Effect of Harvesting on Temporal Papyrus (cyperus papyrus L.) Population among Swamps of Winam Gulf in Lake Victoria Basin, Kenya

J. J. L.Osumba, J. B.Okeyo-Owuor
Department of Environmental Biology & Health, School of Environmental Studies, Moi University, Eldoret Kenya.

P.O Raburu
Department of Fisheries & Aquatic Science, School of Natural Resource Management, Moi University, Eldoret Kenya.

Abstract

Experiments were set to determine the effect of monthly and seasonal harvesting on temporal papyrus population density. Mean initial culm count was 21.6±2.26/m2. Initial culm counts varied across sites, but spatial differences were not significant. Mean monthly culm counts declined with successive harvests, and each sequential harvest significantly reduced culm counts. Seasonal culm counts were generally higher in unharvested than in harvested plots, and the differences were significant in Nduru ($F=13.569$; $p<0.05$). There were no culm counts differences within and among sites between initial and seasonally harvested plots. Overall, there were more culms in seasonal (32.3±3.34/m2) than in initial counts. It was found that culm counts do not depend on site, and that harvesting reduces culm counts. It is evident that seasonal harvesting does not affect culm counts. Leaving a papyrus crop stand unharvested for more than a season increases its culm count. Given that frequent harvesting reduces culm count, and considering that initial papyrus population densities were the lowest across sites, it may be concluded that Winam Gulf papyrus is harvested faster than the wetlands can replenish. This finding highlights the need for urgent conservation measures in the area. It is suggested that papyrus conservation steps be undertaken most urgently in Winam Gulf. A minimum-harvesting regime at the start is once per patch per season. However, fewer patches were studied relative to the entire swamps. A more elaborate assessment, covering larger areas and more swamps, with greater effort, should be undertaken to determine the replenishment break-even point.

Key words: Papyrus, Harvesting, Replenishment, Winam, Swamps, and Wetlands.

Introduction

Papyrus (Cyperus papyrus L.) is harvested by riparian communities for fuel, handicraft and building (Shepherd et al., 2000; Nyunja, 2003; Mbaria, 2006). Attempts have also been made to commercialize papyrus economy (Jones, 1983). If this affects papyrus swamps on a wider scale, it will be necessary to exhaustively understand the ecology of this vital wetland resource in order to assess the impact of continued harvesting. In general, not much is known about papyrus ecology to facilitate policy interventions, which can lead to sustainable exploitation of the macrophyte.

It is widely believed that papyrus harvesting has led to a decline in papyrus wetlands in Lake Victoria Basin (McClanahan & Young, 1996; Mallory & Chandler, 2001; Twong'o and Sikoyo, 2004). This ecosystem shrink is a threat to ecological integrity of the Lake Victoria and its watershed. In Winam Gulf Swamps, the data available is not sufficient to guide planning, management and sustainable utilization of papyrus-dominated swamps. No study has targeted the effect of harvesting on temporal papyrus population density to provide reliable information on the sustainability of its extraction in the study area. Empirical studies therefore needed to be undertaken to quantify the effect of harvesting on the population density of papyrus in these swamps. Against this background it was necessary to determine papyrus culm counts in harvested (disturbed) and unharvested (undisturbed) plots. Field experiments and visual observations, including riparian community probes, were used.

It has been established that papyrus can be used for several socio-economic purposes by riparian communities (Omollow, 2003; http://en.wikipedia.org, May 2007) or preserved by farmers as dry season fodder for livestock. Renewed interest is also being accorded this plant due its critical ecological role in wetland ecosystems (Archer, 2004). Given its dual role as an ecological and socioeconomic resource, it is therefore important that innovative ways of utilizing papyrus without damaging the ecosystem be developed and promoted. Such a situation requires determination of the rates of removal and the potential for replenishment of papyrus. Prior to this study valuable information on temporal papyrus population density was lacking in Winam Gulf. Yet this parameter is essential in determining the sustainability of papyrus harvesting, and involving community in conservation of wetlands. The findings from this study have helped to enrich scientific database needed for biodiversity conservation and sustainable use of wetland resources in the LVB.

Papyrus (Cyperus papyrus L.) is a common wetland perennial herbaceous monocot plant of the sedge family, native to Africa (http://en.wikipedia.org, May 2007). It is a plant with a rich history and tradition (Cotton et al., 1995). The sedge has been important in global academia and commerce since ancient times (Elhorst, 1912; Ryan, 1988; Wallert, 1989). In its natural habitat papyrus occurs in large, dense populations. At any one time there are 6-23 papyrus shoots/m2 (Kvét et al., 1998). It is a major feature of tropical and subtropical freshwater wetlands especially in Africa (Mitsch and Gosselink 2000) but is also found in Israel (Kaplan et al., 1998), Palestine, Jordan River and parts of the Mediteranian Basin (Duke, 1996), and Greece (Archer, 2004). In Kenya, papyrus swamps are found mainly along river inflows on the basins and shores of major lakes (Jones & Muthuri, 1997; Boar et al., 1999; Harper et al., 2004). Out of an estimated 78,000Ha of littoral wetlands on the Kenyan part of Lake Victoria, papyrus swamps account for 21,000Ha or 27 per cent (Thenya, 2006). Several authors have observed that wetlands around Lake Victoria support papyrus as the main constituent plant of fringing swamps (Emerton, 1998; Gichuki et al., 2001; Azza et al., 2006). In the Lake Victoria Basin papyrus swamps are reported to have declined (Vignoli et al., 2004).

The ecology of papyrus swamps around Lake Victoria was first studied in the late 1950s and early 1960s (Lind & Visser, 1962). Although the nature of plant vegetation is affected by water level (ibid), papyrus population density is not influenced by water depth (Boar et al., 2006). Jones and Muthuri (1985), in a study of papyrus swamps in the East African part of the Rift Valley, found a papyrus population density range of 9.2±1.8 18.6±1.2culms/m2. Mnaya et al (2007) reported a papyrus population density of 117±18culms/m2 in Rubondo Island, Tanzania.

Various authors postulate that papyrus exploitation around Lake Victoria is uncontrolled, excessive and unsustainable (Owino, 2005; Denny et al., 2006; Kipkemboi, 2006). However, published studies do not establish the extent to which papyrus harvesting affects its population density in the area. There have been no comparative studies on papyrus resource harvesting and its population dynamics. Several studies have been conducted on papyrus in East Africa but the studies have not addressed that problem especially in Winam Gulf. None of the studies, at least in the public domain, has focused on the effect of papyrus harvesting on its population density. Consequently bilogical dynamics of such wetlands in the LVB, especially along Winam Gulf, are not yet well understood. This has compromised the ecological integrity of Lake Victoria ecosystems and the surrounding watershed.

This study set out to assess the dynamics of papyrus harvesting and temporal replenishment. The study investigated and documented valuable information on papyrus population dynamics, a factor that is essential in determining the sustainability of papyrus utilisation. Its findings will enrich local scientific knowledge database needed for biodiversity conservation and sustainable use of LVB wetland resources. This paper presents the plant population density aspect of papyrus ecology, which is relevant in determining its regeneration in Winam Gulf of Lake Victoria, Kenya.

Materials and Methods

Sampling sites

This study was undertaken in a 60-kilometre stretch of palustrine wetlands in Kano Plains along Winam Gulf shores of Lake Victoria (Figure 1). Three of the swamps were selected at random for study, namely Dunga (0o08'01"S, 34o44'37.2"E, 1135m as!), Nduru (0o15'14.9"S, 34o49'17.9"E, 1134m as!) and Ogenya (0o16'27.0"S, 34o51'15.2"E, 1160m as!). There were signs of disturbance at all the three sites, but each was unique in its own way.

Sampling Design

Representative sampling procedures were applied. In each swamp three papyrus patches, isolated from each other by at least a 5 metre open space, were selected. A 30m x 30m experimental block was marked in each patch. Plots and quadrats (2x2m2) were chosen and nested as recommended by Sutherland (1996) and Bullock (1996) for single species studies. A quadrat was marked within each of the blocks. A perimeter ring was cleared around each quadrat to act as a buffer zone and footpath. The quadrats were then cleared by cutting papyrus at 5 centmetre from the base rhizome as recommended by Roberts et al (1993). Sampling points at each site were located at least 20 metre from the land-edge to minimize edge effects. Sampling involved monthly culm counts.

In a second experiment a strip of the experimental plot was cleared within each of the nine (30m x 30m) blocks to determine seasonal culm counts (Plate 1). Another strip was left unharvested to serve as the control. Distances between the treatment and the control strips were about 3 5m, depending on within-block accessibility. At the end of the six months three quadrats were marked out in each strip and their culm counts determined.

To characterize the ecological conditions of the sites, water and sediment samples were taken for analysis of ecological variables. Water depth was taken in all the plots for the duration of the study. Water variables sampled included temperature (T), pH, elecrical conductivity (EC), disolved oxygen (DO), biochemical oxygen demand (BOD), nitrate-N and phosphate-P content. Sediment was sampled towards the end of the study. Sediment variables taken included pH, EC, nitrate-N and phosphate-P. Temperature, pH, DO, BOD and EC readings were taken directly in the field using various Hach method instruments. Temperature readings were taken using a standard laboratory thermometer, pH readings were taken with an electronic Jenway model 370 pH meter, DO readings were taken using model H19143 DO meter, EC readings were taken using model 4010 EC meter. Nitrate-N and phosphate-P were determined using the Hach Direct Reader (DR/2000) spectrophotometric methods as used by Thenya (2006) in Yala Swamp.

Data analysis

Data was processed and analysed using Ms EXCEL (graphics), MINITAB (normality tests, non-parametric tests) and SPSS (descriptive statistics, graphics, homogeneity, One-Way ANOVA, Univariate ANOVA, trend analysis ANOVA, Bonferroni Post Hoc Multiple Comparisons) as recommended by Fry (1994). Results were presented in the form of text descriptions, tables and graphs. A combination of descriptive statistics, graphical presentations and ANOVA (F-test), correlation (r) techniques were applied all at ±=0.05 in space and time (Zar, 1984; Underwood, 1997).

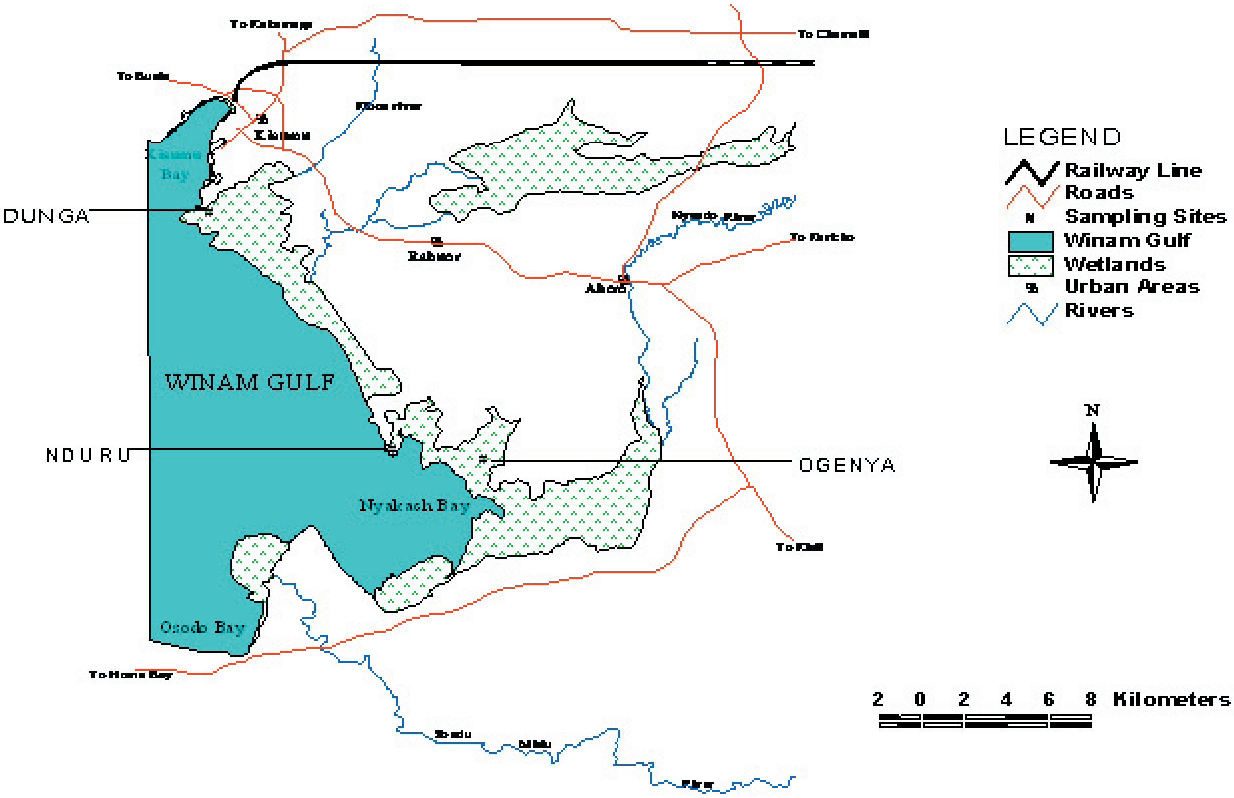


Figure 1: Location of sampling sites on the map of Kenya

Results

Initial papyrus population density

Initial papyrus population density measurements varied considerably among the nine quadrats across the three sites. Separate site data analysis revealed that mean papyrus plant counts or population density were lowest in Dunga (19.8±6.20 plants/m2) and highest in Nduru (23.3±2.49 plants/m2) while Ogenya had 21.7±3.63 plants/m2. For the three study sites overall quadrat plant counts ranged 30 110 plants/quadrat (or 7.5 27.5 plants/m2) with a grand mean of 86.3±9.02 plants/quadrat (or 21.6±2.26 plants/m2). Overall initial plant counts for the entire study area ranged 8 28/m2 with a mean plant count of 21.6±2.26 plants/m2. One-Way ANOVA showed no difference in initial papyrus plant counts among sites (F=0.167; p>0.05).

Temporal papyrus population density

Table 1 compares papyrus plant counts at start and end of season during the study period. End-of-season papyrus plant counts for Dunga ranged 22 33/m2 with mean of 28.7±3.61/m2 for the harvested plot, and 29 40/m2 with a mean of 33.2±3.22/m2 for the unharvested plot. Plant counts for Nduru ranged 21 24/m2 with mean of 22.4±0.80/m2 for the harvested plot, and 25 31/m2 with a mean of 28.4±1.99/m2 for the unharvested plot. Plant counts for Ogenya ranged 39 54/m2 with mean of 45.9±4.57/m2 for the harvested plot, and 21 49/m2 with a mean of 35.1±8.16/m2 for the unharvested plot. Generally plant counts were highest at Ogenya and lowest at Nduru. Plant counts were generally highest in the unharvested plots and lowest in the initial plots except in Ogenya where plant counts in the harvested plot were extraordinarily higher than the rest. Univariate ANOVA showed that end of season within site papyrus population densities were significantly different in Nduru (F=13.569; p<0.05) but there was no difference in papyrus population densities for Dunga and Ogenya.

Table 1 Mean papyrus plant counts at start and end of season during study period

Plant counts / Site	Before (plants/ m²)	After (plants/ m²)		
		Harvested	Unharvested	Overall
Dunga	19.8±6.20	28.7±3.61	33.2±3.22	30.9±2.39
Nduru	23.3±2.49	22.4±0.80	28.4±1.99	25.4±1.40
Ogenya	21.7±3.63	45.9±4.57	35.1±8.16	40.5±6.37
Overall	21.6±4.11	32.3±3.90	32.2±2.78	32.3±3.34

Site papyrus population densities are presented in Figure 2 below for initial, harvested and unharvested plots at the end of the season. In Dunga end-of-season papyrus population density was higher than initial papyrus population density both for harvested and unharvested transect plots, and the unharvested plot yielded higher papyrus population density than the harvested plots. In Nduru the unharvested plot yielded higher papyrus population density overall but the harvested plot yielded less papyrus population density than the initial harvest. In Ogenya the highest papyrus population density was obtained from the harvested plot and the lowest from the initial harvest.

Papyrus population densities were lowest in the initial plots and highest in the unharvested plots, with harvested plots falling almost halfway (Table 1). Papyrus population densities were generally highest in Ogenya and lowest in Nduru, again with Dunga plant population densities falling almost halfway as can be observed in the table.

Effect of monthly harvesting on culm counts

Mean papyrus plant counts declined steadily from 52.9±5.70 plants per quadrat in the first month to 5.0±1.34 plants per quadrat in the sixth month. Month 2-recorded 48.6±8.66plants/quadrat, month 3 (16.3±9.15), month 4 (9.0±4.30), and month 5 (6.2±3.09). Figure 3 shows that overall papyrus plant count decreased with successive harvests, although the decline was more for Dunga and Ogenya than Nduru. For Nduru, plant counts increased sharply in the second month but declined steadily in the next four months of the study period. For Dunga and Ogenya, plant counts declined sharply in the second and third month, remained extremely low up to the fifth month then increased slightly in the sixth month of the study period.

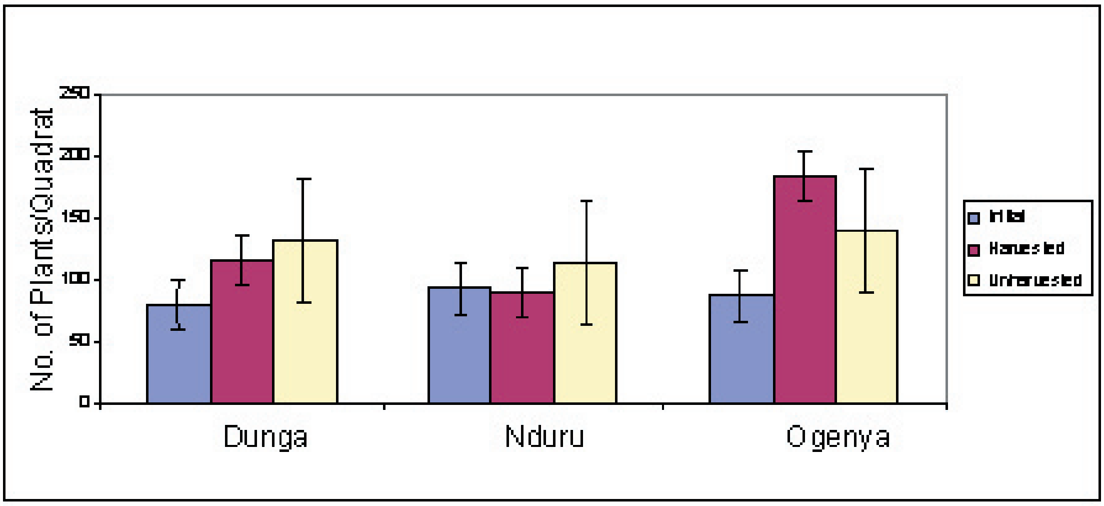
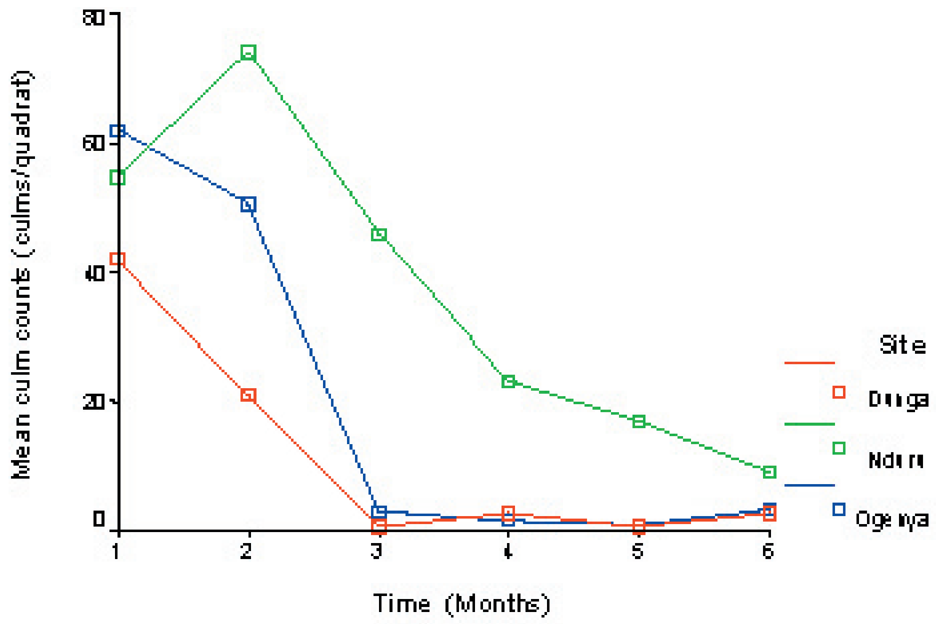


Figure 2 Initial and end-of-season papyrus population density during the study period

Figure 3 Average culm counts for monthly harvests during the study period



GLM Repeated Measures ANOVA Trend Analysis showed that there was a highly significant linear relationship between harvest interval and regeneration potential ($F=117.042$; $p<0.001$), and also a significant quadratic relationship between harvest interval and regeneration potential ($F=9.617$; $p<0.05$) as given by papyrus population density. No interactive relationship was observed between site (space) and harvest interval (time). Bonferroni comparison reveals that there is no difference between Dunga and Ogenya ($p>0.05$) but there is a significant difference between Nduru and Dunga/Ogenya ($p<0.05$).

Pearson's Correlation Analysis

Table 2 presents correlations between different variables of the sequential harvests. No correlation was observed between harvest interval (time) and site (space). This may suggest that the effect of harvest interval on papyrus regeneration does not depend on site, and also the effect of harvesting on plant counts does not depend on site. However, frequency of harvesting (monthly) negatively affects plant counts ($r=-0.694$; $p<0.001$).

Table 2 Pearson's Correlation Analysis for papyrus counts, heights and biomass during the study period

Variable	r	Site	Papyrus
	p		Population counts
Month	r	0.000	-0.694**
	p	1.000	0.000
Site	r		0.134
	p		0.335

** Correlation is significant at the 0.05 level (2-tailed).

Water depth and water quality and sediment analysis

Mean water depth for the plots was 67.6±3.59cm for Dunga, 5.9±0.41cm for Nduru and 55.1±3.99cm for Ogenya. Mean water depth was lowest in Nduru and highest in Dunga. Univariate ANOVA for water depth showed no difference within sites ($F=0.016$; $p>0.05$), but returned significant differences among sites ($F=355.734$; $p<0.001$) and through the months ($F=44.243$; $p<0.001$). Bonferroni showed that water depth was significantly different for across the sites. One-Way ANOVA showed no difference among sites for most water quality variables except nitrate N ($F=280.697$; $p<0.001$) and altitude ($F=31.500$; $p<0.001$). Bonferroni comparisons revealed that available nitrate in the water column was similar for Dunga and Ogenya but significantly different for Nduru. There was no difference in altitude between Dunga and Nduru but there was a significant difference between Ogenya and the other two. One-Way ANOVA revealed no differences among sites for pH and phosphate-P, but returned a significant difference for electrical conductivity ($F=13.244$; $p<0.05$) and a nitrate-N ($F=30.014$; $p<0.001$). Post hoc (Bonferroni) tests showed no difference in EC and nitrate-N between Nduru and Ogenya, but detected a significant difference between Dunga and the other two sites.

Discussion

In this study, attempts have been made for the first time to determine the effect of harvesting on temporal papyrus population density in Lake Victoria Basin. The philosophy behind the study was that each site had an inherent plant population density, which was then modified by the effect of harvesting applied to it (Mead, 1990).

Papyrus population densities

Measurements taken at the beginning of the study revealed that initial papyrus population density for the entire study area ranged 6 28/m2. This population density range tends to agree with observations made by Kvét et al. (1998) that at any one time there are 6 23 papyrus shoots/m2. Other studies observed papyrus culm densities of 17culms/m2 (Gaudet, 1977), 12.7 17.9culms/m2 (Jones & Muthuri, 1985). However, Mnaya et al (2007) observed a papyrus population density of 117±18culms/m2 in Rubondo Island, Tanzania. The Mnaya et al (2007) figure is exceptionally high probably because it was conducted in an area receiving a higher rainfall (1300mm p.a) than the current study area (910mm p.a.).

Although initial papyrus population density was different from site to site, the differences were not statistically significant. Nduru Swamp had the highest papyrus population density while Dunga had the lowest. The lower plant counts observed in Dunga could be attributed to the higher harvesting frequency occasioned by, among other factors, a high influx of immigrant papyrus harvesters observed at the site. The highest papyrus population counts observed in Nduru could be attributed to the low exposure of the Nduru swamp to papyrus harvesting. Most of the papyrus harvesting observed in Nduru was mainly for building and domestic fuel, but not for commercial handicraft as is the case in Dunga and Ogenya. Immigrant harvesters were also not common at this site and, when they appeared, the local people regulated their activities. Plant counts in Ogenya fell in-between those of Dunga and Nduru but were not significantly different from those of Dunga. Ogenya does not have a high concentration of immigrant papyrus harvesters but a considerable number of local papyrus harvesters do so for handicraft making to earn income since there is no major fishery beach at the site. That handicraft connection could explain why the papyrus population density in Ogenya is similar to that in Dunga.

Papyrus population densities for end-of-season plots were higher than for the initial plots. For Dunga, end-of-season plant counts were higher in the unharvested plots than in the harvested plots. In Nduru the unharvested plots yielded higher plant counts overall but the harvested plots yielded less counts than the initial plots. In Ogenya the highest plant counts were obtained from the harvested plots and the lowest from the initial plots harvests. Ogenya had the highest end of season plant counts while Nduru had the lowest, although for the initial harvest Nduru had the highest plant counts followed by Ogenya. Thus Dunga and Ogenya have surpassed Nduru during the study period. It could mean that flooding led to a higher papyrus proliferation in ther former sites than in the latter. In Dunga and Ogenya, initial plot plant counts were lower than plant counts from the harvested (disturbed) plots, but in Nduru the initial plots plant counts were higher than the plant counts from the disturbed plots. This appears to provide evidence that where flooding is not substantial, harvesting affects papyrus proliferation more than where flooding is considerable. In all the three sites, plant counts from the unharvested plots were higher than the initial and the harvested plots. Generally, there were more plants in the end-of-season harvests than in the initial harvests across sites. This could mean that at the start of the study the papyrus stands had not reached their regeneration threshold.

The fact that in Dunga and Nduru the end of season plant population density was higher in unharvested plots than in harvested plots suggests that harvesting contributed to the difference. Comparing harvested plots and initial plots plant counts, the former were higher in Ogenya and Dunga but lower in Nduru. The difference was considerable in Ogenya, moderate in Dunga and negligible in Nduru. The significant difference in plant counts between treatments for Nduru and the no difference in plant counts for Dunga and Ogenya suggests that flooding could have played a role, contrary to the conclusions of Boar (2006), who observed that natural papyrus regenerative capacity is influenced by water depth but papyrus population density is not. Considering that Dunga and Ogenya were more flooded and Nduru less flooded, there is a possibility of flooding effect on plant population density among the sites. Given that there were significant differences in water depth between Dunga and Ogenya but no difference in papyrus plant counts, it appears that there is a critical flooding threshold, beyond which there can be no significant difference in plant counts. Comparing papyrus plant counts at start and end of the six months study period, it is evident that leaving a papyrus crop unharvested for at least six months increases its regeneration potential, as shown by the results of the unharvested plots, which was not harvested at the start of the experiment.

Effect of monthly harvesting on papyrus population densities

Frequent papyrus harvesting generally affected papyrus variables negatively, with mean monthly regenerated papyrus plant counts declining from month one to six. This finding concurs with observations by Kasoma (2003) that shorter harvests affect the ecology of swamps and hence reduce yields. Generally papyrus plant count decreased with successive harvests, although the decrease was more in Dunga and Ogenya than in Nduru. The effect in Dunga and Ogenya is likely to have been compounded by the influence of flooding, as similar observations have been made by Thenya (2006) in Yala Swamp. Kotera & Nawata (2007) also observed that flooding and submergence leads to yield losses. The submergence could probably have suffocated the young tender plants and affected regeneration, resulting in lower plant counts per quadrat than expected. However, the effect of harvesting could be evidenced in Nduru, where the sampling points were the least flooded.

Dunga and Ogenya were heavily flooded at the time (November/December 2006) of collecting the second month's data. These high floods seem to have affected regeneration in Dunga and Ogenya but not in Nduru, which was only slightly flooded during the entire study period. The slight overall improvement at the end of the study period can be attributed to flood recession towards the end of the rains. This observation is supported by findings by Boar (2006) that papyrus regeneration rates tend to be higher in shallower waters and when flooding subsides. **I**nspection of the data suggests that even though floods might have affected papyrus plant counts, harvesting also seemed to have impacted on the population density since Nduru, which had very low floods throughout the study period, also maintained a downward plant count trend. Data for Nduru give a realistic trend of the effect of harvesting without the influence of floods. The slight overall improvement was probably contributed by the specific improvements in Dunga and Ogenya for month 6 when the flooding tide began to ebb. This trend suggests that apart from frequent harvesting, flooding also appears to have had an effect on the population density of papyrus because the decline was substantial when floods increased, and the potential for regeneration was slightly regained when floods reduced towards month 6. The effect of harvesting is realistically depicted by the results for Nduru, where flooding took longer to reach, and where the extent of flooding was not substantial as illustrated by water depth measurements. There were positive but weak correlations observed between site (space) and papyrus population counts as compared to harvest frequencyplant count correlations. Seasonal harvesting did not appear to affect papyrus plant counts as much as monthly harvesting. This means that if increasing harvest interval can reduce harvesting frequency, then papyrus plant counts can increase. And if these reduced harvest frequency regimes can be employed in sites with potential for higher papyrus plant counts then the wetlands stand a chance of generating higher papyrus plant populations overall.

Water and sediment variables

There was no discernible relationship between Nitrate-N, EC, altitude and plant counts. It is, however, surprising that altitude differences can be significant in this study area given that all the sites are on or near the same lakeshore. But a casual observation of Figure 2 reveals that Nduru site was nearest to the water edge while Ogenya site was furthest from the water edge indicating that distance from the lake edge might have contributed to altitude differences. However, the effect of altitude is likely to be compounded by the effect of rainfall (Ssegawa et al., 2004), as lower altitudes tend to receive low rainfall and vice versa.

The similarity of available nitrate in the water column for Dunga and Ogenya and the significant difference for Nduru suggests that growing conditions were poorer at Dunga\ Ogenya than at Nduru. However, although these factors recorded significant difference in water or sediment samples, their influence was probably countered by the effect of floods. This argument may find support in the observations made by Bowden (1987) that biogeochemistry of N in freshwater wetlands is complicated by vegetation characteristics, hydrologic characteristics and by the diversity of the nitrogen cycle itself. Sediments are the single largest pool of nitrogen in wetland ecosystems. Atmospheric N inputs, such as dry deposition, are essentially unknown and could be as large or larger than deposition by rainfall or floods. Nitrogen fixation is an important supplementary input in some wetlands but is probably limited by the excess of fixed nitrogen usually present in wetland sediments.

The observations made in this study tend to concur with the findings of Jones and Muthuri (1985) that generally there is no major difference in phosphorus and pH levels among swamps, and that EC and nitrogen levels tend to vary among sites being lower where nutrient status is lower. Wetland ecosystems are largely dependent on the extent and duration of flooding, which in turn affect the spatial-temporal variability of their physico-chemical parameters. Lower nitrogen values (in water) in Dunga and Ogenya could be attributed to the accelerated denitrification that was favoured by the prevailing low redox potential occasioned by high flooding. In Nduru the high N levels could be attributed to the nitrate fertilizer use in the nearby rice fields.

Socioeconomic issues in papyrus harvesting

For various commercial purposes most of the papyrus is harvested beween three to six months of age. Harvesters identified the responses. Papyrus harvesting is done at three stages namely: Young/tender plants harvested for twining to make ropes, furniture, baskets; Middle/mature age plants harvested for making mats; Overgrown plants harvested for house construction and firewood purposes. Exploitation is worsened by harvesting its rhizomes (for houeshold fuel) thereby reducing its regeneration potential further.

Conclusion and Recommendations

There is no difference in papyrus population densities in undisturbed papyrus stands. Both monthly and seasonal harvesting reduces papyrus population densities, unless compounded by flooding. Papyrus population densities tend to increase with time in undisturbed papyrus stands - leaving a papyrus crop stand unharvested for at least six months increases its plant counts. There is a possibility that differential flooding also affects papyrus population density. There is need for more elaborate assessment of papyrus population replenishment potential, covering larger areas and more papyrus swamps, with greater effort, in order to generalize the findings in the entire Gulf. There is need for more stratified sampling design across months to determine papyrus population break-even point within the 3 6 months papyrus utilization age bracket, in order to develop sustainable papyrus harvesting regimes in Winam gulf. There is need for studies to establish the critical threshold water depth limits for papyrus.

References

Archer, C. (2004). Cyperus papyrus L. National Herbarium, Pretoria May 2004. http://www.plantzafrica.com 2pp.

Azza, N., Denny, P., van de Koppel, J. and Kansiime, F. (2006). Floating mats: Their occurrence and influence on shoreline distribution of emergent vegetation. Freshwater Biology **51**: 1286 1297

Boar, R. R., Harper, D. M. and Adams, C. S. (1999). Biomass Allocation in Cyperus papyrus in a Tropical Wetland, Lake Naivasha, Kenya. 1999. Biotropica 31(**3**): 411 - 421.

Boar R. R. (2006) Responses of a fringing Cyperus papyrus L. swamp to changes in water level. Aquatic Botany **84** (2): 85-92

Bowden, W. B. (1987). The biogeochemistry of nitrogen in freshwater wetlands Biogeochemistry **4** (3): 313 348

Bullock, J. (1996). "Plants". In: W. J. Sutherland (ed.) Ecological Census Techniques: A Handbook. Cambridge University Press. Cambridge. pp. 111 138.

Cotton, H. M., Cockle, W. E. H and Millar, F. G. B. (1995). The papyrology of the Roman Near East: A survey. The Journal of Roman Studies **85**: 214 235

Denny, P., Kipkemboi, J., Kaggwa R. and Lamtane. H. (2006) The potential of Fingerpond systems to increase food production form wetlands in Africa.

International Journal of Ecology and Environmental Science **32:** 41-47

Duke, J. A. (1996). "Cyperus papyrus L." In: Handbook of Energy Crops. Unpublished. www.hort.purdue.edu 1996. 3pp.

Elhorst, H. J. (1912). The Passover papyrus from elephantine. Journal of Biblical Literature 31(3): 147 149

Emerton, L. (1998). Economic Tools for Valuing Wetlands, Nature and Economy Programme. IUCN, Eastern Africa Regional Office Nairobi, Kenya. 18pp.

Fry, J. C. (1994). Biological data analysis. Oxford University Press. New York. 241pp.

Gaudet, J. J. (1977). Uptake, Accumulation and Loss of Nutrients by Papyrus in Tropical Swamps. Ecology **58**: 415 - 422.

Gichuki, J., Guebas, F. D., Mugo, J., Rabuor, C.O., Triest, L. and Dehairs, F. (2001). Species inventory and the local uses of the plants and fishes of the Lower Sondu Miriu wetland of Lake Victoria, Kenya. Hydrobiologia 458 (1): 99-106

Harper, D., Adams, C., Hickley, P., Muchiri, M., Boar, R., Britton, R. and Gichuru, N. (2004). Habitat degradation and subsequent fishery collapse in Lakes Naivasha and Baringo, Kenya. International Journal of Ecohydrology and Hydrobiology **4** (4): 503 517

Wikipedia http://en.wikipedia.org, (May 2007). Cyperus papyrus. The free encyclopedia. http://en.wikipedia.org, 8pp.

Jones, M. (1983). Papyrus: A new fuel for the Third World. New Scientist, **17**: 418-421.

Jones, M. B. and Muthuri, F. M. (1985). The canopy structure and microclimate of papyrus (Cyperus papyrus) swamps. The Journal of Ecology **73** (2): 481 491

Jones, M. B. and Muthuri, F. M. (1997). Standing biomass and carbon distribution in a papyrus (Cyperus papyrus L.) swamp on Lake Naivasha, Kenya. Journal of Tropical Ecology 13(3): 347-356

Kaplan, D., Oron, T., Gutman, M., (1994) Development of Macrophytic Vegetation in the Agmon Wetlands of Israel by Spontaneous Colonization and Re-Introduction. Wetlands Ecology and Management 6: 143 150

Kasoma, P. (2003). Lake Victoria Research (VicRes) Initiative. Wetland Research in the Lake Victoria Basin, Uganda Part: Analysis and Synthesis Report. The Inter-university Council of East Africa. SIDA SAREC, May 2003. 64pp.

Kipkemboi, J. (2006). Fingerponds: Seasonal integrated aquaculture in East African freshwater wetlands Exploring their potential for wise use strategies. Ph.D dissertation. Wageningen University. The Netherlands. www.crcpress.com 178pp.

Kotera, A. and Nawata, E. (2007). Role of plant height in the submergence tolerance of rice: A simulation analysis using an empirical model. Agricultural Water Management **89** (2): 49 -58

Kvét, J., Westlake, D.F., Dykjova, D., Marshall, E.J.P. and Ondok, J.P.(1998) "Primary Production in Wetlands" In: D.F. Westlake, J. Kvét, and A. Szezepariski (eds.) The Production Ecology of Wetlands: The BP Synthesis. Cambridge University Press. Cambridge. UK. pp.78-168.

Lind, E.M. & Visser, S.A. (1962). A study of a swamp at the north end of Lake Victoria. Journal of Ecology **50**: 599613.

Mallory, K. and Chandler, M. (2001) Lake Victoria: Africas Inland Sea. New England Aquarium. Central Wharf. Boston. Massachussetts. USA. 02110-3399. 21pp.

Mbaria, J. (2006). Linking Research to Extension for Watershed Management: The Nyando Experience. ICRAF Technical Manual No.1. World Agroforestry Centre (ICRAF). Nairobi. 72pp. www.worldagroforestry.org

McClanahan, T.R. and Young, T.P. (1996). East African Ecosystems and their Conservation. Oxford University Press. New York. 421pp.

Mead, R. (1990). The design of experiments: Statistical principles for practical application. Cambridge University Press. Cambridge. U.K. 439pp.

Mitsch, W. J. and Gosselink, J.G. (2000) Wetlands. Third Edition. John Wiley & Sons, Inc. New York. 913pp.

Mnaya, B., Asaeda, T., Kiwango, Y. and Ayubu, E. (2007). Primary production in papyrus (Cyperus papyrus L.) of Rubondo Island, Lake Victoria, Tanzania. Wetlands Ecology Management **15** (4): 269-275.

Nyunja M. (2003) "Summary of state of environment in Nyando District." In Onyango Leah, Swallow B. and Roy Jessica L. (eds.) Proceedings of a Workshop on Integration of Research, Planning and Environmental Management in the Nyando River Basin Tea Hotel, Kericho, Kenya September 17, 2003. World Agroforestry Centre, Nairobi, Kenya and Maseno University, Maseno, Kenya. Pp11 14.

Omollow, M.O., (2003) The Importance of Wetland Plant Resources and Agricultural Products in the Nyando River Wetlands, Kenya: A Comparative Study of Papyrus and Rice. M Phil Thesis. School of Environmental Studies. Moi University. Kenya. 122pp.

Owino, A. O. (2005). Papyrus swamp habitat loss and degradation: Impacts on endemic birds in Kenya. Msc Thesis. University of Capetown, South Africa. www.nrf.ac.za May 2007

Roberts, M. J., Long, S. P., Tieszen, L. L., and Beadle, C. L. (1993). "Measurement of plant biomass and net primary production of herbaceous vegetation" In: D. O. Hall, J. M. O. Scurlock, H. R. Bolhar-Nordenkampf, R. C. Leegood and S. P. Long (eds.) Photosynthesis and production in a changing environment: A field and laboratory manual. 1993. UNEP/Chapman & Hall. London. pp 1 21 of 477.

Ryan, D. P. (1988). Papyrus. The biblical archaeologist **51** (3): 132 140

Shepherd, K. Walsh, M., Mugo, F., Ong C., Svan-Hansen, T., Swallow, B., Awiti, A., Hai, M., Nyantika, D., Ombalo, D., Grunder, M., Mbote, F. and Mungai D. 2000). Improved land management in the Lake Victoria basin Linking Land and Lake, Research and Extension, Catchment and Lake Basin Final Technical Report Startup Phase July 1999 to June 2000. Working Paper 2000-2. ICRAF Working Paper Series. Natural Resource Problems, Priorities and Policies Programme. ICRAF/MoARD. Nairobi. Kenya. 88pp

Ssegawa, P., Kakudidi, E., Muasya, M. and Kalema, J. (2004) Diversity and distribution of sedges on multivariate environmental gradients. African Journal of Ecology **42**(1): 21 33

Sutherland, W. J. (1996) "Why census?" In: W. J. Sutherland (ed.) Ecological Census Techniques: A Handbook.. Cambridge University Press. Cambridge. Pp1-10

Thenya, T. (2006) Analysis of macrophyte biomass productivity, utilization and its impact on various eco-types of Yala Swamp, Lake Victoria Basin, Kenya. Ph.D Thesis. University of Bonn. Germany. 207pp.

Twong'o, T. K. and Sikoyo, G. M. (2004) "Status of Lake Victoria Ecosystems". In: T. K. Twong'o, G. W. Sikoyo, and J. W. Wakhungu (eds.) An Overview of the Status of Shared Aquatic Ecosystems in East Africa: Status and Trends. African Centre for Technology Studies (ACTS). www.acts.or.ke/biodiversity pp.4 40

Underwood, A. J. (1997) Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge university press. Cambridge. UK. 504pp.

van Dam, A. A., Dardona, A., Kelderman, P. and Kansiime, F. (2007). A simulation model for nitrogen retention in a papyrus wetland near Lake Victoria, Uganda (East Africa). Wetlands Ecology and Management. **15**(6): 469 480

Vignoli, L., Carpaneto, G. C. and Cozar, A. (2004) An Ecological Research on Fish Species in the Papyrus Stand Ecotone of Lake Victoria, Uganda and Kenya. www.bio.nu.nl

Wallert, A. (1989). The reconstruction of papyrus manufacture: A preliminary investigation. Studies in conservation **34** (1): 1 8

Zar, J.H. (1984) Biostatistical Analysis. Prentice-Hall. New Jersey. USA. 718pp.

Bioassessment of the Water Quality of River Kipkaren, Nzoia River Basin, Kenya

C. M. Aura, P.O. Raburu
Department of Fisheries & Aquatic Sciences, School of Natural Resource Management, Moi Uinversity, Eldoret, Kenya

J. Herrmann
Department of Natural Science, University of Kalmar, Kalmar, Sweden

Abstract

The study set out to investigate the possibility of establishing an Index of Biotic Integrity (IBI) using macroinvertebrates to assess the water quality of River Kipkaren in the upper reaches of River Nzoia Basin, Kenya. Water parameters like pH, conductivity, and temperature were measured in situ while parameters such as DO, total phosphorus (TP) and total nitrogen (TN) were determined calometrically in the laboratory using standard methods. Habitat and land use characteristics were also recorded. Triplicate macroinvertebrate samples were collected semi-quantitatively in five stations on a monthly basis from December 2006 to May 2007 using a 0.5mm mesh size scoop net in different macrohabitats. EPT and Shannon-Wierner diversity indices for each station were calculated. There was an increase in TN and TP concentrations downstream with a significant positive correlation for TN and TP and macroinvertebrates obtained (r = 0.39). Pair wise comparison in all the stations, which provided nine macroinvertebrate metrics that contributed significantly ($p<0.05$) to the final IBI. The IBI scores ranged from 27 to 39 points, due to variations in anthropogenic impact. The index was able to delineate impacted from less impacted sites along the river. The study recommends introduction and enforcement of better catchment management practices including protection of the riparian zones to reduce environmental degradation and improve the river health and thus biotic integrity. Further improvement of IBI using a combination of fish, invertebrates, algae and amphibian assemblages could be explored to provide an integrated bio-index for Nzoia River Basin.

Key words: River Kipkaren, macroinvertebrates, Index of Biotic Integrity (IBI), water quality.

Introduction

The ultimate factors forcing change in running waters, include ecosystem destruction, physical habitat and water chemistry alteration, and the direct addition or removal of species, stem from proximate influences from urbanisation, industry, land use change and water-course alterations (Buttle & Metcalfe, 2000). Rather than focusing only on biology, water quality evaluation for much of the twentieth century concentrated on the effect of chemical contaminants with rare connection between chemical criteria and ambient biotic condition. The Chemical method is expensive as it involves chemicals and not environmentally friendly. Therefore, there was need to use less costly and environmentally friendly method of assessing the water quality, thus biomonitoring procedures. During the past two decades, life in the waters has again come to the fore, and biological monitoring that involves detecting human-caused biotic changes apart from those occurring naturally, is again part of water managers' tool kits (Karr & Chu, 1997).

There is a wide spectrum of biotic indices for assessing the ecological health of a running water ecosystem, but to date IBI stands out to be one of the best methods (Sabater et al., 2004) as it helps to gain a well-rounded perspective of the chemical, physical and biological conditions of a particular stream station. An IBI is suitable because it satisfies the requirements that an index should be relevant, simple and easily understood by laymen, scientifically justifiable, quantitative and acceptable in terms of cost. The development of biological criteria to asses the biological integrity of an ecosystem is based on regionalization, multi-metric approach and the use of the reference conditions (Barbour et al., 1999). Regionalization categorizes ecologically discrete units based on a number of characteristics such as soil type, climate and land use. This is because, according to Karr and Chu (1997), geographic separation of within region-homogeneity and between region-heterogeneity (discrete units) has become integral part of bioassessment. On the other hand, Babour et al. (1999) denotes that multi-metric indices are composed of ecologically sound measurements that have known responses to anthropogenic impacts. This implies that when metrics are organized and selected systematically within a regional framework, multi-metric indices measure changes along disturbance gradients (Karr and Chu, 1997) such as agricultural, urbanization and forestry. Reference conditions are a suite of sampling points or sites, which are chosen to represent the region regardless of their expectations (Barbour et al., 1999). Probability-based sampling designs, in concert with knowledge of metric responses to human impact, are appropriate for the random selection of reference conditions (Griffith et al., 2005). This affirms the use of macroinvertebrate metrics, stations and reference site that were used in this study.

