Oceanography & Fisheries
Open Access Journal

Research Article
Volume 1 Issue 1 - April 2016

Oceanogr Fish Open Access J

Temporal And Spatial Changes In Water Quality In Lake Malawi/Niassa, Africa: Implications For Cage Aquaculture Management

Macuiane MA[1,2]*, Hecky RE[1,3] and Guildford SJ[1,3]

[1] *1Large Lakes Observatory, University Minnesota Duluth, USA*

[2] *Instituto Nacional de Desenvolvimento da Aquacultura, Moçambique*

[3] *Biology Department, University of Minnesota, USA*

Submission: February 17, 2016; **Published:** April 05, 2016

***Corresponding author**: Macuiane MA, Large Lakes Observatory, University Minnesota Duluth, 2205 East 5th St, Duluth, MN, 55812, United States of America, Tel: +258 842264947; Fax. +258 251 23002; Email:macui001@d.umn.edu

Abstract

Water temperature (WT), Secchi depth (SD), Percent dissolved oxygen (%DO), Dissolved oxygen (DO), Total nitrogen (TN), Total phosphorous (TP), and Chlorophylla (Chla) were measured in three sites, one at the farm (site 2) and two, 5 km northwest (site 1) and southeast (site 3) of the farm respectively, in February, April, June, and August 2012 to assess their spatial and temporal change in relation to cage aquaculture. There was clear seasonal change in % DO, DO, Chla, and SD at all sites. WT, % DO, and DO were consistently greater at site 1 than at site 3. Chla and SD were inversely correlated. The highest Chla and lowest SD occurred in April. The water was less clear at the farm, relative to the non-farm sites. Interestingly, this pattern was not seen in the Chla suggesting that decreased transparency at the farm was caused by some other factors in addition to Chla. DO, TP, and Chla are among the water quality parameters frequently used to assess aquaculture impacts. In this study, none of these indicators including the TN were consistently different at the study sites, suggesting that fish stocking densities present during the sampling period did not affect these water quality parameters; alternatively, it may suggest that high dispersion of nutrients mask the effect on water quality. However, water quality should be monitored at the farm during the upwelling period between April and July to avoid potential stress or fish kills.

Keywords:Lake Malawi; Cage aquaculture; Water quality; Nutrients

Abbreviations: WT: Water Temperature; SD: Secchi Depth; %DO: Percent Dissolved Oxygen; DO: Dissolved oxygen; TN: Total Nitrogen; TP: Total Phosphorous; Chla: Chlorophylla; FAO: Food and Agriculture Organization; P: Phosphorous; N: Nitrogen; C: Carbon; CTD: Conductivity Temperature and Depth; ANOVA: Analysis of Variance; LSD: Least Significant Difference; SRP: Soluble Reactive Phosphorous; PP: Particulate Phosphorous; PC: Particulate Carbon; PN: Particulate Nitrogen

Introduction

Aquaculture continues to be the world's fastest growing animal-food industry with global contribution of about 46 percent of total food fish supplied in 2008, when landings from both capture fisheries and aquaculture accounted for 142 million tons [1]. In 2011, the industry achieved a remarkable fish production overtaking beef; this gap further increased in 2012 when the industry produced about 66 million tons compared to 63 million tons of beef produced in this year [2]. This growth increases fish consumption, creates employment opportunities, and boosts local economies; however, concerns are often expressed about possible negative impacts on receiving waters due to accumulation of nutrients linked to primary production of aquatic ecosystems.

Håkanson et al. [3] estimated that about 80% of phosphorous (P) provided in fish feed is lost to the environment in particulate (70%) and dissolved (10%) form, and only 20% of P is used for fish growth and eventual harvest, while only 25% of nitrogen (N) in feed is used for fish growth, 75% lost is to the environment. Islam (2005) [4]estimated that in one ton of fish produced, about 132.5 kg of N and 25 kg of P are released into the environment. Bristow et al. [5] investigated the effect of a rainbow trout (*Oncorhynchus mykiss*) cage farm in the Experimental Lakes Area in Canada during the first three years of its operation and concluded that the annual input of P from waste (67-100 kg) exceeded the natural budget inputs (4-18 kg) from atmospheric deposition and inflows to the small study lake. In an earlier study of the impact of aquaculture in Lake Malawi, Gondwe et al. [6]

estimated average discharges of 12,341; 1,303; and 534 kg/year of carbon (C), N, and P, respectively at Maldeco Aquaculture farm at a production capacity of ~200 tones fish/year in 2007.

In poorly flushed areas, the increase in suspended solids derived from fish farms in the form of uneaten feeds and feces, organic and inorganic nutrients mainly N, P, and C in the water column and sediments [3] is accompanied by increased lake productivity, a process called cultural eutrophication (Laws, 2000) [7] , characterized by overall degradation of water quality status. The effects of eutrophication include oxygen depletion in the water column [8], increased phytoplankton production and blooms [9], presence of *cyanobacteria associated* with organic enriched nutrients [7], presence of sulphur bacteria *Beggiatoa* spp. beneath the cages [10], impacts on benthic diversity and communities [11], and dominance of opportunistic polychaetes *Capitella capitata* and *Scolelepis fuliginosa* [10]associated with organically polluted areas [12-13]. Impacts from increased nutrients may be severe in oligotrophic lakes such as Lake Malawi where N, P, and iron are the main limiting nutrients [14]. Thus, addition of large amounts of these nutrients, especially P, whether from aquaculture operations, agricultural runoffs, or other point or non-point sources will not only increase phytoplankton biomass, but will favor nitrogen fixing bacteria and the presence of potentially toxic phytoplankton species to fish and humans [15].

