A Synthesis of Simple Empirical Models to Predict Fish Yields in Tropical Lakes and Reservoirs

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Contents

1 INTRODUCTION

1.1 Executive Summary

1 A primary database has been constructed using dBase software, containing annotated statistics on morphology, hydrology, chemistry, biology, fisheries and catchment demography for tropical and sub-tropical lakes, reservoirs, swamps and coastal lagoons. The database contains data series for 2481 water bodies; useable fishery catch statistics are available for 398 of these. Most major water bodies in developing countries are included, together with some systems in more developed countries in the sub-tropical zone. Small water bodies (<1 km^2) for which data were available have also been included, although a complete inventory has not been made. Asia, Latin America and Africa are all covered. There are also a few entries for some eastern Pacific Islands (Oceania) that have been grouped with data from Asia.

2 The primary database has been summarised to one representative value for each variable to facilitate comparative studies between water bodies. This secondary database contains records only for water bodies for which fishery catch statistics were available.

3 Both primary and secondary databases are available on a floppy diskette, with a run-time version of the required software and an accompanying manual outlining the structure of the databases, and instructions for sorting, retrieving and summarising the data, as well as entering new records and editing existing ones.

4 The breadth of data coverage in the primary database makes this compilation useful for a variety of water resource and catchment management and planning applications outside fisheries. The database provides scope for the empirical analysis of a variety of scientific hypotheses concerning the role of various factors affecting the productivity of aquatic ecosystems, and is thus of interest to the wider academic community as well as fishery organisations and regional planning authorities in the countries covered by the database.

5 The summary table was used to explore relationships between fish catch and a range of parameters in inland water bodies (excluding rivers). A number of significant relationships were found. These varied in the extent of their applicability and data requirements. Simple, broadly applicable relationships between fishery yield, fishing effort (as number of fishers) and water body area and volume explain much of the variability in total catches on a global and continental scale. Relationships between water body area and yield, and between the number of fishers and catch, do not differ significantly between continents, but these relationships have high variance for Asian and Latin American lakes.

6 Hydrology and climate data are not often available on a catchment (as opposed to regional) basis. A global relationship exists between fish yields and annual mean rainfall in the catchment, with fish yields increasing approximately linearly with increasing rainfall.

7 The chemical features of water bodies do not correlate well with fish yields; the morphoedaphic index and its derivatives are not applicable at either the continental or global scales. A relationship between total phosphorus, total nitrogen and fish yield was obtained for stocked Asian lakes and reservoirs, which are essentially farm systems, where nutrient inputs have a direct and measurable effect on fish harvest.

8 The productivity base of tropical fresh waters is diverse and ill-defined quantitatively. Phytoplankton are only one of a range of sources of organic carbon supporting fish production. It is therefore un-surprising that relationships between chlorophyll a or

phytoplankton production are only applicable to limited datasets. A small series of Asian lakes where fish are not stocked showed a significant relationship between fish yield and surface Chlorophyll *a*, and a larger series of African lakes, including Melack's (1976) original data set, showed a significant relationship between gross photosynthesis and fish yields, but as predictors of fish yields, they are only likely to be useful in conjunction with other variables.

9 Attempts to correlate other components of the food web with fish yield were hampered by lack of data. There is little quantitative information on the role of macrophytes, zooplankton and zoobenthos in tropical systems. Tilapia-based capture- fisheries yield the highest harvests, with Tilapia/Carp fisheries and haplochromine cichlid fisheries also being high yielding. Fisheries based on a mixture of predatory fish, catfish etc, are less productive on an areal basis, as are fisheries based on small pelagic species and wild carp populations. Most culture based fisheries are based on either carp or Tilapia, in all three continents. No difference in fish yields was observed in a comparison of reservoirs with fisheries based on introduced and on native fish of riverine origin.

10 Close relationships between catches and the number of fishers or number of boats indicate that tropical artisanal inland fisheries are broadly comparable on a global scale. A median catch rate of 2 t fisher^{-1} y^{-1} is observed in a wide range of fisheries suggesting that this is a fairly universal requirement to support a full time artisanal fisher. Strong linear relationships between catch per unit area and fishing intensity (fishers km^{2}) and weak relationships between catch rates and fishing intensity indicate that the values of fishing effort used in the analyses represent sustainable averages for most water bodies. These relationships should not be interpreted to suggest that there are no overfished water bodies: a plot of the most recent catches and fishing intensities, rather than long-term averages, may reveal if this is the case or not.

11 The database highlights gaps in the knowledge of tropical lake and reservoir systems, and can be used to prioritise research and development projects. Major gaps located were: i) Socio-economic studies of Latin American inland fisheries, ii) estimates of primary production that include macrophytes, periphyton and allochthanous inputs rather than just phytoplankton photosynthesis, iii) Catchment-based studies of land use, hydrology, climate and demography.

1.2 Introduction

For many low-income groups in developing countries, fish is the main source of animal protein in the diet. Much of the fish consumed comes from small inland water bodies, which are individually not important enough to merit fisheries surveys, especially as the resources of Government Fisheries Departments are usually very limited.

Without fisheries survey data, managers cannot recommend measures to ensure that fish populations are managed sustainably, and without resource inventories, they cannot prioritise allocation of resources for sectoral development. Estimates of potential sustainable fish yields are not only valuable for sound management of existing fisheries, they are also useful when planning and evaluating the likely benefits of constructing new reservoirs for irrigation, electricity generation or domestic water supply.

This project aimed to provide a simple method of estimating the fishery potential of lakes and reservoirs by establishing predictive relationships between fish yields and simple environmental, climatic and demographic parameters. This was accomplished using published information from the wide range of tropical and sub-tropical water bodies that have been studied or monitored to some extent.

Simple empirical estimators have been used to predict fish yields in lakes and reservoirs for over 30 years (e.g. Ryder, 1965, Henderson *et al.,* 1973; Hansen & Legget, 1982; Moreau & De Silva, 1991; Moyo, 1994). The theoretical basis for such models is that fish production is largely determined by the level of primary production in an aquatic system. As production rates are difficult to measure, factors thought likely to affect primary production, such as the depth of a lake and some measure of its nutrient status (such as conductivity) have been correlated with fish yield (a function of fish production) obtained from fishery data. This is the well-known morpho-edaphic index (MEI) where MEI is total dissolved solids or conductivity/depth (Ryder *et al.,* 1974; Oglesby, 1982; and Ryder, 1982 for reviews) and it has since been used, often in conjunction with other explanatory variables such as lake surface area and temperature, for prediction of fish yields per unit area in lakes and reservoirs around the world (e.g. Toews & Griffith, 1979; Jenkins, 1982; Schlesinger & Regier, 1982; Machena & Fair, 1986). Variability in the relationship between fish production and yield has been allowed for by incorporation of data on the likely intensity of fishing on the lakes used to establish the predictive models (Henderson & Welcomme, 1974; Bayley, 1988).

In the MEI, conductivity is used as a measure of nutrient concentration, which is assumed to determine primary production and hence fish production and yield. The disadvantage of the MEI is that it only applicable to lakes which are relatively homogenous with regard to their chemical composition and geographical location (Ryder*,* 1982) so that a different MEI relationship should be derived for each region.

Although not as easy to estimate, primary production, usually expressed as gross or net phytoplankton photosynthesis has often been used as an alternative to the MEI to establish predictive relationships with fish yields in lakes (Melack, 1976; Oglesby, 1977). These studies have generally been based on small data-sets - 10 to 20 lakes - usually in a geographically restricted region, and their application assumes that the majority of primary production is by phytoplankton, which may not always be the case.

The literature on empirical yield estimators contains many claims and counter-claims for the predictive power of a number of modifications to the relationships cited above (e.g. Oglesby, 1977; Youngs & Heinbuch, 1982; Downing *et al.,* 1990). These new relationships generally follow attempts to apply previously published estimates to different sets of lakes. Thus, the situation has arisen where a variety of estimators are available, all of limited applicability. The fishery biologist or manager therefore generally applies a range of such models and usually obtains a wide range of fish yield estimates; there is then little basis for choosing one estimate in preference to the others.

There is clearly a need for a wider synthesis of data and more objective, direct comparisons of the existing empirical models. Considerable progress has recently been made with a synthesis of data and production of new empirical models for African lakes (Crul, 1992), Latin American Reservoirs (Quiros, 1994), lakes and reservoirs in Thailand, Sri Lanka and the Philippines (Moreau & De Silva,

1991) and SE Asian and Latin American rivers (MRAG, 1993). This work extends the coverage of these studies to lakes and reservoirs throughout the tropics, and provides preliminary syntheses of data on swamps, floodplain lakes and coastal lagoons.

All the above recent lake and reservoir studies have made use of the conventionally collected parameters of lake area, mean depth, conductivity, chlorophyll a concentration, phytoplankton photosynthesis and number of fishers or boats, and there is considerable scope for improvement in the choice of explanatory variables by making use of advances in understanding of trophic-transfer processes in lakes (Hecky *et al.,* 1981; Carpenter *et al.,* 1985; McQueen *et al.,* 1986; Leach *et al.,* 1987; Downing & Plante, 1993) and factors affecting lake and reservoir productivity, (Brylinsky & Mann, 1978) particularly in the tropics (e.g. Payne, 1986; Thornton, 1986; Talling, 1992). In particular stratification and mixing regimes in lakes are crucial in regulating primary production (Talling, 1969; 1992) and its transfer to higher trophic levels, including fish (Allison *et al.,* 1995). The trophic level at which fish are harvested is also likely to be a major factor affecting the efficiency of transfer between primary production and yield to fisheries (Hecky, 1984; Pauly & Christensen, 1995).

Existing empirical models can also be improved by taking into account more recent work on determining the limits of predictions based on statistically valid relationships between variables (Rempel & Colby, 1991). In particular, the change from using ratios to single variables in multiple regression relationships (Schneider & Hadrich, 1989) is emphasised. Multivariate methods are also used increasingly in relating fish yields to a combination of several correlated variables (e.g. lake morphometric measurements) (Quiros, 1990; Moyo, 1994), although these are less directly applicable to obtaining a prediction of fish yield for a given water body.

This report presents predictions of fish yields from relationships with parameters that are readily available or easy to measure, but, at the same time, whose effects on fish yields are sufficiently well defined theoretically to allow potential users to decide whether the application of the models is appropriate in their situation. The collation of an extensive data set has allowed screening of all parameters incorporated in previous empirical fish yield models, together with a number of new parameters that will form the basis for original approaches to fish yield prediction.

1.3 Review of Existing Empirical Yield Models

1.3.1 Potential Fish Yield and Fish Production from Morphometric and Edaphic Models

The first application of Ryder's morphoedaphic index to tropical fisheries was that of Henderson & Welcomme (1974):

$$Y = 14.3136\ \mathrm{MEI}^{0.4681}\ (r = 0.6864)$$

This relationship was derived from 17 of an original data set of 31 African lakes. The reduced data set includes only those lakes considered to be fully exploited (>1 fisherman km^{-2} lake area). The regression line has a similar slope but higher intercept than the original MEI proposed by Ryder (1965) for a series of North American lakes. If lake surface area is included in the relationship it becomes:

$$\log_{10}Y = 1.4071 + 0.3697\ \log_{10}\mathrm{MEI} - 0.00005465\ A; \qquad r = 0.81\ \text{(Toews \& Griffith, 1979)}$$

where Y = potential sustainable fish yield in kg $\mathrm{ha}^{-1}\ \mathrm{yr}^{-1}$, MEI = morphoedaphic index = conductivity (µmho cm^{-1} at 20° C)/mean depth in metres and A = lake surface area (km^2).

Oglesby (1977) found that mean depth (z) was an irrelevant variable in lakes > 25 m deep, and derived the following MEI relationship:

$$\log Y_d = -2.24 + 0.69 \log x; \qquad n = 17,\ r = 0.62 \qquad \text{(Oglesby, 1977)}$$

where Y_d = fish yield in kg dry weight ha^{-1} and $x = \mathrm{MEI}_{z25}(\mathrm{TDS}/z)$. Dry weight was assumed to be 25% of wet weight.

Schlesinger & Regier (1982) recognized that fish yield - MEI relationships generally applied only to lakes within restricted regions and attempted to generalize the relationship by incorporating mean annual air temperature (T; °C) to account for latitudinal variations:

$\log_{10}Y = 0.044\ T + 0.482\ \log_{10}MEI + 0.236$; $n = 43$, $r = 0.90$. (Schlesinger & Regier, 1982)

Hanson & Legget (1982) found that, although total dissolved solids (TDS; mg l^{-1}), (where TDS/mean depth in feet was the original MEI of Ryder (1965)) and total phosphorus concentration (TP; g l^{-1}) were highly correlated, the latter was a much better predictor of fish yield. Of the several equations proposed by Hanson & Legget (1982), the following multiple regression equation, which includes both TP and TDS, has the best predictive power:

$$Y = 0.066\ TP + 0.141\ z + 0.013\ TDS - 1.513;\ n = 21,\ r = 0.98$$

(Hanson & Legget, 1982)

A more recent analysis by Downing *et al.* (1990) has established a relationship between fish production (P_f) and TP:

$$\log_{10}P_f = 0.332 + 0.531\log_{10}TP;\ n = 14,\ r = 0.82$$

(Downing *et al.,* 1990)

The use of fish production, rather than yield, removes the variability due to differences in exploitation rates and variability in the relationship between fish production and yield, but is less useful in fisheries management terms as fish production is not normally known, whereas yield data are commonly available.

Recent models have tended to the trivial conclusion (Schneider & Hadrich, 1989) that lake area explains most of the variance in fish landings (bigger lakes yield more fish!). Crul (1992) derives the following relationship between catch (t y^{-1}) and area (km^2) for 46 lakes and 25 reservoirs in Africa:

$$\text{Catch} = 8.32*\text{Area}^{0.92} \quad r^2=0.93$$

This relationship explained a high proportion of the variance because the range of areas and catches was large. Predictions for individual waterbodies from this relationship are very imprecise, and no relationship incorporating other morphometric, chemical or biological parameters could be derived. Quiros (1994) derived a number of yield:area relationships of the same general form for Latin American water bodies.

It is often mistakenly assumed that because yield-area models explain such a high proportion of the variance in a data set, that they provide a fairly precise prediction. These relationships are based on large datasets of lakes covering orders of magnitude in size, any residual variation may therefore appear small, and efforts to include other predictor variables may appear unnecessary as they provide an apparently trivial improvement in fit to the data, or may even result in decrease in fit (r value) as addition of covariates generally reduces the size of the data set and may reduce the range of areas. Calculation of confidence intervals of such predictors will determine which relationships provide more precise predictions for any given size of water body, and this approach is taken in evaluating and recommending empirical relationships to use, rather than relying solely on r-values. In practice, the choice of relationship will often be determined by data availability, so in this report, a range of univariate and multivariate predictors are given for each data set, together with recommendations as to which type of system each equation should be applied to.

Moreau & De Silva (1991) propose the following multiple regression models for predicting the fish yields of lakes and reservoirs in a) Sri Lanka, b) Thailand and c) Philippines:

a) $Y = -63.7 + 0.111*\text{Area} + 5.898*\text{Effort}$ $n=20$, $r^2 = 0.857$

b) $Y = 112.3 + 0.010*\text{Area} + 0.309*\text{Effort}$ $n=19$, $r^2 = 0.786$

c) $Y = 436.2 + 0.336*\text{Area} + 0.745*\text{Effort}$ $n=17$, $r^2 = 0.929$

Where Y = total yield per water body (t y^{-1}), Area (ha), effort (no. fishermen).

The addition of catchment area to the multiple regression equations for Sri Lanka and Thailand resulted in slight, but not significant, increases in the variance explained by the models. It was noted that effort and area were correlated in Thailand and the Philippines.

Moreau & De Silva (1991) also tested a number of models using yield ha^{-1} and catch per unit effort as the dependent variables and catchment/lake area ratio, mean depth, transparency, total alkalinity, chlorophyll *a* concentration, primary productivity and fishing effort per unit area as independent (predictor) variables. Morphometric variables were found to the best predictors of yield, with fishing effort also being important. Chemical and productivity data were incomplete, but transparency and total alkalinity proved useful for some of the datasets. MEI relationships were only found for data from the Philippines. No attempt was made to find predictive relationships for the whole aggregated data set, and it was suggested that indicators of biological status, such as primary productivity, would be more successful predictors on a regional scale than the morphometric and chemical parameters, and fishing effort.

1.3.2 Potential Fish Production and Yield from Algal (Primary) Production or Algal Biomass

A relationship between gross photosynthesis (PG) and fish yield was obtained from seven African lakes:

$\log_{10}Y = 0.95 + 0.00034\ PG$; $r = 0.82$ (Melack, 1976)

and for a data set of Madras lakes:

$\log_{10}Y = 0.95 + 0.00034\ PG$; $r = 0.82$

where PG = gross photosynthesis (g $O_2\ m^{-2}\ yr^{-1}$)

Oglesby (1977) has derived relationships between fish yield (Y_d = g dry wt $m^{-2}\ yr^{-1}$; Y_c = g C $m^{-2}\ yr^{-1}$, assuming 25% dry wt: wet wt, and 1 g C = 10 g wet wt or 2.5 g wet wt) and summer standing crop of phytoplankton (CHL_s, mg m^{-3}, of Chl *a*) or primary production (P, in g C $m^{-2}\ yr^{-1}$).

$\log Y_d = -1.92 + 1.17 \log CHL_s$; $n = 19$, $r = 0.92$ (Oglesby, 1977)

$\log Y_c = -6.00 + 2.00 \log P$; $n = 15$, $r = 0.86$

The only tropical lake included in Oglesby's relationships was Lake George, for which summer was taken to be the season of maximal mixing.

Machena & Fair (1986) found that Melack's (1976) and Oglesby's (1977) primary production-based models were reasonable predictors of fish yield for L. Kariba, but gave six-fold underestimates for L. Tanganyika. As the bulk of the fish yield is from the same species (*Limnothrissa miodon*) in both lakes, they hypothesise, like Hecky & Fee (1981), the existence of a bacteria-based food chain in L. Tanganyika, but reject those authors' hypothesis that trophic transfer efficiencies are also exceptionally high in L. Tanganyika.

Several other empirical relationships have been derived between some measure of primary production and fish production. These include Jones & Hoyer (1982), who correlated sportfish harvests with summer chlorophyll a concentrations in US reservoirs and lakes and McConnell *et al.,*

(1977) who demonstrated that gross photosynthesis was related to fish production in ponds where all fish were harvested. Liang *et al.,* (1981) derived the following relationship between net fish yield (kg ha^{-1} y^{-1} minus weight of stocked juveniles)and gross primary production (mg 0_2 l^{-1} d^{-1}) in sub-tropical Chinese lakes and ponds:

$$\log_{10}FYn = 0.0457{*}P+2.44 \qquad n=18,\ r^2 = 0.76$$

A more recent global analysis of the relationship between fish production (P_f ; kg ha^{-1} yr^{-1}) and primary production (Pp; g C m^{-2} yr^{-1}) suggests the following general relationship:

$$\log_{10}P_f = 0.600 + 0.575 \log_{10} P_p;\ n = 19,\ r = 0.89$$ (Downing *et al.,* 1990).

These authors suggest that the conversion of phytoplankton into fish production is dependent on the trophic status of lakes, and may be 100 times more efficient in oligotrophic than hyper-eutrophic lakes, but that a much lower fraction of fish production can be channelled to sustainable yield in oligotrophic lakes - as little as 10% of total annual fish production.

Relative fish biomass (expressed as gillnet CPUE) were found to be correlated to chlorophyll *a* and nutrient concentrations (total phosphorus and total nitrogen) as well as total organic matter in a large number of Argentinean lakes and reservoirs (Quiros, 1990).

1.3.3 Fish Production from Analysis of Zooplankton Communities

Mills & Schiavone (1982) indicate that it is possible to draw broad inferences about the structure of a lake's fish community from zooplankton samples but don't give any quantitative relationship from which predictions of fish yields can be derived.

McQueen *et al.,* (1986) derive relationships between planktivore biomass and zooplankton biomass, and between piscivore and planktivore biomasses, but the data are derived from biomass indices in Mills & Schiavone (1982) and are not generally applicable.

1.3.4 Fish Production or Yield from Fish Biomass

Empirical estimators of potential yield from unexploited fisheries based on surveys to quantify fish biomass have commonly been applied in tropical lakes and reservoirs. Most are developed from Gulland's estimator of: $Y = 0.5MB_0$, where M = natural mortality rate and B_0 is the virgin biomass (Gulland, 1971). A constant of lower value (0.2-0.3) is now thought to provide a more realistic estimate of potential sustainable yield (Kirkwood *et al.,* 1994). These relationships only apply to unfished stocks.

Downing *et al.,* (1990) propose that average standing biomass of fish (B; kg ha^{-1}) is related to total production of the fish community (kg ha^{-1} yr^{-1}) by:

$$\log_{10}P_f = -0.42 + 1.084\log_{10}B_f;\ n = 23,\ r = 0.82$$ (Downing *et al.,* 1990)

If data on the mean annual biomass (B) and maximum size (W_{max}; g) of the fish of every species in the community is available, population specific estimates of production (kg ha^{-1} yr^{-1}) can be estimated. Annual mean air temperature (T) allows for the dependence of production rates on water temperature, but is more readily available:

$$\log_{10}P_f = 0.20 + 0.93\log_{10}B - 0.19\log_{10}W_{max} + 0.02T;\ n = 100,\ r = 0.94$$
(Downing & Plante, 1993)

The relationship applies to all fish populations, irrespective of their trophic level, as W_{max} correlates broadly with trophic level in aquatic food webs (Sheldon *et al.,* 1977).

The same authors propose a similar relationship, with total phosphorus concentration (TP; ugl^{-1}), B and W_{max}:

$$\log_{10}P_f = -0.25 + 0.90\log_{10}B - 0.15\log_{10}W + 0.29\log_{10}TP;\ n = 52,\ r = 0.90.$$

The residuals of the models are found to correlate with chlorophyll *a* concentration, primary production and pH, suggesting a general bottom-up control of lake ecosystems, with top-down control (predation) modifying the potential productivity of each trophic group (c.f. McQueen *et al.,* 1986).

The above two relationships can be applied to each of *i* species or species groups, and the predictions summed to give the total fish production (P_{tf}; kg ha^{-1} yr^{-1}):

Plante & Downing (1993) go on to suggest that exploited populations are more productive than unexploited ones by an average of 70%.

1.3.5 Fish Yields from Trophic Relationships

Hecky *et al.,* (1981) suggest that fish production can be predicted from mean trophic level and assumed trophic transfer coefficients of 10%. Thus, if primary production is known, and fish eat herbivorous zooplankton, fish production should be approx. 1% of primary production.

Relationships between production, size and trophic level were used by Sheldon *et al.,* (1977) to predict production of Peruvian anchoveta from primary production. A similar approach has been used to predict fish production in L. Malawi (Allison, in press), and may be of general applicability to fisheries based on pelagic food chains (Boudreau & Dickie, 1992). These analyses indicate the existence of general relationships between size, productivity and trophic level. These relationships can be used at a coarser scale to establish empirical predictors of fish yields from productivity and trophic level of fish in the catch (from diet studies and catch-compositions).