The sampling stations in this study were found in agricultural dominated areas, urbanized localities, forested stations, swampy areas, and sites of before and after the confluence between River Kipkaren and Sosiani, another tributary of River Nzoia. Thus sampling of such areas would form a good case study, which could be replicated in the upper reaches of Lake Victoria Basin. This study targeted to confirm the water quality characteristics through macroinvertebrate attributes, because of their ease in the collection and identification, limited mobility, short life spans and differential tolerance to a number of pollutants. Macroinvertebrate assemblages are integrally linked to in-stream physical and chemical characteristics and have been frequently used as indicators of water quality (Roy et al., 2001). Information on anthropogenic impacts on streams and rivers in this catchment and Kenya as a whole is scanty. Gaps in knowledge exists concerning the impacts of many pollutants and human activities that may stimulate environmental degradation which could have far reaching consequences to these valuable ecosystems (Postel, 1998). This study aimed at providing data to bridge the existing knowledge gaps on riverine integrity and health by relating macroinvertebrate variables to anthropogenic influence in River Kipkaren, and developing a multi-metric index for macroinvertebrate communities using metrics that respond to the range of conditions found in the River Kipkaren. This may provide necessary data to ultimately improve the quality of the effluent discharged into the watercourses from human activities that threatens the diversity of aquatic fauna and health in the riverine environments within the Lake Victoria Basin.

Materials and Methods

Study area

This study was conducted on River Kipkaren, that lies between latitude 1° 30'N and 0°05'S and longitude 34° 15'W and 35° 45'E on the upper reaches of the basin at an altitude of 2000 m to 2180 metres above sea level. River Kipkaren is one of the rivers that drain into River Nzoia (Fig. 1). Served with seven tributaries, River Kipkaren has an approximate length of about 50 km with a mean depth of 1.2 metres. The maximum depth and maximum width of River Kipkaren is about 3.6 metres and 17 metres respectively. The River originates from Kipchamo swamp in Uasin Gishu District. River Sosiani, about six kilometres before confluencing near Kipkaren Town, joins it.

The rainfall in the River Kipkaren catchments is bimodal with a mean annual rainfall of about 1500 metres (Jaetzold and Schmidt, 1983). The mean annual temperature is 18ÚC with a maximum of 24ÚC. The topography of the area is mainly undulating and the soils are mainly oxisols on the hill slopes and luvisols on the valley bottoms. The area experiences four seasons in a year as a result of the inter-tropical convergence zone. There are two rainy seasons and two dry seasons with short rains occurring from October to December and the short rains from March to May. The dry seasons occur in the months of January to February and from June to September. However, short rains were experienced throughout the study period from December 2006 to May 2007.

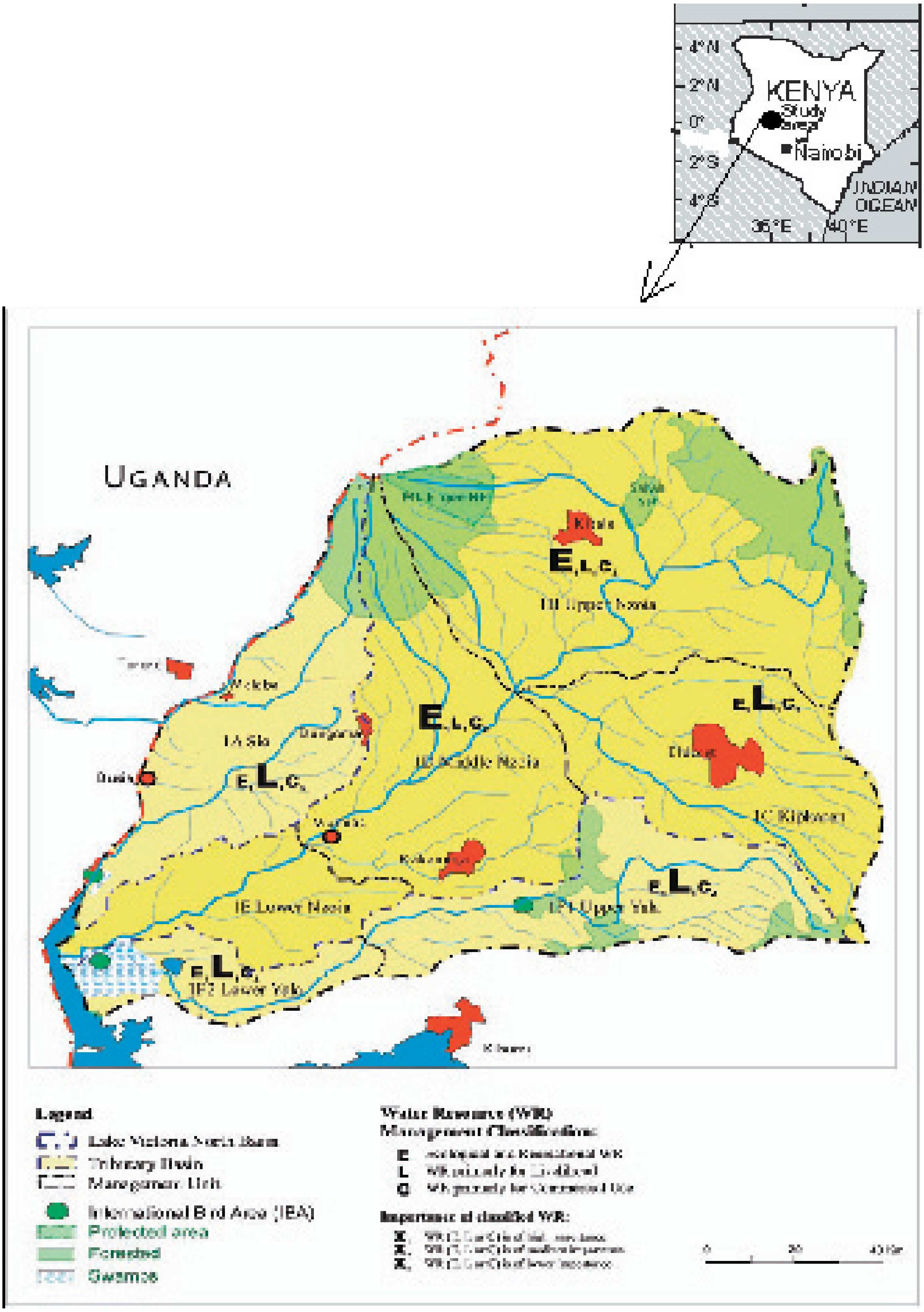


Figure 1: Map of River Nzoia Basin and its tributaries, notably, River Kipkaren labeled as 1C. (Source: GoK, 2007).

A total of five sampling stations were established and sampled from December 2006 to May 2007 where triplicate samples were collected (Fig. 2). The sampling stations along River Kipkaren were chosen after considering the human activities in the upstream. Station S1 was located at the source of River Kipkaren at latitudes and longitudes of 0°35'N and 35°07'E respectively. Station S2 was 100 m away from the bridge on the way to the Eldoret Airport with latitudes of 0°35'N and longitudes of 35°10´E. Station S3 was located 100 m before the confluence of Rivers Kipkaren and Sosiani (0°35'N and 35°12'E). Station S4 was located 100 m after the confluence of Rivers Sosiani and Kipkaren, after the Kipkaren Training Institute (at latitudes and longitudes of 0°35'N and 35°16´E respectively). Station S7 was located near Kipkaren Town on River Kipkaren (0°35'N and 35°18´E), about 100 m after Kipkaren Town.

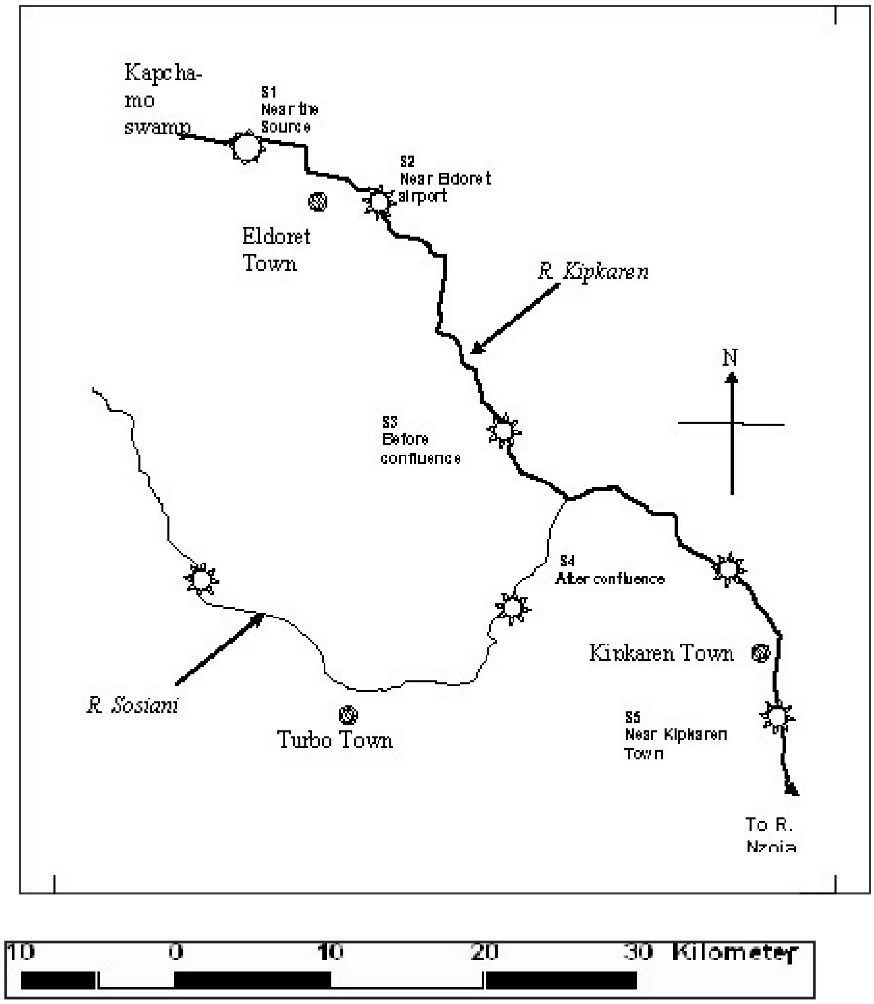


Fig. 2: Sampling stations on River Kipkaren, labeled downstream from the source of the River

Sampling

Triplicate samples were collected per station randomly in the riffles, pools and runs. The water physico-chemical parameters of temperature, pH, Oxygen and conductivity were measured insitu using standard methods (APHA, 2000). The TN and TP were determined using Kjedahl method and Persulfate digestion method respectively (APHA, 2000). Triplicate samples of macroinvertebrates were also randomly taken from all the stations using a scoop-net of 0.5mm mesh size at a one metre by one metre breadth, sorted live in a white plastic tray and placed into vials and preserved with 70 per cent ethanol. Macroinvertebrate samples were transported to the laboratory for further sorting, counting and identification using available identification keys (IFM, 2006; Merritt & Cummins, 1997) to genera levels. The macroinvertebrates were analyzed for Shannon-Wierner diversity and EPT indices (Karr & Chu, 1997). Kruska-Wallis ANOVA was used in determining the significant difference between and within the stations at $p < 0.05$. The two- way ANOVA was used to establish any significant difference between stations for physico-chemical parameters and for total phosphorus and total nitrogen. The Spearman's Rank correlation analysis was used in determining the relationship between macroinvertebrates abundance and diversity and nutrient levels. The Mann-Whitney U test and Kolmogorov-Smirnov test were used for eliminating the metrics with no significant differences ($p > 0.05$) after pair wise comparison in all the seven stations, before arriving at the final IBI.

Macroinvertebrate IBI

Reference and Station Identification

Reference station was defined as an area with minimal anthropogenic disturbance, based on thresholds established in this study for water chemistry (of conductivity, pH, temperature and DO), physical habitat, and land use within the catchment upstream of the sampled stations (Robert & Rankin, 1998). In this case, the station at the source of River Kipkaren was selected as the reference station. However, completely undisturbed stations are virtually nonexistent and even remote waters are impacted by factors such as atmospheric pollution and presence of households (Mason, 2002). This study utilized the best values observed in this study to set the baselines of expectation for each metric attribute (Karr & Chu, 1997) and hence delineate degraded stations from nondegraded ones basing on the data from water chemistry and physical characteristics observed at each station.

Metrics

A metric in this context, is defined as an attribute with empirical change in value basing on ones study, along a gradient of human disturbance or environmental condition change (Mason, 2002). In this study, various metrics were selected that acted as indicator attributes in assessing the status of macroinvertebrate assemblages in response to perturbation in the study area. The metrics that were considered for this study were obtained from literature in relation to the data obtained from this study on occurrence of a given genera in the stations. Table 1 shows the full list of candidate metrics that fell into four groups of taxa richness, composition attributes, taxa tolerance and trophic function for biocriteria and testing.

Table 1: Macroinvertebrates metrics considered for assessing index of biotic integrity

Taxa richness	Composition Attributes	Taxa Tolerance	Trophic Function
No. Ephemeroptera taxa	% Diptera	% Tolerant taxa	% Filterers
No. Plecoptera taxa	%EPT: % Diptera	% 5Dominant taxa	% Predators
No. Trichoptera taxa	% Mollusca		% Gatherers
	%Hemiptera		% Shredders
	%Odonata		
	% Oligochaeta		

IBI Thresholds and Biocriteria

Threshold values for each selected metric were established as approximately the 20th and 50th percentile (median) to the reference station. For each metric expected to decrease with degradation, values below the 20th percentile were scored as 1, as they showed greatest deviation from the reference station. Values between the 20th and 50th percentiles were scored as three, as they fell short of median expected values for the reference station. Values above the 50th percentile were scored as five. Scoring was reversed for the metrics expected to increase with degradation (Karr & Chu, 1997). To arrive at the final IBI value for each station, scores for each metric were summed. The highest expected value of 45 points served as a benchmark for the ranges for qualitative assessments of the final IBI scores that was done according to Barbour et al (1999) and Griffith et al. (2005), but modified to suit local conditions (Table 2).

Table 2: Integrity classes for final IBI development for River Kipkaren

Class of integrity	Ranges for IBI
Excellent water quality	36-45
Good water quality	28-35
Fair water quality	21-27
Poor water quality	< 27

Results

Physico-Chemical Parameters

The highest temperature occurred at station S2 with a mean of 22.2 ± 0°C while the lowest was recorded at station S3 with a mean of 19.8 ± 0°C. There was no significant difference between the stations and sampling dates. The lowest mean pH value of 6.8 ± 0.5 was recorded at station S2, whereas, the highest mean pH value was recorded at station S5 (7.1 ± 0.3). As noticed with temperature, there was no significant difference in pH between sampling stations and sampling dates. The highest mean conductivity of 121.8 ± 8 μS/cm was recorded at station S5, while; the lowest mean value was recorded at station S1 (101± 4 μS/cm). Significant differences in conductivity occurred between stations ($F = 16.8$; $p<0.05$) but not between the sampling dates. The highest mean Dissolved Oxygen was observed at station S2 (7.6 ± 0.02 mg/L) and the lowest was recorded at station S3 (4.0 ± 0.01mg/L). Dissolved Oxygen concentration differed significantly between the stations ($F = 3.6$; $p<0.05$), but not between the sampling dates.

The amount of total phosphorus (TP) did not differ spatially or temporally during the study. However, station S5 recorded the highest TP of 0.12 ± 0.23 μg/L while the lowest TP value of 0.05± 0.02 μg/L was recorded at station S1 (Fig. 3). Unlike TP, the total nitrogen (TN) significantly varied among the stations ($F = 629.52$; $df = 6$; $p = 0.00$) but not temporally. The highest TN of 0.35 ± 0.03 was recorded at station S5 and the lowest at station S1 (0.07± 0.04 mg/L).

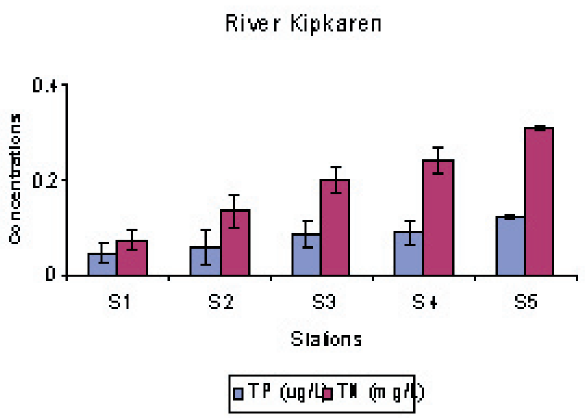


Figure 3: Mean (± SEM) of TP and TN for the Sampling Stations in River Kipkaren during the study period.

Macroinvertebrates Composition

A total of 1009 macroinvertebrates belonging to thirteen orders, 28 families and 31 genera were sampled. The orders Ephemeroptera, Hemiptera and Coleoptera were the most diverse taxa, consisting of four families each (Table 3). Baetis sp. was dominant in station S1 with a relative mean abundance of 29.10 ± 0.21, while Chironomus sp. had the lowest relative mean abundance of 0.33 ± 0.01. Station S3 experienced a high relative abundance of Caenis sp. (23. 12 ± 0.63) but with lowest mean relative abundance of Pisidium sp. (0.86 ± 0.02). Baetis sp. had the highest relative mean abundance of 27.78 ± 0.95 whereas Polycentropus sp. had the lowest relative mean abundance value of 0.28 ± 0.06 in station S2. Station S5 was dominated by Chironomus sp. with a mean relative abundance of 26.1 ± 0.12 whereas Heptagenia sp., had the lowest relative mean abundance of 0.74 ± 0.31. Tubifex sp., with a relative mean abundance of 27.56 ± 0.07 dominated station S4 and Elmis sp. had the lowest relative mean abundance (0.74 ± 0.01).

Table 3: Summarised taxonomic list for the sampling station in River Kipkaren

Order	Family	Genus
Ephemeroptera	Baetidae	Baetis sp
	Caenidae	Caenis sp
	Heptageniidae	Heptagenia sp.
	Ephemerellidae	Ephemerella sp
Hemiptera	Gerridae	Gerris sp
	Notonectidae	Notonecta sp
	Veliidae	Velia sp
	Corixidae	Corixa sp
	Nepidae	Nepa sp
	Belostomatidae	Belostoma sp.
Coleoptera	Dytiscidae	Dineutus sp
	Elmidae	Elmis sp, Limnius sp
	Gyrinidae	Gyrinus sp.
	Hydraenidae	Hydraena sp.
Diptera	Chironomidae	Chironomus sp
	Culicidae	Culicidae sp
Prosobranchia	Valvatidae	Valvata sp
	Hydrobiidae	Bithynia sp.
Odonata	Aeshnidae	Aeshna sp
	Gomphidae	Gomphus sp
	Agriidae	Agrion sp.
Oligochaeta	Lumbriculidae	Lumbriculus sp
	Tubificidae	Tubifex sp
Plecoptera	Nemouridae	Nemoura sp.
	Leuctridae	Leuctra sp
Bivalvia	Unionidae	Pisidium sp, Sphaerium sp.
	Bithyniidae	Gabbia sp.
Isopoda	Asellidae	Asellus sp
Pulmonata	Lymnaeidae	Lymnaea sp
Trichoptera	Polycentropodidae	Polycentropus sp.
Hirudinea	Erpobdellidae	Erpobdella sp, Glossiphonia sp

The relative abundance of the Diptera increased downstream while the intolerant group of Ephemeroptera, Plecoptera and Trichoptera (EPT) decreased downstream (Fig. 4). More EPT were recorded in station S1 (44%), where Dipterans recorded the lowest overall relative abundance of 10%. Results of the mean abundance of macroinvertebrates differed significantly (F= 16.31; p = 0.00) among the stations, with station S5 recording the highest mean number (10.91 ± 0.90) of macroinvertebrates and stations S3, the lowest (7.03± 0.70). Notably, significant differences in Shannon-Wiener mean diversity index of macroinvertebrate genera was recorded among the stations (H=7; p=0.00). Station S1 had the highest Shannon-Wiener diversity (3.08±0.90), followed by station S2 (3.02± 1.21), whereas, stations S5 and S4 had the lowest diversity of 2.9±0.90 and 2.94± 0.80 respectively. The highest genera diversity was recorded in the month of May (3.02±1.10) and the lowest in the month of December (2.88±1.0).

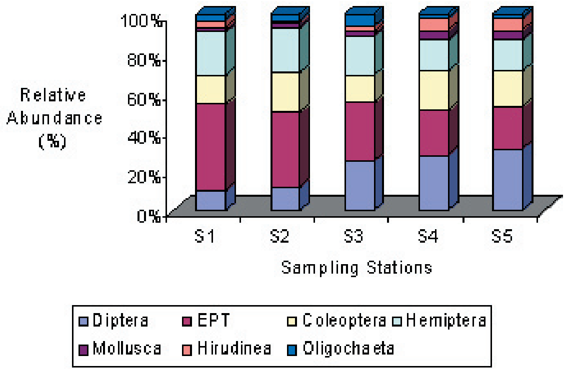


Figure 4: Relative abundance of macroinvertebrate groups in River Kipkaren during the study period

Relationship between Macroinvertebrates Abundance and Diversity and Nutrients

Relationship of TP and TN variables to macroinvertebrate Shannon-Wierner diversity resulted in significant correlations. Station S5 had the highest correlation between macroinvertebrate Shannon-Wierner diversity, respectively, with TP and TN concentrations (r =0.94± 0.57), whereas, Station S2 recorded the lowest correlation (r =0.49± 0.47). The overall correlation value for all the sampling stations was r = 0.39. All the stations indicated significant differences (p = 0.00) between macroinvertebrate Shannon-Wierner diversity and TP and TN concentrations. Stations with the highest Shannon-Wierner diversity of macroinvertebrates recorded the lowest values of TP and TN concentrations. With a Shannon-Wiener value of 3.08±0.8, the source of River Kipkaren had 0.046 ± 0.02 µg/L and 0.073 mg/L for TP and TN respectively. Two-way ANOVA showed significant differences between mean abundance per station and TP (F = 2.6; p = 0.00) and between mean abundance per station and TN (F = 3.9; p = 0.00).

Macroinvertebrate Index of Biotic Integrity

Among the fifteen metrics tested, nine metrics passed the Mann-Whitney U and the Kolmogorov-Smirnov tests because they exhibited a significant difference (p<0.05) after pair wise comparisons of attributes of macroinvertebrates in all the five stations. Metrics that performed poorly under the pair wise comparisons in all the five stations in these initial stages were not used in subsequent analyses. With a decrease in the final IBI scores downstream, station S2 emerged with the highest overall Macroinvertebrate IBI (37 points), whereas station S5 recorded the lowest IBI (27 points) (Table 4).

Table 4: The M-IBI scores for different sampling stations along River Kipkaren during the study period.

	Scoring criteria							
Metric for IBI	5	3	1	S1	S2	S3	S4	S5
No. Ephemeroptera taxa	18-11	11-6	<6	5	5	3	3	1
No. Plecoptera taxa	10-6	6-3	<3	5	5	3	5	3
No. Trichoptera taxa	6-4	4-2	2-1	5	5	3	5	3
% Diptera	<46	46-88	>88	5	3	3	3	1
% EPT : Diptera	>38	16-38	<16	5	3	3	3	3
% Mollusca	<5	5-10	>10	3	3	3	3	3
% Tolerant taxa	<35	35-42	>42	5	5	5	3	3
% Gatherers	>30	15-30	<15	3	5	5	5	5
% Predators	>10	6-10	<6	3	3	5	5	5
Total IBI Score				39	37	33	35	27

Discussion

Variations were recorded in the nutrient concentrations among the stations, with an increase in concentrations downstream in the river (Fig. 3). The increased concentration of nutrients caused oxygen deficit downstream affecting the distribution of macroinvertebrates. This was in relation to the tolerant species like Chironomus sp., Tubifex sp., Lumbricus sp. and Dipterans that dominated stations S4 and S5. This could be attributed to the fact that these animals have got high glycogen content and reduced activity which allows them to withstand increased nutrient and conductivity levels in the macrohabitats (Welch, 1992). The intolerant group, as represented by the EPT group, coupled with high Shannon-Wierner index values, were higher in Stations S1, S2 and S3 because of probably less anthropogenic impact in the riparian zones in such areas. This seems to support why insects like Heptagenia sp., Baetis sp., Elmis sp. and Caenis sp. were most abundant in stations of less hydrological and human disturbance, such as station S1. The significant differences among the mean abundance of macroinvertebrates in the sampled stations therefore can be directly linked to the changes in human activities including urbanization, agricultural inputs and forested or wetland areas along the river, which contributed to either in and/or reduction of the amount of nutrients into the river system.

Metric variability and response of metrics to impaired sites indicated that the developed IBI responded to the range of biological conditions found in the ecoregion. These metrics also followed the predicted ecological-dose response relationships with perturbations using the subset (pair wise) of impaired sites (Barbour et al., 1999). The final IBI scores decreased downstream reflecting the increase of perturbations down the river. For example, according to the calculated IBI (Table 5), station S5 scored 27 points while station S2 37 points out of the total 45 points. Basing on the integrity classes (Table 2), station S2 falls in the first category of excellent water quality while Station S5 falls in the fourth category of poor water quality. The difference in water quality between station S2 and stations S5 could be partly attributed to the urban discharges from Kipkaren town located upstream of S5 as opposed to the presence of a swamp and a forest upstream of station S2. Station S3 recorded 33 points and classified as good water quality probably due to the dilution effect of pollutants because of increased water volume that was observed in the area. Another reason could be the uncultivated farmland and dense vegetation that forms the riparian zone of the area, which to some extent buffers any runoffs into the river. Station S4 recorded 35 points also being classified as excellent water quality. This can be attributed to organic farming in the riparian zones and dense bank vegetation that minimizes nutrient and other pollutant discharges into the river. The sampling stations were probably less affected by urbanization and agricultural activities due to the presence of a single urban centre (Kipkaren Town) that has no major industries and the presence of vegetation cover in the zones and swamps closer to or around the river. The calculated IBI therefore depicts that River Kipkaren waters are generally of good water quality. This also compares with the studies done on other streams (Roy et al., 2001). The IBI has also shown a similarity with those IBI scores that have successfully correlated with human activities like urbanization and agriculture (Carpenter et al., 1998; Griffith et al., 2005) and riparian destruction (Griffith et al., 2005). This is an indication that the index could probably be a preliminary estimate of the current biotic integrity of all the stations and for River Kipkaren, especially during the period of short rains.

With the increase of anthropogenic activities in the Lake Basin, it would be important to come up with comprehensive biomonitoring protocols, which could be used to monitor the environmental changes in the basin on the findings of this study. A modification of this preliminary IBI using a combination of fish, invertebrates, algae and amphibians to provide a complete bio-index assessment can be developed to determine the water bodies' health within the upper reaches of River Nzoia Basin, and Lake Victoria Catchment as a whole. The analysis of impaired sites, using a targeted approach, could also strengthen the overall index and lead to more accurate assessments by calibrating criteria lines and narrative interpretations of the IBI. A suite of the impaired sites that are affected by specific stressors could be used to test the index against various anthropogenic disturbances.

References

APHA .2000. Standard methods for the analysis of water and wastewater, 15th ed. American Public Health Association and Water Pollution Control Federation. Washington DC, USA. 12- 56Pp.

Barbour, M.T., Gerritsen, J., Griffin, G.E., Frydenborg, R., Mccanon, E., White, J.S., & Bastian, M.L. 1999. Journal of the North American Benthological Society, 15:185-211.

Buttle, J. M. & Metcalfe, R. A. 2000. Boreal forest disturbance and stream flow response, northeastern Ontario. Canadian Journal of Fisheries and Aquatic Sciences, 57, 5-18.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharply, A.N. & Smith, V.H. 1998. Non-point Pollution of Surface Waters with Phosphorus and Nitrogen. Ecological Applications, 8, 559-568.

Griffith, M. B., Hill, B., Mccormick, H., Kaufmann, R., Herlihy, T. & Selle, A. R. 2005. Comparative application of indices of biotic integrity based on periphyton, macroinvertebrates, and fish to southern Rocky Mountain streams. Ecological Indicators 5:117- 136.

IFM 2006. Aquatic Ecology. Department of Biology, Linkoping University, Sweden. 14 58Pp.

Jaetzold, R., and Schmidt, H. 1983. Farm Management Handbook of Kenya. Ministry of Agriculture, Kenya, and the German Agency for Technical Cooperation. 34pp.

Karr, J.R. & Chu, E.W. 1997. Biological Monitoring and Assessment: Using Multimetric Indices Effectively. EPA 235- R97-001. University of Washington, Seattle, WA. 45pp.

Mason, C. F. 2002. Biology of freshwater pollution. 4th Ed. Pearson Education Ltd. Essex. London. 388pp.

Merritt, R.W. & Cummins, K.W. 1997. An Introduction to Aquatic Insects of North America. 3rd Edition. Kendall/Hunt Publishing Company, Dubuque, Iowa, USA. 67pp.

Postel, S.L. 1998. Water for food production: will there be enough in 2025? Bioscience 48: 629-637.

Robert, J.M. & Rankin, T.E. 1998. Primary nutrients and the biotic integrity of Rivers and streams. Ohio Environmental Protection Agency, 1685 Westbelt Drive, Columbus, OH 43228, U.S.A. Freshwater Biology, 40, 145-158.

Roy, A.H, Rosemond, D.A., Leigh, D.S., Paul M.J. & Wallace, J.B. 2001. Efforts of changing land use on macroinvertebrate integrity. Georgia Water Resource Conference. University of Georgia, Athens. 73pp.

Sabater, S., Acuna, V. & Giorgi, A. 2004. Flow extremes and benthic organic matter shape the metabolism of a stream. Freshwater Biol. 49, 1960-1970.

Welch, E.B. 1992. Ecological effects of wastewater River. Chapman and Hall publishers London. 35pp.

The Agony of Fishing at Lake Naivasha, Kenya: Is Community Participation in Management the Solution?

Rodrick Kundu
Ministry of Fisheries Development, Bondo, Kenya

Christopher Aura, Murithi Njiru
Department of Fisheries & Aquatic Sciences, School of Natural Resource Management, Moi University, Eldoret, Kenya.

Jacob E. Ojuok
Kenya Marine and Fisheries Research Institute, Naivasha, Kenya.

Abstract

Lake Naivasha, unlike other lakes in the tropics has low fish species diversity. The fishery is based on introduced fish species that are not native to the lake. The lake ecosystem is very fragile and this has been reflected in the fluctuating fish catches. The fishery came to almost a total collapse in 2001 partly due to mismanagement and ignorance on conservation measures. The Kenyan government, like most governments worldwide, recognized the need to involve fishers and other stakeholders for better management of fisheries resources. This kind of arrangement provides the opportunity to share responsibility of managing the resource between the government and the community, also referred to as collaborative management (co-management). A total ban on fishing was imposed in February 2001 and was in operation for a year to allow fish stocks to recover. This paper outlines the co-management process at Lake Naivasha and discusses the role played by the community during the fishing ban, successes and challenges encountered and fishers' tribulations and perception of the new management strategy. It also forms the first documentation since community participation in fisheries management began at Lake Naivasha in the year 2001.

Key words: *Lake Naivasha, fishery, fishing ban, fisher folk, and co-management*

Introduction

Co-management involves the sharing of roles and responsibilities of resource management between the government, resource users, and other interested stakeholders (Pomery, 2004). This kind of strategy was initiated at Lake Naivasha in the year 2001. Lake Naivasha (0º 45´ S, 36º 20´ E; altitude 1890 metres above sea level) is a small and shallow freshwater lake in the eastern Rift Valley covering a surface area of about 160 sq. kilometres (Hickley *et al*., 2002) about 100 kilometres North West of Nairobi. The lake supports a number of economic activities, fishing being among them. Other activities include horticulture, tourism, water for domestic use and geothermal generation. Because of its high and unique biodiversity, coupled with threats from anthropogenic activities it was declared a wetland of international importance in 1994 under the Ramsar Convention (LNRA, 1999). The lake has six species of fish and a crustacean was also introduced. They include large mouth bass, *Micropterus salmoides* (Lacépède), tilapia *Oreochromis leucostictus* (Trewewas), *Tilapia zillii* (Gervais), common carp *Cyprinus carpio*(Linneaus), *Barbus amphigramma* (Blgr), guppy *Leticulus reticulate* (Peters) and crayfish *Procambrus clarkii*. The only endemic species *Aplocheilichthys antinorii* (Vinc.) was last recorded in 1962 (Elder *et al*., 1971). Litterick et al., 1979 and Muchiri & Hickley 1991 cover the history of fish introductions. Commercial fishing started in 1959 based on the large mouth bass and the two tilapias (Muchiri and Hickley, 1991) and recently (2002) the common carp. Currently the fishing industry at the lake employs more than 1000 Kenyans and provides a source of protein for area residents and others in nearby towns.

Several factors are a threat to the fishery. Chief among them is uncontrolled and excessive fishing which seriously affects restocking rates. Associated with this is the rampant use of prohibited fishing gears, trampling in the shallow waters around the lakeshore where the fish breed and weak enforcement of fisheries regulations.

Like in many other parts of the world the fishery has been treated as a common property to be exploited by each and every individual (both legal and illegal) according to their needs, ability and capacity to harvest (Hardin, 1968). Other threats include unpredictable lake level fluctuations (Becht and Harper, 2002), encroachment on riparian land and potential pollution from the surrounding farmlands (Harper *et al.*, 1990), armed and violent illegal fishers, dishonesty on the part of government officials and lack of awareness on sustainable exploitation. All these factors contributed to the near collapse of the fishery. This paper therefore highlights the use of co-management arrangement at Lake Naivasha for biological sustainability and continued economic viability of the fisheries resource for the present and future generations.

Materials and Methods

Two methods were used in the preparation of this paper. The historical background and secondary information was sourced from records kept by Fisheries Department (FD), Lake Naivasha Riparian Association (LNRA), which is a local community, based organization and research reports on Lake Naivasha Research Project by Kenya Marine and Fisheries Research Institute (KMFRI). The other method employed is reviews of existing publications on co-management. The input of lead authors experience and involvement right from the inception of the process in 2001 to 2004 when he was the Fisheries Officer- in-Charge of the area is also taken into account.

Co-management process at Lake Naivasha

Towards the end of the year 2000, the Fisheries Department held consultative meetings with Lake Naivasha stakeholders, which included fishermen and landowners. The aim of these meetings was to address the problem of declining fish stocks after years of excessive fishing. It was decided that since the government has been unable to manage the fishery due to budgetary constraints, there was need to change the management approach and bring on board the stakeholders. This defined a paradigm shift in management from top-down to participatory and collaborative approach, which is in this case co-management. Thus, through consultative meetings between the government and stakeholders, a fish recovery strategy was put in place. Through consensus, it was unanimously agreed that the lake should be closed to fishing for a specified period of time to allow fish stocks to rejuvenate. This was achieved through a legal gazette notice, which enforced a total fishing ban with effect from February 10^{th}, 2001.

Enforcement of the fishing ban

A task force management committee was formed immediately when the fishing ban was imposed and was mandated to work out modalities and make guidelines for the proper management of the fishery. The composition of the task force consisted of the Fisheries Department (FD), Kenya Marine and Fisheries Research Institute (KMFRI), Kenya Wildlife Service (KWS), Lake Naivasha Riparian Association (LNRA-representing landowners), Beach Management Committees (BMC-representing fishers) and Lake Naivasha Fishermen's Cooperative Society (LNFCS). However, the membership of the task force was later expanded to include the provincial administration, Kenya police, Ministry of Water, Fish Traders Association and Naivasha Municipal Council. The expansion of the task force enabled the formation of the Fish Protection Unit (FPU) chaired by the local district officer. Among the highlights of the guidelines which were to be implemented by FPU included: involvement of active participation of the local community in fisheries management (policing, research and licensing); creation of awareness among resource users and those in authority to promote responsible fishing practices in the industry; identification of alternative and complementary sources of livelihood; working out modalities for reducing the number of fishers when the lake is opened to fishing; identification of fish breeding zones involving fisher folk; and sourcing funds to supplement the government funding. In order to enhance policing the lake to enforce the ban, a community sponsored vigilante group was formed to assist the FPU. The composition of the vigilante group comprised fishers and reformed fish poachers.

During the first year (2001), public education campaigns were conducted to increase the general public's understanding of sustainable use of the lakes` fishery. The campaigns involved conducting public assemblies (barazas) that ranged from government to fishers/community, government to government officials and fisher/community to fisher/community. Through LNRA, members of the community contributed funds and provided material support to supplement the cost of establishing the new management strategy (Table 1).

Table 1. Contribution from stakeholders 2001

Name of stakeholder	Cash (Ksh)	Other support
Anonymous	100,000	
Lake Crops (Mr Burch)	5,000	Land transport, petrol, surveillance
Sher Agencies	200,000	Land transport, redeployment of fishers
Orpower 4, Inc.	60,000	
Homegrown	50,000	Land transport, redeployment of fishers
Dr & Mrs Irvine	3,000	
Dr Leon Bennun	1,500	
Mr John Barton	10,000	Surveillance
Sanctuary Farm	10,000	
Brig Wilson Boinett	10,000	
Longonot Farm	40,000	Land transport, redeployment of fishers
Mr Jeremy Block	400,000	Air surveillance
Kijabe Ltd (Ms S Higgins)		Land transport, air surveillance, petrol, redeployment of fishers
Crescent Island (Mr Gaymer)	86,100	Land, water and air surveillance, petrol
Oserian Dev Company		Land & water transport, surveillance, redeployment of fishers
Mr Michel Lejeune		Water transport, petrol, surveillance
Mr Waithaka Mbuthia		Water transport
Wildfire Ltd (Mr Szapary)		Land transport, petrol, surveillance, redeployment of fishers
Shalimar Flowers		Redeployment of fishers, surveillance
Ms Joan Root	1,343,400	Land transport, petrol, surveillance
Horticulture Farm		Land transport, petrol, surveillance
Mr Peter Low		Land transport, petrol, surveillance
Mbegu Farm		Land transport, surveillance, redeployment of fishers
Lake Naivasha Country Club		Water transport
Elsamere Conservation Centre		Water transport, petrol
Fisherman's Camp, Crayfish Camp & Fish Eagle Inn		Surveillance
Mr Robertson	35,000	
LNRA	100,000	School fees for fishers kids, liaison office, financial sourcing
Hort Tech (Mr Schuppach)		Land transport, petrol
Yatch club (MrMoses Kinyua)		Water transport, surveillance
John Dolier		Land transport
L. Naivasha Growers Group	300,000	

Source: LNRA and Fisheries Departmen

This amount was used towards training workshops for fishers, traders, police and judiciary officials; supported patrols and research activities, repair of fisheries boats and purchase of out-board engine/mobile phones, consultative meetings and payment of honoraria to the vigilante group. This was the period for the development of co-management regulations by the FPU. The main actors in the co-management process and their interests are as shown in the Table 2 and Figure 1. The roles of various stakeholders were also spelled out (Table 3).

After one year of the fishing ban, fishermen were subjected to interviews conducted by the FPU. Guidelines were developed and agreed upon by all stakeholders for screening fishermen and reduce fishing effort as recommended by research work. The guidelines included: Fishermen's licenses to be issued only to those people who have no other source of livelihood. This was to keep in line with the government's strategy to poverty alleviation; priority to be given to fishers who personally go for the fishing trips. This was aimed at weeding out absentee/telephone fishers; only one boat to be licensed per family, where more than one member has applied; preference to be given to those people who are supportive of the current fisheries management set up; a few reformed illegal/uninformed fishers to be considered. The FPU arrived at the following score board (Table 4) for selecting 43 boat owners out of the more than 200 applicants. As a result of the screening, the best 43 interviewees who scored highest marks were licensed to carry out fishing after the ban was lifted. These were fishers using gill nets and canoes.

Table 2: Stakeholders and their interests in Lake Naivasha

Actor	Interest
Fisheries department/ government, KWS	Revenue, management, conservation
LNRA	Conservation
Naivasha Municipal council	Cess from fish, sewage disposal
Lake Naivasha Fishermen Cooperative Society	Cess from fish
KMFRI	Research
Fishers/Traders	Livelihood

Table 3: Responsibilities of the various groupings

Task	FD	FPU	BMC
Rules formulation		X	X
Enforcement	X	X	X
Control of access			X
Licensing	X	X	X
Research		X	X
Financial sourcing		X	
Sanctions & appeals		X	

Source: Fisheries Department

Key stakeholders

Fisheries Department

Mandated to provide for the exploration, exploitation, utilization, management, development and conservation of fisheries resources. The mandate is derived from the Fisheries Act Cap 378 of the Laws of Kenya. The vision of the Department is to have a dynamic fishery industry with a potential to contribute towards food security, employment and generate wealth among the fishers. The mission is to facilitate sustainable management and development of the fishery resources and products for socio economic development in an ecologically viable environment.

Kenya Marine and Fisheries Research Institute

The institute was formed through an Act of parliament and is mandated to do research on fisheries resources and the aquatic environment and advise the government accordingly.

Fisher fork

These are the people who earn their livelihoods, directly or indirectly from the fishing industry at Lake Naivasha. Some of them started fishing in the early 1960s and have a lot of experience and knowledge on the “dynamics” of the lake fishery. They are organized at various levels into management units and welfare groups at beach level, fish traders association and fishermen’s cooperative society at district level.

Lake Naivasha Riparian Association

Formed in 1929 by landowners around the lake, it was originally mandated to administer an agreement by the government over the use of riparian land. However in the absence of an environmental legislation to back up the mandate, the association initiated the development of a management plan for the lake that promotes voluntarily adopted codes of conduct for relevant sectors. Its efforts for long-term and sustainable use of Lake Naivasha got international recognition and were jointly awarded the 1999 Ramsar Wetland Conservation Award.

Lake Naivasha Management Committee (LNMC)

The committee was appointed by the government through a gazette notice under the Environmental Management and Co-ordination Act, 1999 in 2004. Its purpose is to implement the Lake Naivasha Management Plan. The committee comprises fifteen representatives from institutions and organizations. Government institutions representatives are from fisheries, wildlife, agriculture, water, lands, environment, local authority, provincial administration, and energy. Other organizations are LNRA, Lake Naivasha Growers group, Naivasha tourist group, Lake Naivasha fishermen cooperative society, pastoralists and the World Conservation Union.

Kenya Wildlife Service

KWS plays conservation and management roles as set out in the Wildlife (Conservation and Conservation) Act Cap 376. The organization represents the government in implementing the Ramsar Convention in the country. Through funding from the Wetland Program, several fisheries and wildlife officers from around lake were trained in wetland management.

Naivasha Municipal Council

Lake Naivasha falls under the jurisdiction of the Naivasha local authority. The success of co-mangement process depends on the political good will from local leaders.

Results

As a result of the co-management process, several measures were agreed upon through consensus and put into place to enhance management of the resource after the fishing ban was lifted. They included among others: annual stakeholder consultative meetings where information is shared and progress reports on research presented; annual closed season introduced every June to September of each year as per legal notice number 214 of 2003; collaborative research and monitoring involving the relevant stakeholders to be carried out on a continuous basis; effort limit of 40-50 boats as recommended by researchers to be licensed every year. Each boat should have three crews and a maximum of ten nets and of recommended mesh size; a bag limit for sport fishers of five fish per rod per day; introduction of daily fish movement passes for fish traders to account for the fish bought at landing beaches to the markets. These were monitored by law enforcers that involved the Beach Management Units to ensure compliance of the fisheries regulations at the beach, surveillance of areas in their jurisdiction and awareness creation and conflict resolution at fishers' level and FPU role to oversee surveillance, licensing and sanctions against way ward fishers.

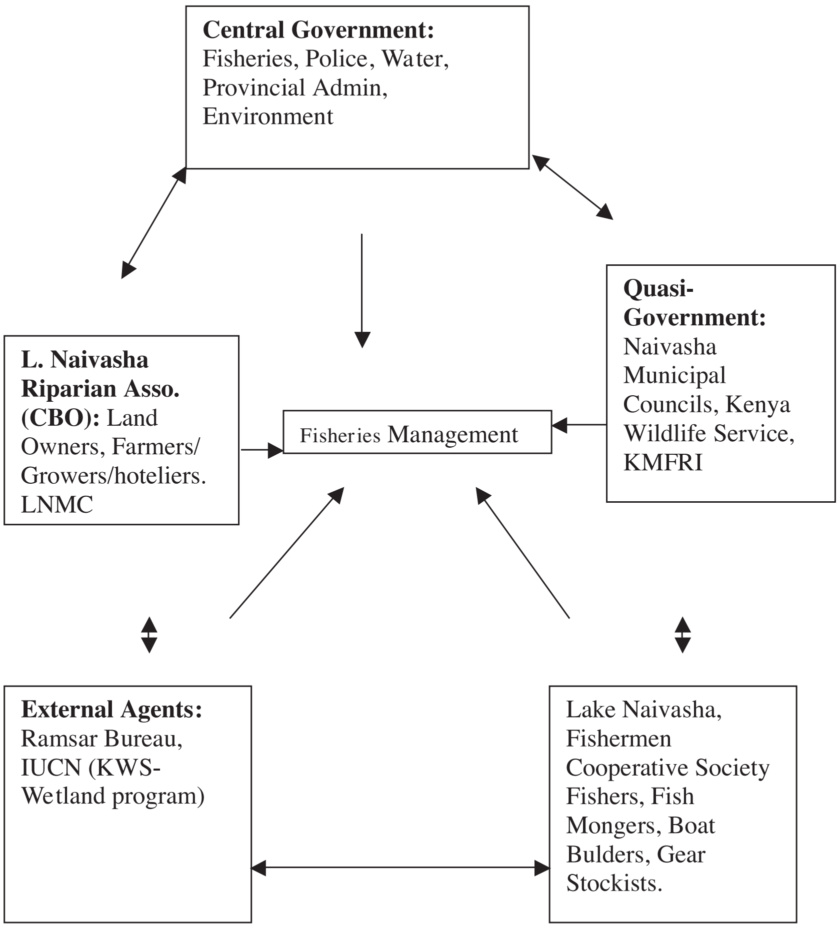


Figure 1: The stakeholders involved in Lake Naivasha co-management of fisheries resources

There is a general improvement in fish catches since the introduction of co-management. The high catches experienced before the ban was composed mostly of juvenile fish caught by undersized nets (Figure 2). A comparison of catch per boat in a month shows that in January 2001 a single boat landed 44 kilograms on average in the whole month with uncontrolled number of fishing gears. However, for the same month four years later in 2005, a boat landed on average 310kilograms in a month with a maximum of ten fishing gill nets (Table 5).

