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An interdisciplinary evaluation of the status and health of African lake fisheries using a rapid appraisal technique

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Data from biological, economic, sociological, and technological attribute lists for 32 African lake fisheries were analysed with multivariate statistics. Multidimensional scaling (MDS) was used to create two-dimensional graphic ordinations of the fisheries for each of these four attributes lists. An overall MDS ordination was also generated, based on the fisheries' scores in the four ordinations. Groupings in each MDS ordination were achieved through cluster analysis. Multiple correlations was used to help determine the attributes which were most important in creating the MDS ordinations. This work showed that relatively fast and simple assessments of the status of African lake and other fisheries can be achieved. The technique also provided insight to help resolve the confounding information often associated with fisheries assessment. Diagnostic information may also be a product of such investigations as this research identified African lake fisheries at risk of declining standards. Indeed, many of the fisheries studied demonstrated similar interdisciplinary symptoms of fisheries decline as other small-scale tropical fisheries.

Key words: ordination; multivariate; assessment.

INTRODUCTION

Fisheries in Africa have experienced significant recent change. This is especially true of lake fisheries, impacted by species change. A famous example of this was the introduction of the large Nile perch *Lates niloticus* into Lake Victoria (Reynolds & Greboval, 1988) and its subsequent dominance as top predator, creating an entirely new mix of species taken by small-scale fishers in Kenya, Uganda, and Tanzania. Another example of species change was the introduction of the small sardine *Limnothrissa miodon* in Lake Kariba (Marshall, 1995) and Lake Kivu (de Iongh *et al.*, 1995) which also resulted in entirely new fisheries. More ominous is the potential loss of biodiversity in Lake Malawi (Turner, 1995) where many species are still poorly defined yet threatened by extinction through the effect of being by-catch in fisheries on more numerous species.

Such biological issues do not exist in a vacuum, however. In developing nations, including those of Africa, there are also critical issues of economic and social change to consider which affect the fishery. For instance, up to 70% of the protein intake in Malawi may come from fisheries (Turner, 1995). This only hints at the magnitude of difficulties that might arise with declining fisheries. Hidden under such overt symptoms are more subtle problems such as Malthusian overfishing. Pauly (1994, 1997) introduced Malthusian overfishing as a concept to help explain the tendency to overfishing in small-scale fisheries of many developing countries. This pathology is a result of the interaction between

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human society, economics, and the ecology of an affected country. In many developing nations, the influence of social phenomena, such as the migration of landless peoples, has been well documented [Blaikie (1985) discussed such phenomena on terrestrial ecosystems].

Malthusian overfishing may result in a developing nation experiencing explosive population growth coupled with migration of dispossessed peoples to fishing areas. Fishery managers are often unwilling, or unable to restrict the entry of such newcomers. This results in the cessation of traditional management leading to human and natural community disturbances and the increased use of destructive and non-selective gears to maintain catches (Pauly, 1994, 1997).

Many of these symptoms have been observed in African lake fisheries. For instance, large increases in numbers of fishers and fishing effort have been noted in Zambia and Zimbabwe, on Lake Kariba (Marshall, 1992), the former experiencing an eightfold increase in fishing effort on the sardine fishery, the latter a fivefold increase in the 10 years to 1989. The Ugandan sector of Lake Victoria (Kudhongania *et al*., 1992), experienced an increase in the number of fishing canoes from about 3300 in 1971 to 8000 in 1990. The Tanzanian sector of Lake Victoria has experienced even more dramatic increases in the numbers of fishers (Mwamoto & Hoza, 1992). The fourfold increase in landings, between 1974 and 1990, for the Kenyan sector of Lake Victoria reported in Adhiambo (1991) indicates a similar trend.

Such changes have caused biological upheaval, but the resources to track these accurately have often been scarce. If it were possible to compare easily measured changes in social, economic, and technological disciplines with biological changes it might be possible to develop a rapid appraisal tool to assess African lake fisheries or, indeed, any fishery. Preikshot & Pauly (1998) examined biological, economic, social, and technological attribute sets for small-scale fisheries in tropical developing nations. They showed that assessments of fishery ‘ health ’ within each discipline were similar across disciplines. Pitcher *et al*. (1998*a*,*b*) examined attribute sets for global fisheries and found similar results, as well as time trends suggesting such analyses may be used to predict future fishery conditions.

