ENVIRONMENTAL VARIABILITY, EFFORT DEVELOPMENT AND THE REGENERATIVE CAPACITY OF THE FISH STOCKS IN LAKE CHILWA, MALAWI

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1. INTRODUCTION

In between recessions[1], Lake Chilwa is one of the most productive freshwater lakes in Malawi with a fishery production of between 80 and 160 kg/ha resulting in a long-term annual average catch of around 15 000 metric tonnes. The lake has an important bearing on the nutrition of Malawians, in particular within the nearby districts of Zomba, Phalombe and Machinga. The contribution of its fishery to the total fish catch of Malawi ranges between 16 percent and 43 percent, with an average of 22 percent (Figure 1A). Lake Chilwa is shallow, not exceeding 6m depths at peak levels. It has an open water area of around 678 km^2 surrounded by about 600 km^2 of *Typha* swamps, 390 km^2 of marshes and 580 km^2 of inundated floodplain. Early commentators already noted that fish yields were not constant and seemed to depend on lake-water levels (Hickling, 1942; Lowe, 1952; Furse *et al.*, 1979). In good years, the annual catch can approach up to 25 000 metric tonnes, but drops below 10 000 tonnes are not uncommon. Lake Chilwa has shown large fluctuations in catch and effort since 1845, with periods where fishing stopped completely when the Lake dried up (Nicholson, 1998; McCracken, 1987). In addition to seasonal cycles of about 0.8–1.0 m, water levels fluctuated annually around 2–3 m which sometimes led to complete desiccation of the lake. For instance, during and after the 1995 recession, fishing operations were suspended on Lake Chilwa for two years (Figure 1B). Shortly after refilling and stabilization of water levels fishing resumed. Complete recessions have been recorded for about six times (Table 1). Spectral analysis of a time-series of water levels from 1949 to 1976 indicated a periodicity of very low water levels of around six years, explaining around 30 percent of the total variance in lake levels (Lancaster, 1979).

Year	High	Low	Very Low (dry)
1859	Livingstone		
1860	O'Neill, 1884		
1870	Buchanan, 1893		
1879			Buchanan, 1893
1880		O'Neill 1884	
1888	Drummond, 1902		
1900			Chipeta, 1972; Duff 1906
1913-		------------- Chipeta, 1972 --------------	
1920-		------------- Garson & Campbell-Smith, 1958	
Late	Burgess (pers.comm)		
1943		Chipeta, 1972	
1949		Chipeta, 1972	
1960-		Kalk, 1979	
1967-			Kalk, 1979
1973		Kalk, 1979	
1976	Kalk, 1979 (highest)		
1994-5			Njaya, 1996

Source : Kalk, McLachlan and Howard-Williams (1979) see references there; Njaya (1996).

[1] The word recession in this text refers to periods with low to very low lake water levels.

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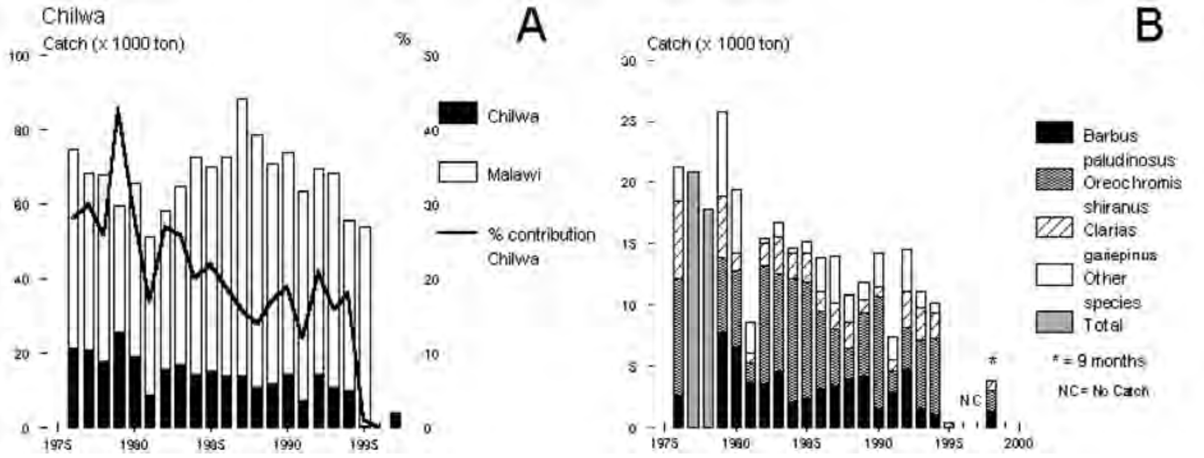

FIGURE 1 ***A***. *Total catch from Lake Chilwa as a proportion of the total catch of Malawi.* ***B***. *Total catch of Lake Chilwa broken down by species and species groups. In 1976 and 1977 no breakdown to species is available. In 1996 and 1997 the lake dried up completely. For 1998 only nine months of data are available.*

How do fish populations react to the recurrent recessions of the lake? The dominant commercial fish species are the endemic *Oreochromis shiranus chilwae* (Makumba), and the ubiquitous *Barbus paludinosus* (Matemba) and *Clarius gariepinus* (Mlamba): typical representatives of the three species groups that survive in highly dynamic systems (Leveque, 1995, 1997). Kalk (1979) gave an account of the fate of the three species in a comprehensive study on the biological effects of recessions before and after the 1968 major recession. Between 1965 and 1968, as the lake dried up, *Oreochromis* catches declined severely, *Barbus* catches initially increased but dropped in the last year and *Clarias* fishing only stopped in 1968, the year of complete drought. During a recession, remnants of the fish stocks find refuge in the mouths of larger inflowing rivers and in deeper lagoons, where water remains. These stocks appear to serve as a nucleus for a natural restocking of the lake after refilling: *Clarias* populations, as reflected in the catches, recovered in two years, *Barbus* in three years and *Oreochromius* after four to five years.

As fish stocks in Chilwa have exhibited an enormous regenerative capacity shown time and again after lake level recessions, the value of MSY estimates based on steady state assumptions of environmental stability can be questioned. The annual variation the lake ecosystem exhibits in fish production, points to a fisheries management approach primarily directed to the protection of remnant stocks during periods of recession and immediately after refilling of the lake, while populations are rebuilding. Therefore the issue of what sustainable levels of fishing effort are is relevant only to the period in between recessions. In the literature on Lake Chilwa different points of view exist on this matter. Furse (in: Kalk 1979, p.228) asserts that detrimental effects due to fishing when water-levels are high seem unlikely because: “stocks that can recover in two to three years from virtual annihilation by drought are never likely to be overfished to the point of disappearance”. He recommended maximizing catches in between recessions. On the other hand, in the same book, Kalk (1979, p.422) contends that a limit on the minimum mesh size of gillnets in normal years is needed. This “demonstrably protected the breeding stocks of *Oreochromis* species, without seriously affecting the catch of “other” species”, thus implying that fishing could have a detrimental effect on fish production levels of Lake Chilwa.

Since 1976 Malawi has a well established Catch and Effort Data Recording System (CEDRS) to monitor this fishery. Data collections as carried out in practice sometimes have been criticized severely to the extent that the information obtained was considered not useful to answer questions on the efficiency of the fishery and predict future developments through formal stock assessment methods. Attempts to determine maximum sustainable levels of production and associated effort levels have failed (Tweddle, Alimoso and Sodzabanja, 1994), and the unsatisfactory notion exists that the system could be overexploited while effort levels keep on increasing without being able to point out what would or could be sustainable levels of efficiency. Nevertheless, data are still being collected, mainly for the purpose of establishing total catch and effort levels. In this paper we will show that, despite their apparent deficiencies, this may be a severe under utilization of the information contained in the data collected that are still useful for management purposes.

Information that could be derived from the time series of catch and effort is not limited to formal stock-assessment methods. An analysis of trends and variability in catches and catch-rates, can produce empirical relationship, which can be used to predict – not necessarily when something happens but what happens if something changes. This will lead to knowledge of what can be perceived on the basis of which expectations can be formulated. The only long-term time series of catch and effort data of Lake Chilwa collected in a systematic way is through the CEDRS. Our present study aims to address, with the present Malawian catch and effort data, the possibility of detecting changes in fish stocks as a result of changes in fishing activity (effort) under the typical cycles of recession and subsequent refilling of Lake Chilwa. The emphasis is on the usage of catch and effort data as they exist in Malawi and the information contained in them to answer questions on effects of natural changes and changes in fishing effort. We will examine the potential to draw conclusions on observed trends in catch-rates – which are considered as an index of fish-stock levels – and relate these to trends in effort and water levels. In this report we will not examine the sources of error and bias that are present in the data collected through the existing CEDRS.[1] For this we refer to Weyl *et al.* (1999), who makes a number of recommendations for improving data collection and handling.

2. OBJECTIVES OF THE STUDY AND RESEARCH STRATEGY

The possibility to detect time trends in fish stocks through catch-rate data and to evaluate the effectiveness of fisheries management on that basis depends both on the strength of the time trend and the variance around it (Peterman, 1990; Pet-Soede *et al*. 1999; Densen, 2001; Zwieten, Njaya and Weil, 2003). Ultimately, 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. Aggregation of independent observations belonging to the same distribution lowers the number of observations but at the same time reduces the variation around a possible trend as well. The time series of estimated monthly catch-rates from CEDRS surveys of Chilwa by major stratum represent the lowest level

[1] Problems outlined by Alimoso (1988), Stamatopoulos (1990) and Weyl *et al.* (1999) are:

a. The CEDRS does not take into account gear distribution and the way the gears are operated. Consequently, significant fishing activities may take place without being recorded: relatively rare gears which make large catches e.g. Matemba seines in Lake Chilwa, may result in severe under or overestimation of daily catches.

b. The use of raising factors in view of actual fishing operations: e.g. some methods use two boats and since the raising factor is based on the ratio of the number of fishing craft in the minor stratum to that of the sampled fishing beach during the sampling exercise catches are overestimated.

c. CAS data forms are complex, leading to recording errors. The manual transfers of data from form to form and the manual calculations, which follow, have been shown to be responsible for significant errors in the accepted statistics.

of data aggregation for this lake that in Malawi is used in reports on the status of the fishery. The capacity of the Malawian fisheries authorities to perceive trends and relate these to changes in the fishery is given with these time series of catch and effort data (Zwieten *et al.*, 2003).

2.1 Structure of the paper

After a description of data collected and methods of analysis we will:

(1) Examine trends and variability (between years, seasonal) in the catch-rates of Lake Chilwa;
(2) Examine changes in water levels and relate these to changes in catch-rates;
(3) Examine trends in fishing effort and relate them to trends in catch-rates taking into account the effect on catch-rates due to changes in water levels;

Data used to examine trends and variability are monthly average catch-rates by species (or species groups) and gear, fishing effort by gear and daily water levels from 1976 to 1998. The analysis will lead to conclusions on the possibility to detect trends and relate these to changes – natural or fishing effort – observed. Thereafter we will shortly address the present fisheries management set up of Lake Chilwa, and discuss whether the present CEDRS and the type of conclusions that can be drawn from it will address the information needs. We will

(4) Discuss present management strategies before, during and after recessions;
(5) Discuss the required information in relation to management of catch and fishing effort; and finally
(6) Ascertain whether the present CEDRS and monitoring of water levels fulfils the requirements related to the management of the fisheries resources in the lake

2.2 Research strategy

A short explanation on the research strategy contained in points 1–3 is needed:

(1) Examine trends and variability in the catch-rates and fishing effort of Lake Chilwa;
Catch-rate – i.e. the catch per time unit and per unit of fishing effort (C/f) – is an important indicator both for the average income of fisherman and the abundance of stocks. As an indicator of abundance a constant efficiency in the fishing methods over time and constant average fish behavior is assumed. Though the assumption of constant efficiency is problematic, the idea is that if a number of different fishing methods employed in more or less the same way over the period examined give similar trend information, the signal is clear. Trend here is loosely understood as a long-term change in the mean levels of the catch-rates (Chatfield, 1996) and the basic question is whether the catch-rate has gone up, remained stable or has gone down over the period over which there are data. For that reason it is sufficient to define trend as a linear regression over time. Obviously it is the downward trend that is most interesting, as this is the main management concern: how do catch-rates develop with increasing fishing effort given the natural variation of the lake system.