Although predator-prey models and the effects on yields of introducing alien species have been extensively discussed, there are few empirical data to support any argument as to whether introduced species produce higher yields than native species, or even if fisheries based on herbivores are always more productive than those based on carnivores. Fernando & Holcik (1982) argue that high primary production and low fish yields in new reservoirs and young lakes are due to the riverine origin of the fish fauna that are only able to exploit the littoral habitat. These authors suggest that the niche for pelagic planktivores remains vacant unless exotic species are introduced. The success of clupeid fisheries in L. Kariba support this finding, but it is far from clear whether certain groups (e.g. the clupeids) are always more productive than some of the native species. The role of species diversity and niche packing in the utilization of food resources in fish communities is not well understood, and there is little to indicate whether diverse species assemblages provide greater or lesser sustained yields to fisheries than mono-specific stocks (Ryder *et al.,* 1981). Moreau & De Silva (1991) attempted to explore relationships between fish yields and ratios of predators to other species in the catch, catches of indigenous and exotic species, number of species to area of the water body, all without success, but Paiva *et al.,* (1994) found that fish yields in Brazilian reservoirs were optimised when two predatory fish species were present.

1.3.6 Fish Yields from Socio-economic Variables

The most often cited socio-economic variable in models to predict fish yield is some measure of fishing effort, usually number of fishermen (Henderson & Welcomme, 1974; Bayley, 1988) or number of boats or units of fishing gear. The establishment of such relationships relies on the comparability of the unit of effort between different lakes. Thus, boats are a good comparative unit if all fishing takes place from dugout canoes, but if some fisheries use stern-trawlers, while others use small plank-boats and some don't use boats at all (e.g. beach seines) then the unit is not comparable. For tropical fisheries, the fisherman (or fisher) seems an appropriate unit for all artisanal fisheries. Highly mechanised fisheries should not be considered, as the effort/yield relationship is likely to differ.

Only two studies consider other socio-economic factors as potential predictors of fish yields. Bayley & Petrere (1989) derive fish yield estimates for the Amazon basin using per capita fish consumption data and demographic statistics. Quiros (1993) shows how pollution and urbanization affect inland fisheries in Argentina. The database collated here indicates the paucity of such data in the fisheries literature.

2 MATERIALS AND METHODS

2.1 Sources of Information

Information provided in the database is all attributable to a published source. Some of the major sources of information were not primary sources; these include the existing compilations of fishery and limnological data of Vanden Bossche & Bernacsek (1990a; 1990b; 1991) for Africa; Moreau & De Silva (1991) for the Philippines, Thailand and Sri Lanka, and the world reviews by Serruya & Pollingher (1983) and the Lake Biwa Research Centre/International Lake Environment Committee (1988; 1989; 1990; 1991). These secondary sources enabled a large amount of information to be compiled rapidly, forming a preliminary synthesis around which this more detailed database was constructed. Many of the primary sources cited by the above publications are to internal reports and unpublished data not readily available. In cases where several values of a given variable exist for a water body, the primary data sources are cited. Where only one study has been conducted, and the original source was not seen, the data is attributed to the compilation in which it was reported.

As this report was being completed, a number of publications containing syntheses of information relating to the general theme of 'intensification of management of fisheries in small water bodies' were received from FAO, Rome (Juarez-Palacios & Varsi, 1993; Quiros, 1994; Marshall & Maes, 1994). These publications result from an on-going research strategy of the FAO Inland Water Resources and Aquaculture Service to compile and disseminate information that can be used to improve the management of small, multi-use water bodies. While some previously undocumented information resulting from this recent research has been included here, it was not possible to include all new data in time. The projects AQUILA II in Latin America and ALCOM (Aquaculture for Local Communities) in the Southern African Development Community countries are continuing, and will provide information complementary to that synthesized here.

In addition to the above sources, an extensive survey of the scientific literature was conducted. The majority of citations are to recent studies (1978-1995), partly reflecting the coverage of computerised bibliographies, and also an attempt to provide an up to date synthesis of information on tropical inland water bodies. A total of 448 of the much larger number of papers and reports scanned contained data included here, and are cited as sources in the database (Appendix 1). Most of the literature was obtained from the library of the Freshwater Biological Association/Institute of Freshwater Ecology, Windermere. Papers were also obtained from a number of individual authors, cited in the acknowledgements.

2.2 Structure of the Database

The main aim in constructing the database was to facilitate the storage and retrieval of data to be used in the analysis of relationships between fish yields and a number of morphological, edaphic, biological and demographic parameters for tropical and sub-tropical water bodies. It is also intended that the database serve as an tool for the storage and analysis of information pertaining to tropical lake and reservoir management in the broadest sense, so that a great deal of information on systems for which fish catch data are not available, or no fishery exists, have also been included.

With these potential uses in mind, the database is supplied with an application programme that allows the user to retrieve existing records, enter new data and references, edit existing records, and select subsets of data for analysis.

The database contains the full citation details of each reference examined, together with the details of the data cited in each reference. Where data covering a series of years are listed in a reference, a separate entry of data for each year was made, enabling examination of data series for a number of variables. Each datum is attributable to a published source through cross-reference to a citation table. In this way it is possible to view any aspect of the data on any water body and make comparisons between figures derived from different sources. In the event of conflicting statistics discovered during analyses, it is possible to return to the precise source of the data to resolve questions about the provenance of the figures.

The fields included in the database were selected with regard to their potential effects on determining fish yields, and more, generally, system productivity. Their availability varies considerably: for example, only five records of catchment-based studies of per capita fish consumption were located, there are hundreds of records of primary production (not all from systems with fish catch data) and there are thousands of records of basic water body morphometry (surface area and depth).

There are seven editable tables in the database. The citation table (Table 1) contains full details of the source of the data. The primary data tables (Tables 2-6) contain the statistics derived from each reference, together with a notes field in which is held any information necessary for the interpretation of the statistics. Table 7 is a summary table, with a single row of data for each water body - or two rows in the case of a few systems that have undergone well-documented changes, and for which a 'before and after' comparison is useful - e.g. Lake Victoria.

The summary table included has been constructed including only those water bodies for which fish catch statistics were located. The data in the summary table were used for the analysis of predictive fish yield models reported here. Users who wish to use the database for establishing predictive models using variables other than fish catches as the dependant variable should note that the summary table may not contain all values of the variables they are interested in. In these cases, users are advised to create their own summary tables from the primary database.

The editable tables and their fields are listed below, together with some explanatory notes.

Table 1: Reference Citation

Field Name	Description	Units
AUTHORS:	Name (s) of Author (s)	
TITLE:	Title of paper / book	
EDITORS:	Editors of book (if appl.)	
ED2:	Other editor info.	
JOURNAL:	Source Journal	
CONF_DAT:	Conference date (if appl.)	
CONF_WHE:	Conference place (if appl.)	
CITY:	Conference city (if appl.)	
WHO:	Who held conference	
YEAR:	Publication Year	
VOLUME:	Volume number	
ISSUE:	Issue number	
PAGES:	Pages	
SERIES_E:	Series Editor	
SERIES_T:	Series Title	
SERIES_N:	Series Number	
NOTES:	Notes / Abstract	
KEYWORDS:	Keywords	
REF_NAME:	Reference Name	
REF_NR:	Reference Number	

Table 2: Location & Morphology

Field Name	Abbreviation	Units
REF_NO	Citation reference number	N/A
COUNTRY	Country where water body/part of water body located	N/A
INT_W	Water body shared by countries or not	True/False
WB_NAME	Name of water body	N/A
WB_NR	Water body serial number	N/A
WB_TYPE	Lake, Reservoir, Swamp, C_Lagoon, FP_Lake, Pond	N/A
ALTITUDE	m above sea level (negative indicates below SL)	N/A
LATITUDE	midpoint in degrees and minutes	□, '
LONGITUDE	midpoint in degrees and minutes	□, '
YEAR_MD	year morphology data collected	N/A
AREA	mean surface area	km^2
AREA_PART	for international waters, the area in the specified country	km^2
AREA_MIN	seasonal minima in fluctuating systems	km^2
AREA_MAX	seasonal maximum area in fluctuating systems	km^2
MAX_L	maximum length	km
MAX_W	maximum width	km
SHORE	shoreline length	km
Z_MAX	maximum depth	m
Z_MEAN	mean depth	m
Z_FLUCT	annual fluctuation in level/drawdown in reservoirs	m
VOLUME	volume	m^3
CMENT_ AREA	catchment area, excluding area of water body	km^2
RIVER_IN	name of main inflowing river	N/A
RIVER_OUT	if closed basin write NONE	N/A
CONST_DATE	Year dam closed for reservoirs	N/A
PERM_OPEN	permanent opening to the sea, for C_Lagoons	True/False
NOTES_2	Notes on general/morphological features.	N/A

For water bodies shared by more than one country, separate entries were made for the basic morphometric information for the same water body in each country. Subsequent or conflicting data were usually added with 'INTERNATIONAL' in the COUNTRY field. Data in the succeeding data tables are usually reported in the country where the study was carried out. If the values pertain to the whole water body, 'INTERNATIONAL' is entered in the COUNTRY field.

Each water body is given a serial number. Shared water bodies have the same serial number in each country, e.g. Lake Malawi/Niassa is given the serial number 729 regardless of whether the COUNTRY field entry is Malawi, Mozambique, Tanzania or INTERNATIONAL. Many waterbodies are known by differing names, sometimes due to changes (e.g. Lake McIlwaine in Zimbabwe is now Chivero Reservoir) and at other times due to different spelling or interpretation of local names during Romanisation (e.g. Bum Borapet or Bung Boraped in Thailand, Lake Ziway, Zwai or Zwei in Ethiopia). The original spelling used by the author from whom the data was obtained was reported in the database to facilitate future searching, but the same water body serial number, is of course applied to the various spellings. It is possible that some such differences have gone undetected, and a few waterbodies may have different serial numbers incorrectly applied.

Table 3: Hydrology & Climate

Field Name	Abbreviation	Units
REF_NR	Citation reference number	N/A
WB_NR	Serial number of water body	N/A
COUNTRY	Location of water body & study	N/A
YEAR_TEMP	Year temparature/mixing regime data collected	N/A
S_TEMP	Annual mean surface water temperature	°C
T_MIN	Annual minimum, surface water temperature	°C
T_MAX	Annual maximum surface water temperature	°C
STRAT	Type of stratification: Mero, Mono, Poly, Diurnal, Mixed	N/A
DAYS_MIX	Estimate of time mixed	d
MIX_START	For monomictic lakes, month of destratification	N/A
MIX_END	For monomictic lakes, month of stratification	N/A
Zmix	Mixing depth during stratified period	m
RAIN_YEAR	Year, or range of years for rainfall data	N/A
RAINFALL	Annual mean rainfall in catchment	mm y^{-1}
RAIN_START	Month wet season starts	N/A
RAIN_END	Month wet season ends	N/A
RAIN_DUR	Duration of wet season or seasons	mo
RESID_T	Mean water residence time	mo
NOTES_3	Notes on hydrology and climate in catchment	N/A

Wet season start and finish are only reported for areas with a single rainy season. The occurrence of more than one wet season is noted in NOTES_3. Dimictic lakes are included in the mixing-type category 'Poly', and a note made in NOTES_3.

Table 4: Chemical & Biological Features

Field Name	Abbreviation	Units
REF_NR	Citation reference number	N/A
WB_NR	Serial number of water body	N/A
COUNTRY	Location of water body & study	N/A
YEAR_CD	Year chemical/biological data collected	N/A
TDS	Total dissolved solids	mg l^{-1}
COND	Conductivity	µScm^{-}
SALIN_L	Lowest recorded salinity (coastal lagoons)	^{1}(25°C)
SALIN_H	Highest recorded salinity (coastal lagoons)	0/00
pH	pH	0/00
ALKALINITY	Total alkalinity	N/A
TOT_P	Total phosphorus in surface waters	meq l^{-1}
TOT_N	Total nitrogen in surface waters	µg l^{-1}
SECCHI	Secchi disk transparency	µg l^{-1}
SUSP_SOLID	Suspended solids	m
SURF_CHLa	Chlorophyll a concentration in surface waters	mg l^{-1}
NM_CHLa	Number of months Chl a measured	µg l^{-1}
AREAL_CHLa	Areal chlorophyll a	N/A
DOM_PHYTO	Dominant algal class, e.g. Chrysophyta, Chlorophyta	mg m $^{-2}$
MACRO_BIOM	Macrophyte biomass	N/A
PERI_BIOM	Periphyton and benthic microalgal biomass	g dwt m $^{-2}$
GR_PHOT	Gross Photosynthesis	g dwt m $^{-2}$
NET_PPROD	Net phytoplankton production	g O_2 m^{-2} y^{-1}
MACRO_PROD	Macrophyte production	g C m^{-2} y^{-1}
PERI_PROD	Periphyton and benthic microalgal production	g C m^{-2} y^{-1}
ZOO_BIOM	Zooplankton biomass	g C m^{-2} y^{-1}
ZOO_PROD	Zooplankton production	g dwt m $^{-2}$
MBENTH_BIOM	Macrozoobenthos biomass	g dwt m^{-2} y^{-1}
MBENTH_PRO	Macrozoobenthos production	g dwt m $^{-2}$
D	Notes on biological and chemical features	g dwt m^{-2} y^{-1}
NOTES_4		N/A

Conductivity values were standardised to 25°C when temperature was given, using the conversion formula given in Mackereth *et al.,* (1978). Many authors, however, do not report the temperature at which conductivity measurements were taken - a fact that reduces the value of the measurement made, which changes by about 2.3% per °C (Mackereth *et al.,* 1978).

Alkalinity is often reported in units of mg l^{-1} of calcium carbonate, with the assumption that carbonate alkalinity is responsible for the total. All values reported in these units were assumed to have been measured under this assumption, and have been converted to milliequivalents per litre (meq l^{-1}).

Total phosphorus and total nitrogen were chosen in preference to nutrient concentrations as nutrient concentrations in tropical systems are not good indicators of system productivity. Uptake of limiting nutrients by phytoplankton is extremely rapid and efficient, so that high productivity can exist despite low concentrations of biologically available inorganic phosphates, nitrates and nitrites (Talling, 1992). Nutrient flux rates are seldom known, so total N and total P are preferred. Total P is a good measure of available phosphorus in a system, but total N is not, as a high proportion of total N is in the form of organic compounds unavailable to phytoplankton and other primary producers. Inorganic nitrogen concentrations are normally very low in surface waters of tropical water bodies. It may be possible to distinguish systems with high organic N due to high phytoplankton biomass and high organic N due to import of allochthanous material by examining catchment land cover (Table 6) with forested catchment likely to have high allochthanous input of organic nitrogen. Despite these drawbacks, Brylinsky & Mann (1973) consider total nitrogen to be a more useful predictor of system productivity in the tropics that total phosphorus, as in many cases phosphorus in not limiting.

A small number of chlorophyll *a* values reported here were obtained by converting cell volume or biomass values of algae, assuming 0.75% by weight chlorophyll *a* content (Reynolds, 1984). The chlorophyll content of phytoplankton is highly variable among taxa, water bodies and with physiological state of the algal populations, and this conversion should therefore be treated as highly approximate (Reynolds, 1984). Where such conversions have been made, this is recorded in the NOTES_4 field.

Measurements of phytoplankton primary production are usually undertaken by one of two methods: the light and dark bottle method, which measures oxygen production, or the ^{14}C method, which measures the uptake of inorganic carbon. The former is thought to give a measure of gross photosynthetic rate, while the latter is usually assumed to measure net production (Lewis, 1974). Practical difficulties with both methods mean that both probably measure something between the two. The relationship between gross and net production has empirically been determined as: net photosynthesis = 0.75-0.80 * gross photosynthesis (Melack, 1976), although the relationship is highly variable; in Lake George, net production was less than half gross photosynthesis (Ganf, 1974). Values given in the primary database are as reported by the authors of each study. If no explicit mention of gross or net production was made, Oxygen-method measurements were assumed to measure gross photosynthesis and ^{14}C methods net production. No conversions of net: gross have been made, and the two variables are used separately in predictive analyses of potential fish yields.

Photosynthetic rates were often reported in hours. In the tropics, daily rates can be calculated empirically from hourly rates by multiplying by a factor of nine (Erikson *et al.,* 1991); which accounts for mean day length and the diurnal variations in light intensity and, therefore, in photosynthetic rates.

The units used throughout this table are chosen because they are the most commonly reported, thereby minimising the use of conversion factors to standardize them. Conversions between wet and dry weights and carbon: dry weight relationships were sometimes necessary. For macrophytes a wet:dry weight conversion of 10% was assumed. For zooplankton and zoobenthos 15% was used (Dumont *et al.,* 1973). Carbon was assumed to be 44% of dry weight for animals (Burgis 1974) and 50% for plants (Reynolds, 1984). For algae wet weight:volume equivalence was assumed (Munawar *et al.,* 1974). It was not always possible to ascertain what conversion factors had been used to collect the original information, so that figures may differ from those reported elsewhere.

Table 5: Fish & Fisheries

Field Name	Abbreviation	Units
REF_NR	Citation reference number	N/A
WB_NR	Serial number of water body	N/A
COUNTRY	Location of water body & study	N/A
YEAR_FD	Year to which fishery data applies	N/A
CATCH	Total annual catch from the water body	t ww y^{-1}
NR_FISHERS	Number of active fishers	N/A
NR_BOATS	Number of boats	N/A
BOAT_TYPE	e.g. Canoe, Plank, Liftnet Platform, Trawler	N/A
FISH_BIOM	Total fish biomass	kg ww ha^{-1}
FISH_PROD	Biological production (not yield) of fish	kg ww $ha^{-1}y^{-1}$
STOCKING	Is the waterbody regularly stocked?	True/False
AQUACULT	Does some of the yield come from aquaculture	True/False
FY_TYPE	Type of fishery: Commercial, Artisanal, Subsistence, Sport	N/A
NR_ SPP	Number of fish species recorded from water body	N/A
CATCH_SPP	Number of species significantly represented in fish catches	N/A
INTRO_SPP	Number of species introduced into water body	N/A
YEAR_INTRO	Year fish species introduced into water body	N/A
ORIGIN_F	Origin of fish species upon which the fishery largely depends: Lacustrine, Riverine, Euryhaline, Marine, Introduced	N/A
FISH_ TYPE	Category of fish upon which fishery largely depends: e.g. Tilapia, Carp, Catfish, Salmonid, Small Pelagic	N/A
F_DET	% of catch (by weight) which feeds on detritus	%
F_PLANT	% of catch (by weight) which is phytophagous	%
F_ZOOPL	% of catch (by weight) which is zooplanktivorous	%
F_PISC/MINV	% of catch (by weight) which is piscivorous or feeds onmacroinvertebrates.	%
NOTES_5	Notes on fish species and fisheries	N/A

For the purposes of this database, stocking was defined as regular release of fingerlings into a waterbody, such that the fishery could not be described as depending on a self-sustaining fish population or community. The release of a batch of fish in one year, which then became established as a self-reproducing population, was not classed as stocking, but as the introduction of a species.

Additional criteria for deciding whether or not the addition of fingerlings could be classed as stocking, rather than aquaculture, were that the fish should be unconstrained in the system and should feed on the natural food resources available in the water body. Conversely, aquaculture activities were deemed to be present if some of the fish harvest came from fish constrained in cages or impoundments within the water body, or if the fish received supplementary feeding. These definitions follow the criteria of Lorenzen (1995) in defining culture-based fishery systems.

The origins of the fish community on which the fishery was based were defined by the habitat in which they originated in the case of endemic or indigenous species (lacustrine, riverine, euryhaline or marine) and simply as 'Introduced' if they were not indigenous to the water body or its catchment area.

Fish types were defined into broad functional/taxonomic groups: e.g. 'Tilapia', which includes all tilapiine cichlids (*Tilapia, Oreochromis, Saratherodon, Danikila*), Cichlids - the haplochromines and similar forms, Catfish - e.g. clariids and bagriids, S_Pelagic: small pelagic clupeids, cyprinids and atherinids. Some coastal lagoon fisheries are dominated by shellfish species, and these are variously categorized as penaeids, mussels, oysters etc. Many fisheries are not dominated by one or other group, and these were simply classed as 'Mixed'.

Table 6: Demography & Land Use

Field Name	Abbreviation	Units
REF_NR	Citation reference number	N/A
WB_NO	Serial number of water body	N/A
COUNTRY	Location of water body & study	N/A
YEAR_DD	Year demographic data collected	N/A
CMT_POPN	Catchment population	N/A
FISHING	Number of people involved in fishing	N/A
PRIMARY	People involved in primary industry, including fishing	N/A
URBAN	Urban population within the catchment	N/A
PC_FISH	Per capita fish consumption	kg ww y^{-1}
RFOREST	Rainforest in catchment or drainage basin area	%
FOREST	Other natural forest types in catchment	% SCRUB
	Scrubland in catchment	%
GRASS	Grassland/Savannah in catchment	%
SWAMP	Permanently or seasonally inundated swamps	%
DESERT	Unvegetated/sparsely vegetated arid zone	%
MOUNT	Montane vegetation/unvegetated uplands	% ARABLE
	Arable farmland	%
PASTURE	Grazing/Pastureland	%
PLANT	Plantation land (tree crops: banana, rubber, coconut etc.	%
URBAN	Residential and industrial land	%
W_USE	Water used for irrigation, domestic supply etc	m^{-3} y^{-1}
W_USE_TYPE	Main water uses (other than fisheries or aquaculture):	
	Domestic, Power, Irrigation, Industrial, Recreation	N/A
POLLUTION	Presence or absence of pollution	True/False
POLL_TYPE	Sewage, Chemical, Eutrophication, Salinization	N/A
NOTES_6	Notes on catchment land use, pollution and demography	N/A

Table 7: Summary Information for Waterbodies for which Fishery Catch Statistics are Available.

