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__Technical Report Number 1__

BENTHIC ALGAL PRODUCTIVITY
IN LAKE TANGANYIKA AND
THE EFFECTS OF DEFORESTATION
by
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Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika (RAF/92/G32)
Lutte contre la pollution et autres mesures visant à protéger la biodiversité du Lac Tanganyika (RAF/92/G32)

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EXECUTIVE SUMMARY

This project was designed to collect baseline data on benthic algal productivity in Lake Tanganyika and to determine with increased sediment input is affecting benthic algal dynamics. This work was approached with the following goals:

1. To examine seasonal variation in benthic primary productivity.
2. To examine to effect of upwelling on benthic primary productivity.
3. To compare the following in impacted and forested watersheds:
   - net primary productivity
   - respiration
   - algal biomass
   - light availability
   - amount of inorganic material settled on rock surface

The results of this project are as follows:
- Benthic net productivity does not differ significantly between the forested and deforested watershed.
- Benthic respiration is significantly higher at the impacted watershed.
- There are significantly greater amounts of inorganic material on the rocks at the impacted site.
- Algal biomass is significantly higher at the impacted site.
- There is significantly less oxygen in the water at the impacted site.
- Seasonal variation in net productivity and respiration is not significant in the Kigoma area sites.
- Seasonal variation in net productivity, respiration, and biomass is significant at the Mpulungu site.

CHAPTER 1 INTRODUCTION

Ultimately, lake productivity is dependent on primary producers in the aquatic ecosystem. While planktonic productivity is considered to provide most of the fixed carbon to upper trophic levels in Lake Tanganyika, benthic algae may be an important component of the lake. Most of the biodiversity in this lake is contained within the littoral zone and is supported by a complex food web that may rely heavily on benthic productivity. To date, very little is known about benthic algal productivity in Lake Tanganyika or the potential impacts of land use changes on this important food source.

Deforestation is increasing throughout the Lake Tanganyika catchment. Erosion rates are as high as 28 to 100 metric tons per year (Bizimana and Duchafour, 1991) in intensively cultivated areas in the northern area of the watershed. Increased erosion and sediment input into the lake may have many negative consequences for lake dynamics. Increased sediments can lead to habitat loss, changes in nutrient dynamics, and changes in food quantity and quality for upper trophic levels. The negative effects of increased sedimentation on biodiversity in the lake have already been noted by other researchers (Cohen *et al.*, 1993; Alin *et al.*, 1999).

This project had two main goals:

 1. To collect baseline information on benthic productivity in Lake Tanganyika.

 2. To determine whether deforestation is affecting benthic algal productivity.

This report provides data on epilithic productivity for southern Lake Tanganyika and on epilithic and epipelic productivity for the northern Tanzanian shoreline. The data covers both the wet and dry season, which is particularly important for the southern end of the lake, where seasonal upwelling may affect algal dynamics. By determining the magnitude of benthic productivity and the effects of increased sediment input, this study aimed to quantify the impact of deforestation and to provide some insight to littoral zone dynamics.

CHAPTER 2 METHODS

2.1 Study sites

Four study sites were used throughout the year (Figure 1).

2.1.1 Benthic productivity and seasonal variation

Jakobsen's Beach (JAK), south of Kigoma, Tanzania was used to do some preliminary work and to establish the methodology. The watershed area is small and human impacts are relatively minor. The lake bottom contained both sandy and rocky substrate.

Mbita Island (MPU), directly north of the port in Mpulungu, Zambia was sampled to determine whether there are seasonal effects on benthic productivity in Lake Tanganyika. The southern end of the lake is subject to upwelling of nutrient-rich waters during the dry, windy season, and these are known to affect pelagic dynamics (Coulter, 1991). This study examined whether these upwelling events might also affect the benthic environment. Possible human impacts at this site include pollution from Mpulungu and the harbour and periodic fishing. However, the sampling site was located at the base of a cliff on the north side of the island, and this location allowed for maximum exposure to the lake and minimized exposure to human influences along the Mpulungu shoreline. The substrate was a rocky talus slope that extended to 16 m depth.

