates from the gillnet and Nkacha fishery obtained in the MTF from 1994 to 1998 were examined to assess the effect of outliers resulting from administrative errors in the data on the CV. The series contained both catch and effort data (number of hauls and length of the net). The data series contained daily catch rates of 3 031 gillnet and 7 901 Nkacha seine recordings, effort expressed as size of the net and, in case of Nkacha nets, number of pulls as well. From these sets random samples of 30 data were taken without replacement (Jack-knife procedure) repeated 30 times. This procedure was carried out both with the raw sampled catch rate data and the same catch rate data corrected for effort. Mean, standard deviation and CV were calculated for each sample and a frequency distribution of CV’s was obtained (Figure 16).

The mode of the distribution of CV’s in raw daily catch rate data in gillnets is at CV = 70 percent, which falls within the range observed in other gillnet fisheries. But, the average CV of the original series of sampled catch rates is 136 percent. Taking into account monthly and annual variance reduced this to a CV = 104 percent, indicating that the outliers in the distribution cause the remaining excess variability. The mode of the frequency distribution of CV’s calculated from the random samples increased slightly when corrected for effort. However, the average CV for the corrected series increases considerably to 190 percent. Removing monthly and annual variability reduced this CV to 110 percent, indicating again that outliers cause the excess variability. Aggregation of the corrected catch rates over months according to the procedure followed by the Malawi fisheries information system reduced the CV to 50 percent. This is somewhat lower than the CV = 63 percent of the basic uncertainty (i.e. with trend and seasonality removed) in monthly average catch rates of the complete series from gillnets analysed in this paper, while this behaviour is close to the expected reduction in CV through aggregation by multiplication with √a (with “ a” the level of aggregation, under the condition of independence of data). Annual variability in the monthly average catch rates calculated from the daily samples was significant, but the CV did not reduce when corrected for this source of variability.

Sampled catch rates in Nkacha nets exhibit more or less the same behaviour, though the distributions show less outliers: the mode of both the corrected and uncorrected distributions is CV = 80 percent. Average CV of the raw catch rate data = 92 percent, increasing only slightly to 96 percent as a result of correction by effort. However, aggregation of corrected catch rates over month only lowers the CV to 50 percent, more than twice as high than would be expected based on the theoretical behavior of the CV through aggregation. Removing significant annual variability reduced the CV to 34 percent, somewhat closer to the expected value. In other words, both examples show that outliers have a strong effect on the total variability of the data. The examples of gillnets and Nkacha nets were chosen as they clearly showed the narrow range of CV's to be expected from samples of daily catch rates of a reasonably well defined gear. Both for Kambuzi seines and Chambo seines this range was much broader both for sampled catch rates and corrected catch rates, though in both cases with a mode not much different from Nkacha nets. This indicates that a much less well-defined unit (gear size and activity) from which the daily catch rate samples are taken induces a lot variability.

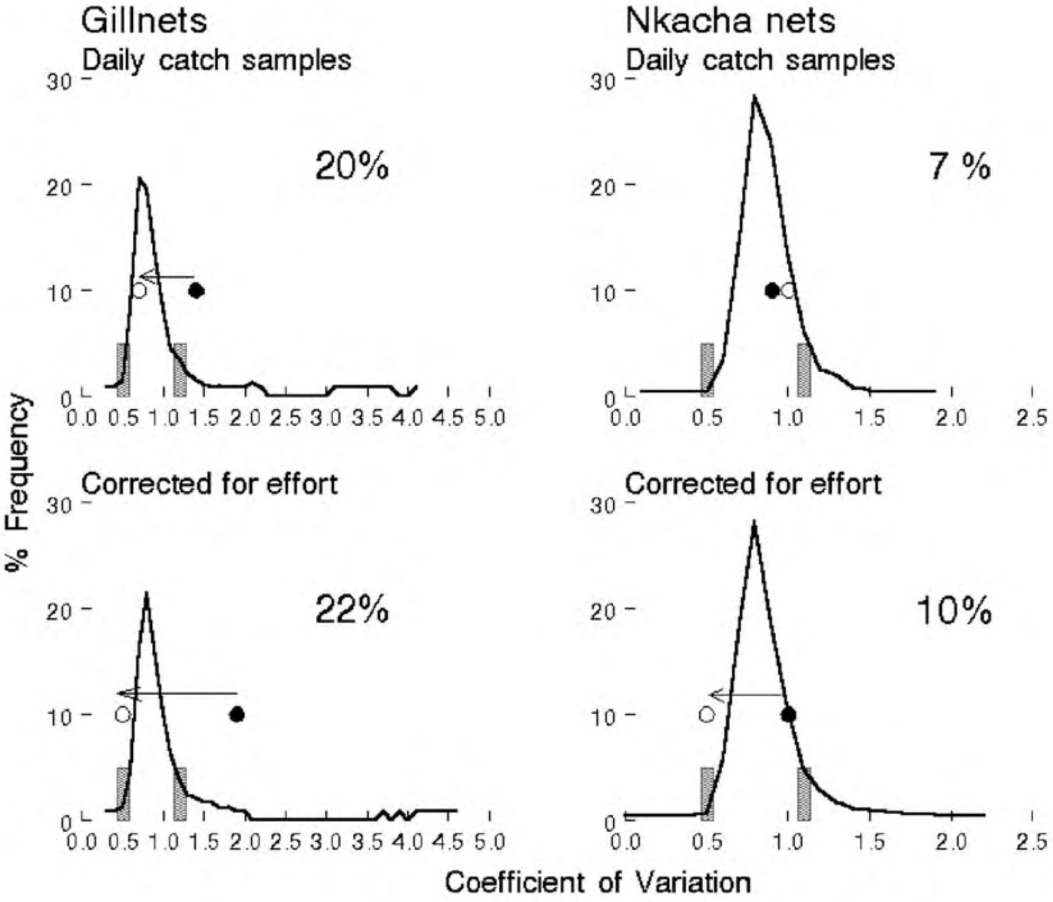


FIGURE 16. *(Top): % Frequency distribution of coefficients of variation (CV) calculated from 30 repeated random samples without replacement of daily catch rate samples from gillnets and* Nkacha *nets in the CEDRS of Malombe between 1994 and 1998. (Bottom): Same but sampled catch rates corrected for effort. The areas outside the vertical bars are outliers, the percentage outliers are indicated in each graph. Black dots: CV of the complete data set, open circles CV of the same data aggregated by month. See text for further explanation*

Probably, most of the high variability in the total series is caused both by administrative errors in data collection and handling and the effect of correction and raising factors. The behavior of the data from 1994 to 1998 in the MTF differs not much from the complete monthly catch rate series analysed here which is based on two different data collection systems. As there is no reason to believe that the administratively induced error changes over time it can be considered random.