Field Name	Abbreviation	Units
CONTINENT	Continent where water body located	N/A
COUNTRY	Country where water body located	N/A
WB_NAME	Name of water body	N/A
WB_NR	Water body serial number	N/A
WB_TYPE	Lake, Reservoir, Swamp, C_Lagoon, FP_Lake, Pond	N/A
LATITUDE	m above sea level (negative indicates below SL)	N/A
LATITUDE	midpoint in degrees and minutes	□, '
AREA	mean surface area	km^2
SHORE	shoreline length	km
Z_MAX	maximum depth	m
Z_MEAN	mean depth	m
Z_FLUCT	annual fluctuation in level/drawdown in reservoirs	m
VOLUME	volume	m^3
CMENT_ AREA	catchment area, excluding area of water body	km^2
CONST_DATE	Year dam closed for reservoirs	N/A
PERM_OPEN	permanent opening to the sea, for C_Lagoons	True/False
S_TEMP	Annual mean surface water temperature	□C
T_MIN	Annual minimum, surface water temperature	□C
T_MAX	Annual maximum surface water temperature	□C
STRAT	Type of stratification: Mero, Mono, Poly, Diurnal, Mixed	N/A
DAYS_MIX	Estimate of time mixed	d
Z_mix	Mixing depth during stratified period	m
RAINFALL	Annual mean rainfall in catchment	$mm\ y^{-1}$
RAIN_DUR	Duration of wet season or seasons	mo
RESID_T	Mean water residence time	mo
TDS	Total dissolved solids	$mg\ l^{-1}$
COND	Conductivity	μScm^{-}
pH	pH	^{1}(25□C)
ALKALINITY	Total alkalinity	N/A
TOT_P	Total phosphorus in surface waters	$meq\ l^{-1}$
TOT_N	Total nitrogen in surface waters	$\mu g\ l^{-1}$
SECCHI	Secchi disk transparency	$\mu g\ l^{-1}$
SUSP_SOLID	Suspended solids	m
SURF_CHLa	Chlorophyll a concentration in surface waters	$mg\ l^{-1}$
AREAL_CHLa	Areal chlorophyll a	$\mu g\ l^{-1}$
DOM_PHYTO	Dominant algal class, e.g. Chrysophyta, Chlorophyta	$mg\ m^{-2}$
MACRO_BIOM	Macrophyte biomass	N/A
PERI_BIOM	Periphyton and benthic microalgal biomass	$g\ dwt\ m^{-2}$
GR_PHOT	Gross Photosynthesis	$g\ dwt\ m^{-2}$
NET_PPROD	Net phytoplankton production	$g\ O_2\ m^{-2}\ y^{-1}$
MACRO_PROD	Macrophyte production	$g\ C\ m^{-2}\ y^{-1}$
PERI_PROD	Periphyton and benthic microalgal production	$g\ C\ m^{-2}\ y^{-1}$
ZOO_BIOM	Zooplankton biomass	$g\ C\ m^{-2}\ y^{-1}$
ZOO_PROD	Zooplankton production	$g\ dwt\ m^{-2}$
MBENTH_BIOM	Macrozoobenthos biomass	$g\ dwt\ m^{-2}\ y^{-1}$
MBENTH_PRO	Macrozoobenthos production	$g\ dwt\ m^{-2}$
D	Total annual catch from the water body	$g\ dwt\ m^{-2}\ y^{-1}$
CATCH	Number of active fishers	$t\ ww\ y^{-1}$
NR_FISHERS	Number of boats	N/A
NR_BOATS	e.g. Canoe, Plank, Liftnet Platform, Trawler	N/A
BOAT_TYPE	Total fish biomass	N/A
FISH_BIOM	Biological production (not yield) of fish	$kg\ ww\ ha^{-1}$
FISH_PROD		$kgwwha^{-1}y^{-1}$

STOCKING	Is the waterbody regularly stocked?	True/False
AQUACULT	Does some of the yield come from aquaculture	True/False
FY_TYPE	Type of fishery: Commercial, Artisanal, Subsistence, Sport	N/A
NR_ SPP	Number of fish species recorded from water body	N/A
CATCH_SPP	Number of species significantly represented in fish catches	N/A
INTRO_SPP	Number of species introduced into water body	N/A
ORIGIN_F	Origin of fish species upon which the fishery largely depends: Lacustrine, Riverine, Euryhaline, Marine, Introduced	N/A
FISH_ TYPE	Category of fish upon which fishery largely depends: e.g. Tilapia, Carp, Catfish, Salmonid, Small Pelagic	N/A
TL_FY	Trophic level at which the fishery operates	N/A
CMT_POPN	Catchment population	N/A
FISHING	Number of people involved in fishing	N/A
PRIMARY	People involved in primary industry, including fishing	N/A
URBAN	Urban population within the catchment	N/A
PC_FISH	Per capita fish consumption	kg ww y^{-1}
FOREST	All types of forested land in catchment	%
SAVAN	Scrubland, grassland and pasture in catchment	%
MOUNT/DES	High mountain and desert areas (unvegetated)	%
ARABLE	Arable farmland	%
URBAN	Residential and industrial land	%
W_USE	Water used for irrigation, domestic supply etc	m^{-3} y^{-1}
W_USE_TYPE	Main water uses (other than fisheries or aquaculture): Domestic, Power, Irrigation, Industrial, Recreation	N/A
POLLUTION	Presence or absence of pollution	True/False
POLL_TYPE	Sewage, Chemical, Eutrophication, Salinization	N/A

The secondary database contains only those fields used, or potentially useful, for the analysis of factors affecting the fishery productivity of a water body. These include both numerical variables (e.g. Area, conductivity, number of fishers) and category variables useful for classification of sub-sets of data (e.g Continent, Water body type, Fishery type) or for analysis of their effects on productivity (e.g. Dominant algal type, type of fish on which the fishery depends).

All variables are the same as those reported in Tables 2-6, with the exception of TL_FY, the trophic level at which the fishery operates, which is calculated from the diet and catch-composition data reported in Table 5, fields F_DET, F_PLANT, F_ZOOPL, F_MINV/PISC.

Fish consuming primary production and detritus are at trophic level = 2, so a fishery exclusively on these species has a trophic level of 3. A weighted average trophic level is calculated for the fishery, using an approach similar to that taken by Christensen & Pauly (1991) in their ECOPATH software. The range of values is truncated slightly, in that fish feeding on macroinvertebrates and fish are all assigned trophic level 4, where as they are likely to range from 4-5. Very detailed diet composition and catch-composition data would be required to refine these figures. Catchment land use data have been reduced from ten to six main categories to simplify categorization of water bodies.

A single value of each variable has been calculated for each water body. In most cases, average reported fish catches were calculated from series of catch data, and all other data collected during this period were also averaged. Fishery data series were examined to determine the developmental status of the fishery in each water body, and early data for the 'development phase' were excluded in calculating what should represent the sustainable yield for each water body. For waterbodies where catches had been reduced drastically due to lack of (or inappropriate) management catches were averaged over the peak period and for several years before and after the occurrence of peaks in catches, to give an approximation of likely sustainable yield. In some cases, application of surplus-production models to calculate a theoretical MSY may give a figure less dependent on subjective judgement.

In many cases, fish yields fluctuated independently of effort (e.g. Lago do Rei, Brazil) or catch and effort were both influenced by climatic variations that affected the size of waterbodies (e.g. Lake Chilwa, Lake Chad). For these fluctuating systems, the data pertaining to the phase most commonly encountered, or for which most data were available, was selected. Occasionally, when well-documented changes in important aquatic systems were available, more than one record for a particular water body has been retained (e.g. Laguna de Bay, Philippines; Lake Victoria, Africa).

Many inland water bodies have altered as a result of pollution, the introduction of new species, changes in fishing techniques or management systems. In a comparative synthesis of this type, it is not possible to incorporate all such changes, and for the majority of such systems, only the most recent data is used. For example: artificial permanent channels to the sea were constructed for a number of Mexican coastal lagoons in the late 1970's (Cervantes-Castro, 1984) and fish yields from these lagoons have increased greatly as a result of this engineering work - only data for yields after these alterations are included here. In Lake Malombe, Malawi, a fishery based on large tilapiine cichlids has given way under increasing exploitation pressure to one based on small haplochromine cichlids, with a concommitant increase in yield, if not in economic value (GOM/FAO/UNDP, 1993).

Finally, the question of data quality must be addressed: there are many cases where contradictory values are reported by different authors (and sometimes the same authors in different publications). Usually, the most recent source is considered to be the most applicable, but occasionally, older primary sources are preferred to newer secondary sources when there is a conflict. The choice is sometimes informed, sometimes subjective. Users with direct knowledge or experience of particular areas or waterbodies will be able to judge whether the values selected are the most representative. Particularly notable are order of magnitude differences in reported catches for such major lakes as Laguna de Bay (Philippines) given by different sources. Other more subtle differences include differing catch statistics in some (but not all) years in a catch series for Lake Naivasha reported by Vanden Bossche & Bernacsek (1990a) and Muchiri and Hickley (1991); both quote the Kenya Inland Fisheries Dept. as the source of their data.

The above examples serve to illustrate the decisions made in producing the summary table, and are intended to encourage users to check values they do not agree with via the original entries in the primary database.

2.3 Analytical Methods

Simple and multiple linear regression models of the form $\log_e y = \log_e a + b \log_e x$ have been used to establish easily applicable relationships between fish yields and the range of parameters outlined in Section 2.2. Double-logarithmic plots were preferred to the original untransformed variables as many of the parameters spanned orders of magnitude. Ordinary least squares regression was used throughout.

The first stage in the analysis was to compile univariate predictive relationships between all available variables for the following categories of waterbody:

a) African lakes, floodplain lakes and reservoirs

b) Asian lakes, floodplain lakes and reservoirs with fish yields based on capture fisheries

c) Asian lakes, floodplain lakes and reservoirs with fish yields based wholly or partially on artificial stocking and/or aquaculture production.

d) Latin American lakes, floodplain lakes and reservoirs

Subsidiary analyses based on less extensive datasets for swamps, floodplain lakes (separately) and coastal lagoons were also performed.

A number of new variables were created from those in the secondary database. Mainly, categorical variables were grouped into fewer, broader, more easily comparable groups: e.g. percentage catchment land use was grouped into three categories Forest, Savannah and Farmland on the basis of whichever category covered >50% of the catchment.

The following morphometric variables were created (defined in Cole, 1983):

1) Shoreline development = $D_L = SL/2(\pi A)^{0.5}$
2) Catchment development = C/A

Where SL = Shoreline length (km), A = Surface area (km^2) and C = Catchment area (km^2)

High shoreline development indicates lots of inlets and indentations. The minimum value is 1, which corresponds to a perfectly circular lake. Catchment development could be <1 as some catchments are smaller than the lake area. Catchment areas are sometimes measured including the lake surface, sometimes excluding it, so errors in this ratio may be common.

For numerical variables, each relationship was first plotted both untransformed and log-transformed, and a visual inspection made to determine the general shape of any relationship. Outlying points and those having large leverage (ie - relationships where one or two points have a strong influence on the statistical relationship between the variables) were noted, but were only omitted from the regression if theoretical grounds could be found for their removal. Plots of residuals were examined for outliers and trends in the residuals indicating poor or inappropriate model fit.

Multiple linear regression relationships were also fitted. Variables for inclusion were chosen on the basis of the preliminary screening of all univariate models. It was not possible to test all combinations of variables, or to include more than a maximum of 3-4 variables in a predictive relationship, as reduction in sample sizes generally led to increase in variance, or the possibility of over-parameterization. Criteria for retaining variables in a multiple regression relationship were based on ensuring tolerance > 0.15, to minimise autocorrelation of independent variables, and on significance of partial regression coefficients $p < 0.20$.

Where possible, ratio data were avoided, as the error structure of such models is difficult to define, but a number of simple linear regression models were established using catch per unit area, rather than total catch, as the dependent variable.

Analysis of variance of log-transformed fish yields with some categorical variables (e.g. Dominant algal type, origin of fish community) was also done.

3 RESULTS

3.1 Data Coverage

3.1.1 Lakes

Most of the large lakes in all three continents were included in in the total of 164 natural lakes for which fishery catch statistics were available. The largest dataset was for Africa (92 lakes), the smallest for Latin America (12).

There are no, or few, recent available catch statistics for major Latin American lakes such as Valencia, Nicaragua and Managua. The fishery in the Bolivian waters of Lake Titicaca is also poorly documented.

For many of the Asian lakes, data series were not available, and for many systems, no recent catch statistics were available: the catch figure used for Great Lake, Kampuchea, dates back to the 1940's. Contradictory data were obtained for Laguna de Bay, Philippines, which supports one of Asia's largest inland fisheries; recorded catch statistics varied by 1-3 orders of magnitude in different publications. A very high single catch estimate was obtained for Bung Boraped (Thailand); this reservoir and Laguna de Bay were consistent outliers in morphometry-catch relationships, and the catch figures require checking.

The dataset for Africa includes many well-studied large systems (e.g. Victoria, Tanganyika, Malawi, Turkana, George) with long catch data series, but there are around 20 smaller lakes with published catch estimates but no published estimate of lake surface area.

3.1.2 Floodplain Lakes

It was not always possible to determine from published sources whether a lake was located on a river floodplain or not, and the floodplain lakes dataset therefore only contains a sub-set of the available data on this type of water body, which includes the varzea lakes of the Amazon, the villus lakes of Sri Lanka and the beels of Assam, India. Fishery data for only 17 of these lakes is available: most fishery statistics are applicable to whole floodplains, rather than individual water bodies on the floodplain. The best case-study of a floodplain lake is for Lago do Rei, on the Amazon floodplain (Merona & Gascuel, 1993; Merona & Bittencourt, 1993).

Little chemical and biological data are available for floodplain lakes, and the values are highly seasonal. Seasonal flooding mixes most floodplain lakes, although Garapota beel in India is meromictic. Little socio-economic data beyond the number of fishers and boats are available. Muktapur beel is used for fish culture, but otherwise, the floodplain lakes for which information is available support artisanal and subsistence capture fisheries only; dugout canoes are the most usual fishing craft. These fisheries are based on stocks of fish of riverine origin; major fish types include carps, tilapia and catfish.

3.1.3 Reservoirs

Reservoir fisheries are receiving increasing attention, and compilations of data are now available for many small reservoirs as well as the large, well-known African dams (Kariba, Kainji, Nasser/Nubia, Volta). Large datasets for Sri Lankan, Indian and Thai reservoirs are available, and although data coverage is not broad, catch statistics are now available for series of reservoirs in Brazil and Cuba.

A total of 226 reservoirs are included in the catch data analysis; the largest series are for Asia, where reservoir fish production in culture-based fisheries is an important use of these waterbodies. In Latin

America, fish production from reservoirs has not been as high a priority, but initiatives to encourage fish culture may increase their importance to local economies.

3.1.4 Swamps

Although swamps are associated with many lakes and rivers, fisheries data for swamp ecosystems are scarce. Of the four large African swamps and two small Indian swamps in the secondary database, chemical and biological data are available only for the Sudd, Sudan. Tasek Bera swamp, Malaysia, has been well studied as part of the IBP programme (Furtado & Mori, 1982), but no fish catch statistics are available. The area is lightly populated, and a small amount of subsistence fishing takes place.

3.1.5 Coastal Lagoons

Catch data and surface area were available for 67 coastal lagoons: 31 in Africa, 4 in Asia and 32 in Latin America. Basic morphometric data, temperature and salinity were available for 22 of these. Other hydrological, chemical and biological data are scarce in the database: there were only 3-6 values for such potentially important explanatory variables as gross photosynthesis, chlorophyll *a* concentrations, total phosphorus, rainfall etc. Fringing macroflora (Mangroves, *Spartina* grasses) and *Zostera* sp. are a feature of many coastal lagoon and estuarine systems, yet only one estimate of macrophyte production is available (for Edku lagoon). Many lagoons suffer pollution stress and do not yield to their full potential (Nixon, 1982). Only for Mariut has chemical pollution been documented.

Fishery data was usually restricted to an estimate of total catch and number of fishers.

3.1.6 Data on Catchment Land Use and Demography

The dataset assembled for Table 6 is small, and probably does not reflect the availability of the information, but rather its availability in the fisheries and water-resource management literature.
Data on catchment land use, even at the level of whether a catchment was primarily forest or savannah or arable land, was not available for most lakes and reservoirs.

Demographic statistics are seldom reported on a catchment basis. It may be possible to use regional data on population density, together with an estimate of catchment area, to estimate catchment populations.

Only three catchment-based estimates of per capita fish consumption were obtained, for Kaptai Reservoir, Bangladesh (9.9 kg y^{-1}), Ubolratana, Indonesia (39.2 kg y^{-1}) and Bangweulu Lakes, Zambia (40 kg y^{-1}).

3.2 Global Comparison of Fish Landings, Yields and Fishing Intensity in Tropical Inland Aquatic Ecosystems

3.2.1 Total Landings from Inland Fisheries

The latest available global inland capture fisheries statistics are for 1992 (IWRAS/FAO, 1995).
Landings for Latin America were 474 702 t, landings for Africa were 1 748 116 t and landings for Asia were estimated at 3 721 075 t, with approximately 80% of the total for Asia originating from the tropical and sub-tropical countries covered in this database. The information available relating to fisheries reflects their relative importance in the three continents to some extent.

3.2.2 Yields and Fishing Intensity

The yields, on an areal basis, from inland aquatic ecosystems vary over an enormous range (Table 8). It is the purpose of this study to identify the factors responsible for this variability. Means are of little comparative value, as the distributions are invariably skewed, with a few very high values distorting the mean. The median is perhaps a more useful comparative statistic. Median fish yields from all inland waterbodies combined (swamps, lagoons, lakes, reservoirs) are slightly lower in Africa than Asia or Latin America (59 kg ha^{-1} y^{-1}, compared with 77-84 kg ha^{-1} y^{-1}), but when individual water body types are examined, the differences are not consistent: African lakes are more productive than Latin American ones, but both are much less productive than Asian lakes, even when no stocking or aquaculture activities are recorded in the latter. African and Asian reservoirs yield similar quantities of fish on an areal basis, but Latin American reservoirs are more productive. The dataset indicates that stocked/farmed reservoirs in Asia are no more productive than ones based mainly on capture fisheries, but the variability is large and the stocked reservoir dataset contains a number of high altitude low productivity systems in Northern India and Nepal.

Coastal lagoons are no more productive than most inland waters, but often yield species of high economic value.

Swamps can be productive, but appear, at least in Africa, to be underexploited (<0.1 fisher km^2; Table 9). The Sudd and Okavango occur in areas where fishing is not a traditional means of livelihood; the population adjacent to these areas are nomadic pasturalists.

Asian lakes are the most intensely exploited aquatic systems, in terms of fishers km^{-2} (Table9). Recorded density of fishers for three Indian floodplain lakes are extremely high: these reflect the number of subsistence and part-time fishers active on river floodplains; much of the fishing activity by these people probably takes place in the river and other floodplain water bodies, rather than just on the specified floodplain lakes. The value of 19.5 fishers km^{-2} for Asian lakes (excluding floodplain lakes) is perhaps more representative: this is still ten times higher than the density of fishers operating on African lakes.

Henderson & Welcomme (1974) selected systems with >1 fisher km^{-2} as being fully exploited in establishing a MEI model for African Lakes and reservoirs. There is a danger of excluding systems which are simply not productive enough to support this level of exploitation, but it is recognized that models independent of effort data are required for predicting fishery potential of new or unexploited waterbodies.

With the exception of a small set of data for African swamps and the three Indian floodplain lakes mentioned above, median catch rates (catch $fisher^{-1}$ y^{-1}) are very similar across a range of systems (Table 10), with a global average of 2 t $fisher^{-1}$ y^{-1} for the artisanal fisheries of developing countries.

3.3 Empirical Predictors of Fish Yields

3.3.1 Lakes, Floodplain Lakes and Reservoirs

Screening of relationships between total fish catches, or yields per unit area, and potential explanatory variables are summarised in Table 11.

Relationships between total catch and total area were, as expected, significant in all cases. Area explained >90% of the variability in the catch data for Africa, where the range of water-body sizes was greatest (Figure 1a). Relationships between area and catch were weaker for other datasets, particularly for the culture-based fisheries of Asia. No significant differences in catch-area relationships were observed, probably due to the high variances in some of the datasets. There were several outliers, and the data were not pooled for subsequent multiple regression analyses.

Volume, theoretically a determinant of total material flux through a system, was also significantly correlated with fish catches, except for Latin American lakes & reservoirs. The proportion of variance explained was generally lower than for Area, probably due in part to the difficulties in measuring volume accurately.

Catchment area and shoreline explained a significant proportion of the variance in most of the catch datasets, but this proportion was once again lower than that explained by surface area in most cases.

Table 8 - Summary of Yields (kg ha^{-1} y^{-1}) by continent and water body type.

Water body type	Continent	Range	Mean	s.e.	Median	n
Coastal Lagoons	Africa	5 - 894	231.5	47.1	116	31
Coastal Lagoons	Asia	29 - 67	42.6	0.8	37.4	4
Coastal Lagoons	Latin America	1 - 350	74.8	16	32.5	32
Coastal Lagoons	All	1 - 894	145	24.9	66.7	67
FP Lakes	Asia	67 - 1000	297.2	75.3	203.2	12
FP Lakes	All	43 - 1000	246.7	60.6	170.6	16
Lakes	Africa	1 - 2230	130.9	28.8	52.6	89
Lakes	Asia	1 - 5937	573.1	195.2	280.1	31
Lakes (Stocked)	Asia	56 - 11625	2635	800	646.9	22
Lakes	Latin America	2 - 290	55.2	2.4	18.5	12
Reservoirs	Africa	4 - 670	107.9	20.7	61.7	45
Reservoirs	Asia	2 - 488	108.4	15.9	59.4	57
Reservoirs (Stocked)	Asia	1 - 35583	1573	751.8	40.4	55
Reservoirs	Latin America	2 - 766	139.2	16.3	105.6	71
Swamps	Africa	1 -- 8	3.2	1.6	2.3	4
Swamps	Asia	40 - 628				2
Swamps	Africa + Asia	1 - 628	113.4	103	5.2	6
All inland waterbodies	All	1 - 35583	470.2	103.1	71.6	472
All inland waterbodies	Africa	1 - 2230	139.8	18.4	58.8	171
All inland waterbodies	Asia	1 - 35583	941.1	252.7	83.5	184
All inland waterbodies	Latin America	1 - 11777	213.3	101.2	77.3	116

Table 9 - Fishing Intensity (number of fishers/sq-km) by Continent and Water Body Type

Water body type	Continent	Range	Mean	s.e.	Median	n
Coastal Lagoons	Africa	1.49 - 107.1	23.5	6.2	12.5	20
Coastal Lagoons	Asia					
Coastal Lagoons	Latin America	0.39 - 4.48	2.9	0.8	3.7	6
Coastal Lagoons	All	0.39 - 107.1	18.4	4.9	9.5	27
FP Lakes	Asia	315.0 - 591.0	419	86.5	352	3
FP Lakes	All	1.5 - 590.9	252.3	112.7	315	5
Lakes	Africa	0.1 - 47.9	5.5	1.1	1.8	71
Lakes	Asia	5.7 - 83.3	32.2	6.5	19.5	17
Lakes (Stocked)	Asia	1.8 - 5.6				2
Lakes	Latin America	0.1 - 30.2	5.6	3.3	1	9
Reservoirs	Africa	0.3 - 19.4	4.1	0.9	2.4	26
Reservoirs	Asia	0.4 - 43.3	6.3	1.4	3.3	36
Reservoirs (Stocked)	Asia	0.8 - 22.3	8.3	2.6	5.7	8
Reservoirs	Latin America	0.7 - 27.8	9.7	4.2	4.9	6
Swamps	Africa	0.1 - 0.3	0.2	0.1	0.1	4
Swamps	Asia					
Swamps	Africa + Asia					
All inland waterbodies	All	0.1 - 590.9	15.2	3.7	3.7	211
All inland waterbodies	Africa	0.1 - 107.1	7.9	1.4	2.3	121
All inland waterbodies	Asia	0.4 - 590.9	31.6	11	5.9	67
All inland waterbodies	Latin America	0.1 - 30.2	6	1.8	4.1	22

Table 10 - Catch per fisher (tonnes/year) by continent and water body type

Water body type	Continent	Range	Mean	s.e.	Median	n
Coastal Lagoons	Africa	0.15-5.94	1.73	0.34	1.17	20
Coastal Lagoons	Asia					
Coastal Lagoons	Latin America	1.8-24.5	6.05	3.14	2.27	7
Coastal Lagoons	All	0.2-24.5	2.76	0.86	1.38	28
FP Lakes	Asia	0.1-0.2	0.14	0.02	0.13	3
FP Lakes	All	0.1-7.1	1.86	1.35	0.17	5
Lakes	Africa	0.2-22.7	3.27	0.42	2	76
Lakes	Asia	0.7-53.4	5.54	3.02	2.24	17
Lakes (Stocked)	Asia	5.8-164.0				2
Lakes	Latin America	0.2-7.7	2.2	0.75	1.29	9
Reservoirs	Africa	0.1-23.6	2.98	0.65	2.25	37
Reservoirs	Asia	0.2-10.8	2.86	0.4	2.2	36
Reservoirs (Stocked)	Asia	0.4-10.4	2.87	1.04	2	9
Reservoirs	Latin America	0.0-5.2	2.45	0.7	2.31	9
Swamps	Africa	1.0-4.0	2.26	0.53	2.41	5
Swamps	Asia					
Swamps	Africa + Asia					
All inland waterbodies	All	0.0-164.0	3.83	0.76	2	232
All inland waterbodies	Africa	0.1-23.6	2.97	0.3	1.76	138
All inland waterbodies	Asia	0.1-164.0	5.79	2.49	2.14	68
All inland waterbodies	Latin America	0.0-24.5	3.33	0.97	2.25	25

Table 11 Screening of regression relationships between lake and reservoir morphometry, hydrology, water chemistry, biological features and catchment demography. Statistically significant relationships ($p<0.05$) are highlighted in bold text.