2.1.2 Human impact study

Mitumba and Mwamgongo were used in a comparative study to examine the effects of human land use change on benthic productivity in Lake Tanganyika. Both sites have similar drainage area, topography, geology, with similar exposure to wind and wave action along the shoreline.

Mitumba (MIT) is the northernmost watershed of Gombe Stream National Park. The watershed is 4.5 km^2 and is almost completely forested. Human impacts are low, with population densities of < 25 people / km^2. The substrate was boulders until 3 – 4 m, after which coarse grained sands dominated with large boulders in isolated groups.

Mwamgongo (MWA) is the next watershed north of Mitumba. The area of the watershed is approximately 8 km^2 and has been almost completely deforested. Population densities are currently > 750 people/ km^2. There were numerous boulders until 3 m, isolated rocks and fine grained to muddy sands at 5 – 7 m, and rocks with muddy sediments after 7 – 9 m. All rock surfaces were blanketed with sediment.

2.2 Measurements and sampling methodology

Benthic productivity was measured using oxygen change in light and dark chambers. Chambers were constructed by J.S. MicroProducts, Canada, using clear and opaque plexiglass. The chambers for epilithic productivity covered an area of 0.1 m^2 and held a volume of 0.8 l. The chamber was surrounded by a neoprene skirt that was covered with a lead sock to hold it in place on the rock. The chambers for epipelic productivity covered an area of 0.09 m^2 and held a volume of 10.8 l. A metal strip on the open edges of the chamber allowed the chamber to be pushed at least 5 cm into the sediment.

Dissolved oxygen was measured using Winkler titration (Stainton et al., 1977). Water samples were taken using a 50 ml syringe with a needle pushed through a serum stopper in the chamber wall. Water samples were fixed with an injection of 0.5 ml of $MnSO_4$ and 0.5 ml of alkaline iodide while in the syringe. Upon return to the laboratory, 0.5 ml of concentrated sulfuric acid was added and the sample was titrated using 0.025 N sodium thiosulphate. Incubations were done at around solar noon for 10 to 25 minutes, depending upon depth, with the shorter times for the shallower depths. Light profiles were taken during or immediately following incubation.

Algal biomass was measured by scraping off a area of the rock surface after the chambers were removed using an algal scraper made by J. S. MicroProducts. An area of 11.5 cm^2 was removed by the scraper and samples were taken in triplicate from inside each chamber. Samples were filtered through Whatman GF/C filters and stored on ice. Pigments were extracted in cool 90% methanol and left overnight in the dark, and samples were centrifuged before analysis. The chlorophyll *a* values were calculated by applying the calibration factor and the formula given by Talling and Driver (1963) based on spectrophotometric absorbance at 665 nm corrected for turbidity by subtracting absorbance at 750 nm. Caroteniod ratios were determined by dividing the chlorophyll value by the carotenoid absorbance at 480 nm.

Epilithic productivity was measured at 2, 5, and 10 m. Sampling was done approximately every month from November 1997 to July 1998 in Tanzania and once during the wet season (March 1998) and the dry season (July 1998) in Zambia. Epipelic productivity was measured at 2, 5, and 10 m at the beginning of the wet season at the Tanzanian sites. Epipelic biomass was determined by extracting pigments from sediment samples using 90% methanol and analyzing as described above.

2.3 Data analysis

A non-parametric repeated measured test (Wilcoxin Signed-Ranks; Sokal and Rolf, 1981) was used to examine the paired differences between productivity at Mitumba and Mwamgongo. ANOVA (SYSTAT 6.0, 1996) was used to look at other differences between both these sites and to look at seasonal differences in the southern end of the lake.