It has been observed that legal fishermen are now using larger nets as recommended by the Law. This is a sign of compliance since the fishers were part and parcel in the development of the co-management regulations. It demonstrates a sense of ownership of rules, which they participated in making. The participation of the community in the management process has enhanced trust and cooperation between fishers, government officials and landowners. This has been proved through the contribution of larger amounts of money by landowners towards management of the lake (Table 1). This has improved the lake and market surveillance (Table 6). Security of the patrol team has improved unlike before when violent confrontations were experienced between government officers and illegal fishers. This is attributed to elaborate awareness creation among community members. There has been formation of Beach Management Units and Welfare groups at the beaches. These groups have been supportive in solving conflicts at the beaches especially at fisher to fisher level. They have also opened bank accounts to open channels for savings and provide credit facilities among fishers and traders at beach level.

Table 4: Scoreboard

Criteria	Score
Boat owner/ Bonafide fisher/ Real fisher	5
Applicant with no other livelihood	4
Applicant has no criminal record	3
Applicant a member of BMU	2
Applicant shortlisted by BMC	1
Applicant attended interview	1
Total score	16

Source: Fisheries Department

Table 5: Catch comparison for January 2001 and 2005

Year	2001	2005
Production (kg)	5000	13942
Value (KShs)	213000	585788
No. Of boats	113	45

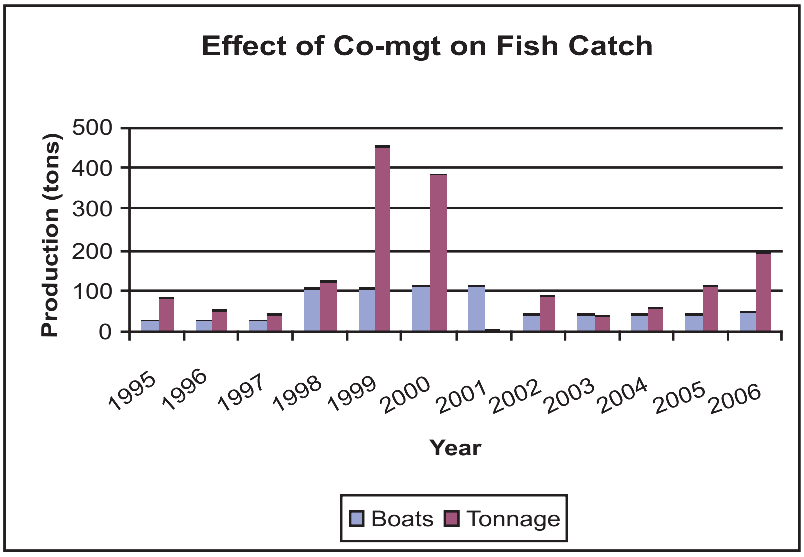
Source: Fisheries Department

Table 6: Monitoring, control and surveillance

Year	Suspects arrested	Illegal nets impounded	Illegal boats impounded
2000	46	62	7
2001	112	793	25
2002	238	3000	26
2003	94	1198	15
2004	136	310	13
2005	38	738	10
2006	82	261	13
2007	16	480	2

Source: Fisheries Department

Figure 2. Fish production and number of boats Source: Fisheries Department



Community policing had its own pitfalls in the sense that there was resentment from un-informed fishers who felt it was illegal to be arrested by fellow fishers. In retaliation, illegal fishers engaged in stealing boats and fishing gears belonging to licensed fishermen. As a result, there was reluctance on the part of some licensed fishers to fully participate in patrols. In addition to this, some of the fishers leaked patrol information to their friends who never succeeded to be licensed but engaged in illegal fishing activities.

Discussion

The essence of establishing a co-management system at Lake Naivasha constitutes a framework to promote involvement of the community in the management of the fishery. Their wealth of experience and indigenous knowledge is an asset in the decision-making process and this instills a sense of stewardship in the lake and its resources. For over forty years after independence, the administration of fisheries resources in this country was based on top-down approach controlled by the central government. This style of management had no provision for involving fisheries stakeholders in decision-making process (Lwenya and Abila 2003). The Fisheries Act, Chapter 378 (revised in 1991) is applied on a command and control basis and for a long time it was considered by fishers to be a repressive tool. Its implementation at Lake Naivasha is weak partly because of insufficient funding to the fisheries station and shortage of personnel due to staff retrenchment and voluntary early retirement. These factors undermine mounting effective surveillance activities.

The Fisheries Act is too "lenient" and is not a deterrent to illegal fishing since most offenders get light sentences and fines or committed to do community service. But it is also worth to note that the changing economic times, coupled with a poor pay package in the civil service has compromised the role of the fisheries staff as law enforcers. Instead some of the officers collude with unscrupulous fisher folk to destroy the fishery resource to supplement their earnings. This sad situation is common in most lakes in eastern Africa (Owino 1998). Another factor that promotes unethical behaviour is having staff working in the same office for long periods (more than twenty years) and whose only source of motivation is leaking surveillance plans in return for bribes. That is why it was imperative to overhaul the staff establishment at the onset of the fishing ban to give room for new officers from other fisheries stations around the country.

The interaction between government officials and stakeholders in the old management system made fishers develop perceptions about the fishery and the new management style. Some had the impression that fisheries management is a government affair and expected little change with the new strategy. Despite being part and parcel of the initial process, the fishing community cried foul when the fishing ban was put in place claiming marginalization from the only source of livelihood. The fishers pointed an accusing finger at the horticultural farms for responsibility of declining water levels in the lake through abstraction and water pumps sucking out fish fry in the canals. They further accused the farms of retrenching thousands of young men who turn to the lake to steal fishing equipment and poach for survival (Yongo, 2002). With this kind of attitude, compliance with the ban period remained poor as some fishers joined illegal poachers to violate the legal Notice. Even after the lake was opened for trial fishing, there was lack of conformity with mesh size requirements and recommended fishing effort limits by some licensed boats. Most interesting was the return of fishers from formal employment in horticultural industry back to the lake whether licensed or not. This means that time is required to change old habits that have built for decades through the top-down approach. Poor compliance with regulations at lake Naivasha by fishers is consistent with what happened at Lake Kariba when co-management was introduced in the 1990s (Nyikaradzoi and Songore, 1999).

Although the ban on fishing had positive environmental consequences, its effects on the lifestyles of fisher folk were very harsh. Yongo (2002) noted that most of the fishers do not make savings and those who were not successful to be employed in the flower farms either due to ill health or old age ended up doing odd jobs such as breaking stones in quarries. Cases of family break-ups and evictions by landlords were not uncommon. The fishing ban was a very trying moment for the fisher folk community.

Ikwaput (2005) noted the significance of having necessary structures on the ground to enhance the co-management set-up. At Lake Naivasha some structures are already in place to boost the new management strategy. A Lake Naivasha management plan developed to address sustainable management issues of the lake environment through consensus building is in place (Enniskillen, 2002). Although its legality has been challenged in courts of law, the plan is gazetted through a legal notice by the government under the Environmental Management and Coordination Act, 1999. A government-appointed Management Committee is implementing it with representation from fisher folk. Through this committee fisher's views are heard at the topmost unifying organ dealing with sustainable management of the lake and the wider catchment.

A subsidiary legislation to legalise the formation of Beach Management Units (BMUs) countrywide by the government was effected in 2007. This will address delegated authority frameworks and create an enabling legal environment to support co-management efforts by fishers at beach-level (Pomeroy and Berkes, 1997) and hold bmu committee members accountable for their responsibilities. However these reforms in the beach leadership are likely to create social friction by disrupting the traditionally established leadership and powerbase among the fisher folk at the beach level (Sen *et al*., 1996). The formation of beach management units is based on democratic principle where the various stakeholders at the beach have equal chance to compete for leadership positions. People who never had a voice in the previous leadership arrangement like fishing crews, boat and net repairers or even fishmongers have now assumed powers through democratic process. This is bound to create discomfort among the people who previously controlled affairs at the beaches unchallenged. These were mostly influential people like boat owners, fishing gear owners and powerful middlemen or fish traders (Hara and Jul-Larsen, 2003). Sometimes, such disgruntled former officials will tend to undermine the present establishment especially where the beach leader or chairman is regarded, by beach standards, to be of lower social status. Likewise through the same democratic process, local power and authority may fall into the hands of leaders, or groups who lack leadership skills or capabilities and may reverse the gains of the new process for lack of commitment to the values and goals of co-management.

The violence that followed the disputed December 2007 general elections impacted negatively on the lake fishery. Authentic and experienced fishers were chased away from fishing activities and their place taken over by increased numbers of unruly poachers who are resistant to law and order in the lake. As a result of the post election violence, the only gazetted fish-landing site was closed down (V. Kinywa pers. com). This scenario poses a big challenge to co-management and the fragile fishery in general.

The issue of equity on the part of fishers is partly addressed by the amendment of the Fisheries Act to establish BMUs since the fisher's participation in co-management is now legitimized. The fisher folk's proposal to open up two more ungazzetted fish landing sites at Kamere (southlake) and Tarambeta (northlake) was considered and can be interpreted as acceptance of their views in decision-making. However the BMU legislation does not cater for the local residents around the lake, some of whom were appointed as fisheries co-managers by the Director of Fisheries awaiting to be made honorary fish wardens once the relevant legislature is place. Currently, they can not arrest or give prosecution evidence in court of law since they are not empowered to do so. This category of stakeholders was very instrumental in providing logistics to jumpstart and establishes the co-management process. There's a possibility that a delay in giving them legal backing would be perceived as a disinterest on the part of government to cede power and management responsibilities to sections of the community.

Challenges

The current population growth around lake Naivasha possesses a big threat to the fishery. Many unemployed youth who cannot find opportunities in the flower farms tend to switch to fishing for economic reasons. The large numbers of employees in the horticulture industry provide an incentive for illegal fishing since there is ready market for poached fish. This problem is further complicated by the current reforms of decongestion in the Prisons Department that allows many convicts including fisheries offenders to serve non-custodial sentences and continue fishing to earn a living.

A section of the local political establishment was not happy with the new management strategy on the lake. They felt that the new method was put in place to deny people their livelihoods. As such, there were cases of incitement for people to promote illegal fishing activities. However, this is an issue that was addressed during annual stakeholders meetings. Another threat is that long term financial support may not be feasible because after the first two years of co-management, contribution from the community started going down. Therefore, unless proper structures are put in place to source for funding to supplement the government support, then, this may affect the flow of the implementation process.

Lessons learnt

Basing on the co-management initiative conducted around lake Naivasha, the following are some of the lessons learnt during the process: community participation in making rules increases effectiveness of implementation and sense of ownership of the same rules; collaborative work in patrols together with constant interactions creates trust and transparency among fishers and extension officers; through organized beach leadership, the fisher folk are able to solve their own conflicts; education of community creates sense of appreciation towards responsible fishing and the community has the potential to organize themselves if empowered; illegal fishermen appreciate the reason behind the new approach unlike before when enforcement was surrounded with hostility, there was minimal confrontation after the first two years; old habits die hard as fishermen will always try to cheat on the new guidelines of responsible fishing. Also, those fishermen redeployed to other sectors like the horticulture industry eventually return to fishing whether legally or illegally.

Conclusions and Recommendations

Co-management at Lake Naivasha came as a result of problem recognition in resource management, which was related to resource deterioration. It has offered opportunity for increased participation and empowerment of the fisher community. Co-management is viewed as an evolving process that adjusts and matures over time; therefore there is need for a revisit and evaluation of the ongoing co-management process at Lake Naivasha.

- There is need for a revisit of Lake Naivasha to evaluate the level of understanding and acceptance of co-management process among stakeholders.
- Legal structures should be put in place to create positions of honorary fish wardens and sustainable funding from stakeholders.
- Fisheries personnel should not be deployed at Naivasha station for more than three years unless otherwise.
- The government should improve package of staff or consider providimg incentives for officers working at the station since they work beyond the official hours.
- Strict enforcement of Lake Naivasha management plan to ensure ecological integrity of the lake.
- Creation of income generating opportunities to divert unemployed youths from the lake fishery.

References

Becht, R. and Harper D. M. 2002. Towards an understanding of human impact upon the hydrology of Lake Naivasha. *Dev. Hydrobiol.* **488** (168), 1-11

Elder, H. Y., Garrod D T and Whitehead, P. J. P. 1971. Natural hybrids of the African cichlid fishes *Tilapia spirulus nigra* and *T. leucosticta*, a case of hybrid introgression. Biol. J. linn. Soc. 3: 103-146.

Enniskillen, 2002. Introduction: the Lake Naivasha Management Plan – consensus-building to conserve an international gem. *Dev. Hydrobiol 488* (168), ix-xii.

Hara M. and Jul-Larsen, E. 2003. The "Lords" of Malombe: An analysis of fishery development and changes in fishing effort on Lake Malombe, Malawi. In *Management, co-management or no management? Major dilemmas in Southern African freshwater fisheries,* Jul-Larsen, E., Kolding, J., Overå, R., Raakjær Nielsen, J., and Zwieten, P. A. M. van (eds.), FAO Fisheries Technical Paper. No. 426/2, FAO. Rome.

Hardin, G. 1968. The tragedy of the commons. *Science* **162**, 1243-48.

Harper, D. M., Mavuti K. M and Muchiri S.M. 1990. Ecology and management of Lake Naivasha, Kenya in relation to changing climate, alien species introductions and agricultural development. *Evn. Conserv*. 17, 328-336.

Hickley, P., Bailey R., Harper, D. M., Kundu, R., Muchiri, M., North, R. and Taylor, A. 2002. The status and future of the Lake Naivasha fishery, Kenya. *Dev. Hydrobiol.* **488** (168), 181-190.

Ikwaput, J. N. 2005. Community participation in fisheries management: prospects and challenges for co-management. pg 595-612, *In:* Knowledge and experiences gained from Managing Lake Victoria Ecosystem. Colour Print (T) Ltd, Dar es Salaam, Tanzania. ISBN 9987-8976-5-7.

LNRA (Lake Naivasha Management Plan) 1999. Lake Naivasha Riparian Association, Naivasha, Kenya. 77 pp.

Lwenya C. and Abila R. O. 2003. Co-management in the Lake Victoria fishery, realities, constrains and opportunities in Kenya. In van der Knaap M. and Munawar M. (eds) Lake Victoria Fisheries:status, biodiversity and management. *Aquatic Ecosystem health and Society.* www.aehms.org

Muchiri, S.M. and Hickley, P. 1991. The Fishery of Lake Naivasha, Kenya. pg 382-392, In : I.G Cowx. (ed.), Catch Effort Sampling Strategies: Their Application in Freshwater Fisheries Management. Oxford: Fishing News Books, Blackwell Scientific Publications.

Nyikahadzoi K. and Songore N. 1999. Introducing Co-management arrangement in Lake Kariba Inshore Fishery: Progress, Opportunities and Constrains. Proceedings at International Workshop on Fisheries Co-management, Penang Malaysia 23-28 August 1999.

Owino, J. O., 1999. Traditional and Central Management Systems of the Lake Victoria Fisheries in Kenya. Socio-economics of the Lake Victoria Fisheries. IUCN Eastern Africa Programme, Report No 4. 24pp.

Pomery, R.S. 2004. Devolution and Fisheries Co-management. Manila. ICLARM. 62 pp.

Pomery, R.S. and Berkes, F., 1997. Two to tango: the role of government in fisheries co-management. *Marine Policy*, **21** (5), 465-480.

Sen, S. and Raakjaer-Nielson, J. 1996. Fisheries Co-management. A comparative analysis. *Marine Policy*, 20(5),405-416.

Yongo E. O. 2002. Lake Naivasha: the Dilemma of Resource Use and Conservation. In Kenya Marine & Fisheries Research Institute: Current status of fisheries, water quality and socio-economics of Lake Naivasha. Final Report December 2002.

Effect of Varying Dietary Crude Protein Levels on Reproductive Performance of Nile Tilapia (oreochromis nilioticus, Linn. 1858) Reared in Earthen Ponds

James Bundi Mugo, Charles Chege Ngugi and Julius Manyala
Department of Fisheries and Aquatic Sciences, Moi University, Eldoret Kenya

James Bowman
Department of Fisheries and Allied Aquaculture Auburn University, Alabama, USA

Abstract

Growth performance of many fish species has been manipulated by subjecting fish to various iso-proteinous feeds. This study applied similar treatments to *Oreochromis niloticus* to evaluate the reproductive performance under varying dietary protein levels. Aspects of reproductive performance evaluated during this study were gonad maturation, size at first maturity and fecundity. Two month old *O. niloticus* fingerling averaging 2.70 ± 0.75 g sourced from Moi University Fish Farm were stocked in 100m^2 ponds and fed at recommended proportion of body weight daily using formulated diets containing fifteen per cent, 25 per cent and 35 per cent crude protein levels for a period of five months from August 24th, 2006 to January24th, 2007. Data obtained was analyzed by descriptive statistics, analysis of variance and regression to discern significant differences in reproductive performance subject to varying protein levels. Results indicated that higher dietary protein levels improved gonadal maturation than those fed on lower protein level diets ($r = 0.95$, $p = 0.047$). Size at first sexual maturity was larger in fish fed with higher dietary protein levels than those fed lower protein diets. Feeding of *O. niloticus* at higher proteins levels (25% and 35%) had significantly ($P < 0.05$) higher fecundity than those fed lower proteins levels. This study demonstrated the significance of dietary protein levels as a functional determinant of reproductive strategies in *O. niloticus*. On this account, taking cognizance that protein is the most expensive ingredient in diet; it is recommended that farmers should use 25 per cent CP during formulation of feeds for *O. niloticus*.

Key words: *Nile tilapia, dietary protein levels, and gonad maturation, size at first maturity, fecundity*

Introduction

There has been a tremendous global expansion in food demands due to the increased population coupled with reduction in food production capacity for most countries. Increase in food production is therefore required to satisfy increased protein demands that now affect many countries of the world (FAO, 2002). According to Food Agricultural Organization (FAO) estimates, the global expansion of food demand is projected to increase by 50 million metric tones between the year 2000 and 2015 (FAO, 2002). Despite evidence of low food production in most developing countries, much of these demand subsist within the precincts of these countries largely attributable to the rapid population growth rates (FAO, 2004). In response to the above problem, there is urgent need to increase the current protein supply to meet the increased demand from the burgeoning population. In line with such perspective, fish supply promises to bridge the existing gap between food supply and demand.

Despite aquaculture being a new and upcoming science in most developing countries, it is believed to be the best way forward in bridging the widening gap between fish supply and demand. Though the contribution of aquaculture is still quite low and pales in shadow in comparison to production from capture fishery (Subasinghe, 2006) considerable increase in contribution of aquaculture is beginning to gain relevance. In Kenya, aquaculture relies on the culture of species that are simplistic in culture conditions, resistance to water quality conditions and acceptable to the consumers. Thus, fish production in Kenya relies heavily on the culture of Nile tilapia (*Oreochromis niloticus*) due to its rapid growth, high plasticity in food habits as well as high productivity in culture conditions.

It is apparent that in proper pond management practices, reproduction of *O. niloticus* is highly enhanced. However, the persistent problems of slow growth, early sexual maturation at small size and low fecundity is experienced during rearing stage from combined effects of several variables in the pond including poor water quality parameters, improper stocking densities and poor feeding regimes. Water quality management and proper stocking densities have partially solved the problem, hence creating a more need to understand diet effect on growth and reproduction.

In semi-intensive system, culture of *O. niloticus* remains constrained by early sexual maturation where females mature and reproduce early at small sizes (Longalong *et al.*, 1999). In a pond culture this results in stunted growth in the reproducing females, overcrowding of ponds, feed competition and poor growth performance, highly variable sizes at harvest and consequently unpredictable yields and income to the farmers. Poor spawning synchrony of *O. niloticus* culture results from unpredictable percent of the maturing females (Longalong *et al.*, 1999). Increased percent of female gonad maturation increases the fish population. This could either result into an overpopulated pond leading to stunted growth due to feed competition and exceeds pond size carrying capacity. In hatchery set-ups where seed production is carried out throughout the year, lack of spawning synchrony among tilapia females constrains the management of mass seed production (Jalabert and Zohar, 1982; Little *et al.,* 1993) and this impact upon the tilapia industry as a whole.

Tilapia maturing at small size produces smaller eggs but relatively more eggs than a larger fish per unit body weight (Hughes and Behrend, 1983; Rana, 1988). The disadvantage of producing high numbers of smaller eggs has to be balanced against the fact that, the smaller eggs produce small and weak larvae at hatching, with consequent reduction in survival under some farming regimes (Rana and Macintosh, 1988; Rana, 1985; 1988).

In fish production, nutrition is critical because feeds represent 40-50 per cent of the production cost (Shang, 1990). Poor feeding regimes will not only cause impairment to growth and early sexual maturation but will affect fish fecundity. It will thus be feasible for majority of small-scale peasant farmers in developing countries aiming at rearing fish, to utilize proper diets that would no compromise reproduction. Growth performance of *Oreochromis niloticus* is often improved by subjecting fish to various iso-proteinous feeds. However, data currently lacks on the reproductive performance of *O. niloticus* under varying protein feeds for many fish farmers in Kenya. This study, as a way of bridging the gap, evaluated the reproductive performance of pond reared *O. niloticus* under three crude protein levels.

Materials and Methods

Twelve ponds (100 m^2) were stocked with tilapia fingerlings average weight (SE) of 2.7 ± 0.75 g at a rate of four fingerlings per sq. metre. Three treatments of different dietary protein levels (formulated diet at 15 per cent CP, 25 per cent CP and 35 per cent CP) with each three replicates being randomly assigned was used. A control of 0%CP feed was used as a base line of the project. Ten months old Nile tilapia broodstock (average size of 250g) were selected from the grow out ponds within Moi University Fish Farm and stocked at a stocking density of 1 brood fish per m^2 at a ratio of 1:3, male to female respectively in a pond measuring 15m by 20m. These brooders were fed with a formulated diet (25% CP) for one month. The broodstock was transferred into another pond after spawning one month. The fry left in the pond after removal of the broodstock fish were nursed and reared to average size of 2.7 g. The proximate analysis of the diets was performed according to the methods prescribed by Association of Official Analytical Chemist (AOAC, 1990) to verify their contents (Table 1). Fish were fed the test diets to apparent satiation twice a day at 10.00hrs and 16.00hrs for five months from August24th, 2006 to January24th, 2007.

Table 1.Percent composition and proximate analysis of the protein diets

Ingredients (%)	Diet 1 (15% CP)	Diet 2 (25% CP)	Diet 3 (35% CP)
Omena meal	1	25	65
Wheat bran	96	45	5
Maize germ	2	15	15
Cotton seed cake	1	15	15
Crude protein	15.23	24.95	35.57
Crude lipid	4.22	5.57	5.00
Total ash	5.86	7.94	11.62
Crude fiber	9.81	7.97	4.61

Fish were sampled once per month with a seine net. In each sample, 30 females were picked randomly, total length (TL) measured to the nearest 0.1 cm using a measuring board, and weighed to the nearest 0.1 gram using a weighing balance (E550R model, Ohaus Corporation, USA). Out of the 30 females, ten were analyzed for reproduction; gonad maturity (gonad maturation stage, gonad weight and gonado-somatic index), fecundity and egg size.

Determination of maturation status of the gonads

The ten female fish were dissected and gonads extracted to determine their maturation status, using Legendre and Ecoutin maturity scale (1989) (Table 2). Total length and body weight of each female *O. niloticus* were recorded to determine fish size at every gonadal maturation stage.

Table 2: Classification of gonadal maturation stages in female Nile tilapia (Legendre and Ecoutin maturity scale (1989).

Gonad Maturity stage	Appearance of the ovary
Stage1 (Immature)	The ovary is small and transparent.
Stage 2 (developing)	Inside the ovary starts turning yellow in colour. Blood vessels start developing.
Stage 3 (mature)	Inside the ovary turns yellow to orange colour. Blood vessels start developing. As t he fish begin spawning the ovary contains hydrated eggs.
Stage 4 (spent)	All viable eggs have been released. Ovary becomes greyish and wrinkled in appearance.

Determination of fish fecundity

Gonads were extracted and fixed in five per cent formalin for subsequent estimation of fecundity and oocyte size in the laboratory. Total number of eggs per ovary (fecundity) was directly counted and recorded while relative fecundity was also determined according to the following relationship:

$$\text{Relative fecundity} = \frac{\text{Number of eggs}}{\text{Weight of female fish}}$$

In each ovary, a sample of 30 eggs was taken and the diameter (both axis; short and long axis) of each egg measured using a Vanier caliper to the nearest 0.01mm. Each egg was surface dried using an absorbent paper and then weighed to the nearest 0.01mg (U3600 model, Sartarius GMBH, Germany).

Data analyses

Frequency distribution was used to compare the effect of different protein diets on gonad maturation of *O. niloticus*. Significance difference in gonad maturation of fish fed under varying diets was analyzed using non- parametric, Chi-squire (c^2) test. The gonad maturation data was modeled and fitted using polynomial regression models. Differences in mean total length and body weight in gonad maturation stages, mean gonado-somatic index, mean egg diameter and mean egg weight of fish among the protein diets was analyzed using one-way ANOVA. Fecundity, F was related to the total length, TL (cm) exponential expression as given by Bagenal, 1967 and also by Caward (1999):

$F=aTL^b$

Where, a and b are constants and b is approximately 3.

The egg diameter versus body length and egg weight versus body weight were plotted to obtain a linear graph to predict the relationship between egg diameter and the fish body length and also between egg weight and fish body weight. These relationships were analyzed by Pearson's regression. The significance of the regression line was tested using the Analysis of Covariance (ANCOVA). All statistical analyses were done at a significant level of P< 0.05.

Results

Effects of dietary protein levels on gonad maturation and body size

Gonad maturation and body size of *O. niloticus* subjected to different protein diets (Table 3). Fish fed lower protein levels (15%) resulted to lower mean total lengths at maturity that were significantly ($F_{3.709,}$ df = 3, p < 0.001) different from fish fed higher protein levels diets. Fish fed higher protein levels (25% and 35% CP) gave highest body weight at maturity that was significantly ($F_{2.568}$, df = 3, p=0.046.) different from fish fed lower protein levels diets. Increasing protein levels resulted in significant increase in percent of maturing fish gonads (r = 0.95, p = 0.047).

Table 3. Gonad maturation, length and weight of *O. niloticus* fed at different protein levels during the study period

Percent crude protein	Mean length (cm)	Mean weight (g)	% Maturing gonads
0	10.99 ± 0.31[a]	24.24 ± 2.62[a]	17.6[a]
15	11.11 ± 0.27[a]	25.64 ± 1.73[a]	19.6[a]
25	11.36 ± 0.27[ab]	27.85 ± 2.34[ab]	30.4[b]
35	12.20 ± 0.27[b]	33.49 ±2.57[b]	32.4[b]

Means ± SEM within each column followed by superscripts not sharing a common letter are significantly different ($p < 0.05$).

Mean gonadal somatic index of *O. niloticus* ranged from 0.011 ± 0.00084 to 0.097 ± 0.0074. Feeding fish with proteinous diets didn't result to any significance differences in gonado-somatic index ($F_{0.446}$; df = 3; p = 0.720).

Effects of dietary protein levels on size at first sexual maturity

Total length of *O. niloticus* at first sexual maturity under different dietary protein levels (Figure 1). Feeding *O. niloticus* at 35 per cent CP resulted to the highest length at first maturation (11.8 cm), followed by fish fed on 25 per cent (11.2 cm). *O. Niloticus* that were not fed any proteins had the lowest length at first maturation (10.6 cm).

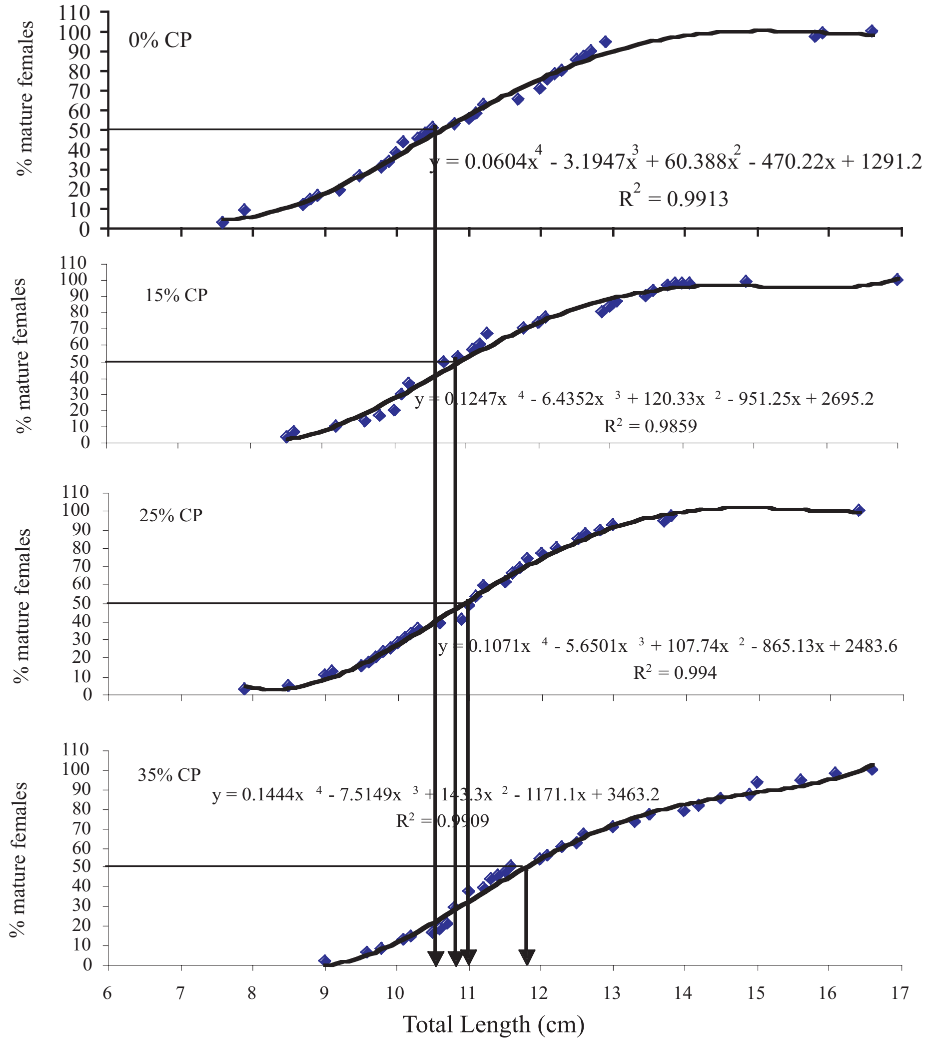


Figure 1. Total Length (cm) at first sexual maturity of *O. niloticus* fed different dietary protein levels.

Figure 2 depicts body weight of *O. niloticus* at first sexual maturity under different dietary protein levels. Feeding *O. niloticus* at 35 per cent CP resulted in the highest body weight at first maturation (28 g), followed by weights of fish fed at 25 per cent (25 g). Least weights of *O. niloticus* (22 g) were recorded when fish were fed diets containing no amounts of dietary proteins.

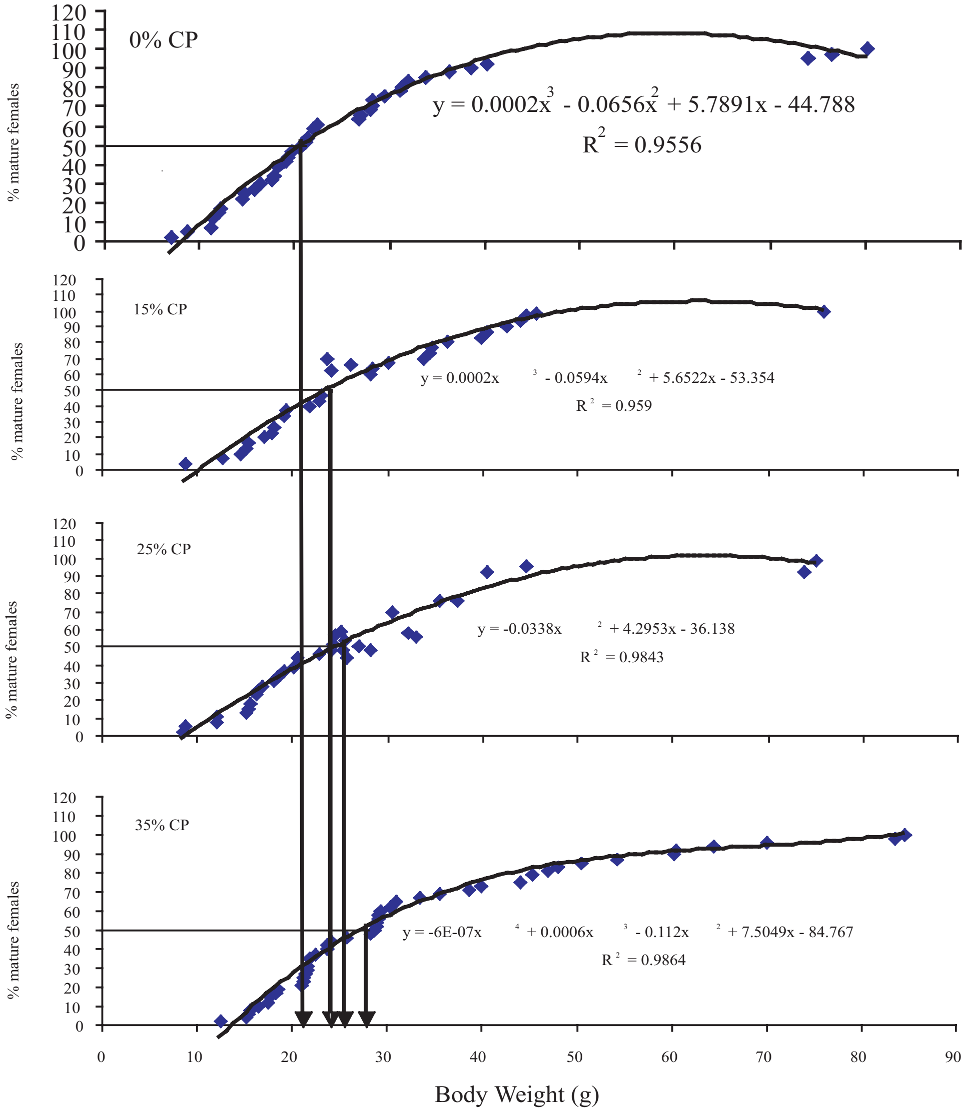


Figure 2: Body weight (g) at first sexual maturity of *O. niloticus* fed different dietary protein levels.

Effects of dietary protein levels on fecundity and egg size

The number of eggs per fish and number of eggs per unit weight (g) of *O. niloticus* fed different dietary protein levels is shown in Table 5. The number of eggs per fish ranged from 228 to 268. Variation in number of eggs of fish under different protein levels was significant ($F_{3.636}$; df = 3; p = 0.015). Feeding of *O. niloticus* at higher proteins levels (25% and 35%) resulted to significantly ($p < 0.05$) higher number of eggs than feeding at lower proteins levels (15%) and in fish consuming diets with no dietary protein. Number of eggs per unit weight (relative fecundity) of fish did not differ significantly ($F_{1.007}$; df = 3; p = 0.392) among the dietary protein levels.

Table 5. Number of eggs per fish and number of eggs per unit weight of *O. niloticus* fed different dietary protein levels.

Percent crude protein	Number of eggs/fish	Number of egg/g of fish weight
0	228 ± 10^{a}	11.67 ± 1.36^{a}
15	234 ± 16^{a}	10.79 ± 0.80^{a}
25	253 ± 12^{ab}	10.42 ± 0.81^{a}
35	268 ± 70^{b}	9.54 ± 0.56^{a}

Means ± SE within each column followed by superscripts not sharing a common letter are significantly different (p<0.05).

Results of egg diameter and egg weights of *O. niloticus* fed different dietary protein levels are shown in Table 6. Fish eggs diameter ranged from 0.3mm to 2mm. Significantly ($F_{11.4811}$; df = 3; $p < 0.001$) higher egg diameter were recorded in fish under diets containing 35 per cent of crude proteins in comparison to other protein diets. Fish feeding in diets containing fifteen per cent and 25 per cent CP produced eggs that did not have significant differences in egg diameters; however, fish fed under the two protein levels produced eggs that had larger egg diameters than fish that fed on diets without proteins. Fish eggs weight recorded ranged from 0.1mg to 5mg. Mean egg weight of fish fed at 35 per cent was significantly ($F_{27.873}$; df = 3; $p < 0.001$) higher than fish egg weights fed 25 per cent, fifteen per cent and 0%CP. Feeding at fifteen per cent, 25 per cent and 0% CP did not result to any significant ($p > 0.05$) differences in the fish egg weights.

Table 6: Egg diameter and egg weight of *O. niloticus* fed different dietary protein levels.

Percent crude protein	Egg diameter (mm)	Egg weight (mg)
0	1.05 ± 0.02^{a}	1.38 ± 0.04^{a}
15	1.10 ± 0.03^{ab}	1.42 ± 0.05^{a}
25	1.15 ± 0.02^{b}	1.49 ± 0.03^{a}
35	1.23 ± 0.02^{c}	1.85 ± 0.04^{b}

Means ± SE within each column followed by superscripts not sharing a common letter are significantly different (p<0.05).

Relationships between number of eggs and Total Length (TL) of *O. niloticus* fed different dietary protein levels are shown in Figure 3. Significant increases in egg diameter were observed in relation to total length (TL) in all the diets; 0% CP ($p = 0.000$), fifteen per cent CP ($p = 0.000$), 25 per cent CP, ($p = 0.000$) and 35 per cent ($p = 0.000$) (Figure 3). The strength of the relationships increased with increasing dietary protein levels. Relationships between egg diameter and total length of *O. niloticus* fed different dietary protein levels are shown in Figure 4. Significant increases in egg diameter were observed in relation to total length (TL) at 0% CP ($p = 0.000$), 15 per cent CP ($p = 0.000$), 25 per cent CP, ($p = 0.000$) and 35 per cent ($p = 0.000$). The strength of the relationships increased with the increase of dietary protein levels.

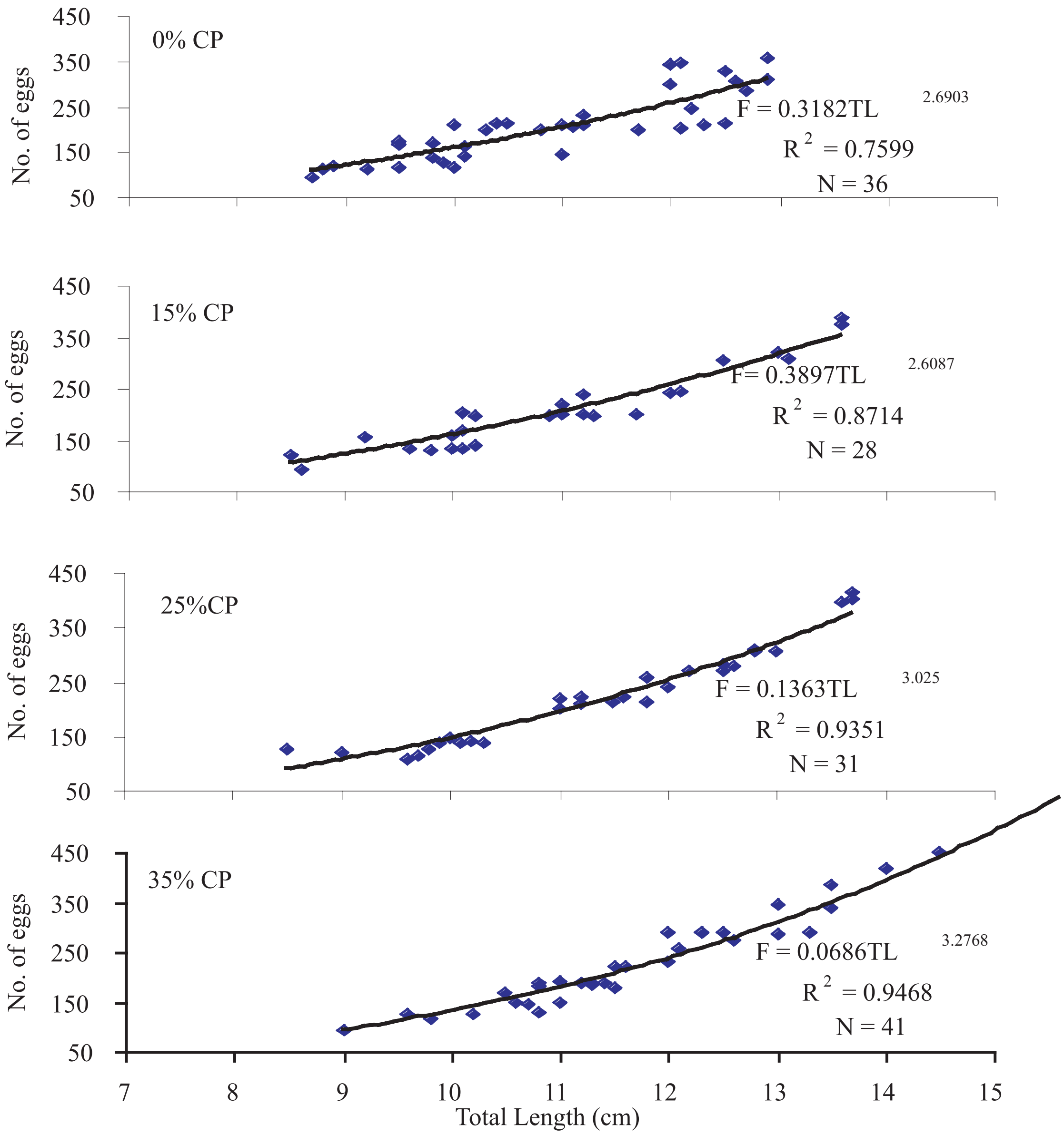
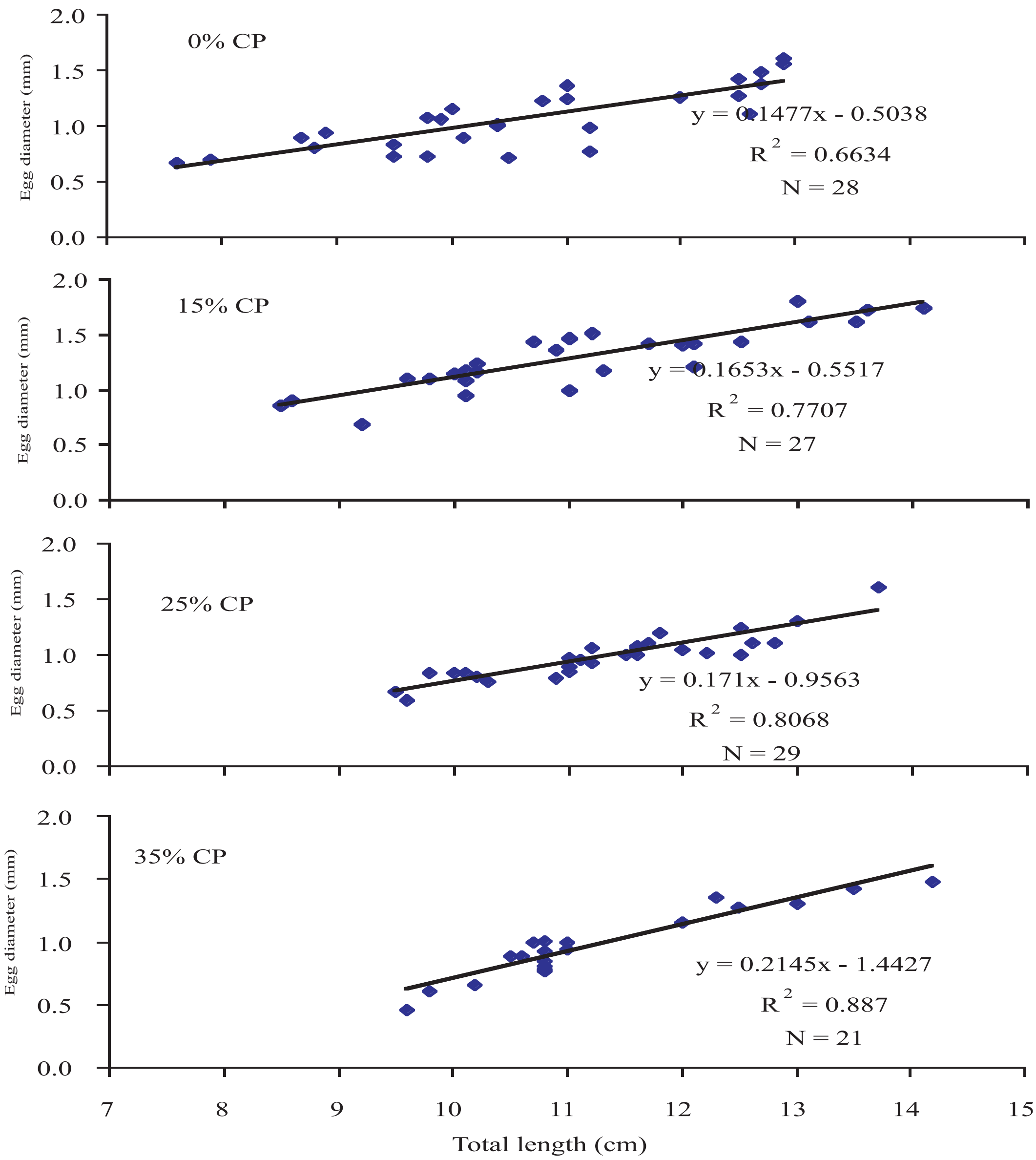


Figure 3: Relationship between fecundity and the total length of *O. niloticus* fed different dietary protein levels



Fgure 4. Relationship between egg diameter (mm) and the total length (cm) of *O. niloticus* fed different dietary protein levels

Figure 5 shows results of relationships between egg weight and body weight of *O. niloticus* fed different dietary protein levels. Significant increases in egg weight were observed in relation to body weight at 0% CP (p = 0.000), fifteen per cent CP (p = 0.002), 25 per cent CP, (p = 0.000) and 35 per cent (p = 0.001). The strength of the relationships increased with increasing dietary protein levels except for the lower dietary protein levels (0% and 15% CP), which did not show much variation.