The next question is whether such a trend can be perceived within a time window that is useful in a management context. In other words: how variable are the catch-rates around the trend, and in what way does this variation obscure the general trend so that it may not be detectable within time windows of decision making and evaluation given a management framework.

Variability can be attributed to predictable variation, e.g. seasonality, and temporally unpredictable variation, which we will call basic uncertainty (Zwieten *et al*, 2002). Quantifying these attributions will give a first indication of the possibility to perceive a trend.

The development of catch-rates under increasing fishing effort in a system like Chilwa is unlikely to be linear, and fluctuations as a result of strong environmental signals may take place. These fluctuations will be seen as reversals in the direction of long-term trends, and will show as non-random residuals around a linear trend that we will call long-term persistence. The effect of “favorable” or “unfavorable” environmental conditions caused by variation in average water levels could induce persistence in stock biomass of longer lived species. A first approach to examine whether such reversals in trends take place, and obtain an indication how a linear description of a trend diverts from more complex descriptions, is by fitting more complex regression models to the data. We follow the method as outlined by Fiorentini, Caddy and Leiva (1997). They examined a large number of time series catches of different species in the Mediterranean Sea by fitting a simple polynomial regression model to the data. Based on the shape of the resulting fit they decided whether a trend in catches could be described as increasing, stable or declining – including dome shaped fits – with varying speed. Periods of natural increase or decrease in abundance or availability of the resource, followed by a reversal will result in a dome shaped trend, which could be a result either from over-fishing or a change in environment. The peak or trough gives an indication of the period in which a reversal of catch-rates took place, and can be used as a starting point for further analysis of possible events leading to such reversals. Thus, the extra information obtained compared to a linear description of trend is an indication at what stage of development a stock is – increasing, decreasing, collapsed or recovering –, the speed with which this takes place, and, most importantly, the timing of possible reversals.

The relationship of trend and variability can be understood as a signal-to-noise ratio. An analysis of this ratio gives an indication of the time frame needed for trends to be detected, which is in fact an analysis of statistical power. To answer the question on trend perception in statistical terms, we examine the change in the slope of a linear trend over time in relation to the variation around the slope. We can investigate how this *trend-to-noise* ratio changes over time by stepwise increasing the number of data in the analysis. We take two approaches:

(1) Every month more data are added, and this will affect the *trend-to-noise* ratio. We are interested in changes in strength (slope) of trends and timing of reversals in the direction of a trend: when is a negative/positive trend first seen in a long-term perspective?
(2) Questions of effectiveness of regulative management measures often need to be answered in a short time frame. Whether or not a regulation, or measure, intended to change the usage of a natural resource is working, should usually be answered within a framework of around 3–5 years. By investigating trend-to-noise ratio’s over five year steps, we will obtain a feeling for the strength of short-term trends and the timeframe over which reversals of trends can be seen.

Finally, we will examine the effect of multi-annual environmental variation, on the possibility to perceive trends caused by the fishery, or, in other words: which driver, fishing or environment has the strongest effect on the variability observed.

(2) Examine changes in water levels and relate these to changes in catch-rates
Sorting out empirically correlations of time series of processes that have only one realization, such as the processes underlying the relation between catch-rates, fishing and water level in

lake Chilwa, is fraught with difficulties (Bakun, 1996). Time series of continuous processes, be it catch-rates or water levels, contain considerable auto-correlation or persistence. Persistence is simply the correlation of the present observation of a parameter with previous observations in time, i.e. yesterday's water level or fish-biomass will to a large extent determine today's level or biomass. This has as consequence that when two auto-correlated time series are cross-correlated, significant but uninformative correlations will always be found. To answer the question whether a fish population, as indexed by catch-rates, collapses due to fishing effort or due to natural variation – where water level is used as a proxy environmental indicator – is typically a situation where auto-correlated time series are involved. One way to address this problem is to correlate the time-series of water level and catch-rates after removing long term and seasonal trends. This will remove most of the auto-correlation, while both series will then be reduced to series revealing possible "anomalies" – i.e. variations deviating from trend and seasonality – that can be subsequently correlated with each other. This could result in statistically significant, and possibly meaningful, correlations of fluctuations in water level explaining fluctuations in catch-rates. This analysis leads to information on:

- The amount of variation in the annual catch-rate series that can be explained by "anomalous" (i.e. non-average) changes in water level, and the possibility to perceive such a signal in the catch-rate data.
- The lag in time (years) over which changes in water level are reflected in changes in catch-rates of fish and hence the regenerative speed of fish production.

Water level is considered an environmental driver, which through a complex of natural processes regulates fish stocks (Junk, 1989; Karenge and Kolding, 1995; Kolding, 1994; Leveque and Quensiere, 1988; Furse *et al*., 1979). This is of course obvious for the years of complete recession - where there is no water there is no fish. But the question is whether changes in water levels have a predictive value for the periods when the lake is filled, and how well observed fluctuations in catch-rates can be explained by such changes.

(3) Examine trends in fishing effort and relate them to trends in catch-rates taking into account the effect of changes in water levels

Further problems arise when attempting to assess multiple causes, in this case distinguishing between the simultaneous effect on catch-rates both of changes in fishing effort and of changes in water levels. In a multiple-gear fishery it is generally not possible to give a single definition of fishing effort, and it is difficult to standardize the fishing effort of different gears. Furthermore the different gears used often target the same stocks of species either in the same or at different stages of their life cycles, leading to so-called technical-interactions, i.e. the outcome of one fishery will affect the outcome of the other. Both problems in defining fishing effort and interactions are important reasons why standard stock-assessments could fail in these situations.

The problem of technical interactions adds another level of difficulty in the statistical approach to explain the relative effects of changing environment and fishing effort. However, if it appears that effort development is mainly due to simple addition of numbers of gears and people – more of the same – then selectivity and technical interactions can be assumed "constant". This means that a multiple regression of fishing effort by gear type and water levels on catch-rates by gear – using the time lags found in the correlations of the de-trended time series of water levels versus catch-rates – could make sense. But selectivity and technical interactions cannot not be considered “constant” if shifts in fishing patterns have taken place – due to changes in technology or changes in spatial allocation of effort – as a reaction of fishermen to changes in stocks. A multiple regression of fishing effort by gear type on catch-rates by gear will be impossible, or at least difficult, to interpret. We will see that the condition of constant selectivity and technical interaction is generally met in the case of Chilwa (but not in Malombe: see Zwieten *et al*., 2003). Therefore, before analysing the combined effect of fishing effort and water levels an analysis of changes in fishing effort is needed:

a. Effort defined as the number of active fisherman and boats disregarding types of fisheries will give an indication of the demographic changes in fishing effort.
b. Effort analysed by gear will indicate possible shifts in fishing patterns. Such shifts can then be examined on changes in available biomass (indicated by changing catch-rates).

Another difficulty in assessing multiple causes is when trends in the explanatory variables (i.e. effort and water level) are confounded. Confounding will take place if no reversals in trends have taken place in both of two explanatory variables. As an example we discuss three possible situations of trends in the annual data:

a. <u>Both water levels and effort levels are increasing.</u>
   In this case it cannot be decided directly if a possible downward trend in catch-rates can be attributed to either variable. An analysis where both variables follow the same trend stands a high possibility that either one or both explanatory variables will not be significant. However, a correlation analysis of deviations obtained by de-trending water levels and de-trending catch-rates may indicate a positive correlation between water level and catch-rates, possibly with a certain time lag. From this it can be inferred that fluctuations (“rates of change”) in water levels have a positive effect on changes in catch-rates (“growth rates”). In principle the same could be done with de-trended effort levels, though this requires a high reliability in total effort data. If this relation is negative, it could be inferred that the decline in catch-rates could be attributed to the increase in effort, but delayed by increasing water levels.
b. <u>Water levels are decreasing while fishing effort is increasing and catch-rates are decreasing</u>. In this case the time series are entirely confounded and it will be difficult to distinguish cause and effect. Correlation of de-trended series will give an indication of effects but again no decision on size of each effect (proportion of total variation explained) can be reached.
c. <u>Water levels are fluctuating while fishing effort is increasing</u>
   Here downward trend in catch-rates will be attributed to fishing effort, and it can be decided how much of the variation around the trend can be attributed to a changing environment.

From this discussion it will be clear that no decision on effects of effort and environment can be reached if there is no contrast in at least one of these two parameters over time, while the other parameter remains either stable or is continuously changing in the same direction. For example, if fishing effort is continuously increasing only a significant increase and subsequent decrease in water levels or vice-versa can provide for the necessary contrast and the effects of both parameters for changes in stocks can be determined.

3. METHODOLOGY

3.1 Data collection

The statistical Catch and Effort Data Recording System (CEDRS) of the Lake Chilwa fisheries has been developed according to the methods described by Bazigos (1972) and has been implemented by Walker (1974). It is based on the method of stratified random sampling. An estimate of total catches (C) is reached through sampling the catch-rates by boat stratified by gear type. The catch-rates (C/f) are raised to total catch by an estimate of total effort by gear (f) obtained through a Frame Survey. Lake Chilwa is stratified into two major strata coinciding with major ecological areas, which are subdivided into five minor strata. Each minor stratum has several beaches on which fish is landed. After the annual frame survey, a number of beaches are randomly selected to record landed catch during so-called Catch Assessment Surveys (CAS). Field-staff spend each month four consecutive days on a beach collecting data according to their monthly CAS itinerary. In total 16 days are spent for fish recording in every month.

During the first day the number and types of boats, fishermen, and type and sizes of fishing gears are counted. In the following three days, all boats leaving for fishing are recorded. Boats landing on a particular beach are recorded and randomly sampled to obtain the fresh weight of the catch by species. The name of the fisherman, amount of fish caught (in kilos), number, size and usage of fishing gear, estimated beach prices and destination of the fish are recorded on the same form. Units of effort are recorded for all seines as number of pulls or hauls; for gillnets it is the number of gillnets of 91 m (100 yards) set. For fish traps the unit of effort is number set and for long lines 100 hooks.

Our analysis of the Lake Chilwa catch and effort data was carried out on four dominant gears although the CEDRS includes in total eight gears. The four gears are fish traps, gillnets, longlines and *Matemba* seine. A *Matemba* seine is used either as a beach-seine or is set in shallow open lake areas. It has a length of around 50-300 m, no restriction on mesh sizes, and is operated by five to six persons. Each of these gears represents more than 20 percent of the data and all four in total approximately 92 percent of the data set. Recently, a new important fishery with hooks was included in the CEDRS called *nchomanga*. Weyl *et al.* (1999) described this as a passive gear used in densely vegetated areas where it is difficult to find enough space for a long line. A large hook (size 1-3/0) is attached to a length of line onto which a float is attached. This float has enough buoyancy so as not to be submerged by the hooked fish. Alternatively the line is attached to a short length of bamboo which is wedged into reeds or mud to anchor the hook and line. *Nchomanga* are normally set overnight and baited with small dead fish. Since these data were available for only two years, they were excluded from this study.

Monthly catch per unit effort (CPUE) is estimated as follows (Alimoso Seisay and Zalinge, 1990, FAO 1993): at the end of each survey, all sampled catch-rates are added to obtain a total sampled catch by minor stratum. Similarly, all sampled effort data by gear are added to get a total monthly sampled effort (f) by gear by minor stratum. An estimate of the monthly CPUE by gear is then obtained by through C/f.