Following the methods developed in the aforementioned interdisciplinary work, the present study applied multivariate statistics to interdisciplinary data sets for 32 African lake fisheries. Such a method could allow the identification of particularly stressed fisheries. This would be valuable information for countries which need to maximize the returns on money spent on research. Lastly, the ease of data collection of such analyses mean they should be quite cheap, providing valuable knowledge for fairly limited investments in time and money.

MATERIALS AND METHODS

Data were collected for attributes in ecological, economic, sociological, and technological data sets for 32 African lake fisheries (Table I). The attribute sets used were the same as those in Preikshot & Pauly (1998) to describe small fisheries in developing nations. The 32 fisheries from which data were collected were not all from different geographic locations: several of the fisheries were from the same place but different time periods. Since two of the economic attributes addressed capital the resultant changes of cash values were standardized by converting all currencies to their U.S. dollar value for

TABLE I. Attributes used in the analysis

Attribute	Scoring	Notes
Ecological		
1 Catch/fisher	Tonnes	Tonnes/person/year
2 Exploitation status	0; 1; 2	FAO scale; low, full, over
3 Trophic level	Number	Average trophic level of species in catch
4 Migratory range	0; 1; 2	1, 2–3, >3 jurisdictions encountered during migration
5 Catch<maturity	0; 1; 2	None; some; lots caught before maturity
6 Discarded bycatch	0; 1; 2	Low 0–10%; medium 10–40%; high >40% of target catch
7 Species caught	0; 1; 2	Low 1–10; medium 10–100; high >100 species
8 Primary production	0; 1; 2	g/m^2C/year; low=0–50; medium=50–150; high=150+
Economic		
1 Price	U.S.$/tonne	U.S.$/tonne of landed product for analysis time
2 Fisheries in GNP	0; 1; 2	Importance of fisheries sector in country: low; medium; high
3 GNP/person	U.S.$/capita	In country of fishery
4 Limited entry	0; 1; 2	Almost none; some; most (includes informal limitation)
5 Other income	0; 1; 2	Mainly casual; part time; full time fishers
6 Earnings by fishers	0; 1; 2	Below; same; above national average for workers
7 Market	0; 1; 2	Principally local; national; international
Sociological		
1 Socialization of fishing	0; 1; 2	Do fishers fish as individuals, families, or community groups
2 Fishing comm. growth	0; 1; 2	Population, over past 10 years: <10%, 10–20%, >20%
3 Fisher sector	0; 1; 2	Households in fishing in the community: <1/3; 1/3–2/3; >2/3
4 Education level	0; 1; 2	Below; same; above population average
5 Conflict status	0; 1; 2	Level of conflict with other sectors
6 Information sharing	0; 1; 2	None; some; lots
7 Fisher influence	0; 1; 2	Strength of fisher direct influence on actual fishery regulations
8 Fishing income	0; 1; 2	Fishing income % of total family income: <50%; 50–80%
9 Kin participation	0; 1	Do kin sell family catch and/or process fish: no or yes
Technological		
1 Trip length	Days	Average days at sea per fishing trip
2 Landing sites	0; 1; 2	Dispersed; some centralization; heavily centralized
3 Processing	0; 1; 2	None; some; lots gutting etc before sale
4 Use of ice	0; 1; 2	None; some; lots
5 Gear	0; 1	Passive=0; active=1
6 Mesh	0; 1	Net meshes not in gear=0; net mesh in gear=1
7 Selective gear	0; 1; 2	Device(s) in gear to increase selectivity: few; some; lots
8 FADS	0; 1	Fish aggregation devices not used=0; are used=1

the assessment year, and then inflated or deflated according to the U.S. consumer price index such that July 1983=100 (Anon., 1998). Also analysed were three other small-scale fisheries from developing nations which served as a reference for a global comparison of African Lake fisheries. Lastly, hypothetical ' good ' and ' bad ' fisheries (Table II) were