Monitoring of water quality is important not only for the sake of complying with regulations and providing data to regulatory authorities to show that the farm is not having negative impacts in water bodies, but also because it is important to the fish being cultured as they are dependent on water for all their bodily requirements and functions; therefore, it becomes important to monitor the water quality for the overall farming success. Thus, the current study assessed temporal and spatial changes of water quality associated with cage aquaculture operation in Lake Malawi. DO and Chla, the two parameters most associated with poor water quality were the main focus of the study. Other parameters measured that are highly relevant to Chla concentration are algal nutrients N and P. SD, a measure of water transparency which can inform about the amount of light available for algal growth and can also be highly correlated to Chla concentration was measured. In addition, WT was measured as it can impact metabolism of all organisms from bacteria to fish and it can determine the strength and duration of stratification in the water column.

Materials and Methods

Study area

Lake Malawi as it is known internationally and in Malawi, Lago Niassa in Mozambique, and Lake Nyasa in Tanzania lies in south/central Africa between 9°30'S and 14°30'S. Lake Malawi as it will be treated throughout the study is the third largest lake in Africa after Lakes Victoria and Tanganyika. Internationally, the lake is known for its spectacular species diversity of endemic cichlid fauna [16-17]. Importantly, the lake has more fish species diversity than any other lake in the world which is estimated between 500 and 1000 species in which more than 90% are endemic[17-18]. The majority of fish species are haplochromine cichlids [19]. Being a shared water resource, the riparian countries benefit from Lake Malawi as a source of drinking water, domestic use, irrigation, fishing, transportation, tourism, scientific research, and electricity [20].

Maldeco Aquaculture farm was established in the year 2004 and is the only commercial cage operation in Lake Malawi, farming *chambo* species, an aggregate of three endemic cichlids native to Lake Malawi (*Oreochromis karongae, O. lidole*, and *O. squamipinnis*). In addition to *chambo, O. shiranus*, a native cichlid species similar to *chambo* is farmed and sold as chambo. There are 51 circular cages, each with 16 m diameter and 6 m deep. The average stocking density per cage during the study period was 130,000 fish corresponding to 108 fish per $m^{3.}$

Sampling sites

The data set in the current study was measured in three sites, one at the farm (site 2) and two, 5 km northwest (site 1) and southeast (site 3) of the farm in February, April, June, and August 2012, during the day in the south east arm of Lake Malawi (SEA) along a 10 km south-northwest transect (Figure 1) which include the Maldeco cage aquaculture farm, the focal study area. Sites 1 and 3 were at similar distance from the shoreline but had the same water depth (~16 m) range as site 2 at the fish farm. At each of the three widely separated sites, *in situ* measurements and water sample collections were made at two closely spaced locations to provide replication of the measurements for each site (Figure 1).

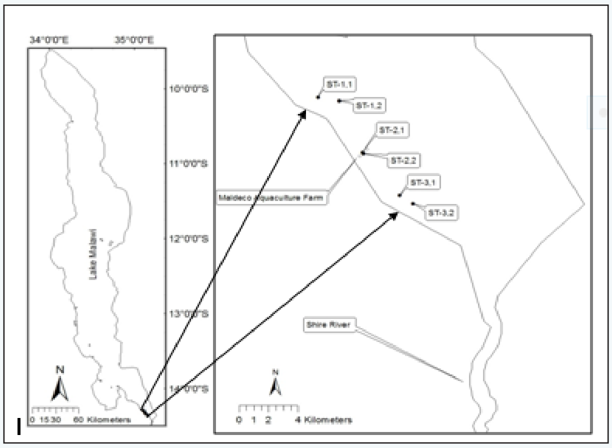

Figure 1: Lake Malawi (left) and sampling sites (ST-1,1 is site 1 replicate 1, ST-1,2 is site 1 replicate 2, ST-2,1 is site 2 replicate 1, ST-2,2 is site 2 replicate 2, ST-3,1 is site 3 replicate 1, and ST-3,2 is site 3 replicate 2) including Maldeco Aquaculture farm (right).

In-situ measurements

In-situ measurements for WT (°C), %DO (%), DO (mg/l) and Chla fluorescence (μg/l) were made using a Conductivity

How to cite this article: Macuiane M, Hecky R , Guildford S. Temporal And Spatial Changes In Water Quality In Lake Malawi/Niassa, Africa: Implications For Cage Aquaculture Management. Oceanogr Fish Open Access J. 2016; 1(1): 555552

Temperature and Depth (CTD) (Branckner, XR- 620). Inspection of the profiles revealed no persistent thermal stratification at any of the sites. However diel heating and cooling of the surface at 3 m was observed occasionally. In order to eliminate these diel variations which could depend strongly on time of sampling and to examine the portion of the water column that is within the same depth range as the aquaculture cages (6 m), only the data from 4.5 to 5.5 m in the profiles was used. This depth range was chosen after examining all the profiles and was found to be the most representative depth. SD was determined by manual deployment of the Secchi disk, a white and black disk with 20 cm diameter Wildco Secchi disk attached to measuring line. The depth at which the disk was no longer visible was the measured Secchi depth.

Water sample collection

Water was collected at each sampling site by dipping a clean nalgene bottle just under the water surface (0-0.1 m). Water was used for extraction of Chla which was used as an estimate of phytoplankton biomass in this study. Water samples were first pre-screened with a Nytex netting material (210 µm nominal pore size) to remove large organisms such as zooplankton or suspended organic and inorganic particles and then passed onto 47 mm Whatman GF/F filters (0.7 µm nominal pore size). The filters were then wrapped in aluminum foil and kept frozen for subsequent analysis. Chla was extracted from filters in 90% acetone for approximately 24 hours and fluorescence readings were made using a Turner 10AU fluorometer calibrated with a pure Chla standard.

