ANALYSIS OF GROWTH AND MORTALITY FROM DAILY GROWTH INCREMENTS IN THE OTOLITHS OF DAGAA (RASTRINEOBOLA ARGENTEA) IN NYANZA GULF, LAKE VICTORIA, KENYA

by

MURITHI NJIRU

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Department of ANIMAL SCIENCE

The University of British Columbia
Vancouver, Canada

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Abstract

Prior to 1960, *Rastrineobola argentea* was of little economic importance in terms of catches in Lake Victoria. Catches have increased in the last 15-20 years and it is now become the second most important commercially targeted fish species. Growth and mortality parameters of *R. argentea,* a tropical cyprinid, were estimated using growth increments in otoliths and length-frequency analysis to gather more biological data on the species.

The Gompertz growth curve yielded the best fit for the juvenile population. Growth and population parameters for the commercial catch show a growth rate coefficient (K) of 1.8 yr^{-1} with L_∞ of 5.0 cm standard length (SL) in Nyanza Gulf and K of 1.5 yr^{-1} with L_∞ of 6.5 cm SL in the open waters site. Instantaneous growth rates decreased with age, with fish from open waters showing a more gradual decline. The weight (g)-length (mm) relationship is $W = 5.562L^{3.3}$. Fish immersed in 600 mg/L of tetracycline hydrochloride showed its incorporation within 12 hours and increments were likely formed daily.

Juvenile fish mortality ranged from 11.3 to 29.9 yr^{-1}. Total mortality (Z) for adults estimated from length-converted catch curves was 4.0 and 4.8 yr^{-1} for Nyanza Gulf and the open waters respectively. Fishing mortality (F) estimated from catch and biomass was 0.98 yr^{-1} for Nyanza Gulf, while that of open waters from length-converted catch curve was 1.4 yr^{-1}. The exploitation rate is 0.25 and 0.29 for Nyanza Gulf and open waters respectively. Two annual breeding peaks were observed in both Nyanza Gulf (May/ October) and open waters (May/November). Length and age at recruitment for L50% for Nyanza Gulf was 11.6 mm and 34.5 mm in open waters, corresponding to age of 44 and 175 days respectively. In comparison with published data on the growth and mortality of some small pelagics of African waters, *R. argentea* had low values of L_∞, K, M and Z.

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Its almost over.

1. INTRODUCTION

The indigenous fishery of Lake Victoria

The earliest surveys of Lake Victoria conducted by Worthington (1929) and Graham (1929) showed that the native multispecies fauna of the lake were dominated by haplochromine fishes with more than 500 species. The most abundant and highly cherished fish species were *Oreochromis esculentus* (Tilapia) and *Bagrus docmac* (catfish). Excellent catches were obtained using simple gears with little fishing effort (Kudhongania *et al.*, 1992). With the introduction of synthetic fibre gill nets in the 1940s yields increased temporarily. In the late 1950s it was unprofitable to use the recommended 127 mm mesh nets and so fishermen used smaller gill mesh size. This lead to overexploitation of immature fish and endangered the recruitment process. With the decline of the more valued species, exploitation of haplochromines was intensified. Beach seine use was increased and haplochromine catch increased from 19% in 1958 to 37% in 1970 (Kudhongania *et al.*, 1992). Unfortunately, the beach seines damaged some haplochromine and tilapiine stocks especially the eggs, fry, breeding and nursery areas (Welcomme, 1964). In the 1970s the fishery was still dominated by haplochromines and trawling in 1971 showed that traditional commercial fish species were continuously declining (Kudhongania and Cordone, 1974). Nile perch (*Lates niloticus*) were introduced in the early 1960s to convert the bony, "trash" haplochromines into Nile perch flesh which started to dominate the catch by the early 1980s (Kudhongania *et al.*, 1992). Since the 1980s Lake Victoria fisheries are dominated by two introduced species *L. niloticus, O. niloticus* and by the indigenous *Rastrineobola argentea* (CIFA, 1988).

The *Rastrineobola argentea* fishery

Prior to the 1960s *R. argentea* was of little economic importance, forming insignificant proportions of fish landed from Lake Victoria (Chitamwemba, 1992; FAO, 1992). Catches of *R. argentea* have undergone explosive changes in the last 15-20 years in Lake Victoria (Manyala *et al.,* 1992). In the Kenyan waters portion of the Lake, *R. argentea* landings increased to 30 % of the total fish landing by weight in 1985 as compared to 4.5% in 1969 (CIFA,1988), making it the second commercially important fish after Nile perch (FAO, 1992). Recent figures indicate an increase to 38.5 % in 1986 for *R. argentea,* a decline in Nile perch from 62.3% to 54.4 % and Nile tilapia from 2.4 to 1.7% (Asila *et al*., 1991). In 1991 *R. argentea* contributed 31%, Nile perch 31%, and Nile tilapia 15% of the total fishing landing by weight (FAO, 1992). Annual catches for dagaa were 0.24 $t.km^{-2}\ yr^{-1}$ in 1971-1972 and 4.23 $t.km^{-2}\ yr^{-1}$ in 198985-1986 (Moreau *et al*., 1993), rising to 8.2 $t.km^{-2}\ yr^{-1}$ in 1987 and were 24.3 $t.km^{-2}\ yr^{-1}$ in 1989 (Manyala *et al*., 1992).

The *Rastrineobola* fishery is currently in the inshore areas and around the numerous islands of Lake Victoria. Wanink (1989) reports an increasing biomass and mean size with increase in depth up to a maximum between 10-20 meters in the Mwanza Gulf in Tanzania. Methods used to capture *R. argentea* may or may not utilize "light fishing" (Manyala *et al*., 1992). Fishing by light attraction is done on moonless nights, where kerosene pressure lamps are used to concentrate the fish (Mous *et al*., 1991; Chitamwemba, 1992). Lamps are anchored with a sinker and, after some time, they are moved slowly towards the beach, bringing the fish within the reach of nets. The fish are either scooped by lift nets or towed to the beach by a beach/mosquito seine. In the scoop net fishery, the lamps are hauled close to the canoe after attracting *R. argentea,* then the fish are scooped with hand nets into the canoe. Beach seines up to 100 m made of nylon and having a stretched mesh size of 4-12 mm are used in Kenyan waters (Manyala *et al.*, 1992). In Ugandan waters two mesh size nets of 10 and 5 mm are used. Smaller mesh size although preferred by fishermen captures immature fishes of *R. argentea* and non-target species of *O. niloticus* and *L. niloticus* (Ogutu-Ohwayo *et al.*, 1988). *R. argentea* is processed by sun drying on the beaches (Chitamwemba, 1992), and a small percent (20%) is sold fresh (Katunzi, 1992).

The piscivorous Nile perch introduced in the 1960s has produced radical changes in Lake Victoria's ecology. The perch is believed to have eliminated most of the haplochromine cichlids, and now *R. argentea* contributes 10-20 % of its diet (Ogari and Dadzie, 1988). Over-fishing and fishing with the wrong gears are believed to be among other factors affecting *R. argentea* population structure. The mean size and age at maturity of fish now caught in Ugandan and Kenyan waters have decreased and this has posed a question of the future of the *Rastrineobola* fishery in Lake Victoria (Wandera, 1992).

Distribution, local names and nomenclature

The small cyprinid *R. argentea* is endemic to Lakes Victoria, Kyoga and Nabugabo in Uganda. *R. argentea* is locally known as omena in Kenya, dagaa in Tanzania, and mukene in Uganda (Manyala *et al.*, 1992; Wandera, 1992). Dagaa has a short life span of 1-2 years and its total length (TL) rarely exceeds 100 mm (Wanink, 1989). *R. argentea* was previously placed in the genus, *Engraulicypris,* until revised by Howes (1980, 1984) and reassigned to the genera *Rastrineobola.*

The following is the species nomenclature.

Class: Osteichthyes Family: Cyprinidae

Order: Cypriniformes Species: *Rastrineobola argentea*

Food and feeding habits

Zooplankton, mainly copepods, form the major diet of *R. argentea*, although aquatic insect larvae and pupae, mainly of chaoborids and chironomids, are also eaten (Wanink, 1989; Wandera,1992). *R. argente*a is a visual feeder (Wanink, 1988a, 1989) and Wandera (1992) found that the major feeding time for *R. argentea* occurred during daylight hours, while the least feeding was at night. An examination of a twenty four hours feeding cycle by Corbet (1961) and Wandera (1992) revealed that, during day time zooplankton formed the main food, while at night insect larvae and /or pupae were the main food. Juveniles (< 30 mm) fed only during the day almost exclusively on copepods and early instar of chironomid larvae (Wandera 1992).

The feeding pattern of *R. argentea* is related to the species distribution over time and space. HEST (1988) indicated that adult *R. argente*a stay near the bottom of the lake during daytime and move to the surface at night while the juveniles and parasitized adults stay at the surface throughout. Zooplankton undergoes a similar diel migration (Katunzi, 1992). This migration has also been associated with depth-related abiotic factors such as dissolved oxygen in the water column and light penetration (Katunzi, 1992). Okedi (1982) suggests that *R. argente*a could be the most abundant species in waters less than 10 meters deep in Tanzanian waters.

Reproduction

Graham (1929) reported that *R. argentea* spawns in Lake Victoria producing planktonic eggs. Preliminary studies by Okedi (1973) revealed that the species breeds in the months of June, July and August and that fecundity increases with size. Wandera (1992) found that *R. argentea* breeds throughout the year with peaks after the two rainy seasons April-

May and August-September, findings which differ to that of Okedi (1973).

The periods after rainy seasons in Lake Victoria are associated with the lake's turnover when the lake completely or partially mixes. The subsequent algal bloom provides a lot of food for growing *R. argentea* larvae. Availability of enough food resources to the species encourages gamete production (Wandera,1992). It is therefore not surprising that there may be two principal spawning peaks after the rainy season. Females mature at 43-44 mm and males 40-41 mm standard length (SL) and all individuals above 47 mm SL were mature in Ugandan waters. Manyala *et al* (1992) estimates the fecundity of dagaa at 1350 eggs for specimens of 60 mm total length (TL) and 170 eggs for specimens of 41 mm TL.

Why this project was chosen

Despite *R. argentea's* commercial and ecological importance very little biological information on the species is available. *R. argentea* plays an important role in the lake ecosystem other than being a cheap source of protein for both humans and animal feeds. In the absence of once abundant haplochromine cichlids, *R. argentea* is the major food of the Nile Perch (Ogari and Dadzie, 1988; Manyala *et al.*, 1992) . It therefore serves as a bridging role in the transfer of energy from invertebrates to higher trophic levels (Wandera, 1992). Available information on *R. argentea* from the scientific literature is scarce and it is therefore difficult to make reliable assessments of its population dynamics and its fishery potential. It is not possible to understand biological changes that have occurred in the species during the last thirty years due to lack of data from the past (Mannini,1992; Wandera and Wanink, 1995).

The available data which can be used for management are the annual catches, catches from different beaches and catch effort (Manyala *et al.*, 1992). The findings from these investigations apply only to small areas and are based on different sampling methods. Unfortunately, this information lacks biological parameters, although annual landings records date back to 1968 in Kenyan waters (Manyala *et al.*, 1992) and in Tanzanian waters to 1979 (Katunzi, 1992). Recent work on *R. argentea* includes those of Wanink (1989; 1988a), Manyala (1991), Katunzi (1992), Manyala *et al* (1992) Wandera (1992), Wandera and Wanink (1995). *R. argentea* is a renewable resource and requires sound management policies for maintaining a sustainable stock. Such steps can only be taken adequately if the biology of the fish is sufficiently known.

Why use otoliths

The structures which encode age information in fishes are fin rays, vertebrae, opercular bones, scales, statoliths and otoliths (Jones, 1992). Otoliths have several advantages over other hard structures. Unlike other hard parts which get reabsorbed under conditions of food deprivation and severe stress, otoliths continue to grow throughout fish life (Neilson and Geen, 1984; Campana, 1985; Jones, 1992). A further advantage of using otolith microstructure examination for age determination is that otoliths are often the first calcified structures that appear during the early development of teleosts. In most instances scales which are commonly used do not record daily events, they cannot be used to age fish under one year, they can be lost, regenerated, and deposition ceases to occur at older ages. Therefore, production of daily otolith increments facilitates age determination of bony fishes with potentially higher accuracy than scales. The daily increments consist of a continuous zone with calcium carbonate and a discontinuous zone with proteinaceous material (Alhossaini and Pitcher, 1988).

Disadvantages of using otoliths are that they entail killing the fish, they can be difficult to read, thus giving false age, they are time consuming, they require training and specialized equipment which may be lacking in most developing countries (Jones, 1992).

The purpose of this study

The specific aims of this project on *Rastrineobola argentea* are to:

(1) use otolith readings to estimate growth rates

(2) validate daily growth increments in the otolith

(3) use otolith readings to estimate mortality rates

(4) compare growth rate and mortality of fish in the Nyanza Gulf with those in the open lake

(5) investigate recruitment

Study area

The major portion of the Kenya waters of Lake Victoria (Figure 1) is a narrow gulf, known to various authors by several names. The Victoria Nyanza (Graham, 1929), Kavirondo Gulf (Copley, 1953), the Winam Gulf (Okach, 1982) and Nyanza Gulf (Ogari and Dadzie, 1988) all refer to the same place. The Kenya portion of the lake has an irregular shoreline of about 300 km and comprises only 6% (3 755 km^2) of the entire lake area of 68 800 km^2 (Rabour, 1991). The Nyanza Gulf has an area of approximately 1 920 km^2 with a length of about 60 km and a width varying from 6 to 30 km (Manyala *et al.*, 1992). The Gulf lies between latitudes 34° 13' and 43° 52' east and 0° 4' and 0° 32' south of the equator. The Nyanza Gulf is a swallow bay with an average depth of 6-8 m, and a maximum of 43 m at the open waters, and has an elevation of 1136 m above sea water (Rabour, 1991).