L = Lake
R = Reservoir
S = Stocked (Culture based fishery)
NS = not stocked (capture fishery on naturally reproducing stocks)
a,b = intercept and slope of fitted regression relationship
n = number of water bodies in comparison
r = correlation coefficient
p = significance level for ANOVA test for goodness of fit of the regression mod

Eq.	Comparison	Continent	Dataset	*a*	*b*	*n*	*r*	*p*	
	MORPHOMETRY								
1	**ln(Catch) vs ln(Area)**	**Africa**	**L (NS)**	**2.761**	**0.786**	**88**	**0.903**	**<0.001**	[1]
2	**ln(Catch) vs ln(Area)**	**Africa**	**R (NS)**	**2.274**	**0.876**	**45**	**0.907**	**<0.001**	[1]
3	**ln(Catch) vs ln(Area)**	**Africa**	**L & R (NS)**	**2.590**	**0.816**	**133**	**0.903**	**<0.001**	
4	**ln(Catch) vs ln(Area)**	**Asia**	**L (S)**	**4.545**	**0.552**	**25**	**0.765**	**<0.001**	[2]
5	**ln(Catch) vs ln(Area)**	**Asia**	**R (S)**	**3.048**	**0.413**	**54**	**0.495**	**<0.001**	[3]
6	**ln(Catch) vs ln(Area)**	**Asia**	**L (NS)**	**2.895**	**0.856**	**39**	**0.765**	**<0.001**	[4]
7	**ln(Catch) vs ln(Area)**	**Asia**	**R (NS)**	**2.278**	**0.823**	**57**	**0.697**	**<0.001**	
8	**ln(Catch) vs ln(Area)**	**Asia**	**L & R (S)**	**3.664**	**0.365**	**79**	**0.466**	**<0.001**	
9	**ln(Catch) vs ln(Area)**	**Asia**	**L & R (NS)**	**2.552**	**0.828**	**96**	**0.712**	**<0.001**	
10	**ln(Catch) vs ln(Area)**	**L_America**	**L (NS)**	**2.646**	**0.665**	**12**	**0.597**	**0.040**	
11	**ln(Catch) vs ln(Area)**	**L_America**	**R (NS)**	**2.767**	**0.726**	**70**	**0.728**	**<0.001**	[5]
12	**ln(Catch) vs ln(Area)**	**L_America**	**L & R (NS)**	**2.845**	**0.678**	**82**	**0.744**	**<0.001**	
13	**ln(Catch) vs ln(Volume)**	**Africa**	**L & R (NS)**	**-6.698**	**0.633**	**92**	**0.804**	**0.001**	[6]
14	**ln(Catch) vs ln(Volume)**	**Asia**	**L & R (S)**	**0.849**	**0.213**	**64**	**0.394**	**0.001**	
15	**ln(Catch) vs ln(Volume)**	**Asia**	**L & R (NS)**	**-5.351**	**0.565**	**74**	**0.704**	**<0.001**	
16	ln(Catch) vs ln(Volume)	L_America	L & R (NS)	1.572	0.211	29	0.364	0.052	
17	**ln(Catch) vs ln(Catchment)**	**Africa**	**L & R (NS)**	**2.039**	**0.599**	**33**	**0.659**	**<0.001**	
18	**ln(Catch) vs ln(Catchment)**	**Asia**	**L & R (NS)**	**1.780**	**0.601**	**42**	**0.656**	**<0.001**	
19	**ln(Catch) vs ln(Catchment)**	**Asia**	**L & R (S)**	**2.065**	**0.351**	**31**	**0.389**	**0.031**	
20	ln(Catch) vs ln(Catchment)	L_America	L & R (NS)	1.684	0.452	15	0.483	0.068	
21	**ln(Catch) vs ln(Shore)**	**Africa**	**L & R (NS)**	**0.818**	**1.168**	**37**	**0.807**	**<0.001**	
22	**ln(Catch) vs ln(Shore)**	**Asia**	**L & R (NS)**	**0.560**	**1.406**	**14**	**0.737**	**0.003**	
23	ln(Catch) vs ln(Shore)	Asia	L & R (S)	5.781	0.172	16	0.059	0.829	
24	**ln(Catch) vs ln(Shore)**	**L_America**	**L & R (NS)**	**-0.279**	**1.218**	**12**	**0.628**	**0.029**	
25	ln(CPUA) vs ln(Shore_Dev)	Africa	L & R (NS)	6.301	0.837	35	0.241	0.162	
26	ln(CPUA) vs ln(Shore_Dev)	Asia	L & R (NS)	3.104	-0.856	12	0.267	0.402	
27	ln(CPUA) vs ln(Shore_Dev)	Asia	L & R (S)	3.279	-1.037	12	0.533	0.075	
28	ln(CPUA) vs ln(Shore_Dev)	L_America	L & R (NS)	5.634	-0.249	13	0.064	0.835	
29	ln(CPUA) vs ln(Altitude)	Africa	L & R (NS)	9.716	-0.439	81	0.134	0.233	
30	**ln(CPUA) vs ln(Altitude)**	**Asia**	**L & R (NS)**	**4.271**	**-0.570**	**25**	**0.514**	**0.009**	
31	ln(CPUA) vs ln(Altitude)	Asia	L & R (S)	0.999	0.050	38	0.046	0.785	
32	ln(CPUA) vs ln(Altitude)	L_America	L & R (NS)	7.278	-0.342	30	0.281	0.132	
33	ln(CPUA) vs ln(Latitude+1)	Africa	L & R (NS)	6.050	0.155	109	0.053	0.588	
34	ln(CPUA) vs ln(Latitude+1)	Asia	L & R (NS)	-0.005	0.701	19	0.317	0.185	
35	**ln(CPUA) vs ln(Latitude+1)**	**Asia**	**L & R (S)**	**-11.653**	**4.552**	**37**	**0.533**	**0.001**	[7]
36	ln(CPUA) vs ln(Latitude+1)	L_America	L & R (NS)	4.398	0.758	22	0.199	0.375	
37	**ln(CPUA) vs ln(Zmax)**	**Africa**	**L & R (NS)**	**4.645**	**0.757**	**89**	**0.404**	**<0.001**	
38	ln(CPUA) vs ln(Zmax)	Asia	L & R (NS)	2.524	-0.363	27	0.242	0.224	
39	ln(CPUA) vs ln(Zmax)	Asia	L & R (S)	3.072	-0.489	38	0.317	0.052	
40	ln(CPUA) vs ln(Zmax)	L_America	L & R (NS)	6.504	-0.365	19	0.220	0.366	
41	**ln(CPUA) vs ln(Zmean)**	**Africa**	**L & R (NS)**	**5.288**	**0.666**	**93**	**0.309**	**0.003**	
42	ln(CPUA) vs ln(Zmean)	Asia	L & R (NS)	3.028	-0.332	74	0.258	0.066	

Eq.	Comparison	Continent	Dataset	*a*	*b*	*n*	*r*	*p*
	MORPHOMETRY Cont.							
43	**ln(CPUA) vs ln(Zmean)**	**Asia**	**L & R (S)**	**2.230**	**-0.997**	**63**	**0.535**	**<0.001**
44	ln(CPUA) vs ln(Zmean)	L_America	L & R (NS)	7.018	-0.594	23	0.262	0.228
49	ln(CPUA) vs ln(Cment/area)	Africa	L & R (NS)	8.835	0.153	33	0.133	0.462
50	ln(CPUA) vs ln(Cment/area)	Asia	L & R (NS)	2.165	0.066	41	0.062	0.699
51	**ln(CPUA) vs ln(Cment/area)**	**Asia**	**L & R (S)**	**3.040**	**0.497**	**30**	**0.576**	**0.001**
52	ln(CPUA) vs ln(Cment/area)	L_America	L & R (NS)	7.018	0.465	15	0.353	0.197
53	ln(CPUA) vs ln(Zfluct)	Africa	L & R (NS)	7.831	-0.143	35	0.069	0.692
54	**ln(CPUA) vs ln(Zfluct)**	**Asia**	**L & R (NS)**	**0.420**	**0.581**	**21**	**0.478**	**0.028**
55	ln(CPUA) vs ln(Zfluct)	Asia	L & R (S)	2.398	-0.471	17	0.392	0.120
56	ln(CPUA) vs ln(Zfluct)	L_America	L & R (NS)	1.251	-0.259	6	0.215	0.682
	HYDROLOGY							
57	ln(CPUA) vs ln(S_Temp)	Africa	L & R (NS)	1.221	0.113	73	0.013	0.916
58	ln(CPUA) vs ln(S_Temp)	Asia	L & R (NS)	-5.314	2.194	14	0.164	0.575
59	ln(CPUA) vs ln(S_Temp)	Asia	L & R (S)	-0.765	0.965	15	0.070	0.803
60	ln(CPUA) vs ln(S_Temp)	L_America	L & R (NS)	-0.633	0.370	14	0.082	0.779
61	ln(CPUA) vs ln(S_Temp)	All	L & R (NS)	-2.253	0.140	99	0.140	0.166
62	ln(CPUA) vs ln(1+Days_mix)	Africa	L & R (NS)	0.769	0.186	27	0.278	0.161
63	ln(CPUA) vs ln(1+Days_mix)	Asia	L & R (NS)	1.644	0.003	8	0.160	0.704
64	ln(CPUA) vs ln(1+Days_mix)	Asia	L & R (S)	-0.003	0.010	14	0.412	0.144
65	ln(CPUA) vs ln(1+Days_mix)	L_America	L & R (NS)	0.522	0.042	9	0.023	0.953
66	ln(CPUA) vs ln(1+Days_mix)	All	L & R (NS)	0.730	0.169	43	0.168	0.282
67	ln(CPUA) vs ln(Rainfall)	Africa	L & R (NS)	3.381	-0.305	27	0.091	0.650
68	**ln(CPUA) vs ln(Rainfall)**	**Asia**	**L & R (NS)**	**-13.739**	**2.113**	**12**	**0.716**	**0.009**
69	ln(CPUA) vs ln(Rainfall)	Asia	L & R (S)	0.830	0.268	20	0.094	0.694
70	ln(CPUA) vs ln(Rainfall)	L_America	L & R (NS)	-11.352	1.835	9	0.473	0.198
71	**ln(CPUA) vs ln(Rainfall)**	**All**	**L & R (NS)**	**-6.017**	**1.093**	**49**	**0.357**	**0.012**
72	ln(CPUA) vs ln(Rain Duration)	Africa	L & R (NS)	1.303	0.287	21	0.056	0.810
73	ln(CPUA) vs ln(Rain Duration)	Asia	L & R (NS)	-0.879	1.649	13	0.354	0.235
74	ln(CPUA) vs ln(Rain Duration)	Asia	L & R (S)	0.239	1.395	11	0.172	0.614
75	ln(CPUA) vs ln(Rain Duration)	L_America	L & R (NS)	-0.856	0.695	11	0.105	0.758
76	ln(CPUA) vs ln(Rain Duration)	All	L & R (NS)	-0.822	0.252	45	0.252	0.095
77	**ln(CPUA) vs ln(W_Residence)**	**Africa**	**L & R (NS)**	**3.545**	**-0.339**	**6**	**0.841**	**0.036**
78	ln(CPUA) vs ln(W_Residence)	Asia	L & R (NS)	3.163	1.949	4	0.787	0.213
79	ln(CPUA) vs ln(W_Residence)	Asia	L & R (S)	1.546	-0.023	20	0.014	0.952
80	ln(CPUA) vs ln(W_Residence)	L_America	L & R (NS)	3.460	-0.519	4	0.920	0.080
81	ln(CPUA) vs ln(W_Residence)	All	L & R (NS)	2.514	-0.219	20	0.318	0.171

Notes

[1] L. Abaya, L. Tana, Ikimba R., Burigi R. consistent outliers (low catches); for all morph. relationships

[2] Laguna de Bay (high catches with cage aquaculture & shellfish landings) a consistent outlier.

[3] Bung Boraped a consistent outlier (high catches); removed from all morphometric relationships

[4] Laguna de Bay, (before cage aquaculture - high catches), outlier removed.

[5] Chuza reservoir (low catches, sport fishery), outlier removed.

Eq.	Comparison	Continent	Dataset	*a*	*b*	*n*	*r*	*p*
	WATER CHEMISTRY							
82	ln(CPUA) vs ln(TDS)	Africa	L & R	0.733	0.081	22	0.074	0.744
83	ln(CPUA) vs ln(TDS)	L_America	L & R (NS)	-0.378	0.173	13	0.172	0.575
84	ln(CPUA) vs ln(Cond)	Africa	L & R (NS)	1.064	0.057	84	0.048	0.665 [8]
85	ln(CPUA) vs ln(Cond)	Asia	L & R (NS)	1.593	0.179	37	0.117	0.491
86	ln(CPUA) vs ln(Cond)	Asia	L & R (S)	-0.754	0.392	37	0.260	0.120
87	ln(CPUA) vs ln(Cond)	L_America	L & R (NS)	-0.057	0.079	18	0.075	0.768 [8]
88	ln(CPUA) vs ln(pH)	Africa	L & R (NS)	0.811	0.349	84	0.031	0.781
89	**ln(CPUA) vs ln(pH)**	**Asia**	**L & R (NS)**	**-13.196**	**5.508**	**35**	**0.433**	**0.009**
90	ln(CPUA) vs ln(pH)	Asia	L & R (S)	1.614	-0.042	45	0.002	0.992
91	ln(CPUA) vs ln(pH)	L_America	L & R (NS)	-4.479	2.459	19	0.202	0.406
92	ln(CPUA) vs ln(Alkalinity)	Africa	L & R (NS)	1.477	-0.132	56	0.108	0.430 [9]
93	ln(CPUA) vs ln(Alkalinity)	Asia	L & R (NS)	2.326	0.033	40	0.033	0.841
94	**ln(CPUA) vs ln(Alkalinity)**	**Asia**	**L & R (S)**	**1.508**	**1.082**	**19**	**0.473**	**0.041**
95	ln(CPUA) vs ln(Alkalinity)	L_America	L & R (NS)	0.255	0.170	11	0.128	0.707
96	ln(CPUA) vs ln(Total P)	Africa	L & R (NS)	1.609	-0.105	22	0.120	0.596
97	ln(CPUA) vs ln(Total P)	Asia	L & R (NS)	3.548	-0.190	6	0.354	0.491
98	**ln(CPUA) vs ln(Total P)**	**Asia**	**L & R (S)**	**0.507**	**0.821**	**27**	**0.745**	**<0.001**
99	ln(CPUA) vs ln(Total P)	L_America	L & R (NS)	-1.416	0.421	8	0.483	0.225
100	ln(CPUA) vs ln(Total N)	Africa	L & R (NS)	0.963	-0.054	8	0.089	0.833
101	**ln(CPUA) vs ln(Total N)**	**Asia**	**L & R (S)**	**-3.696**	**1.302**	**25**	**0.625**	**0.001**
103	ln(CPUA) vs ln(Secchi)	Africa	L & R (NS)	1.321	0.120	29	0.120	0.536
104	ln(CPUA) vs ln(Secchi)	Asia	L & R (NS)	2.391	-0.124	53	0.073	0.603
105	ln(CPUA) vs ln(Secchi)	Asia	L & R (S)	1.572	-0.177	36	0.061	0.726
106	ln(CPUA) vs ln(Secchi)	L_America	L & R (NS)	0.312	-0.702	12	0.511	0.090
	BIOLOGICAL FEATURES							
107	ln(CPUA) vs ln(Areal Chla)	Africa	L & R (NS)	0.832	0.124	14	0.105	0.721
108	ln(CPUA) vs ln(Areal Chla)	Asia	L & R (S)	2.173	0.213	8	0.338	0.413
109	ln(CPUA) vs ln(Areal Chla)	L_America	L & R (NS)	0.337	-0.147	6	0.143	0.788
110	ln(CPUA) vs ln(Areal Chla)	All	L & R (NS)	-0.209	0.217	23	0.172	0.433
111	ln(CPUA) vs ln(Surface Chla)	Africa	L & R (NS)	0.821	0.112	23	0.106	0.630
112	**ln(CPUA) vs ln(Surface Chla)**	**Asia**	**L & R (NS)**	**-3.468**	**2.183**	**8**	**0.898**	**0.002**
113	ln(CPUA) vs ln(Surface Chla)	Asia	L & R (S)	2.339	0.261	17	0.405	0.106
114	ln(CPUA) vs ln(Surface Chla)	L_America	L & R (NS)	0.346	0.231	9	0.221	0.567
115	ln(CPUA) vs ln(Surface Chla)	All	L & R (NS)	0.748	0.229	40	0.186	0.251
116	ln(CPUA) vs ln(M'phyte biom)	All	L & R (NS)	2.819	-0.017	10	0.021	0.954
117	ln(CPUA) vs ln(M'phyte biom)	Asia	L & R (S)	-1.473	0.248	8	0.248	0.554
118	**ln(CPUA) vs ln(Gross Phot.)**	**Africa**	**L & R (NS)**	**-4.607**	**0.767**	**21**	**0.606**	**0.004** [10]
119	ln(CPUA) vs ln(Gross Phot.)	Asia	L & R (NS)	1.250	0.240	15	0.122	0.665
120	**ln(CPUA) vs ln(Gross Phot.)**	**Asia**	**L & R (S)**	**-8.290**	**1.340**	**27**	**0.447**	**0.019**
121	ln(CPUA) vs ln(Gross Phot.)	L_America	L & R (NS)	3.694	-0.537	7	0.369	0.415
122	ln(CPUA) vs ln(Gross Phot.)	All	L & R (NS)	1.160	0.077	43	0.047	0.765

Eq.	Comparison	Continent	Dataset	*a*	*b*	*n*	*r*	*p*
	BIOLOGICAL FEATURES Cont.							
123	ln(CPUA) vs ln(Net Phyto Prod)	Africa	L & R (NS)	1.446	-0.056	15	0.058	0.836
124	ln(CPUA) vs ln(Net Phyto Prod)	Asia	L & R (NS)	-1.689	0.606	9	0.381	0.312
125	ln(CPUA) vs ln(Net Phyto Prod)	Asia	L & R (S)	0.054	0.523	9	0.454	0.220
126	ln(CPUA) vs ln(Net Phyto Prod)	L_America	L & R (NS)	7.290	-1.444	8	0.497	0.210
127	ln(CPUA) vs ln(Net Phyto Prod)	All	L & R (NS)	-0.696	0.311	32	0.212	0.243
128	ln(CPUA) vs ln(M'phyte prod)	All	L & R (NS)	1.983	0.001	7	0.695	0.083
129	ln(CPUA) vs ln(Zoo biomass)	All	L & R (NS)	0.876	0.102	14	0.356	0.212
130	**ln(CPUA) vs ln(Zoo prod)**	**All**	**L & R (NS)**	**4.822**	**-0.984**	**8**	**0.801**	**0.017** [11]
131	ln(CPUA) vs ln(Mbenthos biom)	All	L & R (NS)	1.796	0.179	12	0.269	0.398
132	ln(CPUA) vs ln(Fish biomass)	All	L & R (NS)	0.833	0.000	15	0.200	0.476
133	ln(CPUA) vs ln(Fish prod)	All	L & R (NS)	1.195	-0.037	10	0.049	0.839
134	ln(CPUA) vs ln(Trophic lev, fy)	All	L & R (NS)	5.766	-3.143	22	0.355	0.105
135	trophic effic. vs trophic level fy	All	L & R (NS)	-6.433	3.044	13	0.155	0.614
	DEMOGRAPHY							
136	**ln(Catch) vs ln(C'ment popn)**	**All**	**L & R (NS)**	**-4.611**	**0.950**	**21**	**0.708**	**<0.001**
137	**ln(Catch) vs ln(popn primary)**	**All**	**L & R (NS)**	**0.984**	**0.739**	**8**	**0.754**	**0.031**
138	**ln(Catch) vs ln(no. fishers)**	**Africa**	**L & R (NS)**	**0.472**	**1.040**	**113**	**0.927**	**<0.001** [12]
139	**ln(Catch) vs ln(no. fishers)**	**Asia**	**L & R (NS)**	**1.662**	**0.821**	**52**	**0.875**	**<0.001**
140	ln(Catch) vs ln(no. fishers)	Asia	L & R (S)	1.475	0.755	13	0.465	0.109
141	**ln(Catch) vs ln(no. fishers)**	**L_America**	**L & R (NS)**	**-1.141**	**1.255**	**17**	**0.875**	**<0.001** [13]
142	**ln(Catch) vs ln(no. boats)**	**Africa**	**L & R (NS)**	**1.298**	**1.079**	**85**	**0.929**	**<0.001** [14]
143	**ln(Catch) vs ln(no. boats)**	**Asia**	**L & R (NS)**	**1.765**	**1.047**	**21**	**0.845**	**<0.001**
144	ln(Catch) vs ln(no. boats)	Asia	L & R (S)	-0.321	1.429	7	0.744	0.055
145	**ln(Catch) vs ln(no. boats)**	**L_America**	**L & R (NS)**	**3.642**	**0.569**	**10**	**0.689**	**0.028** [5]
146	**ln(CPFM) vs ln(FMUA)**	**Africa**	**L & R (NS)**	**1.237**	**-0.070**	**113**	**0.281**	**0.003**
147	**ln(CPFM) vs ln(FMUA)**	**Asia**	**L & R (NS)**	**1.109**	**-0.200**	**52**	**0.333**	**0.016**
148	**ln(CPFM) vs ln(FMUA)**	**Asia**	**L & R (S)**	**1.256**	**-0.446**	**12**	**0.645**	**0.023**
149	ln(CPFM) vs ln(FMUA)	L_America	L & R (NS)	1.039	0.009	17	0.109	0.676
150	**ln(CPUA) vs ln(FMUA)**	**Africa**	**L & R (NS)**	**0.981**	**0.673**	**98**	**0.721**	**<0.001**
151	**ln(CPUA) vs ln(FMUA)**	**Asia**	**L & R (NS)**	**1.109**	**0.800**	**52**	**0.817**	**<0.001**
152	**ln(CPUA) vs ln(FMUA)**	**Asia**	**L & R (S)**	**1.256**	**0.554**	**12**	**0.724**	**0.008**
153	**ln(CPUA) vs ln(FMUA)**	**L_America**	**L & R (NS)**	**0.430**	**1.002**	**14**	**0.854**	**<0.001** [5]

Notes

[6] Excluding Lake Chilwa (highly variable system)

[7] Relationship driven by series of highly productive high-latitude Chinese Reservoirs and ponds

[8] For Conductivity < 8000 microseimens/cm

[9] For Alkalinity < 50 meq/l

[10] L Turkana an outlier - Gross prod. figure is for Ferguson's Gulf (most productive part of lake)

[11] Driven by 2 points - probably spurious

[12] Itezhitezhi an outlier

[13] Murago an outlier

[14] Salvajina an outlier

Shoreline development was not significantly related to yield (catch/area). High altitude lakes in Asia (mainly in Nepal and Kashmir) had lower yields than lowland lakes; relationships with altitude in other datasets with a narrow range were not significant. Mean and maximum depth has a significant effect on yield only in the datasets for African lakes and reservoirs, and for culture-based systems in Asia; in all cases deeper lakes are less productive.