Water samples (0-0.1 m) for TP and TN were also collected directly into clean nalgene sample bottles and preserved by storing them frozen. Before proceeding with preservation, the samples were pre-screened by passing through a netting material (210 µm nominal pore size). TP analyses followed a protocol adapted from Stainton et al., Murphy and Riley, and by Wetzel and Likens [21-23]. Freshly made saturated potassium persulphate ($K_2S_2O_8$) was added to the samples and digested in a Harvey sterileMax sterilizer for an hour. TP (µg/l) was quantified after the addition of the reagents and development of color [21] by reading the absorbance at 885 nm in a UV spectrophotometer (UV-1800). Digestion with $K_2S_2O_8$ was also applied in TN analysis. TN (µg/l) was analyzed and the concentrations estimated by the flow injection method in a Lachat (QuikChem, series 8000).

Statistical methods

Bi-monthly and site mean values were plotted to visualize and describe seasonal and spatial trends in water quality parameters. Analyze of Variance (ANOVA) using SPSS Statistics v-20 was applied to identify significant differences within and between months and sites, respectively. In addition to general p-values provided by ANOVA; Post Hoc multiple comparison used Least Significant Difference (LSD) to discriminate months and sites that were significantly different from each other and those that were not, at a significance level of $p \leq 0.05$.

Results

Surface Chla concentrations were low in February (site 1=0.57±0.01 µg/l, site 2=0.63±0.06 µg/l, and site 3=0.65±0.05 µg/l) (Figure 2a) but increased to significantly higher concentrations in April (site 1=3.95±0.19 µg/l, site 2=4.79±0.65 µg/l, and site 3=5.54±0.29 µg/l) than those recorded in February, June, and August ($p<0.05$) (Figure 2a). Since changes in surface Chla concentrations were similar at all three sampling sites, no significant differences were detectable among the sites in February, June, and August ($p>0.05$), except in April ($p<0.05$) between site 3 (5.54±0.29 µg/l) and site 1 (3.95± 0.19 µg/l) (Figure 2a), but not between sites 1 and 2, nor between sites 2 and 3 in April ($p>0.05$).

WT exhibited a clear seasonal pattern characterized by coolest temperatures in June (site 1=22.73±0.05°C, site 2=22.40±0.04°C, site 3=22.49±0.00°C) and warmest in February (site 1=28.15±0.04°C, site 2=27.95±0.09°C, site 3=27.77±0.01°C) (Figure 2b). Overall, the lake WT dropped by 5.42°C, 5.56°C, and 5.28°C in sites 1, 2, and 3 respectively between the warmer (February) and cooler (June) month. Significant differences in February were observed between sites 1 and 3 ($p<0.05$), but not between sites 1 and 2, nor between sites 2 and 3 ($p>0.05$). The first drop in WT was observed in April and the WT measured in this month was significantly lower than that recorded in February ($p<0.05$); the loss of heat in the lake in April was strong and similar at all sites, therefore, no significant difference were detected among the sites ($p>0.05$, Figure 2b). Lake water was significantly cooler in June than the rest of the months (February, April, and August) ($p<0.05$) (Figure 2b). Although June was the coolest month, site 1 had significantly warmer waters than sites 2 and 3 ($p<0.05$), but no significant difference was detected between sites 2 and 3 in June ($p>0.05$). A rise in WT was noted in August when the lake became significantly warmers than the WT measured in June in all sites ($p<0.04$) (Figure 2b). In August the sites were not significantly different from each other with respect to WT ($p>0.05$) (Figure 2b).

Low SD, which indicates reduced water clarity or increased turbidity was recorded in April in all sites (Figure 2c), resulting in April being significantly different from February, June, and August ($p<0.05$, Figure 3-2c). Sites 1 (6.00± 0.00 m) and 3 (6.25± 0.35 m) had similar SD values in February, and both had significantly higher values with those measured in site 2 ($p<0.05$). Site 1 maintained higher water clarity than other sites even when all the sites had increased turbidity in April; as such site 1 (4.00±0.00 m) clarity was significantly higher than those recorded in sites 2 (1.9±0.10 m) and 3 (2.00±0.00 m) ($p<0.001$, Figure 2c), but sites 2 and 3 were not significantly different from each other ($p>0.001$). Although there was no significant difference in SD values among the sampling sites in June and August ($p>0.05$, Figure 2c), the values recorded in these month were significantly different from those recorded in April ($p<0.05$, Figure 2c).

How to cite this article: Macuiane M, Hecky R , Guildford S. Temporal And Spatial Changes In Water Quality In Lake Malawi/Niassa, Africa: Implications For Cage Aquaculture Management. Oceanogr Fish Open Access J. 2016; 1(1): 555552

Significant temporal changes observed in %DO (p=<0.05) (Figure 2d). The lowest values (site 1=76.06±0.07%, site 2=74.07±0.14%, and site 3=71.06±0.77%) and the highest (site 1=98.31±0.39%, site 2=91.94%, and site 3=93.61±0.24%) were recorded in June and February respectively (Figure 2d). The waters from site 1 were significantly closer to saturation than sites 2 and 3 in February (p<0.001), April (p<0.05), and in August (p<0.001) (Figure 2d), but not in June. Sites 1 and 2 were similar in June and both had significantly higher %DO than site 3 (p<0.05). Sites 3 had higher %DO than site 2 in February (p<0.001). %DO was similar between sites 2 and 3 in April and August. As the lake was becoming cooler (Figure 2b), the %DO also followed suit; the lake gradually becomes less oxygen saturated towards June, but in August the oxygen saturation returns to previous values seen in April (Figure 2d), therefore, there was no significant difference in %DO recorded between April and August in sites 1 and 3 (p>0.05). Other significant differences were observed between February and April (p<0.05), February and June (p<0.05), and between June to August (p<0.05, Figure 2d).