Figure 1. Map of sampling locations. Stars indicate the different sampling locations around the lake. The inset shows a more detailed view of the study areas used for the human impact study. The drainage patterns are included in these watershed basins.
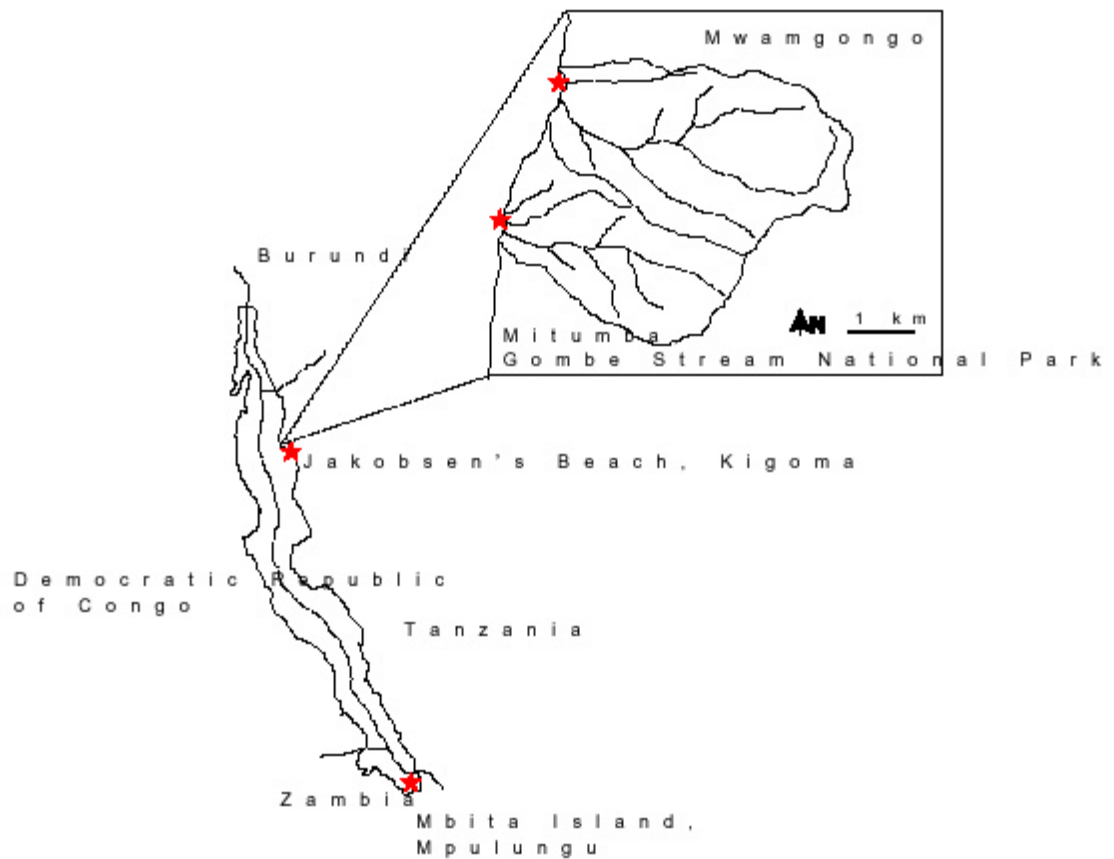
CHAPTER 3 RESULTS AND DISCUSSION

3.1 Seasonal variations—Mbita Island, Mpulungu, Zambia

3.1.1 Productivity

An inter-season comparison of epilithic productivity was made at depths of 1, 2, 3, 5, and 10 m (Table 1). Net productivity ($p < 0.001$, ANOVA) and respiration ($p < 0.01$, ANOVA) between the two seasons was significantly different.

depth	*Net productivity*		*Respiration*	
	wet season	dry season	wet season	dry season
1	189.87	486.43	39.54	118.86
2	194.05	347.53	72.75	138.13
3	166.45	196.6	31.46	69.22
5	88.4	203.25	38.71	65.97
10	54.11	89.93	26.86	65.79

Table 1. Seasonal average net productivity and respiration during the wet and dry season at Mbita Island, Mpulungu, Zambia (in mg $O_2\,m^{-2}\,hr^{-1}$).

3.1.2 Biomass

Averaged over all depths, the overall annual average chlorophyll value was 11.31 with a standard deviation of 7.52 mg/m^2. Table 2 shows the seasonal average values for each depth. Algal biomass was significantly different with season ($p < 0.004$). Carotenoid ratios had an annual average of 0.50 with a standard deviation of 1.18. The carotenoid ratio was also significantly different with season ($p < 0.001$).

depth	*Chlorophyll*		*Chl:carotenoid ratio*	
	wet season	dry season	wet season	dry season
1	12.71	13.68	0.34	0.41
2	12.75	10.34	0.31	0.41
3	4.03	11.10	0.10	0.50
5	8.19	10.31	0.44	0.59
10	11.35	10.07	0.55	0.77

Table 2. Seasonal average values of chlorophyll and the carotenoid ratios at Mbita Island, Mpulungu, Zambia (in mg/m^2).