Table II. Fisheries analysed and their acronyms in the MDS ordination graphs

Acronym	Fishery place, date
aby86	Aby Lagoon, 1986
Bad	Modelled ‘ bad ’ fishery
bang94	Lake Bangweulu, 1994
bel96	Belize barrier reef fishery, 1996
bol91	Bolinao reef fishery, Philippines, 1991
ca-ba84	Cahora Bassa Reservoir, 1984
chil86	Lake Chilwa, 1986
chil94	Lake Chilwa, 1994
chiu86	Lake Chiuta, 1986
chiu93	Lake Chiuta, 1993
chiw89	Lake Chiwero, 1989
Good	Modelled ‘ good ’ fishery
it-te94	Lake Itezhi-tezhi, 1994
karZA94	Lake Kariba, Zambia, 1994
karZI95	Lake Kariba, Zimbabwean sector, 1995
kivu92	Lake Kivu, Rwandan sector, 1992
llus94	Lake Llusiwashi, 1994
luka94	Lukanga Swamp, 1994
malb93	Lake Malombe, 1993
malw47	Lake Malawi, Malawian sector, 1947
malwe93	South-east Lake Malawi, 1993
malw96	Lake Malawi, 1996
mwer80	Lake Mweru, 1980
mwer94	Lake Mweru, 1994
ok-ng90	Okavango Swamp, 1990
ruk93	Lake Rukwa, 1993
sak71	Sakumo Lagoon, 1971
sak94	Sakumo lagoon, 1994
tangTZ93	Lake Tanganyika, Tanzanian sector, 1993
ubol85	Ubolratana Reservoir, Thailand, 1985
vicKE85	Nile Perch Fishery, Lake Victoria, Kenyan sector, 1985
vicKE89	Nile Perch Fishery, Lake Victoria, Kenyan sector, 1989
vicTZ85	Nile Perch Fishery, Lake Victoria, Tanzanian sector, 1985
vicTZ89	Nile Perch Fishery, Lake Victoria, Tanzanian sector, 1989
vicTZ93	Lake Victoria, total Tanzanian sector, 1993
vicUG85	Nile Perch Fishery, Lake Victoria, Ugandan sector, 1985
vicUG89	Nile Perch Fishery, Lake Victoria, Ugandan sector, 1989

modelled to serve as an internal benchmark by scoring the fishery such that the ‘ good ’ one would be ecologically sustainable, providing work for a stable fishing community over the long term using highly selective fishing gear. The ‘ bad ’ fishery was modelled to reflect the opposite.

The fisheries were analysed first in the four attribute groups with multidimensional scaling (MDS) using the Statistical Package for the Social Sciences (SPSS Inc., 1996). All data were transformed by variable on a scale of 0 to 1 so that all attributes would have equal weighting in the resulting distance matrices. A Euclidian distance matrix was generated for each of the four attribute groups, from which the first two principal co-ordinates were extracted resulting in four two-dimensional ordinations of all fisheries. A fifth overall ordination was constructed by re-analysing the scores for the first two principal co-ordinates for each fishery from the four attribute ordinations. In the MDS

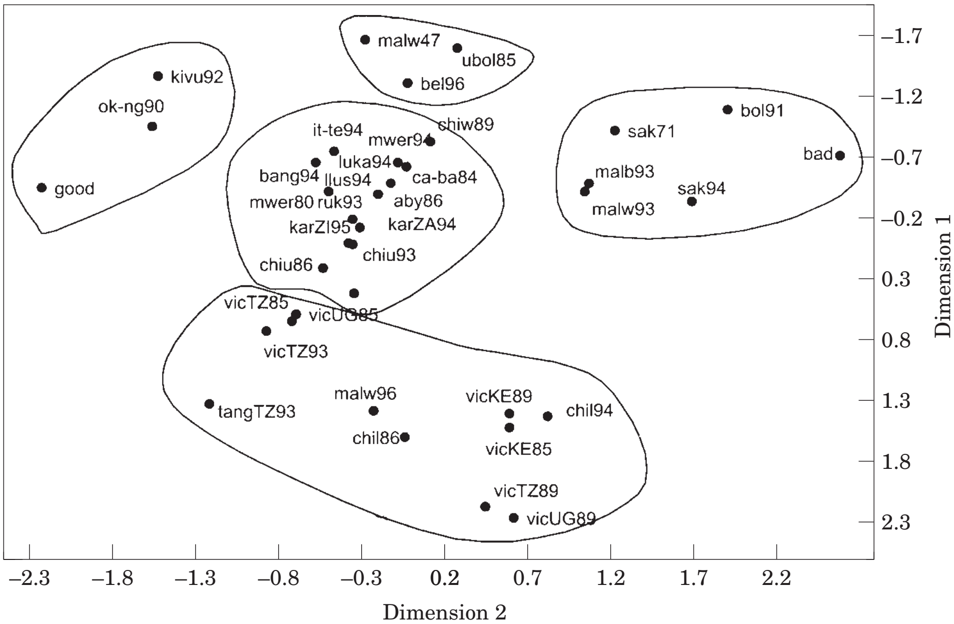

FIG. 1. Both axes flipped and rotated 90° to reflect positive characteristics of under exploitation, low catch before maturity, and small target species in the upper left-hand quadrant.

ordinations the axes were flipped if necessary such that the 'good' fishery was in the upper-left quadrant, while the 'bad' fishery was to the lower right. Axis rotation and flipping do not affect the meaning of the graph (Clark & Warwick, 1997), since the groupings remain the same. Flipping made the MDS ordinations more intuitive, since positive characteristics would be either to the left and/or the top.