There was a strong seasonal effect on DO concentrations (Figure 2e). Site 1 had significantly higher DO than sites 2 and 3 in February, April, and August (p<0.05) but not in June. In June, the DO was similar in sites 1 and 2, but were both sites had significantly higher than DO that recorded in site 3 (p<0.05) (Figure 2e). Site 3 had higher DO than site 2 in February (p<0.05), but the concentrations were similar in April and August. Oxygen concentrations were significantly different between February and April (p<0.05) (Figure 2e) when the lake was cooling; the difference was even higher between February and June, the beginning of the windy, upwelling season (p<0.05) when the lake recorded the minimum DO (site 1=6.53±0.01 mg/l, site 2=6.39±0.02 mg/l, and site 3 = 6.13±0.07 mg/l). Regardless of increased DO in August, the concentrations were significantly different with those measured in June and February (p<0.05), there was no significant difference with those recorded in April (p>0.05). The concentrations remained significantly higher in August in site 1 compared to sites 2 and 3 (p<0.05) (Figure 2e).

Relative temporal changes in TN concentrations over the sampling period had similar trend at sites 2 and 3, but with different values (Figure 2f). For instance, in February the TN at site 2 (148.45±1.67 mg/l) was significantly higher than that recorded at site 3 (93.85±0.64 mg/l) (p<0.05). TN concentrations declined at sites 2 and 3 in April to minimum values June and stayed relatively low in August. Sites 1 and 3 had similar TN concentration in February but then the concentrations increased in site 1 and reached the highest TN in August.

Similar to the temporal trends observed in TN, TP concentrations exhibited almost a similar pattern. For instance, sites 2 and 3 had similar trend (Figure 2g). Both sites started with relatively high TP in February though they were significantly different from each other (p<0.05, site 2=23.64±2.01, site 3=17.36±0.65 μg/l). Site 2 lagged behind in reduction of its TP compared to site 3, while the concentrations dropped immediately in site 3 in April (Figure 2g) and were then stable in April, June and August (non-significant months, p>0.05), the concentrations in site 2 dropped to a minima in June and this concentration was significantly lower than those recorded in February and April (p<0.05) at the same site, but higher than those recorded in sites 1 and 3 (p<0.05) in the same month (Figure 2g).

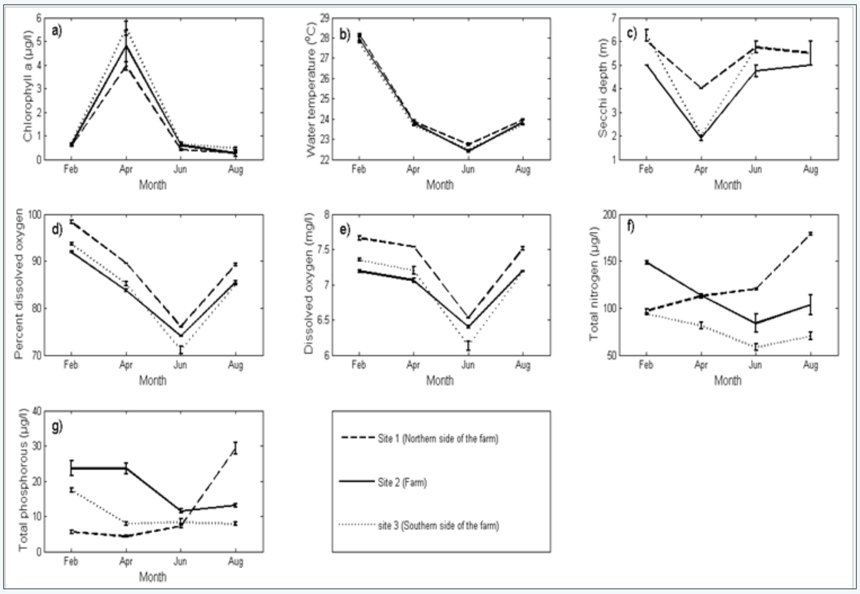

Figure 2: Temporal (month) and spatial (site) changes in surface water quality parameters in Lake Malawi along a northwest-southeast 10 km transect including the tilapia cage aquaculture farm.

Discussion

High %DO, DO, and SD readings were first recorded in February when the highest WT were reported for all sampling sites. The lake became less oxygen saturated with relatively low DO starting in April and reached minimum concentrations in June, but in August it recovered to previous saturated values seen in April (Figure 2d) at all sampling sites. Minor lags in cooling and warming of water, decrease and increase in %DO and DO were observed among the sampling sites. For instance, April and August marks the months on which there was no significant difference in WT in the three sites. Site 1 had high WT in June, while in February the WT at site 1 was only higher compared to that recorded in site 3 ($p<0.01$). The slightly warmer site 1 (Figure 2b) had significantly higher %DO than sites 2 and 3 (the significantly cooler sites) (Figure 2d). %DO concentration was always higher in site 1, as was the DO concentrations regardless of changing WT. When water is equilibrated with the atmosphere, warmer waters hold less oxygen than colder water. The fact that %DO was higher at site 1 compared to site 2 and 3 suggests that whatever phenomenon was causing oxygen to be depleted at sites 2 and 3 was stronger than at site 1. These results are an important component for both Maldeco farm and lake wide management.

DO plays an important role in fish production as it directly effects feed consumption, energy expenditure, and the rate of metabolism in farmed fish [24, 25]. Thus the DO concentrations have the potential of affecting farm's operational costs if they fall below optimum recommended levels for a particular organism. Although DO varies inversely with WT, WT is a difficult physical parameter to control in cage aquaculture systems. Therefore, farms should try to control the DO required by the fish to aerobically generate required energy for growth [25]. Some active management strategies to prevent oxygen stress would include avoiding overcrowding of fish in cages, frequent sampling for DO, and partial harvests in the farm to prevent low DO if the problem is thought to be due to high stocking biomass.