The ratio GA, which is termed “gear activity indicator”, is estimated by dividing the total number of gears that were found to be fishing at the time of sampling by the total number known to exist at the landing sites. Total monthly fishing effort, f in the major stratum is estimated by:

$$f = D^* \, GA * M \qquad (1)$$

where M is the total number of fishing gear units in the major stratum that were counted during a frame survey and D is the number of fishing days in a month The estimated total monthly catch, Y, for a particular gear in the major stratum is:

$$Y = CPUE \times f \qquad (2)$$

Monthly catch and effort data from the Catch Assessment Survey (CAS) for the traditional fisheries sector were obtained from Monkey Bay Fisheries Research Unit and Kachulu Fisheries Office in Zomba in April 1999. The frame survey data were obtained from the Mangochi Fisheries Office and Monkey Bay Research Unit. Water level data, measured daily at the gauge situated near Kachulu, were obtained through the Water Department in Lilongwe.

3.2 Analysis of variance of catch-rates: Differences between years and between months

As processes affecting fish stocks can generally be said to have a multiplicative character, all our analysis are done on ^{10}log-transformed catch-rates: linear trends are thus descriptions of the speed with which these multiplicative processes take place. All analyses were done on mean monthly catch-rate data (CPUE) aggregated over the whole lake. Total CPUE and CPUE by species (group) of four gears fish traps, gillnets, longlines, *Matemba* seine over a period from 1976 to 1998 were subjected to an Analysis of Variance (ANOVA) with year and month as class variables. This analysis leads to an assessment of the total amount of variation that can be explained by differences between years and between months. The statistical model describing this analysis is:

$$G(m)_{ijh} = \mu_{ijh} + year_i + month_j + \varepsilon ij_h \qquad (3)$$

Where:

$G(m)_{ijh}$ = timeseries of ^{10}log transformed mean monthly catch-rates
μ = overall mean
Year = effect of i^{th} year (1976 - 1998)
Month = effect of j^{th} month (1 - 12)
ε_{ijh} = residual error

3.3 Trend analysis in catch-rates

Trends were analysed with the following polynomial regression model.

$$G(m) = a + b*year + c*year*year + \varepsilon_t \qquad (4)$$

Where:

G(m)	=	time series of ^{10}log transformed mean monthly catch-rates
a	=	intercept
year	=	represents the linear regression term
year*year	=	represents the quadratic term
ε_t	=	residual error

To examine whether catch-rates went up, down or remained the same the quadratic part (year*year) of the model was removed and the linear regression was fitted to the monthly data.

Only significant parts of the model were retained, which resulted in four possible models:

1) no regression (when both linear and quadratic terms were non-significant)
2) a **linear** regression model if only the linear term was significant.
3) a **quadratic** regression model if only the quadratic term was significant
4) a **polynomial** regression model if both terms were significant. In this case it was also evaluated how much the quadratic and linear terms each contributed to the explanation of the total variance.

If this amount was very small for the quadratic term, a linear model was chosen
The averages (μ), standard deviations (s) are back-transformed from log-scale to obtain (geometric) means and a factor F around the (geometric) mean. This is done and interpreted as follows:

- 10^{μ} = 10 to the power of the mean of the log transformed data = geometric mean (GM)
- 10^{2*s} = 10 to the power 2 x standard deviation This factor (=F) means that that 1 in 20 observations fall outside the range given by F*GM and GM/F.

3.4 Seasonality in catch-rates

Differences between months detected with an Analysis of Variance in (1) give an indication of seasonality. A more formal deterministic description of seasonality could then be made by fitting an appropriate model to the data, and examine the amount of variation explained to judge the strength of the seasonal signal (Zwieten *et al.*, 2002; Densen, 2001). However, as will be seen later, little seasonal effects could be detected in the monthly catch-rate data and this line of inquiry was not continued. As the observed variation between months in the data therefore is not predictable it becomes part of the basic uncertainty in the data.

3.5 Basic uncertainty in catch-rates

The total amount of variation explained through the year effect in the statistical model (3) expresses differences between years. This includes both short-term annual variation and trends and long-term trends (long-term = over the whole series examined). Annual variation, including short-term trends, and seasonality obscure the long-term trend. The total amount of residual variation after removing a long-term trend and seasonality can be deemed basic uncertainty**.** This part of the total variance that cannot be explained by analysis of trends and seasonality consists of process error (i.e. natural variation), measurement error and observation error. If no variability can be explained by trend and seasonality then the total variation is basic uncertainty.

3.6 Trend-to-noise: power analysis

The slope parameter b in the linear regression (2) divided by the standard deviation(s) of the residuals of the linear regression, is the trend-to-noise ratio. How the trend-to-noise ratio affects the number of years (n) over which a trend may be perceived with a power (1-?), given probabilities for the statistical decision levels of a type I error ? and a type II error ? can be derived as follows (Zwieten *et al.*, 2002; Densen, 2001).

An estimate of the variance of the slope estimate b is:

$$s_b^2 = \frac{s^2}{\Sigma(t-\bar{t})^2} = \frac{s^2}{s_t^2} * \frac{1}{n} \qquad (5)$$

where s^2 is an estimate of the variance in the residuals around the regression line, t is the independent variable time and n is the number of observations. If catch-rate estimates are taken at regular intervals in time (or space), s_t^2 ca n be rewritten as (Gerodette, 1987):

$$s_t^2 = \frac{(n-1)(n+1)}{12} \qquad (6)$$

The power of a test is the probability that a decision rule will lead to the conclusion that an alternative hypothesis $H_a : \beta_0 \neq \varphi$ is true, i.e. that a trend or deviation from a trend will be detected in the cases of $\varphi=0$ or some specified value. The test statistic for b is $t^* = (b-\varphi)/s_b$. This probability (P) is given by:

$$P\{|t^*| > t_{(1-\alpha/2;n-2)} | \delta\} \qquad (7)$$

where δ is a measure of non-centrality, or how far the true value β_0 of b is from H_0: $\beta_0 = \varphi$:

$$\delta = \frac{|\beta - \varphi|}{s_b} \qquad (8)$$

To reduce the statistical errors to the specified levels of ? and ? = 0.05 or 0.1 as used here, with the zero hypothesis of no trend ($H_0 : \beta_0 = \varphi = 0$) the following inequality should hold:

$$t^* = \left|\frac{b}{s_b}\right| \geq t_{\alpha/2} + t_\beta \qquad (9)$$

for a two tailed test. Substituting (5) and (6) into (9) gives:

$$\left|\frac{b}{s}\right| \sqrt{\frac{n(n-1)(n+1)}{12}} \geq (t_{\alpha/2} + t_\beta) \qquad (10)$$

In the presence of auto-correlation the variance the residuals is underestimated by a factor $1/(1-r^2)$, where r is an estimate of the auto-correlation coefficient ρ (Neter *et al.*, 1985; Gerodette, 1987). We studied the effect of serial correlation at lag 1 on trend perception by including this factor in equation 7, leading to:

$$\left|\frac{b}{s}\right| \sqrt{\frac{n(n-1)(n+1)(1-r^2)}{12}} \geq (t_{\alpha/2} + t_\beta) \qquad (11)$$

where:

b	=	trend parameter (slope) in the linear regression
n	=	the number of observations
$t_{\alpha/2}$, t_{β}	=	the test statistic or decision rule of a *t*-distribution, where α is the specified probability of making a type I error (a trend is rejected where in fact there is a trend) and β the specified probability of making a type II error (a trend is accepted where in fact there is none). In our case $\alpha=\beta=0.1$ or both errors are set at the 10 percent level.
s	=	the standard deviation of the residuals

This formula is solved for n (the number of months of data collected) with given trend and variance. From the formula it can be inferred that the variance in a series exhibiting auto-correlation will be reduced, which could result in a conclusion of a trend where in fact there is no trend.

3.7 Analysis of water levels related to catch-rates

^{10}Log-transformed annual average catch-rate series were de-trended by subtracting the linear trend from the series through linear regression. There was no need to de-trend the water level series as there was no long-term trend present in the time series and the seasonal signal in monthly variation was low. The resulting residuals of the catch-rates were subsequently cross-correlated with annual mean, minimum and maximum water levels. Cross-correlation is done by shifting the two series with steps of one year against each other and calculate correlations at each successive lag. As the two series were 20 years with a maximum of 18 data up to five lags could be investigated. This, however, is sufficient as the regenerative response (recruitment processes) of the species under investigation to environmental changes is fast – for *Barbus* probably even within a year (see earlier and Kalk, McLachlan and Howard-Williams, 1979). Subsequently, the lags with highest correlation coefficients were investigated through regression analysis. The amount of variability explained by the regression analysis is an indication of the magnitude of the effect of changing water level that can be seen in the time series. A similar analysis was done on monthly catch-rates correlated with monthly water levels, both after de-trending. This analysis did not yield more information than the previous analysis and is therefore not presented.

3.8 Multiple regression of water levels and fishing effort on catch-rates

Multiple regressions were performed with ^{10}log-transformend total catch-rates by gear, or catch-rates by species(group) by gear, as dependent variable. Fishing effort as total number of gears and annual mean, maximum or minimum water levels – the latter with or without a lag phase from the cross-correlation analysis – were the explanatory variables. Both water levels and fishing effort each are made orthogonal by subtracting the mean from the original series. In the previous analysis it was established whether there was a lag-phase between de-trended annual mean water levels and annual mean catch-rates, and which of minimum, maximum or mean water levels was more informative. Missing values for numbers of gear, as taken from frame surveys, were interpolated by linear regression. Lag(1) means that previous years water level is compared with this years catch-rate.

The multiple regressions were always of the form:

$$G(m)_t = \mu + effort_t + water\ level_{t\text{-}lag(x)} + effort_t * water\ level_{t\text{-}lag(x)} + \varepsilon_t \quad (12)$$

Where:

$G(m)_t$	=	time series of annual mean ^{10}log(CPUE) by gear (1979-1998)
μ	=	overal mean
$effort_t$	=	total number of gear
$water\ level_{t\text{-}lag(x)}$	=	water level at lag(x) where x = 0 – 5
$effort_t$*water levelt$_{t\text{-}lag(x)}$	=	interaction of effort and water level at lag(x)
ε_t	=	residual error

In all cases non-significant explanatory variables were removed from the model. The interaction effect is interpreted as reflecting possible changes in catch-rate as a result of changes in efficiency or of usage of gears in relation to water levels. Such changes could be a result of spatial effects of accessibility of species to gears and the effectiveness of gears (e.g. concentration of fish with receding water levels). All ANOVA and regressions are carried out with the General Linear Models procedure (SAS Institute Inc., 1993). Cross-correlations are carried out with the ARIMA procedure (SAS Institute Inc., 1989).

3.9 Analysis of effort data

All effort data were compiled by major strata, and graphically displayed with regression lines to display trends. Total effort data of Lake Chilwa are considered unreliable, in particular concerning fishing operations conducted by migrant fishermen in the swamp area of lake who live in temporary shelters (*Zimbowera*). These fishermen are not recorded. Fish landed on beaches from these operations is mostly in dried form ready for marketing. The swamp areas are difficult to access. However, as all annual frame surveys are conducted in a similar fashion, the effort data can be considered indicative for relative changes taking place.

4. RESULTS

4.1 Analysis of catch-rates

The time series analysed included one low water recession period with no fishery from 1996–1997. This recession occurred 33 years after the previous major recession in 1968, which was extensively documented in Kalk, McLachlan and Howard-Williams (1979). Another minor recession occurred in 1973–74. No catch-rate data are available for the years 1976 and 1977. The results of the analysis of variance and subsequent trend analysis are summarized in Table 2 and Figures 2 to 6.