Multiple correlations were then used, in the canonical correlation package of Statistica (Statsoft Inc., 1996), to show how the original attributes related to the derived MDS ordinations. Such an analysis allows the interpretation of the meaning of derived axes from the attributes most highly correlated with them (Stalans, 1995). Therefore, high positive correlations imply that when a particular attribute score was high for any fishery, it was likely to score high on an ordination axis. High negative correlations implied that low attribute scores were associated with high values on an ordination axis.

The cluster analysis (CA) package of Statistica (Statsoft Inc., 1996) was then used to produce groupings in as objective a fashion as possible. The groups were created using the complete Euclidian distance rule, which promotes clumpiness, since groups are created by identifying each member's furthest neighbours (Statsoft Inc., 1995). In this analysis, the first four or five readily identifiable groups were chosen, since there are no clearly accepted rules for defining what constitutes a mathematical group in such investigations (Cooper & Weekes, 1983). Amalgamation schedules (in the CA package of Statistica) were used to judge the amount of variation explained by creating more groups. If such a plot showed little new variation being explained by adding extra groups then the linkage distance was essentially the same (Statsoft, 1995*a*). From this justification it was seen that most of the variation was accounted for by the first four or five groups in all ordinations.

RESULTS

Fisheries associated with the low, or right-hand side of the ecological MDS ordination (Fig. 1) tended to stay so in the other ordinations (Figs 2–5), although

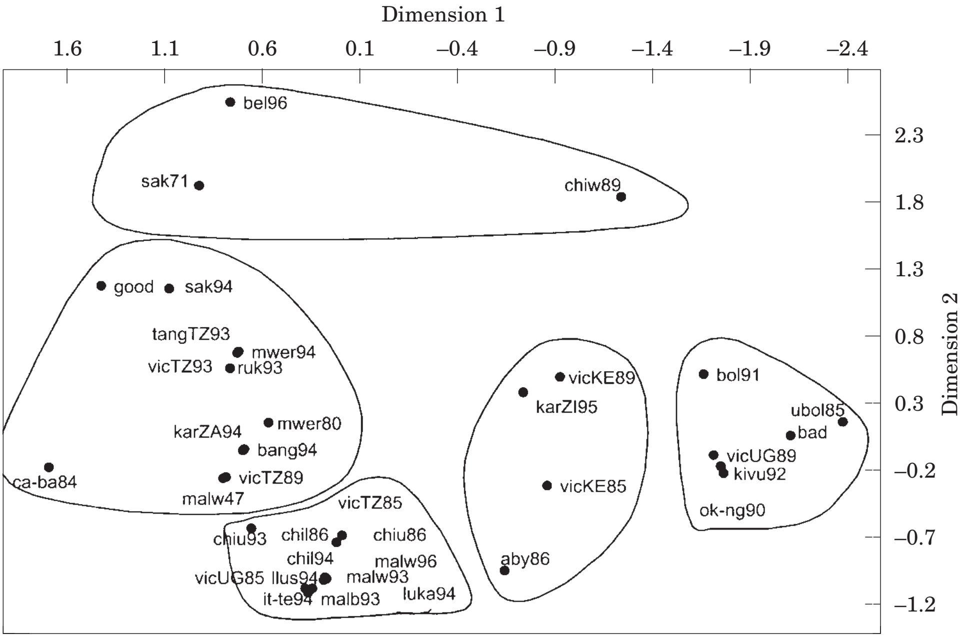

FIG. 2. *x*-axis flipped so that upper left-hand quadrant denotes limited entry fisheries with relatively well-off fishers, in economies where fisheries were important.