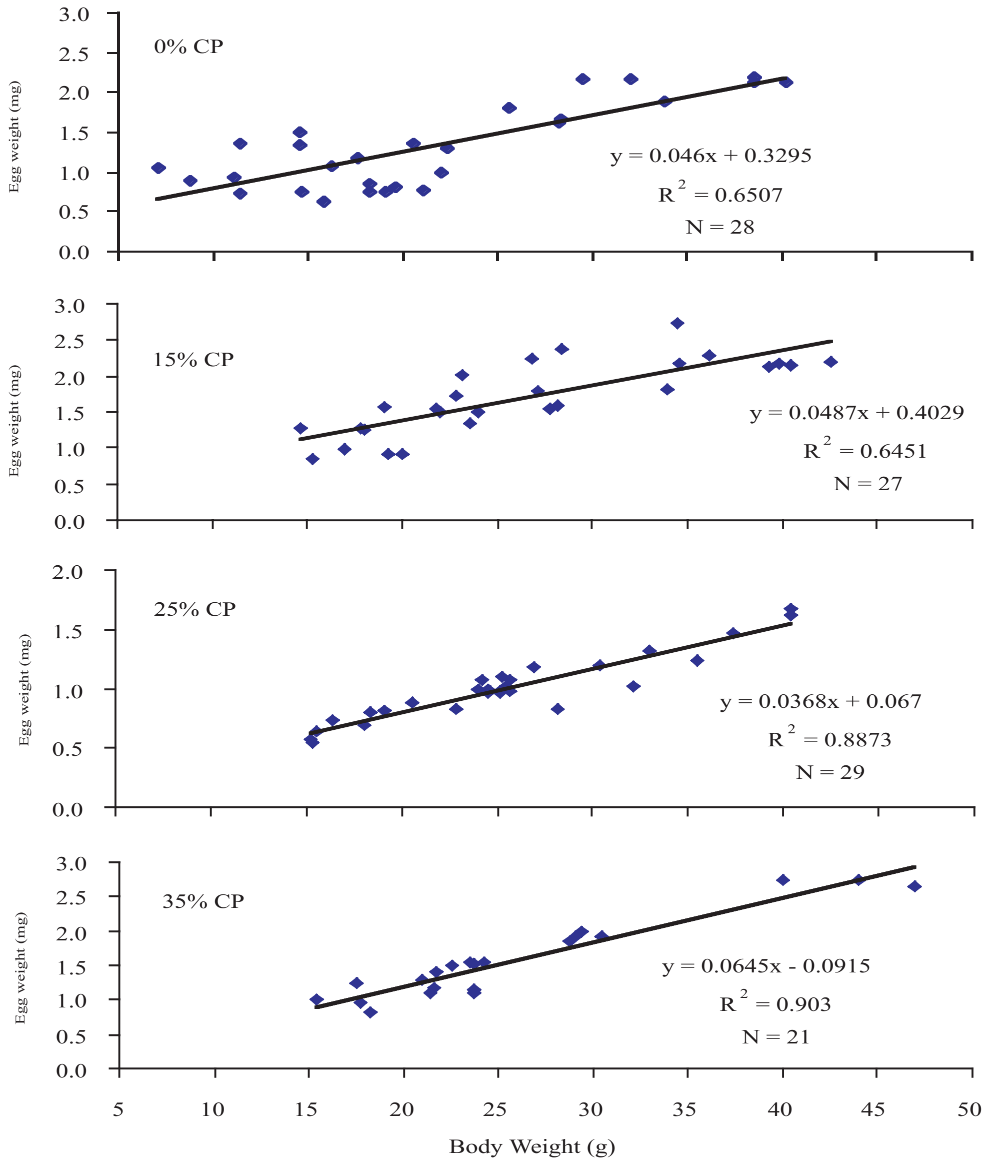


Figure 5: Relationship between egg weight (mg) and the body weight (g) of *O. niloticus* fed different dietary protein levels

Discussion

Effects of dietary protein levels on gonadal maturation and body size

Nutrition has been seen to have a significant effect on gonadal maturation of *O. niloticus* (Watanabe, 1985; Finn, 1994; Bhujel *et al.,* 2001; El-Sayed *et al.,* 2003). Varying dietary protein levels either encourages or discourages gonadal maturation in fish. In intensive systems where mass seed production is practiced in hatcheries, percentage of the maturing females is highly considered. Total seed output from *O. niloticus*, a multiple spawner and a mouthbrooder, depends mainly on percent of maturing females as well as frequency of spawning (Lowe-McConnell, 1955; Nikolskii, 1969). Increase in percentage of mature females, would lead to the increase in total seed output.

In the present study higher dietary protein levels encouraged maturation of female *O. niloticus* fish. The percentage of maturing females increased with the increasing dietary protein levels. This could be as a result of the nutritional value of the diet, which showed that it played a crucial role in supplying essential nutrients required for gonadal development (El-Sayed *et al.,* 2003). A well balanced diet would meet the fish nutritional requirements with respect to any of a number of physiological functions ranging from growth to reproduction (Cowey and Sargent, 1972). During the period of somatic growth any excess of materials is stored in the body to be later mobilized for gonadal growth implying that the more the excess materials stored, the more of it is mobilized for gonadal growth hence encouraging more maturation. Higher dietary protein could be resulting in more excess material storage in the fish body.

Supply of inadequate protein (low protein level in the diet) for a long period has been observed to result in slow ovarian recrudescence hence encouraging fish immaturities (Gunasekera and Lam, 1996). In the present study, higher proteinous diets resulted into highest number of maturing females, most probably meaning that the diet resulted to more deposition of excess materials hence faster ovarian recrudescence consequently resulting to increased number of maturing fish.

Al Hafedh *et al.* (1999) made similar observations and reported that the mean percentage of mature fish rose with increasing dietary protein levels (25%, 30%, 40% and 45% CP). In the study carried out by Gunasekera *et al.* (1995), *O. niloticus* fed a low protein diet (<17%CP) did not show oocyte maturation hence encouraging immaturities, female fed 25 per cent protein showed slow oocyte growth, where as females fed > 32 per cent protein level had early oocyte maturation.

In this study, results showed that varying dietary protein levels had no significant effect on Ganado-somatic index (GSI). This could probably mean that, increasing dietary protein level does not affect gonadal somatic index. Somatic growth and gonadal growth could be proportional meaning that both do not alter the body weight and gonadal weight ratios. The above observation is contrary with what Shim *et al.,* (1989), and Santiago *et al.,* (1985) observed. In their research, female dwarf gourami and Nile tilapia fed on 35 per cent protein diets recorded significantly highest ovary weight and gonad somatic index.

Effects of dietary protein levels on size at first sexual maturity

Protein composition in fish diet plays a crucial role in reproductive performance (Gunasekera, *et al.,* 1996; Mokoginata, *et al.,* 1998). Size at first sexual maturity, which is a function of the size of fish, has been influenced by dietary quality of food (Nikolsky 1963, Babiker and Ibrahim 1979 and Gomez-Marquez, *et al.,* 2003). Increased crude protein levels in the diet, effectively enhances somatic growth due to the fact that they are body building nutrients and especially when the fish is at young stage. It has been a major problem in tilapia culture with the tendency of females maturing sexually at small sizes. In pond culture, this results in stunted growth in reproducing females, overcrowding of ponds, feed competition and poor growth performance, highly variable sizes at harvest and consequently unpredictable yields and income to fish farmers (Longalong *et al.,* 1999). This is contrary with fish farmers' main goal, which is having large size fish at harvest.

In the present study size of *O. niloticus* increased with increasing dietary protein levels. Fish size increase may be due to the fact that there was deposition of protein nutrients, whose accretion is a balance between protein anabolism and catabolism (Tytler and Calow, 1985). In fishes, absorbed nutrients influences secretion of hormones especially growth hormone and this response differs with diet. Growth hormones are responsible for fish growth, regulation of protein synthesis, stimulation of appetite and improvement of food conversion (Donaldson *et al.,* 1979). It is then probable that fish that received higher protein efficiently utilized higher nutrients resulting into increased secretions of growth hormones hence, building the body tissue thus increasing fish size.

Fish that sexually mature at large sizes have prolonged spawning intervals (Wee and Tuan, 1988), which the fish is advantaged to locate its energy resources towards reproduction at few numbers of times per year unlike small fish spawning frequently (many number of spawns per year) at short spawning intervals. This means that much of the nutrients are allocated towards somatic size increase resulting into increased fish production hence a high farmer's income.

De Silva and Radampola (1990), Wee and Tuan (1988) and El-Sayed, *et al.,* (2003), found concurring results with the present study where the mean weight of *O. niloticus* at first maturation tended to increase with increasing dietary protein level. This is also in agreement with the results reported by Al-Hafedh, *et al.*, (1999) that fish fed highest dietary protein levels resulted into a largest size and that size at first maturity increased with increasing dietary protein. Nile tilapia females that, Al-Hafedh, *et al.*, (1999) fed at 40 per cent CP diet were larger than those which were fed with a diet of 25 per cent CP. Though in the present study the highest dietary protein was at 35 per cent CP, it is clear that the higher the dietary protein level the larger the size of fish at maturity. However, Al-Hafedh, *et al.*, (1999) was feeding younger fish (average weight; 0.5±0.2g) than those used in the present study (average size; 2.7±0.75g). In many fish species including tilapia, it has been reported that the protein requirement of fish decreases with increasing size of fish (Wilson, 1989). Based on results of various studies, Balarin and Haller (1982) made a generalized conclusion that tilapia weighing less than 1g should be fed 35-50 per cent protein, 1-5g fish 30-40 per cent, and 5-25g fish 25-30 per cent protein.

De Graaf, *et al.,* (1999) reported that pond reared *O. niloticus* mature at about 30g though generally, the size at first maturation of tilapia under aquaculture conditions ranges from 30 – 50g (Siraj, *et al.,* 1983; De Silva and Radampola, 1990). Bolivar, *et al.* (1993) reported that length at maturity often vary from 100mm to 390mm which supports the present study.

Though Lowe-McConnell (1982) observed that *O. niloticus* matured at smaller size in lagoon and pond conditions than fish in the lake, it appears that environmental factors like food quality (dietary protein level) influences size at first sexual maturity (De Silva and Radampola, 1990; Wee and Tuan, 1988; El-Sayed, *et al.,* 2003; Al-Hafedh, *et al.*, 1999). Fish reaching first sexual maturity at small size tends to spawn frequently meaning that much of its energy is allocated towards reproduction (Gadgil and Bossert, 1970) rather than toward increase in size hence stunting in the ponds.

Effects of dietary protein levels on fecundity and egg size

In tilapia, the quality of food affects both the frequency of spawning and the number of seed per cutch (Guerrero and Guerrero, 1985; Macintosh and Little, 1995; Rana, 1986, 1988). Fish fecundity and egg size indicates seed production potential in a fish farm. In cases where the fish farmer has low fecund fish with small size eggs, there will be poor seed production unlike in cases where fish are highly fecund with large sized eggs. This is highly recommended in mass seed production hatcheries. A large size egg produces healthy hatchlings hence high survival of good quality seed (Rana and Macintosh, 1988; Rana, 1985, 1988).

The increase in fish fecundity with increasing dietary protein in the present study concurs with the results reported by Gunasekera *et al.* (1996a). Similarly, El-Sayed *et al.* (2003) also showed that fecundity increased with increasing dietary protein levels (25 - 40% CP). The higher fecundity may be a result of larger female size in the 35 per cent diet group. Many factors influence potential fecundity of an individual fish namely age, size, and reproductive histology, and physical condition and in particular its nutritional status (Manissery, *et al.,* 2001).

Alhafedh *et al.* (1999) also reported that fecundity increased with increasing dietary protein levels, but significant differences were found only between 40 - 45 per cent and 25 - 35 per cent dietary protein levels. This means that between 25 and 35 per cent dietary protein levels didn't differ hence concurring with the present study. However, this is in contrary with Santiago *et al.,* 1983 who reported that fecundity of *O. niloticus* females was not affected by varying dietary protein levels from 20-50 per cent. The initial stocking sizes of females by Santiago *et al.* (1983), was large (ranged from 90-124g) compared to those were stocked in the present study (average weight, 2.7g). These fish may have spawned a number of times before stocking, which in turn may have affected their fecundity and spawning efficiency.

Other fish species also fed with different dietary protein levels have exhibited similar results on fish fecundity. Pathmasothy (1985) reported an increase in fecundity with increasing dietary protein from 24- 32 per cent protein in *Leptobarbus hoevenii*. Also, Raj and Sampath (2002) working with Siemese fighting fish showed that fecundity increased with increasing dietary (ten per cent, fifteen per cent, 25 per cent, 35 per cent) and that the fish fed an 35 per cent animal or plant protein had the highest fecundity than any other tested levels.

According to Shim *et al.* (1989) female dwarf gourami receiving a diet of 25 - 45 per cent protein had the highest fecundity. In contrast, Dahlgren, 1980 established that female guppy (*Poecilia reticulata*) receiving dietary protein feed between fifteen per cent and 47 per cent showed no significance difference in fecundity. Unlike guppy fish which are live bearers, Nile tilapia and dwarf gourami (*Colisa lalia*) fish have some common reproductive characteristics such as both fish are egg spawners with an average fecundity range of 100 to 3500 eggs while guppy averages a fecundity of 20 per spawning and nest builders (Sales and Janssens, 2003).

In the present study, the number of eggs per unit body weight (relative fecundity) didn't differ significantly among varying dietary protein levels. However, there was an increase in relative fecundity with decrease of dietary protein levels. This concurs with Dahlgren (1980) and Gunasekera *et al.* (1996a) who reported that relative fecundity remained almost unaffected by a reduced amount of protein. On contrary, De Silva and Radampola (1990) observed that tilapia receiving a lower protein (20%) diet had a higher relative fecundity.

It is generally accepted that, the number of eggs produced by females' increases with age, length and weight whereas relative fecundity (number of eggs/wt. of the female) decreases (Rana, 1986). However, Rana, 1986 working with *O. niloticus* have shown that fecundity is more closely associated with maternal size than age. This means that, size of female is more important than age in terms of fecundity and total number of eggs produced (Rana, 1986, 1988). Some authors have indicated that the number of eggs produced is related to the body length (Lowe-McConnell, 1955; Welcomme, 1967; De Silva, 1986; Rana, 1986) while others have claimed that it is more related to the body weight of the female (Peters, 1983; Rana, 1988). Generally the number of eggs produced per spawning is a function of body size (Bagenal, 1967 and Caward, 1999).

The present study showed that fecundity of *O. niloticus* generally increased with the length of the fish at different strengths of the relationships and it was probable that size affects the number of eggs produced by an individual fish, which is a factor of diet influencing growth, hence size at maturity. Fecundity generally is linearly related to female fish length in all species (David, 1988). These strong fish fecundity- total length and fecundity-body weight relationships observed from the fish fed higher dietary protein levels means that once a female *O. niloticus* becomes committed to a spawning, irrespective of her energy input, she has only slight regulatory powers over the energy that will be exported in the form of eggs.

Duponchelle *et al.,* 2000; Albert, 1982; Legendre and Ecoutin, 1989, results concur with the present study indicating that fecundity is positively correlated to size and to the body weight in tilapia. On contrary, Wootton (1973) reported no significant correlation between the number of eggs spawned by female three-spined sticklebacks (*Gasterosteus aculeatus*) with the size of the fish expressed as total length or as weight. This observation could probably mean that this was related to the race of the stickleback unlike in tilapia (Wooton, 1973). However, these variations in fecundity are primarily a reflection of variations in the size of fish at maturity and that size is related to environmental conditions such as food quality.

Tilapia maturing at small size produce smaller eggs but relatively more eggs than a larger fish per unit body weight (Hughes and Behrend; 1983, Rana; 1988). The advantage of producing high numbers of smaller eggs has been balanced against the fact that, the bigger eggs produce larger and stronger larvae at hatching, with consequent improved chances of survival under some farming regimes (Rana and Macintosh; 1988, Rana; 1985; 1988). Increased survival of strong Nile tilapia larvae enhances fish production, which is the main objective of a fish farmer.

In the present study, egg diameter and egg weight of *O. niloticus* females increased with increasing dietary protein levels. Wee and Tuan (1988) reported similar results where high protein diets (42.6 and 50.1%) produced heavier and larger eggs of Nile tilapia. This could be mostly attributed by the varying deposition of nutrients within the egg. Less proteinous diets have inadequate nutrients leading to slow deposition of substantial amount of nutrients within the egg, hence reducing the egg size.

El-Sayed *et al.,* 2003 reported similar results as in the present study that egg diameter of Nile tilapia was significantly affected by dietary protein levels but showed irregular trends. Contrary to Gunasekera *et al*. (1996b, 1997), dietary protein level did not affect egg diameter of spawned eggs of *O. niloticus*.

Bigger eggs that were found in female tilapia fish receiving the highest dietary protein level resulted from increased fish size in the present study. This could probably mean that larger female tilapia produce bigger eggs than small ones. Bagenal and Tesch, 1978; Wootton, 1979; Mann and Mills, 1979; Hislop, 1984; Rana, 1986, reported the same where Nile tilapia female of larger size were found to produce bigger eggs. In addition, these results were supported by the reproductive pattern of cichlids where tilapia produces either a large number of small eggs or small number of large eggs (Peters, 1983). This could probably have resulted from the nutritive value of the diet, which varied.

Conclusion

The findings of this study suggest that the use varying dietary proteins affected reproductive performance of *O. niloticus*. Increase in dietary protein level increased size at first sexual maturity and encouraged maturation of the female fish resulting into higher fecundity of large size eggs.

This study has therefore aptly demonstrated the significance of dietary protein levels as a functional determinant of reproductive success in *O. niloticus* by affecting reproductive strategies. Thus, fish farmers striving to enhance reproduction in their culture units should not overlook the importance of protein levels in the diet.

Recommendation

On this account, supported by data in the current study to increase the percentage of the maturing *O. niloticus* females, in mass seed producing hatcheries, higher dietary protein level ranging from 25 - 35 per cent CP should be used. In fish farms specializing in table size fish production, also higher dietary protein levels should be used to increase size at first maturity which eventually will increase fecundity and increase survival rate due to production of strong larvae hatching from large size eggs.

Taking cognizance that protein is the most expensive ingredient in diet; it is recommended that farmers should use 25 per cent CP during formulation of feeds for *O. niloticus*. However, further research on the cost, availability and impact on growth at 25 per cent CP should supplementarily be undertaken to establish whether it can be both financially and biologically feasible to most small scale farmers as the best crude protein level in fish diet.

References

Al Hafedh, Y. S., Siddiqui, A.Q., Al-Saiady, M.Y. (1999). Effects of dietary protein level on gonad maturation, size and age at fist maturity, fecundity and growth of Nile Tilapia. Aquaculture International, 319-332.

AOAC (1990). Official Method of Analysis of Association of Official Analytical chemist, 15th edn. AOAC, Arlington, VA, 1298pp.

Babiker, M. M., Ibrahim, H. (1979). Studies on the biology of reproduction in the cichlid *Tilapia nilotica* (L): Gonadal maturation and fecundity. J. Fish. Biol. 14: 437-447.

Bagenal, T.B. (1967). A short review of fish fecundity, pp 89-111.In S.D. Gerking (ed). The Biological Basis of Fresh water Fish production. Blackwell, Oxford, England.

Bagenal, T.B., Tesch, F. W. (1978). Age and growth. In T. Bagenal (ed), Methods for assessment of fish production in fresh waters, 3rd edn, IBP. Handbook No.3. Blackwell Scientific Publication, Oxford, pp. 101-136.

Balarin, J.D., Haller, R.D. (1982). The intensive culture of Tilapia in tanks, raceways and cages.In: *Recent Advances in Aquaculture* (ed. By J.F, Muir & R.J. Robert), pp, 265 – 356. Croom Helm, London.

Bhujel, R. C., Yakupitiyage, A., Turner, W. A., Little, D. C. (2001). Selection of commercial feed for Nile tilapia (*Oreochromis niloticus*) Broodfish breeding in a hapa-in-pond system. Aquaculture, 194, 303-314.

Binh, C.T., Phillips, M. J., Demaine, H. (1997). Integrated shrimp mangrove farming systems in the Mekong delta of Vietnam. Aquaculture Research, 28: 599-610.

Bolivar, R. B., Eknath, A. E., Bolivar, H. L., Abella, T. A. (1993). Growth and reproduction of individually tagged Nile tilapia (*Oreochromis niloticus*) of different strains. Aquaculture 68, 221-241.

Coward, K., Bromage, N.R. (1999). Spawning frequency, fecundity, egg size and ovarian histology in groups of *Tilapia zilli* maintained upon two distinct food ration sizes from first feeding to sexual maturity. Aquat. Living Resour. 12, 11-22.

Cowey, C. B., Sergent, J. R. (1972). Fish nutrition. In: F. S. Russell and C. M. Youge (eds), Advances in Marine Biology, Vol. 10, Academics press, New York, pp. 383-492.

Dahlgren, B.T. (1980). The effect of three protein levels on the fecundity in guppy (*poecilia reticulata petes*). Journal of fish Biology 16:83-97.

David, C. (1988). Length-dependent changes in egg size and fecundity in females and brooded embryo size in males, of fork-tailed catfishes (Pisces: Ariidae) from the Sepik River, Papua New Guinea, with some implications for stock assessments. Journal of Fish Biology 33 (3), 455-464.

De Graaf, G. J., Galemoni, F., Huisman, E. A. (1999). Reproductive biology of pond reared Nile tilapia*, Oreochromis niloticus L*. Aquaculture. Research, 30, 25-33.

De Silva, S.S., Radampola, K. (1990). Effect of dietary protein on the reproductive performance of *Oreochromis niloticus*. In: Hirano, R., Hanyu, I. (Eds.), The second Asian Fisheries Forum, Asian Fisheries Society, Manila, Philippines, pp. 559-563.

De Silva, S. S. (1986). Reproductive biology of *Oreochromis mossambicus* populations of man-made lakes in Sri Lanka. Aquaculture and Fisheries Management 17, 227-237.

Donaldson, E. M., Fegerlud, U. H., Higgs, D. A., McBride, J. R. (1977). Hormonal enhancement of growth. In: Hoar, W. S., Randall, D. J. AND Brett, J. R. (ed.). Fish physiology, vol. VIII, pp. 455-597. New York, Academic Press.

Duponchelle, F., Panfili, J. (1998). Variations in age and size at maturity of female Nile tilapia, *O. niloticus*, populations from man-made lakes of Cote d'Ivoire, Environmental Biology of Fishes 52, 453-465.

Duponchelle, F., Legendre, M. (2000). *Oreochromis niloticus* (Cichlidae) in Lake Ayame, Cotedvoire: Life History traits of a strongly diminished population. 24, 161-172.

El-Sayed, A. F. M., Mansour, C. R., Ezzat, A. A. (2003). Effects of dietary protein level on spawning performance of Nile Tilapia broodstock reared at different water salinities. Aquaculture, 220, 619-632.

FAO. (2002). FAO Fish stat plus. Aquaculture production 1970- 2000. Rome, Italy.

FAO. (2004). FAO Fish stat plus. Aquaculture production 1970- 2002. Rome, Italy.

FAO. (2006). FAO yearbook, Fishery statistics, Aquaculture Production 2004. Vol. 98/2, Food and Agriculture Organization of United Nations (FAO), Rome.

Finn, R. N. (1994). Physiological energetics of developing marine fish embryos and larvae. PhD dissertation, Zoological Institute, University of Bergen, Norway, 206pp.

Fryer, G. and Illes, T.D. (1972). *Cichlid fishes of the Great Lake of Africa: Their Biology and Evolution*. Oliver and Boyd, London. 641pp.

Gadgil, M., Bossert, W.H, (1970). Partitioning of energy in fish. J.exp. Biol. Vol. 8: Pp 107-141.

Gunasekera, R. M., Lam T. J. (1997). Influence of dietary protein level on ovarian recrudescence in Nile Tilapia (L.). Aquaculture, 149:57-69.

Gunasekera, R. M., Shim, K. F., Lam, T. J. (1995). Effects of dietary protein level on puberty oocytes, growth and eggs chemical composition in the Tilapia (*O. niloticus*) (L). Aquaculture, 134,169-183.

Guerrero, R.D., Guerrero, L. A. (1985). Effect of breed size on fry production of Nile Tilapia in concrete pools. Trans Natl. Acad. Sci. Technol. Philip 7, 63-66.

Gunasekera, R.M., Shim, K.F., Lam, T. J. (1996a). Effects of dietary protein level on Spawning performance and amino acid composition of egg of Nile tilapia, *Oreochromis niloticus.* Aquaculture, 146:121-134.

Gunasekera, R.M., Shim, K.F., Lam T. J. (1996b). Influence of protein content of broodstock diets on larval quality and performance in Nile Tilapia, *Oreochromis niloticus*. Aquaculture, 146:245-259.

Gunasekera, R., Shim., K. F., Lam, T.J. (1996). Effects of dietary proteins level on spawning performance and amino acid composition of eggs of Nile Tilapia, *Oreochromis niloticus.*

Hislop, J .R. G. (1984). A comparison of the reproductive tactics and strategies of cod, hadlock, whiting and Norway pout in the Northern Sea. In g. w. Potts and R. J. Wooton (eds), Fish reproduction: Strategies and tactics, Academic press, London, pp. 311-329.

Hughes, D.G., Behrends, L.L. (1983). Mass production of *Tilapia nilotica* suspended in net enclosures, pp.394-401.

Jalabert, B., Zohar, Y. (1982). Reproductive physiology in cichlid fishes, with particular reference to *Tilapia* and *Sarotherodon*, p. 129-140.

Legendre M., Ecoutin, J. M. (1989). Suitability of blackish water tilapia species from the Ivory Coast for lagoon aquaculture. Reproduction, Aquat. Living Reservoir, 2: 71-79.

Little, D.C., Macintosh, D. J., Edwards, P. (1993). Improving spawning synchrony in the Nile tilapia, *Oreochromis niloticus* (L). Aquaculture and Fish Management. 24, 399-405.

Longalong, F. M, Eknath A. E, Bentsen A. B. (1999). Response to bi-directional selection for frequency of early maturing females of Nile tilapia (*Oreochromis niloticus*). Aquaculture, 178, 13-25.

Lowe-McConnell, R. H (1955). The fecundity of tilapia species. The East African Agricultural Journal. 21, 45-52.

Lowe-McConnell, R.H. (1982). Tilapias in fish communities. In: Pullin, R.S.V., Lowe McConnell, R.H. (Eds), *The Biology and Culture of Tilapias*. ICLARM conference Proceedings, vol. 7. ICLARM, Manilla, pp. 83-114.

Macinitosh, D. J., Little, D. C. (1995). Nile Tilapia (*Oreochromis niloticus*).In: Bromage, N.R.R., R. J. (Eds). Broodstock Management and egg and larval quality. Blackwell, UK, pp.277-320.

Manissery,J. K., Krishnamurthy, D., Gangadhara, B., Nandeesha, M.C. (2001). Effect of varied levels of dietary protein on the breeding performance of Common Carp, *Cyprinus carpio*. Fisheries Science 14, 317-322.

Mann, R. H. K., Mills, C. A. (1979). Demographic aspects of fish fecundity. In P.J. Miller (ed.), Fish phenology: Anabolic adaptiveness in teleosts, Symp. Zool. Soc. Lond. No. 44. Academic press, London, pp. 161-177.

Mokiginata, I. T., Takeuchi, D., Moeljohardjo, S., Sumawidjaja, K.and Fardiaz, D. (1998). The effects of different ratio of n-6/n-3 fatty acids in broodstock diets on egg quality of catfish, *Clarias batrachur*. Asian Fisheries Science11:157-168.

Nikolski, G.V. (1969). Fecundity, quality of the sex products and course of spawning, pp 33-37. In: Jones, R. (Ed), Theory of fish population dynamics as the biological background for rational exploitation and management of fishery resources, Published by Olive and Boyd.

Nikolsky, D.V. (1963). The ecology of fishes. Part II. Academic Press, New York: 352pp.

Ofojekwu, P. C., Ejike, C., (1994). Growth response and feed utilization in tropical cichlids (*Oreochromis niloticus*) fed on cotton seed-based artificial diets. Aquaculture, 42: 27-36.

Pathmasothy, S. (1985). The effect of three diets with variable protein levels on ovary development and fecundity in *Leptolarbus hoevenii*. In:Fish Nutrition Research in Asia(Ed C.Y. Cho) ,I.D.L.C,Ottawa,p.107-112.

Peters, H. M. (1983). Fecundity, egg weight and oocyte development in tilapias (Cichlidae). Manila, Philippines.

Popma, T. J. (1982). Digestibility of selected feedstuffs and naturally occurring algae by tilapia. PhD. Diss., Auburn University, Auburn, AL.

Poumogue, V., Takama, G., Pouemegne, J. (1997). A preliminary evaluation of cacao husks in practical diets for juvenile Nile tilapia (*Oreochromis niloticus*). Aquaculture 156:211-219.

Pullin, R.S.V. (1982). Creneral discussion on the biology and culture of tilapia, pp.331-351. In: Pullin, R.S.V., Lowe.Mc Connell. R. H. (Eds). The biology and culture of tilapia, ICLARM Conference Proceedings. International Center for Living Aquatic Resource Management, Manila, Phillippines, 432pp.

Rana, K. J. (1985). Influence of egg size on growth, onset of feeding, point-of-no return and survival of unfed *O. mossambicus* fry, Aquaculture, 46, 119-131.

Rana, K. J. (1986). Parental influences on egg quality, fry production and fry performance in *Oreochromis niloticus (Linnaeus*) and *O. mossambicus (Peters*). PhD Thesis, Institute of Aquaculture, University of Stirling, UK, 295pp.

Rana, K. J. (1988). Reproductive biology and the hatchery rearing of tilapia eggs and fry. Mur, J. F., Roberts, R. J (Eds), Recent Advances in Aquaculture, Vol. 3. Croom Helm, London, pp. 343-406.

Rana, K. J., and Macintosh, D. J. (1988). A comparison of the quality of hatchery reared *O. niloticus* and *O. Mosambicus* fry. In: Pullin, R. S. V., Bhukaswan, T., Tonguthai, K., Madean, J. L. (eds). The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 15. International Centre for Living Aquatic Resources Management, Manila, Phillipines, pp. 497-502.

Sadleir, R. M. (1973). The Reproduction of vertebrates. Academic press. New folk.

Santiago C. B., Aladaba, M. B., Abuana E.F., Laron, M.A. (1983). Effect of varying dietary protein levels on spawning frequency and growth of *Sarotherodon niloticus* breeders. *Fish. Res. J. Phill*: pp. 8, 9-18.

Santiago C. B., Aladaba, M. B., Abuana E.F., Laron, M.A. (1985). The effects of artificial diets on fry production and growth of *Oreochromis niloticus* breeders. Aquaculture, 47,193-203.

Shang,Y. C. (1990). Aquaculture Economic Analysis. World Aquaculture Society, Baton Rouge, Louisiana.

Shim K. F., Landesman, L., Lam, T. J. (1989). Effect of dietary protein on growth, ovarian development and fecundity in dwarf gourami, *Colisa lalia* (Hamilton). Journal of Aquaculture in the tropics, 4: 111-123.

Siraj, S. S., Smitherman, R. O., Castillo-Galluse, S., Dunham, R.A. (1983). Reproductive traits of three classes of *Tilapia nilotica* and maternal effects on their progeny. In: Fishelson, L., Yaron, Z (Eds), Proc. Inst Int.Symp. On Tilapia in Aquaculture. Tel Aviv. Press, Israel, pp.210-218.

Stickney, R. R. (1979). Principles of warm water Aquaculture. John Wiley and Sons, Inc, New York.

Subasinghe R.P. (2006). Use of fishery resources as feed inputs for aquaculture development: trends and policy implications. FAO Fisheries Circular No. 1018. Rome.

Trewavas, E. (1966). Tilapia aurea and the status of *Tilapia nilotica*, *T. monodi* and *T. lemassoni*, (Pisces, Cichlidae). Israel J. Zool. Bot. 74: 50-62.

Trewavas, E. (1983). Tilapia fishes of the genera *Sarotherodon*, *Oreochromis* and Danakilia. British Museum (Natural History), London. 583pp.

Trewavas, E. (1982). Genetic groupings of Tilapiine used in aquaculture. Aquaculture, 27, 79-81.

Tytler, P. and Calow, P. (1985). Fish Energetics. New perspectives. USA.

Watanabe, T. (1985). Importance of the study of broodstock nutrition for further development of aquaculture. In: Cowey, C. B., Mackie, A. M., Bell, J. G. (Eds.), Nutrition and Feeding in Fish. Academic press, London, pp. 395-414.

Wee, K.L., Tuan, N.A. (1988). Effects of dietary protein level on the growth and reproduction of Nile Tilapia (*Oreochromis niloticus*). In: Pullin, R.S.N. Bhukaswan. T.S Tonguthai, K., K., Madean, J.L. (Eds). The second International Symposium on Tilapia in Aquaculture. ICLARM conference proceeding, 15. Department of fisheries of Bangokok, Thailand and International Center for living Aquatic Resources, Manila, Phillipines, 623 pp.

Welcomme, R. L. (1967). The relationship between fecundity in the mouth breeding cichlid fish *Tilapia Lencostricata*. J. Zool. (London) 151, 453-468.

Wilson R.P. (1989). Protein and amino acid requirements of fishes. In: Progress in Fish Nutrition (ed. By S. Shiau), pp. 51-76.

Wootton R. J (1978). Fecundity of the three spined stickleback, *Gasterosteus aculeatus* (L). Blackwell, Oxford, England. pp 683-688.

Wootton R. J. (1979). Energy Cost of Egg production and environmental determinants of fecundity in teleosts fishes. In. P. J. Miller (ed.), Fish phenology: Anabolic adaptiveness in teleosts, Sym. Zool. Soc. Lond. No. 44, Academic press, London, pp. 133-159.

Sustaining the Health of River Ecosystems: Is the Index of Biotic Integrity Part of the Solution?

C. M. Aura and P. O. Raburu
Department of Fisheries & Aquatic Sciences, Moi Uinversity, Eldoret, Kenya

Abstract

River biotic indices offer the best means of telling whether our actions are allowing the water cycle to continue unimpaired. Index of Biological Integrity (IBI) was first developed to measure the ecological integrity of such waters in rivers using fish assemblages and has subsequently been adapted for use with macroinvertebrates in the assessment of the ecological integrity of most rivers around the world. It can also be used with algae, plankton, and vascular plants in wetlands, streams, and coastal estuaries. Index of Biotic Integrity (IBI) was developed to measure river health, and included development of measurements, known as metrics, for diagnosing causes of degradation. As a result, the biological signals that make up the IBI analyses are broader, including taxa richness and composition, trophic or other aspects of ecological organization, presence and relative abundance of tolerant and intolerant taxa, and presence of diseased individuals or individuals with other anomalies. The primary goal of IBI is to define the attributes of living systems that change systematically in diverse situations when exposed to the activity of humans. Amid the resurgence of IBI, the procedure has also been criticized as less adequate for its intended purpose. This paper examines recent applications of the index and reviews both the weaknesses and successes that have been attributed to its use. A firm stand is set that proposes its wide use for water quality assessment and monitoring programs.

Key words: *index of biotic integrity, ecological integrity, rivers, and metrics.*

Introduction

Riverine ecosystems are perhaps the most impacted ecosystem on the planet as they are the focus for human settlement. The factors forcing change in running waters, include ecosystem destruction, physical habitat and water chemistry alteration, and the direct addition or removal of species, stem from proximate influences from urbanisation, industry, land use change and water-course alterations (Buttle & Metcalfe, 2000). During the past two decades, life in the waters has again come to the fore, and biological monitoring that involves detecting human-caused biotic changes apart from those occurring naturally, is part of water managers' tool kits (Karr, 1981; Morris *et al.*, 2007). At large scales, such a method involving the use of biotic factors in determining the riverine ecosystem health, integrate and reflect the effects of the chemical and physical impacts occurring in rivers over extended periods of time (Karr, 1981). Apart from criticisms on the weaknesses of the IBI, this report is also emphasizes the strengths and use of the index of biotic integrity (IBI), the intent being to supplement, not to replace the existing methods.

Index of Biotic Integrity (IBI)

Dr. James Karr first developed the Index of Biotic Integrity (IBI) for use in small water streams in Central Illinois and Indiana for fish assemblages with twelve metrics that reflected fish species richness and composition, number and abundance of indicator species, trophic organization and function (Table 1). The same procedure was adopted using macroinvertebrates in the development of macroinvertebrate IBI for rivers (USEPA, 2000; Butcher *et al.,* 2003; Griffith *et al.,* 2005; Maloney *et al.*, 2008). In Africa, this system has been applied in South Africa on the Crocodile River (Roux, 1997) and in the Okavango River of Namibia (Hay *et al.,* 1996). Based on empirically defined 'dose-response' relationships between particular human influences and the biological responses they provoke, IBI is to date one of the most commonly used "and arguably the most effective" biological monitoring approaches (Butcher *et al.*, 2003; Schmutz *et al.*, 2007).

In this procedure, the median or a given 90 and above percentile can be chosen to represent the upper bound of reference conditions. The ranges of values from zero to the upper-bound-percentile are then trisected.

Table 1. List of original Index of Biotic Integrity Metrics proposed by Karr (1981) for streams in the Central United States

Category	Metrics
Taxa richness and habitat composition	1. Total number of fish species
	2. Number of intolerant species
	3. Number of Darter species
	4. Number of Sunfish species
	5. Number of Sucker species
	6. Percent of individuals as Green Sunfish
Trophic composition	7. Percent of individuals as omnivores
	8. Percent of individuals as insectivores
	9. Percent of individuals as Piscivores/carnivores
Fish condition and abundance	10. Number of individuals in sample
	11. Percent of individuals as hybrids
	12. Percent of individuals with anomalies

Values above the upper-bound receive a score of 5, those in the middle received a score of 3 while those in the lower-bound receive a score of 1, corresponding to unimpaired, moderate deviation and impaired stations respectively (USEPA, 2000). To determine the discriminatory ability of the various metrics, they can be evaluated by comparing the value distribution of each across all sites that is done by graphical displays using box-and-whisker plots, use of regression or other pair wise statistical tests (Maloney *et al.*, 2008). If there is minimal or no overlap between the distributions, then the metric can be considered to be a strong discriminator between reference and impaired sites (Schmutz *et al.*, 2007). In order to arrive at the overall multi-metric macroinvertebrate IBI value for each site, scores for each metric are summed. In order to determine the quality of a given riverine ecosystem, ranges for qualitative assessments of the IBI scores obtained can be subdivided into quartile water quality ranges or using other methods from literature but modified to suit local conditions in order to obtain integrity classes (Morris *et al.*, 2007).

Strengths of Index of Biotic Integrity

Index of Biological Integrity, along with its component metrics: works in streams, rivers, lakes, wetlands, estuaries, and coastal marine systems; integrates elements that conventionally have been fragmented in water policy and decision making, such as water quality and water quantity, surface water and groundwater; defines the health of a water resource system and aids in diagnosing and identifying causes of any detected degradation; enables us to identify and protect the places most deserving of conservation (defines places where restoration is possible and practical, and guides development activities to prevent or minimize damage to water resources); integrates precise biological measurements of the condition of waters and their associated resources into numbers and words that are easily understood by diverse audiences; permits comparisons across time and space: of the effects of different human activities through time at the same site or of watershed condition in different geographic regions; and, can be applied with a broad range of taxa, from algae and vascular plants to invertebrates and fishes.

Criticisms and Weaknesses of the Index of Biotic Integrity

The IBI has been criticised with strong counter arguments although the ecological principles on which the IBI is based are sound. The following are some of the criticisms and weaknesses of IBI if it is considered for uses. The IBI development is expensive in terms of investment. The IBI as applied by certain environmental management organizations in the US obviously represents a very large investment in equipment, financial resources and in a sufficiently large and trained workforce (USEPA, 2000). On the other hand, the use of IBI involves macroinvertebrates multi-metric approach in relation to the ecological health of a river. On the other hand, several of the metrics of the IBI require detailed historical and ecological information that is often not available. Metrics requiring proportionality are a particular problem as little pre-impact information on this is usually available.

The adaptability of the macroinvertebrates biota to the instream characteristics not only is it a challenge to aquatic scientists, but also to the IBI developers. Many South African rivers can be expected to have a naturally high disturbance regime to which the biota are adapted. Several anthropogenic changes may actually mimic these natural disturbance regimes. In the US, it was found that in prairie streams, the IBI did not indicate a degradation of biotic integrity following the intensive testing of armoured vehicles. This is because the river biota in that study were hardy and naturally adapted to droughts and flash floods. Their presence and the structure of the community depend on their rate of colonisation rather than habitat changes (USEPA, 2000).

One of the most important uses of biological survey data is to determine the cause of changes in ecosystem properties. He further suggested that by combining the individual metrics into a single value causes loss of resolution when attempting to diagnose the responsible entity. The greatest use of IBI is the ability to discern differences in individual metrics and determine cause and effect using additional information such as habitat, chemical water quality and toxicity information. Noble *et al.* (2007) suggested that combining multi-metric measures into a single index value suggests only a single linear scale of response and, therefore, only one type of response by ecosystems to disturbance. They failed to recognize that the individual patterns exhibited by the various individual fish metrics usually reduced to single patterns in the community. Thus, although multiple measures of the individual metrics results in multiple vectors explaining those dynamic patterns, *a priori* predictions of the metric response will result in the biological integrity categories defined by Karr (1981). The above argument suggested that the IBI would only work if all ecosystems in all cases became unhealthy in the same manner. The IBI multi-metrics are assumed to measure a specific attribute of the community. Each metric is not an answer unto itself and not all measure only attributes of a properly functioning community (e.g., percent anomalies). The metric must be sensitive to the environmental condition being monitored. The definition of degradation responses is justified if clear patterns emerge from specific metrics. Although the probability of all ecosystems becoming unhealthy in the same manner is unrealistic, it is important to note that response signatures are definable and based on patterns of specific perturbations.

Variance demonstrated in indices of the IBI may be high due to the compounding of individual metric variances. Schmutz *et al.* (2007) further suggest that other statistical properties of multi-metric variables may be difficult to define. In studies conducted by USEPA (2000), it was shown that IBI variability increased at highly degraded and disturbed sites but was low and stable at high-quality sites with increased biological integrity. The amount of variability within any of the component IBI metrics is irrelevant and does not necessarily have to be on the same scale assuming that proper metrics are expected and knowledge of how the metrics are applied are assessed by the field biologist. The high degree of resultant variability at sites that exhibit low biological integrity is an important indicator of site structure and function (Morris *et al.*, 2007).

The IBI uses reference sites as benchmarks for assessing the level of perturbation for degraded sites. Nevertheless, completely undisturbed environments are virtually nonexistent, and even remote waters are impacted by factors such as atmospheric pollution, "minimally impacted" sites have been used to define the "best attainable reference condition" (Karr & Chu, 1997). By doing so, already perturbed sites are used to assess other areas and this introduces errors to the assessment. This means that the best sites are already degraded and this makes it difficult to obtain the original pristine conditions that existed prior to any level of degradation. In trying to solve this problem, use of literature and expert opinion have been suggested (USEPA, 2000). Consequently, due accord needs to be given to the residency status of species and the role they take in establishing reference conditions and assessing status interactions (Noble et al., 2007). However, this is difficult because most parts especially in Africa lack recorded data and expert opinion is always subjective and sometimes lacking.

Conclusions

When it comes to sustaining living rivers and the other life-giving services ecological systems provide, the stakes are too great and the obstacles too large to simply do 'more research.' The ultimate goal of riverine ecosystem conservation is to protect biotic integrity from watershed features and actions such as human impacts. This is very difficult because there are numerous changes taking place at a given time. This may require a layering of actions to conserve the biotic integrity that involves the use of multimetric tests that are linked to the ecosystem. This report has provided a baseline that index of biotic integrity stands out to be the most current monitoring procedure that encompasses the multi-metric responses from a given riverine ecosystem, although like other indices, carries unanswered criticisms.