In few cases were hydrological parameters (temperature, mixing regime, rainfall, water residence time) shown to have an effect on fish yields (Table 11). A global relationship with rainfall is implied, with higher catches from water-bodies in humid areas. The small dataset for African lakes that indicates a negative relationship between yield and residence time includes the Rift Valley lakes that have residence times of hundreds of years.

Few of the commonly-compiled chemical parameters correlate with fish yields (Table 11). Alkalinity, total phosphorus and total nitrogen are all significantly correlated with fish yields in culture-based systems in Asia; these datasets include some fertilized Chinese pond systems with very high nutrient concentrations and some of the highest fish yields recorded for inland fisheries (Liang *et al.,* 1981). The relationship between total phosphorus and fish yield is driven by a cluster of points from this dataset (Figure 2).

Data on biomasses and productivity of major trophic and functional groups (Algae, macrophytes, zooplankton, macrozoobenthos and even fish) are not available for many tropical systems. The largest datasets are for surface or euphotic zone chlorophyll *a* concentration and for gross phytoplankton photosynthesis. Surface chlorophyll a is related to fish yield only in a small dataset of Asian lakes and reservoirs. Gross photosynthesis and fish yield are significantly correlated in both African and stocked Asian lakes and reservoirs, but the proportion of variance explained is rather low, so that, as univariate predictors of fish yields, they are not really useful. The dataset includes the lakes used by Melack (1976), together with new data from some smaller lakes, and from some of the larger reservoirs.

Melack's (1976) relationship between CPUA (t km^{-2}) and gross phytoplankton photosynthesis (g O_2 m^{-2} y^{-1}), originally based on eight African lakes, was re-established for a larger dataset (standard errors in brackets):

$$\ln(\text{CPUA}) = -4.602\ (1.814) + 0.767\ (0.231) * \ln(\text{GP});\quad n = 21,\ r = 0.606,\ p = 0.004.$$

There are a number of outliers, and fairly large scatter (Figure 3). This model was not used in subsequent analyses, but area was included as an independent variable, and total catch was used as the dependent variable.

No significant difference was detected in fish yields from systems where the phytoplankton is dominated by cyanophyta, chlorophyta or chrysophyta (ANOVA, F=0.166, d.f. = 72, 2, p = 0.85).

The nature of the fish community is related to the average yield (ANOVA, F = 9.494, d.f. = 101, 5, $p < 0.001$); fisheries were divided into those systems dominated by one of six categories of fish: Carp, Haplochromine cichlids, Small pelagics, Tilapia/Carp mixtures and Tilapia. Fisheries based on a mixture of the above and other categories were grouped together as 'mixed' as data were insufficient for any other categorization. Capture-based fisheries dominated by Tilapia, either introduced or indigenous, were the most productive, with Tilapia-Carp mixtures and haplochromine cichlids tending to support productive fisheries also (Table 12). To a certain extent, the differences reflect inherent differences in system productivity; Tilapia fisheries will do well in systems with high productivity. Introducing Tilapia may not always result in higher yields, and this result should not be interpreted as such. Capture fisheries for carp had low productivity, but this dataset was mainly composed of fisheries supported by indigenous Indian major carps in low productivity high altitude lakes. Indian major carps and common carp support some of the world's most productive culture-based fisheries, in India and China. Culture-based fisheries were not compared, as the amount and type of stocking or aquaculture carried out will have the most impact in determining productivity, and detailed statistics on these factors were not collated.

Table 12: Mean Fish Yields (kg ha^{-1} y^{-1}) from Tropical and Sub-tropical Capture Fisheries Based on Different Categories of Fish.

Fish type	Yield kg ha^{-1} y^{-1}	s.e. (yield) kg ha^{-1} y^{-1}	*n*
Tilapia	95.7	12.1	46
Tilapia + carp	75.2	15.8	8
Haplochromine cichlids	50.0	15.8	8
Mixed species	26.9	12.8	26
Small pelagics	19.6	15.8	8
Carp	5.7	15.4	9

No relationship was detected between yield and dependence on introduced or native, riverine species in reservoirs (ANOVA, F = 1.996, d.f. = 66.1, p = 0.162). The dataset included a number of small reservoirs, and a comparison of larger reservoirs only, where an extensive pelagic zone may remain unutilized unless a pelagic planktivore is introduced (Fernando & Holcik, 1982), may give different results.

Catchment population and the number of persons involved in primary industry (Agriculture & fisheries) is related to fish catch (Table 11), although a significant part of these relationships may be due to covariance of catchment population and catchment area, and catchment area and lake area. The relationship is driven to some extent by large lakes with highly populated catchments in southern China.

The relationship between catch and number of fishers (Figure 1b) is linear in African lakes (*b* = 1.04), and significant relationships also exist between fishers and catch in all but the dataset for stocked lakes and reservoirs in Asia, so that approximate catches can be determined by counting fishers, rather than fish. There is no significant difference in the catch-fishers relationships in the three continents (ANCOVA, d.f. = 183, 2, p> 0.05), but datasets for Asia and Latin America contain several outliers and have high variance. Therefore, the data sets have not been pooled for subsequent analyses in multiple-regression equations.

The number of boats (usually a mixture of dugout canoes and small plank or fibreglass boats in artisanal inland fisheries) also correlates with fish catches, although one may expect outliers (e.g shore-based subsistence fisheries). Boats are relatively easy to count, and can give an indication of likely catch through the relationships presented here.

Catch per unit area tends to increase linearly with fishing intensity (number of fishers km^{-2}), showing no sign of reaching an asymptote or decreasing at higher intensities (Figure 4a), as in a surplus-production type model (e.g. Bayley, 1988). The fish catch and effort values used in the database are supposed to represent average, sustainable catches. The absence of a surplus production type relationship may therefore indicate that the selection of catch data has successfully factored out the effects of over-exploitation. Figure 4b supports this suggestion, as it indicates a relatively weak (low slope, high variance) relationship between catch per unit effort and fishing intensity, indicating that catch per unit effort is largely determined by the productivity of the fish resource, not the extent to which it has been overexploited. Thus, with the exception of a few under-exploited systems, variations in catch and catch per area should be largely attributable to the explanatory variables discussed in this report.

A small dataset (*n* = 16) of catchment land use data indicated no significant difference in mean yields from lakes with farm, forest or savannah catchments (ANOVA, F = 2.403, d.f. = 13, 2, p = 0.129), but the power of the performed test was low, and more data on land use are required to explore its effect on lake and reservoir productivity.

3.3.2 Coastal Lagoons

Catches from coastal lagoons were correlated to area and number of fishers and boats, but yields (catch/area) were not significantly related to any of the available chemical and biological variables (Table 13). A parabolic relationship between yield and mean surface water temperature (range 9.5 -

36 C) was observed, described by the following polynomial regression equation (s.e. in brackets):

$$\ln(\text{Catch/Area}) = -47.846\ (22.752) + 4.463\ (1.961) * \text{Temperature} + -0.087\ (0.041) * (\text{Temperature})^2$$

$n = 19$, $r^2 = 0.444$, $p = 0.009$, Residual mean square = 3.999

The large increase in yield following establishment of permanent connections to the sea in some Mexican Lagoons (Cervantes-Castro, 1984) and the higher fish catches from Togo lagoon in years when the lagoon is open to the sea (Lae, 1994) suggest that a permanent connection to the sea favours high yield as water circulation is improved, preventing excessive fluctuations in salinity and temperature and allowing the ingress of marine species. A comparison of fish yield on an areal basis for lagoons with and without permanent connections to the sea did not detect a significant difference, however.

Analyses of variance on areal fish yield against the origin of the fish community (Marine, Euryhaline, Introduced) the type of fish landed (Crustaceans, molluscs, finfish) showed no significant differences either, although the power of the performed tests was low as sample sizes were small and it was not possible to account for the many other sources of variability in catches due to lack of data. All ANOVA tests were performed on log-transformed catch/area at a significance level of 0.05.

3.3.3 Floodplain Lakes

Small datasets for floodplain lakes did not allow establishment of multiple regression equations. The univariate predictors based on area, volume or number of boats (Table 13), all of which are highly significant, could be used, but the incorporation of floodplain lakes in a broader analysis of lakes and reservoirs did not identify them as outliers, so it is recommended that the models based on these larger datasets are used instead.

3.3.4 Swamps

There were insufficient data to derive meaningful predictive relationships between fish yields and other variables for swamps.

3.3.5 Summary of Applicable Simple and Multiple Regression Equations for Fish Yield Prediction, with Confidence Intervals

Extensive testing of various combinations of variables found to have an influence on fish yields indicate that the following models are among the most useful for fish yield predictions:

(Standard errors of the estimated model coefficients are given in brackets; the residual mean square is also reported. Full regression statistics are given in Appendix 2. Dependent variables are either ln(Catch) in t y^{-1}, or ln(CPUA) in t km^{-2} y^{-1})

1) Models for All Continents - Lakes and Reservoirs

a) Models Independent of Fishing Effort, for Capture-based Fisheries

Model 1: Area (km^2), Altitude (m a.s.l.)

$\ln(\text{Catch}) = 3.844\ (0.726) + 0.891\ (0.052) * \ln(\text{Area}) + -0.342\ (0.104) * \ln(\text{Altitude})$

$n = 132$, $r^2 = 0.711$, $p < 0.001$, RMS = 2.355

Model 2: Area (km^2), Catchment area (km^2), Rainfall (mm y^{-1})

$\ln(\text{Catch}) = -10.502\ (5.001) + 0.484\ (0.215) * \ln(\text{Area}) + 0.451\ (0.212) * \ln(\text{Catchment}) + 1.573\ (0.645) * \ln(\text{Rainfall})$

$n = 32$, $r^2 = 0.844$, $p < 0.001$, RMS = 2.382

b) Models Independent of Fishing Effort, for Capture and Culture-based Fisheries

Model 3: Area (km^2), Gross photosynthesis (g 0_2 m^{-2} y^{-1})

$\ln(\text{Catch}) = -0.090\ (1.679) + 0.842\ (0.069) * \ln(\text{Area}) + 0.331\ (0.230) * \ln(\text{G\_Phot})$

$n=72$, $r^2 = 0.693$, $p < 0.001$, RMS = 2.868

c) Models Including Fishing Effort, for Capture Based Fisheries

Model 4: Area (km^2), Number of fishers

$\ln(\text{Catch}) = 1.048\ (0.207) + 0.221\ (0.048) * \ln(\text{Area}) + 0.762\ (0.058) * \ln(\text{Fishers})$

$n=163$, $r^2 = 0.839$, $p < 0.001$, RMS = 0.827

2) African Lakes and Reservoirs

a) Models Independent of Fishing Effort

Model 5: Area (km^2)

$\ln(\text{Catch}) = 2.590\ (0.174) + 0.816\ (0.034) * \ln(\text{Area})$

$n=133$, $r^2 = 0.816$, $p < 0.001$, RMS = 1.172

Model 6: Area (km^2), Maximum depth (m)

$\ln(\text{Catch}) = 2.625\ (0.288) + 0.879\ (0.052) * \ln(\text{Area}) + -0.121\ (0.096) * \ln(\text{Zmax})$

$n = 83$, $r^2 = 0.820$, $p = < 0.001$, RMS = 1.073

Model 7: Area (km^2), Volume (m^3)

ln(Catch) = 3.036(0.700) + 0.950 (0.062) * ln(Area) + -0.063 (0.045) * ln(Volume);

n = 85, $r^2 = 0.885$, $p < 0.001$, RMS = 0.759

Model 8: Area (km^2), Gross photosynthesis (g 0_2 m^{-2} y^{-1})

ln(Catch) = -3.625 (1.453) + 0.867 (0.046) * ln(Area) + 0.780 (0.175) * ln(G_Phot)

n=20, $r^2 = 0.954$, $p < 0.001$, RMS = 2.868

b) Models That Include Fishing Effort

Model 9: Area (km^2), Number of fishers

ln(Catch) = 1.065 (0.254) + 0.332 (0.067) * ln(Area) + 0.653 (0.083) * ln(Fishers)

n=98, $r^2 = 0.871$, $p < 0.001$, RMS = 0.861

Model 10: Area (km^2), Number of boats

ln(Catch) = 1.806 (0.250) + 0.377 (0.065) * ln(Area) + 0.622 (0.087) * ln(Boats);

n = 74, $r^2 = 0.891$, $p < 0.001$, RMS = 0.751

Model 11: Area (km^2), Number of boats, Number of fishers

ln(Catch) = 1.484 (0.331) + 0.326 (0.084) * ln(Area) + 0.342 (0.167) * ln(Boats)
+ 0.322 (0.199) * ln(Fishers)

n = 64, $r^2 = 0.904$, $p < 0.001$, RMS = 0.718

Model 12: Area (km^2), Gross photosynthesis (g 0_2 m^{-2} y^{-1}), Number of fishers

ln(Catch) = -3.000 (1.492) + 0.680 (0.132) * ln(Area) + 0.645 (0.194) * ln(G_Phot)
+ 0.235 (0.152) * ln(Fishers)

n = 19, $r^2 = 0.957$, $p < 0.001$, RMS = 0.297

3) Asian Lakes and Reservoirs (Capture-based Fisheries)

a) Models Independent of Fishing Effort, Capture Fisheries

Model 13: Area (km^2), Altitude (m a.s.l.)

ln(Catch) = 5.568 (1.876) + 0.859 (0.157) * ln(Area) + -0.700 (0.247) * ln(Alt)

n = 25, $r^2 = 0.797$; $p < 0.001$, RMS = 2.856

Model 14: Area (km^2), Altitude (m a.s.l.), Maximum depth (m)

$$\ln(\text{Catch}) = 6.155\ (1.735) + 0.645\ (0.180) * \ln(\text{Area}) + -0.961\ (0.264) * \ln(\text{Alt}) + 0.462\ (0.331) * \ln(\text{Zmax})$$

$n = 22$, $r^2 = 0.850$; $p < 0.001$, RMS = 2.333

b) Models Including Fishing Effort, Capture Fisheries

Model 15: Area (km^2), Number of fishers

$$\ln(\text{Catch}) = 1.368\ (0.342) + 0.133\ (0.090) * \ln(\text{Area}) + 0.800\ (0.080) * \ln(\text{Fishers})$$

$n = 50$, $r^2 = 0.801$, $p < 0.001$, RMS = 0.486

c) Models Independent of Fishing Effort, Culture-based Fisheries

Model 16: Area (km^2), Total phosphorus ($\mu g\ l^{-1}$)

$$\ln(\text{Catch}) = 2.422\ (0.467) + 0.593\ (0.061) * \ln\ (\text{Area}) + 0.519\ (0.089) * \ln(\text{TP})$$

$n = 23$, $r^2 = 0.827$, $p < 0.001$, RMS = 0.371

d) Models That Include Fishing Effort, Culture-based Fisheries

There were no useful predictive models incorporating either number of boats or fishers.

4) Latin American Lakes and Reservoirs

a) Models Independent of Fishing Effort

Model 17: Area (km^2)

$$\ln(\text{Catch}) = 2.845\ (0.258) + 0.678\ (0.068) * \ln(\text{Area})$$

$n = 82$, $r^2 = 0.553$, $p < 0.001$, RMS = 1.765

b) Models That Include Fishing Effort

Model 18: Number of fishers

$$\ln(\text{Catch}) = -1.141\ (1.149) + 1.255\ (0.179) * \ln(\text{Fishers})$$

$n = 17$, $r^2 = 0.765$, $p < 0.001$, RMS = 1.007

Model 19: Area (km^2), Number of fishers

$$\ln(\text{Catch}) = -1.292\ (1.260) + 1.218\ (0.229) * \ln(\text{Fishers}) + 0.064\ (0.175) * \ln(\text{Area})$$

$n = 14$, $r^2 = 0.0.796$, $p < 0.001$, RMS = 1.090

5) Coastal Lagoons - All Continents

a) Models Independent of Fishing Effort

Model 20: Area (km^2)

$\ln(\text{Catch}) = 2.293\ (0.0.537) + 0.900\ (0.103) * \ln(\text{Area})$

$n = 66$, $r^2 = 0.545$, $p < 0.001$, RMS = 2.103

b) Models That Include Fishing Effort

Model 21: Area (km^2), Number of fishers

$\ln(\text{Catch}) = 1.450\ (0.585) + 0.427\ (0.148) * \ln(\text{Area}) + 0.576\ (0.126) * \ln(\text{Fishers})$

$n = 26$, $r = 0.854$, $p < 0.001$, $RMS = 0.582$

More detailed statistics for these equations are given in Appendix 2.

Observed and predicted fish yields and confidence limits are illustrated for 10 water bodies from each dataset (Table 14). Although high r^2 values were obtained for most of the relationships between fish catch and explanatory variables in regression models 1-21, examination of the 95% confidence limits for the predicted catches reveals that any predictions should be treated with caution. For most of the relationships, 95% CI span at least an order of magnitude. Inclusion of parameters additional to the main explanatory variables; area and number of fishers, results in some reduction in confidence intervals for individual water bodies, but the comparisons are inevitably based on smaller datasets and a great deal of variability remains unaccounted for by the simple parameters used here. The addition of even these extra variables does, however, account for several outliers to the basic catch-area or catch-fishers relationships, and is therefore useful in broadening the range of conditions to which the models can be applied: e.g. addition of altitude explains why Lake Titicaca and the mountain lakes of Nepal are outliers in catch-area relationships. Of the ten African lakes and reservoirs illustrated (Table 14a), the catch-area model provides a reasonably accurate prediction (within 20% of the observed catch) for only two lakes out of ten, while Model 12 (area, number of fishers and gross photosynthesis provides accurate predictions for four of the eight waterbodies illustrated.

Perhaps the best approach to obtaining a yield prediction is to use as many of the appropriate models for which data are available, and to examine the range of predicted means. Averages can be taken if all the models predict similar catches, or choice of the model which takes into account the most variables should be made if there are large discrepancies.

Table 13 Screening of regression relationships for coastal lagoons

	Comparison	Continent	*a*	*b*	*n*	*r*	*p*
	COASTAL LAGOONS						
1	**ln(Catch) vs ln(Area)**	**Africa**	**2.538**	**0.953**	**31**	**0.728**	**<0.001**
2	**ln(Catch) vs ln(Area)**	**Asia**	**2.016**	**0.871**	**4**	**0.998**	**0.002**
3	**ln(Catch) vs ln(Area)**	**L_America**	**1.626**	**0.920**	**32**	**0.724**	**<0.001** [1]
4	**ln(Catch) vs ln(Area)**	**All**	**2.293**	**0.900**	**66**	**0.739**	**<0.001** [2]
5	**ln(Catch) vs ln(Volume)**	**Africa**	**-8.059**	**0.777**	**18**	**0.722**	**0.001**
6	**ln(Catch) vs ln(Volume)**	**All**	**-3.927**	**0.545**	**22**	**0.608**	**0.003**
7	ln(CPUA) vs ln(Zmax)	All	2.635	-0.693	20	0.386	0.093 [3]
8	ln(CPUA) vs ln(Zmean)	All	2.118	-0.705	22	0.396	0.068 [3]
9	ln(CPUA) vs ln(min Salinity)	All	2.220	-0.221	20	0.190	0.423
10	ln(CPUA) vs ln(max Salinity)	All	3.025	-0.338	22	0.334	0.112
11	ln(CPUA) vs ln(pH)	All	-16.500	9.062	10	0.365	0.299
12	ln(CPUA) vs ln(Secchi)	All	1.800	-1.430	5	0.774	0.124
13	ln(CPUA) vs ln(Gross Phot)	All	3.757	-0.254	6	0.149	0.778
14	**ln(Catch) vs ln(no. Fishers)**	**Africa**	**0.477**	**0.969**	**20**	**0.924**	**<0.001**
15	**ln(Catch) vs ln(no. Fishers)**	**L_America**	**1.283**	**1.001**	**7**	**0.876**	**0.010**
16	**ln(Catch) vs ln(no. Fishers)**	**All**	**1.157**	**0.905**	**28**	**0.877**	**<0.001**
17	**ln(Catch) vs ln(no. boats)**	**Africa**	**0.659**	**1.099**	**10**	**0.747**	**0.013**
18	**ln(Catch) vs ln(no. boats)**	**All**	**0.347**	**1.154**	**11**	**0.762**	**0.006**
	FLOODPLAIN LAKES						
19	**ln(Catch) vs ln(Area)**	**Asia**	**3.165**	**0.847**	**13**	**0.955**	**<0.001**
20	**ln(Catch) vs ln(Area)**	**All**	**3.130**	**0.807**	**17**	**0.958**	**<0.001**
21	**ln(Catch) vs ln(Volume)**	**All**	**-8.034**	**0.777**	**9**	**0.961**	**<0.001**
22	ln(CPUA) vs ln(Zmean)	All	4.035	-0.702	8	0.702	0.052
23	ln(CPUA) vs ln(Zax)	All	4.624	-0.978	7	0.539	0.212
24	ln(CPUA) vs ln(Cond)	All	4.033	-0.246	8	0.262	0.531
25	ln(CPUA) vs ln(pH)	All	-0.581	1.465	7	0.284	0.536
26	ln(Catch) vs ln(no. Fishers)	All	-3.028	1.421	5	0.315	0.606
27	**ln(Catch) vs ln(no. Boats)**	**All**	**1.423**	**1.061**	**7**	**0.828**	**0.022**

Notes

[1] Very high production of mussels in Mundao Lagoon - outlier: excluded in all comparisons

[2] Maracaibo (sometimes classed as a lake) and Ghar El Melh (low temperature, high latitude) are outliers, and have been excluded.

