PROJECT TITLE: IMPROVING LIGHT ATTRACTION TECHNOLOGIES FOR ENHANCED HARVEST OF MUKENE ON LAKE VICTORIA

PROJECT ID NUMBER: CGS/4/29/14

NATIONAL FISHERIES RESOURCES RESEARCH INSTITUTE (NaFIRRI)

A FINAL TECHNICAL REPORT

DECEMBER 2017

BY

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START DATE: APRIL 2014

END DATE: DECEMBER 2017

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PROJECT COMPLETION SUMMARY

Project title	Improving light attraction technologies for enhanced harvest of mukene on Lake Victoria	
Reference Number	CGS/4/29/14	
Lead Organization	National Fisheries Resources Research Institute (NaFIRRI)	
Principal Investigator	Anthony Taabu Munyaho (PhD)	
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	BMU Kiyindi landing site	……..
Purpose	To develop the most appropriate light attraction technology (colour, intensity and source of light) for enhanced and sustainable harvest of mukene on Lake Victoria	
Location	District	Sub-County
	Buikwe	Nyenga
		Nama
	Buvuma	Buvuma
		Ryabana
Start Date	April 2014	
End Date	December 2017	
Total Budgeted Cost	USD 90,000 (UGX: 225,000,000)	
Total Actual Expenditure	USD 90,000 (UGX: 225,000,000)	

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LIST OF ACRONYMS AND ABBREVIATIONS

AAA	Arrow Aquaculture Africa
AGL	African Great Lakes
CGS	Competitive Grant Scheme
FAO	Food and Agricultural Organisation
LVFO	Lake Victoria Fisheries Organisation
NaFIRRI	National Fisheries Resources Research Institute
SoLAT	Solar Light Attraction Technologies
NARO	National Agricultural Research Organisation
WHO	World Health Organisation

EXECUTIVE SUMMARY

The importance of the small pelagic fish species in most African Great Lakes (AGL) has increased, with mukene on Lake Victoria contributing >45% of the commercial landings and >60% of the fish biomass in 2015. However, mukene is currently harvested at less than 30% of its total biomass using the traditional kerosene pressure lamps and encircling net (lampara) technology, yet studies indicate that short lived species (e.g. mukene) can sustainably be harvested up to 60% of their total biomass. The National Fisheries Resources Research Institute (NaFIRRI) secured funding under the National Agricultural Research Organisation's Competitive Grants Scheme (NARO-CGS) in 2014 to implement a study "Improving light attraction technologies for enhanced harvest of mukene on Lake Victoria". The main objective of the study was to develop a commercially viable mukene harvesting technology for improved food and nutritional security as well as enhanced household incomes among artisanal mukene fishers on Lake Victoria, Uganda. The study investigated the effect of light colour, source, and intensity on attraction and concentration of mukene in the shallow inshore (<20 meter depth), mid-island (>20-40 m) and deep open water zones (>40 m) of the lake. The performance of different light settings (floating, surface and submerged) using a low cost rig made from locally available materials for easy adoption by artisanal mukene fishers was also evaluated. The effect of lunar phases on mukene harvest and proportion of by-catch were explored through analysis of commercial catch data collected for a period of one year (2016 - 2017) from industrial rigs operating at Kiyindi in Buikwe district. The green (3.6 ± 0.9 $Kghr^{-1}$) and white (2.3 ± 0.8 $Kghr^{-1}$) light colours harvested high catch rates (>2$Kghr^{-1}$). Generally, the catch rates increased with intensification of light intensity and varied with light source; the solar bulbs harvesting higher catch rates (12.1 ±2.9 kg hr^{-1}) than the traditional pressure lamps (7.2 ±2.9 kg hr^{-1}). Surface lights harvested higher catch rates (2.0 0.4 $Kghr^{-1}$) than other light settings. Although, catch rates were higher during the third quarter (4,322 $Kgday^{-1}$) and new moon (4,167 $Kgday^{-1}$) of the lunar phase, the proportion of by-catch was highest during full moon. The proportion of by-catch, especially juvenile of Nile perch and Nile tilapia, was higher in the Napoleon Gulf than deep open waters of Nkata. Mukene fishing in the shallow inshore areas especially closed bays should be avoided since it negatively impacts on the sustainability of the Nile perch and Nile tilapia which use these habitats as their breeding and nursery grounds. Furthermore, adoption of solar light attraction technologies (SoLAT) using white and green lights in the deep open waters of the lake where high quantities of mature mukene and less by-catch of Nile perch and Nile tilapia is highly recommended. Since SoLAT is a new technology, there is urgent need to formulate a policy to guide its use

in harvesting mukene on Lake Victoria. However, the public should be sensitized on the implications this new technology to avoid conflicts that may arise among the different fisheries. Further research to determine the sustainable fishing effort for mukene stocks in the lake, to avoid a similar scenario of stock decline in the Nile perch and Nile tilapia fisheries due to unregulated fishing effort, is highly recommended

1.0 Background

Stocks of the larger fish species (>20 cm TL) such as Nile perch and Nile tilapia have declined, resulting into shortfall in fish supply required for domestic, regional, and international trade. Subsequently, the per capita fish consumption for Uganda has substantially reduced to 6-8 Kg person^{-1}year^{-1}, which is below the figures recommended by FAO (17.5 kg person^{-1} year^{-1}) and WHO (25 kg person^{-1} year^{-1}) . The levels of malnutrition especially among women and children below five years has increased, and more so in fishing villages (Geheb *et al.* 2007). Stunting and underweight attributed to limited access to balanced diets and prevalent poverty (over 30% of Uganda's population earning is <1 US dollar per day) have increased. Fish that provided considerable animal protein to Ugandans is no longer affordable due to limited supply and high demand. To bridge the gap between fish protein demand and supply, an additional annual production of about 169,000 tons is required.

Two approaches are envisaged to bridge this gap. 1). Increasing aquaculture production and 2). Enhancing the exploitation of emerging small pelagic fishes such *Neobola bredoi* (Muziri), *Brycinus nurse* (ragoogi), and *Rastrineobola argentea* (mukene/omena/dagaa). Until 1960s, small pelagic fishes particularly mukene were mostly harvested for animal feed production. However, the high demand for Nile perch and Nile tilapia in the regional and international markets in late 1980s escalated their cost and made them less accessible by the local population. Subsequently, the artisanal fishers began exploiting mukene not only for animal feeds but also for human consumption.

Mukene is harvested at night using light attraction from kerosene pressure lamps and encircling net (lampara net), a technology that was first introduced on Lake Victoria in the mid-1960s (Okedi, 1981; Wanink, 1999). Studies have shown that, about 40 - 70 kg of mukene are harvested per boat per day using this technology. On the contrary, an industrial rig technology using light from electric bulbs and lift net harvests 280 - 4500 kg rig^{-1} day^{-1}. This implies that improvements in light technology (use of bulbs) can increase the catches of mukene to the sustainable biomass (60% of total biomass), to meet the growing demand for fish protein. The rig technology which was introduced on Lake Victoria from Lake Kariba by Arrow Aquaculture Africa (AAA) in 2006 is ten-fold expensive compared to the kerosene pressure lamps and has not been adopted by artisanal fishers. There is a need to develop a cost effective technology that will enable increased but sustainable exploitation of mukene on Lake Victoria.

Accordingly, this study investigated the effect of light colour, source, intensity, and setting (surface, floating, and submerged) on mukene catch rates on Lake Victoria. Improved light attraction technologies is envisaged to increase mukene production to at least 60% of its stock biomass, a level considered sustainable given the short regeneration period for this species.

1.1 Objective of the study

To develop a commercially viable mukene harvesting technology for improved food and nutritional security as well as enhanced household incomes among artisanal mukene fishers on Lake Victoria, Uganda

1.2 Specific objectives

1. To test the efficacy of light colours in attracting and concentrating mukene on Lake Victoria.
2. To evaluate the effect of light source (kerosene pressure lamps, generator powered AC bulbs and solar powered bulbs) on mukene catch rates.
3. To determine the appropriate light intensity (number of lamps or bulbs) for mukene harvest.
4. To compare the performance of surface, floating, and submerged light sources in attraction and concentration of mukene.
5. To investigate the effect of light source, colour, and intensity on by-catch during light fishing.

1.3 Expected outputs

1) The most appropriate light attraction technology (colour, intensity and source of light) for harvesting mukene on Lake Victoria determined.
2) A cost-effective rig for attraction and concentration of mukene on Lake Victoria developed.
3) Performance of surface, floating and submerged light sources for mukene harvest on Lake Victoria determined.
4) Ecologically safe sources of light (solar and electric bulbs) for mukene harvest determined and recommended for sustainable harvest of the species.
5) Public private partnership strengthened.
6) Capacity developed for two MSc students and two dissertations detailing appropriate light technologies and fishing grounds for mukene produced.

2.0 MATERIALS AND METHODS

2.1 Study area

Three sites (i.e. the shallow inshore waters (<20 m) of Kikondo within the Napoleon Gulf, mid-island waters (20 – 40 m) of Nkembo, and deep open (>40 m) water zones of Nkata on Lake Victoria (Figure 1) were sampled in 2015 (February, April, May, and June), 2016 (April and May), and 2017 (August).The choice of study sites was guided by previous findings that showed a correlation relationship between the distribution of mukene and depth (Taabu-Munyaho, 2004; Tumwebaze et al., 2007).

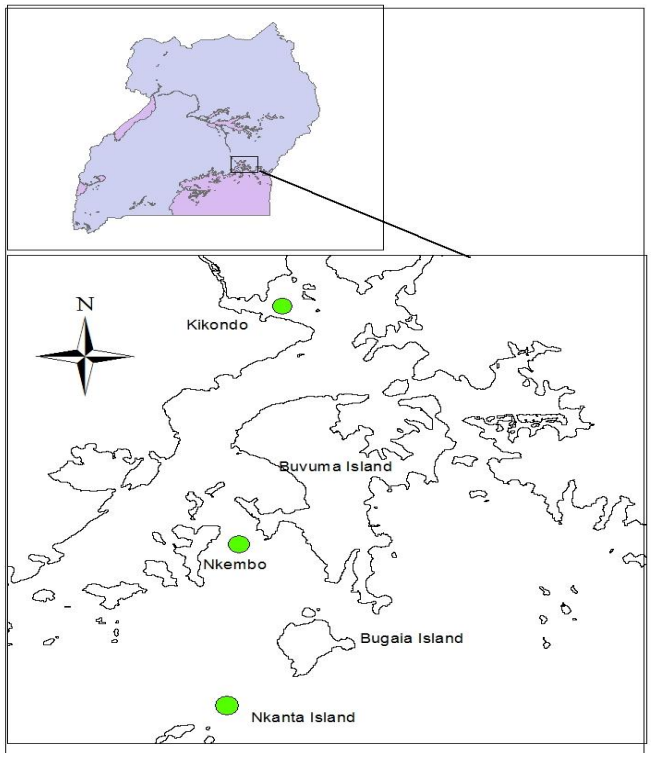

Figure 1: Location of the study sites in the northern portion of Lake Victoria, Uganda

2.2. Acquisition of sample specimen

Two main fishing technologies/gears were used to obtain mukene samples from the study sites i.e. lampara net on Ssese Flat canoe and the lift net on a fabricated rig (Plates 2 & 3, respectively). These are briefly described below.