This study suggests that algal productivity is affected by seasonal variations at the south end of the lake. Increased nutrient availability during times of upwelling is known to produce algal blooms that reduce Secchi depths (Coulter, 1991) and this increase in nutrients may be the reason for the increase in benthic algal productivity. It appears that, even during phytoplankton blooms during the dry season, light availability is not reduced significantly such that benthic algal production is affected at the depths studied.

3.2 Human impact study—Mitumba vs. Mwamgongo

3.2.1 Productivity

Net productivity did not differ between the two sites. However, there did appear to be seasonal trends in productivity at 2 m, with much greater productivity at the beginning of the wet season at MWA, which may be due to an initial flux of allochthonous nutrient input (figure 2).

Respiration was significantly lower at MWA at 2 m (p < 0.0156, Wilcoxin Signed-Ranks), but not at 5 m (p < 0.0781, Wilcoxin Signed-Ranks) or 10 m. The difference in respiration at 2 m is greatest during the wet season, and may actually be due to decay of allochthonous organic matter. Biomass specific net productivity (BSNP) was significantly lower at MWA at 2 m (p < 0.0156, Wilcoxin Signed-Ranks), 5 m (p < 0.0156, Wilcoxin Signed-Ranks), and 10 m (p < 0.0312, Wilcoxin Signed-Ranks). These results suggest that algal productivity is less efficient at the deforested site.

Figure 3 shows net productivity and respiration for 2 m, and figure 4 shows BSNP for all depths. Average annual net productivity and respiration are shown in table 3.

	Net productivity			Respiration		
depth	MIT	MWA	JAK	MIT	MWA	JAK
2	111.18	137.04	118.01	62.62	88.83	34.48
5	71.22	70.64	100.24	44.72	34.16	24.71
10	56.14	64.53	81.21	29.21	50.28	20.90

Table 3. Average annual epilithic net productivity and respiration for Mitumba, Mwamgongo and Jakobsen's beach (in mg $O_2\,m^{-2}\,hr^{-1}$).

Epipelic productivity was much lower than epilithic productivity. Average values during the months sampled can be seen in Table 4. Unlike epilithic productivity, the differences between the two sites are not significant.

	Net productivity			Respiration		
depth	MIT	MWA	JAK	MIT	MWA	JAK
2	60.12	43.42	31.23	9.48	19.86	15.30
5	42.10	55.21	36.57	3.75	12.71	11.66
10	27.84	33.04	54.33	4.25	4.91	12.78

Table 4. Average annual epipelic net productivity and respiration for Mitumba, Mwamgongo, and Jakobsen's beach (in mg $O_2\,m^{-2}\,hr^{-1}$).

3.2.2 Biomass

Chlorophyll *a* and the carotenoid ratio are significantly greater at the deforested site at all depths (p < 0.0, ANOVA). Over all depths, averaged annual chlorophyll was 7.04 ± 3.52 mg/m^2 for Mitumba and 28.89 ± 8.08 mg/m^2 for Mwamgongo. Carotenoid ratios were 0.63 ± 0.17 and 1.02 ± 0.10 respectively (Table 5).

	Chlorophyll		Chl:carotenoid ratio	
depth	MIT	MWA	MIT	MWA
2	5.59	29.64	0.43	0.95
5	5.19	31.18	0.68	1.08
10	10.42	25.85	0.78	0.88

Table 5. Average annual chlorophyll (in mg/m^2) and carotenoid ratios for Mitumba and Mwamgongo.