4.2 Variability in catch-rates is extreme and possibly administratively induced

The variability in catch-rates, expressed as coefficient-of-variation (CV = standard deviation/mean) of the original (non-transformed) data, was extremely high. For instance catch-rates in gillnets, the series with lowest variance (variance = $^{10}\log(s^2)$ = 0.14), the coefficient of variation can be estimated through CV= $\sqrt{(10^{2.303*variance}-1)}$ at 1.04. For other fisheries, daily catch variability (i.e. basic uncertainty as variability with trend and seasonality removed) expressed by CV ranges from 0.1 to 0.5 for trawlers to >1 in sport fisheries and some marine light fisheries. Therefore the aggregated monthly CV in the Chilwa data was about as high as the daily variability that individual sport fishermen experience (Densen, 2001). Individual gillnet fishermen experience a much lower day to day variability in catch-rates, with CV's of around 0.5 to 0.8 (Densen, 2001). The extreme variability in the Chilwa data was even more surprising taking into consideration that the catch-rate series represented aggregations over strata, fishermen and month: the effect of aggregation is that variability is reduced. A dis-aggregation over month and fishermen to daily catch-rates would result in a coefficient-of-variation that is outside the experience even of fisheries exhibiting high daily variability, for example whale fishing (Densen, 2001), sport fishing on pikeperch (CV =1.2, van Densen, 2001), and the Bagan light fishery on small marine pelagics in Ambon, Indonesia (CV =2.4, Oostenbrugge, 2001). The variability in the Chilwa data is definitely outside the range of any gillnet or seine net fishery known from inland fisheries.

Apart from possible effects of trend and seasonality, discussed later, the extreme variability probably is caused by the method of raising the daily catch and effort data to arrive at the estimates of monthly catch and catch-rate. Conversion factors are used to arrive at estimated total catches per standard gear by stratum. After that the effort and estimated catch figures collected during the month are each added to obtain a total catch and total effort. The monthly catch-rate (CPUE) used in our analysis is calculated from these data. This summation procedure induces variability that is not present in the original data collected at the beach. Apart from that, the procedure makes it impossible to detect outliers and typing errors. In other words, much of the variability encountered in the Chilwa time series – and by extension the time series from other fisheries as the same system is used throughout Malawi – is "administratively induced error". However, as the procedure has been maintained over the years, and there is no reason to believe that the administratively induced error changes over time (i.e. it can be considered random), it is still possible to proceed with our intended analyses of trends and their alleged causes. The enormous variability in the data has important consequences for the detection of trends and the analysis of causation: trends and fluctuations will be lost in "noise", most of which unfortunately is administratively induced.

4.3 All gears except traps are selective

The variation in total catch-rates was lowest in gillnets with a factor[1] (F) around the geometric mean of F= 5.6 followed by traps (F = 9.4), seines (F = 16.9) and longlines (F = 20.3) (Table 2, Figure 2). On a species level lowest variation is seen in *Oreochromis shiranus* (F = 7.6) and *Clarias gariepinus* (F=6.5) in gillnet catch-rates. For most other species-and gear combinations the variation is around a factor 20 or higher. Aggregation of catch over species thus leads to a reduction in variation. However, only in traps does the aggregation of various

[1] A factor F=5.6 means that 95 percent of the data fall within the range of 5.6 times the (geometric) mean and the mean divided by 5.6.

species to total catches lead to a significant reduction in variation. This indicates that it is the only truly “multispecies” gear in its target: all species are caught in more or less the same amounts over the same period of time. The main target for gillnets is *O. shiranus*, for a seine is *Barbus paludinosus* and to a lesser extent *O. shiranus*, while longlines target *C. gariepinus*. Other non-target species only reduce the variance in total catches slightly. In the case of longlines this reduction of F is just three percent.

4.4 Annual variability is high

Annual variability in catch-rates was high, and significant inter-annual differences explained much of the total variance (Table 2, Figures 2 and 3). As a result the unexplained factor around the mean was lowered by 50 – 75 percent in 14 out of 20 cases. In the remaining six cases, which were all non-target species for the various gears, no variation at all could be explained by temporal analysis, and catch-rate data of these species-gear combinations on the aggregated level of the lake by month indicated pure chance.

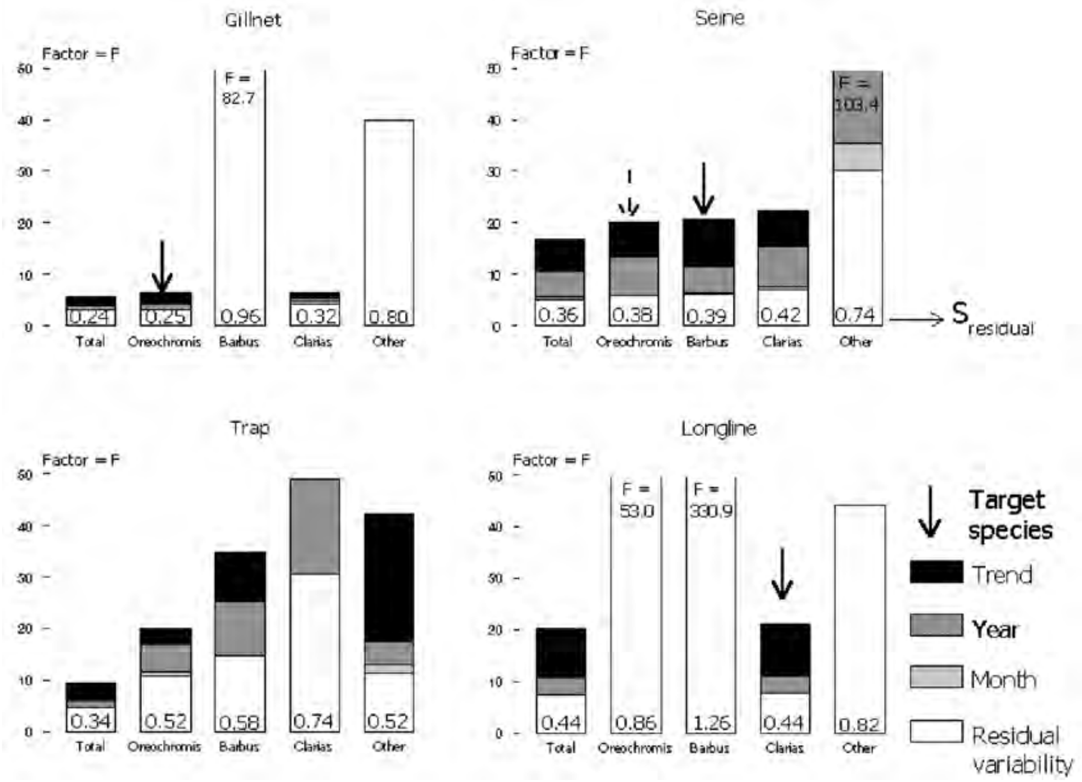

FIGURE 2. *The amount of variability expressed as factor around the geometric mean explained by trends (as linear regression), annual, monthly and residual variation. The residual variation is also expressed as standard deviation (s) at the bottom of each column. The arrow indicates the target species of a gear. Basic uncertainty (see text) is the variability remaining when trend and seasonality are subtracted from the total variation.*

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

Total catches	*Fishtrap*						*Gillnets*					
	Model	**df**	**MSE**	**Factor**	**r2**	**p**	**Model**	**Df**	**MSE**	**Factor**	**r2**	**P**
Total variance		207	0.238	9.4				212	0.139	5.6		
After Year	*Year*	189	0.117	4.8	0.55	***	*Year*	194	0.060	3.1	0.61	***
Trend	*Linear*	206	0.164	6.2	0.31	***	*Linear*	211	0.090	3.9	0.36	***
	Polynomial	205	0.160	6.3	0.33	***	*Polynomial*	210	0.086	3.9	0.39	***
	(quadratic term takes 5.8% of total explained variance)						(quadratic term takes 7.5% of total explainedvariance)					
	Longline						***Matemba seine***					
Total variance		210	0.427	20.3				207	0.377	16.9		
After Year	*Year*	192	0.193	7.6	0.59	***	*Year*	189	0.141	5.6	0.66	***
After Month	-	-	-	-	-	ns	*Year + Month*	178	0.127	5.2	0.71	***
Trend	*Linear*	209	0.279	10.9	0.35	***	*Linear*	206	0.274	10.6	0.27	***
	Polynomial	208	0.271	11.0	0.37	***	*Polynomial*	205	0.224	8.8	0.41	***
	(quadratic term explains 5.8% of total explained variance)						(quadratic term takes 33% of total explainedvariance)					
Oreochromis	***Fishtrap***						***Gillnets***					
Total variance		194	0.410	19.1				208	0.193	7.6		
After Year	*Year*	177	0.287	11.8	0.36	***	*Year*	190	0.063	3.2	0.70	***
After Month	*Year + Month*	166	0.269	10.9	0.43	*	-	-	-	-	-	Ns
Trend	*Linear*	193	0.377	16.0	0.08	***	*Linear*	207	0.136	5.3	0.30	***
	Polynomial	192	0.323	13.7	0.22	***	*Polynomial*	206	0.121	5.0	0.34	***
	(quadratic term explains 62% of total explained variance)						(quadratic term explains 42% of total explained variance)					
	Longline						***Matemba seine***					
Total variance		42	0.743	53.0				204	0.423	20.0		
After Year	-	-	-	-	-	ns	*Year*	186	0.147	5.9	0.68	***
Trend	-	-	-	-	-	ns	*Linear*	203	0.329	13.3	0.23	***
							Polynomial	202	0.261	10.5	0.39	***
							(quadratic term explains 42% of total explained variance)					
Barbus	***Fishtrap***						***Gillnets***					
Total variance		204	0.594	34.8				59	0.919	82.7		
After Year	*Year*	187	0.338	14.6	0.48	***	-	-	-	-	-	Ns
Trend	*Linear*	203	0.513	25.4	0.14	***	-	-	-	-	-	Ns
	Longline						***Matemba seine***					
Total variance		19	1.587	330.9				204	0.432	20.6		
After Year	-	-	-	-	-	ns	*Year*	186	0.165	6.5	0.65	***
After Month	-	-	-	-	-	ns		175	0.155	6.1	0.69	*
Trend	-	-	-	-	-	ns	*Linear*	203	0.292	11.5	0.33	***
							Polynomial	202	0.260	10.5	0.40	***
							(quadratic term explains 19% of total explained variance)					
Clarias	***Fishtrap***						***Gillnets***					
Total variance		181	0.714	49.0				212	0.164	6.5		
After Year	*Year*	163	0.551	30.5	0.31	***	*Year*	194	0.116	4.8	0.36	***
After Month	-	-	-	-	-	ns	*Year + Month*	183	0.102	4.3	0.46	***
Trend	-	-	-	-	-	ns	*Linear*	211	0.140	5.4	0.15	***
	Longline						***Matemba seine***					
Total variance		210	0.437	21.0				207	0.454	22.2		
After Year	*Year*	192	0.200	7.8	0.58	***	*Year*	189	0.193	7.6	0.61	***
After Month	-	-	-	-	-	ns	*Year + Month*	178	0.175	6.9	0.67	**
Trend	*Linear*	209	0.282	11.0	0.36	***	*Linear*	206	0.360	15.3	0.20	***
	Polynomial	208	0.277	11.3	0.53	***	*Polynomial*	205	0.350	15.2	0.24	***
	(quadratic term explains 4% of total explained variance)						(quadratic term explains 16% of total explained variance)					
Other spp.	***Fishtrap***						***Gillnets***					
Total variance		193	0.662	42.4				36	0.640	39.8		
After Year	*Year*	176	0.312	13.1	0.57	***	-	-	-	-	-	Ns
After Month	*Year + Month*	165	0.280	11.4	0.64	**	-	-	-	-	-	Ns
Trend	*Linear*	192	0.400	17.4	0.40	***	-	-	-	-	-	Ns
	Longline						***Matemba seine***					
Total variance		28	0.676	44.1				141	1.015	103.4		
After Year	-	-	-	-	-	ns	*Year*	124	0.600	35.4	0.48	***
After Month	-	-	-	-	-	ns	*Year + Month*	113	0.548	30.2	0.57	*
Trend	-	-	-	-	-	ns	*Linear*	-	-	-	-	Ns
							Quadratic	140	0.790	59.9	0.23	***