2.2.1 The lampara net technology

In this study, mukene was caught by light attraction using traditional kerosene pressure lamps as described by Okedi (1981) and Witte & van Densen (1995), generator powered bulbs tied on rafts constructed out of dry reeds (Phragmites sp.), and solar powered bulbs tied on the wooden rafts. The fish was hauled using a 5 mm mesh size lampara net measuring 30 metres long and 8 metres deep (8 panels).

2.2.2 The rig technology

This is an open flat bottomed pontoon boat made from a fiberglass but supported by galvanized 5 inch pipes (Plate 3). A mechanical winch and fig for the net were added to the side. The winch has bearings and two handles which are held by operators to lower and lift the fishing net. The handles are positioned in opposite direction in a similar way as the bicycle pedals and are operated manually. The drive from the winch is transmitted through the warp hinge by a pulley at the top of the rig to lower and lift the net during fishing activities. The rig is inclined sideways to the boat and supported by two 3m long metal pipes welded to the base and joined at the top making "A" shape. A pair of warp is attached from above for further reinforcement of the rig. The lift net supported by the metal ring is suspended or hangs in the middle of the A-shaped metal bars. Three bulbs which provide light for fishing are suspended from the rig with two on the sides and one directly in the middle of the net. The later bulb is moved freely up (surface), on water (floating) and down (submerged) whilst the two side bulbs are kept static. The switch board that controls the bulbs is fastened to the hull of the boat.

2.3 Experimental design

The most popular light technology currently used to harvest mukene on Lake Victoria by artisanal fishers involves the use of lampara nets and kerosene pressure lamps (white light). However, some industrial rigs (AAA) using lift nets and generator powered bulbs are also being employed in some parts of the lake. These two settings were investigated during the study.

2.3.1 Efficacy of light colours for mukene harvest

In determining the effect of light colour on mukene attraction and concentration (catch rates), five coloured bulbs (i.e. white, blue, green, yellow, and red) of 45W each (readily available on the market) and powered by a generator as an energy (light) source were used (plate 1). Only white solar bulbs were locally available on the market while attempts to paint the kerosene pressure lamps with the above different colours failed due to melting and peeling off of the colours on heating. Accordingly, varying colours were only studied using generator powered bulbs.

In intervals of about five minutes, bulbs of different colours were set at approximately 100 meters apart and left to stand for about an hour before hauling the fish. For each colour setup, the active time (time interval between setting and retrieving the net) and quantity of mukene (kilogram) concentrated during active fishing were recorded. For each site, sampling was conducted for two consecutive days in each month sampled. The catch rates (kg $hour^{-1}$) for the different colour settings were compared to determine the most efficient in the attraction and concentration of Mukene.

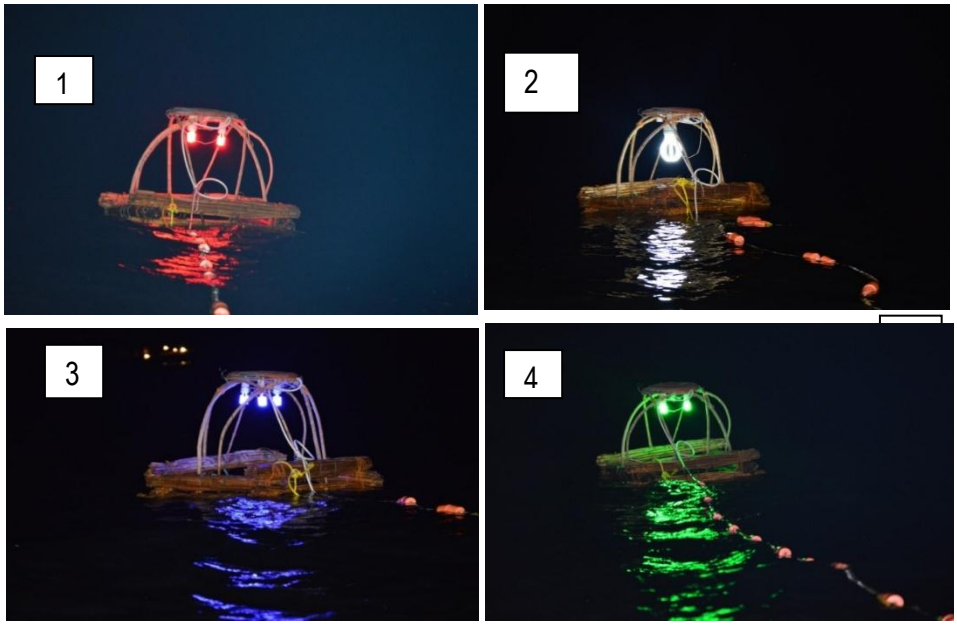

Plate 1: The different light colours used; 1: Red, 2: White, 3: Blue and 4: Green



Plate 2: Different stages of hauling fish using a lampara net. A: (encircling of fish), B &C: (retrieving of the catch), and D: (weighing of the catch)

2.3.2 Effect of energy source on mukene catch rates

The efficacy of three white light sources (i.e. kerosene pressure lamps, bulbs powered by either a generator or solar) in attracting mukene was investigated. Green light generally attracted higher catches of mukene in this study (see section 3.1), but was only accessible for one energy source (Generator). Hence, white light that is popular among artisanal fishers was used to test the effect of light source. The setup and data collection protocols for the different light sources were as described in section 2.3.1. Light source effectiveness at attracting mukene was compared using catch rate estimates (kg $hour^{-1}watt^{-1}$) generated by dividing the total biomass (kg) of mukene harvested in an hour by the capacity of the bulbs (watts) used.

2.3.3 Effect of surface, floating and submerged light on mukene catch rates

Some fraction of the light shining on the surface of the water is lost through reflection and scattering implying that little remains available to attract and concentrate fish and other aquatic organisms in a specific locality. The artisanal fishers for mukene on Lake Victoria have traditionally used the surface lights for many years, notwithstanding the substantial loss of surface light due to processes indicated above. Using the rig fabricated by NaFIRRI from the locally available materials (Plate 3), the performance of surface, floating and submerged light settings in the attraction and concentration of mukene was evaluated. A combination of the surface-submerged and floating-submerged light setting, using white coloured waterproof bulbs of three different intensities i.e. 125 watts (W), 250W and 400W, were also evaluated to estimate their effect in the attraction and concentration of mukene. The bulbs were powered by a 4000W Yamaha model generator stationed on a fabricated rig. For each setting, (and using one light intensity at a time) bulb/s was/were placed on (floating), one meter above (surface) and below (submerged) the water surface, and allowed to fish for one hour before hauling using a lift net. The data collection procedures for the different light settings were as described in section 2.3.1.



Plate 3: Lowering (A) and lifting (B) of the lift net using a fabricated rig

2.3.4 Effect on light intensity on mukene catch rates

The appropriate intensity of light for attracting and concentrating mukene was determined by varying the number of kerosene lamps and bulbs (solar/generator) per fishing experiment (Plate 4), using the white light. The white light was chosen because it was the only available colour across all the light sources i.e. solar, generator and kerosene lamps. In addition, white light is also the most popular among the artisanal fishers targeting mukene on Lake Victoria. The index of light intensity was evaluated by increasing the number of lamps or bulbs. The setup and data collection protocols for the different light intensities were as described in section 2.3.1.

For the fabricated rig, bulbs of different watts (125W, 250W, and 400W) were used to vary intensity at different light settings. Efforts to measure the amount of light emitted (relative light intensity) per experimental setup using a simple hand-held light meter did not succeed due to water turbulence arising from rough weather.

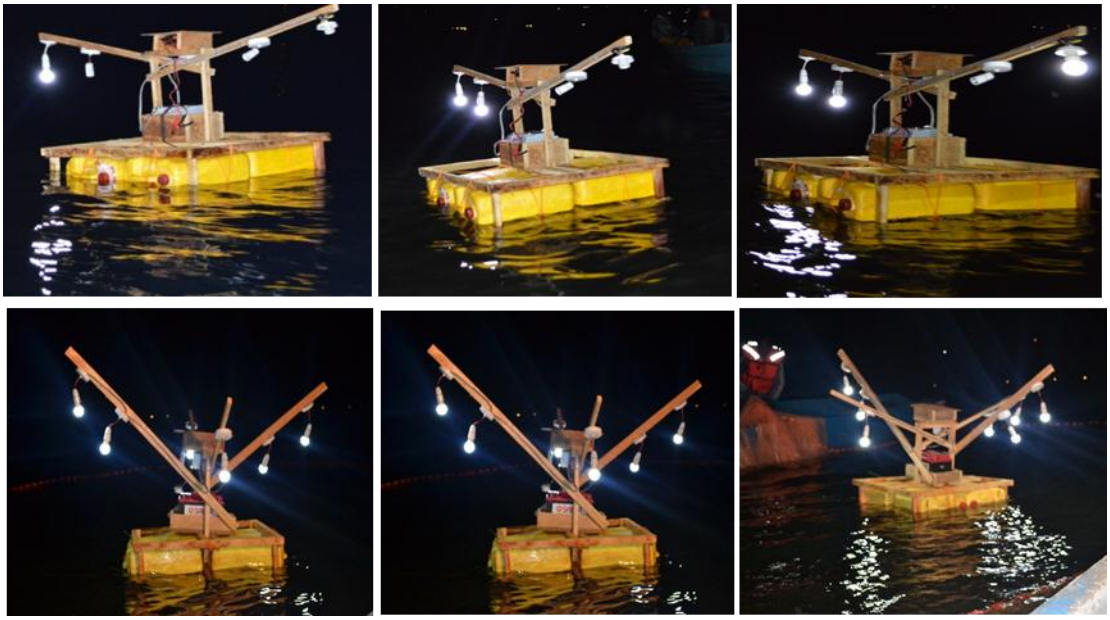

Plate 4: Variation of solar light intensity

2.3.5 Effect of light source, colour and intensity on harvest of by-catch

Fish and other aquatic organisms are known to have colour receptors for optimized vision of their "space" and they are more attracted to particular colours than others. Using a colour that can reduce the capture of non-target fish species in mukene fishery is therefore vital. For each experimental setup, a sample (500 g) of the total catch per haul was obtained after weighing and immediately preserved in a 5% formalin solution in plastic bags and taken to the laboratory for quantification of the non-target species (by-catch). In the laboratory, the samples were washed under running tap water and sorted into their respective species taxa. The numbers and weights of each species encountered were recorded. By-catch was then quantified as a proportion of the non-target species of the total sample.