2. MATERIALS AND METHODS

Sample collection

Samples for juvenile *R. argentea* were collected three times per month from Kichinjio (site A Figure 1) using a 1 x 500 μm mesh size planktonic net from January to May 1994. Comparison samples were taken once a month from open waters, near Mbita (site B Figure 1) from February to May 1994. The net was tied on a canoe and pulled for 15 minutes. Fish captured were transferred immediately into 95% ethanol for subsequent sorting and analysis. Handling specimens this way minimized shrinkage and physical damage due to net capture (Thorrold, 1988). On landing, the standard length of fish was taken with calipers to the nearest 0.5 millimeters. Commercial catch from landings of randomly selected boats was collected from Kichinjio from January to May 1994 and from open waters in February. Total sample for juvenile fish collected were 925 and 236 for Nyanza Gulf and open water respectively. For the commercial catch , 236 were sampled from Nyanza Gulf and 55 fish from open waters.

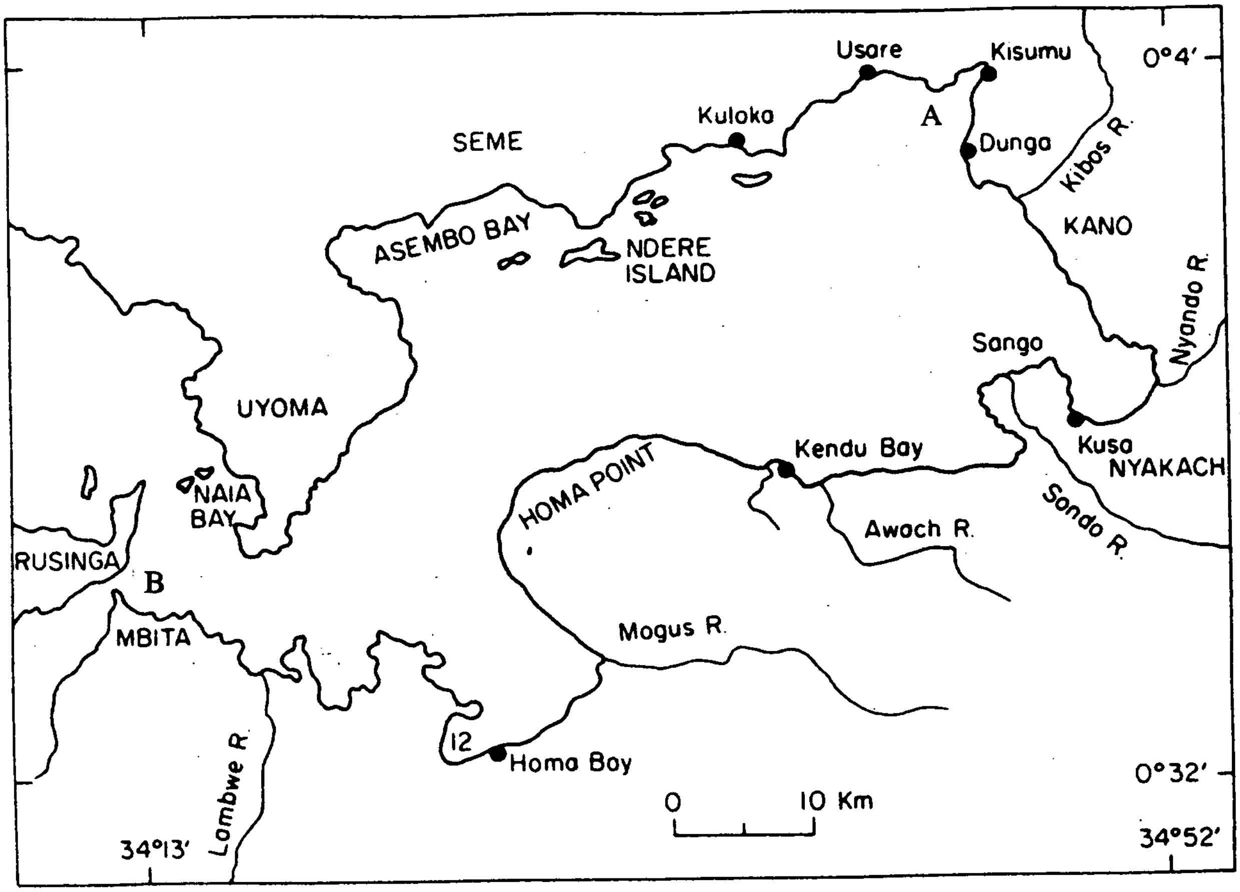


Figure 1. Map showing the Nyanza Gulf of Lake Victoria, the sampling A site and the open waters sampling site B.

Choice of otolith

Like most fish, *R. argentea* has three pairs of otoliths: sagittae, astericus and lapilli. Of the three types of otolith in *R. argentea*, the sagitta is the smallest, very weak and brittle which makes it unsuitable for age determination. The astericus is the largest, but has strong lines with interruptions and individual rings intersect with one another without any pattern (Campana and Neilson, 1985; Muth *et al.*, 1988).

Studies on cyprinids have found that lapillus and sagitta otolith are formed around the time of hatching (Victor and Brothers, 1981) or they are present in the first 4 days of development (Muth *et al.*, 1988) while the astericus developed in the third week. The lapillus, the second largest otolith, shows clear bands in a concentric pattern, and was used here for aging *R. argentea*.

Otolith preparation

Otolith preparation is necessary to enhance the distinction between the incremental and discontinuous zones that comprise each bipartite growth increment (Campana and Neilson 1985; Alhossaini and Pitcher 1988). Grindings act to reduce refractive effects and increase light transmission through the otolith (Campana and Neilson, 1985).

The fish were placed in a drop of water on a microscope slide. The lapilli were then teased out with sharpened needles under a dissecting microscope. The otoliths were then picked and placed on a clean microscope using the tip of a wetted needle. If there was a lot of attached tissues the otolith was immersed in weak solution of sodium hypochlorite for several minutes to dissolve or loosen resistant material (Brothers, 1987).

A small drop of crystalbond thermosetting plastic resin (Hall, 1992) was placed on a standard microscope slide and kept liquid on a hot plate. Each lapillus was carefully placed on top of the resin drop. The plastic resin set in 10 seconds after the slide was removed from the hot plate, allowing enough time to position the otolith to the surface of the slide. If necessary, the crystalbond resin was reheated to reposition the lapillus. Each otolith was ground until the nucleus was reached using abrasive paper of 1200 grit and polished with carborundum aluminium 9-10 μm and cleaned under running water. Grinding was done on both sides to form a thin section. Grinding both sides required more time but produced a superior quality preparation. Caution was taken not to overgrind the otolith as this process is irreversible.

Daily increments were counted for both left and right lapillus under immersion oil using a compound microscope light microscope (LM) at 1000X. Counting was done from anterior to posterior end of the otolith along the most clear path with a hand counter. The hatch check near the nucleus was used as a reference point from which growth increments were counted. For each otolith, counting was done thrice and the mean of the counts was taken as the final count. An otolith was rejected if incremental counts between or within pairs of lapillus differed by more than three. Incremental width were measured in microns under LM at 300x and photographed using a Zeiss III RS photomicroscope.

Preparation for scanning electron microscope (SEM) followed the same procedure as for LM up to the polishing stage with carborundum aluminium 9-10 μm. Otoliths were then cleaned under deionized water before acid etching. The acid etching is a crucial step because the optimum etching media and time have to be determined by trial and error (Secor *et al.*, 1992). Solutions of 0.1 M (pH 7.3) and 0.01 M (pH 7.4) of diasodium ethylenediaminetetraacetate (EDTA) were applied gently with a micropipet to sections with otoliths. After carefully measured time, which ranged from 5 seconds to 6 minutes, the solution was removed by placing the slide and affixed section in a beaker of deionized water. The slide was gently dabbed dry with wipes, carefully avoiding touching the otolith. After etching the section was carefully removed with a tip of syringe needle from the slide by reheating thermoplastic glue and attaching it to a scanning electron microscope (SEM) stub with double sided sellotape. The sections were coated with gold (100 Angstroms) in a Nanotech Semprep II Sputter coater for 4 minutes and examined at 20 kV under SEM. Incremental width was measured from SEM photographs by reference to a recorded scale bar.

Growth models

Estimation of a parameterized growth model is considered to be a standard product of otolith microstructure examination (Campana and Jones, 1992). Although growth models vary, the rationale for their preparation is to allow prediction of an expected mean size or growth rate at some age and/or to facilitate comparison of estimated growth with other published estimates (Ricker, 1975; Campana and Jones, 1992).

Three models were used to describe the growth of *R. argentea* :

(i) Gompertz model: the generalized equation of the model (Zweifel and Lasker, 1976) is as follows;

$$L_t = L_\infty \exp[- \exp(-k(t-t_o))]$$

Where:

L_t = predicted length (mm) at age t,

L_∞= the mean length fish would reach if they were to grow indefinitely,

t_o = age at length = 0,

k = growth coefficient of dimension 1/t of the Gompertz equation

(ii) von Bertalanffy model (VBGF) (Gulland,1983): the generalized equation is

$$L_t = L_\infty[1-\exp(-K(t-t_o))]$$

Where:

L_t = predicted length (mm) at age t,

L_∞= the mean length fish would reach if they were to grow indefinitely

t_o = age at length = 0,

K = the rate at which length tends towards the asymptote of dimension 1/t.

(ii) Linear model (Campana and Jones, 1992)

$$L_t = a+bt$$

Where:

L_t = predicted length (mm) at age t

a = size of fish at age= 0 (Y intercept)

b = growth rate (slope of the line)

t = time in days

The Excel 4.0 solver function was used to fit Gompertz and von Bertalanffy models using least squares which also provided estimates for r^2. A type 1 linear regression was used for the linear model.

Growth performance

Pauly (1979a) found that different stocks of the same species have similar values of phi prime (ϕ'), defined; $\phi' = \text{Log}_{10} K + 2 * \text{Log}_{10} L_\infty$.

Where K and L_∞ are from Bertalanffy model. Using the commercial sample, growth parameters for population for Nyanza Gulf and open waters site were estimated from which ϕ' could be calculated.

Powell - Wetherall's Plot

L_∞ was calculated using the Powell - Wetherall's plot (Sparre and Venema, 1992) using the equation,

$$L_i - L'_i = a + bL'$$

Where:

L_i= mean length of fish calculated from a given cutoff length point L_i

L'_i = the lower class limit from which L_i is calculated

a = y intercept

b = slope of the line

The L_∞ values thus obtained were used to estimate K and t_o using von Bertalanffy growth curve for the fish population from Nyanza Gulf and open waters.

Instantaneous growth rate

Instantaneous growth rate is calculated by the following formula (Ricker, 1975, Pitcher and Hart, 1982),

$$G = (\text{Ln } w_2 - \text{Ln } w_1)/ t_2- t_1$$

Where:

Ln w_1= natural logarithm of weight at the start of time interval

Ln w_2= natural logarithm of weight at the end of time interval

t_2 & t_1 = times corresponding to w_1 and w_2

Data from both Nyanza Gulf and open were grouped in sets of ten with a range of 10 days. Mean length (mm) and mean age (days) for each was calculated. Mean length was converted to mean weight (g) using the equation,

$$W = al^b$$

where:

W = net weight of fish (mg)

l = standard length (mm)

The fitted regression equation is Ln W = b(Ln L) + Ln a. Constants a and b were estimated from the intercept and slope respectively.

Age validation using tetracycline hydrochloride

To verify that the increments observed in the otoliths of *R. argentea* were deposited daily, tetracycline hydrochloride (TC) was used. Tetracycline is incorporated into calcium structures of fish during growth (Thorrold, 1988). This can be restricted to one day's increment on the otolith thus enabling an accurate identification of the treatment date (Alhossaini and Pitcher, 1988).

Fish were first kept in large holding tanks (500 Litres) with fresh lake water for 2 days to acclimatize. The holding tanks were positioned outside at Kisumu, Kenya, exposed to normal photoperiod but sheltered to avoid drastic temperature fluctuations which might stress the fish.The aim was to provide fish with conditions close to those found in the lake for them to recover from capture and transportation stress. Fish were fed twice daily on aquarium food and wild zooplankton captured with 20 μm mesh size from Lake Victoria. Recovery from stress allows fish to resume normal growth again before being exposed to TC. The surviving fish were then divided for TC treatment. Choosing the right concentration treatment and duration is critical for tetracycline (GjΦsaeter *et al.*, 1984). Several trials were tried ranging from 100-600 mg/l TC with exposure time of 2-24 hours.

The test solution was prepared using distilled water because TC combines to calcium ions in hard water, hindering the uptake of TC by otolith (Muth *et al.*, 1988). Addition of

TC lowered distilled water pH from 7.3 to 4.3. TC test solution was adjusted to pH 7.8-8 with tris-buffer (Hetler, 1984) which corresponded to the lake water. During treatment fish were not fed. After treatment the fish were returned to 500 litres holding tanks to resume normal growth. 3 tanks each with 2 untreated fish distributed among tanks with treated fish acted as control. Water in the tanks was replaced with fresh lake water three times a week. Removed otoliths were mounted on epoxy-resin (thermoplastic glue) and kept in light proof slide holders to prevent degradation of tetracycline marks (Hall, 1992). TC treated otoliths were viewed under fluorescent ultraviolent light (UV 360 nm) and bright light illumination with a compound microscope. Under UV light an ocular marker was aligned with the fluorescent band on the otolith. Incremental rings were counted under bright light illumination from the marker to the edge of the otoliths to verify if they do correspond to the number of days since the fish was tagged and the time it was killed. Otoliths were photographed using a Zeiss III RS photomicroscope.