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

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

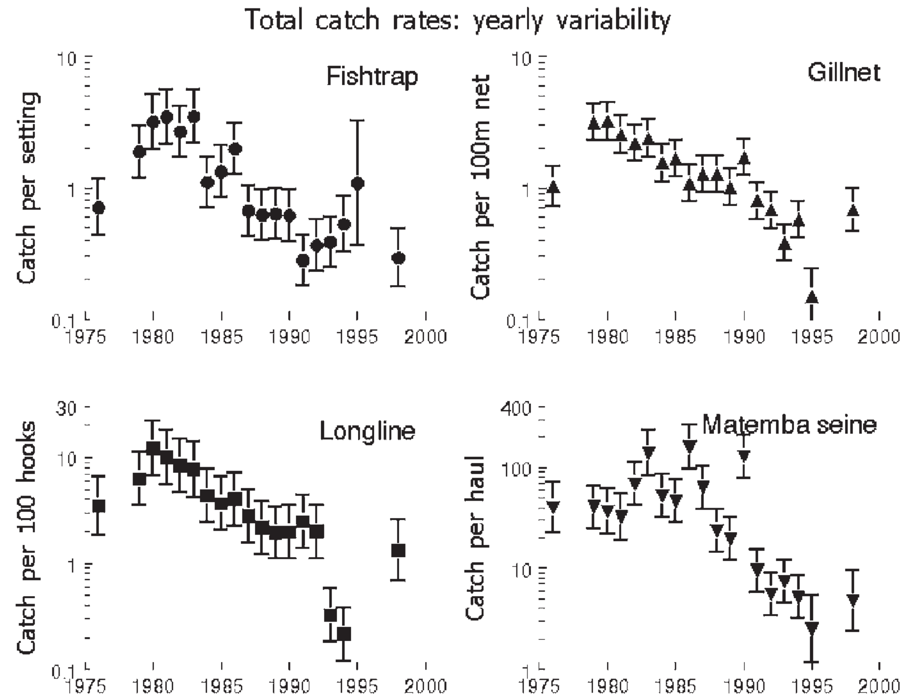

FIGURE 3. *Annual variation in total catch-rates by gear. Vertical bars represent 95 percent confidence limits. Note ^{10}log scale on vertical axes.*

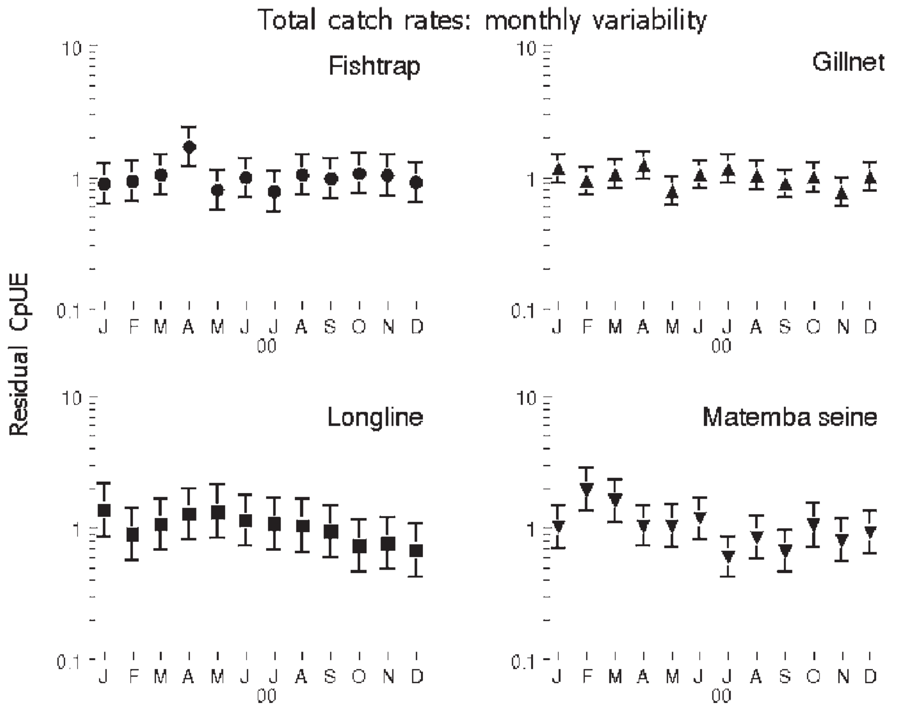

FIGURE 4. *Monthly variation in total catch-rates by gear. Vertical bars represent 95 percent confidence limits. The scale on vertical axes represents a multiplication factor of the of the ^{10}log annual mean catch-rates.*

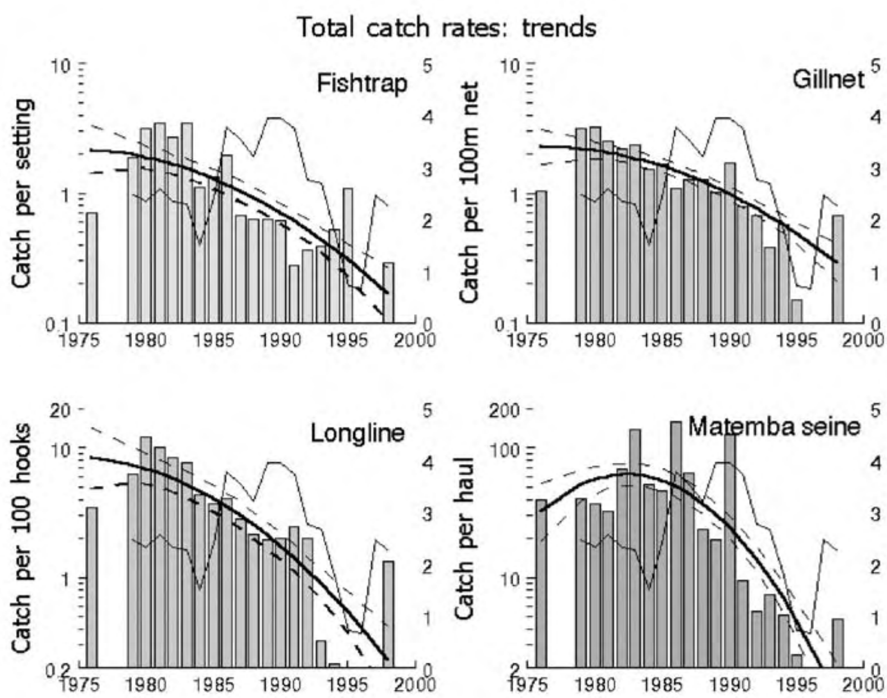

FIGURE 5. *Annual variation (bars) and polynomial trends (thick line) in geometric mean annual total catch-rates by gear in lake Chilwa. Trends are shown with 95 percent confidence limits (broken lines). The thin line is the relative mean annual water level of the lake.*

4.5 No seasonality is present

Generally, no seasonality was observed in the catch-rate data, as no significant differences between months were found in 14 out of 20 series. This indicates that the catch-rate data do not contain a clear seasonal signal for most species(groups) examined (Table 2, Figure 4). Significant differences between months were found in six cases: of *Oreochromis* and of "Other" species caught in fish traps; of *Clarias* caught in *Matemba* seines and in gillnets; of "Other" species caught in *Matemba* seines; and in *Matemba* seines on the aggregated level of total catches. The clearest seasonal signal was seen in traps where 11% of the total variation in catch-rates is explained by the significant differences between months. Overall catch-rates of *Oreochromis* are higher from January to April during rising water levels (Figure 10), however only May, July and December had significantly lower catch-rates compared to the months February to April. "Other" species had significantly lower catch-rates in December and January, the season with lowest water levels, compared to the remaining year. But only 7% of the total variation was explained by this difference. *Clarias* catch-rates of Gillnets and *Matemba* seines were slightly elevated during the low water period in December and January, which explained 10% and 6% of the total variation. Differences between monthly catches of "Other" species in *Matemba* seines explained only six percent of the total variation, and were caused by lowered catch in December compared to the period between March to June and October. On an aggregated level by gear only *Matemba* seines showed monthly differences: February was slightly elevated compared to much of the period from June to December, but the signal was weak as it explained merely 5 percent of the total variation.

4.6 All observed trends are declining

All but six out of 20 time-series revealed a substantial downward trend in average catch-rates ranging in speed from a factor 4 in *Clarias* catch-rates of gillnets to a dramatic factor 120 in catch-rates of "Other" species in fish traps (Table 2, Figures 5 and 6). Polynomial trends

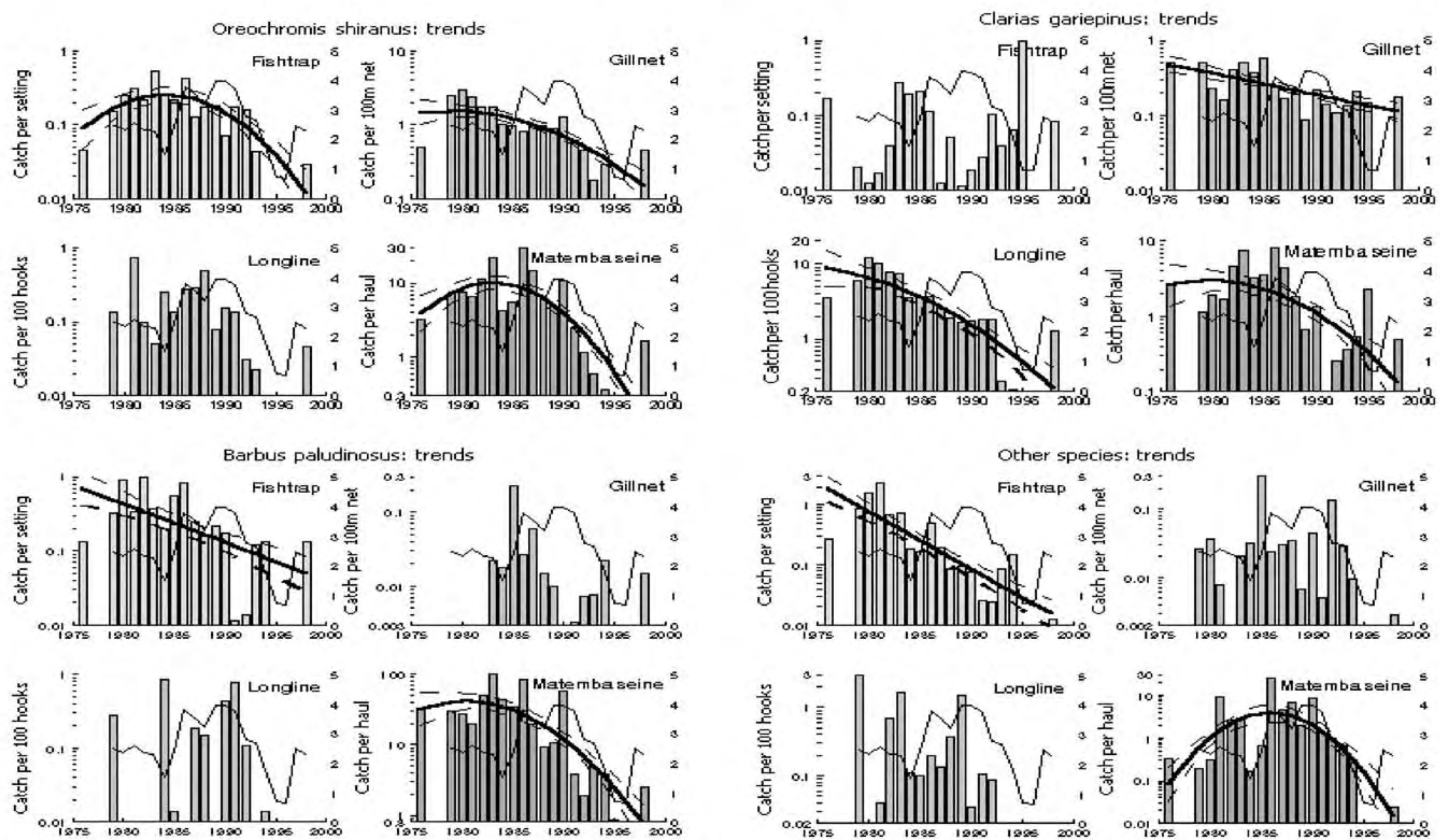

FIGURE 6. *Annual variation (bars) and polynomial trends (thick line) in geometric mean annual catch-rates by species and by gear in lake Chilwa. Trends are shown with 95 percent confidence limits (broke lines). The thin line is the relative mean annual water level of the lake.*