[3] Only two lagoons >10 m depth in dataset

TABLE 14 Confidence limits (95%) on catches for selected waterbodies, estimated from predictive regression equations (Model 1-21; Section 3.3.5).
a) African lakes and reservoirs

WBNAME	WBTYPE	COUNTRY	Area (sq-km)	Catch t	Model 5	LCL5	UCL5	Model 6	LCL6	UCL6	Model 7	LCL7	UCL7	Model 8	LCL8	UCL8
Mirayi	Lake	Rwanda	2	20	26	3	226				17	3	100			
Chivero	Res.	Zimbabwe	26	315	192	23	1635	164	20	1336	138	24	800	296	84	1035
Baringo	Lake	Kenya	160	394	838	98	7132	938	117	7533	725	126	4165	613	180	2084
George	Lake	Uganda	250	3990	1206	142	10274	1401	174	11277	1101	191	6335	2151	644	7186
Alaotra	Lake	Madagascar	570	3818	2363	277	20185	3095	377	25397	2356	408	13613			
Kainji	Res.	Nigeria	1250	6629	4485	523	38462	4449	550	36012	4178	723	24147	4270	1303	13994
Albert	Lake	International	5270	16995	14511	1675	125750	15835	1939	129315	14293	2441	83673	20677	6330	67538
Volta	Res.	Ghana	8590	38426	21620	2484	188198	23589	2868	194045	22499	3831	132137	30473	9285	100013
Chad	Lake	International	21000	80326	44838	5102	394039	66493	7769	569097	55946	9404	332839	57249	17198	190572
Victoria	Lake	International	68800	228571	118087	13237	1053483	145024	17035	1234635	136062	22485	823324	177053	51755	605698

WBNAME	WBTYPE	COUNTRY	Area (sq-km)	Catch t	Model 9	LCL9	UCL9	Model 10	LCL10	UCL10	Model 11	LCL11	UCL11	Model 12	LCL12	UCL12
Mirayi	Lake	Rwanda	2	20	24	4	159	49	8	287	38	7	217			
Chivero	Res.	Zimbabwe	26	315												
Baringo	Lake	Kenya	160	394	287	44	1860	244	40	1473	258	45	1489	475	135	1669
George	Lake	Uganda	250	3990	1186	185	7600	1024	177	5933	1121	200	6273	2082	627	6910
Alaotra	Lake	Madagascar	570	3818	4338	667	28210	8629	1443	51589	6612	1148	38098			
Kainji	Res.	Nigeria	1250	6629	9425	1437	61823	14020	2350	83635	12224	2127	70243	6024	1706	21268
Albert	Lake	International	5270	16995	26224	3974	173042	22781	3856	134587	24785	4269	143884	25619	7696	85287
Volta	Res.	Ghana	8590	38426	37310	5635	247019	67146	11035	408573	52290	8936	305974	37138	11170	123480
Chad	Lake	International	21000	80326	32470	4924	214123							51746	15682	170746
Victoria	Lake	International	68800	228571	89903	13422	602195	119471	19641	726702	100826	17331	586565	157762	46354	536927

Table 14 b) Asian lakes and reservoirs: Capture fisheries

WBNAME	WBTYP	COUNTRY	Area (sq-km)	Catch t	Model 1	LCL1	UCL1	Model 2	LCL2	UCL2	Model3	LCL3	UCL3	Model 4	LCL4	UCL4	Model 13	LCL13	UCL13	Model 14	LCL14	UCL14	Model 15	LCL15	CL15
Kodai	Res.	India	0.3	1.4	1.1	0.0	26										0.4	0.0	18	0.4	0.0	12			
Bahut	Lake	Philippines	2	180										144	23	892							225	51	994
Baao	Lake	Philippines	7	600							47	2	1437	494	80	3057							730	169	3163
Buhi	Lake	Philippines	17	1230							81	3	2528	648	106	3970							888	211	3742
Kew Lom	Res.	Thailand	18	130										137	23	831							173	42	714
PK Samudra	Res.	Sri Lanka	26	732	208	9	4570	472	16	13932	205	7	6382	1212	197	7461	245	6	9755	254	9	7348	1641	385	6989
Maduru Oya	Res.	Sri Lanka	63	669	392	18	8441							340	56	2053	374	10	13585	357	13	9464	395	95	1640
Bhakra	Res.	India	168	400	531	25	11207										269	7	9842	342	12	9761			
Toba	Lake	Indonesia	1130	2420	2392	112	50999	4030	150	108197							932	20	42495	1222	33	45676			
Great Lake	Lake	Kampuchea	6500	52500	53101	2227	1266366										98361	2066	4685230	43745	1121	1707673			

c) Asian lakes and reservoirs: culture-based fisheries.

WBNAME	WBTYP	COUNTRY	Area (sq-km)	Catch t	Model 16	LCL16	UCL16
North	Lake	China	0.1	98	80	21	296
Biandan	Lake	China	2	54	67	17	256
Ink	Lake	China	2	329	298	82	1090
Yu's	Lake	China	2	676	802	202	3187
South	Lake	China	3	203	347	95	1268
Phewa	Lake	Nepal	5	40	95	25	364
Paizhong	Lake	China	8	237	128	34	485
Donghu	Lake	China	32	2128	1634	413	6459
Changshou-hu	Res.	China	60	47	128	30	542
Xin'anjiang	Res.	China	400	3148	1122	283	4455

Table 14 d) Latin American lakes and reservoirs

WBNAME	WBTYP	COUNTRY	Area (sq-km)	Catch t	Model 1	LCL1	UCL1	Model 2	LCL2	UCL2	Model3	LCL3	UCL3	Model 4	LCL4	UCL4
San Gabriel	Res.	Brazil	1	23												
Lebrije	Res.	Cuba	10	110	75	3	1641	95	3	2745						
Mamposton	Res.	Cuba	16	100	104	5	2234									
Parano	Res.	Brazil	40	200	114	5	2423	365	14	9793						
Catemaco	Lake	Mexico	65	1884										2316	377	14235
Patzcuaro	Lake	Mexico	126	1566	258	12	5513	277	10	7477	450	15	13929	2146	353	13058
Guajaro	Res.	Colombia	160	1311										1494	247	9035
Barra Bonita	Res.	Brazil	334	290	1042	49	22032				935	30	29644			
Managua	Lake	Nicaragua	1016	488	6444	290	143033	2632	104	66453	5471	169	176800	747	122	4587
Titicaca	Lake	Bolivia/Peru	8560	8051	8892	397	199297	10225	373	280286				16492	2684	101343

WBNAME	WBTYP	COUNTRY	Area (sq-km)	Catch t	Model 17	LCL17	UCL17	Model 18	LCL18	UCL18	Model 19	LCL19	UCL19
San Gabriel	Res.	Brazil	1	23	19	1	280						
Lebrije	Res.	Cuba	10	110	84	6	1214						
Mamposton	Res.	Cuba	16	100	114	8	1637						
Parano	Res.	Brazil	40	200	210	15	3025						
Catemaco	Lake	Mexico	65	1884	292	20	4216	4339	464	40589	3691	295	46185
Patzcuaro	Lake	Mexico	126	1566	458	32	6663	3001	328	27458	2692	241	30046
Guajaro	Res.	Colombia	160	1311	538	37	7840	1516	170	13498	1408	135	14672
Barra Bonita	Res.	Brazil	334	290	886	60	13076						
Managua	Lake	Nicaragua	1016	488	1884	125	28488	247	27	2246	272	23	3248
Titicaca	Lake	Bolivia/Peru	8560	8051	7995	493	129645	18556	1729	199154	20640	1498	284312

Table 14 e) Coastal lagoons

WBNAME	COUNTRY	Area (sq-km)	Catch t	Model 20	LCL20	UCL20	Model 21	LCL21	UCL21
Sakumo-Tema	Ghana	1	15	10	0	215	21	3	136
Mellah	Algeria	8.7	52	69	4	1341	47	8	276
Piritu	Venezuela	22	167	160	9	2999	217	41	1144
Unare	Venezuela	54	508	359	20	6610	529	104	2698
Tacarigua	Venezuela	63	674	413	22	7579	669	132	3381
Grand Lahou	Côte d'Ivoir	230	4140	1323	72	24244	4378	882	21731
Lagos	Nigeria	460	3956	2470	134	45626	7319	1464	36584
Alvarado	Mexico	500	8812	2662	144	49255	1801	318	10197
Ebrie	Côte d'Ivoir	560	8263	2948	159	54662	9531	1896	47897
Madre de Tamaulipa	Mexico	2158	13302	9927	515	191504	18588	3457	99934

Figure 1. Relationships between a) area and catch, and b) number of fishers and catch for African lakes and reservoirs. Fitted regression line and 95% confidence intervals for the regression are indicated. Regression statistics are given in Table 11.

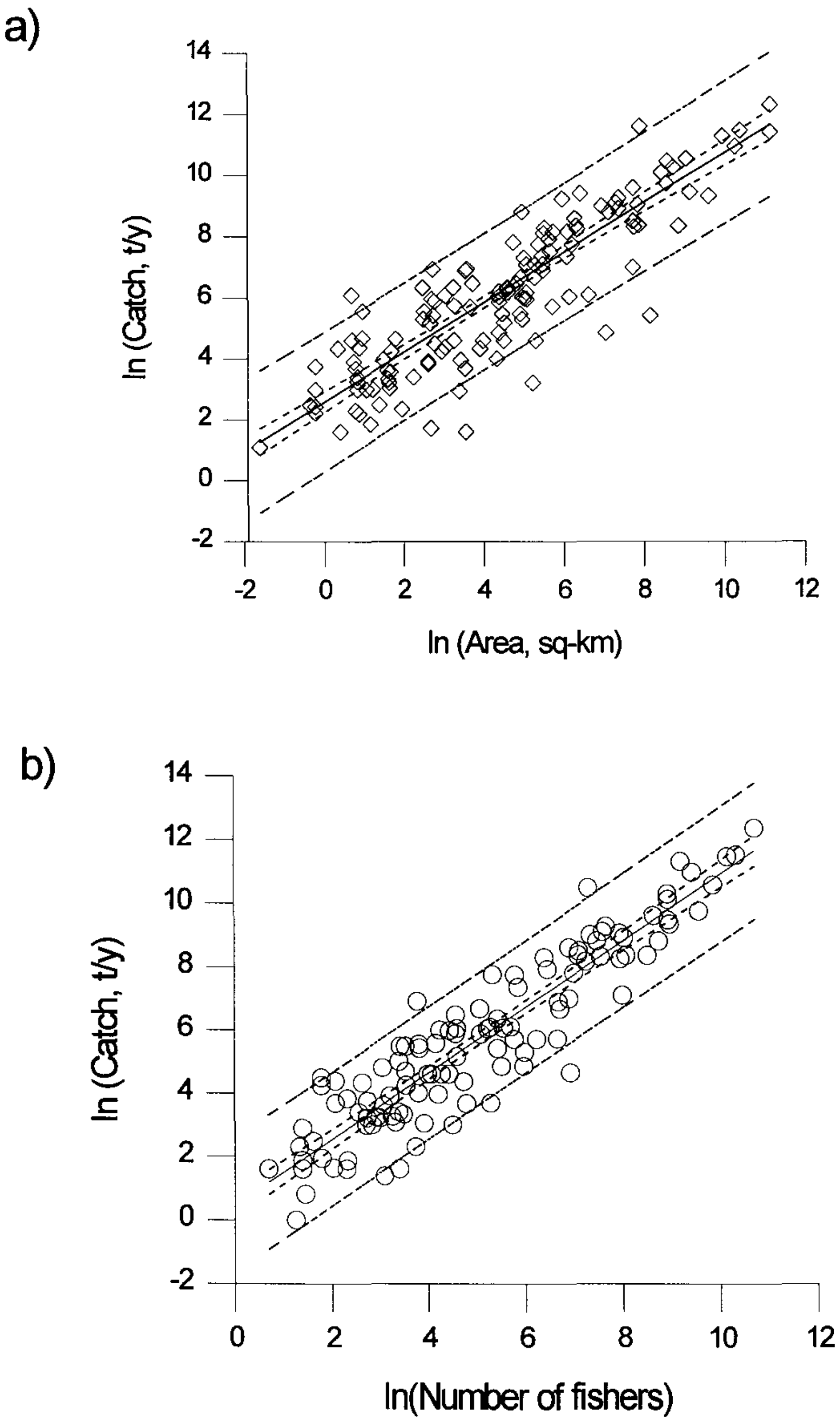


Figure 2. Relationship between total phosphorus concentration and catch per unit area for Asian lakes and reservoirs with culture-based fisheries. 95% CI for both the regression equation (dotted line) and predicted CPUA (dashed line) are shown.

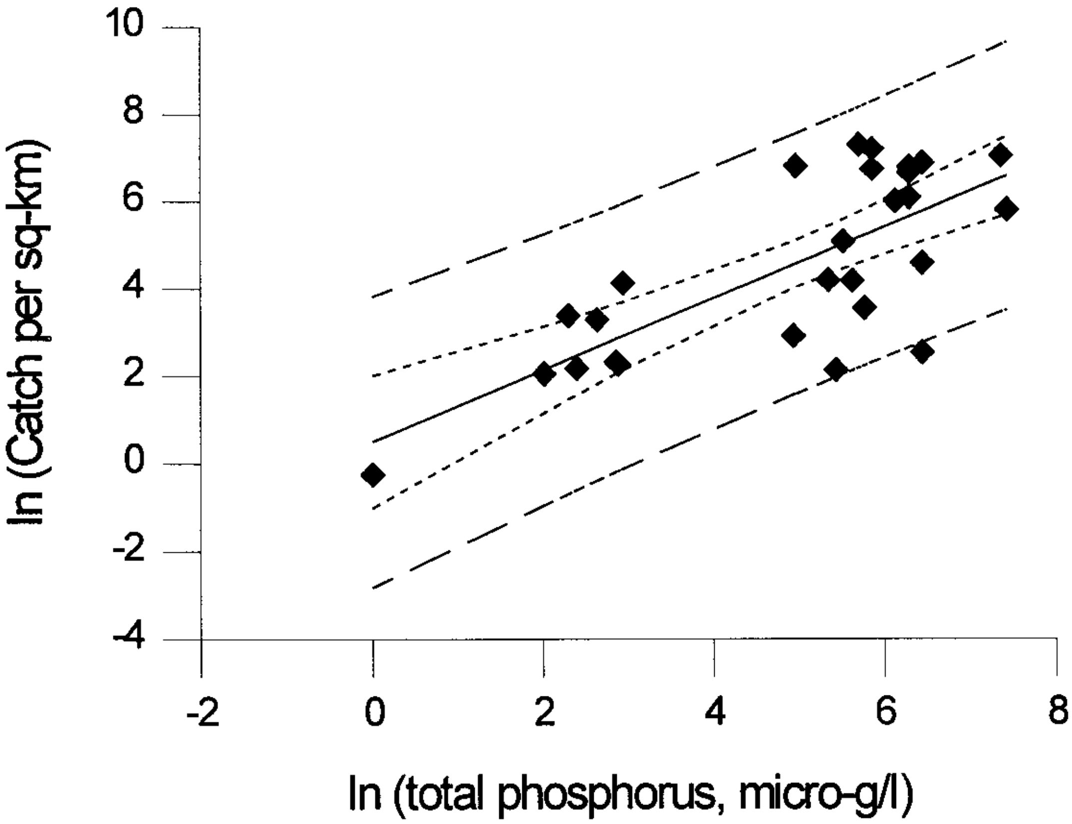


Figure 3. Relationship between gross phytoplankton photosynthesis and catch per unit area in African lakes and reservoirs. Lake Turkana is an outlier and is excluded from the regression.

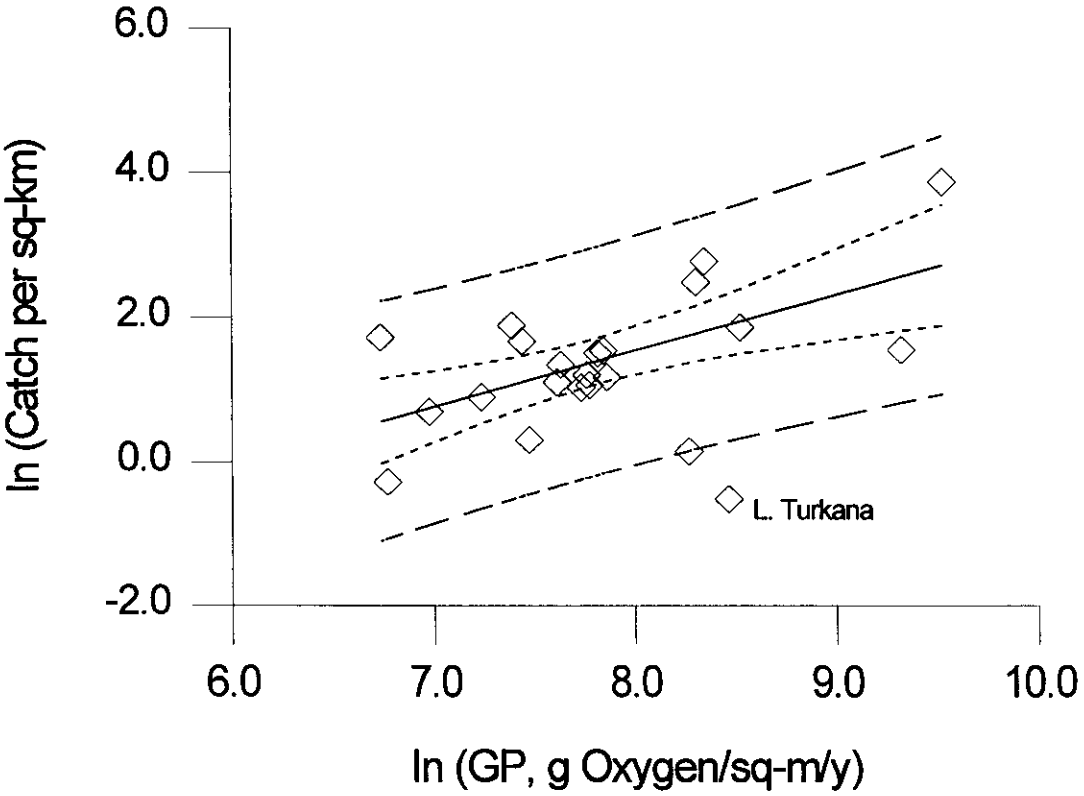
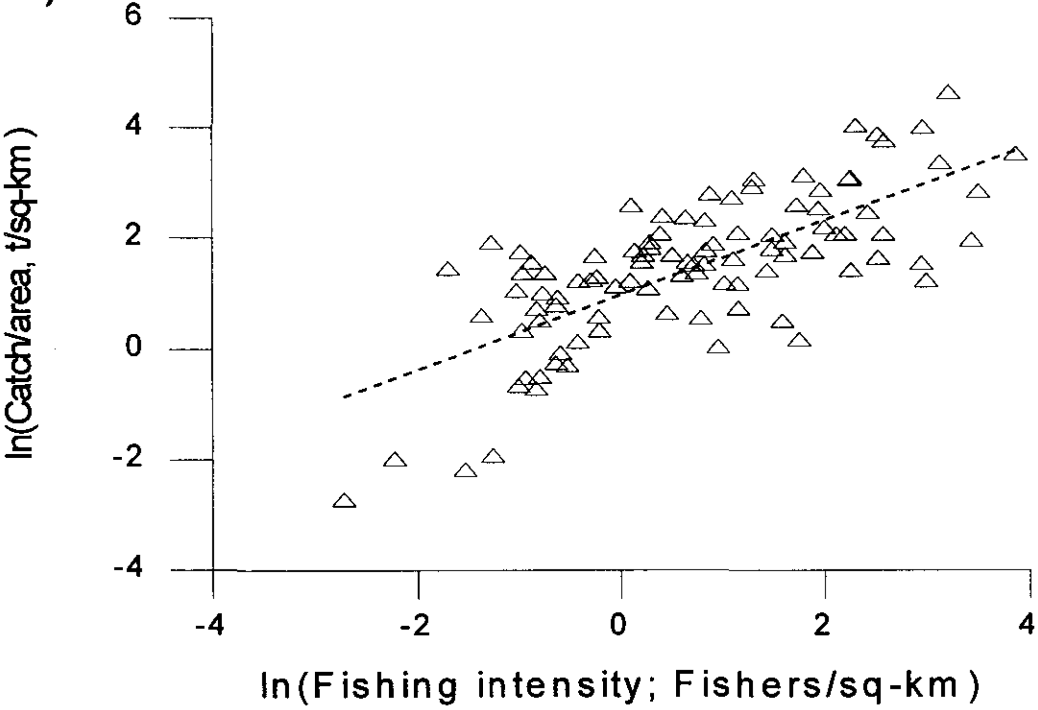
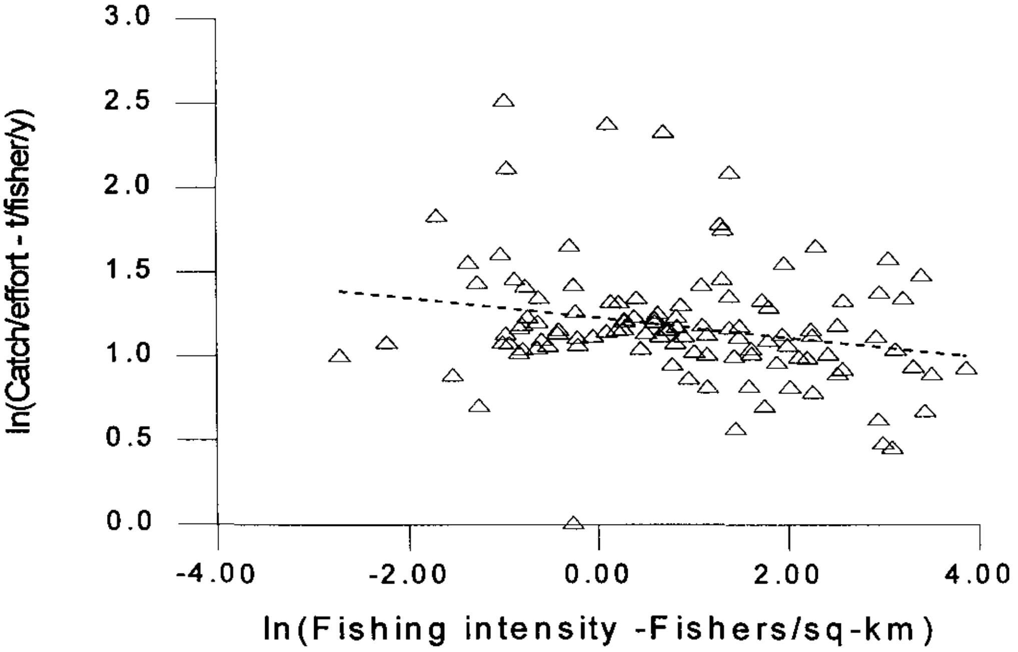


Figure 4 Relationships among a) catch per unit area, b) catch per fisher, and fishing intensity for African lakes and reservoirs. Regression statistics are reported in Table 11.

a)



b)



4 DISCUSSION

The database included with this report provides the most comprehensive attempt yet to compile basic information on tropical lake and reservoirs systems. The analyses presented here provide an introduction to the main relationships between fisheries and lake morphology, chemistry and biological, climatic and demographic features of water bodies and their catchments.

While relationships between area and catch and the number of fishers and catch are obvious, and account, on a large scale, for much of the variability in datasets comparing catches from a number of water bodies, they are not as useful for catch prediction as has sometimes been suggested. There has been a tendency in recent studies compiling large amounts of catch-area data to assume that because area accounts for most of the variance in a dataset, other explanatory variables can be ignored. These relationships are driven by the wide size range in area in most of these large datasets. If the analysis is restricted to lakes and reservoirs in the range 0.1-100 km^2 - covering the sizes of water bodies where this approach to yield prediction may be the only viable alternative - the relationship is less clear, and the scatter around any fitted line is great: harvests from some 10 ha Chinese Ponds exceed those for 100 km^2 African Lakes.

Catch-effort relationships, although characterized by high variability also, are perhaps more useful in obtaining a total catch estimate, as they appear to be based on a fairly ubiquitous basic economic requirement for a catch of 2-2.5 t $fisher^{-1}$ y^{-1} in tropical inland artisanal fisheries (Crul, 1992 and this study). Although useful in estimating catch in a fishery given only effort data and the assumption that the effort is sustainable, these models cannot provide a prediction of the fishery potential of new lakes and reservoirs, or ones which are unexploited, under-exploited or simply lack the required information.

Incorporation of biological, chemical and other variables in the basic catch-area relationship was successful to a limited degree. Data availability is patchy, making more complex multi-variate models difficult to apply. There do not appear to be one or two parameters that can be universally applied to account for the variability in catch-area relationships on a large scale. Conductivity, the mainstay of such relationships in the past, is not correlated to productivity when used to compare chemically diverse systems.