Age validation using growth performance index

Second approach to validation was to compare the values of the growth using the growth performance index (ϕ') (Pauly 1979a, Sparre and Venema, 1992). For the same L_∞, values of K were fitted to the ages and size of the fish under three assumptions about ring deposition rate:

1) one ring per day

2) two rings per day

3) one ring per 3 days

For each assumption, ϕ' was calculated. The three ϕ' estimates were then compared with the mean ϕ' calculated from the literature on this species. This was necessary because number of increments of otolith rings after immersion in TC did not correspond exactly to the number of days the fish survived.

Mortality

The general equation for mortality is

$$N_{t2} = N_{t1}\, e^{-z(t2-t1)}$$

Where:

Z = instantaneous rate of mortality

N_{t1} = number of fish at time t_1

N_{t2}= number of fish at time t_2

t_1 and t_2 are times 1 and 2

also we have

$$Z = F + M$$

where:

Z = the total mortality per year

F = fishing mortality per year

M = natural mortality per year

(Pitcher and Hart 1982; Gulland, 1983)

Age-catch curve

For the juvenile population fish abundance was converted to the natural logarithm of abundance and plotted against age which was read directly from otoliths. Conversion resulted in a straight line with a negative slope which was fitted through ordinary least square regression (Ricker,1975). Starting data points for the regression were established using Robson and Chapman (1961) criteria (see Appendix 4). The equation used was,

$$\text{Ln } N_i = a + bt_i$$

Where

Ln N_i = natural logarithm of number of fish of age t_i.

a = y intercept

b = slope of regression line (Z)

(Pauly, 1984c)

Length-converted catch curve

Length frequency data was converted to their corresponding ages by means of set growth parameters (L_∞ and K of VBGF). Abundance at age decreased exponentially, making the slope an expression of mortality (Essig and Cole, 1986). Total mortality (Z) was estimated as the negative slope of:

$$\text{Ln}N_i/\Delta t_i = a + bt_i'$$

LnN_i = natural logarithm of number of fish in length class i.

Δt = time fish needs to grow through length class i

t'_i = is the age corresponding to the midpoint of length class i

a = y intercept

b = is the regression slope (estimation of Z)

Selection of points to be used in the regression followed Pauly's (1984c) rules (Appendix 5).

Natural mortality

Natural mortality (M) was estimated following Pauly's empirical formula (Pauly, 1980a), linking the natural mortality with the von Bertalanffy parameters, K (yr^{-1}), L_∞ (cm) and mean annual temperature (T °C) of water in which fish stock live.

$$\log_{10}(M) = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} k + 0.463 \log_{10} T$$

Pauly's empirical formula was modified for schooling fish such as *R. argentea* (Mannini, 1992) by multiplying M by 0.8 so the estimation becomes 20 % lower (Sparre and Venema, 1992).

Fishing mortality and biomass

Fish mortality is defined by F = Z - M and can thus be obtained by subtraction, however it was here also necessary to estimate F from F= C/B and P/B = Z (Allen,1971), because Nyanza Gulf data gave an F of zero.

where:

F = fishing mortality per year

C = catch per year

B = the average biomass during the period considered

P = production

Z = total mortality

Biomass was estimated using the same C (4.23 $t.km^2$) and P (17.3 $t.km^2$ yr^{-1}) as in the ECOPATH II model (Moreau *et al.*, 1993), but with a Z of 4.0 yr^{-1} from this study instead of 2.2 yr^{-1}. The ECOPATH II model is structured around a system of linear equations which estimates biomass and food consumption of various species of an aquatic system by analysis of flows between the elements of the ecosystems (Christensen and Pauly, 1992).

Exploitation rate was estimated by E = F/Z.

Recruitment pattern.

The recruitment pattern is estimated from length frequency data by a method which involves;

1) backward projection onto the time axis of a set of length-frequency data;

2) summation of each month of the frequencies projected onto each month;

3) subtraction, from each monthly sum, of the lowest monthly sum to obtain a zero value where apparent recruitment is lowest; and

4) expressing monthly recruitment in percent of annual recruitment (Pauly *et al.*, 1984).

Estimation of gear selection and probability of capture

When estimating mortality the left hand side of the catch curve is not considered because juveniles are not yet fully exploited or recruited. Backward extrapolation of the catch curve estimates the number of juveniles which ought to have been caught, had it not been for incomplete selection and recruitment. To obtain probabilities of capture, the number of fish in each length class caught are divided by the expected numbers (Pauly *et al.*, 1984).

Estimation of age at recruitment

Age at recruitment was estimated using inverse von Bertalanffy equation:

$$t_i = t_o - 1/k^* \ln(1 - L_i/L_\infty)$$

Where:

t_i = age in years,

t_o = age at length = 0,

K = the rate at which length tends towards the asymptote,

L_∞= the mean length fish would reach if they were to grow indefinitely,

L_i = length (mm) at age t_i,

(Sparre and Venema, 1992).

Relative yield-per-recruit analysis

Beverton and Holt (1957) presented an equation requiring only three input parameters, M/K, U (= 1-Lc/L_∞), and E (= F/Z) to access the effect of different exploitation rates on a fishery. Beverton and Holt's relative yield per recruit model is defined by:

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

Where:

(Y/R)' = relative yield (g) per recruit

m = (1-E)/(M/K) and E=F/Z

E= the fraction of deaths caused by fishing (exploitation rate)

F = fishing mortality per year

Z = total mortality per year

M = natural mortality per year

K = the rate at which length tends towards the asymptote of dimension 1/t.

U = 1-Lc/L_∞

L_c = length (mm) of fish at first capture

L_∞= the mean length fish would reach if they were to grow indefinitely,

(Sparre and Venema, 1992)

Plot of (Y/R)' was done by;

1) Assuming knife edge selection

The knife-edge selection assumes all fish below length at first capture (Lc) escape through the mesh of the net, while fish above Lc are assumed to be suddenly exposed to full fishing mortality (F) which remains constant for the rest of the cohort life (Pauly, 1994).

2) Selection ogive. The fraction of fish retained in a fishing net depends on mesh size, fish size and their availability. Plot of fraction of fish retained by a net against length gives a sigmoid curve. Retention by a net of young fish is low because of their small sizes and they have not been fully recruited, while very old fish are in low numbers in fishing grounds. The intermediate size is the one mostly retained (Sparre and Venema, 1992).

3. RESULTS

GROWTH

The aims of the growth study were to use ageing of otoliths and length frequency analysis to determine and compare growth parameters of dagaa in the Nyanza Gulf and in the open waters of Lake Victoria.

Size distribution

Length-frequency diagrams for the Nyanza Gulf and open waters samples are presented in Figures 2 and 3, and from commercial catches Figure 4 and 5.

Comparison of the two sets of length frequency data for the juvenile population indicates incomplete recruitment to my sampling gear by fish less than 3 mm and avoidance of sampling gear by fish more than 25 mm. In Nyanza Gulf, there is incomplete recruitment to the commercial gear by fish less than 10 mm and a diminishing of catch of fish more than 40 mm. In open waters, fish of less 29 mm were absent in the commercial catch. Appendix 1 presents catch in numbers for the entire sampling time.

Age distribution.

Figures 6 and 7 presents age-frequency diagrams for the Nyanza Gulf and open waters and data used is in appendix 2. Nyanza Gulf sample is dominated by fish of ages 20-70 days and lacks fish older than 140 days. In open waters the dominant age groups are 35-70 and 10-25 days in February and March respectively and lacks fish older than 110 days in February and 80 days in March. Nyanza Gulf sample had older juveniles compared to open waters.

Otolith morphology

When observed under a light microscope (LM) the lapillus showed conspicuous marking arranged in concentric patterns radiating from the nucleus (Figure 8a) and right and left lapillus had equal number of increments. Increments were easily read in most otoliths, only 25 (5.6%) were rejected due to either the error of reading, imprecision being greater than 3 rings (10; 2.2 %) or because the otolith could not be clearly read due to nondaily rings (15; 3.4 %). Counts were done for 326 fish from the Nyanza Gulf and 120 fish from open waters, ranging from 3 mm to 25.4 mm SL, and ages ranging from 8-135 days.

Only otoliths etched for 2 minutes or more in 0.1 M EDTA produced recognizable increments on SEM, while application 0.01 M EDTA produced no changes on the surface of otoliths. The best etched lapillus was the one where 0.1 M EDTA was applied for 2 minutes (Figure 9a). Application of 0.1 M EDTA for 5 and 6 minutes over etched the lapilli and only a few increments could be noticed in some areas probably where there was less etching.

No marked changes in increment in morphology was evident both under LM and SEM, although in some otoliths a narrowing and subsequent widening of increments occurred in the first few increments near the nucleus (Figure 8a & 9b) and at the edge of older juveniles under (Figure 8b). Subdaily increments (Figure 8b & 9a) which are morphologically similar to daily increment were more easily distinguished in older juveniles. Daily increments appear in a regular sequence, they are more prominent and do not merge with others like subdaily increments. Careful adjustment of the LM focus could correctly interpret daily increments from subdaily. Use of SEM did not alleviate the subdaily increments problem (Figure 9a).

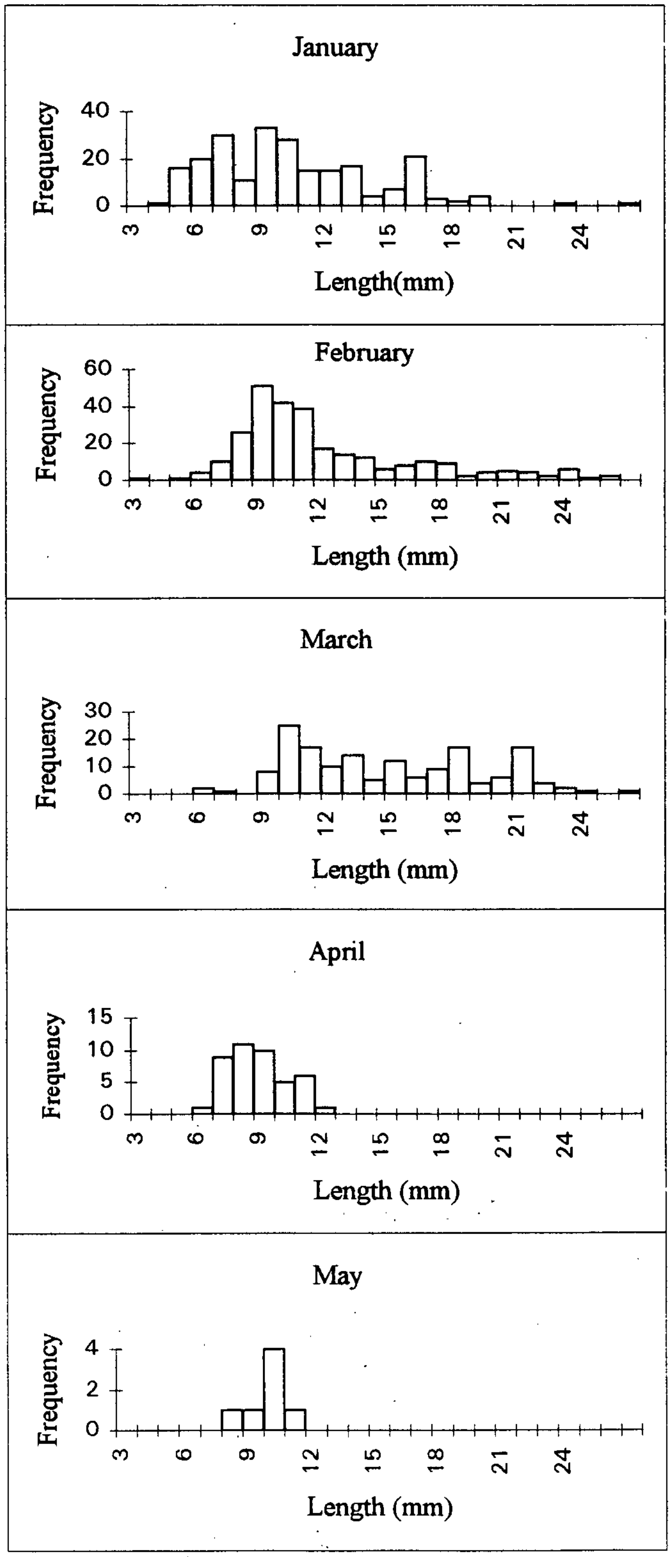


Figure 2. Length-frequency distribution of juvenile *R. argentea* from Nyanza Gulf of Lake Victoria. Juvenile were sampled using a 500 μm mesh size planktonic net from the shore of Lake Victoria.