indicated that all of the downward trend legs of the curves commenced before 1986 and most even before 1982. Trends were linear or concave downward in ten series. The quadratic term of only two of the seven concave downward series contributed more than 10 percent to the total variation explained by the trend, indicating that the linear downward component was dominant in all cases. Four series had a dome shaped trend, but with just a slight upward slope and a strong downward slope after the peak. Three of the peaks within these four series were in 1982 (total catches in *Matemba* seine), 1983 and 1984 (*Oreochromis* catches in fish traps and *Matemba* seine). “Other” species caught in *Matemba* seines peaked in 1986 and this was the only series without a linear component. Thus most of the downward trends could be sufficiently explained by the linear component and the remaining analysis will be done using linear trends.

The trend component in the variation is strong: 44 percent to 88 percent of the observed annual variation was explained by the downward trends (Table 2, Figure 2). Both for fish traps – except in case of *Barbus* – gillnets and longlines more than 60 percent of the annual variation was explained by trends. The highest amount of total variation explained by a linear trend was in ”Other” species caught by fish traps (40 percent). Linear trends in total catch-rates explained between 27 percent (seines) and 36 percent (gillnets) of the variation.

4.7 Basic uncertainty is high

Unexplained variation is the amount of variation that remains after all significant year and month effects (trends) are subtracted from the monthly catch-rate time-series. The unexplained variation is lowest in gillnets (F=3.1), followed by fish traps (F=4.8), seines (F=5.2) and Longlines (F=7.6). Except in traps, the unexplained variation is about the same or somewhat higher for the separate target species of the various gears compared to the total

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

Species	Gear	df	Trend B	Standard deviation S	Trend/ noise B/s	N (months)	Auto-correlation coefficient r	N (months)
Total	Gillnet	211	-0.04	0.30	0.13	19	0.45	21
	Longline	209	-0.07	0.53	0.13	20	0.40	21
	Seine	206	-0.06	0.57	0.10	24	0.58	27
	Trap	206	-0.05	0.41	0.12	21	0.36	22
Oreochromis	Gillnet	207	-0.04	0.37	0.12	23	0.57	26
	Longline		n.s.					
	Seine	203	-0.06	0.57	0.10	24	0.61	28
	Trap	193	-0.05	0.72	0.07	31	0.41	33
Barbus	Gillnet		n.s.					
	Longline		n.s.					
	Seine	203	-0.07	0.54	0.13	20	0.52	29
	Trap	203	-0.03	0.62	0.06	35	0.42	38
Clarias	Gillnet	211	-0.03	0.37	0.08	29	0.25	30
	Longline	209	-0.07	0.53	0.13	20	0.37	21
	Seine	206	-0.06	0.60	0.09	25	0.55	29
	Trap		n.s.					
Other	Gillnet		n.s.					
	Longline		n.s.					
	Seine		n.s.					
	Trap	192	-0.09	0.63	0.15	18	0.36	19

catch-rates (Table 2, Figure 2). The basic uncertainty, or the uncertainty remaining after removing the trend, is a factor F=4 for gillnets and F=6.5 for traps. Basic uncertainty in catch-rates of seines and longlines is excessively high (F=11), indicating strong interannual variation.

4.8 Trend-to-noise: the capacity to detect trends

All linear downward trends were detectable as statistically significant between 19 and 24 months for the total catch-rates of the four gears (Table 3, Figure 7). Persistence (= non-random residuals) had little effect: it increased the number of data points needed to detect the observed trends with two to three months (Figure 7). *Trend-to-noise* ratio was highest in "Other" species in traps, and lowest in *Barbus* caught by traps. The effect of persistence in the species(groups) was an increase in the data points needed, but all observed trends were detectable from 21 to 38 months of data.

A long-term negative trend for total catch-rates in gillnets and longlines became statistically significant in 1987 (Figure 8a), in both cases around seven years after the peak in catch-rates was reached (Figure 5). The negative trend in fish traps was significant in 1988, or around five years after the peak. *Matemba* seines gave a different signal: the negative trend was significant in 1992 or around two, six and nine years after peaks observed in average annual catch-rates and about nine years after the estimated peak in catch-rates through polynomial regression (Figure 5). Reversals in trends seen in all catch-rate time-series took about three to four years during which only the decision of no long-term trend could be made. For example, this was the case from 1984 to 1986 in gillnets (Figure 8a).

Short-term trends, taken over five years, are obviously much more erratic (Figure 8b), but nevertheless gave fairly consistent signals over time. For instance a strong positive trend (b/s = 0.88) seen in 1980 after three years (plus two missing years) of gillnet data, reversed into a fairly

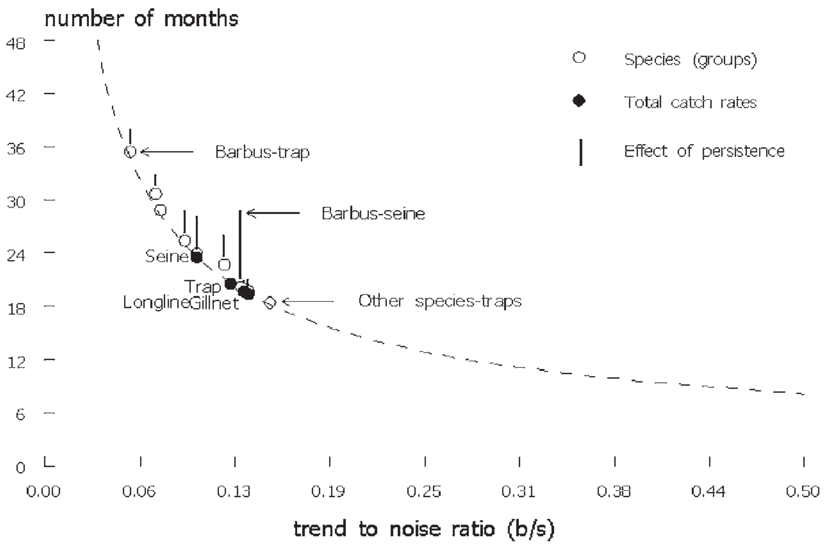

FIGURE 7. *The relation of the trend-to-noise ratio to the number of months of data needed to detect a trend in total catch-rates and catch-rates by species/gear combinations of including the effect of autocorrelation (persistence)*

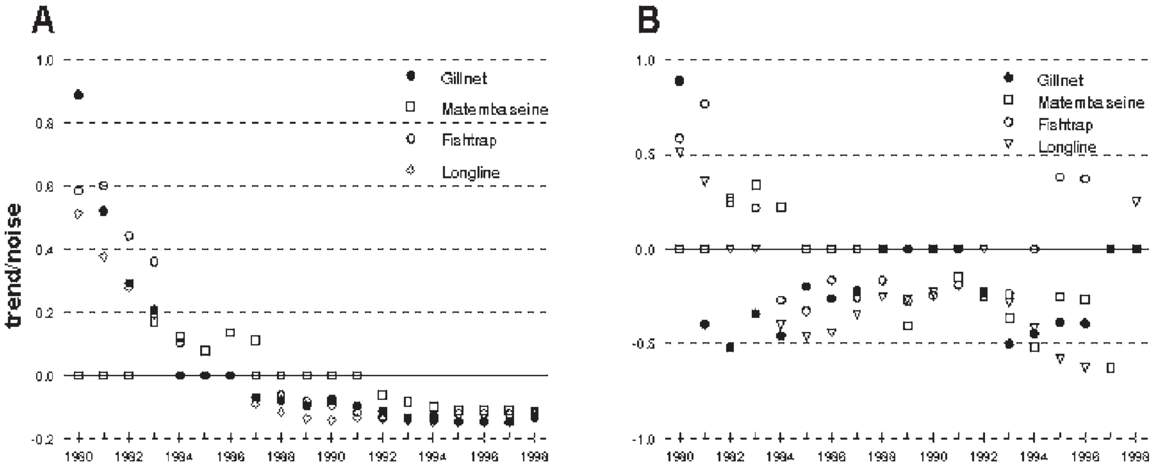

FIGURE 8 A. *Development of the trend-to-noise ratio from five years of catch-rate data in 1980 onwards with successive addition by year of monthly catch-rate data for gillnets, Matemba seines, fish traps and longlines. 1980 is the trend-to-noise over 1976 to 1980; 1981 is b/s of 1977 – 1981 etc.* ***B.*** *Development of trend-to-noise over five year moving periods, each indicated by the last year*

strong negative trend (b/s = -0.40) in 1981. From 1981 to 1988 the short-term trends remained negative, though becoming less strong. Between 1988 and 1991 no short-term trends were seen. During this period of higher water levels, catch-rates levelled out (Figure 5 and Figure 9A). After that short-term trends became significant and negative again. This picture is confused by the behaviour of short-term trends in other gears. Fish traps and longlines did not exhibit negative short-term trends until after 1983 and Matemba seines not even before 1989. Short-term trends in fish traps remained negative until 1995 the year before the lake dried up, while all other short-term trends remained negative until the end of the series in 1998. Furthermore, reversals in short-term trends take place more often in these gears and result in relatively high absolute values of the trend-to-noise ratio.

4.9 Water levels, fishing effort and catch-rates: immediate effect of changes in water level on catch-rates

Average annual water levels increased significantly from 1986 to 1991 compared to the periods before and after. Water levels dropped from 1992 onwards to the drought of 1995 and 1996 when the lake was largely dry. After that the average water level increased to pre-1986 levels (Figure 9). This means that during the period over which we have data on catch-rates (1979–1998) a significant fluctuation in water levels took place providing the necessary contrast to detect the effect of increased effort with changing water levels. In all cases except catch-rates of “Other” species in *Matemba* seines, which peaked in 1986, catch-rates peaked before the onset of the higher water levels. This can be clearly seen in Figures 5 and 6.