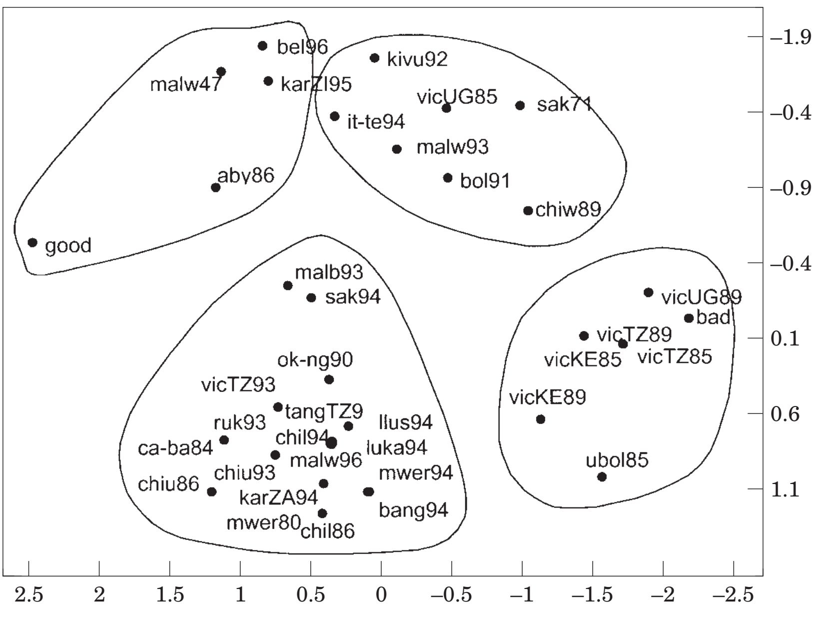

FIG. 3. Both axes flipped so that upper left-hand quadrant contained fisheries with lots of kin participation with most of the family income from fishing and high fisher influence on regulations.

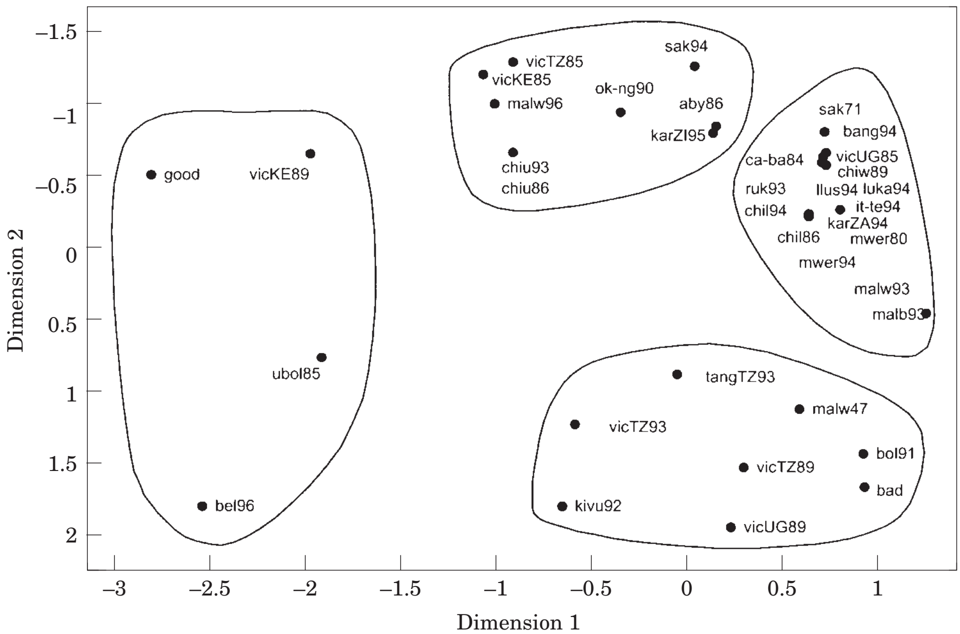

FIG. 4. *y*-axis flipped so that upper left-hand quadrant was associated with fisheries with selective gear, lots of ice use and no FADS.