Sub-samples (250 g) of pure mukene were taken and standard lengths (SL, mm) measured at 1 mm class intervals. The gonadal maturity status of ten specimens from each length class were examined (LVFO, 2007) to determine the proportion of mature and immature mukene harvested by the different light experimental setups.

2.3.6 Relationship between lunar phase and by-catch of mukene

The effect of lunar phases on mukene harvest and proportion of by-catch of the non-target species in mukene catch was determined through analysis of commercial catch data collected between October 2016 and September 2017 from the commercial industrial rigs operated by Arrow Aquaculture Africa (AAA) at Kiyindi fishing ground, Buikwe district.

3.0 RESULTS

3.1 Effect of light colour on mukene catch rates

The mean catch rate (±SE) was highest in the deep open waters (3.11 ± 0.76) and lowest in the mid-island water zones (1.26 ± 0.46, Appendix I). Overall, catch rates were highest and lowest when green (3.6 ± 0.9) and red (0.98 ± 0.2) lights were used, respectively (Figure 2, Appendix II).

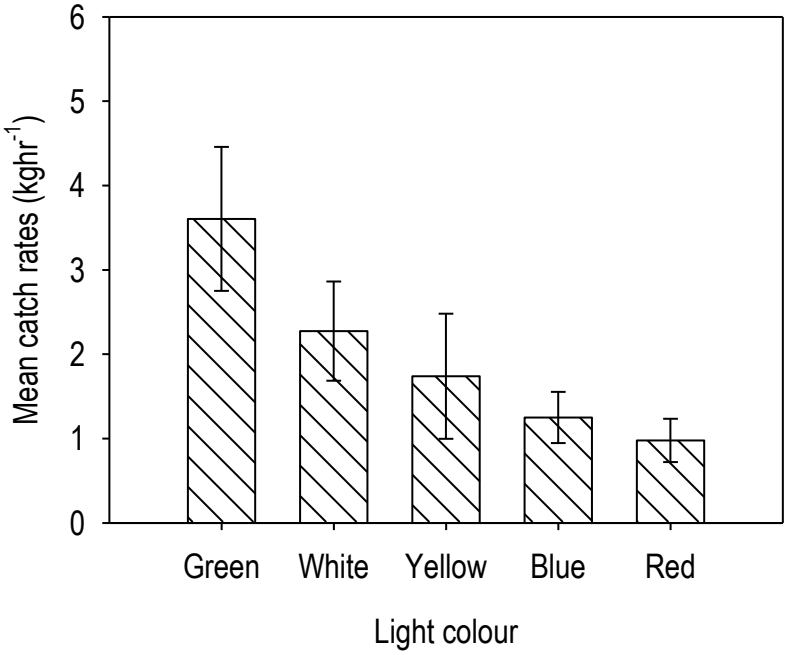

Figure 2: Mean catch rates (kg/hr) of mukene harvested by different light colours on Lake Victoria

There were variations in catch rates across and within sites (due to light colours), albeit not being statistically significant (Figure 3). In the inshore (Figure 3a) and mid island (Figure 3b), catch rates were highest using green colour, whilst yellow registered high catches in the deep open waters (Figure 3c). On the other hand, blue colour attracted the lowest catch rates in inshore and deep open waters; while red registered the least catch rate in the mid-island.

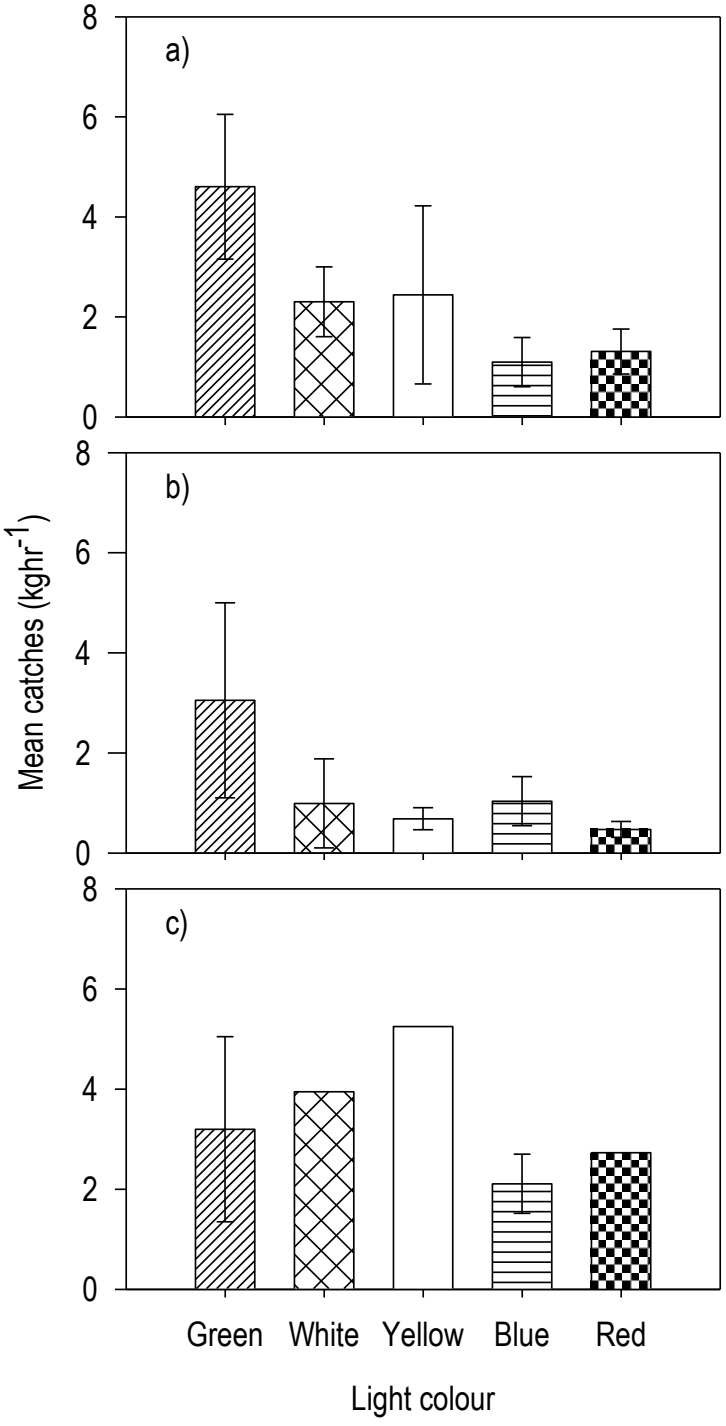

Figure 3: Catch rates of mukene attracted by different colours in the a) Inshore, b) Mid-island, and c) Deep waters of Lake Victoria

3.2 Effect of light source on mukene catch rates

Overall, solar bulbs harvested higher catch rates (12.1 ± 2.9 $kghr^{-1}$) than the traditional kerosene lamps (7.2 ± 0.8 $kghr^{-1}$) and generator powered bulbs (1.9 ± 0.5 $kghr^{-1}$; Figure 4).

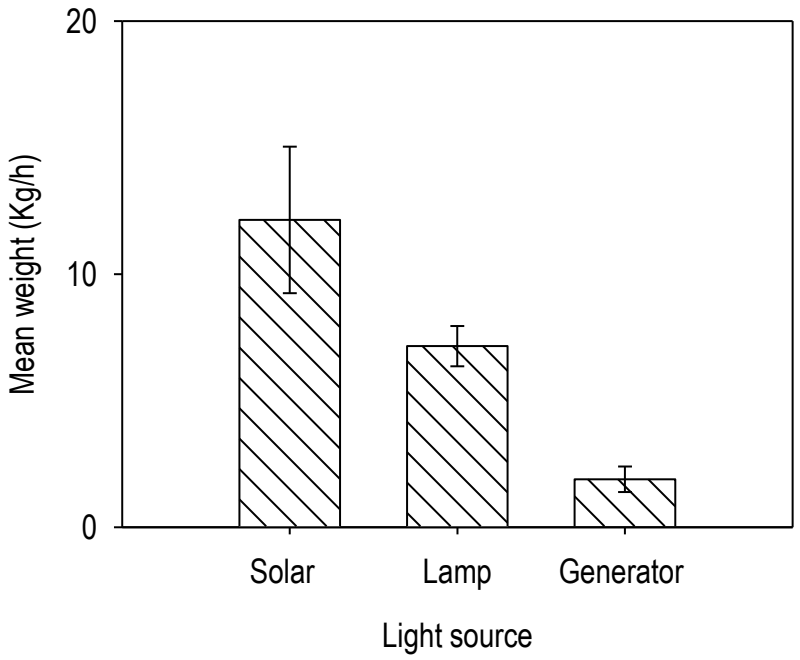

Figure 4: Mean catch (Kg/h ± SE) of mukene harvested by different light sources

There were statistically significant variations in catch rates across and within sites (Table 1). Catch rates in both solar and generator powered bulbs were higher in the shallow inshore than mid-island and deep open waters.

Table 1: Catch rates of mukene harvested by different light sources in the shallow inshore, mid-island and deep open waters of Lake Victoria

	Catch rates ($kghr^{-1}watt^{-1}$)		
Light source	Inshore	Mid-island	Deep open
Solar	1.08 ± 0.18	0.51 ± 0.06	0.48 ± 0.18
Generator	0.02 ± 0.01	0.01 ± 0.01	0.03

Generally, higher catch rates ($kghr^{-1}watt^{-1}$) were harvested by solar bulbs (0.8 ± 0.1) than generator powered bulbs (0.02 ± 0.004; Figure 5).