3.2.3. Ambient oxygen

Dissolved oxygen (DO) concentrations varied at each of the study sites (Table 6). The water was usually near 100% saturation. Ambient DO in the water column was significantly lower at Mwamgongo than at Mitumba (p < 0.025, ANOVA). As water temperature and wave action are similar at each site, this decline in DO must reflect increased biological and/or chemical oxygen demand in the water column. Erosion increases the flux of allochthonous organic matter into a lake, and the decay of this material may be the cause of the lower oxygen levels. The higher values at Mpulungu

reflect the fact that this location experiences a greater temperature range, since the upwelling water is typically around 2 ^{o}C lower than the surface waters of lake.

depth	MIT	MWA	JAK	MPU
2	6.82	6.02	5.98	7.52
5	6.58	5.71	5.91	7.03
10	6.39	5.71	5.75	7.08

Table 6. Average annual dissolved oxygen concentrations for the study sites (in mg/l).

3.2.4. Light

There are no significant differences between light attenuation at Mitumba and Mwamgongo. A logarithmic regression fit to the annual average light profiles shows that in general, the forested site has better light penetration (figure 5).

Unfortunately, light profiles were taken from the boat, which usually anchored further offshore at the disturbed site than at the forested one. Visibility while diving was lower at Mwamgongo than at Mitumba, declining to 1.5 m at 2 m depth in wavy conditions. Mwamgongo has smaller grain sizes which are more prone to resuspension through wave action. Also, since light profiles were rarely taken at both sites on the same day, it is difficult to make actual comparisons.

The relationship of light with net productivity shows further differences between the two sites (figure 6). The regression lines for each site are significantly different, and the difference in slopes suggests that algal growth may be affected by light availability ($p < 0.001$). In particular, a small increase in light produces a much greater increase in net productivity at Mwamgongo, implying that light limitation now prevails to a greater extent than at Mitumba. The higher productivity levels seen at Mwamgongo are likely due to increased nutrient availability. In general, light levels required for algal growth are relatively low, compared with surface light (Hill, 1996). Due to its equatorial location, light should not be a limiting factor in primary productivity in Lake Tanganyika, except for algae at great depths. The depth of the littoral zone generally extends to around 30 m (Coulter, 1991). Therefore, the low light levels and greater influence of light availability at Mwamgongo do suggest greater suspended particulate matter at this site.

3.3 Comparison with benthic productivity in other lakes

As expected, benthic productivity in Lake Tanganyika is high when compared to temperate lakes (Figure 7). Data from Mbita Island compares well with the data collected at Mbemba, Democratic Republic of Congo (Takamura, 1988). The Mbita Island data is an average of the wet and dry season, and the higher productivity during the dry season would increase these averages relative to the values expected for the northern part of the lake. The value for Lake Malawi is based on a single datum (Bootsma, 1993). The temperate lakes are also oligotrophic systems and productivity at these latitudes is much lower (Loeb et al., 1983).

Unlike many other lakes, area-specific net productivity profiles do not suggest that photo-inhibition is occurring at shallow depths in Lake Tanganyika. However, BSNP profiles do show an initial increase in BSNP with depth in the first few meters, which implies that extreme light levels at shallow depths may reduce efficiency in algal productivity.

CHAPTER 4 CONCLUSIONS

4.1 Seasonal variation in benthic productivity

Seasonal upwellings do appear to influence benthic productivity in the southern end of Lake Tanganyika. There are significant changes in net productivity, respiration, and algal biomass during the dry season. Although light penetration must decrease due to phytoplankton blooms, this does not appear to be affecting benthic productivity at the depths studied.

The values for periphyton net productivity compare well with those found for the northwest coast. Takamura (1988) recorded average values that are about 30% lower than those found in this study. This is consistent with the hydrodynamics of the lake basin. Seasonal upwellings are not as extensive in the north, and thus it might be expected that the average net productivity values are lower.

4.2 Effects of deforestation

Deforestation clearly affects benthic productivity. The results of this study suggest that erosion has increased the input of sediments, nutrients, and organic matter into the lake. Changes in light attenuation and the influence of light availability on algal productivity may be due to increased suspended sediments.   Increased benthic respiration and lower ambient dissolved oxygen concentration are likely due to decay of organic matter, which may be of allochthonous origin. However, the increased benthic respiration seen at the deforested site may be because of increased algal stress and less efficient productivity.

In addition, increased sediment inputs from deforestation may reduce the amount of habitat available for colonization. If settling rates are high enough, existing algae will be covered by sediment particles, effectively removing these areas from recolonization. Large volumes of sediment may decrease the nutritive value of this food source and reduce the feeding efficiency of benthic grazers and deposit feeders.