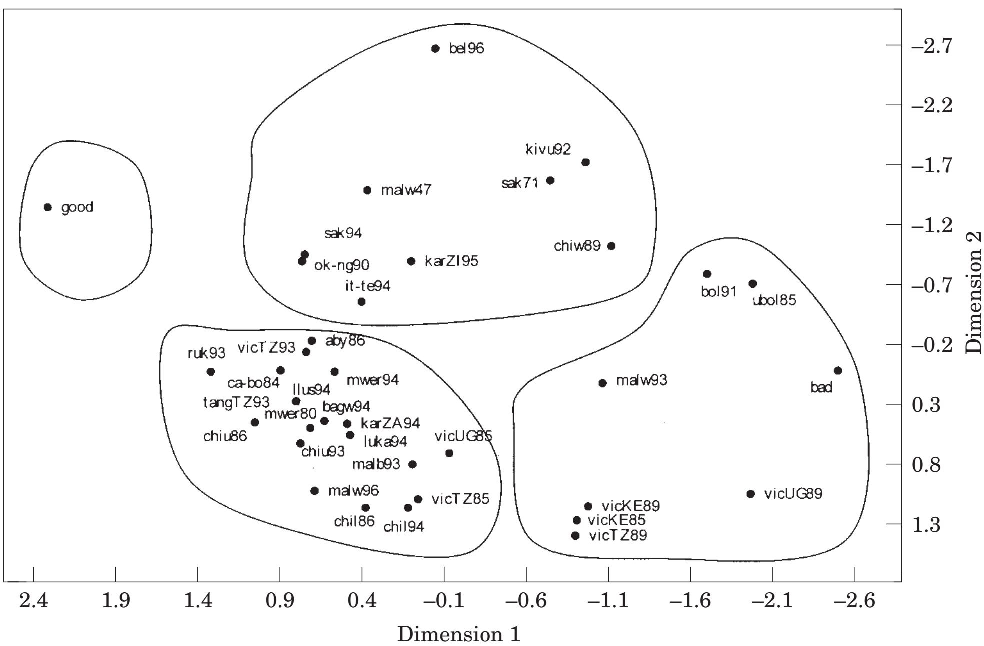

FIG. 5. Both axes flipped so that ' good ' fisheries ordinated in the upper right-hand quadrant.

this relationship was weaker with the technological ordination and cross-discipline ordination. Young's S-stress after two iterations for the ecological ordination, was 0·33. A third iteration, and therefore a third dimension for the ordination was not needed since Young's S-stress improvement was <3%. Such scree tests determine the use of generating new dimensions by calculating the increased distinction resulting from each new dimension (Statsoft Inc., 1995*b*). This was the case for all of the ordinations, so it was deemed acceptable for all to have two-dimensional outputs. Young's S-stress for the economic, sociological, technological, and cross-discipline ordinations after two iterations were 0·33, 0·34, 0·34, and 0·34, respectively.

Kruskal's stress formula 1 when applied to the five ordinations was 0·24, 0·25, 0·26, 0·27, and 0·27, respectively. This was acceptable given that values close to 0 represent better output data fits than values close to 1 (Stalans, 1995). This was supported also by the measured squared correlation (RSQ) values for the ordinations which were 0·76, 0·78, 0·73, 0·78, and 0·73, respectively. The RSQ values measure the proportion of variance of the scaled data in the distance matrix accounted for by the corresponding distances (SPSS, 1996). However, Clark & Warwick (1997) consider values <0·25 acceptable.

In the multiple correlation analysis, the higher the correlation between original attribute scores and the ordination scores, the stronger the influence of the attribute on the ordination axis (Table III). These correlations must always be considered jointly, however, as their effect on the MDS axes are in concert. Isolated consideration of these correlations is simply univariate statistics (James & McCulloch, 1990).

The final statistical procedure performed on the data was cluster analysis to help define groupings. The fisheries were divided into four or five groups for all five MDS ordinations (Figs 1–5).

In the ecological ordination (Fig. 1) dimension 1 (the *y*-axis) correlated positively with catch per fisher, trophic level of catch, and migration range. Dimension 2 (the *x*-axis) was correlated positively with exploitation status and catch before maturity. Thus, after accounting for the flipping and rotation of the graph to place ' good ' fisheries in the upper left-hand quadrant, we see that in African lakes ' good ' fisheries were associated with small, low trophic level fish, with small migratory ranges (dimension 1) but also underexploited ones with little catch before maturity (dimension 2).

A more intuitive result was observed in the meaning of dimension 2 in that fisheries with overexploitation and catch before maturity were grouped as ' bad ' fisheries. Note too, that of the fisheries in which data were available for different times, Sakumo Lagoon, Lake Chilwa, Lake Victoria, Lake Malawi, Lake Chiuta, and Lake Mweru, the ordination scores were almost always more favourable for the younger fisheries when measured on dimension 2.