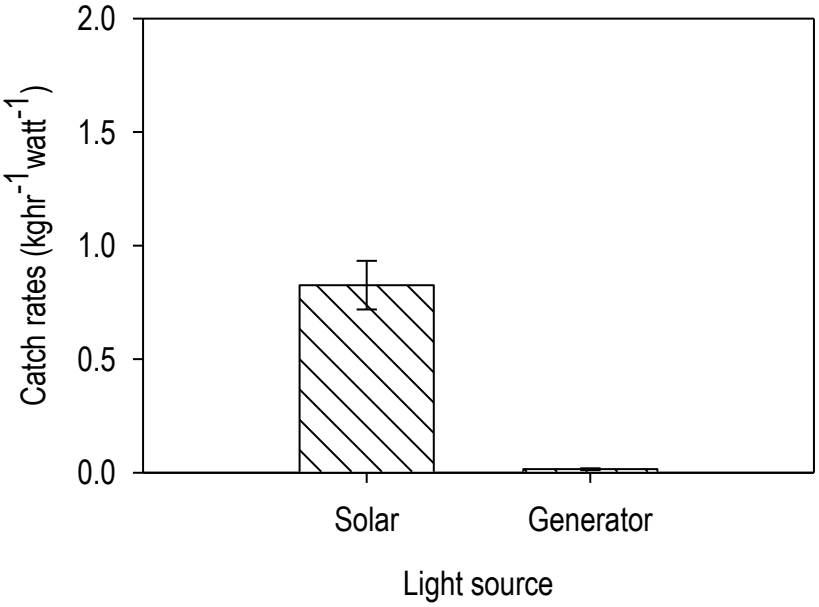

Figure 5: Catch rates harvested by different light sources on Lake Victoria

3.3 Effect of light setting in attraction and concentration of mukene

Overall, catch rates (±SE) were highest and lowest when surface (2.0 ± 0.4) and submerged (1.0 ± 0.4) light setting were used, respectively (Figure 6, Appendix III).

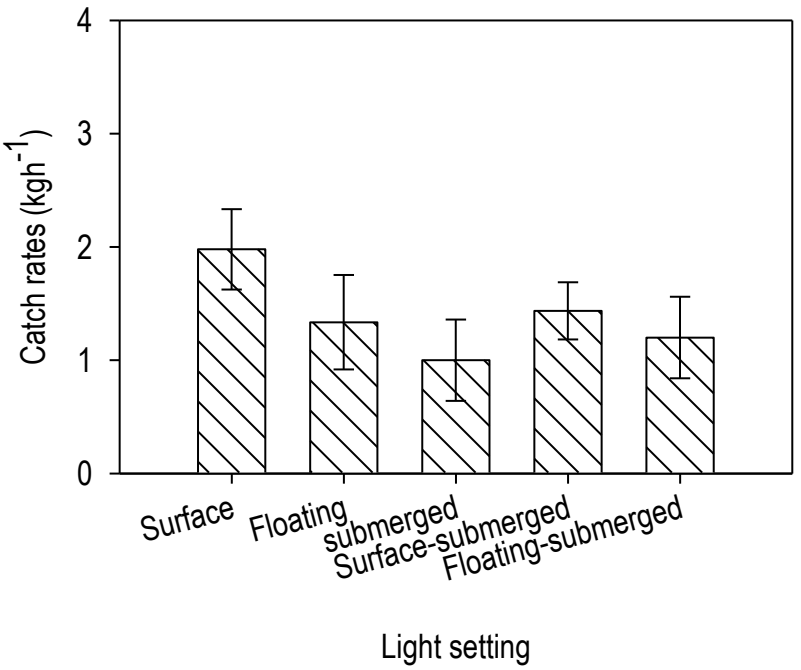

Figure 6: Mean catch rates (±SE) of mukene harvested by different light setting on Lake Victoria

There were statistically significant variations in catch rates across and within sites ($P<0.05$; Figure 7). In the inshore (Figure 7a), catch rates were highest and lowest using surface-submerged and submerged light settings, respectively. In the mid-island (Figure 7b), the highest and lowest catch rates were obtained using surface and surface-submerged light setting, respectively. On the other hand, surface lights generally attracted higher catches in both inshore and md-island waters of the lake.

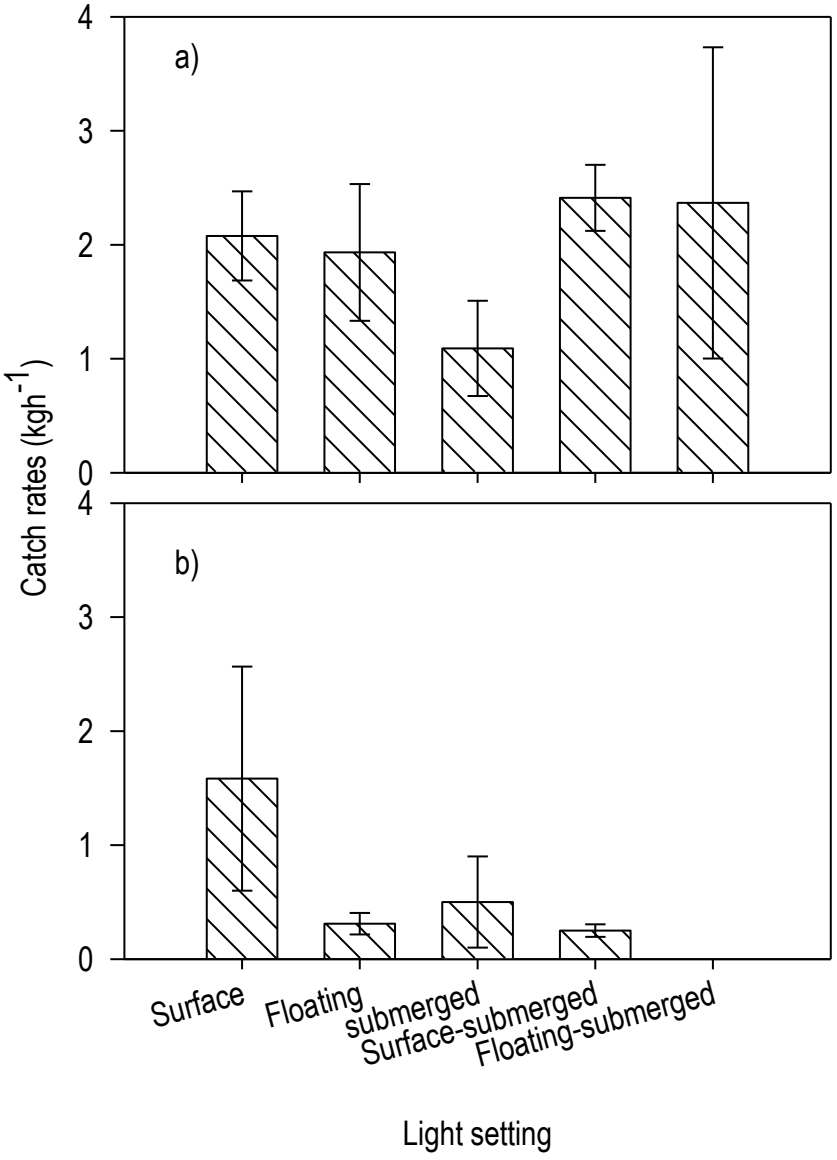

Figure 7: Mean catch rates (±SE) of mukene attracted by different light settings in the a) Inshore and b) Mid-island waters of Lake Victoria

3.4 Effect of light intensity on mukene catch rates

Catch rates (kgh^{-1} ±SE) in different light sources increased with intensification in light intensity (Figure 8). Increasing generator powered bulbs (Figure 8a) and kerosene lamps (Figure 8b) from 1 – 4 increased catch rates from 1.8 ± 0.8 to 2.7 ± 1.1 kgh^{-1}, and 5.6 ± 0.8 to 10.7 ± 2.9 kgh^{-1}, respectively. Tripling solar powered bulbs (Figure 8c) from one to three increased the mean catch rates from 3.1 ± 0.4 to 7.9 ± 2.2K kgh^{-1}; beyond 3 bulbs a general reduction in catch rates was recorded.

There were variations in catch rates across and within sites (Figure 9). In the inshore (Figure 9a), increase in the number of kerosene powered lamps increased catch rates. In the mid-island (Figure 9b), catch rates reduced with increased in the number of lamps although increase in the number of solar powered bulbs generally had no effect on catch rates.

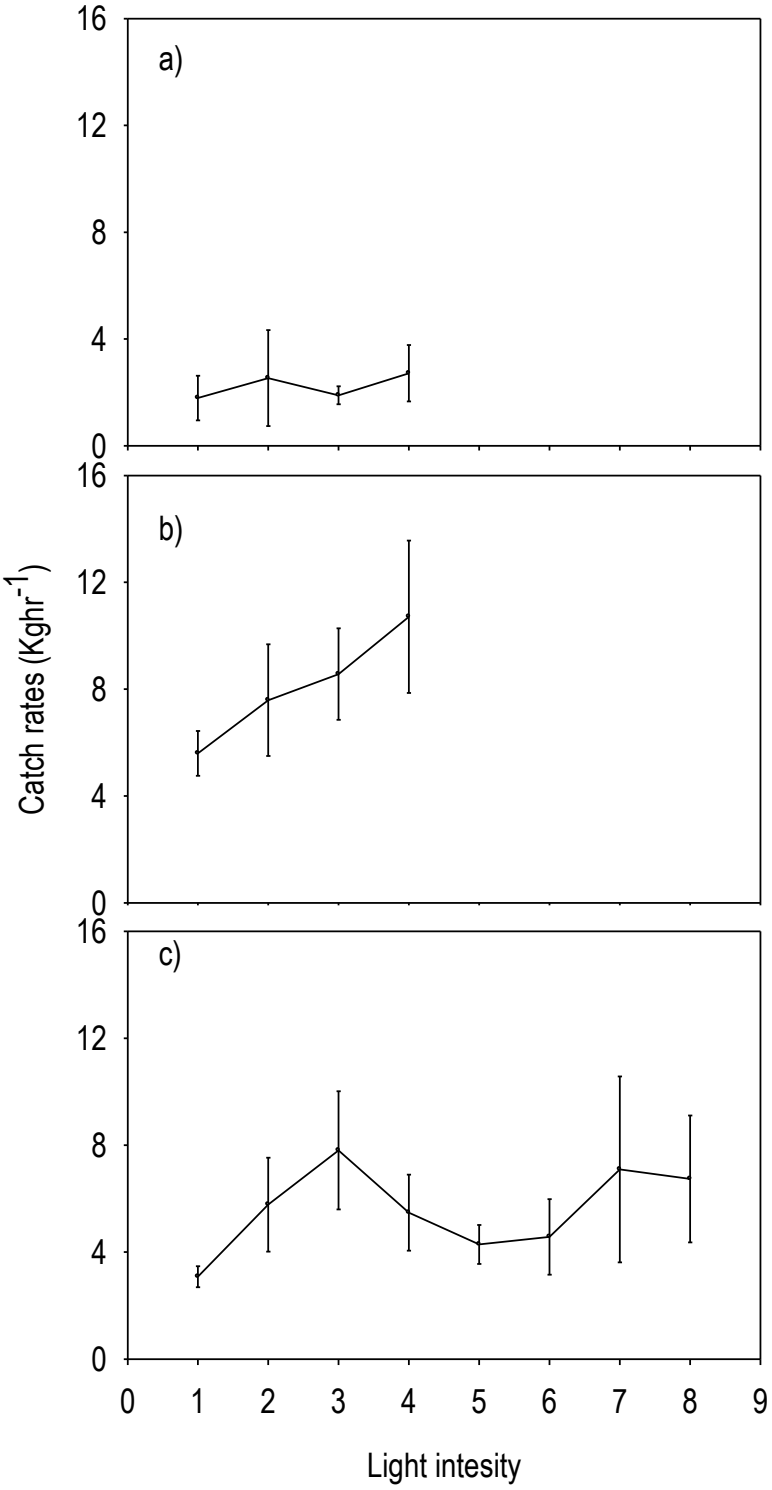

Figure 8: Catch rates of mukene harvested by different light intensities powered by a) generator, b) lamps, and c) solar on Lake Victoria