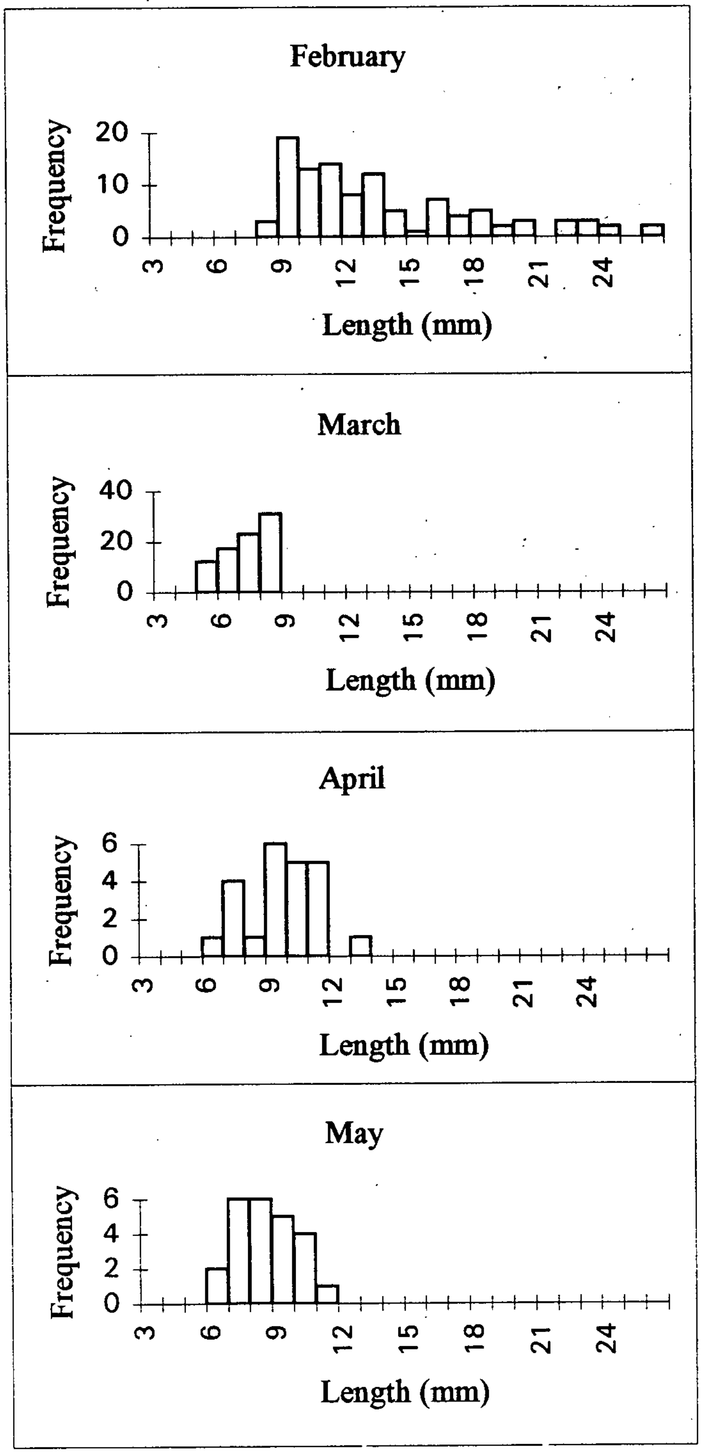


Figure 3. Length-frequency of juvenile *R. argentea* from open waters of Lake Victoria. Juvenile were sampled using a planktonic net (500 microns) from the offshore of L.Victoria.

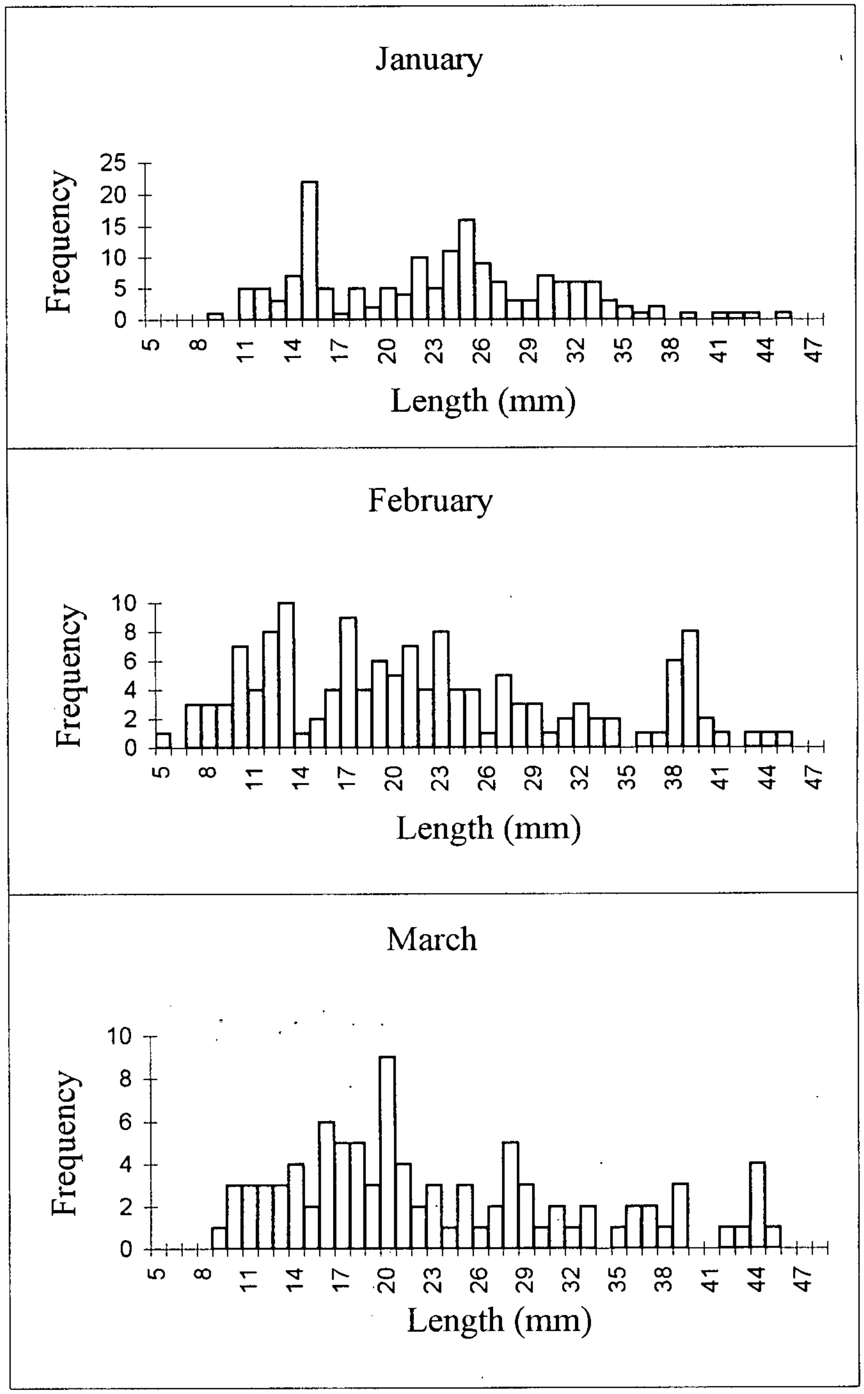


Figure 4. Length-frequency distribution of *R. argentea* commercial catch from Nyanza Gulf. Adult fish samples were obtained from randomly selected commercial boats fishing at same area juvenile samples were collected.

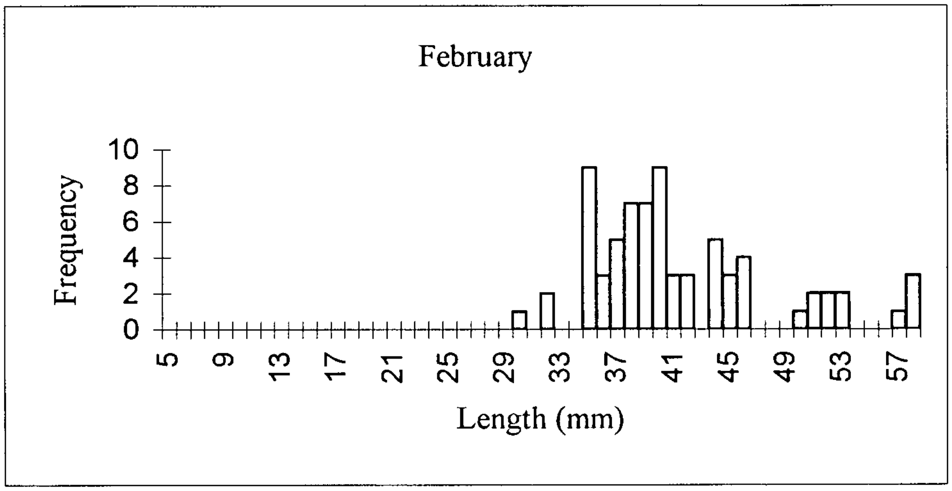


Figure 5. Length-frequency distribution of *R. argentea* commercial catch from open waters. Adult fish samples were obtained from randomly selected commercial boats fishing at same area juvenile were collected.

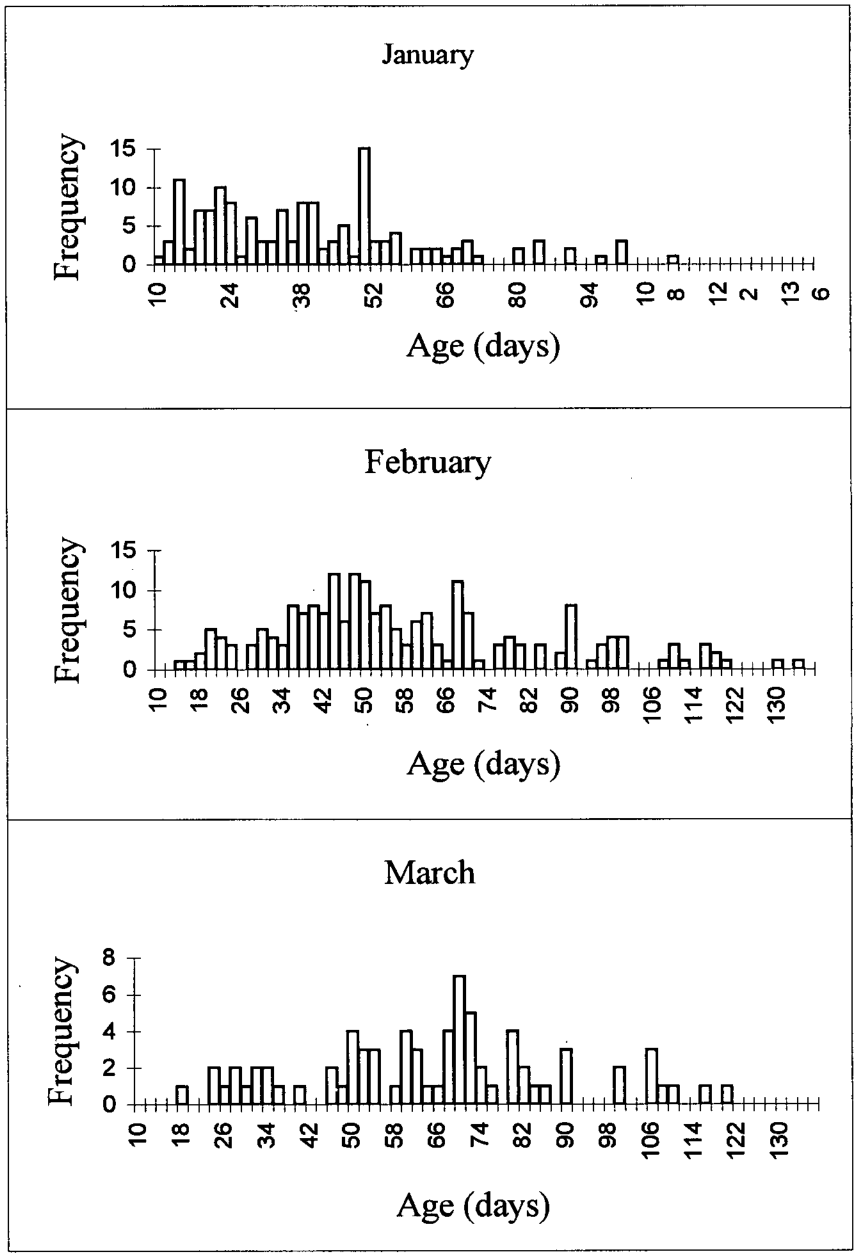


Figure 6. Age-frequency of juvenile *R. argentea* from Nyanza Gulf of Lake Victoria. Juvenile were sampled using a planktonic net (500 microns), age read direct from otoliths and frequency obtained from fish which otoliths had been read.

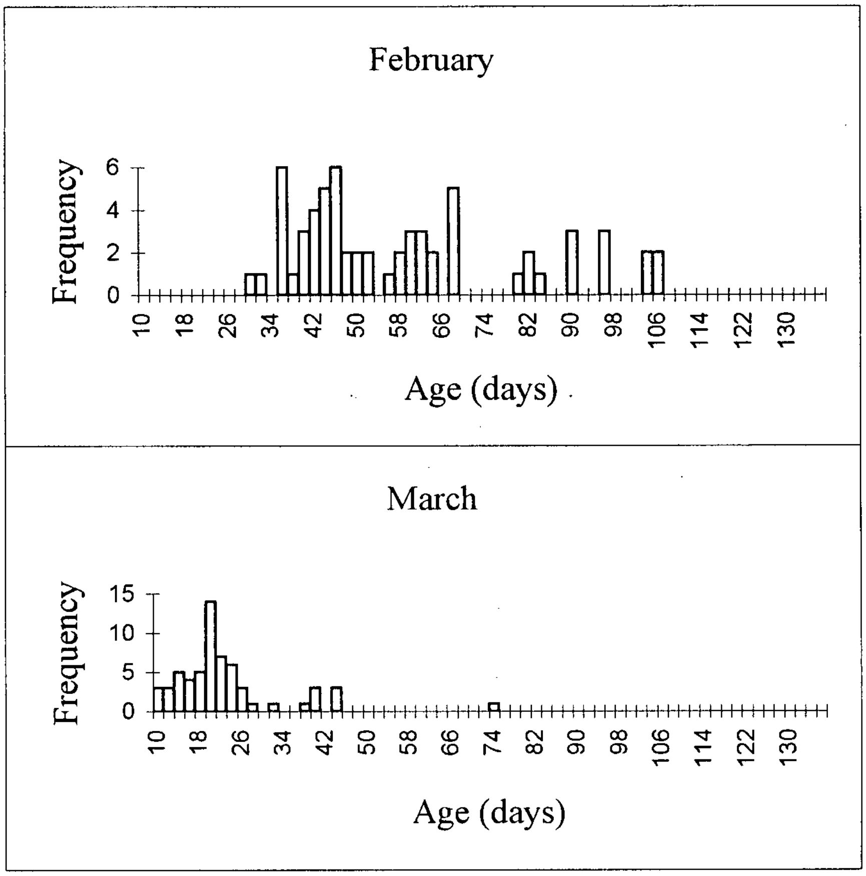


Figure 7. Age-frequency of juvenile *R. argentea* from open waters of Lake Victoria. Juvenile were sampled using a planktonic net (500 microns), age read direct from otoliths and frequency obtained from fish which otoliths had been read.