The climate in Malawi is characterized by warm and dry (October–November), warm and wet (December–April), and cool and dry (May - September) periods [26, 27]. Similar to the current study, Macuiane et al. [28] observed a drop in WT in a nearby Lake Chilwa from 28.0oC in February to 21.6oC between May and July. Low WT during this period was also noted in southern Lake Malawi in Monkey-Bay station in 1967 and 1968 [26]. Although site 1 has statistically significant higher WT than site 2 and 3 the absolute difference in temperature is negligible. What is most interesting is that the DO is much higher at site 1 than at sites 2 and 3. Site 1 closer to the deep open lake is well supplied with oxygen, however site 2 and to some extent site 3 have lower oxygen suggesting that there is some source of lower oxygen water at these sites. Low DO concentrations at site 2 could be influenced by the farm itself due to oxygen consumption by farmed fish and wild fish populations thereby reducing the concentration at the farm perimeter. Site 3 is located at the same depth with sites 1 and 2 and all sites are located at similar distance to the shore. However, the bathymetry surrounding site 3, nearer the southern end of the basins is overall shallower than that of sites 1 and 2, therefore, low DO concentrations at site might be related to the surrounding shallow areas.

Despite the fact that all sampling sites had high WT and DO concentrations most of the time, minimum WT and DO were recorded in June (Figure 2b and 2d). Gondwe et al. [29] observed a similar trend; they also found minimum bottom DO of 3.0 mg/l at 23oC in May. Cooler waters equilibrated with the atmosphere would be expected to have higher DO than warmer waters, but the opposite trend was seen in these sites in the SE arm suggesting that the upwelling during May through June creates upward transport of low oxygen waters to the surface. It is therefore, important for aquaculture operations in Lake Malawi to appreciate that there will be periods of low oxygen in this area created by lake wide processes. Upwelling is important in Lake Malawi. As noted earlier by Bootsma et al. [30], the nutrients at the surface waters are low and increase with depth. Lack of thermal mixing prevents the nutrients from reaching the upper photic zone, especially in deep areas of the lake. Hamblin et al. [31] noted on four occasions from May to August 1997 upwelling driven by offshore south east winds which resulted in longitudinal temperature gradients in the southern part of Lake Malawi.

The minimum DO observed in the current study (above 6.0 mg/l) was higher than 3.0 mg/l regarded as minimum recommended in catfish raceways and tilapia farming [32,33] , thus, the farm and remote sites from it at the time of data collection were well ventilated and the captive fish were provided with optimum DO. In addition, the %DO was above 70%, a level below which is known to affect feed consumption of channel catfish [34]. However, it should be noted that oxygen demand by captive fish depend on the standing biomass in the cages plus that of wild fish populations at the farm which can further reduce DO locally in and around the cages. Taking into consideration that tilapias exhibit optimum growth rates above 3.0 mg/l[33] and based on Brown et al. [32] estimates that only 3.38 mg/l DO is available to fish if the inflowing DO waters are 6.38 mg/l. then it suggests when the inflowing DO at Maldeco farm is 6.0 mg/l, only 3.0 mg/l is available to fish. Therefore, farm operators should carefully monitor farm water quality for low DO and % DO, especially between April and July. April, on the other hand exhibited the highest phytoplankton biomass estimated by Chla concentrations and the lowest water clarity which may have resulted from increased dissolved nutrient concentrations advected from deeper waters early in the upwelling period.

Dissolved inorganic nutrients can affect the pelagic ecosystems most since they are quickly absorbed and assimilated by phytoplankton and bacteria [35] and may consequently increase lake's primary productivity and cause algal blooms and eutrophication when the system is unable to handle increased loading rates of nutrients. Depending on the system, the amount of nutrients released in one system with no signs of negative effects may have deleterious effects in another system which may be more poorly ventilated by current. Thus, it becomes important to investigate the capacity of a particular lake location to process nutrient loadings that are projected for cage culture or expansion of cages while maintaining healthy ecosystem for potential and alternative use of the water resource.

Mass balance analyses have been used to quantify the amount of nutrients released by cage farms into the environment. Unfortunately, association of cage aquaculture effluents to nutrients concentrations in Lake Malawi environment and probably elsewhere seem to be difficult to trace owing to energetic lake dynamics and potential imports of nutrients advected from other areas e.g. during upwelling; the calm and stratified period prior to upwelling of higher nutrient concentrations in the water. Site 2 had significantly higher TN and TP in February compared to other sites, suggesting that this nutrient concentration may be deriving from the farm during this period. A decrease in TN and TP was noted in April in sites 2 and 3 with an opposite trend in site 1 which reached its higher TN and TP concentrations than sites 2 and 3 in August. In addition to maximum upwelling in June, Eccles [26] noted that during April and May the southern winds become predominant in Lake Malawi, suggesting that it is within this period that locally accumulated nutrients are dispersed to the north, hence, site 1 located to the northwest had high TN and TP concentrations. This result is supported by a significant decrease in TN and TP in site 3 between February and August. The minimum and maximum TP of 4.34±0.27 µg/l and 29.19±1.64 µg/l recorded in April and August in site 1 respectively and those recorded in other sites (Figure 3-2g) are comparable to values recorded by Nordvarg and Johansson [36] in fish farming areas of Järsö, Nyhamn, Flisö, and Björkö in the Åland archipelago Baltic coastal areas between 1997 and 1999 where they investigated six farms producing between 4637 and 5274 tons of fish. TN values recorded by Nordvarg and Johansson [36] were relatively higher compared to those recorded in the current study (Figure 3-2f). However, no significant effects of the farms in surface water quality were detected.