Changing water levels have, in all but one case, an “immediate” effect on annual average catch-rates: fluctuations in water levels are reflected in the same or the following year in the catch-rate levels (Table 4). De-trended annual catch-rates in gillnets positively correlated best

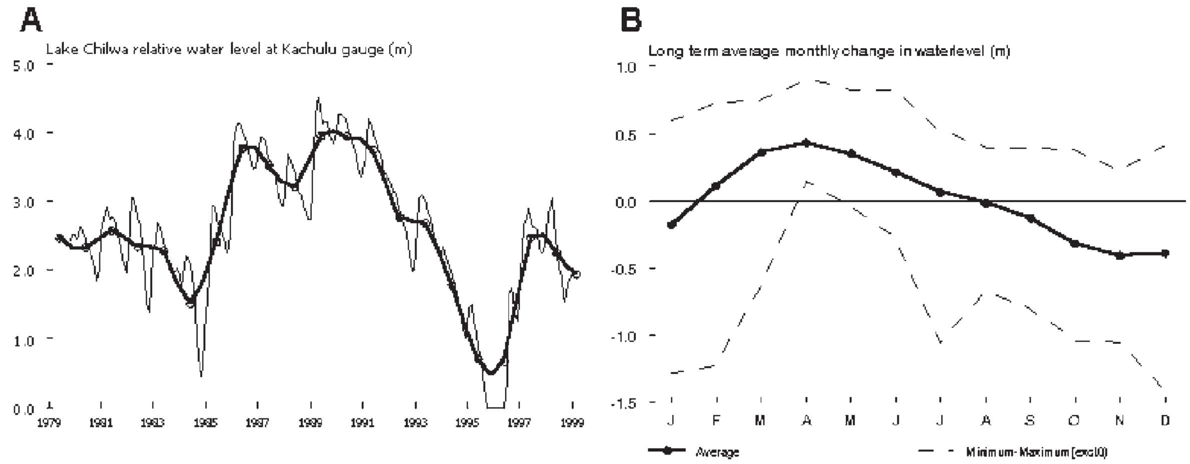

FIGURE 9. ***A***. *Annual average water level (thick line) and mean monthly water levels (thin line) in Lake Chilwa from 1979 onwards.* ***B.*** *Long term average monthly water levels and minimum (excluding periods of recession) and maximum water levels measured by month*

with either mean or maximum average lake levels and significant lags varied between zero years for *O. shiranus* in gillnets and seine nets, to four years for *C. gariepinus* in seine nets. In contrast, regressions between catch-rates by species or gear and water levels with lags higher than one year were not significant, except for total catch-rates in seines. The correlations indicating long-term effects of water levels on catch-rates (i.e. inducing generations of strong and weak year classes of longer lived species) are thus rather weak signals in the variation in catch-rates as observed through the CEDRS data.

TABLE 4. *Cross-correlation between residuals of de-trended annual average catch-rates ("anomalies") and annual mean, minimum and maximum water levels in Lake Chilwa. Analysis is done on total catch-rates by gear and the main target species (groups) of the various gears. Trend is a linear regression on annual average catch-rates. Regressions of anomalies on water levels are done on lags with the highest significant correlation. N=number of observations, r^2 = proportion of explained variation, b = trend parameter. Significance values are denoted by asterixes: * p<0.05, ** p<0.01, *** p<0.001*

Gear	Catch	Trend					Cross correlations						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	Total	18	0.61	0.23	-0.057	***	1	**0.58**	1	0.57	1	0.52	0.23	*
	Oreochromis	18	0.35	0.79	-0.100	***	0	0.56	0	0.38	0	**0.58**	0.36	**
	Clarias	18	0.38	0.22	-0.031	***	4	0.44			4	**0.45**	n.s.	
Seine	Total	18	0.45	0.51	-0.081	**	3	**0.57**	3	0.53	3	0.54	0.22	**
	Total						0	0.55	0	0.51	0	**0.58**	0.36	**
	Oreochromis	18	0.44	0.64	-0.098	**	1	**0.7**	1	0.66	1	0.67	0.36	**
	Oreochromis						0	0.72	0	0.68	0	**0.78**	0.63	***
	Barbus	18	0.46	0.61	-0.098	**	0	0.52			0	**0.55**	0.32	*
	Clarias	18	0.41	0.42	-0.060	**	4	**0.88**	4	0.88	4	0.88		n.s.
	Clarias						3	0.81	3	0.75	3	0.82		
Longline	Total	18	0.61	0.35	-0.077	***	0	0.51	0	0.48	0	**0.54**		n.s
	Clarias	18	0.62	0.34	-0.077	***	0	0.48	0	0.44	0	**0.51**	0.28	*
Fish trap	Total	17	0.80	0.18	-0.065	***	4	0.68	4	0.65	4	**0.69**		n.s.
	Barbus	17	0.48	0.40	-0.068	**	4	**0.79**	4	0.73	4	0.75		n.s.
	Barbus						3	0.6	3	0.57	3	**0.6**		n.s.
	"Other"	17	0.86	0.23	-0.101	***								

Where an effect of water level on catch-rate could be detected, it explained 10 percent to 40 percent of the total variation in annual average catch-rates. Approximately 23 percent of the residual catch-rates of gillnets (amounting to approximately 14 percent of the total annual variation) and 36 percent of the residual catch-rates of *O. shiranus* in seines (= 22 percent of total variation) were explained by the mean water level of previous years. In all other cases, the highest significant regressions between the residual catch-rates were found with "this year's" maximum water levels, which in case of *O. shiranus* in *Matemba* seines amounted to 63 percent of the residual variation (= 40 percent of total variation) explained. Residuals in total catch-rates in *Matemba* seines were explained for 22 percent by the average water level of one year earlier (≈10 percent of the total variation).

4.10 Effort increases fast and is population driven

All indicators of fishing effort increased significantly over the period examined: i.e. number of gear owners, assistants, boats and gears. Trends in numbers of gear owners, assistants, boats, gillnets and longlines indicate a three-fold increase while, traps and *Matemba* seines increased five fold (Figure 10). In the 1980s the number of fishing operators – gear owners and ancillary workers – in Lake Chilwa ranged from 2 060 to 3 403 while the range was from 3 955 to 9 466 in 1998, just two years after refilling of the lake (Table 5). This latter figure represents the highest number of fishermen and assistants ever registered on Lake Chilwa. Apparently many new fishermen entered the fishery after the recession, mainly in the west and north. This increase could be attributed to return migration from South Africa due to phasing out of the working contracts in the mines. We assume that many of the returning migrants took up fishing, as the Phalombe plain does not receive much rain making agriculture around the upland area an unattractive option.

All gears, both the low-investment (traps, longlines and handlines) as well as high-investment gears such as *Matemba* seines, continuously increase in units over the years. However, as the ratio of gear owners to assistants as well as number of boats and gears per owner exhibit a steady decrease over the period from 1983 to 1998 it is likely that low investment gears (traps, longlines, and *nchomanga*) become relatively more popular (Figure 11).

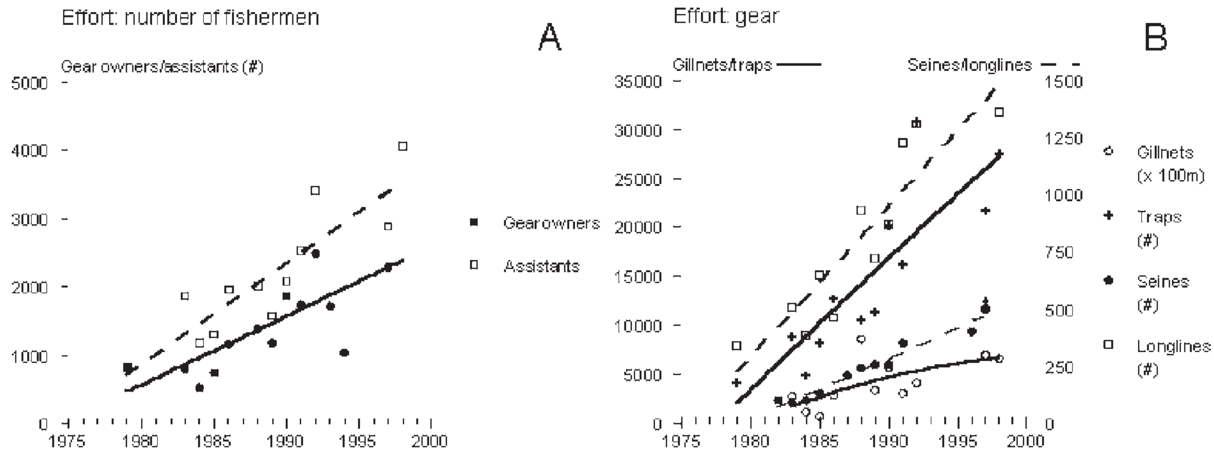

FIGURE 10. *Development in effort expressed as number of gear owners, number of assistants and number of boats in Lake Chilwa. The bold line is the regression of the total numbers over time. The thin regression line refers to the numbers of stratum 1 and the broken line is the regression of numbers of stratum 2 over time.*

Most fishing effort is suspended during recession periods. Many fishermen, especially those operating *Matemba* seines and gillnets, stop fishing or migrate to other water bodies, though such migrations recently have encountered resistance from resident fishermen (Njaya, pers. obs.). Other fishermen migrate to pools of water remaining in the inflowing rivers. Fishermen operating fish traps sometimes set their traps in rivers, often in conjunction with weirs.

4.11 Increased effort negatively affects catch-rates despite high regenerative capacity

We concluded in the previous section that a significant part of the variation in catch-rates is immediately explained by absolute water levels. This implies that catch-rates should increase with higher water levels and vice versa. However, between 1984 and 1991, with elevated water levels, no positive short term-trends were observed though trends became less strongly negative over time or indicated stable levels (Figure 8b). Long-term trends reveal a stabilization in catch-rates between 1984 and 1987 for gillnets, fish traps and longlines and between 1988 and 1991 for Matemba seines (Figure 8a). This would imply that the expected downward trend observed in catch-rates is delayed by increase in production during high water levels. After 1992, during the years before the recession, increased effort and decreasing water levels push stocks in the same direction, as a result of which the decrease in catch-rates will probably accelerate compared to a situation with low effort levels. However, closer examination of the trends versus catch-rates (Figures 5 and 6) show an increase for species (groups) caught in fish traps and for *Clarias gariepinus* caught in Matemba seines in the two to three years before the complete recession, thus confounding the explanations on the general trend.

Multiple regression of water levels and catch-rates confirms these observations: in all cases fishing effort had a significant negative effect on catch-rates. In gillnets 26–40 percent of the variation in annual catch-rates was explained by the number of gillnets for both *Oreochromis* and *Clarias*; in seines this amounted to 52–56 percent for all three species; longline effort explained 57 percent of the variation in annual catch-rates in *Clarias.* In traps the highest significant effect was found with *Clarias* (47 percent), while effort explained only 16 percent in *Oreochromis* catch-rates (Table 6). Water level was positively related to annual catch-rates, but explained much less than fishing effort (7–29 percent). In all gears, except longlines,

TABLE 5. *Number of fishermen, ancillary workers and craft operating in Lake Chilwa (1984-98)*

Year	Fishermen	Assistants	Total	Boats	Boats	Dugout
1984	527	1186	1783	8	71	1289
1985	750	1312	2062	13	75	1180
1986	1167	1962	3129	15	112	1802
1987	No frame survey					
1988	1363	2020	3383	10	146	1683
1989	1185	1597	2782	11	116	1373
1990	1874	2081	3955	4	229	1801
1991	2319	2546	4865	24	268	2045
1992	2496	3412	5908	5	329	1883
1993	1718	3958	5676	27	440	1201
1994	1043	5043	6096	0	507	1190
1995	No frame survey due to recession					
1996	No frame survey due to recession					
1997						
1998	5396	4070	9466	4	582	4090

Source : Fisheries Department Frame Survey (1984-98)

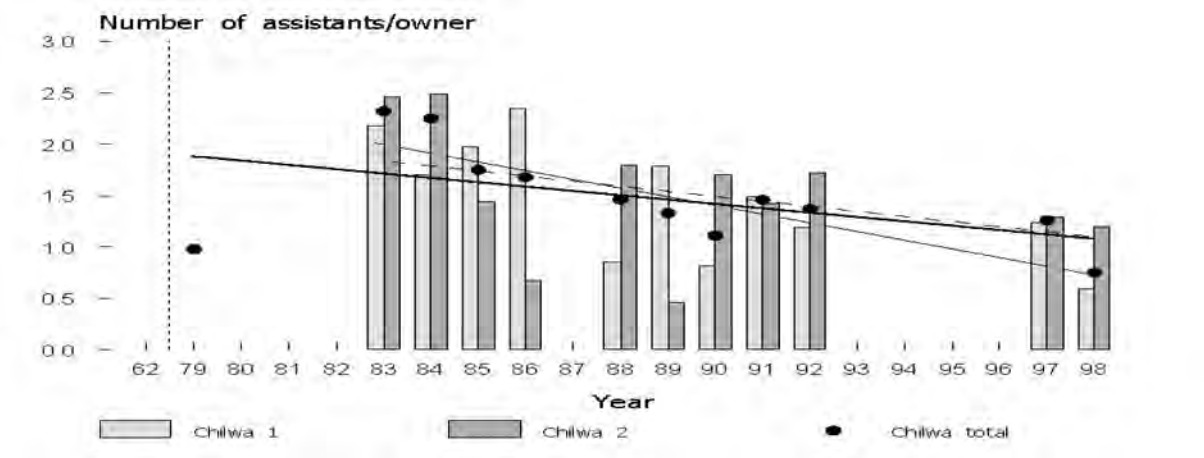

FIGURE 11. *Ratio of number of assistants and gear owners. The bold line is the regression of the total numbers over time. The thin regression line refers to the numbers of stratum 1 and the broken line is the regression of numbers of stratum 2 over time.*

Oreochromis catch-rates were affected most by water levels (20–29 percent). *Clarias* catch-rates were only significantly influenced in seines (15 percent) and longlines (7 percent), but not in gillnets and traps. *Barbus* catch-rates were only influenced by water level in seines (13 percent), but otherwise the regression model could not explain variation in catch-rates of *Barbus*.