In the economic MDS ordination (Fig. 2), dimension 1 (the *x*-axis) was very strongly influenced by one attribute: earnings by fishers. This implied that fishers in economically ' healthy ' fisheries earned more, on average, than the average person in a given country. The second dimension (the *y*-axis) was associated with the importance of fisheries to the country's gross national product, restrictions on entry of new fishers, and the proportion of income fishers received from fishing. Therefore, in ' good ' fisheries these three attributes had high scores.

Dimension 1 (the *x*-axis) of the sociological MDS ordination (Fig. 3), was associated with the proportion of family income derived from fishing and the

TABLE III. Correlations for attributes and associated MDS dimensions

	Dimension 1	Dimension 2
Ecological		
Catch/fisher	0·77	− 0·27
Exploitation status	0·42	0·73
Trophic level	0·76	− 0·48
Migratory range	0·68	− 0·25
Catch<maturity	0·50	0·71
Discarded bycatch	0·13	0·25
Species caught	− 0·05	− 0·03
Primary production	0·40	0·20
Sociological		
Socialization of fishing	0·39	− 0·43
Fishing community growth	− 0·54	0·06
Fishing sector	0·30	0·65
Education level	0·44	0·19
Conflict status	− 0·43	− 0·45
Information sharing	0·29	− 0·11
Fisher influence	0·33	− 0·86
Fishing income	0·62	0·36
Kin participation	0·78	− 0·12
Economic		
Price	0·08	0·53
Fisheries in GNP	0·39	0·65
GNP/person	− 0·46	0·27
Limited entry	0·22	0·65
Other income	0·16	− 0·65
Earnings by fishers	0·94	− 0·16
Market	− 0·16	0·20
Technological		
Trip length	− 0·19	0·34
Landing sites	− 0·52	0·16
Processing	− 0·24	− 0·23
Use of ice	− 0·61	0·13
Gear	0·57	0·52
Mesh	0·75	0·37
Selective gear	− 0·59	0·34
FADS	− 0·28	0·80

extent of kin participation in processing and/or marketing fish. Dimension 2 (the *y*-axis) was influenced by proportion of the households in the community having fishers and the influence fishers had in determining regulations. The fisheries that were favourable were characterized by family income being derived mostly from fishing, with much kin participation, a low proportion of fishers in the community yet a relatively large say in fishing regulations.

For the technological ordination (Fig. 4), dimension 1 (the *x*-axis) was correlated with use of ice, presence or absence of net meshes and selectivity of gear. Dimension 2 (the *y*-axis) was influenced most strongly by use of fish aggregating devices (FADS) but this was associated poorly with the ‘ good ’ group in general. This, however, was not so for African lake fisheries in particular, since the two fisheries in the ' good ' group which scored low on dimension 2 were both non African.

In the cross-discipline ordination (Fig. 5), the good and bad fisheries were, again well separated and the resultant groupings were in tune with what we would expect, given the results of the four single disciplinary ordinations. The two axes cannot be interpreted directly, since they are derived from the inferred disciplinary axes. They do, nevertheless, represent measures of sustainability because of their derivation from the disciplinary ordinations measuring sustainability. In this ordination, dimension one was correlated most with social and economic factors, while dimension 2 was correlated most with ecological factors.

DISCUSSION

To many, the dimension 1 relations of the ecological ordination appear counter-intuitive. For instance, Preikshot & Pauly (1998) demonstrated that other healthy small-scale tropical fisheries were associated with large, high trophic level species. Indeed, Pauly *et al*. (1988) showed a general global phenomenon of fishing down food webs, which they argued reflected unsustainable fisheries practices. The reasons for this apparent anomaly in how African lake fisheries were assessed ecologically are probably the wide influence of introduced species combined with the many traditional African fisheries that targetted small species. Note that in all the ordinations the fisheries of Lake Victoria are found recurrently in ' bad ' groupings. The single trait that dominated these fisheries was the recent introduction of Nile perch, a large, high trophic level predator. The introduction of Nile perch has altered the Lake Victoria ecosystem to such an extent that any measured ecological impact is tainted by the shifted baseline of an entirely new food web (Moreau *et al*., 1993). It was likely that this ecosystem had not achieved a new equilibrium by the time of analysis. Therefore, detecting an ecological impact will require a longer-term investigation.

This tendency thus serves as a useful fingerprint for African Lake fisheries, since so many other small-scale tropical fisheries tend to target larger, predatory species (Preikshot & Pauly, 1998). It also serves as a warning of the difficulty of detecting ecological signs of fisheries decline in African lakes. One of the most common signs of collapse, fishing down the food web, would be difficult to perceive where the fisheries had always been based on small low trophic level species. Indeed, fishing down food webs may not occur as the average trophic level of targetted species tends to increase. An interesting choice facing African nations will be whether the ecology of lake systems should continue to be modified to produce larger fish, potentially to augment catches and their value.