4.3 Directions for future work

There are a number of studies that would increase our understanding of how increased sediment input may be affecting Lake Tanganyika. Probably the most important of these is whether deforestation is accompanied by changes in nutrient concentrations and sediment-nutrient interactions both in the water column and in the sediment substrate. Although we can assume that deforestation would also affect epipelic productivity, the magnitude of this affect remains unclear. Current data is too sparse to show any statistical trends.

Finally, these changes in the benthic habitat represent changes in food quality and quantity. Other studies have documented changes in upper trophic levels that are correlated with changes in land use patterns (Alin *et al*., 1999), but whether this is caused by changes in food web structure or by changes in habitat is unknown. This has important implications for conservation measures in the lake.

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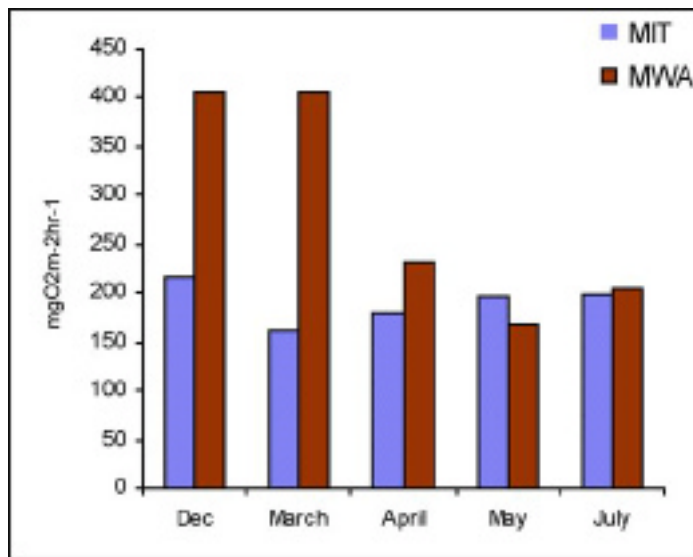
FIGURES

Figure 2. Seasonal variation in gross productivity at 2 m at Mitumba and Mwamgongo.
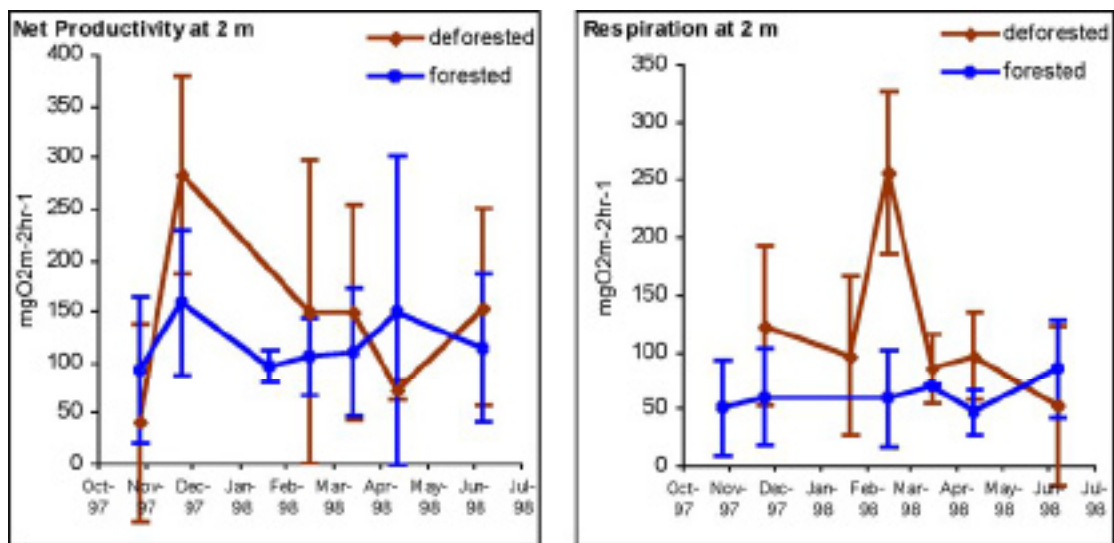