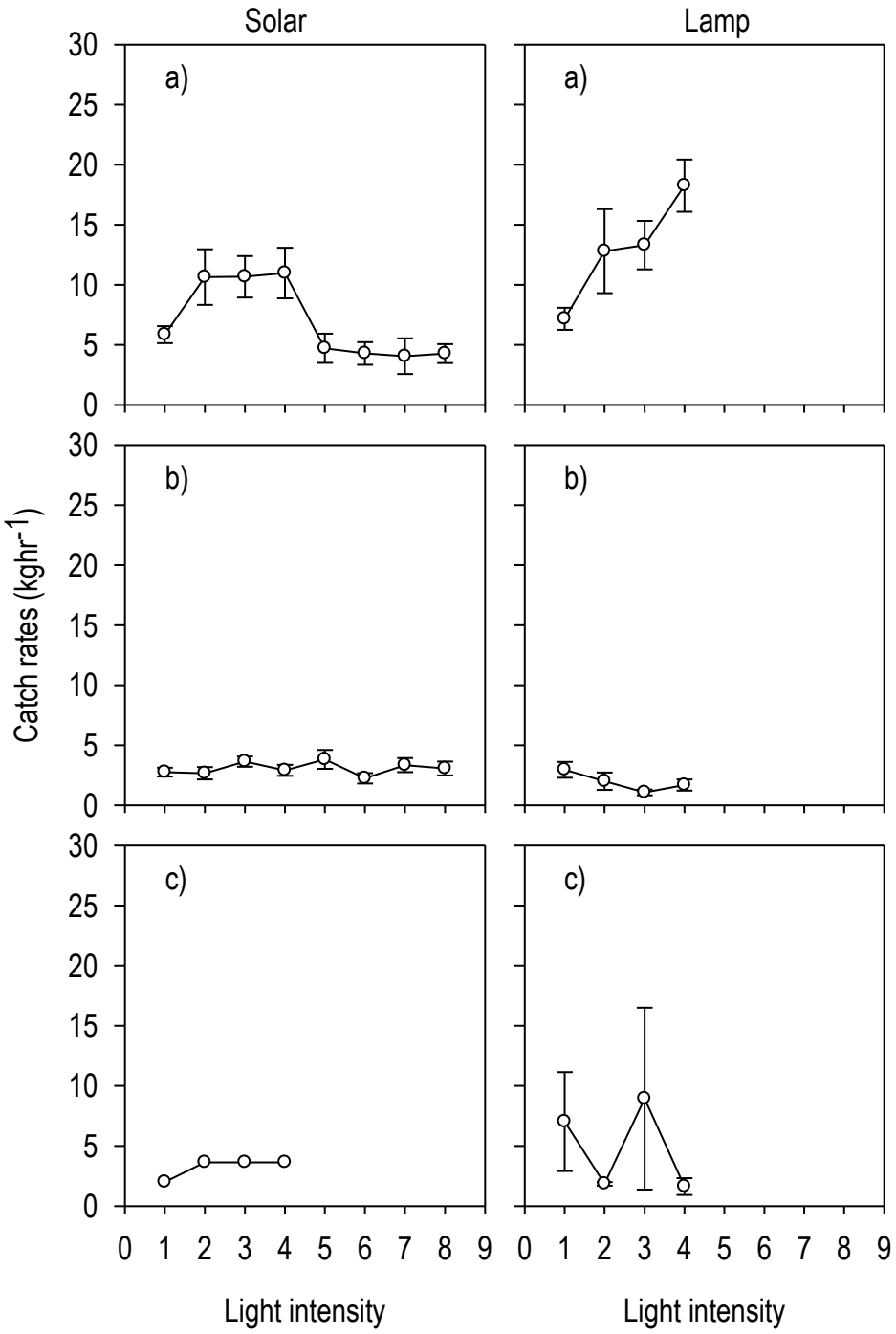

Figure 9: Catch rates of mukene harvested by different light intensities powered by solar and kerosene lamps in the a) shallow inshore, b) mid-island, and c) deep open waters of Lake Victoria

The highest catch rates were harvested by surface lights at higher intensities (Figure 10a). Floating and submerged light setting, however, attracted higher catches at lower intensities (Figure 10b).

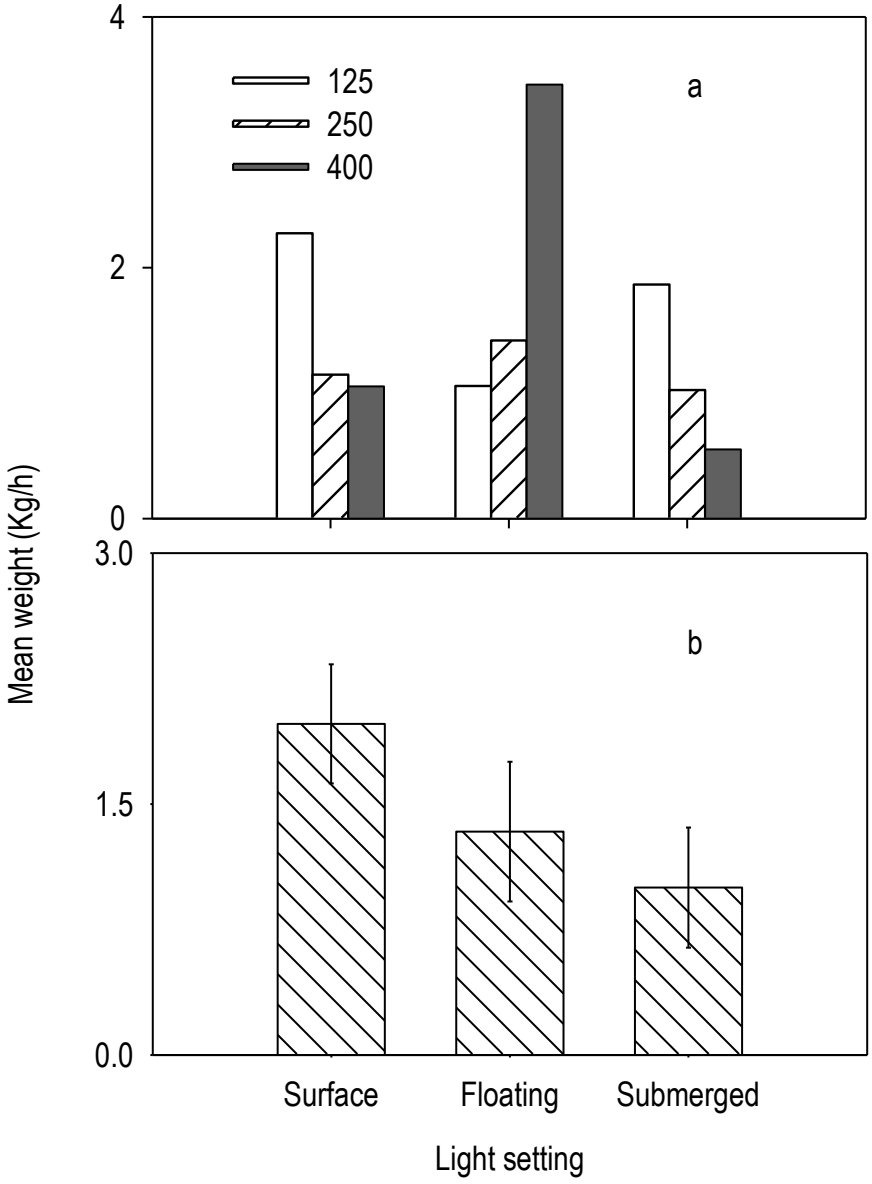

Figure 10: Catch rates of mukene harvested by different light intensities under varying light settings

However, floating-submerged light combination harvested higher catch rates at 400W (floating) and 125W (submerged) light intensities (Figure 11).

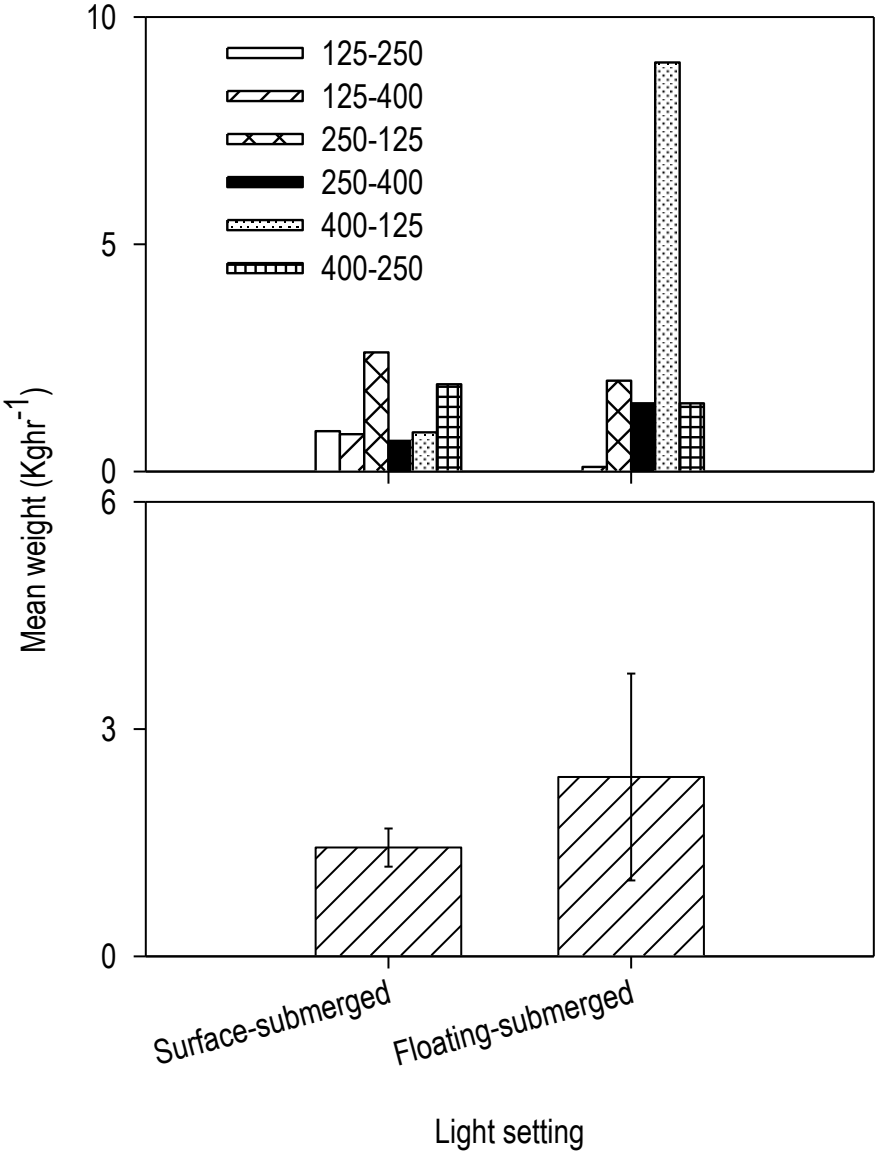

Figure 11: Mean weight ($Kghr^{-1}$) of mukene harvested by different combinations of light setting under varying light intensities

3.5 Effect of light colour, source, setting, and intensity on by-catch

3.5.1 Effect of light colour on by-catch

Nile perch, Nile tilapia, *Caradina nilotica,* and haplochromine cichlids (grouped as a taxon) were harvested as by-catch (Figure 12; Appendix IV). White and blue light colours attracted the highest proportion of Nile tilapia and Nile perch, respectively. Red and yellow light colours attracted higher proportion of Caridina.