This result is not surprising since it is quite difficult to detect the impact of cage aquaculture farms on the environment. Similarly, an earlier study in Lake Malawi found no impact on cage aquaculture on the environment (Gondwe et al., 2011b) [29] . They found slightly or no spatial and temporal changes in ammonium (NH4+), nitrate (NO3-), soluble reactive phosphorous (SRP), particulate phosphorous (PP), particulate carbon (PC), and particulate nitrogen (PN) in the water column, despite high fish biomass at the farm (Table 1). While Gondwe et al. [29] attributed the contribution of strong bottom currents and wild fish populations on dispersion of nutrients and consumption of cage effluents respectively, the current study suggests that more frequent sampling during the stratification and mixing periods is likely required to detect sources or changes in nutrients at sites where cage aquaculture operations are active and currents can be strong.

Table 1: Mean Secchi depth (SD), total suspended solids (TSS), extracted chlorophyll (Chla), ammonium (NH4+), nitrate (NO3-), soluble reactive phosphorous (SRP), particulate phosphorous (PP), particulate carbon (PC), and particulate nitrogen (PN) sampled along four station transects at one km intervals to the southeast (near site 3) and northwest (near site 1) and at the farm. Source: Gondwe et al. (2011b).

Site	SD	TSS	Chla	NH4+	NO3-	SRP	PP	PC	PN
	(m)	(mg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)
Southeast	6.1±1.9	1.22±0.53	0.81±0.49	8.4±3.2	7.1±4.9	4.2±2.4	3.6±1.5	291±77	38±10
Farm	5.7±1.8	1.45±0.89	0.91±0.54	7.9±2.6	8.1±5.9	4.3±2.2	3.8±1.7	284±53	38±6
Northwest	5.9±1.8	1.38±0.86	0.83±0.52	8.2±4.2	6.4±4.4	4.7±3.0	3.4±1.3	294±92	40±12

Other sources, including land clearing and erosion contribute to the nutrient pool in Lake Malawi [20] . Hecky et al. [37] also suggest that agricultural development may have already increased nutrient loading to Lake Malawi by 50% owing to clearing of the forest. These early observations were made before the recent introduction of fertilizer subsidy program that promotes crop production by poor farmers and before the introduction of cage aquaculture in Lake Malawi. Based on the previous observations and finding from the current study, the question is how increased nutrient loading from cage aquaculture and other sources will affect the primary productivity, phytoplankton and phytoplankton communities, wild fish populations in Lake Malawi? Skewed fish abundances towards site 2 and high fishing pressure at site 3 have been noted, however, without any impact of fish diversity [38].

A single peak in April at all sites (site 1=3.95±0.19µg/l, site 2=4.79±0.65 µg/l, and site 3=5.54±0.29 µg/l) with Chla concentrations significantly higher than others months (February, June, and August) ($p<0.05$) which were not different among themselves (Figure 2a) characterized the temporal differences in Chla concentrations. Site 2 which was expected to have high Chla due to its proximity to the farm did not. The results revealed otherwise, the concentrations were significantly higher at site 3 than other sites in April, June and August, except in February, the only month on which Chla concentrations

How to cite this article: Macuiane M, Hecky R , Guildford S. Temporal And Spatial Changes In Water Quality In Lake Malawi/Niassa, Africa: Implications For Cage Aquaculture Management. Oceanogr Fish Open Access J. 2016; 1(1): 555552

were similar at all sampling sites (Figure 2a). It is interesting to note that Chla concentrations increased towards northwest to southeast direction (from site 1 to 3) as revealed by higher Chla concentrations at 3, but also by significantly higher concentrations at site 2 than site 1 in April, June, and August ($p<0.05$). The pattern in extracted surface Chla concentrations found in the current study is similar to that observed extracted Chla by Gondwe [39]. He found low Chla, less than 1.0 μg/l most of his sampling period and a single peak in May (2.4 μg/l) in all sampling sites. The peak Chla concentrations in May [39] and the peak found the current study (April), although occurring at different months (May and April), but same meteorological period, suggest dominance of diatoms which benefit from suspension of nutrients during short mixing period characterized by single peak. In both studies, the peaks seem not having direct effect from the cage aquaculture farm, but from lake wide seasonality. However, Chla concentrations in this study were higher than historical values reported for the main lake, less than 1.0 μg/l recorded before the establishment of cage aquaculture in Lake Malawi and 2.4 μg/l after the establishment [39, 40]. The results shown in Figure 3 reveal underestimation of Chla concentrations from surface samples (Figure 2a) since they are not representative of whole water column and the concentrations are not uniform throughout the depth (Figure 3). In addition, the high Chla concentration of 5.54±0.29 μg/l is the highest recorded in this oligotrophic lake, thereby, suggesting increased lake productivity.

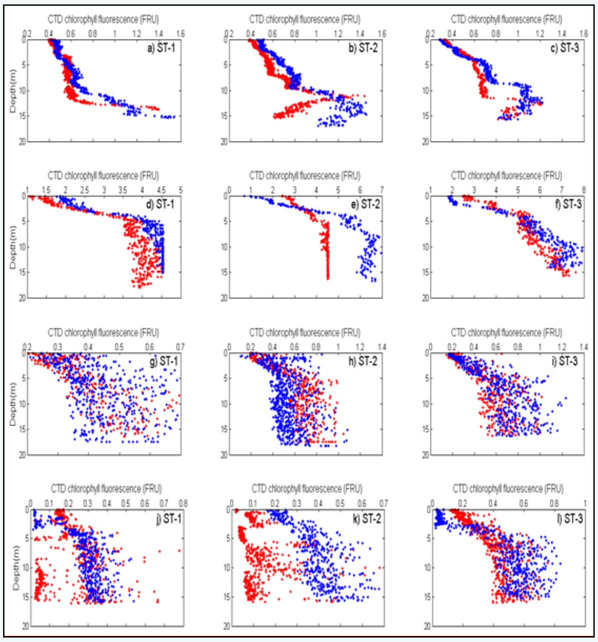

Figure 3: CTD chlorophyll a profiles at sampling sites (1-ST-1, 2-ST-2, and ST-3) in February: a), b), c); April: d), e); f); June: g), h), i); August: j), k), l). Red dot is replicate 1 and blue dot is replicate 2.