Figure 3. Net productivity and respiration at 2 m throughout the sampling period at Mitumba and Mwamgongo.
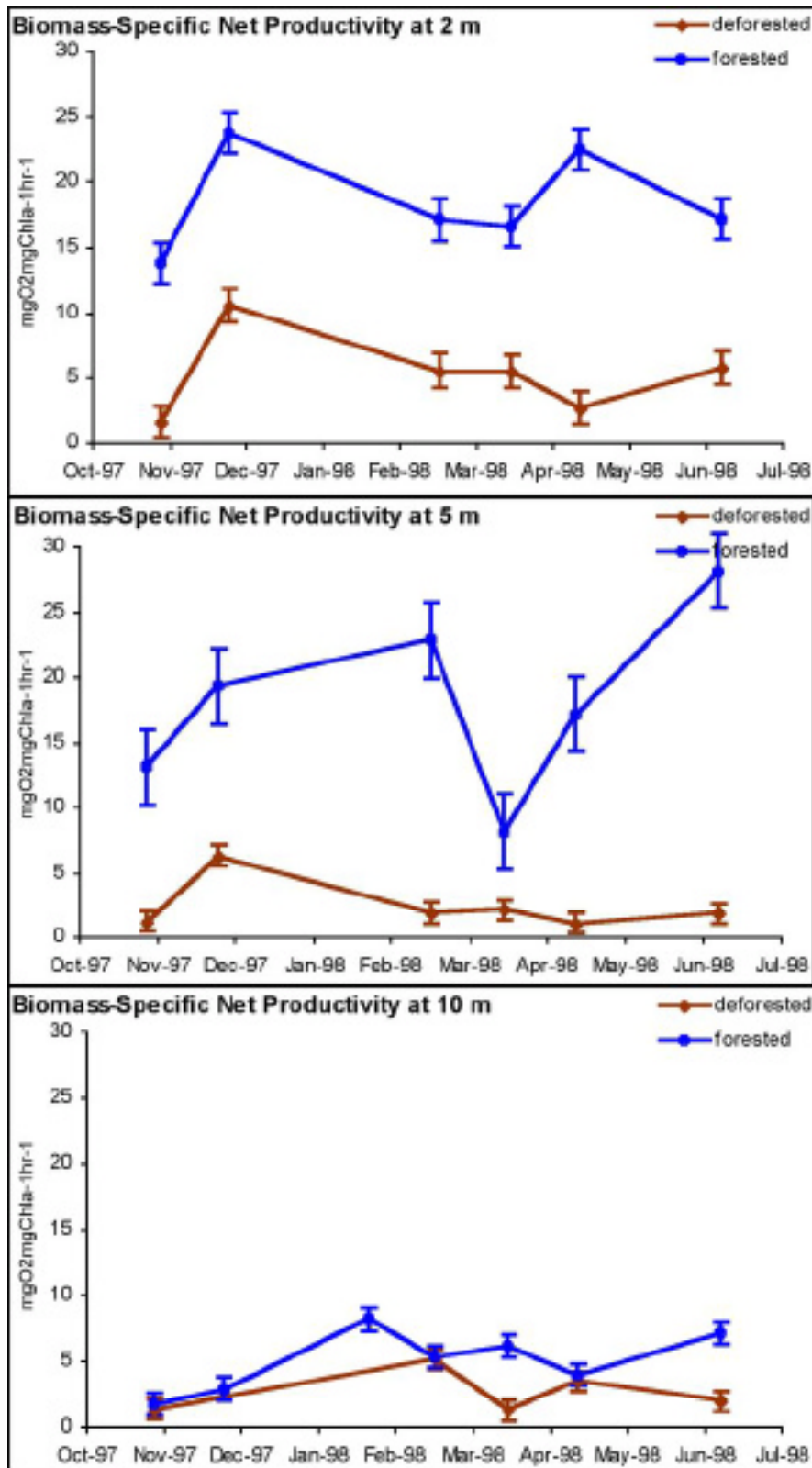
Figure 4. Biomass specific net productivity at all depths sampled at Mitumba and Mwamgongo. Error bars represent standard error.
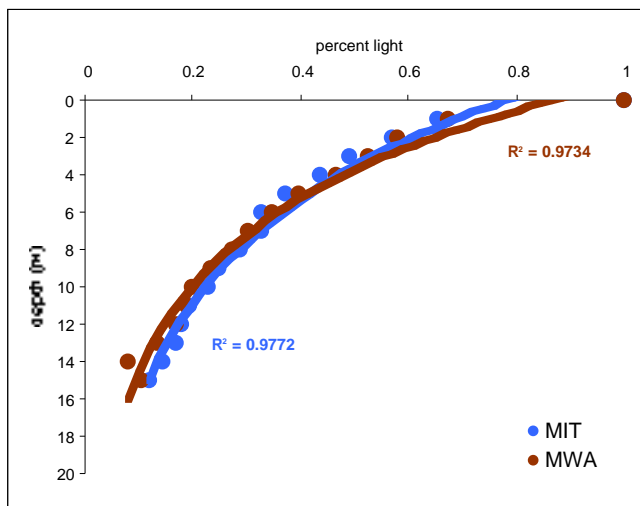
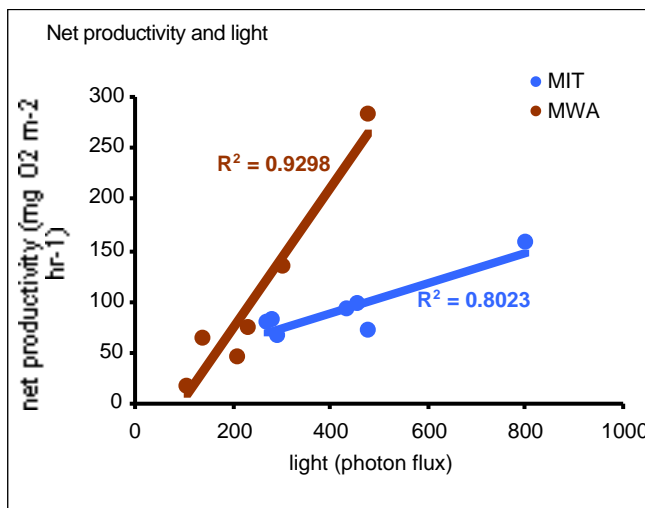Figure 5. Average annual light at Mitumba and Mwamgongo.