Recommendations

- There is need to compare current IBI scores with historical data to make conclusive remarks on the integrity of rivers.
- There is need to note down biota assemblages showing adaptability to in-stream characteristics & include them in the multi-metrics development for the IBI.
- Reference sites should include historical data & should only represent a given water body type in close proximity.
- Many sampling stations could be initiated within a water body type to minimize sampling error and variance.

References

Butcher, T.R., Stewart, P.M., Simon, P.T. 2003. A Benthic Community Index for Streams in the Northern Lakes and Forests Ecoregion. *Ecological Indicators* 3, 181-193.

Buttle, J. M. & Metcalfe, R. A. 2000. Boreal forest disturbance and stream flow response, northeastern Ontario. *Canadian Journal of Fisheries and Aquatic Sciences* 57, 5-18.

Griffith, M. B., Hill, B., McCormick, H., Kaufmann, R., Herlihy, T. & Selle, A. R. 2005. Comparative application of indices of biotic integrity based on periphyton, macroinvertebrates, and fish to southern Rocky Mountain streams. *Ecological Indicators* 5,117- 136.

Hay, B.S. Camara, B. Samoura & Magassouba, M. 1996. Applying an index of biotic integrity based on fish assemblages in a West African river. *Hydrobiologia* 331, 71–78.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6, 21-27.

Maloney, K.O., Dodd, H.R., Butler, S.E and Wahl, D.H. 2008. Changes in Macroinvertebrates and Fish Assemblages in Medium-sized River following a breach of a low-head dam. *Freshwater Biology* 53,1055-1068.

Morris, C.C., Stewart, P.M. and Simon, P.T. 2007. Development of an Index of Biotic Integrity for a Southeastern Coastal Plain Watershed, U.S.A. *American Water Resource Association*43, 2

Noble, R.A., Cowx, G.I., Goffaux, D. & Kestemont, P. 2007. Assessing the Health of European Rivers using Functional Ecological Guilds of Fish Communities: Standardizing Species Classification and Approaches to Metric Selection. *Fisheries Management and Ecology* 14, 381-392.

Raburu, O.P. 2003. Biomonitoring of streams. A case study of River Nyando basin. Index of Biological Integrity. Chapter 7. PhD thesis., Moi University. Kenya. 112pp.

Roux, D.J. 1997. National Aquatic Ecosystem Biomonitoring Programme: Overview of the Design Process and Guidelines for Implementation. NAEBP Report Series no. 6. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa. 80pp.

Schmutz, S., Cowx, I.G., Haidvogl, G., Pont, D. 2007. Fish Based Methods for Assessing European Running Waters: A sythesis. *Fisheries Management and Ecology* 14,369-380.

USEPA .2000. Biological Criteria. National Program Guidance for Surface Waters. U.S. Environmental Protection Agency. Washington, DC. 87pp.

Bioassessment of the Health of Asawo Stream in the Lower Nyando River Basin, Kenya

D. P. Ashitiva, P. O. Raburu and M. Njiru
Department of Fisheries and Aquatic Sciences, Moi University, Eldoret, Kenya

Abstract

Aquatic macroinvertebrates were sampled form Asawo stream within the lower Nyando River Basin, Kenya, between July 2007 to February 2008 with exception of August and January. The objective of the study was to develop an Index of Biotic Integrity (IBI) for bioassessment and monitoring of ecosystem health. Four sampling stations along the stream were identified with station one being the upper most reach of the stream. For each station, a riffle, a pool and a run were sampled for macroinvertebrates and physico-chemical parameters. A total of 2726 macroinvertebrates were identified, classified into 24 genera and ten orders. Nineteen of the genera were in class Insecta, two in class Gastropoda and three in class Clitellata. The riffles had the highest mean relative abundance (7.80 ± 0.79), followed by the runs (5.50 ± 0.68) and the pools (5.34 ± 0.47). The number of the macroinvertebrates differed significantly from one macrohabitat to the other (p = 0.01). The highest Shannon-Weiner species diversity (mean = 2.59±0.22) was recorded in station 4, a station also with the highest mean TN (4.96±0.12µgL^{-1}) and TP (0.17±0.009µgL^{-1}). February recorded the highest species diversity (mean= 3.12 ± 0.08) while July had the lowest (mean= 1.39 ± 0.47). Station 1 had good water quality, based on the M-IBI value, with less than expected intolerant macroinvertebrates. Buffer and riparian zones along Asawo stream affected Macroinvertebrate composition and distribution.

Key words: *River Nyando, bioassessment, M-IBI, macroinvertebrates, buffer zone*

Introduction

Aquatic ecosystems worldwide have been subject to many anthropogenic disturbances, severely degrading the health of streams and rivers. Hydraulic alterations of waterways, alteration of flow rates, and the disruption of wildlife habitats through changes in chemical concentrations and increases in sedimentation, are additional consequences of intensive agriculture (Schultz *et al.*, 1995; Vellidis *et a*l., 2003;Roy *et. al.,* 2003). Biological monitoring in particular has been recognized as one of the most useful tools in assessing water quality (Karr and Chu, 1999; Raburu, 2003). Ideally, a useful biotic indicator would have the combined attributes of responding quickly to problems, diagnostic of differing stressors, readily sampled, and present in sufficient numbers for comparison with reference conditions (Rapport, 1992). Benthic macroinvertebrate assemblages have been often used in biological monitoring, especially to assess agricultural impacts to streams (Gregory, 1996; Davis *et al.*, 2003). Macroinvertebrates offer a spectrum of responses to disturbance and inhabit a wide range of environments while integrating the effects of short-term environmental variation (Barbour et al., 1999). In the Gulf Coastal Plain, Gregory (1996) and Davis *et al.* (2003) showed that macroinvertebrate communities are valuable tools in evaluating the effectiveness of best management practices (BMPs) on streams affected by human land use. Nutrient concentrations have increased in rivers globally and less than ten per cent of the rivers can be classified as pristine in terms of their nitrate status as defined by WHO (Heathwaite *et al.,* 1996). When assessing the nutrient concentrations of forested and agricultural streams, Sabater *et al.* (2004) discovered that the concentrations of nitrogen and phosphorus were within the same range. However, the continuous reception of nutrients caused high chlorophyll concentrations and high community metabolism in the agricultural streams. This study therefore sets out to provide a first step in developing a cost effective biomonitoring protocol and relevant information that can be used in biomonitoring to protect the wetlands in the lower reaches of Nyando River Basin, with the objectives being to determine the composition and distribution of freshwater macroinvertebrates and their spatial and temporal distributions in Asawo stream, to identify suitable metrics for macroinvertebrate assemblage that might be used in development of an index of biotic integrity (IBI) for Asawo stream, to determine the changes in nutrients (phosphorous and nitrate) concentration along the upper Asawo stream and to determine macroinvertebrate index of biotic integrity for Asawo stream

Materials and Methods

Study area

The study was carried out in Asawo stream, a riverine wetlands in the lower Nyando River Basin, Kenya, which drains into the Winam Gulf of Lake Victoria (Figure 1). The catchment is centered on the equator at 35°10’ E. It is situated between

Lake Victoria to the west, Tinderet hills in the east, Nandi escarpment to the North and Mau escarpment to the South. Altitude varies from about 1000 metre above mean sea level at Lake Victoria to over 2000m a.m.s.l in the up-hill regions. The Nyando catchment extends over an area of 3600 sq. kilometres. The climate of the catchment is sub-humid with a mean annual temperature of 23°C. The mean annual rainfall varies from 1000mm near Lake Victoria to over 1600mm in the highlands showing no distinct dry season. Its tri-modal with peaks during the long rains (March-May) and short rains (October-December). The third peak occurs in August.

Four stations were located randomly on Asawo stream (Figure 1). At these stations an area of 800m was considered in which a riffle, a pool and a run were identified and sampled for macroinvertebrates, BOD and nutrients for a period of six month (July 2007 to February 2008 with exception of August 2007 and January 2008). The various human and land use activities along Asawo were also recorded. Station 1 was upstream with minimal anthropogenic impact. The substrate comprised of sand, gravel and organic substrate with detritus material. The station had an average depth of 0.5metre and an average width of 1.5metre. The buffer zone was well covered with dense vegetation with the riparian zone having witnessed expansive gulley erosion. Station 2 was located at the bridge on Ahero – Sondu road after Store Pamba market centre. The substrate varied from organic gravel, pebbles, rocks and sand. Human impacts included animal watering, washing, bathing and channel modification. The stream banks were eroded with partial vegetation cover with an average depth of 0.3metre and an average width of 2.2metres. Station 3 was located in a valley downstream of station 2 with the substrate being mainly organic with detritus material, sand and pebbles. The stream in this station was characterised by high sinuosity and collapsed and eroded riverbanks. The riverbanks and the riparian zone had scanty vegetation cover and had experience soil erosion forming gulley. Human impact included animal watering and it had an average depth of 0.2metre and an average width of 2metre. Station 4 was located downstream at a bridge on Katito - Homa-Bay road. The substrate ranged from organic, with a lot of algal bloom, to sand and pebbles. The average depth at was 0.4metre and average width was 2.4metres. The riparian zone was characterised by agricultural activities mainly banana plantations.

Sampling

Macroinvertebrate communities were sampled from the riffles, pools and runs using a scoop net of mesh 0.5mm. All Macroinvertebrate samples were preserved in 70 per cent alcohol and later sorted from debris in the laboratory. The samples were then identified to the genera level (Quigley, 1977; Merritt and Cummins, 1997; IFM, 2006) and counted. The diversity index for each macroinvertebrate genera was determined using Shannon Weiner index (Karr and Chu, 1999). Total Nitrogen and Total Phosphorous were determined in the laboratory using the Kjeldahl and Persulfate digestion method respectively (APHA, 2000).

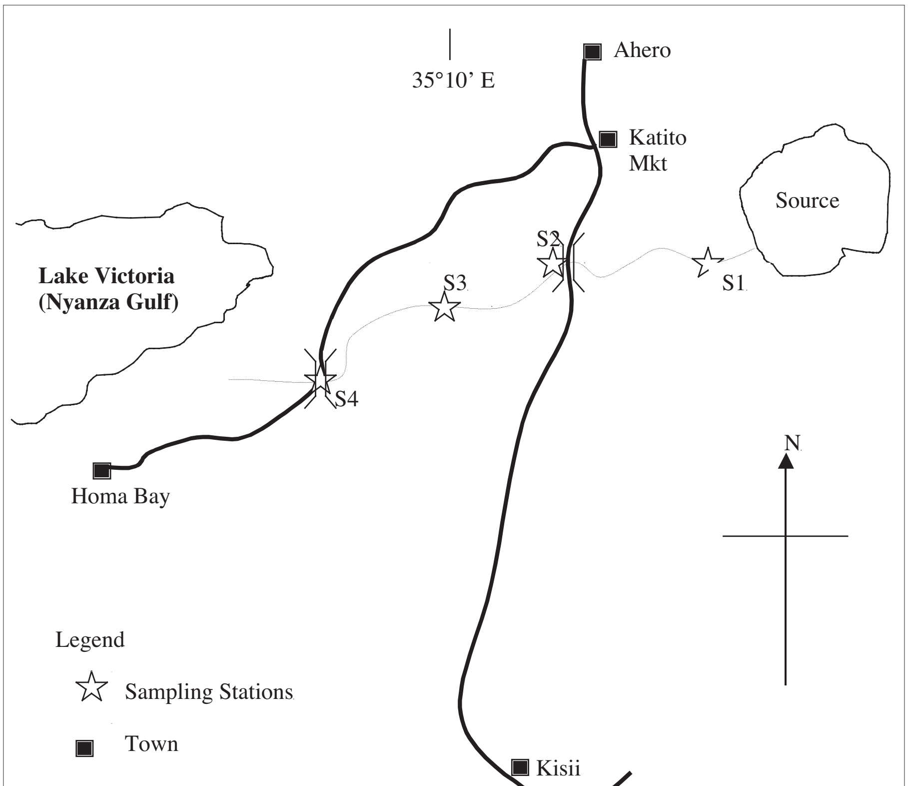


Figure 1: A sketch map of sampling stations on Asawo stream

Index of biotic integrity (IBI) scoring criteria

Reference site selection

Sites with minimal anthropogenic impacts based on standards set for nutrients; physical habitat and community structure of biota in an area were used as reference sites. All sites were sampled across a gradient of human influence along the stream to detect biological responses about resource condition exhibited by macroinvertebrate assemblages inhabiting the stream (Simon and Lyons, 1995). This approach utilized the best values observed in each station to set the baselines of expectation for each metric attribute and hence delineate degraded sites from non-degraded sites.

Metric selection

A number of metrics were selected that acted as indicator attributes in assessing the status of macroinvertebrate assemblages in response to perturbation (Barbour *et. al.*, 1999) in Asawo stream. The metrics that were considered for this study were grouped into taxon richness, composition, tolerance and trophic dynamics (Table 1).

Table 1: Metrics for benthic macroinvertebrates used for assessing biological integrity of Asawo stream

Richness Measures	Composition Measures	Tolerance Measures	Trophic Measures
-No. EPT taxa -No. Ephemeroptera taxa -No. Odonata -No. Non-insects	-% EPT individuals -% EPT - % Trichoptera -% Non-Chironomidae -% Diptera -% Dominant 5 taxa	-% Intolerant Taxa -% Tolerant organisms	-% Filterers -% Predators

Scoring criteria

The highest metric values, in whichever station, were used as reference values. The 95th percentile of each metric value was calculated to help limit the influence of outliers in the scoring process. The metrics were then trisected after which values of 5, 3 and 1 were assigned depending on whether the value of the attribute in a sample approximates, deviates slightly(5) from, or deviates strongly(1) from values at undegraded sites in similar habitats. An M-IBI score was calculated by summing all the metric scores in each station.

Data analysis

The data obtained was analyzed statistically using Statistical Package for Social Sciences (SPSS for windows version 12) and Microsoft Excel package. Two-way ANOVA was used to test for significant differences among the station and macrohabitats at p = 0.05. Duncan's Multiple Range test was used to show stations and sampled dates that differed from each other. Spearman Rank Correlation was also used to correlate the metrics with nutrient concentrations in the stations so as to get suitable metrics for IBI.

Results

Macroinvertebrate composition and distribution

A total of 2726 macroinvertebrates were recorded from the four stations on Asawo stream, classified into 24 genera and in ten orders. Nineteen of the genera were in class Insecta, two in class Gastropoda and three in class Clitellata (Table 2). *Baetis* sp. dominated in Stations one and two with a relative mean abundance of 9.47 ± 2.10 and 9.18 ± 2.73 respectively. *Tipula sp* was the least dominant in station two with a relative mean abundance of 0.06 ± 0.06. *Limnea* sp and *Physa* sp were not encountered in station one. Stations three and four were dominated by *Chironomus* sp with a relative mean abundance of 7.24 ± 3.94 in Station three and a relative mean abundance of 6.33 ± 2.70 in Station four.

Table 2. List of species sampled in different station on Asawo stream in the Nyando River Basin, Kenya.

Phylum	Class	Order	Family	Genera
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Baetis sp*.
			Ephemerillidae	*Ephemerella* sp.
			Ecdyonuridae	*Heptogenia* sp
			Caenidae	*Caenis* sp
		Plecoptera	Nemouridae	*Nemoura* sp.
			Leuctridae	*Leuctra* sp.
		Trichoptera	Rycophillidae	*Rycophila* sp.
			Polycetropidae	*Polycetropus* sp.
		Hemiptera	Corixidae	*Micronecta* sp.
				Corixa sp.
			Notonectiidae	*Notonecta* sp
		Coleoptera	Elmidae	*Elmis* sp.
			Gyrinidae	*Gyrinus* sp.
			Hydraenidae	*Hydraena* sp.
		Diptera	Simuliidae	*Simulium* sp.
			Chironomidae	*Chironomus* sp.
			Tipulidae	*Tipula* sp.
		Odonata	Gomphidae	*Gomphus* sp.
			Agriidae	*Agrion* sp.
Annelid	Clitellata	Oligochaeta	Lumbriculidae	*Lumbricus* sp.
		Hirudinea	Erpobdellidae	*Erpobdella* sp.
Mollusca	Gastropoda	Pulmonata	Planorbidae	*Planorbis* sp
			Lymnaidae	*Limnea* sp.
			Physidae	*Physa* sp

The riffles had the highest mean relative abundance of 7.80 ± 0.79, followed by the runs with a mean relative abundance of 5.50 ± 0.68 while the pools had the mean relative abundance of 5.34 ± 0.47. The number of the macroinvertebrates differed significantly from one macrohabitat to the other (F = 4.52, df = 2, p = 0.01). Duncan's post hoc test showed that the significant difference was between the riffles and the pools (p = 0.03). *Baetis* sp was the most dominant in the riffle with a mean relative abundance of 13.00 ± 4.09 and it was followed closely by *Chironomus* sp with a mean relative abundance of 12.74 ± 2.39 while *Gyrinus* sp was the least dominant species in the riffle with a mean relative abundance of 0.22 ± 0. The pools were dominated by *Planorbis* sp with a mean relative abundance of 6.30 ± 1.65, while with a mean of 0.04 ± 0.04 each, *Erpobdella* sp and *Limnea* sp were the least dominant in the pool. *Planorbis* sp dominated in the runs with mean relative abundance of 8.55 ± 3.48 while *Lumbricus* sp was the least dominant having a mean of 0.10±0.07

Station two had highest mean relative abundance of 6.98 ± 0.85 followed by Station four with a mean relative abundance of 6.33 ± 0.66. Station one had a mean relative abundance of 5.99 ± 0.75 while Station three had the least mean relative abundance of 5.67 ± 0.78. There was however no significance difference (F = 0.52, df = 3, p = 0.67) in macroinvertebrates relative abundance sampled from the different stations on Asawo stream. The total mean relative abundance in the different sampling month was 6.24 ± 0.38 and showed a significant difference (F =2.93; df =5; p = 0.013) from one month to the other. Duncan's post hoc test showed that the significant differences were recorded between the months of July and December and February.

Species Diversity

The lowest and highest species diversity was at Stations three and four with a mean of 2.18 ± 0.19 and 2.59 ± 0.23 respectively. Stations one and two recorded a mean diversity of 2.55 ± 0.27 and 2.30 ± 0.19 respectively. The month of February recorded the highest species diversity of 3.12 ± 0.08 while July had the lowest macroinvertebrate species diversity of 1.39 ± 0.47 (Figure 2).

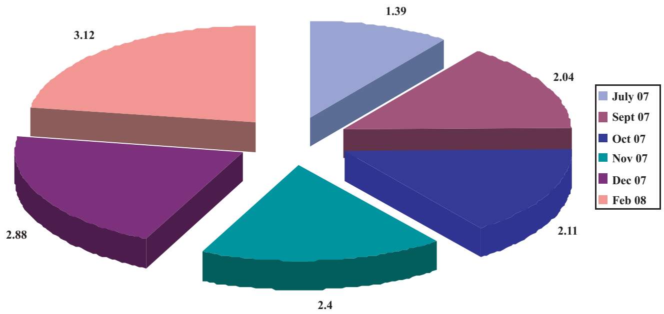


Figure 2. Shannon-Weiner diversity index for Asawo stream in the different sampling month

Nutrients

Station four recorded the highest mean TN and TP at 4.96 ± 0.12mgL^{-1} and 0.17 ± 0.01µgL^{-1} respectively while the lowest TN (3.01 ± 0.10µgL^{-1}) and TP (0.044 ± 0.005µgL^{-1}) were recorded in Station 1(Figure 3). The nutrients showed a significant difference within the stations ($p < 0.01$) as well as among the different dates ($p < 0.01$). December and October recorded the highest (4.81 ± 0.079mgL^{-1}) and lowest (0.87 ± 0.067mgL^{-1}) amounts of TN respectively. July recorded the highest TP (0.21± 0.002µgL^{-1}) while October recorded the lowest TP (0.039 ± 0.0005µgL^{-1}) (Figure 3).

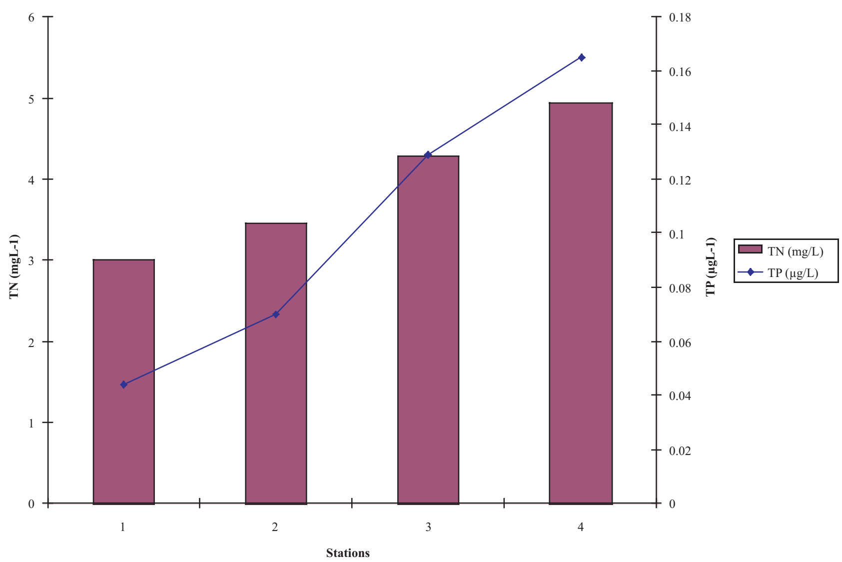


Figure 3. Mean TN and TP in different stations on Asawo stream

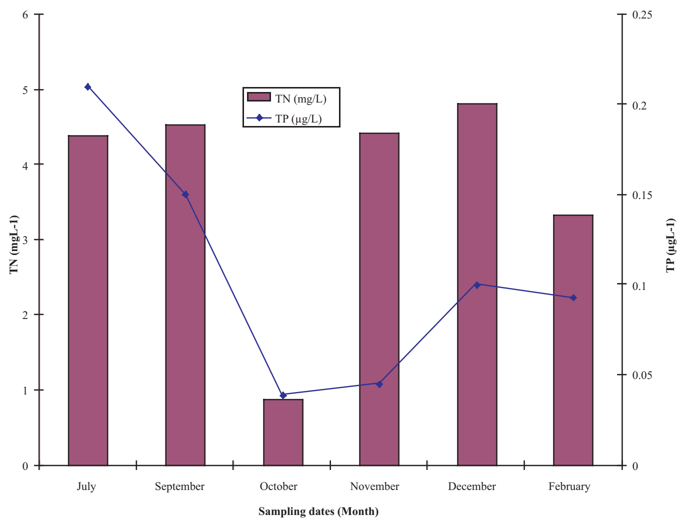


Figure 4. Mean TN and TP in different stations on Asawo stream during different sampling dates

Relationship between macroinvertebrates diversity and nutrients

Station four with the highest Shannon-Weiner index 2.59 ± 0.23 recorded high levels in nutrient concentrations at 4.96 ± 0.12mgL^{-1} and 0.17 ± 0.01µgL^{-1} for TN and TP respectively. Station one with Shannon-Weiner index of 2.55 ± 0.27, recorded a mean of 3.01 ± 0.10 mgL^{-1} and 0.044 ± 0.005µgL^{-1} of total nitrogen and total phosphorous respectively, while Station three with a Shannon-Weiner index of 2.18 ± 0.19 recorded a mean of 4.29±0.13 mgL^{-1} and 0.129±0.004 µgL^{-1} of TN and TP respectively. All the stations recorded a positive Pearson's correlation between the macroinvertebrate diversity verses TN (R = 0.041; p = 0.96) and TP (R= 019; p = 0.98) without any significant differences. The macroinvertebrate abundance in Asawo stream however, showed negative non-significant correlation with both TN (R = -0.723 p = 0.28) and TP (R = -0.756; p = 0.25) concentrations.

Physico-chemical parameters

Dissolved oxygen and Biological oxygen demand

Station 4 recorded the highest mean D.O of 5.36 ± 0.19mgL^{-1} as well as the highest BOD at 3.11± 0.170mgL^{-1} (Figure 4). The lowest BOD (2.00 ± 0.134mgL^{-1}) and lowest DO (4.54 ± 0.10mgL^{-1}) were recorded in Station three. Both D.O and B.O.D showed a significant difference (p<0.01) and (p = 0.002) respectively, among the stations. The significant differences in D.O were recorded between Stations one and four, Stations two and three and Stations two and four. While significant difference in B.O.D was recorded between stations two and four as per Duncan's multiple range test.

Macroinvertebrate community assessment and attribute evaluation.

Fourteen out of 43 metrics tested qualified to perform as metrics for the development of M-IBI (Kerans and Karr 1994, Barbour *et al.* 1999). Spearman Rank correlation was used to determine if an attribute exhibited a significant (P < 0.05) relationship with TN and TP concentrations. Station onerecorded the highest M-IBI while station three recorded the lowest M-IBI (Table 3). Five integrity classes and their description as were established in the study on Asawo stream based on the nutrient and D.O concentrations (Table 4).

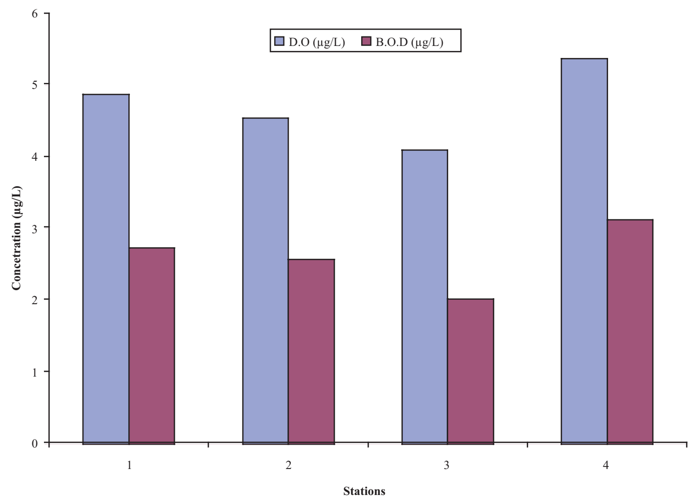


Figure 5. Mean D.O and B.O.D in different stations on Asawo stream

Table 3. Observed scores for individual metrics, scored values and overall M-IBI scores per station on Asawo stream.

	Stations				Reference value	Scoring criteria		
Metrics for M-IBI	**1**	**2**	**3**	**4**		**5**	**3**	**1**
Taxa richness								
# EPT	5	5	3	3	378	>252	126-252	<126
# Ephemeroptera	5	5	3	1	237	>158	79-158	<79
# Odonata	3	5	3	1	123	<41	41-82	>82
# Non-insects	5	1	3	5	174	<58	58-118	>118
Composition								
% EPT individual	5	5	3	3	49.30	>34	17-34	<17
% EPT	5	5	5	5	36.40	>24	12-24	<12
% Dominant 5 taxa	3	5	5	1	11.90	>7	4-7	<3
%Diptera	1	3	1	3	31.54	<11	11-22	>22
% Non-chironomid	1	3	1	5	11.21	<4	4-8	>8
% Trichoptera	3	3	1	5	8.10	>6	3-6	<3
Tolerance								
% Intolerant	5	3	3	1	28.30	>20	10-20	<10
% Tolerant taxa	3	1	1	5	33.30	0-11	12-23	>23
Trophic levels								
% Predators	3	3	1	1	46.60	<11	11-22	>22
% Filterers	5	1	1	3	45.90	>36	18-36	<18
Total M-IBI	**52**	**42**	**32**	**40**				

Table 4: Total IBI scores, their integrity classes and description.

Total IBI	*Class of Integrity*	*Description*
61 – 70	Excellent	Condition comparable to best situation before human influence. TN< 3.01mgL-1, TP<0.04μgL-1
51 – 60	Good	Condition indicative of low integrity with less than expected number of intolerant macroinvertebrates. TN= 3.01mgL-1and TP= 0.04μgL-1
41 – 50	Fair	Dominated by higher than average number of tolerant macroinvertebrates. TN=3.47mgL-1, TP<0.07μgL-1
31 – 40	Poor	Dominated by tolerant macroinvertebrates and few intolerant macroinvertebrates. TN = 4.29mgL-1, and TP<0.129μgL-1
<30	Very poor	Dominated by tolerant macroinvertebrates with complete absence of intolerant macroinvertebrates. TN> 4.29mgL-1, and TP<0.129μgL-1

Discussion

Macroinvertebrate composition and distribution

Class Insecta dominated the sampling station on the Asawo stream, as it exhibits tremendous diversity and occupies a variety of substrate such as surfaces of stones, deep below the substratum, a drift in the current and surface flow. Family *Baetidae, Elmidae, Heptageniidae* of the Class Insecta and Family *Lumbriculidae* and *Erpobdellidae* of class Clitellata are known to dominate most of the lotic systems in the world (Helgen and Gernes, 2001). The insects have further developed strategies for anchor such as curved clinging claws, suction devices and streamlined bodies as adaptations for living in flow system without being carried away by current.

The dominance of *Baetis* sp. in station 1 and 2 may be attributed to the fact that *Baetis* sp. has a streamlined body thus minimises resistance to the strong current in the upstream. *Baetis* sp hatch in large numbers on over cast rainy seasons and can inhabit many water types in streams but prefer weedy riffles and runs (Helgen and Gernes, 2001).

The dominance of *Chironomus* sp in Stations 3 and 4 may be due to their slender and soft body parts that allow them to move between interstices of sand and mud typical of pools and runs, where they were mostly found (Merritt and Cummins 1997). Also, patchiness in distribution of insect species reflects the optimal overlap between macrohabitat and physical environmental conditions that comprise the habitat. Chironomids have been found in association with streams having higher levels of pollution (i.e., sedimentation), and tend to increase in abundance with disturbances such as agriculture (Strand and Merritt, 1999; Davis *et al.*, 2003) as was the case in Stations 3 and 4.

The mean macroinvertebrate abundance was highest in Station 2 and lowest in Station 3. This may have been influenced by low levels of d DO recorded in station 3 as low amounts of DO are a frequently observed limit to invertebrate growth, (Spieles and Mitsch, 2000). The low level of DO in station 3 was most probably caused by siltation and smoothering effect resulting from degradation due to bank erosion. The absence of a buffer zone at the station and an eroded riparian zone caused exposure of water resulting in high temperatures which could have also led to the low levels of DO. The relative abundance of the macroinvertebrates was highest in the riffles, considered to be shallow, as macroinvertebrate abundance has been observed to relate inversely with stream depth (Kennedy, 1967; Herbst and Kane, 2004). The high abundance in the riffle may also be attributed to the habitat diversity that facilitates colonization by different macroinvertebrate species. Key habitats for macroinvertebrates are the benthic sediments, aquatic vegetation and woody debris. The riffles are also considered to have high concentrations of oxygen resulting from the speed and movement of water that allows for oxygen to dissolve and in turn making the riffles suitable habitats for macroinvertebrates.

Species diversity

The high species diversity in station 4 may be attributed to a variety of substrate ranging from organic matter, to sand, to gravel and pebbles which are known to be inhabited by different macroinvertebrates. Pollution tolerant species like *Chironomus* sp., and *Planorbis* sp. were more abundant in this station. In Karr (1999) the distribution of aquatic macroinvertebrate population is set by physco-chemical tolerance of the individuals in the population. The presence of periphyton in the station also ensured availability of food for different macroinvertebrates thus increase their diversity in the station.

Station 1 also had equally high species diversitydue to a thick vegetation cover that provided several macrohabitat for the different macroinvertebrate species. Habitat structure promotes macroinvertebrate colonization and retention by increasing habitat diversity (Brooks 2002). Stones and similar objects also indirectly benefit macroinvertebrates by trapping particulate matter that provides animals with food and additional habitat thus increasing species diversity. Station 2 and 3 recorded low species due to the human activities. Macroinvertebrate communities are known to be influenced by regional landcharacteristics and by the presence of disturbancessuch as those resulting from grazing activities within the riparian area which cause the macroinvertebrate diversity to decrease (Wilson and Dorcas 2003). Sediment disturbance and trampling on vegetation by livestock has been observed to have a direct impact on diversity of macroinvertebrates in river systems (Silla, 2005).

The low diversity in Station 3, apart from lack of a buffers zone, may be attributed to the low levels of D.O recorded in the station. Dissolved oxygen is essential for most forms of developing aquatic invertebrates and lower concentrations seem to inhibit species diversity. Despite the presence of a partial buffer zone in Station 2, species diversity was low than Stations 4 and 1. This may have been caused by the modification of the stream channel which made the substrate at the station impervious resulting in decreased abundance and rapid loss of sensitive species, thus decreased diversity (Paul and Meyer 2001; Gray 2004). The low species diversity in July may be attributed to the high levels of rainfall recorded which probably swept away some macroinvertebrate species causing habitat overlap due to the high water level that burst the stream banks.

Nutrients

Lack of a buffering zone in the riparian zone of Station 4, unlike the case in Station 1 may have also contributed to the high levels of nutrients as most of the run off from the adjoining land ended up in the stream. A protected riparian zone in an agriculturally influenced area, as is the case of Station 4, is widely viewed as a critical component in the protection of surface water quality, instream habitat, and the biotic integrity of aquatic ecosystems (Paine and Ribic, 2002). According to Tomer *et al.*, (2003), buffers protect stream water quality by slowing runoff traveling to the stream, allowing it to percolate into the soil, and intercepting sediment and chemical pollutants.

Relationship between Macroinvertebrates and Nutrients

Macroinvertebrate species diversity showed a positive correlation with both TN and TP. Station 4, which recorded the highest nutrient levels, also recorded the highest species diversity. According to Batzer and Wissinger, 1996, the increased availability of nutrients will increase primary production of photosynthetic periphyton, and increase invertebrate abundance. The high levels of nutrients might have contributed the high species diversity. Given that the nutrient levels increased the number of macroinvertebrates, then the lethal levels of nutrients are not yet reached in this (Asawo) stream and therefore several species can still survive in the stream.

Macroinvertebrate community assessment and attribute evaluation

Since M-IBI indicates environmental impairment of a given site, it is clear that Station 3 on Asawo stream was heavily impacted, as it recorded the lowest M-IBI values that may have been caused by the complete lack of a buffer zone around the station, which facilitated deposition of soil, caused by erosion of riverbanks, into the stream channel. This form of disturbance caused a decrease in the number of less tolerant species, which scored low metric values leading to low overall M-IBI in the station. The station scored poorly in taxonomic diversity, which is considered a good indicator of environmental quality. Station 1 had the highest M-IBI value, indicating that the macroinvertebrate community approximates that of a minimally disturbed site. This may have been enhanced by the thick buffer zone that protected the stream channel from external sources of pollution such as nutrient leaching from the neighbouring farmlands as well as through erosion experienced in the riparian zone as a forested buffer prevents pollution from nutrients and sediments (Viaud *et. al.*, 2004). The highest scoring of the number of order Ephemeroptera and EPT taxa is a clear indication that the site is least impaired as most mayflies are sensitive to low DO as well as high nutrient levels (Mason, 2002).

Based on the overall M-IBI score, Station 1 was classified as 'good' after scoring 52 points based on the integrity class, out of the possible 70 points. The station can therefore be said to have a condition indicative of low integrity with less than expected number of tolerant macroinvertebrates. Stations 2 and 4 were categorized as having 'fair' water quality, in which case they were dominated by higher than average number of tolerant macroinvertebrate species. This may be attributed to the surrounding human activities in the stations, which caused disturbances in these stations leading to the disappreance of intolerant species due to unfavourable conditions. The agricultural activities in Station 4 most likely led to pollution through siltation and sedimentation and therefore dominance by tolerant species which are often found to thrive in areas known to have low DO, high turbidity, eutrophication or heavy siltation. Station 3 was the worst of the four stations sample on Asawo stream, being classified as 'poor'. Being without a buffer zone and a degraded riparian zone due to erosion, this poor condition was expected. Station 3 might have suffered from high siltation and sedimentation, a characteristic of the collapsed riverbanks and total absence of a buffer zone along the river, resulting from increased runoff (Paul & Meyer 2001; Gray 2004).

Lack of a riparian zone with a combination of livestock activities like grazing and watering as was experience in Station 3, have been known to affect species diversity by causing loss of intolerant species (Silla, 2005). Overgrazing by cattle is often characterized by a distinct pattern of deteriorated habitat conditions (Herbst and Kane 2004) as was experienced in Station 3 and often includes loss of riparian cover and associated reduction in organic matter inputs, weed invasion, soil compaction, increased runoff and erosion, nutrient enrichment, increased solar radiation, and prolific algal growth (Belsky *et al.* 1999). The riparian and buffer zones can therefore be said to have played a significant role in dictating the composition, distribution and diversity of macroinvertebrates as well as nutrient concentrations along the stream and they should be maintained whatsoever along the stream.

References

American Public Health Association (APHA) 2000. Standard Methods for Analysis of Water and Wastewater, 18th edn. Port City Press, Baltimore, USA

Barbour, M.T., Gerritsen, J., Snyder, B.D. and Stribling, J.B. 1999. Rapid bioassessment protocols for use in streams and rivers: periphyton, benthic macroinvertebrates, and fish, 2nd edition. U.S. Environmental Protection Agency, EPA 841-B-99-002. Washington, D.C.

Brooks, R. T. 2002. Annual and seasonal variation and the effects of hydroperiod on benthic macroinvertebrates of seasonal forest ("vernal") ponds in central Massachusetts, USA. *Wetlands* 20 (4): 707-715.

Batzer, D. P., and. Wissinger S. A. 1996. Ecology of insect communities in non tidal wetlands. *Annual Reviews in Entomology* 41,75-100.

Belsky, A. J., Matzke, A. and Uselman, S. 1999. 'Survey of livestock influences on stream and riparian ecosystems in the Western United States', *Journal of Soil and Water Conservation* 54, 419-431.

Davis, S., Golladay S. W., Vellidis G. and Pringle C. M. 2003. Macroinvertebrate biomonitoring in intermittent Coastal Plain streams impacted by animal agriculture. *Journal of Environmental Quality* 32,1036-1043.

Gray, L. 2004. Changes in water quality and macroinvertebrate communities resulting from urban streamflows in the Provo River, Utah, USA. *Hydrobiologia* 518, 33-46.

Gregory, M.B. 1996. The effects of riparian zone management on water quality and macroinvertebrate community structure on the southeastern Coastal Plain. M.Sc. Thesis. University of Georgia, Athens, Georgia.

Heathwaite, A.L., Johnes, P.J., and Peters, N. 1996. *Trends in nutrients. Hydrological Processes* 10, 263-293.

Helgen, J. C., and Gernes, M. C. 2001. Monitoring the condition of wetlands: Indexes of Biological integrity using invertebrates and vegetation, Bioassessment and management of North of America freshwater wetlands 8: 150 – 180.

Herbst, D. B. and Kane, J. M. 2004. ‚Response of stream channels, riparian habitat, and aquatic invertebrate community structure to varied livestock grazing exposure and management in the West Walker River watershed', Regional Water Quality Control Board, Lahontan.

IFM, 2006. Aquatic Ecology. Department of Biology, Linkoping University, Sweden. 21pp.

Karr, J. R. 1999. Defining and measuring river health. Freshwater Biology 41:221–234.

Karr, J.R., and Chu, E.W. 1999. Restoring life in running waters: Better biological monitoring. Island Press, Washington, D

Kennedy, H.D. 1967. Seasonal abundance of aquatic invertebrates and their utilization by hatchery reared rainbow trout. Technical papers No.12. Bureau of sport fisheries and wildlife, Washngton DC, U.S.A. pp 1-14.

Merritt, R.W., and Cummins, K.W. 1997. An Introduction to Aquatic Insects of North America. 3rd Edition. Kendall/Hunt Publishing Company, Dubuque, Iowa, USA. 67pp

Mason, C. F. 2002. Biology of freshwater pollution. 4th Ed. Pearson Education Ltd. Essex. London. 388pp.

Paul, M.J., and Meyer, J. L. 2001. Streams in the urban landscape. *Annual Review of Ecology and Systematics* 32,333-365.

Paine, L.K., and Ribic C. A. 2002. Comparison of riparian plant communities under four land management systems in southwestern Wisconsin. *Agricultural Ecosystem Environment* 92,93-105.

Quiley, M. 1977. Invertebrates of Streams and Rivers: Key to Identification. Bedford Square, London. 21pp.

Raburu, P.O. 2003. Water quality and the status of aquatic macroinvertebrates and ichthyofauna in River Nyando, Kenya. PhD Thesis, Moi university Eldoret, Kenya. 313pp

Rapport, D.J. 1992. Evaluating ecosystem health. *Journal of Aquatic Ecosystems. Health* 1,15-24.

Roy J. L., Leah. A. O., and Brent S. 2003 Integration of research planning and environmental management in the Nyando Basin, Kenya. World Agroforestry center and Maseno University, Kenya

Sabater, S., Acuna, V., and Giorgi, A. 2004. Flow extremes and benthic organic matter shape the metabolism of a stream. *Freshwater Biology* 49, 1960-1970.

Schultz, R.C., Colletti, J.P. Isenhart, T.M. Simpkins, W.W. Mize, C.W., and Thompson. M.L. 1995. Design and placement of a multi-species riparian buffer strip system. *Agroforestry Systems* 29, 201-226.

Silla, A. J. 2005. Effect of Cattle Grazing on Benthic Macroinvertebrate Communities in the Kalgan River System, south-west Western Australia. B. Sc thesis, University of Western Australia.

Simon, T.P., and Lyons, J. 1995. Application of the Index of Biotic Integrity to Evaluate Water Resource Integrity in Freshwater Ecosystems. In: Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making, Lewis Publishers, Boca Raton, Florida 3: 245-262.

Speiles, D. J., and Mitsch. W. J. 2000. Macroinvertebrate community structure in high- and low-nutrient constructed wetlands. *Wetlands* 20 (4), 716-729.

Strand, M., and Merritt, R.W. 1999. Impacts of livestock grazing activities on stream insect communities and the riverine environment. *Annual Entomology* 45(1),13-29

Tomer, M.D., James, D.E., and Isenhart. T. M. 2003. Optimizing the placement of riparian practices in a watershed using terrain analysis. *Journal of Soil and Water Conservation* 58,198-206.

Vellidis, G., Lowrance, R., Gay, P., and Wauchope. R.D. 2003. Herbicide Transport in a restored riparian buffer system. *Journal of Environmental Quality* 32, 711-726

Viaud, V., Merot, P., and Baudry, J. 2004. Hydrochemical buffer assessment in agriculture landscapes: from local to catchment scale. *Environmental Management* 34, 559-573.

Wilson, J.D., and Dorcas, M.E. 2003. Effects of habitat disturbance on stream salamanders: implications for buffer zones and watershed management. *Conservation Biology* 17,763-771.

The Status of Black Bass, Micsopterus Salmoides in Lake Naivasha, Kenya: What Does the Future Hold?

Jacob.E. Ojuok, James Mugo, George Morara,
Kenya Marine and Fisheries Research Institute (KMFRI), Naivasha, Kenya

Murithi Njiru, Rodrick Kundu
Moi University, Department of Fisheries and Aquatic Sciences, Eldoret, Kenya

Abstract

A study was done to assess growth and mortality of largemouth bass, *Micropterus salmoides,* in Lake Naivasha from commercial length-frequency data collected in 1995, 2001, 2002 and 2003. Length-frequency data analysis was based on the FAO-ICLRAM Stock Assessment Tool (FISAT) software. Catch trend data from 1992 to 2006 was obtained from Fisheries Department. The asymptotic length (L_∞) ranged from 47.6 to 54.8 cm TL, growth curvature (K) from 0.20 to 0.27 yr^{-1}, fishing mortality (F) from 1.41 to 2.02 yr^{-1}, fishing mortality (F) from 1.41 to 2.02, and exploitation rate (E) from 0.73 to 0.80. The lowest and the longest life span (t_{max}) were estimated at 10.60 and 14.34 years. The growth performance of (⊠') was between 2.66 and 2.99. The probability of capture indicated that 50per cent of *M. salmoides* entered the fishery between 16.79 to 22.64 cm TL. Largebass recruited to the fishery throughout the year with a peak between May to August. The landed catch had more than 80 per cent of the individuals attaining maturity status. The highest and lowest annual catch of 26.6 and 4.3 t was in 1993 and 2004 respectively. Even under intense fishing pressure (*E* ranges from 0.73-0.80) in the lake, black bass still attains big sizes, have a long longevity and grows moderately compared to individuals in their native range. This may suggest that the species has adapted well in its new ecosystem, which may be attributed to availabililty of adeaquate food and optimal breeding conditions. However, this stability may be threatened by fishing pressure, degradation of the environment, which disturbs breeding and nursery areas of the species. Measures to sustain the fishery which include; co-management, alternative livelihood and environmental management are discussed.

Key words: *co-management, growth, mortality, diet, and water abstraction*

Introduction

Lake Naivasha is a freshwater lake, approximately 160 sq. kilometres, situated in the eastern rift valley of Kenya. It is shallow, bordered by papyrus, *Cyperus papyrus* L., and the aquatic macrophytes are in a state of flux (Adams *et al.*, 2002). Lake Naivasha fisheries consist of introduction species with variable catch composition determined mainly by fishing intensity, water levels and changing in aquatic macrophyte densities. The mean annual commercial species composition of the fin-fish landed for the period 1987-2000 was dominated by *Oreochromis leucostictus* (Trewavas) 71.1 per cent, *Micropterus salmoides* (Lacépède) 19.5 per cent and *Tilapia zillii* (Gervais) 8.8 per cent (Hickley *et al.,* 2004). Currently there is a shift in composition with dominance of *Cyprinus carpio* (L) 45.7 per cent, *O. leucostictus* 27.2 per cent, *M. salmoides* 16.2, per cent *T. zillii 10.9* per cent in the 2002-2005 commercial catches (J. Ojuok personal communication). The other important fishery in the lake is the introduced Louisiana crayfish, *Procambarus clarkii* (Girard) that is consumed locally and some is exported. Other fish species found in the lake are *Barbus amphigramma* Blgr, and *Poecilia reticulata* Peters.