To place African lake fisheries in a more global context three non-African fisheries were included. Note that the Belize fishery, a relatively affluent small-scale fishery on valuable invertebrates, always scored relatively well on all ordinations and also was fairly segregated from African lake fisheries. The Bolinao reef fishery, which has been associated with Malthusian overfishing by McManus *et al*. (1992), was associated with fisheries scoring poorly in the ecological MDS. This was true of all the other ordinations, except the sociological one, implying that Malthusian overfishing is a problem, or risk, for several African lake fisheries.

In the economic ordination, the fisheries of Lake Victoria, Lake Malawi, Lake Malombe, and Lake Chilwa appeared to be the most distressed economically. However, in most of the time series data there did not appear to be much movement in any of the fisheries, except for the Ugandan sector of Lake Victoria, which suffered a strong decline on dimension 1. This result indicated that the economic lot of fishers on African lakes has been effectively stagnant, and thus the so-called rescue of fishers' fortunes by Nile perch (Acere, 1988; Reynolds & Greboval, 1988), may be a short-lived, short-sighted phenomenon. This could also refute the argument that altering the ecology of African lakes to larger species would be beneficial in the long term.

Like the ecological ordination, in the sociological ordination there was a marked trend for fisheries with time series to decline on one dimension, without improving on the other, or to decline on both dimensions as time progressed. Most of the Lake Victoria fisheries were relatively stable, although the Ugandan sector showed a large decline on dimension two. This suggests that the effect of Nile perch has not been to increase the social quality of fisheries, in any nation on Lake Victoria.

In the technological ordination ' bad ' fisheries were associated with little ice use, non-selective gears, and the use of FADS. Acere (1988) warned of the hazards of the continued use of non-selective gears despite the apparent boom occurring in the Nile perch fisheries of Lake Victoria. Note that time series data generally showed qualitative declines. An exception was the Lake Malawi fishery, which did decline on the other ordinations. This implies that gear policies may be having no effect on the ecological, economic, or sociological quality of those fisheries. Such trends are consistent with Malthusian overfishing.

The last ordination produced was the cross-discipline one (Fig. 5). This ordination was not investigated in terms of what its axes implied, since they would be, literally, inferences upon inferences. It was, however, interesting to produce this overall ordination to see if any generic tendencies could be seen. A troubling observation was the insularity of the modelled ' good ' fishery. As observed in the other ordinations, the Lake Malawi, and Lake Victoria fisheries were associated with the ' bad ' modelled fishery. Most other fisheries were in the two ill-defined clouds between the good and bad groups. The association of the Bolinao reef fishery, a classic example of Malthusian overfishing, with the ' bad ' fisheries suggests this phenomenon afflicts the African lake fisheries also.

This study has shown that for several of the African lake fisheries there was strong evidence of ecological, economic, sociological and to a lesser extent, technological decline through time. The ordinations when subjected to CA, were useful in distinguishing qualitative changes in African lake fisheries for all attribute groupings. Further, this technique showed that African lake fisheries could be contrasted with other small-scale tropical fisheries.

The consistent association of these fisheries with characteristics of Malthusian overfishing, in all disciplines, confirmed their ecological difficulties. Such results indicate that this rapid assessment technique can give robust assessments, even with minimal information in any discipline. This assessment tool was not able to identify the absolute quality of all fisheries across all attribute sets analysed, but as a rapid assessment tool, it was able to show the most problematic, as well as the most successful. For example, the Lake Kivu 1992 and Lake Malawi 1947 data were almost always favourable. The Lake Kivu fishery would be interesting to resample since the data were collected before the civil war. If other ' middle ground ' fisheries analysed are to be grouped more effectively the assessment tool will have to be refined.

The observed difficulty in grouping several fisheries could have been promoted by the lack of correlation subtended by having little, or no variation in the fisheries' scores in some attributes. A manifestation of this was the fisheries on large species grouping as ' bad '. By jack-knifing the MDS attributes it should be possible to derive more compact attribute sets which allow greater separation of fisheries in the ordinations. Other factors, which may lead to some obfuscation in the final results were attributes with binary scores. Increasing the range of a measure may promote better segregation in the MDS ordinations, but may also involve greater time and money to collect data.

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