While the surface Chla did not represent whole water column, the minimum and peak concentrations (Figure 2a) observed in the current study seem to be responsible to high and low water clarity through accumulated phytoplankton cells (Figure 2c). Secchi depths recorded in February, June, and August are relatively similar to those recorded by Gondwe et al. [29], but significantly different to those recorded in April. The importance of water transparency in African cichlids is well explained by Seehausen et al. [41]. While working in Lake Victoria, they found a relationship between species diversity and color diversity and distinction of male coloration with high water transparency. Finally, reduction of water transparency in Lake Malawi has the potential to affect haplochromine cichlids and therefore, reduce their potential as food source or ornamental fish that fetch high export values, as low fish species diversity are found in turbid areas due to cultural eutrophication [41].

Conclusions

- DO and Chla frequently used as indicator parameters of healthy or impacted aquatic ecosystems did not show any significant association to cage aquaculture farm. Both followed a clear seasonal pattern mediated by seasonal changes in water temperature related thermal mixing in the lake and do not indicate being affected by the farm operation or any other site.
- The peak Chla concentrations above 5.0 μg/l reported here is much higher than previous observations in Lake Malawi and specifically in SE Arm of the lake and suggests increased phytoplankton biomass in the lake. Surface Chla may underestimate whole water column concentrations as Chla increased with depth.
- Surface nutrient concentrations (TN and TP) were higher in southeast and at the farm during the warm stratified period but may have been advected to the northwest by strong south eastern winds starting from April and seem not to be directly responsible for changes in Chla concentrations.
- The farm did not cause any measurable significant effect on WT and SD.
- Given the strong and seasonally variable currents in the SE Arm, much more frequent or even continuous monitoring of temperature and oxygen will likely be necessary to separate farm related impacts from wider scale seasonal ecosystem changes.
- Associations of Maldeco Aquaculture Farm's water quality parameters seem to be difficult to detect probably due to the lake dynamic or because the scale of operation during the sampling period was low and consequently it is difficult to detect the effects. Increased fish production or number of cage aquaculture farms have the potential to overwhelm the capacity of the lake to handle increased nutrients and productivity
- Monitoring programs for cage aquaculture in Malawi should consider the period between April and

How to cite this article: Macuiane M, Hecky R , Guildford S. Temporal And Spatial Changes In Water Quality In Lake Malawi/Niassa, Africa: Implications For Cage Aquaculture Management. Oceanogr Fish Open Access J. 2016; 1(1): 555552

July as potentially stressful because of sub-optimum WT (less than 24oC), decreased %DO, DO, and reduced water transparency.

Acknowledgement

We wish to thank the Malawi Department of Fisheries for allowing us conduct this study in Malawi. Special thanks go to the managing board of Maldeco Aquaculture Limited and staff for granting us permission and support to conduct the study at the farm premise site. We thank the Malawi College of Fisheries for providing the laboratory facility and for the accommodation during the sampling period. The University of Minnesota Office of International Programs provided a Pre-dissertation Award in 2010 that facilitated this study to come through.