Largemouth bass has been introduced widely as a game fish and is now cosmopolitan where it is important as in commercial, aquaculture, gamefish and aquaria fisheries (Froese and Pauly, 2002). Largemouth bass was introduced in Lake Naivasha 1940's and 1951 mainly to form a sport fishery (Muchiri, 1990). Several countries report adverse ecological impact after introduction. In Lake Naivasha, *M. salmoides* probably contributed to extinction of the endemic *Aplocheilichthys antinorii* (Vinc.), which was last recorded in 1962 (Muchiri, 1990; Hickley *et al.,* 2004). The species can inhabit clear, vegetated, ponds and swamps, backwaters, pools of creeks and rivers. Adults feed on fishes, crayfishes and frogs, while the young feed on crustaceans, insects and small fishes (Muchiri, 1990; Froese and Pauly, 2002). Feeding and spawning ceases when temperatures fall below 5^0C of above 37 ^{0}C (Froese and Pauly, 2002). Decline in catches led to closure of Lake Naivasha fishery in 2001.

There is no published scientific information available on population characteristics of *M. salmoides* in Lake Naivasha. The aim of this study was to avail information on population characteristics of *M. salmoides* which could be used in its management and understanding of the lake ecosystem.

Materials and Methods

Muchiri *et al.* (1995) gave a detailed description of Lake Naivasha. Length frequency data on *M. salmoides* caught by gillnets was collected five days a week in January to December in 2001 and 2002, and January to May in 2003 from commercial fishery of Lake Naivasha. All commercial fish caught in Lake Naivasha are landed at designated sites where Fisheries Department and Kenya Marine and Fisheries Research Institute personnel record the catches. Experimental gillnetting was done during 2001 closure period using multifilament fleets nets with stretch meshes from 50 mm to 125 mm by increments of 12.5 mm. Nets were set randomly to cover the entire lake as done in the commercial fishery. For each fish caught, total length (TL) of the fish was measured to the nearest cm using a measuring board. Data analysis was based on length frequency distribution analysis (Pauly *et al.*, 1984; Sparre and Venema, 1998). The Electron Length Frequency Analysis (ELEFAN) computer programs incorporated in FAO-ICLRAM Stock Assessment Tool (FISAT) was used to estimate population parameters. The estimate of the growth parameters was based on the von Bertalanffy growth formula (VBGF) (Sparre and Venema, 1998) expressed by the form:

$$L_t = L_\infty (1 - exp(-K*(t - t_o))),$$

Where, L_t is the predicted length at age t, L_∞ is the asymptotic length, K is a growth constant, t_o is the age the fish would have been at zero length. The growth performance index (⊠') was computed as:

$$⊠' = log_{10} K + 2 \, log_{10} L_\infty,$$

Age at time zero or the birthday of the fish was computed using Pauly empirical formula (Pauly, 1980):

$$t_o = -0.3922 - 0.2752 \log L_\infty - 1.038 \log K$$

Total mortality coefficient (Z) was estimated using length-converted catch curve (Pauly *et al.*, 1984). The natural mortality coefficient (M) was estimated following Pauly's empirical formula (Pauly, 1980), linking natural mortality with the von Bertalanffy parameters, K (yr^{-1}), L_∞ (cm) and the mean annual temperature (T °C) of the water in which the fish stock lives (in this case 22°C):

$$log_{10}(M) = -0.0152 - 0.279 * log_{10} L_\infty + 0.6543 \, log_{10} K + 0.463 \, log_{10} T$$

Fishing mortality (F) was computed from the relationship $F = Z - M$, while the exploitation rate (E) was calculated from the relationship $E = F/Z$. Maximum age (t_{max}) was calculated as

$$t_{max} = t_0 + 3/K$$

Where K and t_0 are functions of VBGF as estimated above (Froese and Pauly, 2002). The relative-yield per recruit (Y'/R) was predicted using the Beverton and Holt model as modified by Pauly and Soriano (1986).

$$(Y'/R) = EU^{M/K} * \{1 - ((3U)/1 + m)) + (3U^2/(1 + 2m)) - (U^3/(1 + 3m))\},$$

where (Y'/R) = relative yield (g) per recruit, $m = (1-E)/(M/K)$ and $E=F/Z$, E= the fraction of deaths caused by fishing (exploitation rate), F = fishing mortality per year, Z = total mortality per year, M = natural mortality per year, K = the rate at which length tends towards the asymptote of dimension $1/t$, $U = 1 - L_c/L_\infty$ = length of fish at first capture, L_∞ = the mean length fish would reach if they were to grow indefinitely, L_c is the length at first capture. Plot of (Y/R) was done using a selection ogive which assumes an increasing probability of capture with length (Sparre and Venema, 1998). Data on annual catches of *M. salmoides* were obtained from the Department of Fisheries, Naivasha office.

Results

Population structure

Majority of *M. salmoides* caught ranged from 21 to 29 cm TL, 28 to 36 cm TL, 27 to 36 cm TL, and 26 to 32 cm TL in 1995, 2001, 2002 and 2003 respectively (Figure 1). Fish more that 21 cm TL, regarded as mature consisted 97.96 per cent , 84.67 per cent, 99.59 per cent and 99.98 per cent of the total catch in 1995, 2001, 2002 and 2003 respectively. There were bigger individuals in 2001, 2002 compared to 1995 and 2003, with no fish more than 50 cm TL caught in 1995, wherease there were six, twelve and two individuals in 2001, 2002 and 2003.

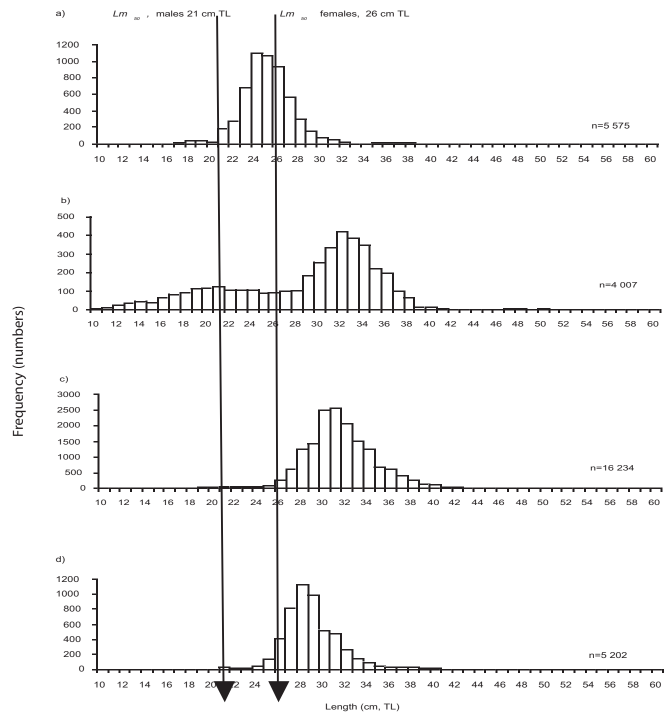


Figure 1. length frequency distribution of *M. salmoidies* in Lake Naivasha, Kenya, a)1995, b) 2001, c)2002, d)2003, n denotes sample sample.

Population characteristics

A summary of population characteristics of *M. salmoides* from Lake Naivasha are represented in Table 1. The lowest and the largest asymptotic length (L_∞) of 47.6 cm TL and 54.8 cm TL were recorded in 1995 and 2003, while the lowest and the highest growth curvature (*K*) of 0.20 yr^{-1} and 0.27 yr^{-1} was recorded in 1995 and 2001 respectively. Total mortality (*Z*) ranged from 1.90 yr^{-1} to 2.55 yr^{-1} recorded in 2001 and 2003 respectively. The lowest and the highest fishing mortality (*F*) of 1.41 yr^{-1} and 2.02 yr^{-1} were recorded in 2001 and 2003. Natural mortality (*M*) was 0.49 yr^{-1} in 1995 and 2001, and 0.58 yr^{-1} in 2002 and 2003. The highest exploitation of 0.80 and the longest life span of 14.34 yrs were recorded in 1995. Growth performance index (Φ’) decreased from 2.81 in 2001 to 2.57 in 2003.

Table 1. Major population parameters for *M. salmoides* from Lake Naivasha

Parameters	Period			
	1995	2001	2002	2003
L_∞ (cm, TL)	47.6	54.5	54.0	54.8
K yr^{-1}	0.20	0.21	0.27	0.24
Z yr^{-1}	2.49	1.90	2.21	2.55
F yr^{-1}	2.00	1.41	1.55	2.02
M yr^{-1}	0.49	0.49	0.58	0.58
E	0.80	0.74	0.73	0.79
L_{50}(cm, TL)	20.61	16.79	21.89	22.64
t_o (*yrs*)	-0.66	-0.62	-0.51	-0.56
t_{max} (yrs)	14.34	13.66	10.60	11.93
_’	2.66	2.80	2.90	2.96

Selection and recruitment pattern

The probability of capture derived from resultant catch-curve indicated that 50 per cent of *M. salmoides* entered the fishery at 20.61, 16.79, 21.89 and 22.64 cm TL in 1995, 2001, 2002 and 2003 respectively (Table 1). Recruitment pattern indicated *M. salmoides* breeds thought the year with one peak (Figure 2). The major recruitment period was in May-September, April-September, April-June and May-June in 1995, 2001, 2002 and 2003 respectively.

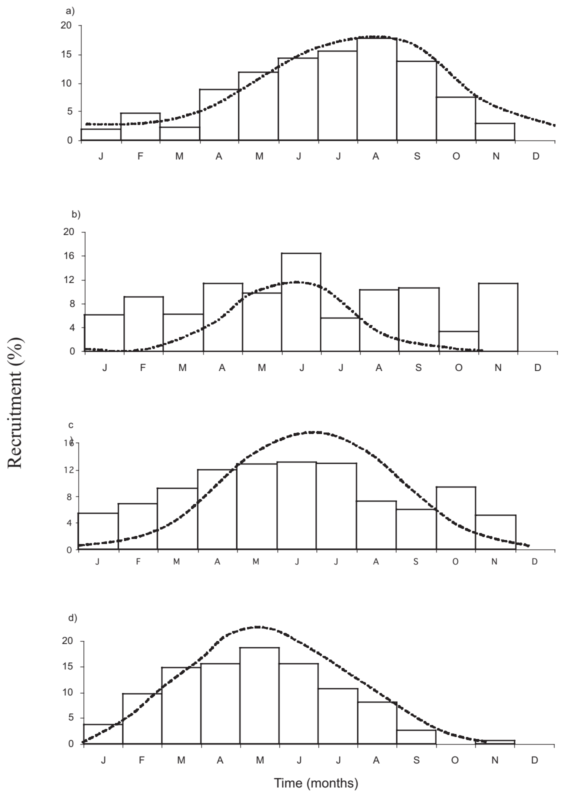


Figure 2: Recruitment pattern of *M. salmoides* in Lake Naivasha, a)1995, b) 2001, c)2002, d)2003,

Discussion

Majority of *M. salmoides* caught in this study ranged from 21 to 36 cm TL (Figure 1) which is length above first maturity of 21 and 26 cm TL for males and females respectively (Ojouk personal communication). The landed catch had more than 80 per cent individuals attaining maturity status and L_∞ increased from 47.6 cm TL in 1995 to 54.8 cm TL in 2003. This indicated that even under the intense fishing pressure (*E* ranges from 0.73-0.80) in the lake, the species attains big sizes which could be attributed to availabililty of adeaquate food in the lake. Largemouth bass feeds mainly on fishes, crayfishes and insects (Froese and Pauly, 2002), whoes food source is not limited in Lake Naivasha (Njiru personal observation). Apart from 1995, the asymptotic length (L_∞) for *M. salmoides* in this study is within the range of the species in other parts of the world (Table 2; Froese and Pauly, 2002). Lower L_∞ in 1995 could be attributed to high exploitation rate (0.80) due to high capacity in the lake by then. In 1995, the number of boats in the lake was around 100 with more than ten gillnets per boat (Ojuok personal communication). The number of fishers and gears reduced drastically after the 2001 fishing ban in the lake. The recommended boats were reduced to 45, each with 10 gillnets of 4 inches (127mm) and this probably led to recovery of the fishery and attainment of L_∞ of 54.8 cm TL in 2003.

Table 2. Growth parameters for *M. salmoides* from various waters bodies in the world, Source: Froese and Pauly (2002)

	Parameters		
L_∞ (cm, TL)	K yr^{-1}	_’	Country
50.5	0.31	2.76	Japan
51.0	0.28	2.87	Italy
57.3	0.28	2.96	Italy
53.5	0.30	2.93	New Caledonia
56.0	0.19	2.78	Canada
51.0	0.36	2.97	USA
62.5	0.28	3.04	USA
66.6	0.21	2.97	USA
71.6	0.11	2.75	USA
91.1	0.08	2.82	USA
126.0	0.06	2.98	USA

The growth rate (K) of 0.21 to 0.27 yr^{-1} shows that *M. salmoides* grows moderately in Lake Naivasha compared to 0.31 yr^{-1} or 0.36 yr^{-1} in USA its native range (Table 2; Froese and Pauly, 2002), suggesting that the species has adapted well in its new ecosystem. The growth performance of (⊠’) of between 2.66 to 2.99 is high. Genetic make up, fishing regime and diet type may determine growth potential of a species (Ssentongo and Welcomme, 1985). Increased fishing pressure results in reduction of the average size and faster growth rate. Intense fishing of the species is confirmed by high exploitation rate (E), which ranged from 0.73 to 0.80 (Table 1). Unlike most tropical fish stocks where recruitment occurs throughout the year with two peaks corresponding to the rainy seasons (Froese and Pauly, 2002; Njiru *et al.* 2005), *M. salmoides,* has maintained one peak spawning period between May to August similar to its native environment in the USA. Spawning of *M. salmoides* peaks between May to August in the USA and March to June in France and (Froese and Pauly, 2002).

Despite attainment of large sizes, the fishery of *M, salmoides* could be threatened if measures put in place for the sustainability of the entire Lake Naivasha fishery are not adhered to. Fishers have continued to use more than 10 nets per boat and poacher's set gillnets of less than 4" in the nearshore areas, which are fish breeding and nursery grounds. Illegal catch is landed late at night when fisheries personnel are not on duty. Continued increase in capacity will lead to reduced catches, capture of immature fish and fishers will further reduce their mesh size and resort to unorthodox fishing to target the smaller fishes. To sustain the fishery, the recommended 45 boats, ten nets per boat, gillnets of 127mm mesh size should be enforced. In addition, the registration of boats should include licensing of nets to reduce their numbers. To succeed in enforcement the entire Lake Naivasha stakeholders should be involved. Community base monitoring, control and surveillance should be given priority because the fisheries department lacks the personnel and is ill equipped. Co-management if successful would drastically reducing use of illegal gears and curb poaching on the lake. Fish landed should be sold through co-operatives societies to improve returns to the fishers. Alternative livelihood, such as aquaculture, ecotourism and farming, should be encouraged to reduce pressure on the lake fishery. About $^1/_3$ of the average inflow of the major river is abstracted by Olkaria Geothermal power station and flower farms (Lake Naivasha Hydrological and Environmental Studies (2005). Water abstraction leads to reduction in water levels affecting the wetlands the feeding and nursery grounds for *M. salmoides.* The relevant government bodies ought to limit water abstraction from the lake by regulating the amount taken by different users.

References

Adams, C.S. Boar, R. R., Hubble, D.S., Gikungu, M., Harper, D.M. and Tarras-Wahlberg N. 2002. The dynamics and ecology of exotic tropical floating plant mats: Lake Naivasha, Kenya. *Hydrobiologia* 488, 115-112

Froese, R. and Pauly, D. 2002. Fish base. A checklist of fresh water fish of Africa (CLOFFA). World-wide web electronic publication. Brussels, ORSTOM Paris Vol. 4.

Hickley, P., Muchiri, S. M., Britton, J. R. and Boar, R. R. 2004. Discovery of carp, *Cyprinus carpio,* in already stressed fishery of Lake Naivasha, Kenya. *Fisheries Management and Ecology* 11**,** 139-142.

Hickley, P. and Harper, D.M. 2002. Fish community and habitat changes in the artificially stocked fishery of Lake Naivasha, Kenya, p 242-254. In *Management and Ecology of Lake and Reservoir Fisheries.* Cowx I.G (Ed.) Oxford. Fishing News Books, Blackwell Scientific publications.

Hickley, P., Bailey, R.G., Harper, D.M., Kundu, R., Muchiri, S.M., North, R. and Taylor, A. 2002. The status and future of the Lake Naivasha fishery, Kenya. *Hydrobiologia* 488**,** 181-190

Lake Naivasha hydrological and environmental studies 2005. International Institute for Geo-Information and Earth Information http://www.itc.nl

Muchiri, M. 1990. The feeding ecology of tilapia and the fishery of Lake Naivasha, Kenya. Ph.D Thesis, University of Leicester, UK 233 p.

Muchiri, S.M., Hart, P.J.B. and Harper, D.M. 1995. The persistence of two introduced tilapia species in Lake Naivasha, Kenya, in the face of environmental variability and fishing pressure. p 299-319. In *The impact of species in Africa lakes.* Pitcher, T.J. and Hart, P.J.B (Eds). Chapman and Hall, London.

Njiru, M., Budeba, Y. and Wandera, S. B. 2005. Reproduction and growth of commercially important fish species. In *The state of the fisheries Resources of Lake Victoria and their Management. The state of the fisheries Resources of Lake Victoria and their Management*. *Proceedings of the regional stakeholders' Conference*. p 85-96. Imperial Resort Beach Hotel, Entebbe 24th -25th Feb. 2005. LVFO Secretariat, Jinja, Uganda.

Pauly, D. 1980. On the interrelationship between natural mortality, growth parameters, and mean environmental temperature in 175 fish stock**.** *J. Cons. Int. Explor. Mer*. 39 (3), 175-192 .

Pauly, D. and Soriano, M. L. 1986. Some practical extensions to Beverton and Holt's relative yield-per-recruit model. In *The first Asian Fisheries Forum.* Maclean, J.L., Dizon, L.B., Hosillos, L.V. (Eds). p 491-496. Asian Fisheries Society, Manila , Philipines,.

Pauly, D., Ingles, J. and Neal, R. 1984. Application to shrimp stock of objective methods for the estimation of growth, mortality and recruitment related parameters from length frequency data (ELEFAN I and II). p 220-234. In *Panaeid shrimps- their ecology and management*. Gulland, J.A. and Rothschilds B.J. (Eds). Fishing News Books. Surrey, England.

Ssentongo, G. and Welcomme G. L. 1985. Past History and Current trends in the Fisheries of Lake Victoria, FAO Fisheries Report 335, 123-138

Sparre, P. and Venema, S. C. (998. Introduction to tropical fish stock assessment. Manual Part 1. *FAO Fisheries Technical Paper* no 306. 376p.

An Assessment of Age and Growth of the Baringo Tilapia (Oreochromis Niloticus Baringoensis) from Lake Baringo, based on Otolith Counts

Chrisphine S. Nyamweya, Chrisestom M. Mlewa and Charles C. Ngugi
Department of Fisheries and Aquatic Sciences, Moi University, Eldoret, Kenya

Abstract

The endemic Baringo tilapia *Oreochromis niloticus baringoensis* has a long history of commercial exploitation in Lake Baringo. However, its catches are characterized by fluctuations, leading to periodic closures of the fishery during seasons of low catch. Age and growth data are important for sustainable management of a fishery, but are lacking for species exploited in Lake Baringo. The present study used otolith analysis technique to determine age and growth of the species. Age was validated using oxy-tetracycline marking, and direct validation with fish of known age, which confirmed that one circuli (a single growth increment), was formed daily. The number of circuli was significantly correlated with length of fish. Gulland-Holt, and von Bertalanffy plots were used to derive age and growth parameters: K, L_∞ and t_o. The derived von Bertalanffy parameters indicated that *O. niloticus* had a growth rate (K) of 0.1432 per year, achieving an asymptotic length (L_∞) of 35.51 cm. The derived low K and high L_∞ values suggest that the species is long-lived and slow growing making its stocks vulnerable to overexploitation. Thus, there is need to reduce fishing pressure and regulate gill net mesh size, so as to realize increase in both size and number of the fish landed.

Key words: *Age, growth, circuli, otolith, and validation*

Introduction

Age and growth information is essential in almost every aspect of fisheries science. Growth provides an integrated assessment of environmental and endogenous conditions (Dervies & Frie, 1996) affecting a fish, and therefore is a useful metric with which to evaluate habitat suitability, prey availability, or the effect of management activities on a target species (Gjerde, 1986). This study determined age and growth parameters of the endemic tilapia *Oreochromis niloticus baringoensis* Trewavas 1983, using the otolith analysis technique. The species has a long history of commercial exploitation in Lake Baringo. In the 1960's, the fishery production ranged from 500 – 600 mt per annum but declined to less than 200 mt per annum by late 1980's (Hickley *et al.*, 2004). Since then, the catches have been characterized by fluctuations, leading to periodic closures of the fishery during seasons of low catch. As *O. n. baringoensis* dominates Lake Baringo catches, there is need to obtain data on its age and growth for input to management of the fishery.

Materials and Methods

Study area

Fish samples were obtained from Lake Baringo (Fig. 1), one of the seven inland drainage lakes in the eastern arm of the Rift Valley, Kenya (Beadle, 1932). The lake is located in the administrative district of Baringo. It is a shallow fresh water lake lying between 0° 32' and 0°45' N, 36° 00' and 36° 10' E at an altitude of 975 above sea level (Ssentongo, 1974) with a surface area of approximately 137 sq. kilometres (Mlewa *et al.*, 2005). However, both the water level and surface area have been fluctuating over the years. According to Onyando (2003), the surface area of the lake was 219 sq. kilometres in 1976, 136 sq. kilometres in 1986, and 114 sq. kilometres in 1995 and 108 sq. kilometres in 2001. Onyando (2003) further documented that in 1969 – 1972 the average depth was eight metres while in early 2003, the average depth was 1.7 metres, before the onset of rains. The lake has no surface outlet and its "freshness" is attributed to an underground spring at its northern end (Beadle, 1932).

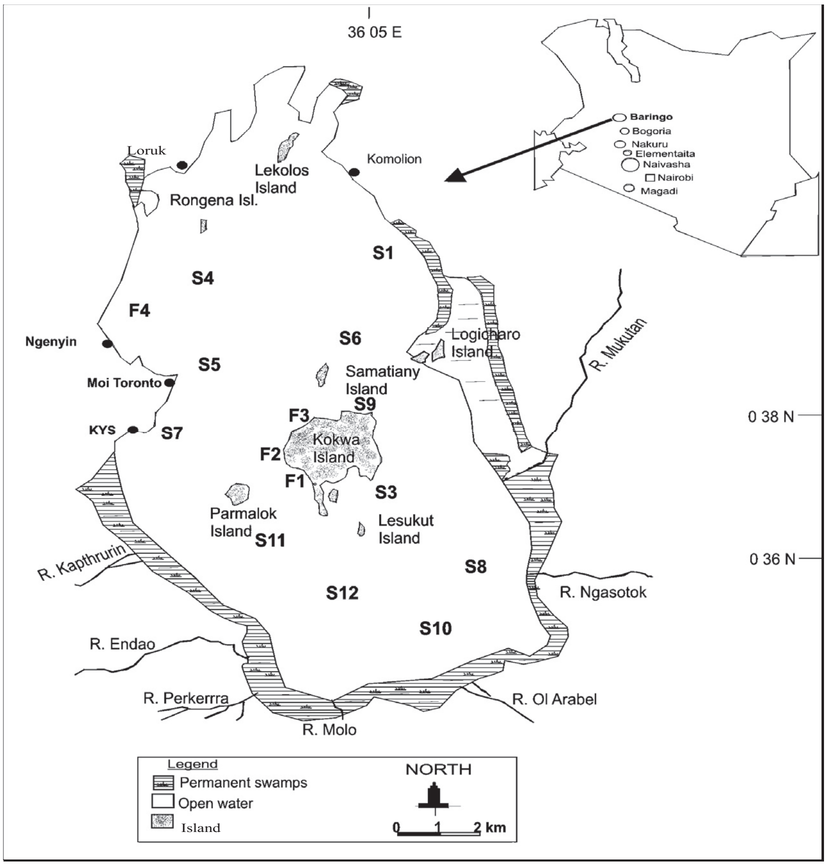


Fig 1: Map of Lake Baringo, showing experimental fishing sites (F), water sampling sites (S) and major fish landing sites

Collection of fish samples

Fish samples were obtained from both experimental fishing and commercial catches during August and October 2007. Experimental fishing involved beach seining at three sites of the shores of Ol Kokwa Island whereas commercial catch samples obtained from landings at the Moi-Toronto, KYS and Ngenyin fish landing sites. Experimental fishing sites were selected in inshore areas, where juvenile fish were expected to be abundant. Each fish was assigned a serial number; total length measured (TL ± 0.1 cm) and weighed (± 0.1g) on a top loading electronic balance.

Otolith extraction and processing

Lapilli otoliths were removed by dissecting the head and opening the otic bulla from under the operculum. Each otolith was mounted using clear nail paint on a serially labeled microscope slide. Mounted otoliths were then observed under an inverted LEICA DM IRB microscope (under ×40 magnification) connected to a computer and their images of otoliths acquired using IM500 software. These images were used to determine areas and radii of otoliths. Circuli were counted under ×40, ×100 or ×200 magnification (Plate 1). Unclear otoliths were ground gently using a fine grinding paper to improve clarity of circuli.

Validation of growth ring formation

Validating counts obtained from otoliths is the confirmation of the temporal meaning of an increment (Dervies & Frie, 1996). We used two procedures: 1) the otolith marking and 2) direct validation. Nine fish were immersed in 25 mg OTC kg^{-1} for a period of 30 minutes. The fish were then kept in tanks for four days. On the fourth day, all surviving fish were sacrificed by stunning them with a blow on the head. Circuli outside OTC mark were counted. Direct validation used 10 specimens of *O. niloticus* aged 34 days obtained from the Chepkoilel Fish Farm. Circuli on their lapilli otoliths were counted. The observed number of circuli was compared to the actual ages. A Chi-square was used test if there were significant differences in observed and actual ages in both procedures.

Data analyses

Length- weight relationship was described by the power relationship: $W = aL^b$; where W is weight, L is length; and *a* and *b* are constants. The von Bertalanffy growth function (VBGF) was fitted to observed length-at-age data using non-linear least squares estimation procedures. The VBGF is defined by the equation: $L_t = L_\infty \{1 - \exp[-k(t-t_0)]\}$, where L_t = length at age; L_∞ = asymptotic length; k = growth coefficient and defines growth rate towards L_∞; t = age of the fish; and t_0 = the hypothetical age at which fish would have zero length if it had always grown in a manner described by the equation. The growth parameters L_∞ and k were obtained from the Gulland-Holt and VBGF Plots (Gulland, 1983). The K and L_∞ values are not normally comparable in different studies, however, linking the two parameters gives comparable index, phi-prime (Ø'), described by the equation: $Ø' = \ln K + 2*\ln L_\infty$.

Results

A total of 150 fish samples distributed over a TL range of 2.9 – 21.0 cm (mean = 11.96 cm ± 0.55 SE) were used for analysis. *O. n. baringoensis* had strong length-weight relationships with an r^2 value of 0.9540. The length-weight relationship was described by the equation: $W = 0.0190TL^{2.8071}$. The determined *b* value was compared with the mean exponent value of 3.00072 (t – test, $P < 0.05$).

All nine fish that were immersed in OTC survived up to last day of experiment. Fluorescent bands were observed in all otoliths of marked fish; they were more distinct in small otoliths than in big otoliths. A Chi-square indicated no significant difference in duration of rearing after introducing OTC and number of circuli after the OTC mark ($\chi^2 = 0.692$, df = 1, $P = 0.405$). According to the Farm Manager the *O. niloticus* samples used for direct validation were 30 days old. A Chi-square showed that there was no significant difference in actual age and number of circuli on otoliths ($\chi^2 = 0.007$, df = 1, $P = 0.935$). Both direct validation and otolith marking results showed that one increment was formed per day on the fish otoliths.

Otolith images showed distinct alternating dark and light bands of narrowly spaced circuli that were easily counted to provide age of fish in days. Both TL and SL showed significant ($P < 0.05$) strong positive linear relationships with age of fish (Fig. 2). The relationships were described by the equations: $TL = 0.1187t + 1.1344$, $r^2 = 0.97$ and; $SL = 0.0964t + 0.7082$, $r^2 = 0.97$. Most of the fish samples (67) were aged between 20 - 50 days old, 40 fish were aged between 51 - 120 days old while 34 fish were aged over 120 days. The slope of length-age regression gave an average growth rate of 0.1187 day^{-1} for the species. Weight and age of fish showed significant ($P < 0.05$) power relationships with the relationship being stronger in fish with ages below 60 days but weaker in those older than 60 days as indicated by the scatter of points about the trend line (Fig. 3).

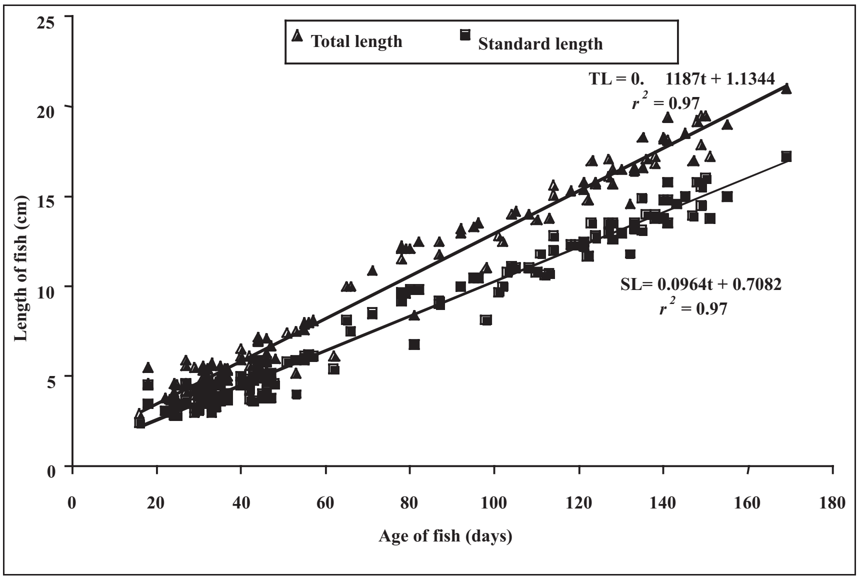


Fig 2: Relationship between length and age of *O. n. baringoensis* estimated from lapilli otoliths

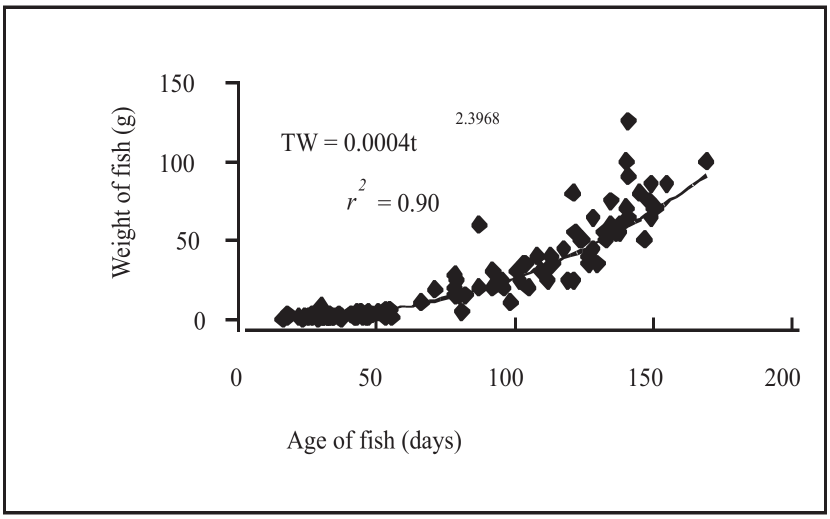


Fig 3: Relationship between weight and age (t) of *O. n. baringoensis* samples collected from Lake Baringo estimated from otoliths.

Figure 4 shows that the area of *O. n. baringoensis* lapilli otoliths was related to age by the equation: $A_o = 30637t + 217434$, $r^2 = 0.56$. Though significant ($P < 0.05$), the relationship was not so strong. When the von Bertalanffy growth curve was fitted to lengths-at-age, the results showed that *O. n. baringoensis*, a growth rate (K) of 0.1432 $year^{-1}$ with an asymptotic length (L_∞) of 35.51 cm while the derived Ø' for the species was 5.196 (Table 1).

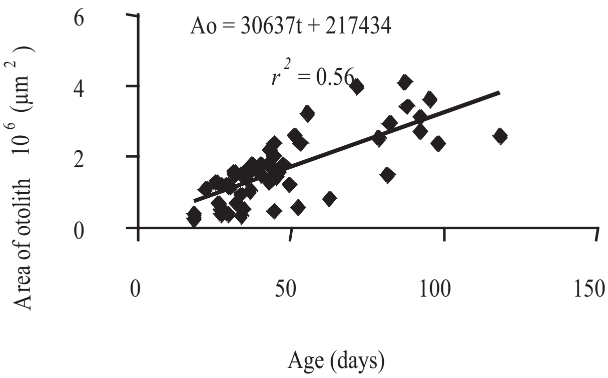


Fig 4: Relationship between the area, A_o, of otolith and the age in days of *O. n. baringoensis* samples collected from Lake Baringo in August and October 2007

Table 1: Growth parameters derived for the von Bertalanffy growth function, Ø' and population characteristics *O. n. baringoensis* **from Lake Baringo**

Parameter (units)	Parameter value
N	150
L_∞ (cm)	35.51
K ($year^{-1}$)	0.1432
t_o	-0.189
TL_{mean} (cm)	9.89
TL_{min} (cm)	2.9
TL_{max} (cm)	21
t_{mean} (cm)	0.2
t_{min} (cm)	0.04
t_{max} (cm)	0.46
$Ø' = \ln K + 2*\ln L_\infty$	5.196

Discussion

The two validation procedures confirmed that one circulus was formed daily on fish otoliths as indicated by the non-significant difference in observed and actual ages of fish. However, some fish deposited less than one increment per day, which can be attributed to presence of unresolved circuli. Fowler (1995) also reported that a single circuli is formed daily on fish otoliths while Al-Husaini *et al.* (2001) observed that circuli deposited in captivity are usually of low visual contrast and sometimes are difficult to discern. The estimated *b*, of 2.8071, was within the range of 2.5 to 3.5 suggested by Pauly and Gayanilo (1997). This value indicated that the species exhibits negative allometric growth, contrary to Britton & Harper (2006) who reported isometric growth for the same species in the same lake. Differences in size range of samples could have been responsible for the disparity in results of the two studies. Our study targeted juvenile fish, unlike the study by Britton & Harper (2006). However, the difference in the type growth probably reflects periodic variations in environmental conditions and primary production and secondary production that routinely occur in Lake Baringo.

Lapilli otoliths were found to be the clearest and easy to read. Although some authors have aged tilapia using their sagittal otoliths (Jacques & Javier, 2001), their thickness in adults makes it very difficult to read circuli under transmitted light without sectioning or polishing them. In another study, Rosa & Ré (1985) found that sagittae in juvenile *Tilapia mariae* were too thick to allow observation of the circuli. All examined samples were aged between 16 – 169 days suggesting they were in their first year of growth. The age of fish showed a significant positive linear relationship with fish length (Figure 2). This finding was not surprising since the study targeted juvenile fish, whose growth rates are usually high. This relationship indicates that monitoring of the age composition of the catches in the Lake Baringo fishery can in future be done from random samples of fish length in the population. This because length-age relationship showed high r^2 values and length could be easy to measure.

The linear relationship between otolith area and fish age indicates that otoliths continuously increase in area with increasing age, an observation also made by Mendoza (2006). The continuous growth of the *O. n. baringoensis* otoliths with increasing age is likely to be independent of somatic growth. The dependence of otolith area on temporal scales directly signifies that otolith size (area) can be confidently used as a substitute for circuli in determining fish age. Unlike length, weight showed a positive power relationship with age of fish (Figure 3). However, this relationship is not reliable as compared to that of length-age as weight of an individual fish can vary greatly in a short duration depending on feeding patterns (Pitcher & Hart, 1994).

The growth index Ø' of 5.20 determined from the growth parameters was somewhat different from the ones determined elsewhere. For instance Gomouez (1999) determined Ø' of *O. niloticus* to be 4.09. The apparent difference is probably because the species aged in the present study is endemic to Lake Baringo and its growth can only be compared to other sub species elsewhere. The estimated growth parameters suggested that the species is slow growing. The relatively slow growth rate exhibited by the Lake Baringo population suggests that fish stock cannot sustain high harvest rates. Our observation during the present study indicated that the largest fish in commercial catches were much smaller than the predicted maximum achievable sizes implying that the exploitation strategies in the lake do not allow fish to attain big sizes. In addition, the capacity of fishers in this fishery to harvest small sized fish (Mlewa & Green, 2006) makes them especially susceptible to over-exploitation. This is supported by the fact that some samples for this study from commercial catches were aged less than two months old. Therefore the level of exploitation of the species in Lake Baringo needs to be carefully monitored. Moreover, the degree of survival of survival of fish below the minimum legal gillnet mesh size of 3.5 cm, needs to be investigated and considered in future assessments.

In conclusion our study demonstrated that circuli were present on lapilli otoliths of *Oreochromis niloticus baringoensis*. Otolith marking and direct validation procedures showed that one growth increment is formed on fish otoliths each day. Estimated growth parameters showed that the species were slow growing and long-lived. Otolith size was found to be the best predictor of age when compared to length and weight. However, at younger ages, fish length is an adequate predictor of age, hence its adoption for the VBGFs.

References

Al-Husaini, M., Al-Ayoub, S. & Dashti, J. (2001) Age validation of nagroor, *Pomadasys kaakan* (Cuvier, 1830) (Family: Haemulidae) in Kuwaiti waters. *Fish. Res.* **53**, 71-81.

Beadle, L. C. (1932) The waters of some East African lakes in relation to their fauna and flora. *J. Linn. Zool. Soc.* **38**, 157-211.

Britton, J. R. & Harper, D. M. (2006) Length-weight relationships of fish species in the freshwater rift valley lakes of Kenya. *J. Appl. Ichthyol.* **22**,334-336.

Devries, D. R. & Frie, R. V. (1996) Determination of age and growth. In: *Fisheries techniques* 2nd ed. (Eds. B.R. Murphy & D.W. Willis), pp. 483-512. ASF, Bethesda, Maryland.

Fowler, A. J. (1995) Annulus formation in otoliths of coral reef fish. A review. In: *Recent Developments in Fish Otolith Research* (Eds. D.H. Secor, J.M. Dean, S.E. Campana & A.B. Miller) pp. 45-63. University of South Carolina Press, Columbia SC.

Gjerde, B. (1986) Growth and reproduction in fish and shellfish. *J.Aquacult.* **57**, 37-55.

Gomouez, M. (1999) Age and growth of *Oreochromis niloticus* (Percifomes: cichlidae) in Mexico. *Rev. Trop. Biol.* **46** (4),

Gulland, J. A. (1983) *Fish stock assessment*. A Manual of Basic Methods. New York; Wiler.

Hickley, P., Muchiri, M., Boar, R., Britton, R., Adams, C., Gichuru, N. & Harper, D. (2004) Habitat degradation and subsequent fishery collapse in Lakes Naivasha and Baringo, Kenya. *Ecohydrol.& Hydrobiol.* **4**, 503-517.

Jacques, P. & Javier, T. (2001) Validation of age estimation and back-calculation of fish length based on otolith microstructures in tilapias (Pisces, Cichlidae). *Fish. Bull.* **99,** 139-150.

Maclellan, S. E & Fargo, J. (1995) Validation of Age for English Sole (*Parophrys vetulus*) in Hecate Strait, British Columbia. In: *Recent Developments in Fish Otolith Research*, no. 19 (Eds. D.H. Secor, J.M. Dean & S.E.Campana), pp.341-355. The Bella W Baruch Library in Marine Science.

Mendoza, R. P. R. (2006) Otoliths and their applications in fishery science. Ribarst., **64**, 89-102. Mlewa, C. M.; Green, J. M. (2006) Translocation of marbled African lungfish *Protopterus aethiopicus* (Telostei: Protopteridae), and its fishery in Lake Baringo, Kenya. Afr. J. Aquat. Sci. **31,** 131-136.

Mlewa, C. M., Green, J. M. & Simms, A. (2005) Movement and habitat use by the marbled African lungfish *Protopterus aethiopicus* Heckel 1851 in Lake Baringo, Kenya. *Hydrobiol.* **537**, 229–238.

Onyando, J. O. (2003) Soil erosion hazard assessment of River Perkerra Catchment. *Consultancy Report Submitted to UNOPS.*

Pauly D, Gayanilo Jr. F. C. (1997) A Bee: An alternative approach to estimating the parameters of a length-weight relationship from length-frequency samples and their bulk weights. NAGA ICLARM, Manila, Philippines.

Pitcher,T. J. & Hart, J. B. (1994) The structure of Fish Populations in Space and time. In *Fisheries Ecology*, pp. 77-108. Chapman and Hall, London,

Rosa,, H.C. & Ré P. (1985) Influence of exogenous factors on the formation daily microgrowth in otoliths of *Tilapia mariae* (Boulenger, 1899) juveniles. *Cyb.* **9,** 341-357

Ssentongo, G. W. (1974) On the fishes and fisheries of Lake Baringo. *Afr. J. Trop. Hydrobiol. Fish.* **3,** 95-105

The Feeding Ecology of the Commersonn Anchovy, Stolephorus Commersonnii (Engraulidae: Lacepede, 1803), ffrom Coastal Kenya

The Feeding Ecology of the Commersonn Anchovy, Stolephorus Commersonnii (Engraulidae: Lacepede, 1803), From Coastal Kenya

Mweruti Abigael Nyansarora, Boaz Kaunda-Arara

Moi University, Department of Fisheries and Aquatic Sciences, Eldoret, Kenya

James Mwaluma

Kenya Marine and Fisheries Research Institute, Mombasa, Kenya.

Abstract

Studies on feeding habit of fishes are important in understanding trophic interactions between species and population flux, but are scarce especially for pelagic marine fish species in the Western Indian Ocean. This study describes, for the first time, the seasonal, ontogenic and, spatial variation in diet of the commersonii anchovy, *Stolephorus commersonnii*, one of the commercially exploited pelagic fish species along the Kenyan coast. Stomach contents were examined in 727 specimens collected monthly between September 2005 and January 2007) from backreef, inshore and offshore sites across the Malindi Marine Park (MMP). Results indicate seasonal variation in feeding intensity and composition of the diet. Feeding activity and diversity of food items increased with increasing size of specimens. The frequency of occurrence, composition and abundance of food items varied between sites at small spatial scales. Comparison of prey abundance in stomachs with their availability in the environment indicated that the species is a selective feeder.

Key words: *Stolephorus commersonnii, stomach contents, prey importance, feeding habit, marine fisheries*

Introduction

The global contribution of anchovies to commercial fish landings is significantly high (Mohanty, 2006). Once they were among the most abundant harvestable fish in the world (Bewa, 2001). In Kenyan coastal waters, the genus *Stolephorus* is the most abundant anchovy landed in the artisanal fishery (Fisheries Department, unpublished data). It is mainly exploited for fishmeal of which a significant fraction is consumed locally. The species is also important in the trophic structure of the pelagic ecosystems, operating at the crucial 'wasp-waist' trophic level (Cury *et al.*, 2000) where one to several small plankton-consuming nektonic species tend to dominate the trophic transfers, as opposed to much greater numbers of species involved at higher and lower trophic levels.

Studies of the feeding habits of anchovies are important in understanding their ecology and population dynamics necessary for stock management. Availability of prey items of sufficient quality and quantity may affect growth, reproductive output and abundance of fishes (Wooton, 1992). This study aimed at generating data on the feeding ecology of *Stolephorus commersonnii*, the most important pelagic fish species on the Kenyan coast.

Materials and Methods

Study area

The study was carried out at the Malindi Marine Park (MMP) from September 2005 to January 2007 inclusive. The park has an area of 6.3 sq. kilometres and was created in 1968. Samples of *Stolephorus commersonnii* were obtained from three sites across the park namely: Inshore, Backreef and Offshore (Figure 1). The sites differ in their level of protection, depth, water movement and topographic complexity. The Inshore site (1) is a shallow (1-2m, low tide) lagoon within the park. The substrate at the site is composed of live corals, sea grass beds and sand. The Backreef site (2) is on the sheltered side of the Leopard reef (Fig. 1). It is much deeper than site 1, with a depth range of 3-10 metres at low tide. It is bisected by a channel (Stoke Passage) with high currents. The substrate is mainly seagrass beds. The site is about 500 metres from site 1. The Offshore site (3) is more exposed to the wind action and the open sea. It is a reef platform on the windward side of the Leopard reef (Fig. 1) the depth ranges from two metres to greater depths on the open sea. It has less coral cover and most of the substrate is sand. The site is about one kilometre from the shore.