Several parameters have been shown to account for some of the variations in catch for more restricted data sets (e.g. large African lakes, stocked Asian lakes and reservoirs), but the relative importance of some of these parameters (total phosphorus, chlorophyll *a*) appears to be highly variable among systems. This must be partly due to the diversity of production systems supporting tropical fish communities - phosphorus is not always the limiting nutrient, phytoplankton is not always the major source of primary production - but the issue of data quality should not be overlooked. When dealing with the relatively small datasets that result from inclusion of some of the biological productivity parameters, one or two unreliable data points can have a significant effect.

It is perhaps better, at the purely practical level of trying to develop useful predictive models, to move away from the large, overviews - the search for a unifying model - exemplified by this and other recent studies (Downing *et al.,* 1990; Crul, 1992,) and, instead, to select subsets of data for more detailed regional analyses. It was from this regionally-restricted type of study that the morphoedaphic index was developed (Ryder *et al.,* 1982). If accurate predictions for individual water bodies are required (rather than a whole-country estimate based on an inventory of waterbodies) then regional comparisons may be the way forward. Recent examples include the studies of Moreau & De Silva (1991) on Sri Lanka, Thailand and the Philippines, Marshall & Maes (1994) on the small waterbodies of Southern Africa, Quiros (1991; 1993) on Argentina, and Paiva *et al.,* (1994) on the reservoirs of NE Brazil. This database provides some scope for this type of study, and has enabled identification of areas where a programme of data collection and model testing may take place (Section 4.3).

A major requirement for comparative study on the productive basis for inland aquatic ecosystems is the source of primary production. It is notable that phytoplankton productivity is routinely collected, even for systems which are supported largely by other sources of production. Secchi disk readings and gross phytoplankton photosynthesis tell you nothing about productivity in a weed-choked turbid tropical impoundment and yet these data are routinely reported, while measurement of suspended solids and macrophyte production are overlooked. There is a need for inclusion of the contribution of other sources of production in studies of the systems supporting fisheries. Measurement of dissolved organic carbon and macrophyte and epiphyte or periphyton biomass and production should complement studies of planktonic algal photosynthesis, particularly in floodplains, swamps, shallow lakes and reservoirs with low hydraulic residence times and high turbidity.

The studies presented here have been least successful when applied to lakes and reservoirs that support a mixture of capture fisheries based on wild stocks, capture fisheries based on the regular release of stocked fingerlings, and various ranching and aquaculture activities. It was not possible to collect the required data to account for the relative importance and intensity of these activities in the context of this type of study. Once again, regionally focused comparative studies of culture-based systems may provide useful insights into productive potential of these systems. Liang *et al.,* (1981) have shown that primary productivity and fish yields are correlated in Chinese culture-based systems, and their dataset, supplemented by additional studies, has been used here to demonstrate a relationship between total phosphorus and fish yields.

Further scope exists for refining the analyses presented here, with more detailed consideration of some of the categorical variables (fish type etc.,) as dummy variables in multiple regression equations. Land use categories could have an important bearing on lake productivity, but detailed data are not available. These and other gaps in the database are outlined below.

Attempts to incorporate variables related to fish community structure in relationships with fish yields show some promise, but are once again hampered by lack of data. The decision to use trophic level at which the fish are harvested as a variable was ambitious, in the light of the scarcity of food web studies for whole systems in the tropics. A recent study in Brazil (Paiva *et al.,* 1994) observed a relationship between fish yields and the number of predatory fish species in a series of reservoirs, and this approach shows some promise, despite inherent problems in deciding whether fish with highly variable diets are predatory or not, and number of species of predator being a rather coarse measure of community structure (no account taken of predator numbers or biomass).

4.1 Gaps in the Database

Synthesis of the tropical limnology, lake and reservoir catchment studies and fishery data has revealed areas where little data is available. Major data requirements are:

i) Socio-economic studies of fishing communities, particularly for Latin America, where basic surveys of the number of fishers and number of boats operating are not widely available. Per capita fish consumption surveys and fish trade statistics at the catchment/individual waterbody level may be useful for comparative studies, but are not generally available.

ii) Land-use and demographic surveys at the catchment level. GIS could be useful in obtaining land use information, while regional population density figures could be used as a substitute for catchment-based figures.

iii) The basis for production. Phytoplankton photosynthesis, as a measure of system primary productivity, and therefore potential fish production, is routinely measured in systems, even if it is evident that this is unlikely to be the major primary carbon source. Where an estimate of primary production is required, consideration should be given to including macrophytes and periphyton (directly important food resources to Tilapia and grass carp) and allochthanous input (important to detritivorous fish in forest and floodplain lakes) as well as planktonic algae.

iv) Catch statistics were not located for some major Latin American lakes and reservoirs - Guri, Brokopondo, Lake Valencia, and recent data are not available for several other major lakes, e.g. Xolotlan (Nicaragua) and Managua. In Asia, available catch statistics for Bung Boraped (Thailand) and Laguna de Bay (Philippines), two of the continent’s major inland fishery systems, are scarce in the former case, and contradictory in the latter. For some of the major shared lakes in Africa, particularly L. Tanganyika and L. Malawi, catch data series are not available from all countries bordering the lakes, and whole-lake catch estimates are unreliable (Greboval *et al.,* 1994).

v) Basic morphometric data were not available for some lakes for which catch statistics have been given. These data can be obtained from GIS or large-scale maps.

vi) Another potential determinant of yield to fisheries, not considered in most studies and omitted from the present database, is competition between man and other piscivores. In Lake Muhazi, the annual consumption of fish by otters is estimated to exceed annual fishery landings, and this lake is an outlier in catch-area-primary production studies. Bird predation is potentially important in many shallow, wetland ecosystems.

4.2 Obtaining Additional Catch Statistics

Morphometric, hydrological, chemical and biological data are available, to a variable extent, for over 2000 lakes for which no catch statistics are presently available. Most of these are small waterbodies, where detailed surveys are unlikely to be possible. For some of the larger waterbodies, data may be available but unpublished. It is hoped that these data will become available through future updates of this database. Preliminary estimates of catch of other waterbodies with existing fisheries could be made most cheaply by collecting data on the number of boats or fishers active on the waterbody. This requires less time and technical expertise than obtaining an estimate of fish landings. The general recommendation is, in resource-limited situations, to direct resources at estimating fishing effort rather than catches, as the relationship between effort and sustainable catch in artisanal fisheries seems to be fairly strong (except in stocked Asian lakes and reservoirs).

Bayley & Petrere (1989) use per capita fish consumption and catchment population statistics to estimate fish landings in the Amazon basin. With a knowledge of fish imports and exports into an area, or assumption that they are negligible, where appropriate, similar data may give a more reliable fish landings estimate than figures based on frame surveys and samples at landing stations.

4.3 Application and Dissemination of Database and Empirical Models

The empirical models deduced in this report can be applied to a wide range of developing country inland fishery assessment studies, although it must be borne in mind that the estimates have very low precision (wide confidence intervals). Scope also exists for use of the database in disciplines outside fisheries, such as catchment management planning, sectoral reviews, environmental audits and reviews of water quality and management issues. A number of possibilities for empirical modelling of other aspects of aquatic ecology and water resource management are reviewed in Appendix 3.

There are several possible regions where resource inventories and limnological surveys could be combined with fishery surveys to test further some of the models proposed here. There is little recent data on fish catches in Central America, with the exception of Mexico. Nicaragua, Honduras and Costa Rica have large numbers of small waterbodies, but the extent of their exploitation, or possibilities for fish production, are largely unknown. Nigeria has a large number of waterbodies, but inland fish catch assessments are centred on Lake Kainji and fishery surveys of other, smaller waterbodies are required. Malaysia and Indonesia also provide possible areas for application of more regionally focused studies.

The report and database will be distributed to interested national and international development agencies, non-governmental organisations, research organisations, national fisheries and natural resource ministries in developing countries with fishery interests and individuals with an interest in the empirical approach to yield prediction.

Dissemination of the report and database could be enhanced by distributing a summary of this report on ICLARM's Network for Tropical Fishery Scientists News Bulletin, published in NAGA magazine. Posting a copy of the summary on appropriate electronic news networks (e.g. FISH-ECOLOGY, FISHERIES, SCI.BIOL.FISHERIES) may also help to reach a wider audience. Publication of the major findings of the report, together with a review of the models, in a primary refereed journal would enhance the credibility of the study and ensure wider use.

While this report suggests some appropriate models, it is not possible to recommend models for every situation. Appropriate future use of the empirical models described here might be enhanced by creation of a simple 'expert system' that would enable users to select the most appropriate model for prediction on the basis of the type of information at their disposal and the type of water body for which the assessment is required. The system would apply the models and provide an estimate of confidence intervals around the yield prediction, as well as warning of any outliers that were encountered in deducing the relationship.

5 CONCLUSIONS

1 Simple models relating fish catches to area and volume and to number of boats or fishers, both good measures of fishing effort in artisanal fisheries, are most useful in predicting yield to fisheries on a global or continental scale.

2 Simple area-catch and catch-effort relationships have many outliers, some of which can be accounted for by the inclusion of other variables, such as altitude, catchment area and rainfall, volume and maximum depth. The application of multiple regression models incorporating 2-3 of these morphological and climate-related variables is hampered by lack of datasets including all these parameters for the same lakes, as well as catch and effort data.

3 The simple chemical and biological variables traditionally collected (conductivity, chlorophyll *a*, gross phytoplankton photosynthesis) do not sufficiently represent the diversity of production systems covered by the present dataset, and are not therefore useful predictors of fishery potential, except in the cases of culture-based systems in Asia, where direct links between chemical and biological indices of productivity and fish yield have been established, and in fairly large African lakes and reservoirs, where food chains supporting fish production are largely based on phytoplankton production:

4 Biological data on food web structure (secondary production, fish trophic levels etc) are potentially useful, but are not presently available and comparable over a large enough number of systems. Increasing interest in simple ecosystem models such as ICLARM's ECOPATH (Christensen & Pauly, 1991) should enable more comprehensive comparative studies in the future, provided such modelling studies encourage the collection and collation of new data, rather than reliance on literature and empirical estimates of parameter values.

5 Socio-economic, climate and land use data are potentially useful, but are not sufficiently available on a catchment basis to establish useful predictive relationships with fish yields. A significant relationship has been established between catchment rainfall and fish yield.

6 The morphoedaphic index, with its use of ratio data, does not allow investigation of the relative effects of area, conductivity and depth on determining fish yields. Conductivity itself is only a useful measure of productivity in series of chemically similar lakes with similar production systems and food webs. Very few, if any, such series of systems exist in the tropics and the morphoedaphic index should be rejected as a means of obtaining estimates of fisheries potential, unless studies focused on restricted regions indicate otherwise.

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APPENDIX 1 - Database Output

(i) List of Lakes included in the Secondary Database

A. Lisboa
Abaya
Abbe
Abijata
Aby-Tendo-Ehy L.C.
Acarau Nirim
Acarei
Agua Brava
Agua Roja
Aheme
Aires de Souza
Akulam
Alaotra
Albert
Aliyar
Alvarado
Amanari
Amaravathy
Amatitlan
Angat
Anggi Giji
Anggi Gita
Angostura
Anony
Apanas
Araras
Araruama
Aruba
Asejire
Atitlan
Avilés
Awassa
Ayame
Azilli
Baao
Babati
Badagiriya
Baghla
Bagula
Bahi
Bahia de Altata-Ensenada del Pabellon
Bahia de Ceuta
Bahia de Guasimas
Bahia de Jiquilasco
Bahia de Lobos
Bahia Santa Maria La Elementeita
Ever Good Harvest
Exp. pond New Spring Brigade
Exp. pond, August 1 Brigade
Reforma
Bahut
Bakolori
Bam
Bang Lang
Bang Pra
Bangweulu Lakes & Swamp
Bardawil
Baringo
Barra Bonita
Basuto
Bathalagoda
Bato
Begnas
Bening
Besbessia
Betania
Bhakra
Bhatgar
Bhavanisagar
Bhumipol
Biandan
Bioka Crater Lakes
Bir M'Chergua
Birira
Bisina
Bizerte
Bogoria
Bonita
Bou Grara
Buhi
Buigiri
Bukit Merah
Bulera
Buluan
Bung Boraped
Burigi
Burullus
Bustos/Angat
Butig
C.M. Céspedes
Cabeza de Toro, La Joya, Buenavista
Cahora Bassa
Caonao
Castillos
Catemaco
Exp. pond, Ever Good Harvest Commune
Fateh Sagar
Fergilha
Gaharwa
Garapota
Cedro
Cele
Ceuta
Chad 'normal'
Chaguin/Chuiga
Chala
Chamwale
Changshou-hu (Shizitun)
Chao-hu
Chapala
Chibumagwe
Chidong
Chila/Penitas
Chilka
Chilwa
Chintamani
Chisi
Chiuta
Chulaporn
Chuza
Cidra
Colorado
Cooperative
Cubano-Bulgaro
Cufada
Cuitzeo
Cyohoha
Dabalo
Dakataua
Dambulu Oya
Danao
Dapao
Darma
Dhir
Dighali Beel
Dok Krai
Donghu
Dongting-hu
Dos Patos
E. Rebelde
East
East Lake
Ebrie
Edku
Edward
El Bibane
El Punto
Gashanga
Gatun
General Sampaio
Gengala
George
Getalsud

Ghar El Melh
Giritale
Gombo
Gomukhi
Govindsagar
Grand Lahou
Grand Popo
Grande de Santa Maria
Great Lake
Guajaro
Guiers
Gulariya
Hago
Handapana
Hatiluhur
Haubi
Hombolo
Hope
Huizache-Caimanero
Hurulu Wewa
I.I.T.A.
Ibitinga
Ichkeul
Ico
Iguape-Cananeia
Igundu
Ihema
Ikimba
Ikowa
Ilopango
Infiernillo
Inginimitiya
Ink
Irmah Campos
Itasy
Itezhitezhi
Izabal
Jatiluhur
Jebba
Jebel Aulia
Jipe
Joaquim Tavore
Jumaguayú
Jupiá
Juventud
Kachira
Kafue Flats/Gorge
Kainji
Kala Wewa
Kandalama
Kang Kachan
Kangsabati
Mirayi
Mirim
Mirim, Imarui, Santo Antonio
Mlowa
Mogra
Mtera
Mugesera
Muhazi
Mujunju
Muktapur
Mulehe
Kanyanya
Kaptai
Karangkates
Karapola
Kariba
Kaudulla
Kayumba
Kelbia
Kerenge
Kew Lom
Khashm El Girba
Khenis
Kho Laem
Kidogo
Kigabagaba
Kijanebalola
Kilosa
Kindai
Kinkony
Kinneret
Kiri
Kirimbi
Kisaki
Kitangiri
Kivu
Kiziramere
Kodai
Koka (Galilea)
Kolleru
Konar D.V.C.
Kossou
Kotmale
Krasiew
Krishnagari
Krishnarajasagar
Kyahafi
Kyle
Kyoga Lakes Complex
L. Campos
La Jia
Lago do Rei
Lagos
Lagos & Lekki Lagoons
Laguna de Bay
Laguna de Bay
Lahor
Lake Wisdom
Lam Dom Noi
Lam Pao
Lam Praplern
Lam Takong
Lanao
Mulungushi
Mundau
Murago
Muthupet
Mutugalla
Mwadingusha
Mweru
Mweru Wa Ntipa
Myombo
Nachaduwa Wewa
Nagarjuna Sagar
Langeno
Las Adjuntas
Lebrije
Lekki
Lessos
Liamberi
Lower Reach
Lualaba Lak. Complex
Luhondo
Lukanga
Lunar
Lunugamwehera
Lusiwashi
Machine
Madarounfa
Madre de Tamaulipas
Maduru Oya
Maga
Magadi
Magat
Mahakandarawa
Mahavilichchiya Wewa
Mainit
Maji Ndombe
Malawi/Niassa
Malombe
Malpaso
Malya
Mampostón
Managua
Mandapam
Manimuthar
Manjalar
Mantasoa
Manyara
Manzalah
Maracaibo
Maravakandu
Mariut
Markonahalli
Masinga
Massingir
Máximo
McIlwaine
Mellah
Mellegue
Mettur
Mgori
Mianji
Miguel Aleman
Minerva
Minneriya
Naivasha
Najasa
Nakivali
Nam Oon
Nam Pong
Nam Pung
Nanak Sagar
Nasho
Nasser/Nubia
Naujan
Ndakolowu

Nebhana
Neusa
Ngami
Ngwazi
Nhumbu
Nicaragua
Nokoue
Nondwa
Nong Harn
North
Nova Avanhandava
Nueva Floresta
Nyabihoko
Nyamusingire
Nyumba Ya Mungu
Nzilo
Ogun
Okavango
Old River Bed
Ooty
Oros
Oualidia
Oubeira
Pacal
Padaviya
Padma
Pagusi
Paizhong
Pangalanes-East L.C.
Paniai
Pantapangan
Paoay
Parakrama Samudra
Paranoá
Pato
Patzcuaro
Pechiparai
Pereira de Miranda
Perinchani
Phewa
Pimburettewa
Piritu
Pompeu Sobrino
Pong
Pool Malebo
Port Foad
Porto Novo
Toho-Todougba, Ahouangau, Dati
Tsiazompaniry
Tucunduba
Tumba
Tungabhadra
Tunis
Turkana
Twali
Ubolratana
Udawalawe
Ukai
Ulhitiya Oya
Um El Rish
Unare
Upemba
Poyang
Pozo de Barro
Pozo de Piedra
Prado
Pranburi
Prijetan
Promissao
Pulangui IV
Pulicat
Qionghai
Quarun
Quixeramobim
Raghavpur
Rajangana
Rana Pratapsagar
Ravishankarsagar
Rawa Pening
Riachuelo
Riachuelo de Sangre
Ridiyagama
Rihand
Rio San Pedro
Rkiz
Robertson
Rocha
Roseires
Rugongi
Rugwero
Rukwa
Rushozi
Rutamba
Rwampanga
Rwanyakizinga
Rwehikama
Saka
Sake
Sakumo-Tema
Salado
Salvajina
San Blas
San Gabriel
San Mateo
San Pedro de Timbaub
San Vicente
Sancha-hu
Sandynulla (Kamarajasagar)
Uppaar
Usiulize
Vaigai
Varzea do Bo
Velame
Velankadu
Verzea de Vella
Victoria (Africa)
Victoria (Asia)
Vidur
Viet Nam
Volta
Wadi Rayan
Wamala
Water Chestnut
Weerawila
Santa Ana
Santa Maria
Santa Marta
Sathanur
Sattal
Sebu
Selorejo
Senenayaka Samudra
Sennar
Sentani
Serreia
Shalla
Shiroro
Shishiyu
Siligurijan
Singida
Sirikit
Sirinthorn
Sisga
South
Srinakarinth
Stanley
Sto. Anto. Aracatiacu
Sto. Anto. de Russas
Sub.
Sudd
Taal
Tabasco
Tabbowa
Tacarigua
Tagba-Ma-Tadio Compl
Tage
Tai-Hu
Tamiahua
Tana
Tanganyika
Temascal
Tenaggano
Tigi
Tilaiya
Tirumoorthy
Titicaca
Toba
Togbadji
Togo
Toho

Winam
Wisdom
Wlingi
Wood
Xin'anjiang
Yercaud
Yodawewa
Yu's
Zaza
Zwai

(ii) Example of Data Tables 1-6 in the Primary Database

Example of References Table - "XLTREF.DBF"

```
 AUTHORS: Abarca-Arenas, L.G. & E. Valero-Pacheco
   TITLE: Toward a trophic model of Tamiahua, a co
 EDITORS: Christensen, V. & D. Pauly
     ED2:
 JOURNAL: ICLARM Conference Proceedings
CONF_DAT:
CONF_WHE:
    CITY:
     WHO:
    YEAR: 1993
  VOLUME: 26
   ISSUE:
   PAGES: 181-185
SERIES_E:
SERIES_T:
SERIES_N:
   NOTES:
KEYWORDS:
REF_NAME: Abarca-Arenas & Valero-Pacheco, 1993
  REF_NR:        1
```

Example of Location and Morphology Data Table - "MORPHOLO.DBF"

```
CONTINEN: AFRICA
  W_TYPE: Lake
   INT_W:     0
 COUNTRY: Nigeria
ALTITUDE:
LATITUDE:
LONGITUD:
 YEAR_MD:
    AREA:     0.01
AREA_PAR:     0.01
AREA_MIN:
AREA_MAX:
   MAX_L:
   MAX_W:
   SHORE:
   Z_MAX:
  Z_MEAN:
 Z_FLUCT:
VOLUME_L:
RIVER_IN:
RIVER_OU:
CATCHMEN:
CONST_DA:
PERM_OPE:
 NOTES_2: In Imo State
  REF_NR:      280
   WB_NR:        1
```

Example of Hydrological Data Table - "HYDROLOG.DBF"

```
CONTINEN: AFRICA
  W_TYPE: Lake
   INT_W:     0
 COUNTRY: Ethiopia
  YEAR_T:
  S_TEMP:
   T_MIN:
   T_MAX:
   STRAT:
DAYS_MIX:
MIX_STAR:
 MIX_END:
   Z_MIX:
YEAR_RAI:
RAINFALL:    1000.
RN_START:
  RN_END:
RN_DURAT:
 W_RESID:
 NOTES_3:
  REF_NR:      142
   WB_NR:        6
CONTINEN: AFRICA
  W_TYPE: Lake
   INT_W:     0
 COUNTRY: Ethiopia
  YEAR_T:
  S_TEMP:      25.
   T_MIN:      22.
   T_MAX:      28.
   STRAT:
DAYS_MIX:
MIX_STAR:
 MIX_END:
   Z_MIX:
YEAR_RAI:
RAINFALL:
RN_START:
  RN_END:
RN_DURAT:
 W_RESID:
 NOTES_3:
  REF_NR:      281
   WB_NR:        6
```

Example of Chemical and Biological Data Table - "CHEMBIOL.DBF"

```
CONTINEN: AFRICA
  W_TYPE: Lake
   INT_W:     1
 COUNTRY: Djibouti
 YEAR_CD:
     TDS:
    COND:
 SALIN_L:
 SALIN_H:
      PH:     10.4
     ALK:    1060.
   TOT_P:
   TOT_N:
  SECCHI:
S_SOLIDS:
SURF_CHL:
 NM_CHLA:
AREAL_CH:
DOM_PHYT:
MACRO_BI:
PERI_BIO:
 GR_PHOT:
NET_PH_P:
MACRO_PD:
 PERI_PD:
ZOO_BIOM:
  ZOO_PD:
MBTHOS_B:
MBTHOS_P:
 NOTES_4: Alkaline soda lake
  REF_NR:      281
   WB_NR:        7
```

Example of Fisheries Data Table - "FISHERIE.DBF"

```
CONTINEN: AFRICA
  W_TYPE: Lake
   INT_W:     1
 COUNTRY: Ethiopia
 YEAR_FD:
   CATCH:       0.
NR_FISHE:
NR_BOATS:
BOAT_TYP:
F_BIOMAS:
  F_PROD:
STOCKING:     0
AQUACULT:     0
 FY_TYPE: NONE
  NO_SPP:
CATCH_SP:
INTRO_SP:
YR_INTRO:
ORIGIN_F:
FISH_TYP:
   F_DET:
F_PLANTS:
 F_ZOOPL:
F_PISC_M:
 NOTES_5: no fishing activity
  REF_NR:      281
   WB_NR:        7
```

Example of Demographic and Land Use Data Table - "DEMOGRAP.DBF"

```
CONTINEN: AFRICA
  W_TYPE: Reservoir
   INT_W:     0
 COUNTRY: South Africa
 YEAR_DD:    1967.
 CMT_POP:   20000.
POP_FISH:
 POP_PRI:
 POP_URB:
PC_FISHC:
 RFOREST:
  FOREST:
   SCRUB:      15.
   GRASS:      10.
   SWAMP:
   MOUNT:
  DESERT:
  ARABLE:      50.
 PASTURE:      10.
   PLANT:      10.
   URBAN:       5.
   W_USE:
W_USETYP: Domestic/Recreation
POLLUTIO:       0.
POLL_TYP:
 NOTES_6: % land use estimated from general statem
  REF_NR:       16
   WB_NR:       36
```

Example of The Secondary Database - "SECONDAR.DBF"

```
CONTINEN: AFRICA
 WB_TYPE: Lake
 COUNTRY: Ethiopia
ALTITUDE:                                 1285.
LATITUDE: 06°19'N
    AREA:                                 1162.
   SHORE:                                  225.
   Z_MAX:                                   13.
  Z_MEAN:                                   7.1
 Z_FLUCT:
  VOLUME:        7924000000.00
CATCHMEN:   17300.
CONST_DA:
PERM_OPE:
  S_TEMP:      25.
   T_MIN:      22.
   T_MAX:      28.
   STRAT:
DAYS_MIX:
   Z_MIX:
RAINFALL:    1000.
RN_DURAT:
 W_RESID:
     TDS:     517.
    COND:    925.2
 SALIN_L:
 SALIN_H:     0.84
      PH:     8.82
     ALK:     8.44
   TOT_P:   272.33
   TOT_N:     650.
  SECCHI:     0.43
S_SOLIDS:
SURF_CHL:      37.
AREAL_CH:
DOM_PHYT: Cyanophyta
MACRO_BI:
PERI_BIO:
 GR_PHOT:
NET_PH_P:
MACRO_PD:
 PERI_PD:
ZOO_BIOM:
  ZOO_PD:
MBTHOS_B:
MBTHOS_P:
 YEAR_FD: 1975-81
   CATCH:     128.
NR_FISHE:     250.
NR_BOATS:     100.
BOAT_TYP:
F_BIOMAS:
  F_PROD:
STOCKING:
AQUACULT:
 FY_TYPE:
  NO_SPP:      25.
CATCH_SP:
INTRO_SP:
```

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Appendix 2 - Summary Statistics for Simple and Multiple Regression Predictors of Potential or Sustainable Fish Yields for Tropical Lakes and Reservoirs

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Dependent variable in all cases is ln(Catch) and all independent variables were log-transformed prior to analysis.