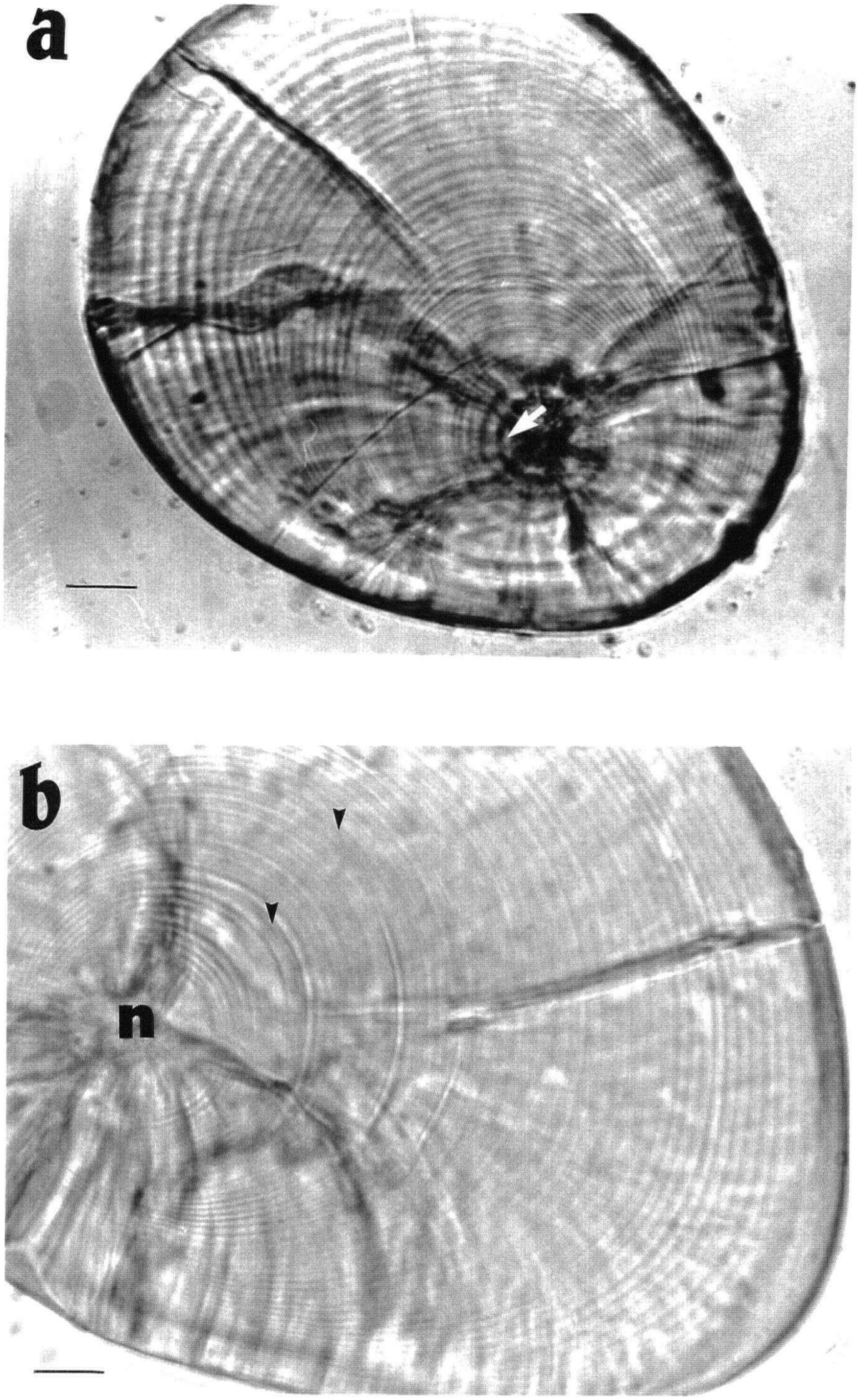


Figure 8. Lapillus otolith of *R. argentea*.
a) Arrow indicates hatch check for a 42 days old dagaa (10.1mm).
Scale bar = 10 μm.
b) Subdaily increments (arrows) and nucleus (n) for a 52 old dagaa (15.3 mm). At the edge of otolith increments are not clearly visible, refocusing helped solve the problem. Scale bar 10 μm.

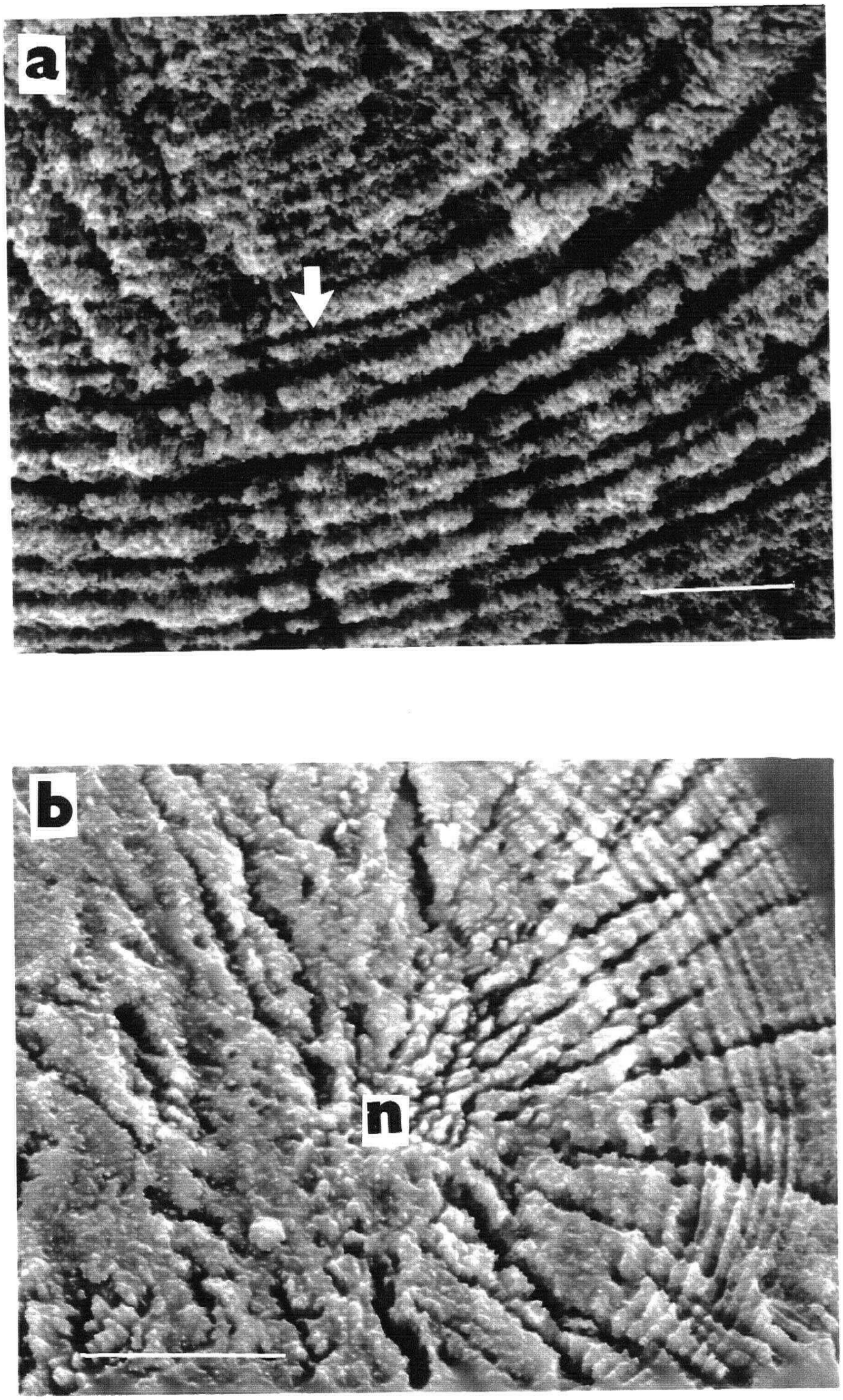


Figure 9. Scanning electron micrographs of *R. argentea* lapillus showing daily increments.
a) Arrow indicates subdaily growth. Scale bar 4 μm.
b) Nucleus (n) which lacks any increment. Scale bar 20 μm.

Growth models

The plot of the fitted models for length versus the age for juveniles is presented in Figures 10 and 11 for Nyanza Gulf and open waters respectively. The Gompertz growth model yields the best fit to the data in Nyanza Gulf and open waters respectively (r^2 = 0.86 & 0.93), although a significance test of the r^2 was not done. The r^2 value derived from regression and total sums of squares was the highest. The worst fit model for Nyanza Gulf and open waters was von Bertalanffy growth model (r^2 = 0.82 & 0.89). The Gompertz growth model produced higher k values and lower asymptotic length in both Nyanza Gulf and open waters compared to von Bertalanffy growth model (Table 1). The fitted equations for the Gompertz growth model were:

$L_t = 24 \exp[-\exp(-8.7(t-31.3))]$ for Nyanza Gulf and,

$L_t = 60.4 \exp[-\exp(-3.5(t-95.7))]$ for open waters.

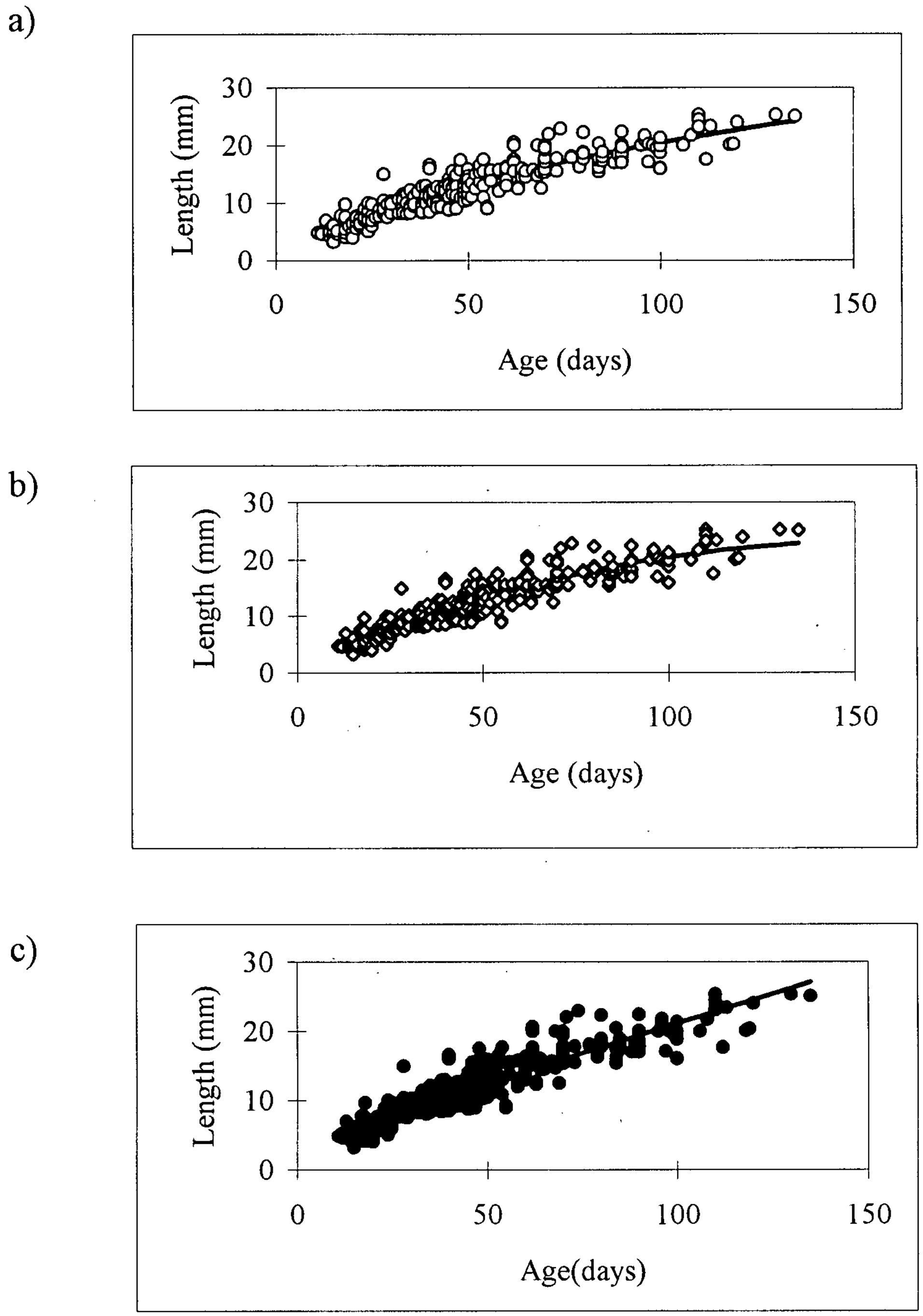
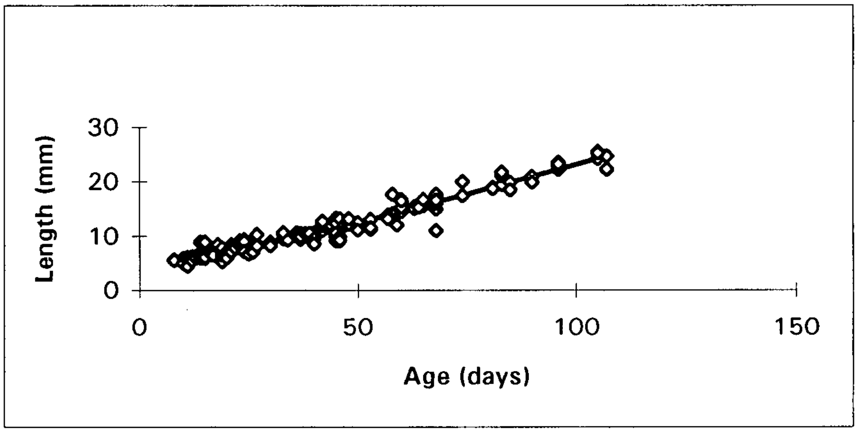
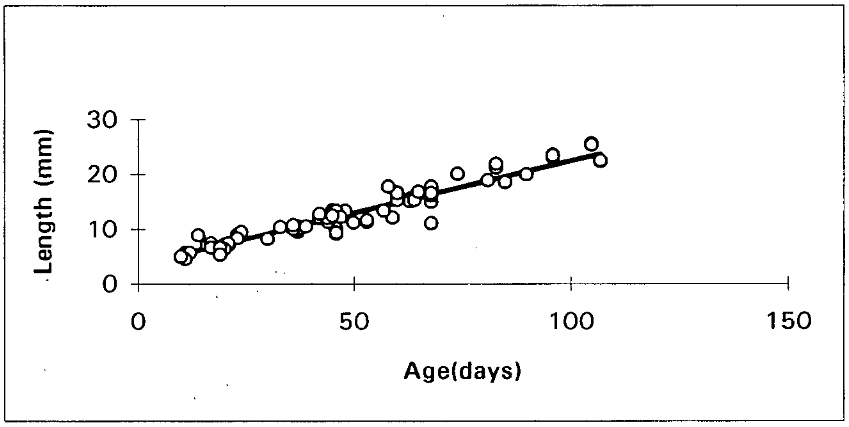