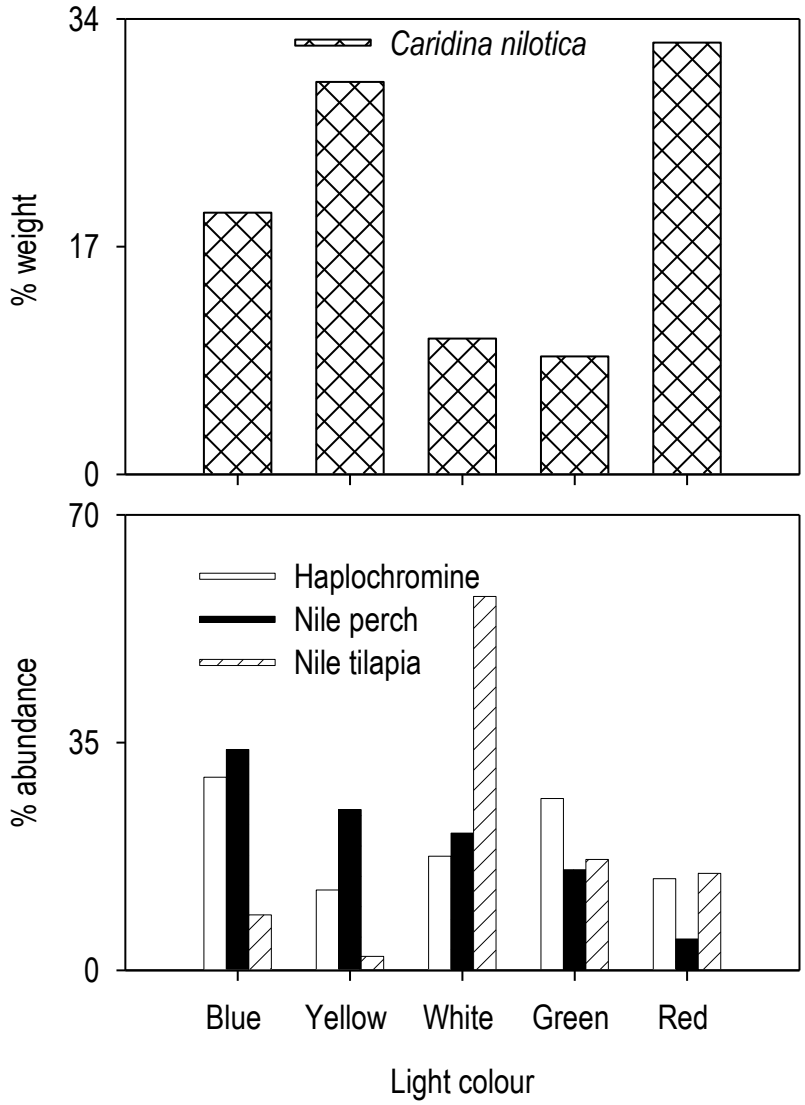

Figure 12: Proportion of by-catch harvested by different light colours

3.5.2 Effect of light source on by-catch

Generally, the kerosene lamps and generator powered bulbs attracted higher catch rates of Caridina and high proportions (abundance) of Nile perch, Nile tilapia and haplochromines than solar bulbs (Figure 13; Appendix V & Appendix VI).

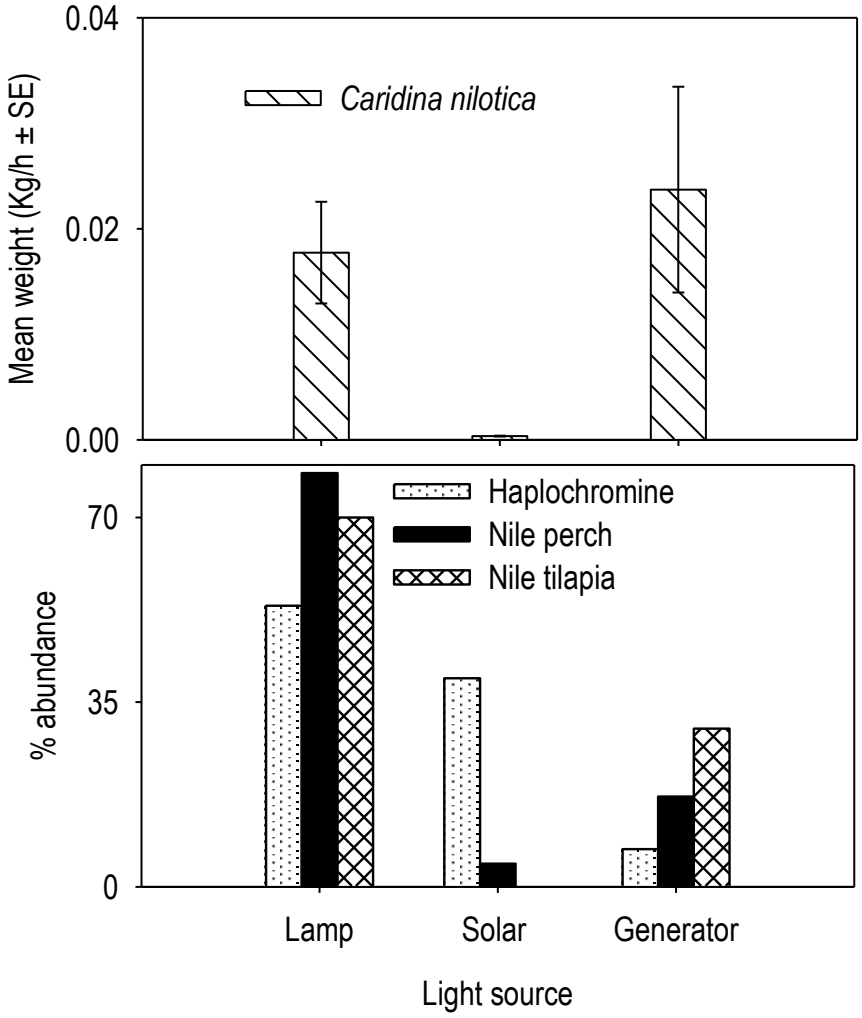

Figure 13. Proportion of haplochromine, Nile perch and Nile tilapia, and mean catch rates of Caridina (Kgh^{-1} ± SE) harvested by different light sources

However, the proportion of the by-catch was higher in the shallow inshore and mid-island water zones (Figure 14). However, Nile tilapia was virtually not harvested in the deep open water zones.

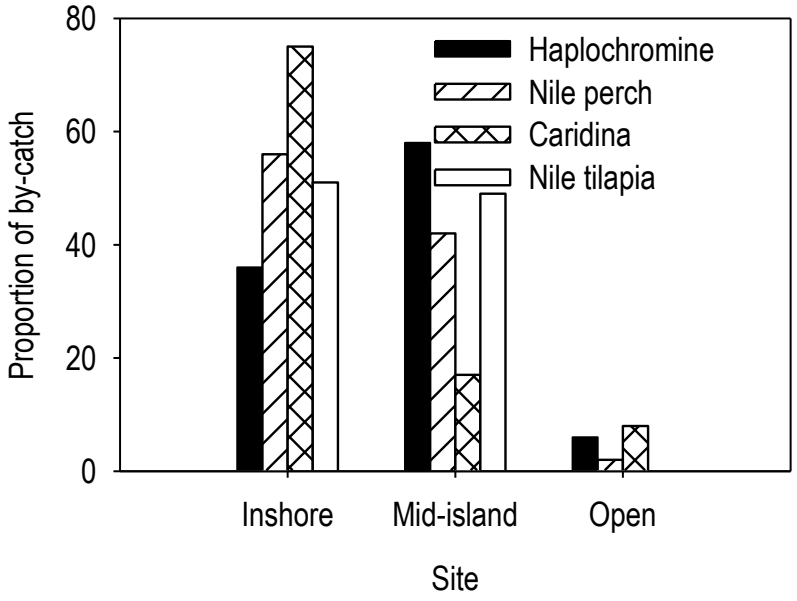

Figure 14: Proportion of by-catch harvested in the different sites of Lake Victoria

3.5.3 Effect of light setting on by-catch

Surface-submerged light setting harvested high proportion of haplochromines followed by Nile perch (Table 2).

Table 2: Proportion of the by-catch harvested by surface-submerged light setting

Species	% abundance	% weight
Haplochromine	52	80
Nile perch	16	17
Odonata	32	3

3.5.4 Effect of light intensity on by-catch

Higher proportions of Nile perch, Nile tilapia and haplochromines were harvested by two lamps (Figure 15b), and three generator (Figure 15a) and solar powered (Figure 15c) bulbs. Increasing the number of kerosene lamps (Figure 15b) and solar bulbs (Figure 15c) resulted into reduction and increase in the catch rates of Caridina, respectively.