Figure 6. Net productivity and light for Mitumba and Mwamgongo. The regression lines for each site are significantly different.
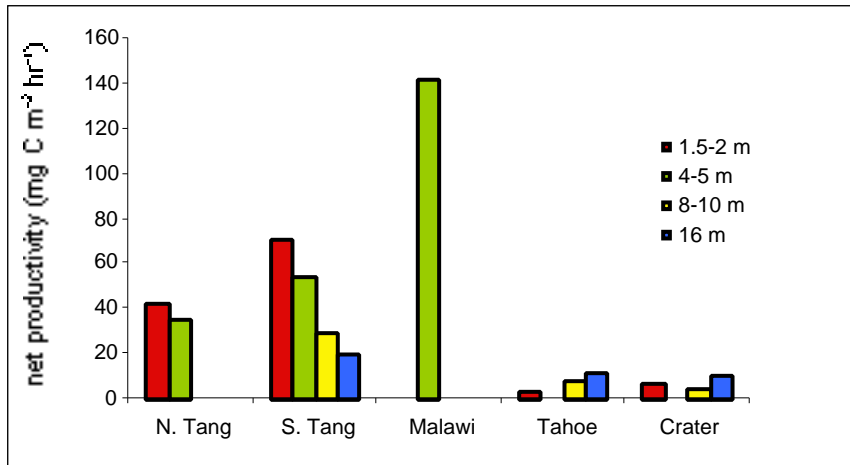
Figure 7. A comparison of benthic productivity across a latitudinal gradient. Northern Tanganyika data is from Takamura (1988). Southern Tanganyika is average annual data from Mbita Island, Mpulungu from this study. Lake Malawi (Bootsma, 1993) and Lake Tahoe and Crater Lake (Loeb et al., 1983) provide a comparison with another tropical and temperate oligotrophic lakes.