Figure 10. Relationship between standard length and number of increments on lapillus of *R. argentea* from Nyanza Gulf (dots), together with fitted growth curves (solid line). a) Gompertz growth curve, b) von Bertalanffy growth curve, c) Linear regression. Details in the text.

a)



b)



c)

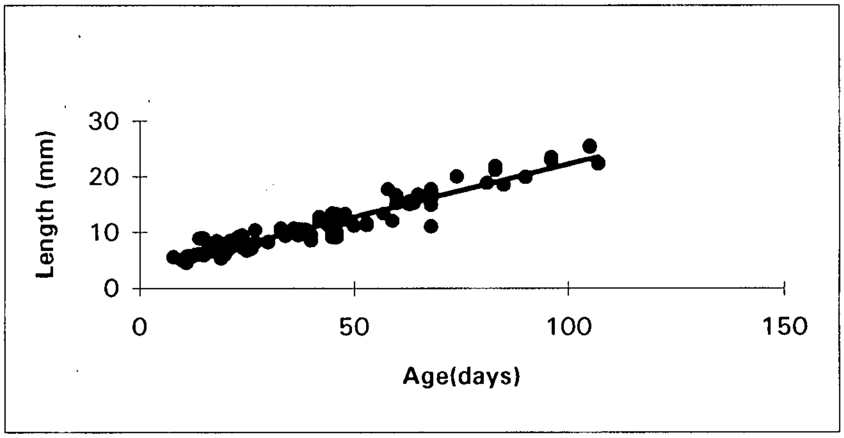


Figure 10. Relationship between standard length and number of increments on lapillus of *R. argentea* from Nyanza Gulf (dots), together with fitted growth curves (solid line). a) Gompertz growth curve, b) von Bertalanffy growth curve, c) Linear regression. Details in the text.

Table 1. Growth parameters, von Bertalanffy, Gompertz, and Linear models fitted to Nyanza Gulf and open waters data of length-at-age. The parameters are defined in the text.

Model	Nyanza Gulf	Open waters
von Bertalanffy		
L_∞ (mm)	35.8	560.6
K (yr^{-1})	2.9	0.13
t_o (days)	-7.1	-17.6
r^2	0.82	0.89
Gompertz		
L_∞ (mm)	24.9	60.4
k (yr^{-1})	8.7	3.5
t_o (days)	31.3	95.7
r^2	0.86	0.93
Linear regression		
a	3.9	3.3
b	0.17	0.19
r^2	0.84	0.92

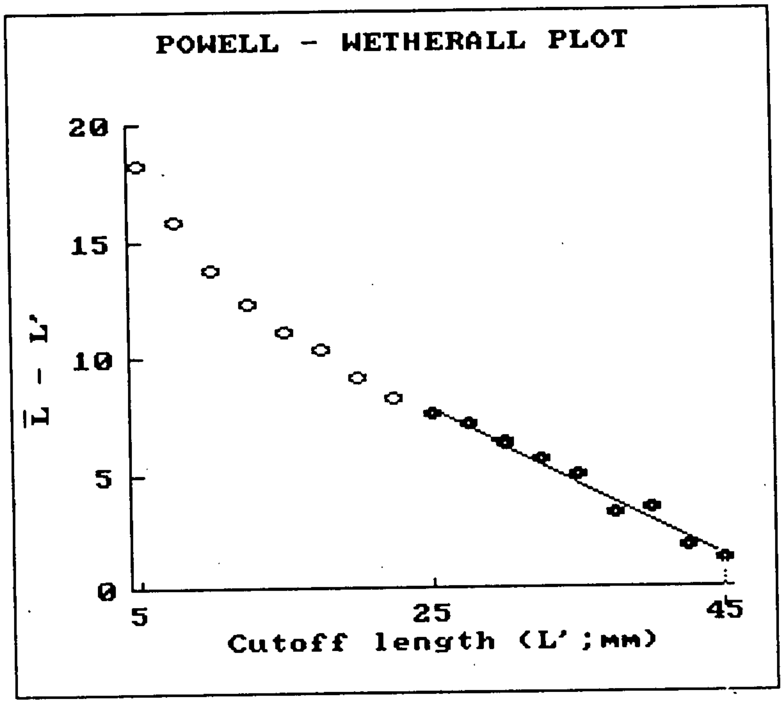
Growth performance

Using Powell and Wetherall's plot, L_∞ of 5.0 cm and 6.5 cm were obtained from the length-frequency data for Nyanza Gulf and open waters sampling sites (Figure 12) and points used for estimation of L_∞ are shown in appendix 3. The resulting von Bertalanffy growth curves for Nyanza Gulf and open waters are shown in Figure 13 and growth parameters on Table 2.

Instantaneous growth rate

Plotted weight (g) against length (mm) graph is shown in Figure 14 and the fitted regression to the natural log transform is shown in Figure 15. Equation for regression is; Y = 5.56 2+ 3.29X, and therefore the length-weight relationship is; W = antilog $(-5.562)L^{3.29}$. Instantaneous growth (G) rates for Nyanza Gulf and open waters are shown in Figure 16. The graphs show a general decrease in instantaneous growth rate with age. In Nyanza Gulf there is a sharp decline of G to about 55 days, but it then increases slightly to 0.02 at round 99 days. In open waters the decline is gradual and starts at a lower G (0.07), but does not go as low as in Nyanza Gulf.

a)



b)

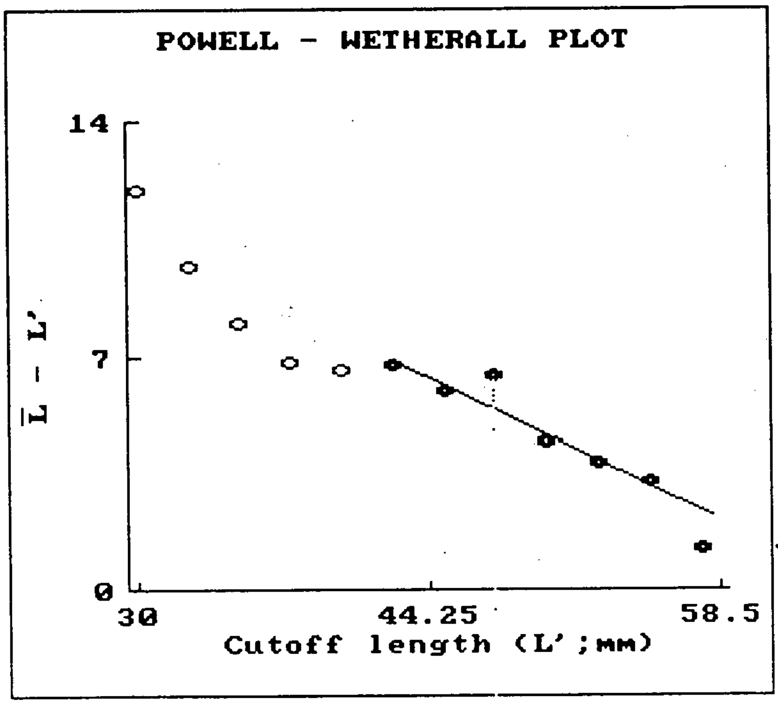
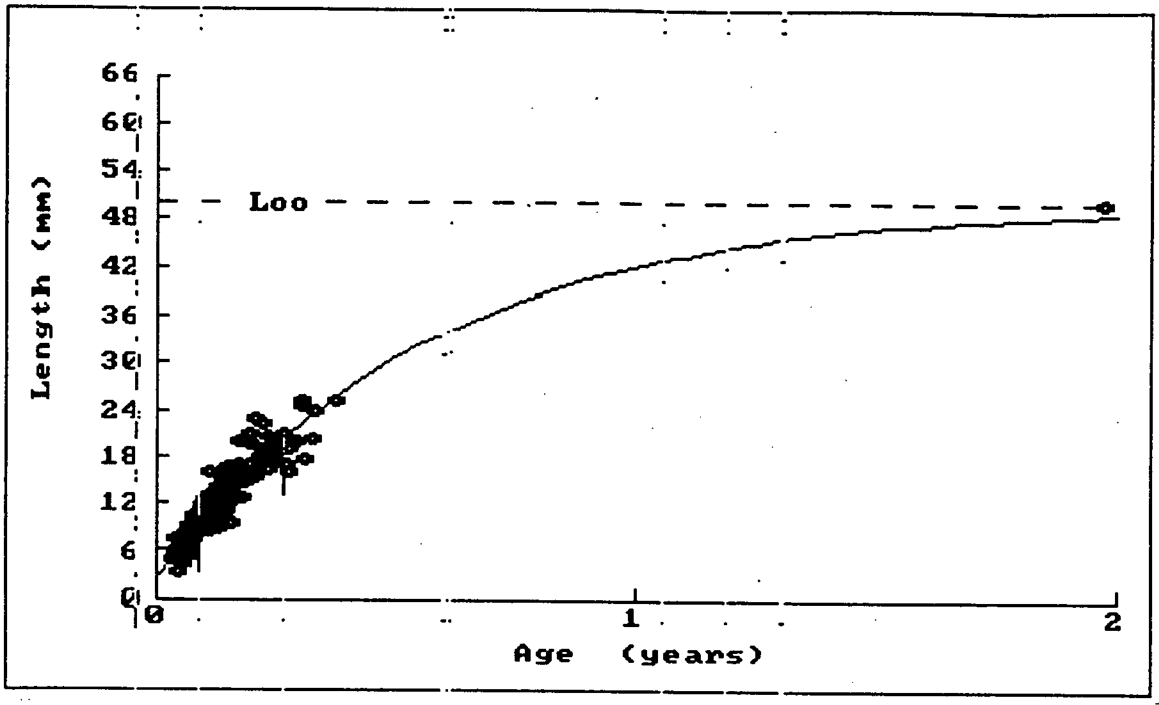


Figure 12. Powell-Wetherall's plot for *R. argentea* using commercial samples from, a) Nyanza Gulf (L_∞ = 5.0 cm), b) open waters (L_∞ = 6.5 cm).