References

1. FAO (2010) The state of world fisheries and aquaculture FAO, Fisheries and Aquaculture Department, Rome, Italy.
2. Larsen J, Roney M (2013) Farmed fish production overtakes beef. Plan B updates.
3. Håkanson L, Ervik A, Makinen T, Moller B (1988) Basic concepts concerning assessments of environmental effects of marine fish farms. Nordic Council of Ministries. Nord 90.
4. Islam MS (2005) Nitrogen and phosphorous budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: review and analysis towards model development. Marine Poll Bull 50(1): 48-61.
5. Bristow CE, Morin A, Hesslein RH, Podemski CL (2008) Phosphorous budget and productivity of an experimental lake during the initial three years of cage aquaculture. Can J Fish Aquat Sci 65(11): 2485-2495.
6. Gondwe MJS, Guildford SJ, Hecky RE (2011) Carbon, nitrogen and phosphorous loadings from Tilapia fish cages in Lake Malawi and factors influencing their magnitude. J Great Lakes Res 37(1): 93-101.
7. Laws EA (2000) Aquatic pollution: An introductory text. (3rd edn), John Wiley and Sons, UAS. pp. 639
8. Aure J, Stigebrandt A (1990) Quantitative estimates of eutrophication effects on fjords of fish farming. Aquaculture 90(2): 135–156.
9. Dillion PJ, Rigler FH (1974) The phosphorus chlorophyll relationship in lakes. Limnol Oceanogr 19(5): 767–773.
10. Brown JR, Gowen RJ, McLusky DS (1987) The effects of salmon farming on the benthos of a scottish sea loch. J Exp Mar Biol Ecol 109(1): 39-51.
11. Alongi DM, Mckinnon AD, Brinkman R, Trott LA, Undu MC, et al. (2009) The fate of organic matter derived from small-scale fish cage aquaculture in coastal waters of Sulawesi and Sumatra, Indonesia. Aquaculture 295(1-2): 60-75.
12. Tsutsumi H (1987) Population dynamics of Capitella capitata (Polychaeta; Capitellidae) in an organically polluted cove. Marine Ecology Progress Series 36: 136-149.
13. Bellan GL (1979) An attempted pollution abatement in the Gulf of La Napoule (Cannes, France). Marine Poll Bull 10(6): 136-166.
14. Guildford SJ, Hecky RE, Taylor WD, Mugidde R, Bootsma HA, (2003) Nutrient enrichment experiments in tropical Great Lakes Malawi/Nyasa and Victoria. J Great Lakes Res 29(2): 89–106.
15. Guildford SJ, Taylor WD, Boostma HA, Hendzel LL, Hecky RE, et al. (1999) Factors controlling pelagic algal abundance and composition in Lake Malawi/Nyasa. In: Bootsma HA and Hecky RE (Eds.) Water quality report. Lake Malawi/Nyasa biodiversity conservation project. Southern African Development Community (SADC)/Global Environmental Facility (GEF). pp. 85-112.
16. Fryer G, Iles TD (1972) The cichlid fishes of the Great Lakes of Africa. Their biology and evolution. Oliver and Boyd, Edinburgh, UK.
17. Ribbink AJ, Marsh BA, Marsh AC, Ribbink AC, Sharp BJ (1983) A preliminary survey of the cichlid fishes of rocky habitats in Lake Malawi. S Afr J Zool 18(3): 149-310.
18. Snoeks J (2000) How well known is the ichthyodiversity of the large East African lakes? Adv Ecol Res 31: 17-38.
19. Eccles DH, Trewavas E (1989) Malawian cichlid fishes. The classification of some haplochromine genera. Lake Fish Movies, Herten, Germany.
20. Bootsma HA and Hecky RE (1993) Conservation of the African Great Lakes: a limnological perspective. Conserv Biol 7(3): 644-656.
21. Stainton MP, Capel MJ, Armstrong AJ (1977) The Chemical Analysis of Freshwater. Freshwater Institute, Winnipeg, Manitoba. pp. 59-61.
22. Murphy J, Riley JP (1962) A modified single solution method for the determination of phosphate in natural waters. Anal Chim Acta 27: 31-36.
23. Wetzel RG, Likens GE (2000) Limnological Analyses. (3rd edn), Springer, New York, USA.
24. Elliott JM (1982) The effects of temperature and ration size on the growth and energetics of salmonids in captivity. Comp Biochem Phys B 73(1): 81–91.
25. Van Dam AA, Pauly D (1995) Simulation of the effects of oxygen on food consumption and growth of Nile tilapia, Oreochromis niloticus (L). Aquac Res 26(6): 427–440.
26. Eccles DH (1974) An outline of the physical limnology of Lake Malawi (Lake Nyasa). Limnol Oceanogr 19: 730–742.
27. Spigel RH, Coulter GW (1996) Comparison of hydrology and physical limnology of the East Africa great lakes: Tanganyika, Malawi, Victoria, Kivu and Turkana (with reference to some North American great lakes). In: Johnson TC, Odada EO (Eds.) Limnology, climatology and paleoclimatology of the East African lakes, Gordon and Breach, Amsterdam, pp. 103–139.
28. Macuiane MA, Kaunda EKW, Jamu D (2011) Seasonal dynamics of physico-chemical characteristics and biological responses of Lake Chilwa, Southern Africa. J Great Lakes Res 37(1): 75-82.
29. Gondwe MJS, Guildford SJ and Hecky RE (2011) Physical-chemical measurements in the water column along a transect through a tilapia cage fish farm in Lake Malawi, Africa. J Great Lakes Res 37(1): 102-113.
30. Bootsma HA, Hecky RE, Johnson TC, Kling HJ, Mwita J (2003) Inputs, outputs and internal cycling of silica in a large, tropical lake. J Great Lakes Res. 29(2): 121–138.
31. Hamblin PF, Bootsma HA, Hecky RE (2003) Modeling nutrient upwelling in Lake Malawi/Nyasa. J Great Lakes Res 29(2): 34-47.
32. Brown TW, Chappell JA, Boyd CE (2011) A commercial-scale, in-pond raceway system for Ictalurid catfish production. Aquacult Eng 44(3): 72-79.

33. Ross LG (2000) Environmental physiology and energetics. In: Beveridge MCM, McAndrew BJ (Eds.), Tilapias: Biology and Exploitation, Fish and Fisheries Series 25, Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 89-128.

34. Buentello JA, Gatlin DM, Neill WH (2000) Effects of water temperature and dissolved oxygen on daily feed consumption, feed utilization and growth of channel catfish (Ictalurus punctatus). Aquaculture, 182(3-4): 339-352.

35. Olsen Y, Olsen LM (2008) Environmental impact of aquaculture on coastal planktonic ecosystem. In: Tsukamoto K, et al. (Eds.), Fisheries for global welfare and environment, 5th World Fisheries Congress 2008, pp 181-196.

36. Nordvarg L, Johansson T (2002) The effects of fish farm effluents on the water quality in the Åland archipelago, Baltic Sea. Aquacult Eng 25(4): 253-279.

37. Hecky RE, Bootsma HA, Kingdon ML (2003) Impact of land use on sediment and nutrient yields to Lake Malawi/Nyasa (Africa). J Great Lakes Res 29(2): 139-158.

38. Macuiane AM, Hecky RE and Guildford SJ (2015) Changes in fish community structure associated with cage aquaculture in Lake Malawi, Africa. Aquaculture 448: 8-17.

39. Gondwe MJGS (2009) Environmental impacts of cage aquaculture in the southeast arm of Lake Malawi: water and sediment quality and food web changes. [PhD Thesis, University of Waterloo, Ontario, Canada], pp. 208.

40. Guildford SJ, Bootsma HA, Taylor WD, Hecky RE (2007) High variability of phytoplankton photosynthesis in response to environmental forcing in oligotrophic Lake Malawi/Nyasa. J Great Lakes Res 33(1): 170-185.

41. Seehausen O, Van Alphen JJM, Witte F (1997) Cichlid fish diversity threatened by eutrophication that curbs sexual selection. Science 277(5333): 1808–1811. .