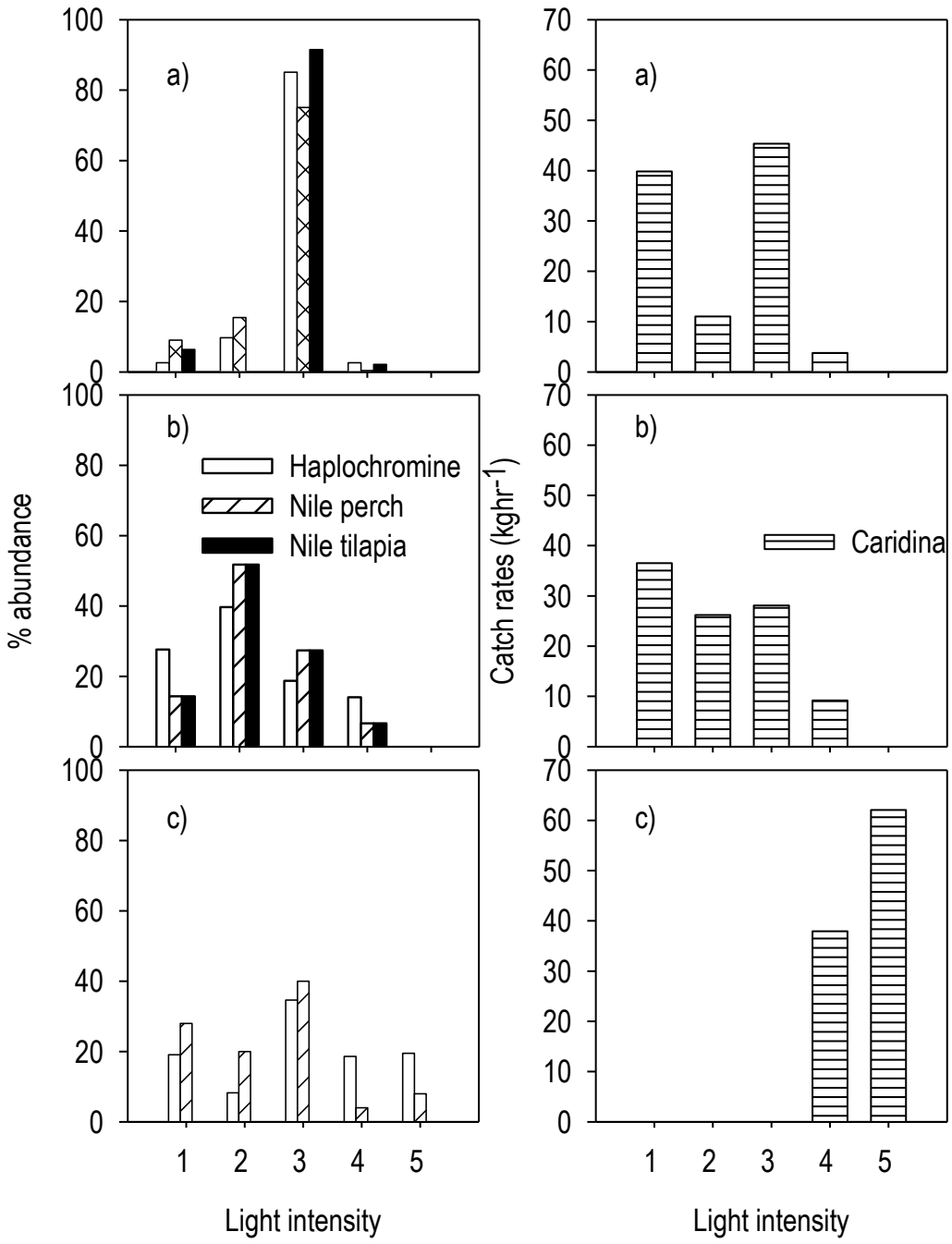

Figure 15: Catch rates of Caridina and percentage abundance of the haplochromines, Nile perch, and Nile tilapia harvested by in different light intensities using a) Generator, b) Kerosene lamp, and c) Solar

3.6 Effect of lunar phases on catch rates of mukene and proportion of by-catch

Although the higher catch rates were harvested during the third quarter and new moon phases of the lunar phase (Figure16), the proportional of by-catch was highest during the full moon lunar phase (Appendix VII).

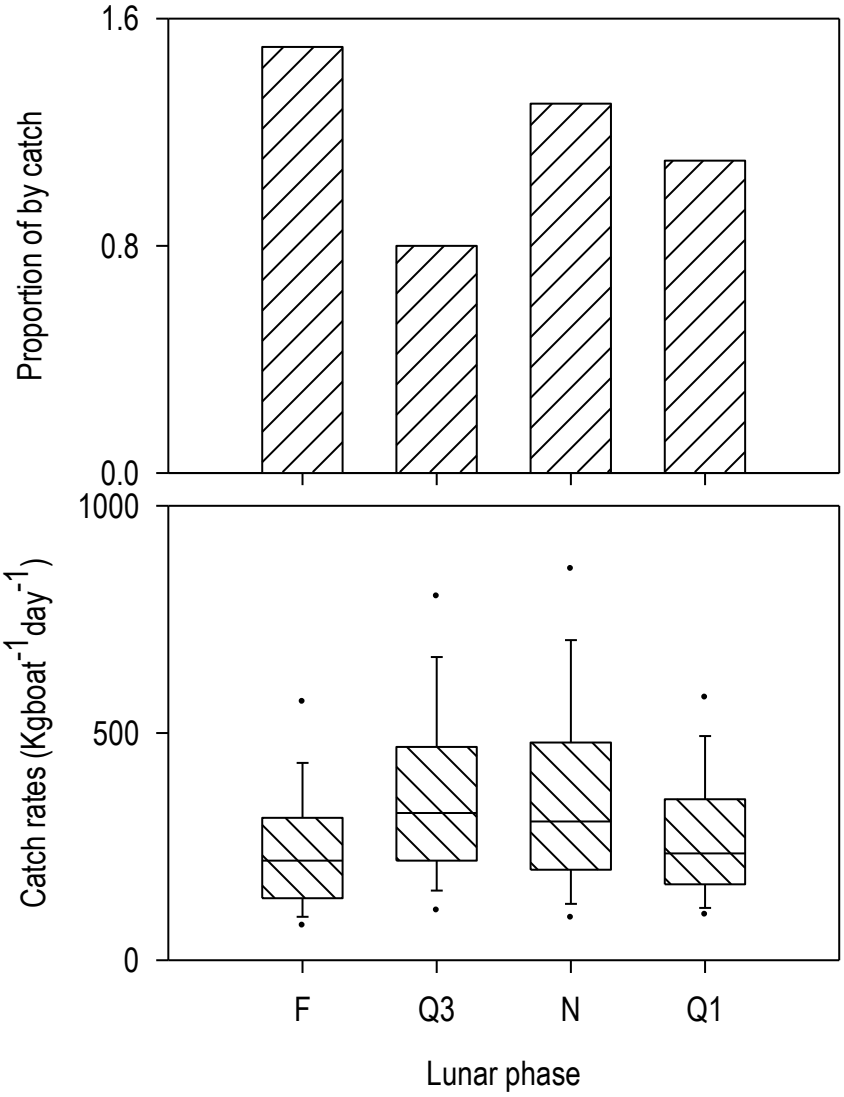

Figure 16: mean catch rates (Kgday^{-1} ± SD) of the mukene and proportion of by-catch harvested in different lunar phases (F= Full moon; Q3=Third quarter; N=New moon and Q1=First quarter)

3.7 Length at 50% maturity of mukene

Mukene matured at larger sizes in the deep open waters of Bugaia-Nkata followed by the inshore water zones of Napoleon Gulf (Table 3). All fish in shallow inshore and mid-island were mature by 42 mm SL except in deep open water habitat.

Table 3: Length at 50% maturity of mukene in different sites of Lake Victoria

	Standard length (mm)		
Site	L50	L100	n
Shallow inshore	36	42	586
Mid-island	35	42	1165
Deep open	38	50	357

3.8 Population structure of mukene harvested in different habitats

The size distribution (SL) of mukene varied across habitats, from 10 – 54 mm in shallow inshore, 10 – 60 mm in the mid-island, and 23 – 58 mm in the deep open water zones (Figure 17). The modal class of fish populations was highest in deep open water zones (45 mm SL) and lowest in Napoleon Gulf (25 mm SL). The proportion of mature fish was higher in the deep open than shallow inshore water zones.

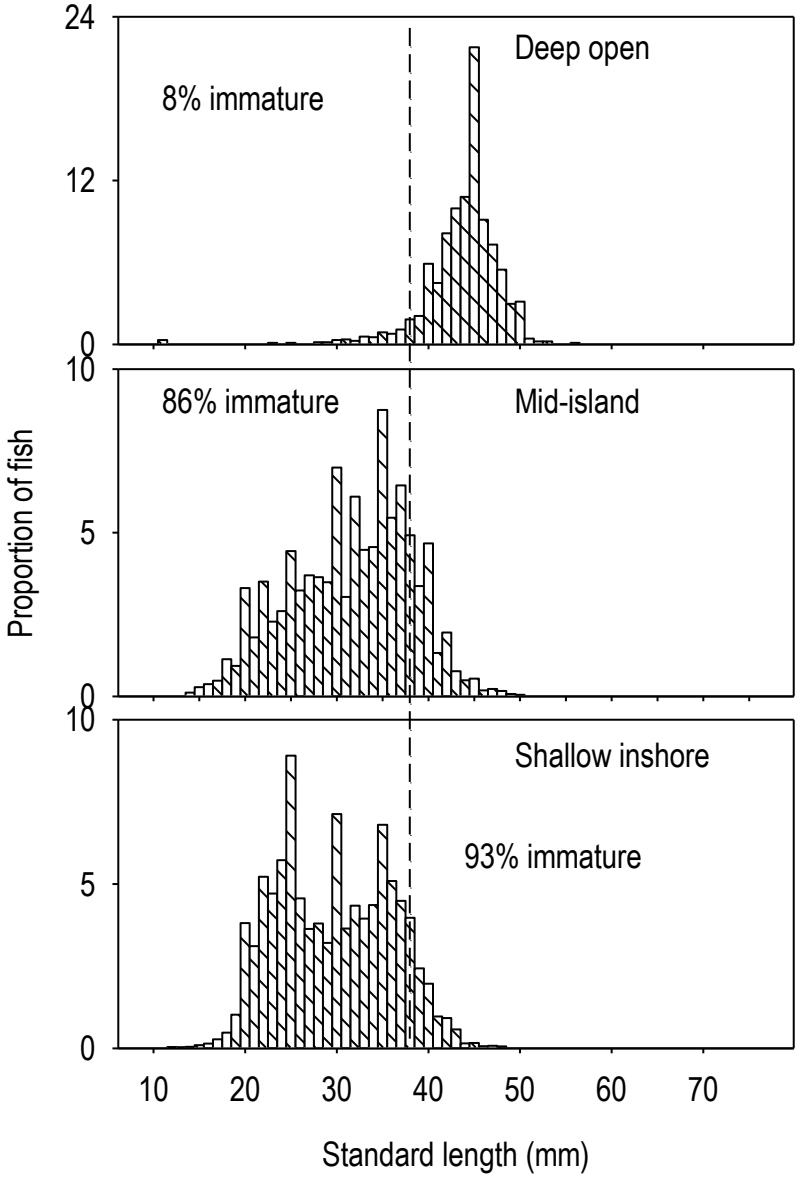

Figure 17: Size structure of mukene harvested in the shallow inshore, mid-island and deep open water zones of Lake Victoria

4.0 CONCLUSIONS, RECCOMENDATIONS, AND FURTHER RESEACH

The solar light attraction technology (SoLAT) harvested higher catch rates of mukene and low proportion of the by-catch than the traditional kerosene white lamps. The catch rates increased with intensification of light intensity (number of bulbs), with the highest catches harvested with 3 bulbs beyond which, a reduction was generally observed. This leaves 3 solar bulbs as the most appropriate light attraction technology for efficient and sustainable harvest of mukene on Lake Victoria.