A) MODELS FOR ALL CONTINENTS - LAKES AND RESERVOIRS

a) Models independent of fishing effort, capture fisheries

Model 1: Area, Altitude

```
DEP VAR:LOGCATCH     N:     132  MULTIPLE R: 0.843  SQUARED MULTIPLE R: 0.711
ADJUSTED SQUARED MULTIPLE R:  .706    STANDARD ERROR OF ESTIMATE:       1.535

VARIABLE     COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT          3.844           0.726          0.000                .       5.297    0.000
LOGAREA           0.891            0.052          0.819             0.996   17.255    0.000
LOGALT           -0.342            0.104         -0.156             0.996   -3.280    0.001

                ANALYSIS OF VARIANCE

SOURCE      SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO      P

REGRESSION      746.849          2          373.425           158.536      0.000
RESIDUAL        303.853        129            2.355
```

Model 2: Area, Catchment area, Catchment rainfall.

```
DEP VAR:LOGCATCH     N:      32  MULTIPLE R: 0.844  SQUARED MULTIPLE R: 0.712
ADJUSTED SQUARED MULTIPLE R:  .681    STANDARD ERROR OF ESTIMATE:       1.543

VARIABLE     COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT         -10.502          5.001          0.000              .        -2.100    0.045
Ln(AREA)           0.484          0.215          0.447           0.260      2.249    0.033
Ln(CATCHMENT)     0.451          0.212          0.438           0.242      2.123    0.043
Ln(RAINFALL)      1.573          0.645          0.269           0.842      2.439    0.021



                     ANALYSIS OF VARIANCE

SOURCE      SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO      P

REGRESSION      165.090          3           55.030           23.102      0.000
RESIDUAL         66.697         28            2.382
```

b) Models independent of fishing effort, for capture and culture-based fisheries.

Model 3: Area, gross photosynthesis

```
 DEP VAR:LOGCATCH      N:      72  MULTIPLE R: 0.832  SQUARED MULTIPLE R: 0.693
 ADJUSTED SQUARED MULTIPLE R:  .684    STANDARD ERROR OF ESTIMATE:        1.692

 VARIABLE     COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

 CONSTANT          -0.090             1.679            0.000            .            -0.053    0.958
 Ln(AREA)           0.842             0.069            0.815          0.985       12.117    0.000
 Ln(GR_PHOT)        0.331             0.230            0.097          0.985         1.439    0.155

                  ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION        445.143            2          222.572            77.718      0.000
 RESIDUAL          197.605           69             2.864
```

c) Models including fishing effort

Model 4: Area, number of fishers

```
 DEP VAR:LOGCATCH      N:     163  MULTIPLE R: 0.916  SQUARED MULTIPLE R: 0.839
 ADJUSTED SQUARED MULTIPLE R:  .837    STANDARD ERROR OF ESTIMATE:        0.909

 VARIABLE     COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

 CONSTANT           1.048             0.207             0.000              .          5.072    0.000
 Ln(AREA)           0.221            0.048             0.250            0.350        4.652    0.000
 Ln(FISHERS)         0.762             0.058             0.703            0.350      13.090    0.000


                  ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION        687.105            2           343.553           415.479      0.000
 RESIDUAL          132.301          160             0.827

 WARNING: L. ATITLAN IS AN OUTLIER (STUDENTIZED RESIDUAL =      -2.807)
 WARNING: SALVAJINA R. IS AN OUTLIER (STUDENTIZED RESIDUAL = -2.682)
```

B) AFRICAN LAKES AND RESERVOIRS

a) Models independent of fishing effort

Model 5: Area

```
 DEP VAR:LOGCATCH      N:     133  MULTIPLE R: 0.903  SQUARED MULTIPLE R: 0.816
 ADJUSTED SQUARED MULTIPLE R:  .815    STANDARD ERROR OF ESTIMATE:        1.083

 VARIABLE     COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

 CONSTANT           2.590             0.174            0.000             .         14.909    0.000
 LOGAREA            0.816             0.034            0.903           1.000      24.118    0.000

                  ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION        681.880    1     681.880     581.695      0.000
```

```
 RESIDUAL          153.562   131        1.172
```

Azilli (Benin) and Mellegue (Tunisia) remain as outliers when Abaya, Tana, Ikimba and Burigi have been excluded.

Model 6: Area, maximum depth

```
 DEP VAR:LOGCATCH      N:      83  MULTIPLE R: 0.906  SQUARED MULTIPLE R: 0.820
 ADJUSTED SQUARED MULTIPLE R:  .816    STANDARD ERROR OF ESTIMATE:        1.036

 VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

 CONSTANT          2.625           0.288          0.000          .      9.127    0.000
 LOGAREA          0.879            0.052          0.940       0.727   16.915    0.000
 LOGZMAX         -0.121            0.096         -0.070       0.727   -1.262    0.211

                   ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION       392.079          2        196.039           82.656      0.000
 RESIDUAL          85.862         80          1.073
```

Model 7: Area, Volume

```
DEP VAR:LOGCATCH      N:      85  MULTIPLE R: 0.941  SQUARED MULTIPLE R: 0.885
 ADJUSTED SQUARED MULTIPLE R:  .883    STANDARD ERROR OF ESTIMATE:        0.871

 VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

 CONSTANT          3.036          0.700          0.000           .        4.336    0.000
 LOGAREA           0.950          0.062          1.016        0.315    15.245    0.000
 LOGVOL           -0.063           0.045        -0.092        0.315     -1.383    0.171

                    ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION       480.783          2           240.391       316.644      0.000
 RESIDUAL          62.253         82             0.759
```

Mellegue, Kyoga Lakes Complex and Nyumba Ya Mungu are outliers - excluded.

Model 8: Area, gross photosynthesis.

```
 DEP VAR:LOGCATCH      N:      20  MULTIPLE R: 0.977  SQUARED MULTIPLE R: 0.954
 ADJUSTED SQUARED MULTIPLE R:  .949    STANDARD ERROR OF ESTIMATE:        0.551

 VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

 CONSTANT         -3.625           1.453          0.000         .         -2.496    0.023
 LOGAREA           0.867           0.046          0.977       0.985     18.729    0.000
 LNGRPHOT          0.780           0.175          0.233       0.985      4.464    0.000

                    ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION       108.080          2         54.040            177.819      0.000
 RESIDUAL           5.166         17         0.304
```

Lakes Turkana and Muhazi (Rwanda) are outliers and have been excluded.

b) Models that include fishing effort

Model 9: Area, number of fishers

```
 DEP VAR:LOGCATCH      N:      98  MULTIPLE R: 0.934  SQUARED MULTIPLE R: 0.871
 ADJUSTED SQUARED MULTIPLE R:  .869    STANDARD ERROR OF ESTIMATE:        0.928

 VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)

 CONSTANT           1.065             0.254            0.000             .          4.196      0.000
 LOGAREA           0.332             0.067            0.371           0.240       4.948     0.000
 LNFISHER          0.653             0.083            0.592           0.240       7.882     0.000

                       ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION       554.204            2          277.102              321.936       0.000
 RESIDUAL            81.770           95             0.861
```

Model 10: Area, number of boats

```
DEP VAR:LOGCATCH      N:      74  MULTIPLE R: 0.944  SQUARED MULTIPLE R: 0.891
 ADJUSTED SQUARED MULTIPLE R:  .888    STANDARD ERROR OF ESTIMATE:        0.866

 VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)

 CONSTANT           1.806             0.250              0.000              .         7.213    0.000
 LOGAREA           0.377             0.065              0.439            0.268     5.803    0.000
 LNBOATS          0.622             0.087              0.540            0.268      7.133    0.000

                       ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION       435.158           2           217.579            289.888       0.000
 RESIDUAL            53.290          71               0.751
```

Model 11: Area, number of boats, number of fishers.

```
 DEP VAR:LOGCATCH      N:      64  MULTIPLE R: 0.951  SQUARED MULTIPLE R: 0.904
 ADJUSTED SQUARED MULTIPLE R:  .899    STANDARD ERROR OF ESTIMATE:        0.847


VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)

 CONSTANT           1.484              0.331             0.000             .          4.481    0.000
 LOGAREA           0.326              0.084             0.386            0.164      3.897    0.000
 LNBOATS           0.342              0.167             0.302            0.074      2.052    0.045
 LNFISHER          0.322              0.199             0.292             0.050     1.623    0.110

                       ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION       403.666            3           134.555            187.446       0.000
 RESIDUAL            43.070          60              0.718
```

Model 12: Area, gross photosynthesis and number of fishers

```
 DEP VAR:LOGCATCH      N:      19  MULTIPLE R: 0.978  SQUARED MULTIPLE R: 0.957
```

```
ADJUSTED SQUARED MULTIPLE R:  .948    STANDARD ERROR OF ESTIMATE:        0.545

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT          -3.000          1.492          0.000          .        -2.011    0.063
LOGAREA            0.680          0.132          0.752        0.136       5.159    0.000
LNGRPHOT           0.645          0.194          0.200        0.800       3.319    0.005
LNFISHER           0.235          0.152          0.226        0.135       1.543    0.144

                   ANALYSIS OF VARIANCE

SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

REGRESSION        98.063        3       32.688        110.076      0.000
RESIDUAL           4.454       15        0.297
```

C) ASIAN LAKES & RESERVOIRS

a) Models independent of fishing effort, capture fisheries.

Model 13: Area, Altitude

```
DEP VAR:LOGCATCH      N:      25  MULTIPLE R: 0.893  SQUARED MULTIPLE R: 0.797
ADJUSTED SQUARED MULTIPLE R:  .779    STANDARD ERROR OF ESTIMATE:        1.690

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT           5.568          1.876          0.000          .         2.969     0.007
LOGAREA            0.859          0.157          0.651        0.651       5.469     0.000
LOGALT            -0.700          0.247         -0.338        0.651      -2.839     0.010

                   ANALYSIS OF VARIANCE

SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

REGRESSION       246.968        2      123.484         43.231      0.000
RESIDUAL          62.841       22        2.856
```

Model 14: Area, altitude, maximum depth.

```
DEP VAR:LOGCATCH      N:      22  MULTIPLE R: 0.922  SQUARED MULTIPLE R: 0.850
ADJUSTED SQUARED MULTIPLE R:  .825    STANDARD ERROR OF ESTIMATE:        1.527

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT           6.155          1.735          0.000             .      3.548    0.002
LOGAREA            0.654          0.180          0.509         0.421    3.625    0.002
LOGALT            -0.961          0.264         -0.486         0.466   -3.634    0.002
LOGZMAX            0.462          0.331          0.158         0.646    1.396    0.180

                   ANALYSIS OF VARIANCE

SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

REGRESSION       238.622        3       79.541         34.097      0.000
RESIDUAL          41.990       18        2.333
```

b) Models that include fishing effort, capture fisheries

Model 15: Area, number of fishers

```
DEP VAR:LOGCATCH      N:      50  MULTIPLE R: 0.895  SQUARED MULTIPLE R: 0.801
```

```
ADJUSTED SQUARED MULTIPLE R:  .793    STANDARD ERROR OF ESTIMATE:        0.697

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT          1.368            0.342          0.000            .      3.997    0.000
LOGAREA           0.133            0.090          0.121         0.635    1.482    0.145
LNFISHER          0.800            0.080          0.817         0.635   10.006    0.000

                 ANALYSIS OF VARIANCE

SOURCE      SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO      P

REGRESSION        92.031          2         46.015          94.643      0.000
RESIDUAL          22.851         47          0.486
```

Bhumipol, Thailand, is an outlier (excluded).

c) Models independent of fishing effort, culture-based fisheries

Model 16: Area, Total phosphorus

```
DEP VAR:LOGCATCH      N:      23  MULTIPLE R: 0.909  SQUARED MULTIPLE R: 0.827
ADJUSTED SQUARED MULTIPLE R:  .810    STANDARD ERROR OF ESTIMATE:        0.609

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT          2.422          0.467          0.000            .        5.191    0.000
Ln(AREA)          0.593          0.061          1.238          0.533      9.722    0.000
Ln (TP)           0.519          0.089          0.744          0.533      5.842    0.000

                 ANALYSIS OF VARIANCE

SOURCE      SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO      P

REGRESSION        35.536          2         17.768          47.863      0.000
RESIDUAL           7.425         20          0.371
```

High altitude L. Begnas (Nepal) and two Chinese Lakes (Water Chestnut, Ever Good Harvest Pond) are outliers and have been excluded.

There were no useful relationships incorporating number of fishers or number of boats.

D) LATIN AMERICA

a) Models independent of fishing effort

Model 17: Area

```
DEP VAR:LOGCATCH      N:      82  MULTIPLE R: 0.744  SQUARED MULTIPLE R: 0.553
ADJUSTED SQUARED MULTIPLE R:  .548    STANDARD ERROR OF ESTIMATE:        1.328

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT          2.845          0.258          0.000            .       11.021    0.000
LOGAREA           0.678          0.068          0.744          1.000      9.958    0.000



                 ANALYSIS OF VARIANCE

SOURCE      SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO      P
```

```
REGRESSION       174.984            1             174.984         99.153      0.000
RESIDUAL        141.183            80               1.765
```

b) Models including fishing effort

Model 18: Number of fishers

```
DEP VAR:LOGCATCH      N:      17  MULTIPLE R: 0.875  SQUARED MULTIPLE R: 0.765
ADJUSTED SQUARED MULTIPLE R:  .750    STANDARD ERROR OF ESTIMATE:        1.004

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT          -1.141             1.149             0.000              .       -0.993    0.336
LNFISHER           1.255              0.179             0.875           1.000      6.992    0.000

                      ANALYSIS OF VARIANCE

SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

REGRESSION        49.235            1          49.235                48.883      0.000
RESIDUAL         15.108            15          1.007
```

Model 19: Area, number of fishers

```
DEP VAR:LOGCATCH      N:      14  MULTIPLE R: 0.892  SQUARED MULTIPLE R: 0.796
ADJUSTED SQUARED MULTIPLE R:  .759    STANDARD ERROR OF ESTIMATE:        1.044

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT          -1.292                1.260             0.000            .        -1.025    0.327
LNFISHER            1.218               0.229              0.859         0.713       5.328    0.000
LOGAREA             0.064               0.175              0.058          0.713      0.362    0.724

                      ANALYSIS OF VARIANCE

SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

REGRESSION        46.760            2          23.380              21.458      0.000
RESIDUAL         11.985            11           1.090
```

E) COASTAL LAGOONS - ALL CONTINENTS

a) Models that are independent of fishing effort data

Model 20: Area

```
DEP VAR:LOGCATCH      N:      66  MULTIPLE R: 0.739  SQUARED MULTIPLE R: 0.545
ADJUSTED SQUARED MULTIPLE R:  .538    STANDARD ERROR OF ESTIMATE:        1.450

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

CONSTANT           2.293              0.537             0.000           .            4.268    0.000
LOGAREA            0.900              0.103             0.739        1.000          8.764    0.000


                      ANALYSIS OF VARIANCE

SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

REGRESSION       161.505            1          161.505             76.812      0.000
```

```
 RESIDUAL           134.566          64          2.103
```

b) Models that include fishing effort

Model 21: Area, number of fishers.

```
 DEP VAR:LOGCATCH     N:     26  MULTIPLE R: 0.924  SQUARED MULTIPLE R: 0.854
 ADJUSTED SQUARED MULTIPLE R:  .842    STANDARD ERROR OF ESTIMATE:       0.763

 VARIABLE     COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)

 CONSTANT          1.450           0.585          0.000            .      2.481    0.021
 LOGFM             0.576           0.126          0.598        0.372      4.583    0.000
 LOGAREA           0.427           0.148          0.376        0.372      2.880    0.008

                       ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P

 REGRESSION        78.584           2          39.292          67.493      0.000
 RESIDUAL          13.390          23           0.582
```

Ghar El Melh, Tunisia (low temperature) and Maracaibo, Venezuela (polluted, deep, meromictic coastal lake) are outliers and are excluded.

Appendix 3 - Some Potential Uses of the Database in Comparative Studies of Freshwater Ecosystems.

The prediction of limnological and biological variables from statistical relationships that are not well defined theoretically, known as empiricism, has its proponents (Rigler, 1982; Peters, 1986) and detractors (Lehman, 1986). Those against empiricism contend that it offers no insight or understanding into the function of systems, and propose the use of experimental studies and species-abundance modelling. The empiricists contend that this approach may tell you a lot about the system you are working on, but does not necessarily lead to an increase in general understanding, nor in the predictive ability sought by those who manage aquatic ecosystems for water quality or fisheries. The empiricist case is that demonstrating a relationship empirically leads to the generation of hypotheses concerning the causative mechanisms underlying the relationship. These hypotheses can then be tested experimentally, so that empirical modelling is in fact an important stage in gaining understanding.

Since Ryder's (1965) morphoedaphic index for the prediction of fish yields and Schindler's (1978) models for predicting eutrophication from phosphorus loadings there has been continuing interest in empirical modelling for lake management (Quiros, 1988; Seip & Ibrelkk, 1988; Downing *et al.,* 1990). Presented below is a brief review of some empirical models pertinent to the management of lakes, reservoirs and coastal lagoons. Many of these relationships could be explored further using this database.

Mixing depth

The mixing of water masses has an important influence of the chemistry and productivity of lakes (Talling, 1969; 1993), and several models exist to predict the depth of mixing from lake morphometry (reviewed by Hanna, 1990); the best predictor variables are effective maximum length (= max. length in regularly shaped lakes), or if not available, area and shoreline length. Size and water clarity have been related to epilimnetic depth by Mazumder & Taylor (1994). It should be noted that fish and plankton are thought to affect lake temperature statification and mixing depth (top-down effects (Mazumder et al., 1990). Mixing depth shows a latitudinal cline, being generally greater at lower latitudes in lakes (Patalas, 1984).

Estimation of phytoplankton biomass and primary productivity

A number of relationships exist for predicting the biomass of phytoplankton from phosphorus concentration (McQueen et al., 1986, for review). All relationships given use Chlorophyll *a* as an index of phytoplankton biomass, and both Chlorophyll *a* and total phosphorus are measured in $\mu g\ l^{-1}$. Nicholls & Dillon (1978) point out that the cellular chlorophyll content of algae varies by two orders of magnitude (0.1-9.7% of fresh weight) and suggest that relationships between total phosphorus and average summer cell volume are preferable for establishing predictive models for algal biomass estimation.

Most models to predict primary production are derived from studies of temperate lakes, where eutrophication is a major management issue. Only Brylinsky & Mann (1973) provide a global analysis of the factors governing algal productivity, based on data from the International Biological Programme. On a global scale, variables related to energy availability (latitude, altitude, input of solar radiation) have a greater effect in determining primary productivity than nutrient availability. Outside north-temperate waters, there is some indication that total nitrogen is the nutrient that has the closest relationship to productivity variations, even though much of measured total nitrogen is in the form of organic compounds unavailable to plants, although it can be incorporated in higher trophic level through the detritus food web.

Estimation of detrital biomass

The standing crop of detritus (D; gC m-2) in an aquatic ecosystem can be predicted from the primary production in that system (Pp; gC m-2 yr-1) and the depth of the euphotic zone (E; m)

$$\mathrm{log10D} = 0.954\ \mathrm{log10Pp} + 0.863\mathrm{log10E} - 2.41;\quad n = 14,\ r = 0.52$$

(cited in Christensen & Pauly, 1991)

This rather supposes that most detritus is in the form of autochthanous material (ungrazed phytoplankton, zooplankton faeces etc).

Estimation of zooplankton biomass and secondary production.

A number of empirical relationships between zooplankton biomass (g l^{-1} dry weight or wet weight) and chlorophyll *a* have been proposed (reviewed in McQueen *et al.,* 1986). An extensive analysis based on 164 invertebrate populations in 51 lakes covering all latitudes has derived a relationship between secondary production (P_s), annual mean biomass (B; g dry wt m^{-2}) and maximum individual body mass (W_{max}; mg dry wt) and the surface temperature (T; C):

$$\mathrm{log}P = 0.06 + 0.79\ \mathrm{log}B - 0.16\mathrm{log}W_{max} + 0.05T;\ n = 137,\ r = 0.89.$$

(Plante & Downing, 1989).

Other variables (e.g. depth, phosphorus concentration, pH, primary production) are also correlated with secondary production, but were not included in the predictive model.

The above equation could be used to predict P_s for each zooplankton species separately. Plante & Downing (1989) use the terms zooplankton, secondary producers and aquatic invertebrates synonymously, and it is not possible to discern from their paper whether only true secondary producers (i.e. phytoplankton grazers) should be included. Note that they mention the applicability of their equations to aquatic insects generally, and to chironomid larvae in particular.

The above discussion outlines but a few examples of potential uses; relationships between hydrology, climate and biological production are not available for the tropics, but would be of wide general interest. Users of the database are encouraged to develop their own comparative studies, and to add new parameters according to their interest.