- • Point used in analysis
- ○ Point not used

a)



b)

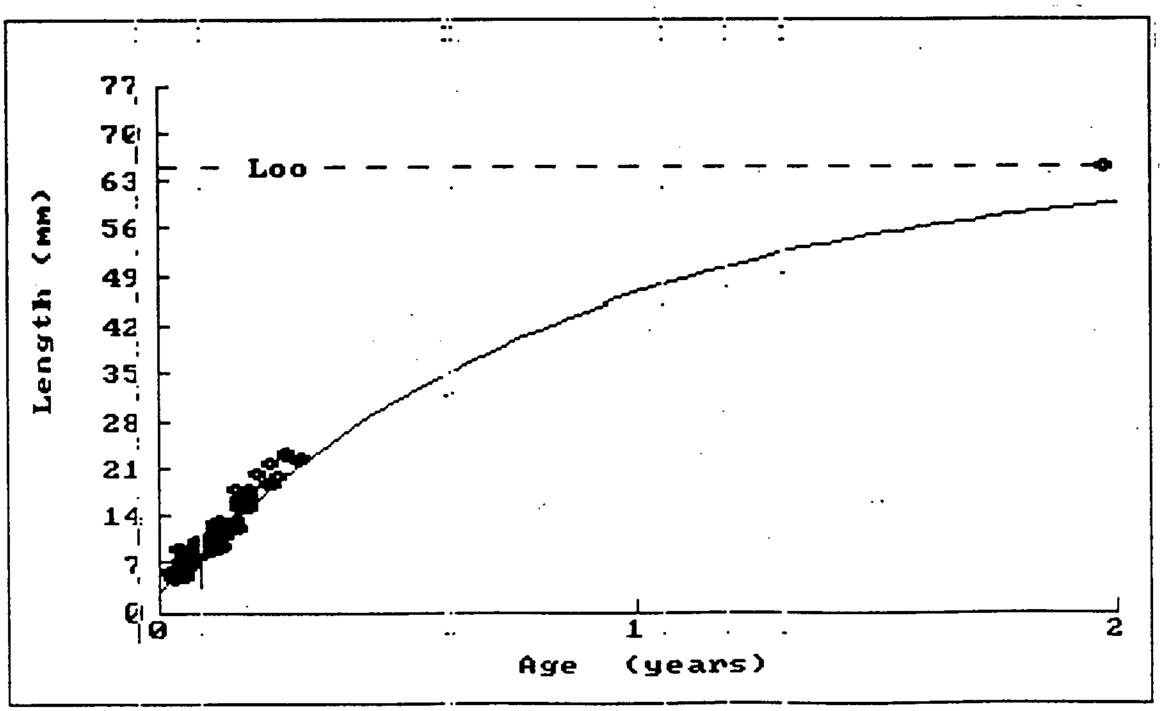


Figure 13. The von Bertalanffy growth curve for adult *R. argentea* based on otolith readings and a fixed L_∞ of, a) 5.0 cm in Nyanza Gulf, b) 6.5 cm in open waters. The first part of the curve (dots) presents age read directly from the otolith.

Table 2. Growth parameters (K yr^{-1}, t_o days) and phi prime (ϕ) estimates with fixed L_∞ (cm) together with their standard error (SE) for *R. argentea.*

Site	L_∞	K	SE	t_o	SE	ϕ	SE
Nyanza Gulf	5.0	1.8	0.129	-0.029	0.006	1.7	0.086
Open waters	6.5	1.4	0.087	- 0.027	0.005	1.7	0.062

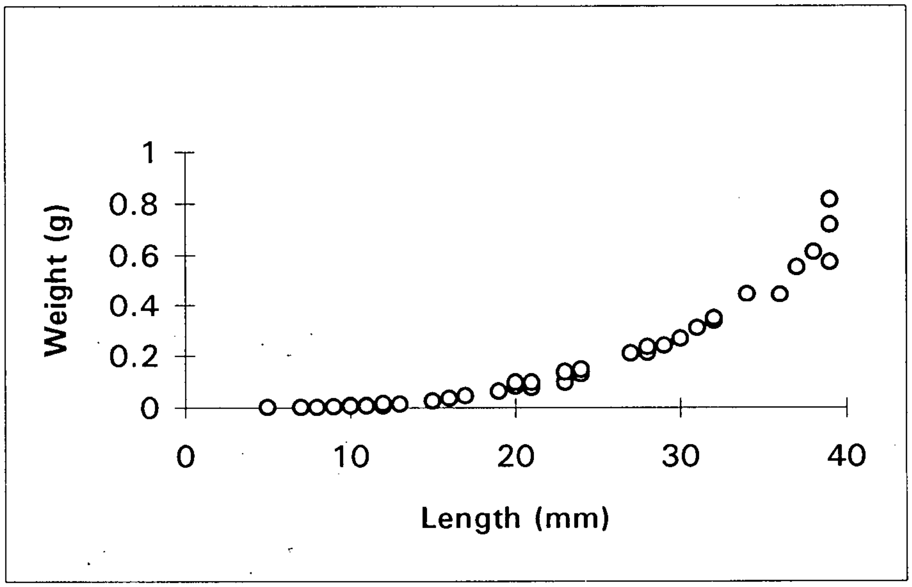


Figure 14. Weight (g) and length (mm) relationship of *R. argentea* from Nyanza Gulf.

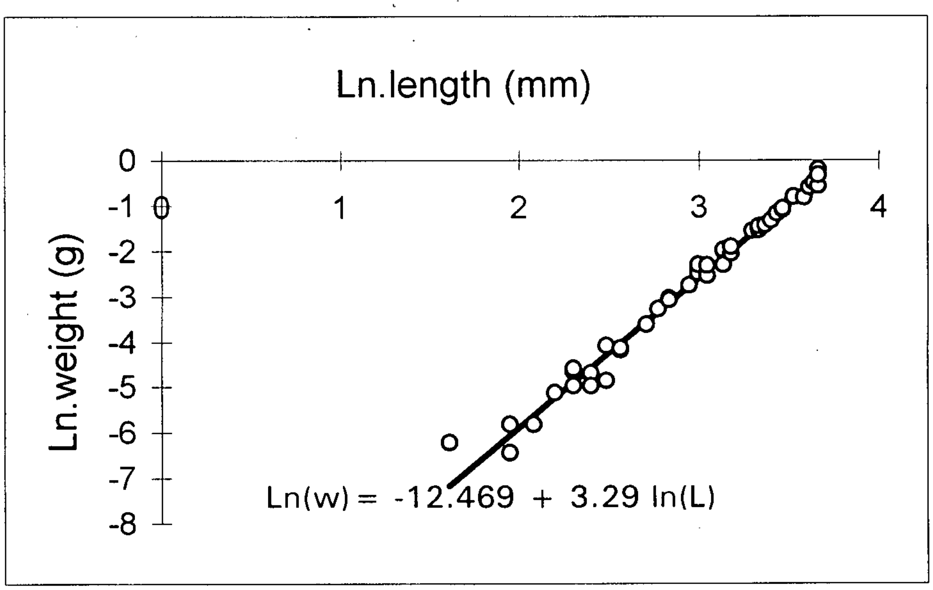


Figure 15. Relationship between natural logarithm of weight plotted against natural logarithm of length (cicrles) of *R. argentea* showing a fitted regression line (solid line)

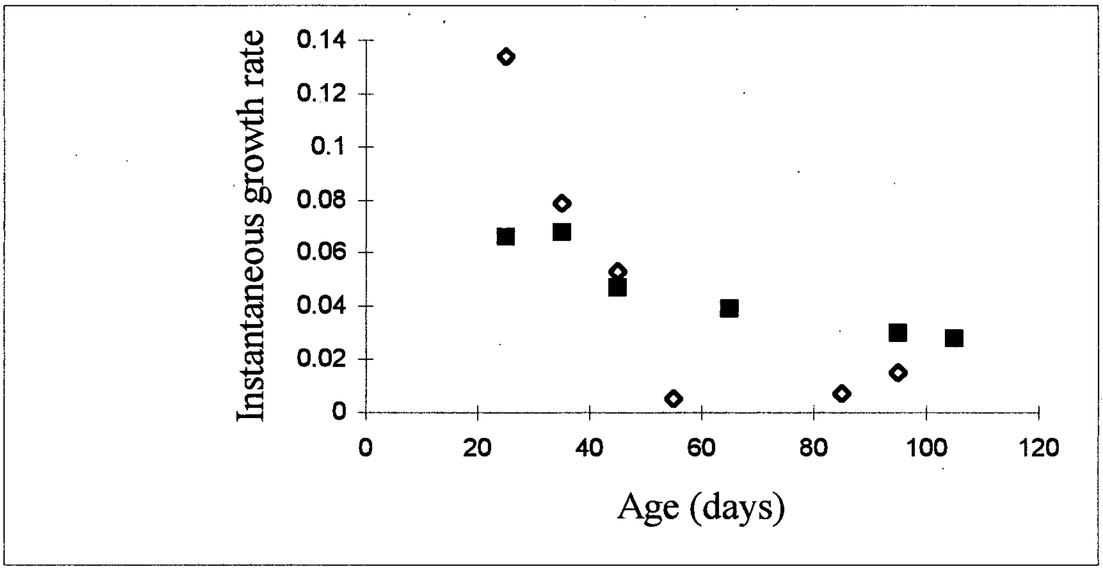


Figure 16. Instantaneous growth of *R. argentea* from Nyanza Gulf and open waters.

Age validation using tetracycline

Table 3 shows the concentration of tetracycline hydrochloride (TC) used on *R. argentea*, the number of fish used and the hours of exposure. Only fish exposed to 600 mg/l TC for 12 hours and 21 hours were marked (Figure 17). The appearance of a second ring at the edge of the lapillus (Figure 17a) is due to a second immersion in 600 mg/l TC for 12 hours after the fish survived the 30 days. After the second immersion the fish lived for three days. Under high magnification (1000x) 30 increments on the lapillus of fish immersion in 600 mg/l TC for 21 hours were found, suggesting the increments were likely deposited daily. Fish immersed in 600 mg/l TC for 12 hours had no visible rings under a light microscope. Figure 17b shows a clear check on the lapillus of the same fish exposure to 600 mg/l TC for 21 hours under bright light illumination. There was higher mortality in fish exposed to low and high concentration (100-200 and 600 mg/l TC) compared to medium concentration (300-400 mg/l TC), which could not be accounted for. There was no stress marks (checks) evident for fish immersed in TC, suggesting TC did not affecting fish growth.

Age validation using growth performance index

Phi prime (Pauly, 1979a) from this study and from other authors has a mean and standard deviation (SD) of 1.65+/-0.084 (Table 4). When increments are assumed to be formed two per day or one per every three days, the estimated phi prime does not lie within this mean +/-SD (Table 5), suggesting that the otolith rings seen were mostly likely deposited daily.

Table 3. Concentration of tetracycline hydrochloride administered to *R. argentea*, exposure time and survival time in holding tanks.

TC (mg/l)	Fish no	exposure time (hrs)	survival time (days)	comments
100	1	4	15	died*
200	3	2	17	died*
200	1	6	1	died*
200	1	24	26	killed
300	2	18	25	killed
400	2	24	30	killed
500	1	24	6	died*
500	1	24	27	killed
500	1	6	26	killed
500	1	6	8	killed
600	3	21	30	killed+
600	2	12	30	killed+
600	1	12	7	died
600	1	6	7	died*

* Dead fish with mould covering which I could not establish its origin. One suggestion could be that water was contaminated through fish feed.

+ Fish which had fluorescent marks under ultraviolet light. Fish were killed to remove otolith for further processing.

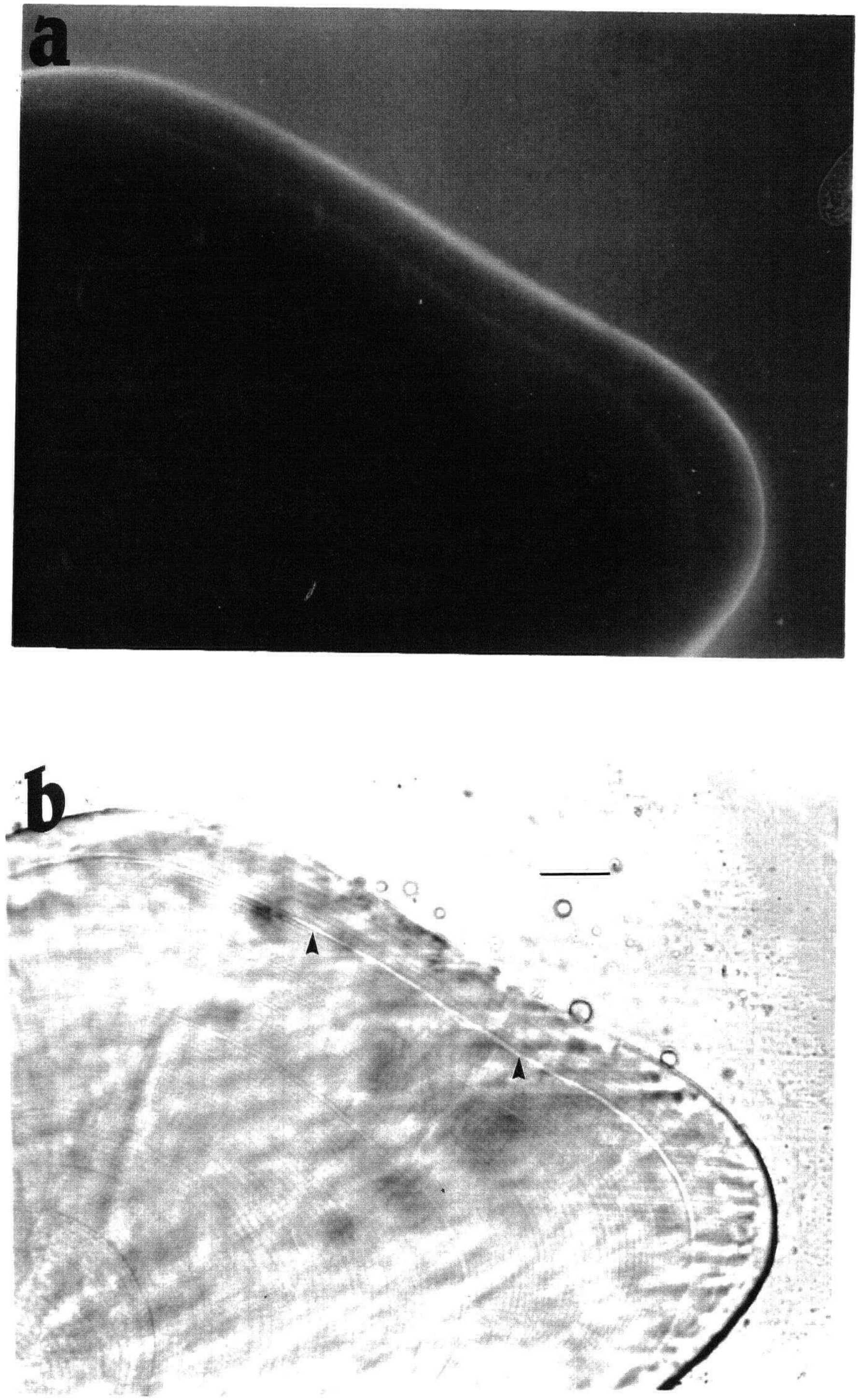


Figure 17. Lapillus of a 24.1 mm *R. argentea* immersed in 600 mg/L TC.
b) Under ultraviolet light showing tetracycline fluorescent bands.
b) Same as photography (a) under bright illumination. Arrows indicates a check corresponding to the tetracycline fluorescent band. Scale bar 10 μm.