As observed earlier the traditional kerosene lamps, commonly used by artisanal and currently recommended by management, harvested low catch rates of mukene than SoLAT. The lamps also harvested high proportions of the by-catch, especially juveniles of Nile perch (mean total length = 4.8 cm) and Nile tilapia (mean total length = 4.7 cm), in the shallow inshore water zones of Napoleon Gulf, and were not suitable for operation in the deep open waters of the lake that were characterised by high water turbulence and therefore imposed a high risk of losing them when they would blow off during the heavy storm. Indeed, majority of artisanal mukene fishers using kerosene lamps were observed concentrating fishing effort within the closed bays, and were operating paddled Ssese pointed boats which could not move long distances to the open waters of the lake. Mukene fishing in the shallow inshore areas especially closed bays should be circumvented since it negatively impacts on the sustainability of the Nile perch and Nile tilapia which use these habitats as their breeding and nursery grounds (Balirwa et al. 2003; Ogutu-Ohwayo et al. 2013; Wandera & Balirwa, 2010).

The green and white light colours harvested higher catch rates (>2Kghr-1) than other colours. SoLAT using white and green lights should target the deep open waters of the lake with high quantities of mature mukene and less by-catch of commercial species such as Nile perch and Nile tilapia. However, the red light colour which harvested higher catch rates of Caridina (constitutes the major diet of juvenile Nile perch) should also be discouraged in the mukene fishery.

SoLAT should, however, be popularized among the target audience and the public should be sensitized on the implications this new technology to avoid any further conflicts that may arise among the different fisheries. Since SoLAT is a new technology, there is urgent need to formulate a policy to guide its use in harvesting mukene on Lake Victoria.

To minimize harvest of by-catch, however, mukene fishers should avoid fishing during the full moon phase when high proportion of the by-catch are harvested, and fishing should be conducted during the other lunar phases, especially the third quarter and new moon lunar phase (total darkness) with highest mukene landings.

The use of SoLAT on Lake Victoria is envisaged to shift a big section of the fish community (including Nile perch fishers) into the mukene fishery. Further research to determine the sustainable fishing effort for mukene stocks in the lake is highly recommended, to avoid a similar scenario of stock decline in the Nile perch and Nile tilapia fisheries due to unregulated fishing effort.

The findings in this report were based on an eight-panel 5 mm lampara net. There is need for further research involving varying number of panels to determine the most appropriate water column for efficient and sustainable harvest of this commercially important fish species.

5.0 LESSONS LEARNT

5.1 General challenges

During bad weather (especially in the deep open water zones), replication of data to eliminate bias due to sampling error and other factors was at times difficult to ascertain.

The long procurement process also affected the project implementation schedule. Besides, some materials such as light meter, coloured solar bulbs, and underwater camera were not easily accessed on the local market and this affected implementation of some experiments. For instance, efforts to measure relative light intensity using simple light meter were futile as they were not locally available on the market, whilst the absence of coloured solar bulbs and lamps limited investigations to only white lights. Further research should consider investigating these factors to determine their effect on the exploitation of mukene.

5.2 Partnership and collaboration

The host institution, NaFIRRI collaborated with the Directorate of Fisheries Resources (DiFR), Makerere University, Arrow Aquaculture Africa (AAA), Lake Victoria Fisheries Organization (LVFO), and Beach Management Units (BMUs) to implement the project. Both DiFR and LVFO representation handled issues of policies and regulations on the project while AAA was instrumental in designing and fabricating of the rig as well as providing data landed from the industrial rigs. The local fisher communities were directly involved in the data collection and were considered a vital arm for the technology adoption and dissemination.

5.3 Environmental Impact

The use of traditional kerosene pressure lamps is associated with the emission of considerable quantity of carbon monoxide to the atmosphere and this poses a variety of health risks to fishers and the aquatic environment. In addition, there are risks to the environment, particularly to the aquatic biota arising from fuel spills on the water. Therefore the use of kerosene pressure lamps demands extra care to avoid fuel spills on water and in the catch that could accelerate fish spoilage leading to heavy post-harvest losses.

The use of diesel powered generators by industrial rigs emit a lot of smoke (especially carbon monoxide) which pose health risks to humans and aquatic life. Besides, the excruciating noise produced by these generators do not only allow other fishers from operating within the same fishing ground but also result into

disorientation and stress in fish. More still, these rigs are operated using fish-finders in-spite of being illegal on Lake. Industrial rig technology using silent generators should be promoted among investors involved in the mukene fishing sector, but use of fish finders should be prohibited. However, there is need to determine total allowable catch (TAC) per rig for sustainable harvest.

5.4 Stakeholders

There were erroneous beliefs among a section of the fishing community, especially Nile perch fishers, that solar bulbs chased away Nile perch from habitats where these lights are operated. They strongly believed that the recently observed declining catches of Nile perch was associated with solar light fishing. Similarly, they also claimed that high quantities of small immature mukene were being landed together with high quantities of the by-catch, especially juvenile Nile perch, haplochromines, and Nile tilapia. Such sentiments attracted management intervention that halted use of solar light attraction technology for harvesting mukene on Lake Victoria pending scientific guidance.

Mukene fishing normally takes place at night when visibility is poor so that lights can attract the fish. It was alleged that mukene fishers (the targeted audience for SoLAT) destroyed nets targeting Nile perch (which were set during day and left fishing overnight) that entangled into their encircling nets in the process of hauling the catch into their boats. They (mukene fishers) also stole the Jericans used as floats on drift nets that target Nile perch resulting into heavy gear losses. These destructive actions resulted into bloody conflicts between the two fisheries (aired on local radios and TVs), and effort to resolve the conflict through dialogue mediated by the principal investigator and Director of research at National Fisheries Resources Research Institute (NaFIRRI), officials from the Ministry of Agriculture Animal Industry and Fisheries (MAAIF), Uganda police force and Resident District Commissioners (RDC) from Buikwe and Buvuma districts (see details at: http://firi.go.ug/mukene/index.html) were made futile by the presidential directive that halted use of solar light attraction technology in mukene fishing.

5.5 Economic impact

Until this study, there were no SoLAT in mukene fishing in Uganda. After one year of project implementation (2015), there was an explosion of fishers adopting solar light for mukene harvest on Lake

Victoria and this quickly spread to the other lakes in Uganda, particularly Lake Albert. Mukene fishers using SoLAT confessed of the increased landings compared to those who were still stuck to the traditional kerosene pressure lamps. Before the SoLAT was banned, it is envisaged that the increase in mukene catch landings resulted into improved income besides creating employment opportunities along the Mukene value chain

Annexes

List other information of dissemination materials

1) A fact sheet entitled " Solar light attraction technology for increased harvest of mukene on Lake Victoria
2) A policy brief entitled "light attraction technologies for sustainable harvest of mukene on Lake Victoria, Uganda"
3) A poster entitled "improving light attraction technologies for enhanced harvest of mukene on Lake Victoria"
4) A 15-minute video detailing use of light attraction technologies for mukene fishing on Lake Victoria, Uganda ……(Patrick to improve the title)

List of publications

1) Efficiency of solar light attraction technology for enhanced harvest of mukene on Lake Victoria (A draft manuscript entitled)
2) Management of emerging small pelagic fisheries in the African Great Lakes: a case study of the Silver cyprinid, *Rastrineobola argentea* (Pellegrin, 1904), in Lake Victoria (Reviewed by Journal of Fisheries Management and Ecology)

List of MSc. dissertations

1) Spatial and temporal variations in population and biological characteristics of Silver cyprinid, Rastrineobola argentea (Pellegrin, 1904), in the Lake Victoria Region (Mangeni Richard Sande)
2) Visual sensitivity and behavioral analysis of Nile tilapia, *Oreochromis niloticus* to LED (Kagoya Esther)

Acknowledgements

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APPENDICES

Appendix I: Mean catch rates of mukene harvested by different colours on Lake Victoria

Site	Mean (kg/hr)	Std. Error	Range	N
Inshore	2.48	0.48	15	36
Mid-island	1.26	0.46	15	33
Deep open	3.11	0.76	8	10

Appendix II: Mean catch rates (kg/hr ± SE) of mukene harvested by different light colours on Lake Victoria

Light colour	Catch rates (kg/hr)	Std. Error	Range	N
Green	3.60	0.9	15	23
White	1.90	0.5	6	12
Yellow	1.74	0.7	8	11
Blue	1.25	0.3	4	17
Red	0.98	0.3	3	16

Appendix III: Mean catch rates (kg/hr ± SE) of mukene harvested by different light settings on Lake Victoria

Light setting	Catch rates ($kghr^{-1}$)	Std. Error	N
Surface	2.0	0.4	15
Floating	1.3	0.4	19
Submerged	1.0	0.4	13
Surface-submerged	1.4	0.3	31
Floating-submerged	1.2	0.4	6

Appendix IV: Proportion of the by-catch (%) harvested by different light colours

Light colour	*C. nilotica*	Haplochromine	Nile perch	Nile tilapia
Blue	20	30	34	9
Yellow	29	12	25	2
White	10	18	21	57
Green	9	26	15	17
Red	32	14	5	15

Appendix V: Proportion of the by-catch harvested by different light sources

Light source	Haplochromine	Nile perch	Nile tilapia
Kerosene lamps	604	481	63
Solar bulbs	448	27	-
Ac bulbs (Generator)	81	105	27

Appendix VI: Mean weight (Kg/h) of *Caridina nilotica* harvested by different light sources

Light source	*Caridina nilotica*	SE
Generator	0.024	0.010
Kerosene lamp	0.018	0.005
Solar	0.000	0.000

Appendix VII: Mean wet weight of mukene and proportion of the by-catch per lunar phase

Moon phase	Mean wet weight (Kg/day)	Proportion of the by-catch
F	2,943	1.5
Q3	4,322	0.8
N	4,167	1.3
Q1	2,968	1.1