4.12 Efficiency of gears (catchability) increases with decreasing water levels

The interaction of water level and gears was significant and positively related to catch-rates, except with seines. The lowest number of gears, counted at the beginning of the time series, as well as the highest number of gears at the end of the series coincided with low water levels, while highest water levels around 1990 are associated with a period of increasing fishing effort with all gears. The drop in water level towards the recession in 1996 and 1997 is thus associated with the highest numbers of gears counted in the time series of fishing effort. Theoretically increased fishing effort would be associated with decreased catch-rates. However, the high proportion of variation explained by the interaction term indicates that the situation is more complex. During receding waters, with a likely subsequent concentration of the fish, some of the gears catch a number of species more efficiently thus maintaining relatively high catch-rates despite increasing effort. This is the case with *Oreochromis* caught with gillnets (30 percent of variation explained by interaction term) and traps (21 percent), and with *Clarias* caught in gillnets (29 percent), traps (26 percent), longlines (18 percent) and to a lesser extent seines (7 percent). This sustains the notion of a crowding effect of these two species during receding water levels. It is particularly clear in the case of *Clarias* where relatively high catch-rates are encountered during very low water levels (Figure 6). There are indications that *Clarias* become more "active" under extreme low water levels in an attempt to find their way out of the desiccating areas changing their catchability.

That the interaction effect does not play the same role in the case of Matemba seines may not be surprising. Seines are active gears used either from the shore, or from boats in and around submerged vegetation, in relatively shallow areas. They are used both with receding or increasing lake levels in the areas where concentrations of smaller species and juveniles of larger species are found. Changes in recruitment levels will therefore affect catch-rates more than crowding effects, which is indicated by the high explanatory value of the water level in the statistical model where seining effort is the explanatory variable. In comparison, longlines show the reverse situation: in this case recruitment variation is much less important (7 percent of variation explained by the effect of water level) compared to the interaction effect (18 percent). Of all gears, the increase in effort of seines and longline explains the highest proportion of variation in their respective catch-rates, indicating a comparatively strong effect on stocks.

TABLE 6. *Proportion of variation in annual catch-rates explained by the multiple regression model with lake water leve l(mean, minimum or maximum), with or without a lag phase of 1 year, fishing effort (number of gear) and their interaction as explanatory variables. Sign indicates the direction of the effect in the model. Left of the vertical line are the statistics of the multiple regression model. Analysis is done on total catch-rates by gear and the main target species (groups) of the various gears. Only regression models explaining the highest amount of variation are shown. Df= degrees of freedom, SS = sum of squares, % = r^2 = proportion of explained variation, 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	Water level	Model (A)							Statistics of model (B)				
				Water level		Gear		Interaction			Total error	Residual error	Total error explained by model	
			Lag	Sign	%	Sign	%	Sign	%	Df	SS	SS	%	P
Gillnet	Total	Mean	1			-	38	+	38	16	2.53	0.60	76	***
	Oreochrom	Max	0	+	20	-	26	+	30	17	15.11	3.67	76	***
	Clarias	Max	0			-	40	+	29	17	5.01	1.57	69	***
Seine	Total	Max	0	+	16	-	54			17	7.58	2.27	70	***
	Oreochrom	Max	0	+	29	-	52			17	11.54	2.08	82	***
	Clarias	Max	0	+	15	-	56	+	9	17	5.01	1.02	80	***
	Barbus	Max	0	+	13	-	55			17	10.89	3.43	68	***
Longlin	Total	Max	0	+	9	-	57	+	20	17	5.04	0.76	85	***
	Clarias	Max	0	+	7	-	57	+	18	17	5.01	1.01	82	***
Trap	Total	Max	0	+	9	-	49	+	24	17	5.04	0.91	82	***
	Total	Min	0	+	17	-	43	+	13	17	5.04	1.34	74	***
	Oreochrom	Max	0	+	29	-	16	+	21	17	3.56	1.19	67	**
	Clarias	Max	0			-	47	+	26	17	5.01	1.36	73	***
	Clarias	Min	0			-	47	+	14	17	5.01	1.94	61	***

5. CONCLUSIONS AND DISCUSSION

Let us return to the question posed in the introduction on how the data collected through the Malawian CEDRS on Lake Chilwa could be utilized to gain information on the status of the fishery, and following the answer to that summarize our conclusions.

5.1 On the data collected

The catch-rate data contain an enormous variability that, to a large extent, we believe to be mostly administratively induced as caused by the method of raising the daily catch and effort data to arrive at the estimates of monthly catch and catch-rate. As a result, for instance, seasonality is hardly detectable. Seasonality is expected to be clearly visible in the data in a system with highly seasonal changes in productivity. Despite the high variability, it is still possible to significantly detect trends in the various catch-rates series within two to three years of monthly aggregated data. The time windows, over which short- and long-term trends in total catch-rates could be detected, are generally between two and three years of data, and occasionally lower than that. Taking into account that the average duration between periods of recession is six years, and that 30 percent of the variation in water levels is accounted for by these cycles, this is rather a long time-frame to evaluate the effects of any management measure that aims at improving catch-rates. The speed of change in fish stocks in Lake Chilwa appears to be much faster than can be detected through the present CEDRS.

5.2 On the effects of fluctuating water levels and increased effort

- The tremendous increase in fishing effort is largely an increase in numbers of gear and labor and not of changed technology. With highly contrasting lake levels, this makes an analysis of the combined effects of effort and changing productivity as a result of changing water levels possible.
- The effect that changing water levels have on stock levels is large: it can be detected despite the high administratively induced “background noise”. Although the effect of water levels seems to be immediate, only a small proportion of the annual variation is explained by it. Two reasons can be given for this:

  (1) The amount of error in the data collection and subsequent handling obscures this effect. This error could be considered as random noise during all the series, as sources of bias and error are the same[1].

  (2) The general trend of decreasing catch-rates is caused by the tremendous increase in effort. Changes in water levels either obscure this general trend if conditions are favorable as was the case between 1986 and 1991, or effects of lowered levels in concentrating fish disguise the effects of increased effort initially during receding water. Eventually the drops in catch-rates speed up during the continued decrease in water levels.

- Changing water levels are reflected in an “immediate” effect on catch-rates in the various gears employed, which means that the effect is on the stock abundance. The time lag in the correlation between water levels and catch-rates is generally short (0-1 year) and long-term effects caused by strong or weak cohorts (year classes) of fish over several years, are not detected – except possibly with *Clarias*. Since most of the variation is accounted for within the “first year” this indicates that the fishing pattern is aimed at small short-lived, or young fish. However, despite the high effort, this fishing pattern does not seem to influence the regenerative capacity of the stock, as this seems to be more a function of water levels. In other words, when the environmental conditions are favorable (strong water influx) the recruitment of new fish could be independent of the fishing pressure, at least within the present range of observations. That the recruitment appears much more dependent on favorable environmental conditions, than on the actual parent stock sizes, is also manifested by the rapid rebuilding of the stocks that is observed after each major lake level recession. The Lake Chilwa fish stocks appear to be adapted to withstand high natural depletions, and are therefore also able to sustain high exploitation rates.

[1] That the effect of water levels on catch-rates can still be seen indicates that the assumption that "administratively induced error" is a random effect may be correct.

- Delayed effects on catch-rates through "dilution" and "concentration" of fish as a result of changes in volumes of water and behavioral change in fish movements, result in changing efficiency of gears. Both effects may be typical for the situation in Chilwa and caused by both the small mesh sizes of the gears employed and the areas fished. Much of the fish caught are small sized (0+ or 1 year old), and an important part of the effort is employed along the shore or in reed beds. The maximum size of *Barbus paludinosus* is only 12 cm while *Oreochromis shiranus* (maximum size 25 cm) reaches maturity already at 12–15 cm (Furse, 1979). The fishery thus is adapted to catching small sizes. This means that as the fishery maximizes on harvesting the production of juveniles or small species before they are subjected to high natural mortalities, yields will also be highly variable due to changing water levels. The amount of variation explained at the aggregated level of years confirms this.

What does this mean for using the information gathered through the CEDRS? Our analysis has concentrated mainly on total catch-rates by gear, with an occasional excursion to individual species (groups). Long-term trends in total catch-rates for all gears all point in the same downward direction. As variation in aggregated total catch-rates by gear is lower than for the individual species, it will be more difficult to detect both long and short-term trends by species (groups), even on the aggregated level of the whole lake. Using the information gathered at lower levels of aggregation – for example at the level of main strata representing ecological areas, at village/beach level or at the level of individual fishermen or by species(group) – will be non-informative within a small time window but may be informative in a large time window. At present, different gears are generally targeting different species(groups), which means that gear specific trends can serve as an indicator for their respective targets species. As some gears – e.g. fish traps – are also fairly habitat specific, such trends will also provide information on changes in those habitats. In a first approximation, short-term trends by gear could be related to existing knowledge – both local-knowledge and scientific knowledge (e.g. Kalk, McLachlan and Howard-Williams, 1979) – of the effects of changing water levels related to the species and area specificity of the gear.

The immediate effect of changing water levels can be illustrated without resorting to sophisticated statistical methods. Peaks in total catch-rates and catch-rates of *O. shiranus*, *Barbus paludinosus*, *Clarias gariepinus* and "Other" species in *Matemba* seines all coincide with the significant increase in water levels in the same year (Figures 5 and 6). This would indicate that relative change in water level is probably a better indicator for changes in catch-rates (≈ stocks), than absolute lake-levels, also indicated by the fact that maximum water levels usually score better than mean or minimum water levels. Also in Kariba annual change in lake levels, reflecting the amount of new inundated land every year (= new nutrients) scored better than mean annual lake levels (Kolding, 1994; Karenge and Kolding, 1995).

By eliminating much of the perceived "administratively induced" variance the information contained in the data collected through the Malawian CEDRS could be made much more sensitive over the short-term to changes both in effort and in productivity. Then the present analysis could be easily extended at a lower aggregated level (by area and by species-gear combination). Furthermore, at a higher aggregated level, overall effects of management measures could be detected more quickly, even with the observed high variation in catch-rates caused by changing water levels. This could make the CEDRS a much better instrument to evaluate the biological effects of (co-) management measures in such an adaptive environment.

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