Figure 3. Malindi Marine Park and the Sampling site; 1 – Inshore, 2 – Backreef and 3 – Offshore sites

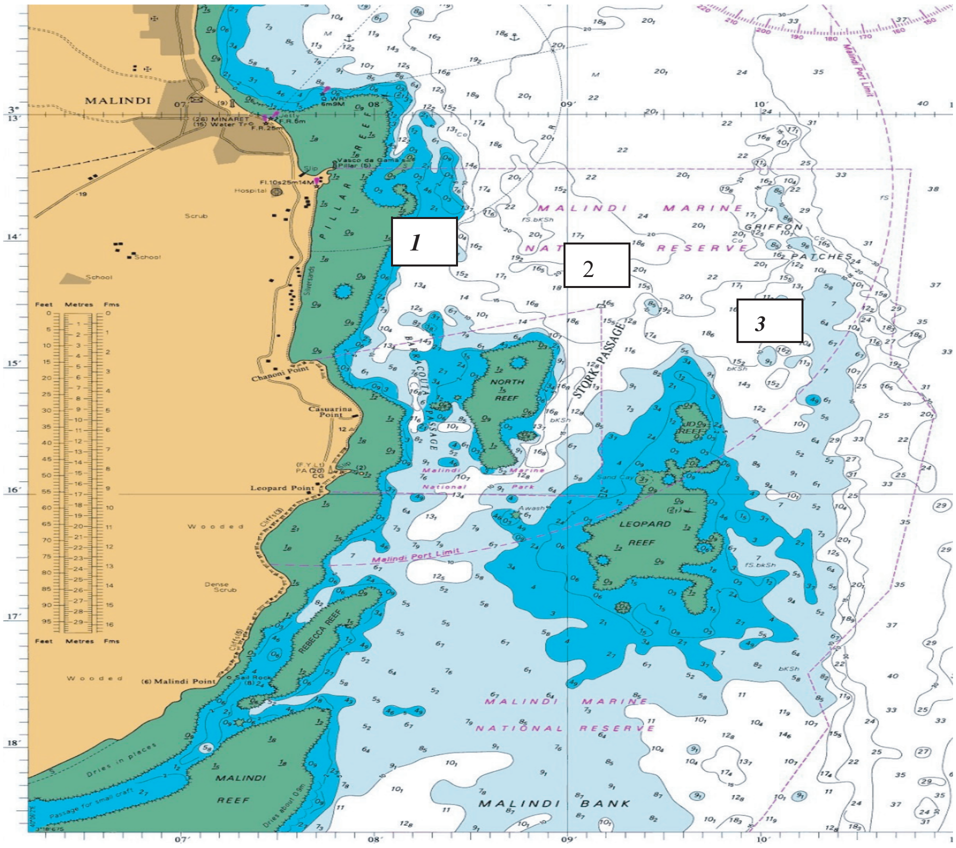


Fig. 1: Map of the study area

Fish sample collection

Samples of *Stolephorus commersonnii* were collected using light-traps (Kaunda-Arara *et al,* 2008). A total of three to five traps were deployed at the sampling sites and left to fish overnight for a period of twelve hours from dust to dawn. The traps were alternated between the sites each night. They caught a mixture of pre-settlement larvae and mixture of juvenile and adult pelagic fishes including *Stolephorus commersonnii.* The *S. commersonnii* specimens caught at each site were sorted and preserved in five per cent formalin for laboratory analysis. Sample Analysis

Preserved fish specimens were measured for total length (TL) and the standard length (SL) to the nearest 0.1 cm using Vernier calipers and weighed (BW) to the nearest 0.1g on an electronic balance. Each fish was disccested and the anterior third of the gut was removed and weighed. Stomach contents were then emptied into a Petri dish, stirred and the content identified to the lowest possible taxon under a dissecting microscope. To estimate selectivity, food items were also collected from the environment using plankton nets from each sampling site.

Data analysis

The fish samples were grouped by size, site, and season. The frequency of occurrence (%F) and the numerical abundance (%N) of the food items in the different size classes, site and season were derived following Hyslop (1980) as: % F = number of stomachs with a food item$_i$ /total number of stomach examined *100, and % N = number of food item$_i$ /total number of all food items*100.

To obtain information on the feeding activity of fish, the percentage of empty stomachs was calculated as Vacuity Coefficient = number of empty stomachs/total number of stomach examined. Feeding intensity of individual fish was derived from the Stomach Content Index (SCI) (Berg, 1979) as: SCI=SCW/ BW*100; where SCW is the wet weight of the stomach contents (mg) and BW is the wet bodyweight (mg) of the specimens. The Shorigin Index (K) index was derived for the food items to evaluate seasonal food selectivity as:

$$K = \frac{\%\ N \text{ in the ingested food}}{\%\ N \text{ in the potentially available food}}$$

Results

Prey composition in fish stomachs

A total of 727 stomachs were analyzed for stomach contents of which 55.3 per cent had some food. Most (75.5%) fish items found in the stomachs were partly or fully digested and could not be identified. Wet weight of stomach contents was variable depending on fish size, ranging from 0.1g to 5.1g. The maximum weight of stomach contents of fish increased with increasing *BW.*

A total of twelve prey taxa were identified in stomachs from the three sites. The frequency of occurrence in Table I show the main prey taxa in the stomachs as amphipods, copepods, mollusc larvae, cumeceans, isopods and carideans. The molluscs dominates the stomachs of the specimens by 24.4 per cent followed by the amphipods (20.1 %), copepods (15.1 %), isopods (5.8 %), carideans (5.5 %), ostracods (3.9 %) and others (stomatopods, carprellids, mysida and sipuriculids) that appear in small quantities. Only a few of these prey taxa were numerically important in the diets of *S. commersonnii* fish (Table 1). In spite their low frequent of occurrence in most of the stomachs examined, hyperids and bivalves larvae were numerically the most dominant in the diet together with calanoids and carideans.

Table 1: Numerical percentage (%N) composition and frequency of occurrence (%F) of the food item consumed by *Stolephorus commersonnii* in MMP, Kenya

Ta xa	%N	%F
Copepods	**23.2**	**15.1**
Calanoids	15.2	5.5
Cyclppoids.	4.6	5.1
Harpacticoids	6.4	4.5
Ampipods	**26.6**	**20.1**
Hyperids	19.1	12.9
Gammarids	7.5	7.2
Isopods	6.2	5.8
Cumaceans	3.5	2.9
Carideans	10.4	5.5
Molluscs	**21.6**	**24.4**
Gastropod larvae	3.4	4.8
Bivalve larvae	10.7	14.0
Crab Zoea	7.5	5.6
ish Larvae	**0.1**	**1.1**
stracods	**4.2**	**3.9**
Stomatopoda	**0.8**	**0.4**
Carprellids	**0.1**	**0.1**
Mysids	**0.1**	**0.1**
Sipuriculids	**0.1**	**0.3**

Size and Seasonal variation in feeding intensity

Mean SCI between the seasons was insignificantly different at p = 0.05, ⊠ = 0.103. The classes that fed on the highest diversity of food items were 6.1-7.0 and 7.1-8.0cm (Figure 2B**).** The small sized fish, 4.1-5.0cm and 5.1-6.0 had a lower diversity of prey items. The food items cyclopoids, isopods, hyperids and bivalves dominated the stomachs of the smaller sizes of fish, while the larger sized fish mostly fed on carideans, calanoids and and hyperids.

Spatial and seasonal variation in diet

During the NEM season, the diet of fish in the backreef site was numerically dominated by calanoid copepods, bivalve larvae and carideans (Table 2). Carideans dominated the diet (23.4%) of fish caught in the inshore site. On the contrary, gammarids (28.4%) and bivalve larvae (21.6%) were more dominant in the stomachs of fish from the offshore site. During the SEM season, hyperids (28.6%) and harpacticoid copepods (22.9%) dominated the stomachs of fish from the backreef site. At the inshore site isopods (32.4%), Crab zoea (23.5%) and gammarids (17.7%) dominated the diet of Stolephorus commersonnii. B

During NEM mollusc larvae occurred most frequently (12%) in all the three sites (Table 4). The isopods (6.8%) and hyperids (7 %) occurred in most stomachs at the backreef and inshore sites. The offshore site had low diversity of food items. During the SEM season, samples from the offshore sites were absent. Mollusc larvae had the highest frequency of occurrence 13.7 per cent and 1.4per cent at backreef and inshore sites respectively.

Table 2: The % N of the major food items in the stomach contents of Stolephorus commersonnii from different sites of MMP during the NEM Monsoon and SEM Monsoon

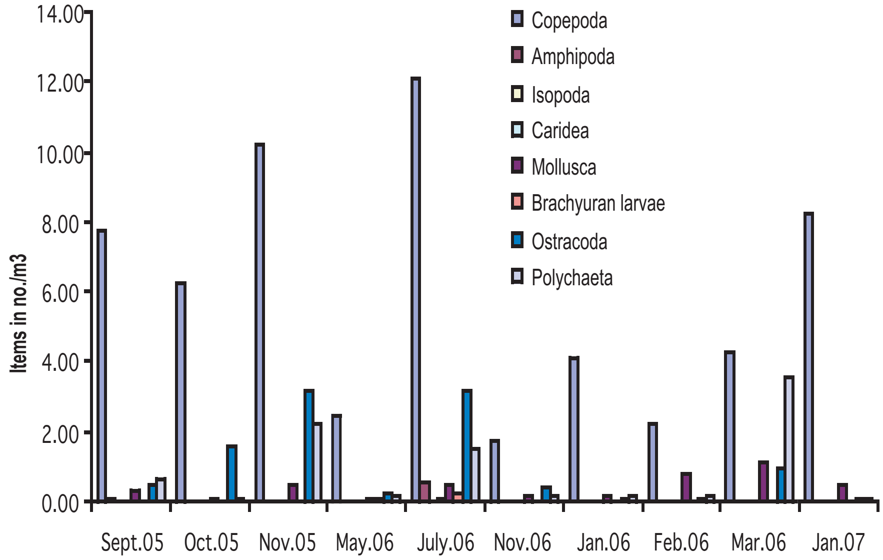
	NEM			SEM		
Food Item	**Backreef x=1196**	**Inshore y=291**	**Offshore z=74**	**Backreef x=406**	**Inshore y=34**	**Offshore Z=0**
Cal.	**23.33(279)**	**10.65(31)**	1.35(1)	7.88(32)	_	_
Cyc.	6.86(82)	0.69(2)	_	4.68(19)	_	_
Harp.	2.26(27)	5.50(16)	_	22.91(93)	8.82(3)	_
Hyp.	9.20(110)	**14.09(41)**	**14.86(11)**	**28.57(116)**	**11.76(4)**	_
Gam.	2.26(27)	2.41(7)	**28.38(21)**	**12.32(50)**	**17.65(6)**	_
Isopods	8.61(103)	1.03(3)	13.51(10)	3.20(13)	32.35(11)	_
Cumaceans	1.76(21)	**15.12(44)**	_	0.99(4)	2.94(1)	_
Carideans	13.55(162)	23.37(68)	5.41(4)	_	_	_
Gastropod larvae	1.92(23)	0.34(1)	14.86(11)	8.37(34)	_	_
Bivalve larvae	12.29(147)	6.51(18)	_	o.49(1)	2.94(1)	_
Crab Zoea	7.53(90)	13.06(38)	_	0.81(3)	23.53(8)	_
Fish Larvae	0.08(1)	0.34(1)	_	0.74(2)	_	_
Ostracode	6.02(72)	7.22(21)	_	0.49(1)	_	_
Stomatopoda	1.42(17)	_	_	0.25(1)	_	_
Carprellid	0.17(2)	_	_	_	_	_
Mysida	0.17(2)	_	_	_	_	_
sipuriculid	2.59(31)	_	_	_	_	_

Table 3: % F of the food items in the stomach of Stolephorus commersonnii from different sites at MMP during the NEM Monsoon and SEM Monsoon

	NEM		SEM			
Food Item	**Inshore**	**Backreef**	**Offshore**	**Inshore**	**Backreef**	
Cal.	1.6	3.9	0.2	_	5.2	_
Cyc.	0.2	**5.8**	_	_	3.8	_
Harp.	2.1	2.1	_	0.9	4.7	_
Hyp.	**7.0**	**6.0**	**1.2**	**1.4**	**10.4**	_
Gam.	3.3	1.9	**1.6**	0.9	**8.1**	_
Isopods	0.4	6.8	0.8	0.9	0.5	_
Cumaceans	2.9	0.4	_	0.5	1.9	_
Carideans	3.5	5.4	0.2	_	_	_
Gastropod larvae	**8.3**	**12.0**	**2.5**	**1.4**	**13.7**	_
Crab Zoea	2.3	3.1	_	0.5	0.9	_
Fish Larvae	0.2	0.2	_	_	0.5	_
Ostracode	2.9	2.5	_	0.5	0.5	_
Stomatopoda	_	0.6	_	_	0.5	_
Carprellid	_	0.2	_	_	_	_
Mysida	_	0.2	_	_	_	_
sipuriculid	_	0.4	_	_	_	_

Food selectivity

Figure 2 shows the major food components consumed by the fish in comparison with their respective availability in the environment. The results indicate that consumption of food items was not dependent on there potential availability in the environment. Molluscs occurred frequently in most of the stomachs examined (42.73 %) but were not numerically important as the amphipods that were consumed (39.71 %F, 26.6 %N) most despite their low abundance (0.21 %) in the environment as copepods (29.62 %F, 23.2 % N and 60 % abundant). Other food e.g. polychaetes abundant in the environment were not consumed but isopods and carideans that were occurred in insignificant abundance in the environment were consumed. Thus, the species showed preference and avoidance of the available food in the environment (Fig. 2a & b). Copepods were abundant in the environment (Fig. 2a) throughout the sampling period but the fish rarely selected them. Amphipods which were fewer in the environment (Fig. 2a) are the preferred food item by the fish (Fig. 2b). This was more so during the NEM. Molluscs and ostracods were prefered during the NEM and SEM seasons, while the fish avoided polychaetes during the study period.



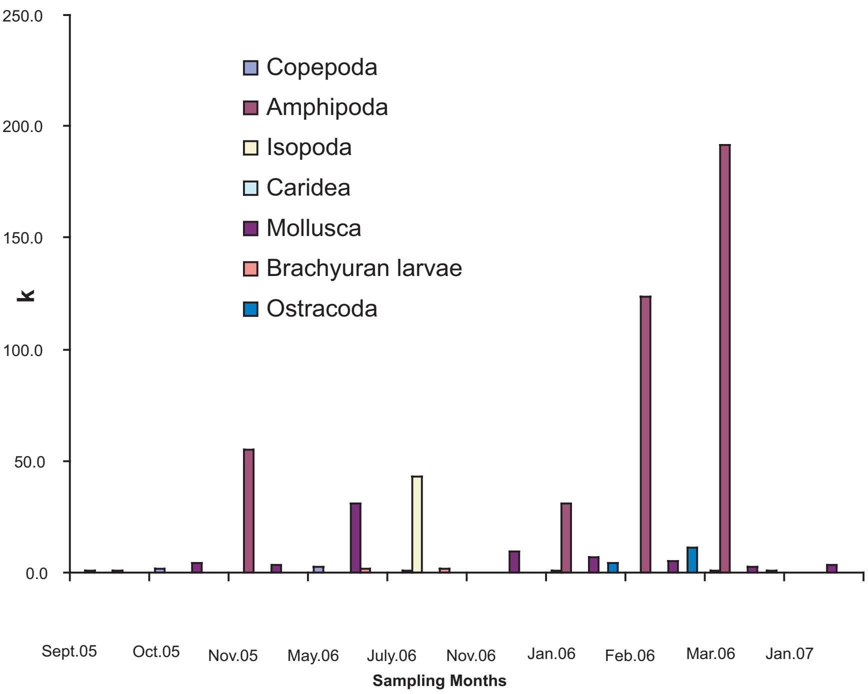


Figure 4: Abundance of prey items in plankton samples and in stomach of *S. commersonii*

Discussion

Seasonal changes in the zooplankton availability and diet composition of S. *commersonnii* were observed. During the NEM seasons (October-March) winds are light, and temperatures are higher allowing water column stratification. Both primary productivity and secondary productivity are higher and benthic algal biomass lower than during the SEM season (McClanahan 1988, Bryceson 1982). In the SEM season (April-September) wind speeds and wave height are higher, water column mixing is high and temperatures are low. The primary and secondary productivity are lower, and algal biomass is higher than during the NEM season. These factors influence the abundance of food items consumed by the fish species. In this study, most of the diet comprised zooplanktonic (e.g. cyclopoid and calanoid copepods, and ostracods), hyperbenthic (e.g. mysids, gammarid and hyperrid amphipods and isopods), and endobenthic taxa (e.g. bivalve and gastropods).

There was high diversity of food items consumed by the species during NEM than in SEM. The overall dominance of mollusc larvae, copepods and amphipods in the stomach contents of the species during NEM than in SEM can be attributed to higher relative abundance of these items in the environment. The NEM season is also associated with high transparency that possibly makes it easier for the species to locate prey visually (Major, 1977). The low transparency during SEM likely resulted in low feeding intensity and low percentage composition of copepods in the diet of the species. Seasonal variation in the intensity of feeding was also observed by Mohanty *et al.* (2006) and they attributed this to variation in availability of the organisms in a particular environment.

Amphipods and copepods were the most important prey items in both seasons. This result agrees with the findings of Mohanty *et al.* (2006) that copepods constitute a fairly good proportion of the diet throughout the year but its percentage composition varies. However, mollusc larvae, mainly bivalve larvae, and carideans constituted the diet during NEM, while during the SEM isopods and crab zoea dominated the diet; which suggests a switch from one type of prey to another that may be related to changes in relative abundance of prey.

The composition of food was markedly different among samples from the three sites. For example, diversity of prey taxa in the backreef was higher than in the inshore and offshore areas. These results indicate that diet of the fish varies at small spatial scale and likely reflects patchy distribution of food items. Some studies have shown that local hydrodynamic conditions, driven by bottom topography and water velocity, favor the patchy distribution of small zooplankton at small spatial scales (Pinca and Dallot, 1997). While studying the spatio-temporal variability of small copepods off the south coast of South Africa, McQuaid and Froneman (2007) found significant differences in spatial distribution of prey.

In the present study, hyperid copepods were often found in juvenile fish as the only food item consumed. This may be as a result of the small size of the mouth of juveniles. Large sized fish consumed more of the hyperids and carideans and this is likely due to the energetic demands of older fish. In Malindi Marine Park, the diet of fish was quite variable between size classes. Smaller fish fed on a lower diversity of food items as compared to larger size classes. Elliott *et al.* (2002) noted that a less diverse diet indicates some degree of specialization while a large number of prey items consumed indicate generalist feeding. In addition, the importance of preferred prey changed: mysids in the small classes replaced copepods in the diet of larger classes. Thus the species exhibited ontogenetic shift in diet preference. Tropical fish in coastal waters are known to be generalists, as they have to cope with a seasonally changing environment (Lowe-McConnell, 1991). Hyperids and gammarid amphipods were the main food item in the diet of *S. commersonii.* Amphipods are much bigger than copepods and likely the species preferred these items to satisfy their hunger faster with less effort spend on foraging thus saving energy.

Conclusion

This study has demonstrated that the pelagic *S. commersonnii* is a carnivorous feeder feeding largely on amphipods. There were marked differences in the numerical abundance and frequency of occurrence of the main prey consumed at the three sites and between seasons. Thespecies exhibited ontogenic shift in feeding with smaller sized fish being more specialized while larger fish were generalists. The diet of *S. commersonnii* varies at small spatial-scales and with season.

References

Bewa, T..M. (2001). Freshwater Fish Distribution. Sun Diego. Academic Press.

Brooks, J.L. and Dodson, S.L. (1965). Predaton, body size and composition of plankton. *Science* **150:**28-35.

Cury P.; Bakun, A., and Crawford, R.J.M. (2000). Small pelagics in upwelling systems: patterns of interaction and structural changes in "wasp-waist" ecosystems. ICES *J. Mar. Sci.* **210**:603–618.

Hyslop, E.J. (1980). Stomach contents analysis – a review of methods and their application. *Journal of Fish Biology* **17**: 411–429.

Lowe-McConnell, R.H. (1991). Ecological studies in tropical fish communities. Cambridge University Press. 382pp.

Major, P.F. (1977). Predator-prey interactions in schooling fishes during periods of twilight: a study of the silversides *Pranesus insularium* in Hawaii. *Fish. Bull.* **75:** 415-426.

McClanahan, T.R. (1988). Seasonality in East Africa's coastal waters. *Mar. Ecol. Prog. Ser*. **44:** 191-199.

McQuaid, C.D., and Froneman, W.P. (2007). Spatio-temporal variability of small copepods (especially *Oithona plumifera*) in shallow nearshore waters off the south coast of South Africa**.** Estuarine, Coastal and Shelf Science 72 (4): 711-720

Mohanty, P.K., Khora, S.S., Panda, U.S., Mohapatra, G.N., and Pravakar, M. (2003). An Overview of Sardines and Anchovies Fisheries along the Indian Coasts. Berhampur 760 007, Orissa, India. 11-12pp.

Morato, T., Santhos, R.S., and Andrade, J.P. (2000). Feeding habits, seasonal and ontogenetic shift of blacktail camber, *Serranus atricauda* (Pisces: Serranidae), from Arizores, north-eastern Atlantic. *Fish. Res.* **49:** 51-59.

Moyle, P. B., Joseph, J., and Cech, J. (2004). Fishes: An Introduction to Ichthyology. 5th ed. Prentice Hall, U.S.A.

Nyunja, J.A., Mavuti, K.M., and Wakabi, E.O. (2002). Trophic Ecology of *Sardinella gibbosa* (Pisces: Clupeidae) and *Atherinomorous lacunosus* (Pisces: Atherinidae) in Mtwapa Creek and Wasini Channel, Kenya. *Western Indian Ocean Journal of Marine Science* **1:** 31-43.

Pinca, S., and Dallot, S. (1997). Zooplankton community structure in the western Mediterranean Sea related to mesoscale hydrodynamics, *Hydrobiologia* 356:127-142.

Mitigation of Illegal Fishing Activities: Enhancing Compliance with Fisheries Regulation in Lake Victoria, Kenya

Etiegni[1] C. A.
Ministry of Fisheries Development, Eldoret

Ostrovskaya E. and Leentvaar J.
UNESCO-IHE Institute for Water Education, DA Delft, The Netherlands

Abstract

This study was conducted to determine the possible reasons for the low compliance level with fisheries regulation used to deter illegal fishing activities, using the 'Table of 11'model which is based on behavioural sciences developed in The Netherlands. The objective was to evaluate the model's suitability for use in Kenya. Structured interviews were conducted in Kisumu, Bondo, Busia and Migori districts in Kenya. Data were analyzed using MS excel and the model. The results showed that about 80 per cent of fishermen have knowledge of the regulation tested but this has not been translated into compliance. Compliance profiles indicated the strong and weak dimensions of compliance. Compliance estimates indicated different percentages of various groups of fishermen violating and complying with the regulation. There was a low level of compliance (50%) and which could be improved through high level of enforcement to ensure that the high knowledge of regulation is converted to compliance. Dimension (T7b) was found to be the most important dimension. It was concluded that the "Table of 11" can be used in Kenya, with minor adjustments, to assess the level of compliance with regulations. It is recommended that the high knowledge of the rule should be transformed into compliance through increased enforcement. Sanction should also be redrafted to make them more severe and there is also need to help fishermen to start other income generating activities to reduce their over-reliance on the lake.

Keywords: *compliance, enforcement, fisheries, Kenya, regulation, 'Table of 11' model*

Introduction

Lake Victoria, the second largest freshwater lake in the world covers an area of approximately 69,000 sq. kilometres. The lake is shared between three East African countries namely Kenya (6%), Uganda (45%) and Tanzania (49%). Despite the fact that Kenya's part is the smallest, it is the most commercialized (Bokea and Ikiara, 2000). The importance of the lake to the economy of Kenya cannot be over-emphasized. The Lake earns the country around Ksh six billion annually from fish export trade and is a source of employment and proteins to the local people. Around 800,000 thousand people are supported directly and indirectly by the fishing industry in Kenya with the majority depending on Lake Victoria. These include fishermen, their dependants, those involved in trade in fishing inputs, fish handling, processing and marketing.

There were traditional ways that ensured that the fisheries resource was being exploited in a sustainable manner. Access to the fishery was limited by allowing fishing only in certain specific stock areas and the number of fishermen was also controlled (Bokea and Ikiara, 2000). The fishing gears that were used by the artisanal fishermen also ensured that fishing load and intensity was controlled. During the last decades, the fishing pressure on the lake has grown tremendously mainly due to the rapid growth of population and new developments in fishing technologies. Nile perch and Nile tilapia stocks, which had been introduced into the lake ecosystem to enhance the fishery, have been heavily impacted. (Ikiara and Odink, 1999)

In 1995, the total number of people employed in Kenya's fishing sector was approximately 560,000. This represented around 25 per cent of Kenya's total employment in the informal sector and 14.5 per cent of the overall employment in the country (Bokea and Ikiara, 2000). This means the total number of people who depend on the fishing sector increased by around 43 per cent from 1995 to 2006. According to the National frame survey (2006), the number of fishermen on the Kenyan part of the Lake increased from

37, 348 in 2004 to 44,263 in 2006, representing an 18.5 per cent increase. The fishing crafts also rose from 12,284 to 15,280 in the two years, representing a 24 per cent rise. The increase in the number of fishermen and their fishing crafts demonstrated an increase in the density of fishermen from nine fishermen per sq. kilometre in 2004 to eleven fishermen per sq. kilometre in 2006. The fishing pressure has been rising as more fishermen enter the fishery. The government as the main enforcing agency of the fisheries regulations is supposed to restrict entry to the fishery through licensing. Unfortunately, government uses licenses for the sole purpose of revenue collection, with more revenue a collected normally taken as a sign of good work done. This has led to many fishermen being licensed resulting in overexploitation of the fish stock through fishing beyond the maximum sustainable yield.

Fishing industry in Lake Victoria also provides raw material for other industries e.g. for animal feed production. Fishing activities in the lake are market oriented with little consideration to the lake ecosystem. To meet the market demand, a lot of pressure has been put on the lake, resulting to a reduction in the catch per unit effort (CPUE) and size of fish landed. This has forced fishermen to engage in illegal fishing activities including use of illegal gears (mainly undersize nets) and fishing in prohibited areas such as fish breeding grounds (e.g., river mouths and areas along the beaches) are known to be rich in fish.

According to the National frame survey (2006), the total gillnets recorded in the eight districts of Lake Victoria were 217,358. Legal gillnets were186, 482 while the illegal ones were 30,876 representing 14.4 per cent of the total gillnets (table 1). It is worth noting that the percentage of illegal gillnets reported may be lower than what is actually on the ground because not all violations are detected. In the same year, a total of 553 beach seines were seized, although beach seines are totally banned in the lake. Only gillnets with mesh sizes equal to or more than 5 inches are allowed for use in Lake Victoria. However, the frame survey indicated that nets with mesh sizes less than 2.5 inches are in use in the lake. Gillnets with mesh sizes less than 2.5 inches are more destructive to the lake ecosystem than other mesh sizes. This is because the net can be used to harvest many young fish at ago than other nets. A mesh size of 4.5 inches though illegal may not catch fish that can be caught by a mesh size of 2.5 inches. In Kisumu district, gillnets with mesh size less than 2.5 inches formed 31.9 per cent of the illegal nets found in the district. Despite the fact that Kisumu is a provincial fisheries headquarters, illegal fishermen have not been deterred by this fact. Table 1 shows a situation where the number of illegal nets is quite high.

Table 1: Percentage of illegal nets ***(Source: National frame survey, 2006)***

District	Total nets*	Total illegal nets*	Percentage illegal nets
Bondo	40,831	6,802	16.7
Busia	15,459	2,333	15.1
Homabay	4,617	1,424	31
Kisumu	19,400	8,637	44.5
Migori	21,749	2,081	9.6
Nyando	3,329	1,294	38.9
Rachuonyo	22,260	5,054	22.7
Suba	90,266	3,804	4.2
Total	217,911	31,429	14.4

Table 2: Number of violators sanctioned in 2006 (*Source: Provincial fisheries office, Kisumu*)

District	Total number of fishers	Total number of violators	% of violators sanctioned	Violators fined 500 -10,000 Ksh	Violators fined 10,000 - 20,000 Ksh	Violators sentenced to community service order of 7-90 days
Bondo	12,625	98	0.8	54	31	13
Busia	4,177	89	2.1	27	46	16
Homabay	325	19	5.8	16	0	3
Kisumu	2,748	86	3.1	44	21	21
Migori	4,716	57	1.2	30	0	27
Nyando	525	38	7.2	29	0	9
Rachuo-nyo	3,562	26	0.7	10	0	16
Suba	15,585	49	0.3	29	12	8
Total	**44,263**	**462**	**1.0**	**239**	**110**	**113**

The sanctions seem to be not severe enough to deter. Matters are even made worse if the violator ends up with a community service order as his sanction. This is work that he can do during the day and go back to violate at night. Going by the number of illegal nets that were reported in the districts, it means that the government has to find a way of making sure that the illegal activities are reduced if the lake is to be protected from the type of destruction it is undergoing.

For many years the management of Lake Victoria was mainly based on central government intervention; however this approach has been proved to be inadequate. Resource users' involvement in decision-making and management is considered to be important to ensure the objective of the regulation is achieved. For this type of co-operation to succeed, the government and resource users need to change their attitudes concerning their roles in such arrangements (Nielsen et al., 2002). They need to work together as it is very important to involve the resource users in decision-making. This is in line with sustainable development principle on subsidiarity. Dilip (2005) noted that co-management is gaining ground and resource users should be encouraged to act as co-managers. Co-management is a better way of managing resources than when only the government is involved. This is because through co-management the resource users are made aware of the need to use the resource sustainably. The top-down management system coming from the government in most cases suffers some resistance because the resource users may not fully understand why they have to abide by what the government wants them to do. When the resource users are involved in decision-making, they take it upon themselves to make sure that the resource is well managed. As a significant element of co-management special Beach Management Units (BMUs) were formed. Their executive committees, which are charged with the responsibility of helping the government to enforce the fisheries regulation, are elected from the assembly of the stakeholders in the Lake Victoria fishery: fishermen, boat owners, crew members, fishing gear owners, fish processors and fish mongers. In this study, the BMU officials are considered as enforcers since they supplement government enforcement activities at the beaches.

Most of the regulations, which were in use during the colonial period, are still a part of the current Fisheries Act of Kenya (1991). At present, the country lacks a comprehensive fisheries policy and this has led to major problems in the management of the fishery (Kariuki, 2005). Currently in Kenya, compliance with fisheries regulation meant to deter illegal fishing activities seems to be insufficient, if the amount of juvenile fish sold in the local fish markets is anything to go by. The government task is to design legislations, which are practical and enforceable. However, the achievement of the objective of the legislations may not be possible if the regulated community does not comply.

The main aims of the study conducted from October 2007 to January 2008 were to determine the current level of compliance with the fisheries regulation meant to protect the lake from illegal fishing activities and to reveal the reasons of non-compliance with the regulations. In addition, some measures for improving the policy and the current enforcement activities in the region are drawn based on the analysis findings.

Methods

The tested regulation was chosen from the Kenya Fisheries Act (1991) under the general management measures. The law prohibits illegal fishing activities such as the use of illegal fishing gears and methods as well as fishing in prohibited areas. The survey included face-to face interviews and direct field observations. The respondents were chosen randomly from sixteen fish landing beaches located in four districts along the shores of Lake Victoria - Busia, Kisumu, Migori and Bondo. The respondents consisted of 45 enforcers from the government and BMUs and fifteen fishermen operating in Lake Victoria as a target group (the minimum required by the procedure is 10). Both enforcers and regulated community are asked to obtain a realistic picture of the current situation to avoid one-sided judgments.

Questionnaires were designed based on "Table of Eleven" (2006), which was developed by the Netherlands' Ministry of Justice on the ground of behavioral sciences. This specific tool makes it possible to estimate the level of compliance with rules, reveal causes of non-compliance and to analyze enforcement efforts, and to develop measures for improving the policy and legislation, as well as enforcement programmes. The checklist of the "Table of Eleven" is a sort of questionnaire composed of eleven dimensions related to spontaneous compliance (factors that affect the incidence of voluntary compliance, which would occur in the absence of enforcement) and enforcement (Table 3).

In this survey dimensions related to record inspection and horizontal supervision are not considered as fishermen do not keep any records and are involved in artisanal fisheries, therefore they have no labour unions, code of conduct etc. that can regulate or control their activities. Data generated from the interviews was analyzed using the electronic version of "Table of 11", which includes generation of compliance profile to map weak and strong points of current regulations and enforcement practices according to dimensions as well as estimation of compliance level.

Table 3: The "Table of Eleven" dimensions

Spontaneous compliance dimensions	Enforcement dimensions
T1 (Knowledge of the rules). The target group's familiarity with and clarity of the rule. *T2 (Costs/benefits).* The tangible and intangible costs/benefits of complying or violating, from the target group's point of view. *T3 (Extent of acceptance).* The target group degree of acceptance of the regulation they are supposed to comply with. *T4 (Target group's respect for authority).* The extent to which the target group respects government authority or any other official authority. The group's respect for their religious and moral standards is also included as competing authority. *T5 (Non-official control).* The risk of being sanctioned by the community inside and outside the target group i.e. the sanction does not come from the official authority. It includes social control and horizontal supervision.	*T6 (Risk of being reported).* The probability as estimated by the target group of being reported in case they are seen violating by other members of the group or the community. *T7 (Risk of inspection).* The possibility of being inspected by the enforcing authorities. Inspection involves both physical and records inspection. *T8 (Risk of detection).* The probability of being detected if inspection is done. The risk of detection is in both physical and records inspection. *T9 (Selectivity).* The perceived risk of inspection and detection of violations, if the areas to be inspected are selected. *T10 (Risk of sanction).* The probability of a sanction being imposed in case a violation is detected during inspection. *T11 (Severity of sanction).* The severity and nature of the sanction and all the disadvantages that accrue from the imposed sanction.

The latter is a step by step analysis, in which the target group is divided into different categories of complying and violating individuals:

- Unconsciously violating - those who do not have knowledge of the regulation hence violate it unknowingly;
- Consciously violating - those who know the regulation but decide to violate it.
- Unconsciously complying - those who do not have knowledge of the rule but comply by looking at what others do. In this case, it is assumed that they copy from fishermen who are not violating.
- Spontaneously complying - those who have knowledge of the rule and will comply on their own accord without any form of enforcement.
- Deterred by enforcement- those who know the regulation but will comply with it only if there is enforcement.

Results

Compliance estimate results

This type of analysis makes it possible to identify the total numbers of people who comply and violate the regulation according to opinion of the different kinds of respondents (Table 4).

Table 4: Level of compliance

	Fishermen	Governmental enforcers	BMU
Complying	58	49	58
Violating	42	51	42

As one can see, the opinions of BMU inspectors and fishermen are identical though there is the difference in their opinions on motives of compliance and non-compliance (Fig.1). The compositions of different types of complying and violating people are quite similar for government enforcers and fishermen, while BMU enforcers' perceptions differ considerably. They divide the majority of the target group (97%) into two groups: consciously violating (41%) and deterred by enforcement (56%). The discrepancy in opinions between BMU and government enforcers may be explained by the fact that working on the grounds, BMU workers have more realistic information about fishermen behaviour than government enforcers. From the other side, being fishermen the BMU officials are aware about their motives, but being enforcers they can answer questions more honestly than fishermen.

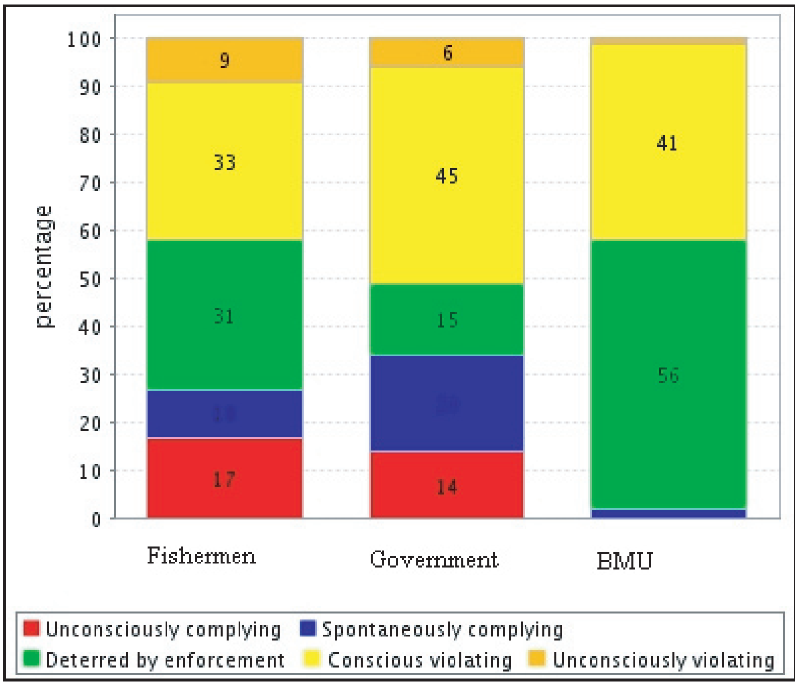


Figure 1 Compliance estimates

All three groups agree that unconsciously violating people are few due to sensitization carried out by the enforcers. The use of awareness creation as a way of increasing compliance cannot be over-emphasized (Hunter, 1998). The regulation should also be clear so that the enforcers can interpret it easily for the purpose of enforcement. Having knowledge and understanding of the rule increases compliance as the regulated community is made aware of what it stands to benefit by complying. If one does not know the rule then compliance becomes a problem. Nonetheless, having knowledge of the rule does not always mean automatic compliance: some people can use their knowledge to find ways of violating it. This is the case that was observed with fishermen: their knowledge of the rule is quite high but their compliance level is low.

Comparing the results of compliance estimate with official data on sanctions, the special attention should be paid to the fact that while around 50 per cent of the target group is considered to be violating, only about two per cent were punished for breaking the regulations. The results indicate that much more can be achieved through improved enforcement activities.

Compliance profile results as estimated by the three groups

The "Table of 11" was used to draw the compliance profiles of the three groups. The profiles show the weak and the strong points of the "Table of 11" dimensions, which are the motives for compliant and violating behaviour of the target group (Table 5).

Table 5: Motives of compliance and non-compliance of the fishermen

Motives of compliance	Motives of non-compliance
1) Good knowledge and understanding of the regulation; 2) Acceptance of the policy; 3) High informal risk of being reported; 4) High risk of imposing sanctions	1) Costs/benefits of compliance and violation including image implications; 2) Weak social control; 3) Insufficient selectivity of inspections; 4) Inefficient sanction system

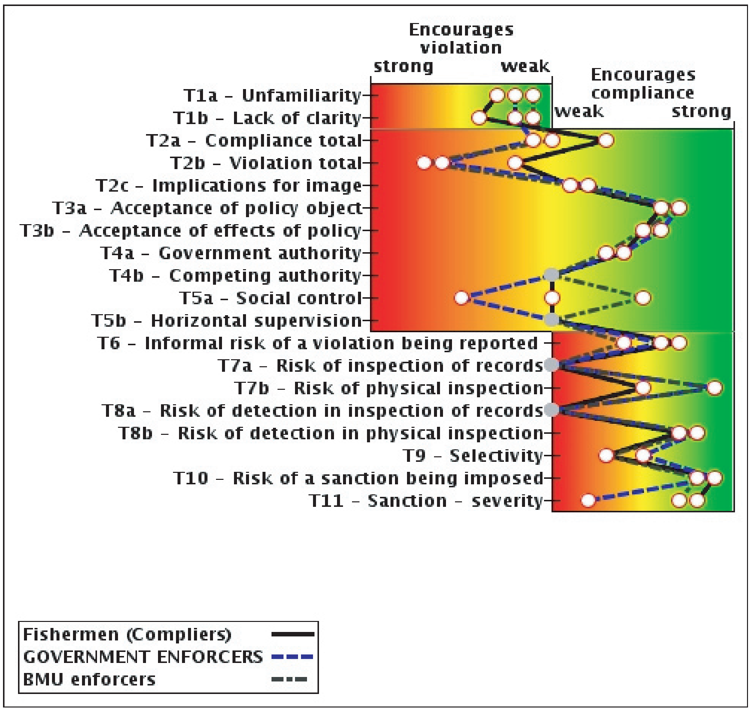
The resultant profile (Fig. 2) shows some similarities in most of the dimensions. However, there are some strong differences in some dimensions: cost/benefits of compliance (2Ta) and violation (2Tb), social control (T5a), informal risk of a violation being reported (T6), risk of physical inspection (T7b) and severity of sanction (T11).

Most discrepancies are revealed between perceptions of enforcers (both government and BMU's) and the fishermen that can be explained by their judgements from opposite sides. The enforcers reported fewer benefits from compliance and costs of breaking the law, than the target group representatives indicated. In our opinion, the enforcers evaluated the situation more realistically, because otherwise higher level of compliance among the fishermen should be expected.

The greatest difference in opinions of the respondents is related to social control. The government officials considered it as extremely low, while BMU reported it as quite high. The target group was out of judgements in this case. The government enforcers' view is that fishermen cannot offer any form of sanction to fellow fishermen in case they detect a violation. The same applies to the general community who are the main beneficiaries of illegal fishing activities since undersize fish are sold at prices they can easily afford unlike the mature fish, which require more money. The difference in opinion between the two enforcers may have been due to the frequency with which they carryout enforcement. BMU offices are located at the beaches hence the BMU officials interact more with fishermen and thus can receive more reports about fishermen's behaviour. Government offices on the other hand are far from the beaches and therefore they may not know what happens at the beaches on a daily basis.

Another point, which should be taken into account, is the low respect for government authority among some fishermen. Respect for the authority among other reasons depends on how the enforcers do their work.

Figure 2: Compliance profile as estimated by the three groups



Unprofessional behaviour, cases of corruption and engagement of some BMU officials in illegal fishing activities were reported. Such behaviour interferes with enforcement activities and makes the target group not to accord the enforcers the respect they expect to have.

Discussion

Illegal, undeclared and unregulated fishing is a worldwide danger. It causes serious environmental damage, contributes to fish stock depletion and creates unfair competition for those fishermen who exploit fish resources legally. In the longer term, it threatens employment and the well being of those people who are dependent on fisheries, as well as the entire economic balance especially in developing countries. There are numerous examples from all over the world, when over-exploitation of fish stocks combining with other factors (anthropogenic and natural) has lead to collapse of the fishery sector. One of the examples is the Caspian Sea, where the total fish catches were decreased 5-10 times (depending on fish species) during the past decade (GIWA regional assessment, 2006). Thousands of people have lost their jobs; some of the valuable fish species are on the brink of extinction. Another example is considerable depletion in stock of Atlantic Cod in the Eastern Scotian shelf of Canada in early 1990s. Since then the stock is not restored yet, despite the prohibition of direct fishing in the area (Management Strategy, 2005).

Lake Victoria's fishery is contributing essentially to the economy of Kenya. However, this is often obtained at the expense of society and the environment. Excessive fishing is the major factor contributing to the decline of Kenyan fisheries of Lake Victoria. Fishing is open to all as long as one can pay for the required license. The current resource base cannot support the present fishing pressure, however the fishermen are not willing to exit the fisheries, as this is their only source of income. Another reason is increasing market demand for fish, which cannot be attributed to the fish export trade and the increasing population only (Bokea and Ikiara, 2000). Fishmeal based animal feeds industry has also developed and generates unprecedented demand on the fishery.

Kenya provided remarkable incentives for investment in industrial fish processing in the past decades. The demand created from the industries coupled with lack of fish price control, ensured that fish business remained lucrative. This business atmosphere attracted new investors and this fact pushed the demand for fish even higher. The highest demand for Nile perch come from the fish processing industries, moreover most importers of the fish prefer small size fish (Odada et al., 2004). Therefore to be able to meet the demand, most fishermen have been forced to engage in illegal fishing activities. This problem requires concerted effort between government and the fish processing industries to eradicate. However, this problem cannot be eradicated easily as long as there is a ready market for the small size fish. This type of demand for fish and poor enforcement activities have led to illegal activities in the lake as fishermen try to satisfy the ever increasing demand for fish.

Illegal fishing activities in Lake Victoria (Kenya) are on the increase nowadays. Compliance with fisheries regulation that deters illegal fishing is found to be around 50 per cent, and only approximately 30 per cent of the fishermen comply with the regulation consciously. The regulated community cannot link the high level of violations to the lack of knowledge of the rule, since the fishermen were found to be familiar with the regulation that was tested. The high knowledge among the target group is attributed to the sensitization carried out by the government and BMU enforcers. The regulation is also clear and straightforward, in the opinion of both enforcers and the fishermen. However, the high knowledge did not translate to compliance.

The intangible and long-term costs/benefits of complying or violating the regulation are not clear to the target group. The fishermen know the immediate economic benefits of complying or violating the regulation, and nowadays they are being encouraged by the economic conditions to violate. Social control and other forms of informal control such as reporting to officials about violations are not well developed. The society is of a traditional type with many strong ties between relatives; therefore serious social sanctions against offenders could rarely be expected, particularly due to the dependence of the entire community's well being on the fisheries. Though most fishermen are in a better position to identify illegal nets and any form of illegal activities being done in the lake, many of them are not willing to report their colleagues and family members. However, what they may not know is the fact that illegal fishing activities affect all of them, as the lake is a common resource. The fishing community should be made aware of the impact and long-term consequences of illegal fishing activities to the lake ecosystem, fish stocks and to themselves.

There are serious loopholes in current enforcement programs. Risk of physical inspection is not as high as should be the case especially in the opinion of the target group. One of the reasons is the insufficient resource provided by the government to carryout enforcement activities. The BMU officials who are supposed to supplement government enforcement do not perform their duties well. Some of them are corrupt and a majority find sanctioning a family member a problem. The co-operation between the government and BMU is insufficient, and that is one of the reasons they do not speak with one voice as expected. The sanction has not been able to provide deterrence in most cases. In the Fisheries Act, only the maximum sanction is set up but the minimum below which a judge should not go is not given. In such a case, the amounts of penalties imposed in most cases are too low and may be less than the environmental damage caused through violation or the benefit obtained by the violator. The situation is made worse if the presiding judge, in a case, does not have some knowledge on environmental issues. All the factors mentioned above results in the lack of the fishermen's respect for the official authority of those responsible for law enforcement.

Conclusions

Lack of comprehensive fisheries policy has caused inconsistence in fisheries management activities in Lake Victoria. Realizing that the current Fisheries Act cannot adequately protect the lake from the threats it is facing, the government is in the process of drafting a policy for the fisheries sector which should pay special attention should be paid to the current fish market regulation and elaborate measures dealing with decreasing strong dependence of local population on the fishery such as helping fishermen to start other income generating activities like aquaculture.

There is a lack of understanding of real costs that local communities pay for illegal activities, hence there is need to create awareness on the long-term negative consequences of over-fishing and illegal fishing. Fishermen should be educated on how they can gain benefits from compliance with the regulations. The government should introduce economic incentives to encourage compliance.

There is a clear indication that the regulations currently in use are either inadequate or there is a problem with enforcement. The government should provide more resources to improve the enforcement programs and activities and increase the level of compliance with the related regulations. The problem of corruption should be addressed with special focus on BMU performance in order to improve the public image of the enforcing bodies. In order to increase deterrence the sanctions should be redrafted and the minimum and maximum sanctions clearly spelt out to reflect the current economic situation in Kenya. Enhanced compliance will ensure the preservation of fish stocks and their availability to the future generations; hence will contribute to sustainable use of the lake's resource.

References

Bokea C, Ikara M, 2000, "The macro-economy of the export fishing industry in Lake Victoria (Kenya)", *in Proceedings of IUCN World Conservation Congress*, *The Socio-Economics of Lake Victoria Fisheries* number 7, pp7-18. Caspian Sea. GIWA Regional Assessment 23 (2006). University of Calmar and UNEP.

Dilip K, 2005, "Community Empowerment for Fisheries Co-Management", in *Proceedings of APFIC Regional Workshop, "Mainstreaming" Fisheries Co-Management in Asia Pacific,* 9-12 August 2005, Siem Reap, Cambodia, pp1-3. Available at www.apfic.org

Government of Kenya. Fisheries Act, Chapter 378, Revised Edition (1991). Part VI- General Management Measures. Laws of Kenya.

Hunter B, M. (1988). *The Reasonable Arm of The Law*: Oxford University Press, Great Britain.

Ikiara, M., & Odink, J. (1999). *Fishermen's Resistance to Exit Fisheries.*

Kariuki, J. (2005). *Review on The State of Capture Fisheries Management in Indian Ocean. FAO Corporate Document Repository.*

Management Strategy for Recovery of Atlantic Cod Stocks (2005). http://www.dfo-mpo.gc.ca/cod-morue/Strategic-mar_e.htm

Ministry of Justice. (2006). "Table of Eleven. A versatile tool (Version: October 2006)" Ministry of Justice, The Hague, Netherlands, 27 pp. Online version available at http:// www.it11.nl

National Report on the Lake Victoria (Kenya), 2006, "Fisheries frame survey - implementation of a Fisheries Management Plan", *EDF* Project No.8 ACP ROR 029. Ministry of Livestock and Fisheries Development, pp 8-24.

Nielsen J, Degnbol P, Viswenathan K, Ahmed M, 2002, "Fisheries co-management - an institutional innovation: perspectives and challenges ahead", in *Proceedings of IIFET 2002 Conference*, August 19-22, Wellington, New Zealand, number 216, pp 2-9.

Odada O.E., Daniel O.O., Kasim K., Micheni N., Shem W. (2004). Mitigation of Environmental Problems in Lake Victoria, east Africa: Causal chain and Policy Options Analyses. J. of Human Environment, 33(1), p. 13-23.

Tietenberg, T., & Segerson, K. (1992). *Defining Efficient Sanctions in Economic and Legal Aspects of Recent Developments in Environmental Enforcement and Liability*. England: Edward Elgan.

Tietenberg, T. (1996). *Private Enforcement of Environmental Regulations in Latin America and Caribbean. An Effective Instrument for Environmental Management?* ( ). No. ENV-101, Washington, D.C.

UNEP (2006). Stolberg F., Borisova O., Mitrofanov I., Eghtesadi P. Caspian Sea,. GIWA Regional Assessment 23. (2006). University of KCalmar, Kalmar, Sweden and UNEP. 79 p.

Parasite of Tilapia (Oreochromis Niloticus) in Chepkoilel Fish Farm of Moi University, Eldoret, Kenya

Geraldine K. Matolla
Department of Fisheries and Aquatic Sciences, Moi University, Eldoret, Kenya

Abstract

Tilapia have been successfully farmed under a wide range of environmental conditions and are an important group of cultured fish species in many parts of the world, particularly in developing countries. They are considered to be hardy, rapid in growth and generally resistant to many diseases. Intensification of their culture has however resulted to deterioration of the environment which have been associated with an increase in parasitic and infectious diseases. A study was conducted to establish the presence of internal and external parasites of Oreochromis niloticus at Chepkoilel fish farm of Moi University in Eldoret, Kenya. Water temperature during the study ranged from 17- 22°C. A total of 44 *Oreochromis niloticus* fish were sampled for parasites. Both internal and external parasites were observed. External parasites included Digenean metacercarial cysts, Trophonts of the protozoan *Ichthyophthirius* sp., crustacean parasite, fungi, the protozoan *Trichodina,* and the monogene *Dactylogyrus.* Internally, Acanthocephalans were found in the intestine while diplostomatid metacercariae were found in the vitreous region of the eye and in the muscles. All the parasites found in this study occur naturally in the environment and become parasitic when fish stressed by factors like water quality, biomass density, handling and nutrition. The most prevalent parasites were acanthocephalans and Diplostomatids. *Ichthyophthirius* sp. and Diplostomatid parasites had the highest mean intensity. Although parasite prevalence and intensity levels are considered as acceptable to the fish, there is need for continuous monitoring to establish critical parasite levels so as to develop control measures to prevent mortalities and economic losses. Furthermore, some of the parasites found may have public health concerns and hence may need further investigation.

Introduction

Tilapia is of great interest in tropical aquaculture. They have been successfully farmed under a wide range of environmental conditions and have become one of the most economically important groups of cultured fish species. Their high fecundity, rapid growth rate, few diseases and availability of fry have resulted in intensification of production. They have a rapid growth rate and relatively few diseases. As a result, they have become one of the most economically important groups of cultured fish species. (Tonguthai and Chinabut, 1997). Tilapia can be reared in ponds, cages, or pens and can grow well in freshwater and brackish environments. The high fecundity of fish, its rapid growth, its few disease problems and the ready availability of tilapia fry have resulted in high intensification of production. This intensification of culture systems and resultant deterioration of the environment have been associated with an increase in parasitic and infectious diseases (Michel, 1989). Potentially pathogenic organisms that present a real threat for cultured tilapia include viruses, bacteria and parasites.

Most studies on African fish parasites have been carried out in Western, Central and Southern Africa. Literature from Eastern and Northern is scanty due to lack of personnel in fish parasitology (Aloo, 2002). In Kenya, a few authors (Malvestuto and Ongoma, 1978; Aloo 2002; Paperna 1996; Schmidt and Canaris, 1976; Tompkins, 1976). Very little work has been done on the parasites of *Oreochromis niloticus* at Chepkoilel fish farm of Moi University in Eldoret. Therefore, this study was undertaken to establish the presence, prevalence and intensity of internal and external parasites of *Oreochromis niloticus* at the farm.

Materials and Methods

The study was conducted for five weeks from June 18th to July 25th, 2008 at Chepkoilel Fish farm of Moi University in Eldoret- Kenya. The farm is about eight acres of which three and a half are under ponds. The ponds receive water from a one and a half acre reservoir. The total number of ponds is forty-three where six are production ponds, four fattening ponds, thirty research and three rearing ponds.

The *Oreochromis niloticus* fish were collected from one pond in the fish farm. Fish specimens were obtained using a seine net. The fish were transported live in a bucket containing water to the laboratory. The fish length was measured (cm) using a meter rule and weight (g) taken using an electronic balance in once in the laboratory. A complete parasitological examination on all fish samples was conducted using standard necropsy procedures for adopted from Woodland (2006).

The entire surface of the fish was examined thoroughly under a dissecting microscope. Mucus was scrapped from the skin, head region, fins, and entire body surface was sampled randomly. Smears were made by touching a cover slip on the side of the fish and wiped on to a side of the fish. Opercular and gill sections were observed under a dissecting microscope. Internal examinations were done through stretching out the intestines and stomach in a Petri dish and cut open longitudinally. The contents were examined under a compound microscope at a magnification of X100. Internal organs were examined by cutting a small piece from each, put on glass slide, squashed by use of a cover slip and observed under a compound microscope.

Results

Surface water temperature during the study period ranged between 17- 24 ° C while at a depth of one meter below the surface it was between 19- 22 ° C. A total of 44 *Oreochromis niloticus* fish were sampled for parasites. Both internal and external parasites were observed. External parasites of Oreochromis niloticus were as follows: Digenean metacercarial cysts, Trophonts of the protozoan *Ichthyophthirius sp.*, crustacean parasite, fungi, the protozoan *Trichodina,* and the monogene *Dactylogyrus.* Acanthocephalans in the intestine and metacercaria of Diplostomatid parasites which were observed in the vitreous region of the eye and in the muscles were the only internal parasites observed (Table 1).

The most prevalent parasites were acanthocephalans and eye diplostomatids (40.9% and 36.4% respectively). *Ichthyophthirius* and eye diplostomatid parasites had the highest intensity of 29.4 and 26.4 per fish respectively. (Figure1 and 2). Despite having the highest prevalence levels of 40.9per cent and 36.4 per cent respectively (Figure 1), acanthocephala and eye diplostomatids did not show pathological signs associated with the presence of these parasites, an indication that the levels are acceptable. Mean intensity levels of *Ichthyophthirius sp.* were highest *at* 29.4 parasites per fish (Figure 2). These levels are considered high since being an obligate parasite; *Ichthyophthirius* is capable of causing massive mortality within a short time (Klinger and Floyd, 2002).

Table 1_ Parasites and site of infection in *Oreochromis niloticus* in Chepkoilel fish farm

Type of Parasite	Site of infection
Acanthocephala	Intestine
Diplostomatids	Eye
Ichthyophthirius	Skin
Muscle metacercariae	Muscles
Crustacea	Skin
Fungi	Skin and gills
Skin metacercariae	Skin
Cestoda	Gall bladder
Monogenea	Gills
Trichodina	Gills
Dactylogyrus	Gills

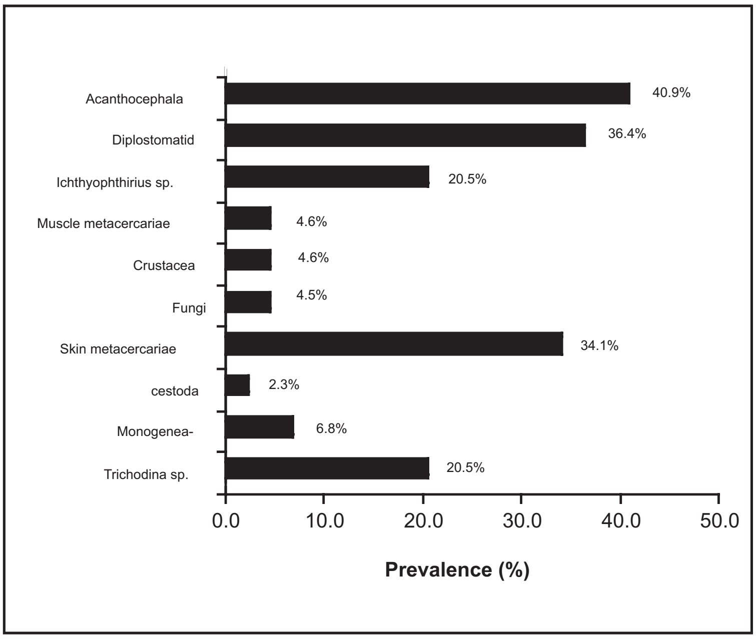


Figure 1: The prevalence (%) parasites in *Oreochromis niloticus* in Chepkoilel fish farm

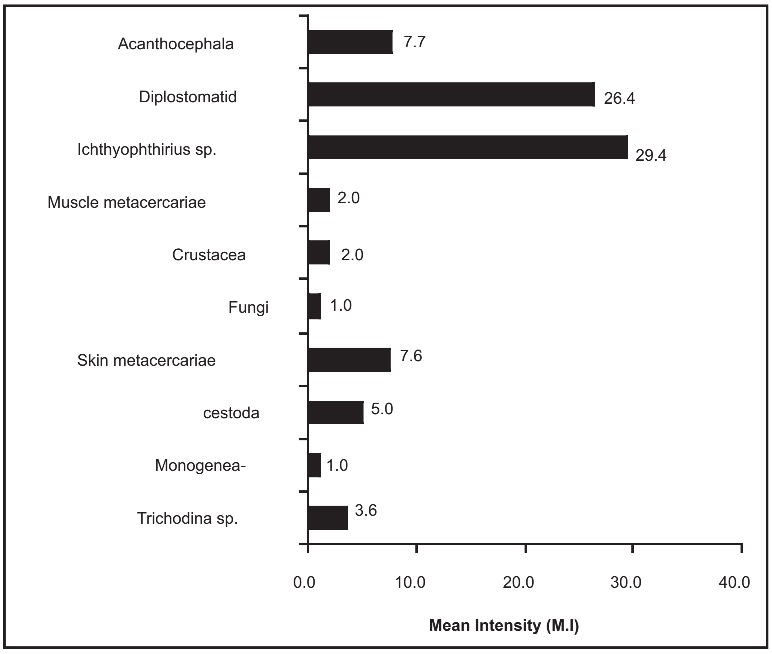


Figure 2: Mean Intensity (M.I) of parasites in *Oreochromis niloticus* in Chepkoilel fish farm

The protozoan ciliate *Trichodina*, was identified by its erratic darting movements and the presence of a circular, toothed disc within its body. *Ichthyophthirius*; which is one of the largest ciliate protozoans was seen as small blister-like lesions on the body wall, which appear as white spots and further observation under the microscope revealed a large macronucleus and a ciliated body. *Dactylogyrus* is a monogenean trematode, which was found on the gills and was identified by the presence of four eyespots, one pair of anchor hooks and an egg sac within the body cavity. Diplostomatid parasites were found within the vitreous part of the eye and were recognized by their pinkish- white color, folk tailed shape and the presence of many calcareous corpuscles in the fore body that are absent in the hind body. Metacercariae of the skin were encysted between the scales while those of the muscle were found within the musculature and were yellowish in color. Acanthocephala were readily recognized by the presence of a retractable proboscis crowned with several hooks. The parasitic stage of a crustacean parasite was seen as a rod-shape and anchored with a holdfast organ to the skin of fish.

Discussion

Internal and external parasites of *Oreochromis niloticus* have been documented by several authors (Aloo, 2002; Michel, 1989; Paperna, 1996;Tonguthai and Chinabut, 1997). Under the extensive or semi intensive culture, they are more resistant to disease than many other fish species (Roberts and Sommerville, 1982). Intensive culture systems have been adapted to boost production of tilapia; resulting in deterioration of water quality associated with an increase in diseases in tilapia.

The presence of the protozoan ectoparasites *Ichthyophthirius* and *Trichodin*a can be attributed to certain water quality parameters and husbandry conditions such as overcrowding, sanitation and handling of fish. Temperature plays an important role in epizootic outbreaks of ectoprotozoan infections such as *chthyophthirius* and *Trichodin*a., with both high (25-30°C) and low temperature (2-17°C) associated with massive infections (Paperna, 1996). Protozoans are always present in the environment of fish and their detrimental effects are enhanced by farming manipulations, which temporarily weaken the fish (Michel, 1989). Ectoparasitic protozoa are variable in their effect on their hosts. Pathological effects are density dependent, when both the size of the parasite population and the nature of tissue Reponses are modulated by physiological condition of the fish; causing temperature related stress in the fish hence the presence of these parasites. Although water temperatures in this study were not within these ranges, records indicate that they could be as low as 10°C.

Ichthyophthirius sp. infections are fatal to fish of all sizes and can cause serious damage to the skin, fins and gills. Corneal infections can impair eye vision. Infections are usually stress-mediated such as overcrowding, poor feeding and excess nitrogenous waste (Paperna, 1996). Ichthyophthiriasis is one of the most prevalent diseases of fresh water fishes, tilapia included and is caused by ichthyophthirius multifiliis; the largest protozoan parasite of fishes. Signs of infestation are irritation and white spots on the gills and skin. Penetration into the epithelium by the tomites of the parasites results in extensive changes in the surrounding integumental tissues. As the parasite grows, the epithelium is pushed outwards to form the white swelling. When the parasite breaks out of the skin, the epithelium may be completely destroyed and the dermis exposed to secondary infection by bacteria or fungi. In severe cases especially with small fish, mortalities may occur due to the direct osmotic effects of

Crustacean parasites can cause severe damage to fish. The most common crustacean parasite of tilapia is *Argulus* sp, *Ergasilus* sp., and *Lernaea* sp. The crustacean parasite identified in *Oreochromis niloticus* of Chepkoilel fish farm was *Lernaea* sp. Clinical effects depends of crustacean largely depends on their abundance and age of the fish. They pose further threats by the fact that they are always present in the environment and difficult to control. The lesions they inflict on the gills and skin of fish during their attachment and feeding serve as entry points for pathogenic bacteria and fungi. Some of the parasites feed on erythrocytes of fish; causing serious and prolonged energy drain (Michel, 1989; Tongthai and Chinabut, 1997).

Monogenean parasites attach to the host by means of an opisthaptor with several hooks causing severe damage to host tissues. They have a high reproductive potential therefore considered as harmful even at low intensities. Infections may cause red spots accompanied by sloughing off of the skin and scale loss, hyperplasia of the gill epithelium; thus resulting in respiratory and osmoregulatory difficulties depending on site of infection. The monogenes found in O. niloticus of Chepkoilel fish farm were attached to the gills and could lead to death of young fish particularly the young ones due to respiratory dysfunctioning. Older fish can tolerate heavy infections of up to 300 parasites per fish (Paperna, 1963).

Trematode infections are frequent in tilapia. They require a diverse number of hosts for development, which include; molluscans, fish and piscivorous vertebrates such as birds. Active larval penetration of massive infestations through the skin of fish can lead to mortalities especially in young fish. They can also be a source of zoonoses, which may have severe consequences. Diplostomatids are transmitted by birds and are extremely frequent in natural environments though rarely lead to massive infestations (Michel, 1989). The presence of aquatic birds and molluscans was established at the farm during the study and may be attributed to the presence of these parasites. Chronic infections by diplostomatids may lead to loss of production due to eye damage characterized by exophthalmia, blindness, emaciation, cataracts, thickening or even complete destruction of the eye lens. (Chappell et. al., 1994). The resulting blindness may lead to difficulties by the fish in finding food and thus become easy prey for predatory birds..

Encysted forms of digenetic metacercariae were found in the muscles and skin of the fish. Digenes are the most predominant group of internal pathogens of tilapia (Tonguthai and Chinabut, 1997). They possess unsegmated, oval or lanceolate bodies and equipped with two attachment organs, the oral sucker and the ventral sucker or acetabulum. Their life cycle involves fish as the secondary host intermediate host where cercaria develops into a metacercaria. Although considered virtually harmless to fish, they may become pathogenic during cercarial invasion in fish tissues depending on their numbers, the paths they travel and the organ where they encyst. As trematode parasites are well visible by naked eye, they can lower the market value of fish or even render it unmarketable. It was not possible to identify the type of digenes found as adult forms are not present in fish (Chappell et al, 1994). However, it is likely that the type of muscle metacercaria found was *Clinostomum* cutaneum type (Fiovaranti, 2008 Pers. Comm), which is considered to be potentially pathogenic to consumers. Other clinostomatid digeneans such as Clinostomum *complanatum* could be pathogenic for humans (Tonguthai and Chinabut, 1997) and therefore further studies are required to identify these parasites and assess their importance to public health.

Acanthocphalan infections may also cause damage to the intestine due to their attachment organ which has a spiny proboscis. This may result to chronic catarrhal inflammation accompanied by deformation and loss of mucosal epithelium; caused by penetration of the proboscis into the submucosal tissue of the intestine (Aloo, 2002; Tonguthai, 1997). Some *Acanthocepahala sp*. produce toxins, which are secreted into the host tissues through pores, present in the proboscis hooks (Kabata, 1985).

In naurally occuring infections, cestodes rarely cause damage to their host in. However, they pose a potential risk to native fish species introduced to farming such as Clarias spp by causing tissue inflammation around the site of infection (Paperna, 1996). Monogenean parasites such as *Dactylogyrus* sp.and *Gyrodactylus* sp. are gill and skin parsites and when in large numbers, they may cause damage to the gill tisues resulting in respiratory problems. Biomass density is an important factor to be considered in development of monogenean infections as they spread by direct contact from fish to fish and could result in economic losses and mortality.

Conclusion

The Prevalence and Mean Intensity levels for parasites in this study were considered to be of minimal or no harm to the fish as there were no pathological signs associated with their presence. Sine this study was conducted over a short period (five weeks), it is necessary to carry out further studies to establish changes in parasite intensities and their effects. Water quality; particularly temperature should be controlled to prevent outbreaks of ectoparasitic protozoan infections as they are opportunistic and tend to multiply very fast under favorable conditions.

The presence monogenean parasites should be controlled as they could cause mortality in infected fish when present at high intensity. Parasites such as monogeneans, diplostomatids and muscle digenean metacercariae, could affect the feeding behavior of fish causing a worsening of productive indexes. Furthermore, some intestinal parasites such as cestodes and acanthocephalans could cause some nutritional deficit in the host (Tonguthai, 1997). Studies on diplostomatid parasites indicate that levels below thirty parasites per fish are acceptable while above 100 parasites per fish are considered pathogenic (Field and Irwin, 1994). Prevalence levels for diplostomatids were within the acceptable limits but should be controlled to prevent eye damage and subsequent loss of feeding of fish.

Infections due to cestodes, nematodes, acanthocephalans and digenean parasites may be attributed to the presence of invertebrates and piscivorous birds, which play an important role in the life cycle of these parasites. These parasites may pose a risk to fish; both farmed and wild, and are sometimes pathogenic to man. They should therefore be reduced as much possible in order to minimize the risk. Invertebrates (snails, crustaceans, annelids, etc.) serve as intermediate hosts while piscivorous birds are definitive hosts and their presence is necessary for the transmission of these parasites to fish. Biosecurity actions for controlling of these invertebrates may include introduction of some carnivorous fish such as *Clarias* sp. in the pond.

Most of the parasites found in this study occur naturally in the environment. However, they may become pathogenic under unfavorable conditions such as water quality, biomass density, handling and nutrition. The presence of intermediate host such as piscivorous birds and molluscs could also be a risk factor in the development of infection at the farm. These aspects are critical in controlling the presence of parasites at the farm and should be investigated further to prevent mortalities and subsequent economic losses.

References

Aloo, P.A. (2002. A comparative study of helminth parasites from the fish *Tilapia zillii* and *Oreochromis leucostictus* in Lake Naivasha and Oloiden Bay, Kenya. Journal of Helminthology (2002). 76**:** 95-102.

Chappell L.H., L.J. Hardie and C. J. Secombes (1994). In: The disease and host-parasite interactions. In: Pike and Lewis (Eds.) Parasitic diseases of Fish. Samara Publishing Limited. Samara House, Tresaith, Dyfed SA43 2JG, Great Britain.

Field J. S. and S.W.B. Irwin (1994). In: The disease and host-parasite interactions. In: Pike and Lewis (Eds.) Parasitic diseases of Fish. Samara Publishing Limited. Samara House, Tresaith, Dyfed SA43 2JG, Great Britain.

Kabata, Z. (1985). Parasites and diseases of fish culture in the tropics. Taylor and Francis, London. 318 pp.

Klinger R. and R.F. Floyd (2002). Introduction to freshwater fish parasites. University of Florida. Institute of Food and Agricultural Sciences (IFAS) Extension.

Michel, Christian (1989). Pathology of tilapias. Aquatic Living Resources. **2.** 117-126.

Paperna I. (1963). *Entergyrus cichlidarum* n. gen. sp. A monogenetic trematode parasite in the intestine of African freshwater fish. Bulletin of Research Council. Israel (B. Zool.), 11; 183.

Paperna, I. (1996). Parasites, infections and diseases of fishes in Africa – An update. CIFA Technical Paper. No. 31. Rome., FAO. 220pp.

Roberts R. J. and C. Sommerville, (1982). Diseases of tilapias. In: The biology and culture of tilapias, R. S. V. Pullin, R. H. Lowe-Mc-Connel, Ed., International Centre for living aquatic resources management, Manila, Philippines.

Schmidt, A. D. and A. G. Canaris. (1976). Acanthocephala from Kenya with descriptions of two new species. Journal of Parasitology. 53: 634-637.

Tompkins, J. A. (1976). The effects of parasites on the condition of *Tilapia nilotica* from Lake Baringo, Kenya. Supplement to Lake Baringo research Report. General Survey. 1975-1976.

Tonguthai K. and S. Chinabut (1997). Diseases of tilapia. In: Egna H.S. and Boyd C.E (Eds.). Dynamics of pond aquaculture. CRS Press. Boca Raton, Florida.

Woodland J. (Ed.) (2006). National Wild Fish Health Survey- Laboratory Procedures Manual. 3.1 Edition. U.S. Fish and Wildlife Survey, Pinetop, AZ.

Effects of Stocking Density on Growth and Survival of Tilapia in Cages

A. Mokoro, M. Njiru, C.C. Chege
Department of Fisheries and Aquatic Sciences, Moi University, Eldoret, Kenya

Abstract

The effects of stocking density on survival and growth performance of Nile tilapia (*Oreochromis niloticus*) fingerlings reared in cages were investigated for fourteen weeks between June and October 2007. Nile tilapia fingerlings averaging 15 ± 0.2 g and 9.0 ± 0.2 cm TL, were stocked in nine rigid wire mesh cages measuring $1m^{-3}$ suspended in a fertilized pond. Fish was stocked in triplicate at densities of 30, 60 and 90 fingerling m^{-3}, fed twice a day to satiation on a locally formulated 32 per cent crude protein diet at five per cent body weight. Stocking density affected significantly ($P < 0.05$) fish survival and growth. Survival rate ranged between 67 per cent and 97 per cent, with higher survival on fish stocked at 30 fish m^{-3} compared to those stocked at 90 fish m^{-3}. The best and the lowest growth performance were obtained for fish stocked at 30 and 90 fish m^{-3} respectively. Food conversion ratio (FCR) was lowest among fish stocked at 30 fish m^{-3} and highest in fish stocked at 90 fish m^{-3}. With the exception of higher concentration of ammonia, all water quality parameters within the cages did not exhibit any significant differences ($P > 0.05$). The present results suggested that the optimum stocking density of Nile tilapia fry in cages was at 30-fingerling m^{-3}.

Key words: *Nile tilapia, cages, stocking density, growth, and survival*

Introduction

Nile tilapia is the second most preferred aquaculture fish in the world after the carps. Nile tilapia has been raised as food fish, recently it has become very important as ornamental fish, and research animal for biotechnology (Guerrero, 2002). Tilapia is a favourable food fish, tolerates a wide range of environmental conditions, has a rapid growth rate, and is resistant to common fish diseases (El-Sayed, 2002). Great attention has been paid to the production of grow-out (table size) fish in high intensity culture systems such as raceways, tanks or cages. The major challenge of tilapia culture is prevention of pre-harvest spawning that leads to overpopulation, stunting, low production from the current culture techniques (Huang and Chiu, 1997; Yi *et al.*, 1996; Liti *et al.*, 2005). The current methods used in the population control are sexing fry at an early stages, hybridisation, hormonal sex reversal, genetic manipulation, use of genetically improved tilapia, use of predator, and rearing a mixed male-female population. However most of these techniques are difficult to be used by ordinary farmers in large-scale fish production, as they require a hatchery operated by trained personnel (Guerrero, 2002).

In Kenya, mixed sex Nile tilapia represents over 75 per cent of fish in aquaculture while polyculture of Nile tilapia and catfish contributes to fifteen per cent of nation production (Ngugi and Manyala, 2004). The low production of *O. niloticus* from the existing culture systems in Kenya is the main obstacles limiting the expansion of semi-intensive cage culture of this fish. In an endeavour to increase production and profit margin, fish farmers have opted to increase the stocking density within the cages, which has resulted in increased production of poor quality fish and deterioration of water quality in those culture units. In Asia, larger size tilapia in cages have been raised to 500 g within a period of 90 days, which is relatively shorter than in the conventional semi-intensive culture techniques (Yi, Lin and Diana, 1996). Therefore, if furnished with the right information, it is feasible for cage culture farmers in developing countries to stock their fish at optimum stocking densities for quality and high value products.

Several studies have found close relationship between stocking density, growth and survival of fish. However, it appears there is no general agreement regarding the effects of stocking density on growth and survival of fish. For example, Liti *et al.* (2005) found that increase in Nile tilapia fingerlings in cages affected their survival and growth, with the lower stocked fish exhibiting higher survival and growth performance. Similarly, El-Sayed (2002) found that in a closed re-circulating indoor system, the rate of Nile tilapia fry were negatively correlated with optimum stocking density. On the contrary, Gall and Baker (1999) reported that body size of tilapia fry was not affected by stocking densities when water was uniform. With these discrepancies on the effect of stocking density on performance of Nile tilapia, it evident that further studies are needed to ascertain the optimum stocking densities. The objective of this study was therefore to investigate the effects of stocking density on cage reared Nile tilapia juveniles.

Materials and Methods

Nile tilapia fry were produced from tilapia brood-stock kept in captivity in the aquaculture farm, Chepkoilel campus, Moi University, Kenya. Mixed-sex Nile tilapia fingerlings (mean length, 9 ± 0.02 cm, mean body weight, 15g ±0.02g) originating from the same brood were obtained by seining tilapia nursery ponds. Triplicate group of 30 fish m^{-3} (90 fish), 60 fish m^{-3} (180 fish), and 90 fish per m^{-3} (270 fish), were randomly stocked in $1m^3$ cages. Cages were constructed using treated hard wood frames and its walls covered with 1.3 cm poultry wire mesh. The cage had a hinged top cover and a feeding screen of 1mm fine mosquito netting sewed in the inner perimeter of the cage stretching ten centimetres below the water level to prevent the floating feeds from slipping out of the sides of the cage during feeding of the fish. The cages were placed around the wooden walkway on a completely randomized design such that they were fifteen centimetres above the bottom of the pond, and tied to the walkway using wires. The pond was fertilized using 60 kilograms chicken manure two weeks before fish stocking was done and this rate was maintained until the end of the experiment. Fish were fed to apparent satiation twice daily at 10.00 hours and 16.00 hours on fresh formulated pellet diet containing 32 per cent protein (*Rastrineobola argentea* (fish meal) and rice bran). Feeding was at five per cent body weight up to harvest. After every two weeks, 30 fish from each cage were randomly sampled for individual total length (TL, cm) and weight (g). The weight obtained after every sampling date was used to calculate the quantity of feed to be given in the next two weeks following the sampling date. Before every feeding and sampling, dead fish were noted and removed. The experiment was carried for fourteen weeks between June 2007 and October 2007.

Water quality parameters including temperature, pH, water transparency, dissolved oxygen, nitrates (NO_3-N), and soluble reactive phosphorus (SRP) were monitored fortnightly. Water temperature and pH were measured at a depth of five cm at 08:00 and 17:00 hours, using a YSI model 58 oxygen meter (Yellow Springs Instruments, OH, USA) and a pH metre (Hanna Instruments, Model 8519N, Singapore) respectively. Values for water transparency were obtained using a Secchi disc. Water quality analyses were done according to procedures adopted from the American Public Health Association standard methods (APHA, 1998).

The survival rate (S_t%) was calculated as:

$S_t = (N_t/N_0) \times 100$,

Where N_t, is total number of fry sampled at t days, N_0 is the total number of fry at start of experiment.The specific growth rate (SGR) was calculated as:

SGR (%day^{-1}) $=[100(\ln W_f - \ln W_i)/t]$,

Where; *ln* refers to natural logarithms, W_f and W_i are the initial and the final weights (g) of the fish, and t is time in days. Feed conversion ratio (FCR) was computed as:

$FCR = F_t / WG_t$,

Where, F_t and WG_t are the total feed consumed in grams over the time (t) and the weight gain during the time t (g) respectively. Daily weight and length gains were calculated as :

Percentage body weight/length increase = $100^*(B_f)-(B_i)/B_i$, where B_i and B_f are the initial and final body weights/length of the homogenous groups respectively.

Data analyses were done using SPSS 11.0 statistical software package. The effects of the three stocking density of *O. niloticus* on growth performance, survival and on the water quality variables were analysed using one-way ANOVA (Zar, 1999). When significant differences were indicated by ANOVA test ($P<0.05$), the mean differences among individual treatments at $P<0.05$ level of significance were evaluated using Duncan's multiple range test (DMRT) (Zar, 1999).

Results

Survival rate ranged from 61.7 per cent to 97.0 per cent at all stocking densities at the end of the experiment (Fig. 1). The survival trend at different stocking densities showed no difference in the first 30 days. The survival trend curves for 90 fish m^{-3} significantly differentiated ($P<0.05$) from that of 60 fish m^{-3} after 10 weeks. At 12 weeks the growth curve of fish stocked at 30 fish m^{-3}, 60 fish m^{-3} and 90 fish m^{-3} had significantly different from each other ($P <0.05$).

Data on growth performance of *O. niloticus* after 14 weeks of the experiment is presented in Table 1. The final lengths and weight of *O. niloticus* were significantly different among the treatments ($P < 0.05$). The highest, intermediate and the lowest mean length and weight were recorded in fish stocked at 30 fish m^{-3}, 60 fish m^{-3} and 90 fish m^{-3} respectively. Highest percentage gain in length and weight was also recorded in the same stocking densities. Mean daily length gain was significantly ($P < 0.05$) higher in fish stocked at 30 fish m^{-3} in comparison to fish stocked at higher stocking densities. Mean weight gain was also significantly higher ($P < 0.05$) in fish stocked at 30 fish m^{-3} compared to fish stocked at $60m^{-3}$ and 90 m^{-3} in the cages. The food conversion ratio (FCR) was significantly higher in fish stocked at 90 fish m^{-3} compared to stocking of 60 fish m^{-3} and 30 fish m^{-3} ($P<0.05$). Specific growth rate (SGR) of fish stocked at 30 fish m^{-3} was significantly higher than fish stocked at 60 fish m^{-3} and $90m^{-3}$ ($P < 0.05$).

Table 1: Growth performance of O. niloticus at three different stocking densities in cages. In each line for every experiment means with the same letters as subscripts are not significantly different (P>0.05).

Parameter	Stocking density (m^{-3}) 30	60	90
Stocking length (cm)	9.02 ± 0.02^a	9.02 ± 0.02^a	9.05 ± 0.02^a
Stocking weight (g)	15.06 ± 0.02^a	15.05 ± 0.02^a	15.04 ± 0.02^a
Harvest length (cm)	14.75 ± 0.02^c	13.01 ± 0.06^b	12.29 ± 0.36^a
Harvest weight (g)	61.61 ± 0.19^c	45.35 ± 0.51^b	32.88 ± 0.36^a
Gain in length (cm)	5.57 ± 0.03^c	3.77 ± 0.07^b	2.94 ± 0.04^a
Gain in weight (g)	45.58 ± 0.19^c	30.33 ± 0.51^b	17.84 ± 0.36^a
%Gain in length (cm)	160.66	140.75	131.52
%Gain in weight (g)	403.11	301.91	218.59
Daily gain in length ($cmday^{-1}$)	0.050^c	0.033^b	0.026^c
Daily gain in weight ($gday^{-1}$)	0.411^c	0.272^b	0.160^c
SGR	$0 .42 \pm 0.03^c$	0.30 ± 0.05^b	0.24 ± 0.03^a
FCR	0.05^a	0.08^b	0.10^c

Fish stocked at $30m^{-3}$ and 90 m^{-3} maintained the highest and the lowest trend in growth (Fig. 2a) and weight (Fig. 2b). Trend in growth in length and weight for fish stocked at $60m^{-3}$ was intermediate. The growth curves were significantly different from each other after 6 weeks of growth (P < 0.05). Water quality data are presented in Table 2. There were no significant differences (P> 0.05) in water quality parameters among treatments except total ammonia nitrogen (TAN-N). Increasing values of TAN-N with increased stocking density were observed (P < 0.05).

Discussion

The observed growth performance of *O. niloticus* was better in fish reared at the lowest density of 30 fish m^{-3}. Survival rates ranged between 61.7 per cent to 97.0 per cent, which were within the range of 59.3 to 71.6 per cent obtained by Liti *et al.* (2005) on *O. niloticus* fingerlings stocked at 150 fish per 2.8 m^3 in cages suspended in fertilized ponds. The survival trend curve for 90 fish/m^{-3} were significantly different (P<0.05) from that of 60 fish/m^{-3} after 10 weeks. This was probably due to crowding, which may have resulted to increased stress. Liti *et al.* (2005) and Kebus *et al.*, (1992) found increased stocking densities to affect fish survival, which they attributed to low feeding rates and stress.

At 12 weeks the all growth curves of Nile tilapia significantly differentiated from each other (Fig. 2). Literature on the effect of stocking density on growth performance of *O. niloticus* is not consistent. For example, Silva *et al.*, (2000) found SGR to be negatively related to stocking in Nile tilapia and tetra hybrid red tilapia. Youssouf *et al.* (2007) evaluated the effect of stocking density on growth of *O. niloticus* in earthen ponds and found that the mean weight gain, the specific growth rate and the apparent food conversion ratio were mostly reduced at the highest stocking density of 5 fish/m^{-2} compared to the density of 1 fish/m^{-2} and 3 fish/m^{-2} respectively. He recommended 3 fish/m^{-2} as the optimum stocking density in ponds at semi-intensive management level. On the contrary, Gall and Baker (1999) reported that body size of tilapia was not affected by stocking densities from 10 to 200 fry L^{-1} when water flow was uniform. Further, Macintosh and De Silva (1984) found that the relationship between the survival of *Oreochromis mossambicus* and *O. niloticus* female x *Oreochromis aures* male fry and stocking density was not consistent.

Inconsistencies in the reported effects of stocking densities on growth performance of Nile tilapia could be due to several factors, which are interrelated. Different authors explain the cause of low survival and poor growth performance as stocking density increases due to competition for food, space limitation, low dissolved oxygen, competition for territories, stress due to crowding, reduced availability of natural food in the cage (Yi *et al.*, 1996, Huang and Chin, 1997, Pankhurst and Van der Kraak, 1997; Liti *et al.* 2005; El-Sayed, 2002; Youssouf *et al*, 2007). The lower growth performance in this study might have been due to varied reasons as explained above, but accumulation of ammonia, low temperatures and reduced fish appetites due to overcrowding might have played the major role.

Most of the water quality variables in the study were not significantly different among treatments except for ammonia. High ammonia and reduced dissolved oxygen in the cages with the highest stocking density could be due to high concentration of fish. Increased stocking density reduced water circulation in the cages reduces dissolved oxygen and allowed accumulation of ammonia. Moreover, increased feeding fish in cages leads to concentration of ammonia through decomposition of protein (Liti *et al.*, 2005). Un-ionized ammonia fluctuated between 0.05-0.06 mg L^{-1} during the course of the study. Liti *et al.* (2005) also observed similar fluctuations (0.04-0.06mg L^{-1}), in an integrated pond cum-cage culture. Poor water quality, especially low dissolved oxygen (DO), depresses fish growth, while chronic levels of unionized ammonia (above 0.08mg L^{-1}) often lead to reduced fish growth and eventual fish mortalities (Hargreaves and Kucuk, 2001). Reduced DO and increase in ammonia as stocking density increased could have contributed to depressed growth observed.

The food conversion ratio (FCR) increased with increase in fish density. Similar results were obtained by Youssouf *et al.* (2007) who evaluated the effect of stocking density on growth of *O. niloticus* in earthen ponds. The authors found that the mean weight gain, the specific growth rate and the apparent food conversion ratio were mostly reduced at the highest stocking density of 5 fish m^{-2} compared to the density of 1 fish/m^{-2} and 3 fish/m^{-2} respectively. He recommended 3 fish/m^{-2} as the optimum stocking density in ponds at semi-intensive management level. As the stocking density increases, the food conversion ratio also increases most probably due to feed wastage, feeds not available to the fish and loss of appetite of the fish. It has also been suggested that high densities impair visual location of food and prevent physical accesses by making it difficult for fish to follow a trajectory towards the food pellets (Silva *et al.*, 2000). Under crowded conditions fish suffer from stress as a result of aggressive feeding interactions and they eat less resulting in growth retardation (Liti *et al.,* 2005). The FCR values observed in the present study of 0.05 to 0.10 are low compared to studies by Liti *et al.* (2005) of 1.0 to 1.5 and Yi and Lin (2001) of 1.22 to 1.70 with young tilapia. The low FCR may be attributed to low temperatures in the study site of 21^0C.Tilapia are strongly thermophilic, and feeding rates increases with increase water temperature. Tilapia activity and feeding decrease as temperature falls below 20^0C and feeding is depressed at 16 ^{0}C and 34 ^{0}C (Chervinski, 1982). The optimum feeding level for Nile tilapia is close to 28^0C (Lovell, 1998).

References

APHA (American Public Health Association) 1998. *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association. Washington D.C., USA.

Chervinski, J. 1982. Feeding, metabolism and growth of tilapias: some quantitative considerations. In: *The Biology and Culture of Tilapias. ICLARM Conference Proceedings* (ed. By R.S.V. Pullin & R. H. McConnell), pp. 157-180. Manila, Philippines.

El-Sayed, A. F. M. 2002. Stocking density and feeding levels of Nile tilapia fry. *Aquaculture Research* 33: 621-626.

Gall, G. A. E and Bakar, Y. 1999. Stocking density and tank size in the design of breed improvement programs for body size of tilapia. *Aquaculture* 173: 173-205.

Guerrero, R. D. 2002. Tilapia farming in the Asia –Pacific region. In: *International Forum on Tilapia farming in the 21st century* (ed. Guerrero R.D and M.R Guerrero) pp. 42-49. Laguna, Philippines.

Hargreaves, J. A. and Kucuk, S. 2001. Effects of diel un-ionized ammonia fluctuation on juvenile hybrid striped bass channel catfish and blue tilapia. *Aquaculture* 195: 163-181.

Huang, W. B. and Chiu, T. S. 1997. Effect of stocking density of survival, growth, size variation, and production in tilapia fry. *Aquaculture* 28: 165-173.

Kebus, M. J., Collins M. T, Brownfield, M. S., Amundson, C. H., Kayes T. B. and Malison J. A. 1992. Effects of rearing density on stress response and growth of rainbow trout. *Journal of Aquatic Health* 4: 1-6.

Lovell, T. (1998) *Nutrition and Feeding of Fish*, 2nd edn. Kluwer Academic Publishers, MA, USA, 267 pp.

Liti, D. M., Fulanda, B., Munguti, J. M., Straif M., Waidbacher, H. and Winkler, G. 2005. Effects of pond density and cage biomass on performance of *O. niloticus*. *Aquaculture Research* 36:1535-1543.

Macintosh, D. J. and De Silva, S.S. 1984. The influence of stocking density and food ration on fry survival and growth in *Oreochromis mossambicus* and *O. niloticus x O. aureus* male hybrids reared in a closed circulated system. *Aquaculture* 41: 345-358.

Ngugi, C. C. and Manyala, J. O. 2004. Aquaculture extension services in Kenya. In: *Aquaculture Extension Services in Sub-Saharan Africa. Fisheries Department Circular* – C1002. (ed. by FAO), pp. 35-42. FAO Fisheries Deparment, Rome, Italy.

Pankhurst, N. W. and Van der Kraak, G. 1997. Effects of stress on reproduction and growth of fish. In: *Fish stress and Health in Aquaculture* (ed. by G. K. Iwama and A. D. Pickering), pp. 73-93. Cambridge University Press, Cambridge.

Silva, P. C., Souza V. L., Padua D. M., Dalacorte P.C. and Goncalves D. C. 2000. Effects of stocking density on growth and fillet composition of tetra hydrid red tilapia, Israeli strain. In: *Tilapia Aquaculture in the 21st Century. Proceedings from 5th International Symposium on Tilapia Aquaculture* (Fitzsimmons & J.C. Filho Eds.), pp. 342-345. Rio De Janeiro, Brasil.

Yi, Y. and Lin, C. K. 2001. Effects of biomass of caged Nile tilapia (*Oreochromis niloticus*) and aeration on the growth and yields in an integrated cage cum-pond system. *Aquaculture* 195, 253-267.

Yi. Y., Lin, C. K and Diana J. S. 1996. Effects of stocking densities on growth of caged Nile tilapia (*Oreochromis niloticus*) and on yield of small tilapia in open pond water in earthen ponds. *Aquaculture* 146: 205-215.

Youssouf, A., Deiogbe, E. and Micha, J. 2007. Effects of stocking density on growth, yield, and profitability of farming Nile tilapia (*Oreochromis niloticus* L) fed Azolla diet, in earthen ponds. *Aquaculture* 207: 595-604.

Zar, J. H. 1999. *Biostatistical analysis*. Prentice-Hall, New Jersey, USA 663 pp.