Table 4. Growth parameters (L_∞, K) and phi prime of *R. argentea* from this study compared with other published data.

Source	L_∞(SL cm)	K yr^{-1}	Phi prime
Wanink ,1989	5.2	1.1	1.5
Wandera, 1992	6.5	0.92	1.6
Wandera and Wanink, 1995	6.5	0.92	1.6
Njiru 1995 (Nyanza Gulf)	5.0	1.8	1.7
Njiru 1995 (Open waters)	6.5	1.4	1.7
Mean+/-SD			1.62-/+0.084

Table 5. Growth parameters (L_∞, K) and phi prime of *R. argentea* when increments are assumed to be deposited twice a day and once per three days in Nyanza Gulf.

Otolith ring assumed formation	L_∞(cm)	K yr^{-1}	Phi prime
Daily	5.0	1.8	1.7
Twice daily	5.0	3.6	2.0
1 per 3 days	5.0	0.63	1.2

Age-catch curve

Figure 18 and 19 present age-catch curves (age vs log frequency) for Nyanza Gulf and open waters respectively. All the regression slopes used to calculate total mortality rate (Z) were significantly different from zero ($P < 0.05$). The Nyanza Gulf age-catch curves gave a Z of 0.038 day^{-1}(13.9 yr^{-1}) in January, 0.031 day^{-1} (11.3 yr^{-1}) in February, and 0.041 day^{-1} (15.0 yr^{-1}) in March (Table 6). The open waters age-catch curve gives a mortality (Z) of 0.026 day^{-1} (9.5 yr^{-1}) in February and 0.082 day^{-1} (29.9 yr^{-1}) in March (Table 6).

Length-converted catch curve

The length-converted catch curve give a total mortality (Z) of 4.0 yr^{-1} for Nyanza Gulf and 4.8 yr^{-1} for open waters (Figure 20). Data used for analysis is shown in appendix 5 and results for total mortality, their 95% confidence interval and coefficient of determination in table 7. The regression slopes were significantly different from zero at $P < 0.05$.

Natural mortality

The mean annual surface water temperature from the study area was 25 ° C. Pauly's equation (Pauly, 1980a) gave natural mortality of 4.1 yr^{-1}, 3.4 yr^{-1} and at 20% reduction natural mortality (Sparre and Venema, 1992) of 3.2, 2.7 yr^{-1} in Nyanza Gulf and open waters respectively.

Fishing mortality and biomass

Nyanza Gulf data give Z of 4.0 yr^{-1}, M of 4.1 yr^{-1}, and F of - 0.1 yr^{-1} by subtraction and open water data give Z of 4.8 yr^{-1}, M of 3.4 yr^{-1} and F of 1.4 yr^{-1}. This F from open waters is compatible with F for Nyanza Gulf that can be calculated from the ECOPATH II model of Lake Victoria (Moreau *et al.*, 1993) where, P = 17.3 $t.km^{-2}$ yr^{-1}, C = 4.23 $t.km^{2}$ yr^{-1}, F = 0.54 yr^{-1}, B (P/Z) = 7.9 $t.km^{2}$, and Z (Z = P/B) is 2.2 yr^{-1}. Redoing estimation of biomass (B = P/Z. Allen, 1971) using Z of 4.0 yr^{-1} with the same catch (C) and production (P), biomass becomes 4.3 $t.km^{2}$ and estimation of F (F = C/B. Allen, 1971) has 0.98 yr^{-1}.

Exploitation rate (E = F/Z) is 0.29 for open waters and 0.25 for Nyanza Gulf. Appendix 6 presents a summary for estimates of Z, M, F and E from age-catch curve, length-converted catch curve and ECOPATH II model.

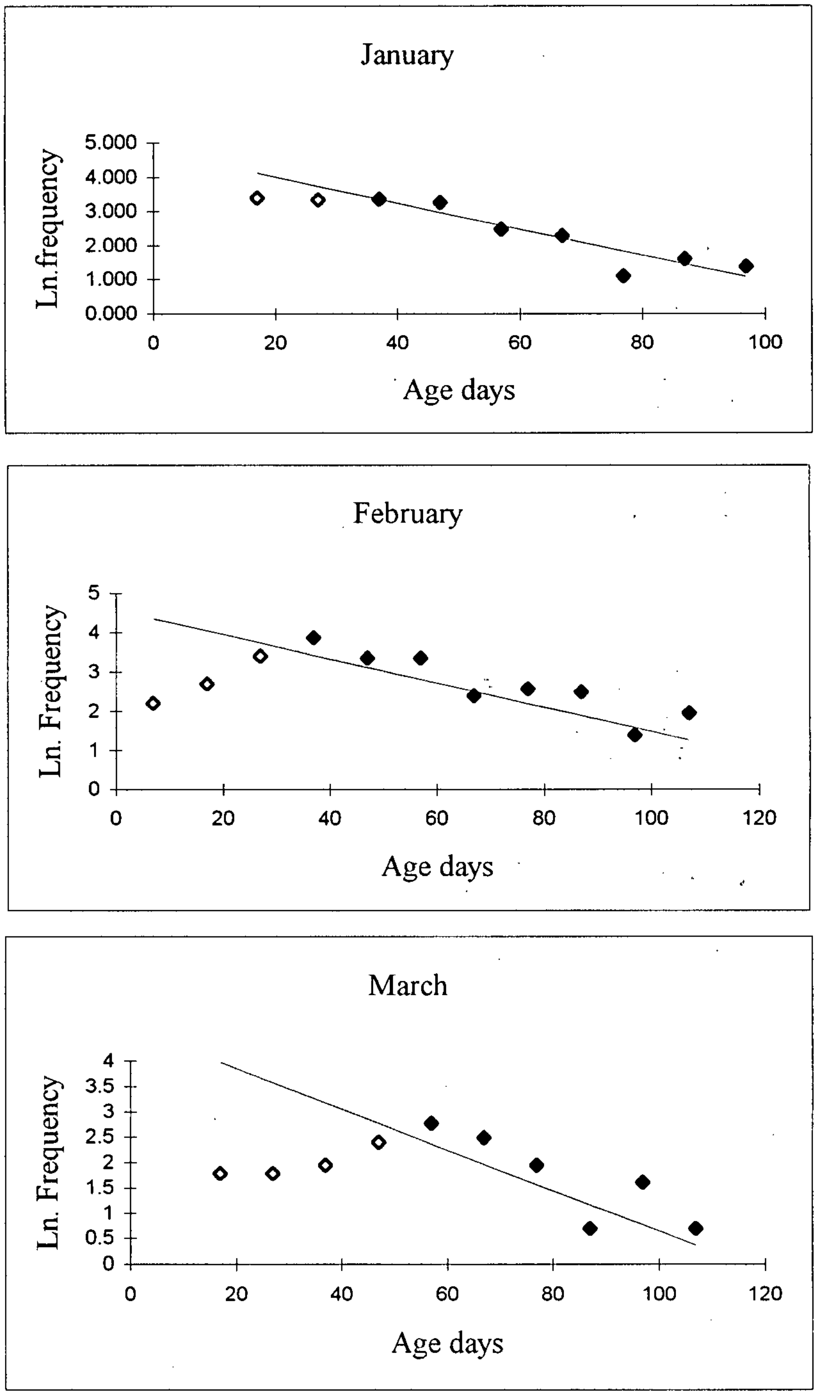
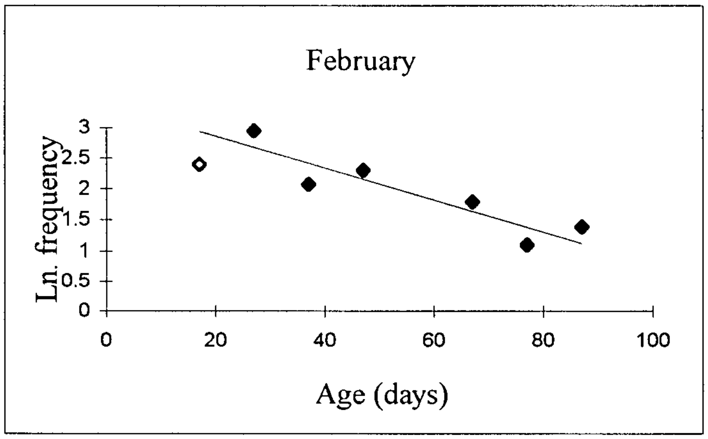


Figure 18. Age catch curve of *R. argentea* from Nyanza Gulf. Ages were obtained by reading otoliths as outlined in chapter 2 and frequencies from the samples of fish which had been read.

■ Points included in analysis

□ Points not included

Points used were established using Robson and Chapman (1961) criteria (Appendix 4).



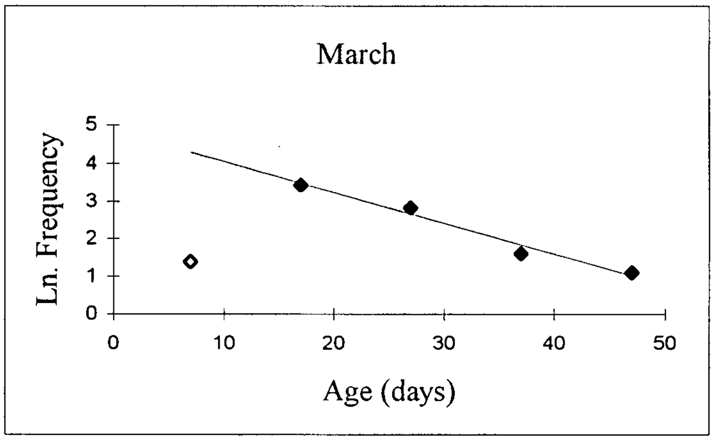


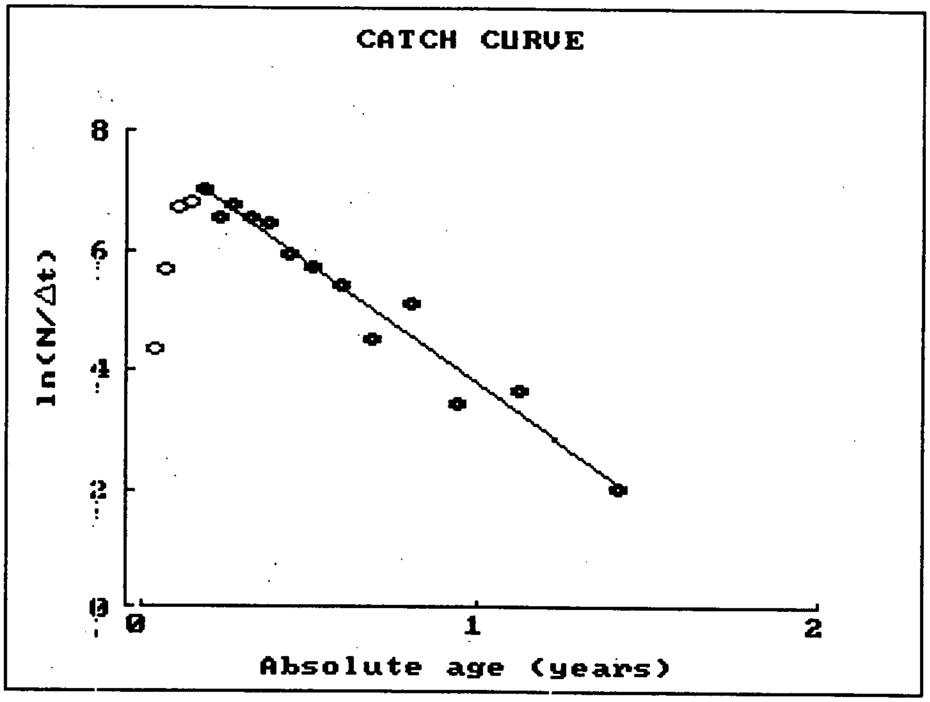
Figure 19. Age catch curve of *R. argentea* from open waters. Ages were obtained by reading otoliths as outlined in chapter 2 and frequencies from the samples of fish which had been read.

■ Points included in analysis

□ Points not included

Points used were established using Robson and Chapman (1961) criteria (Appendix 4).

a)



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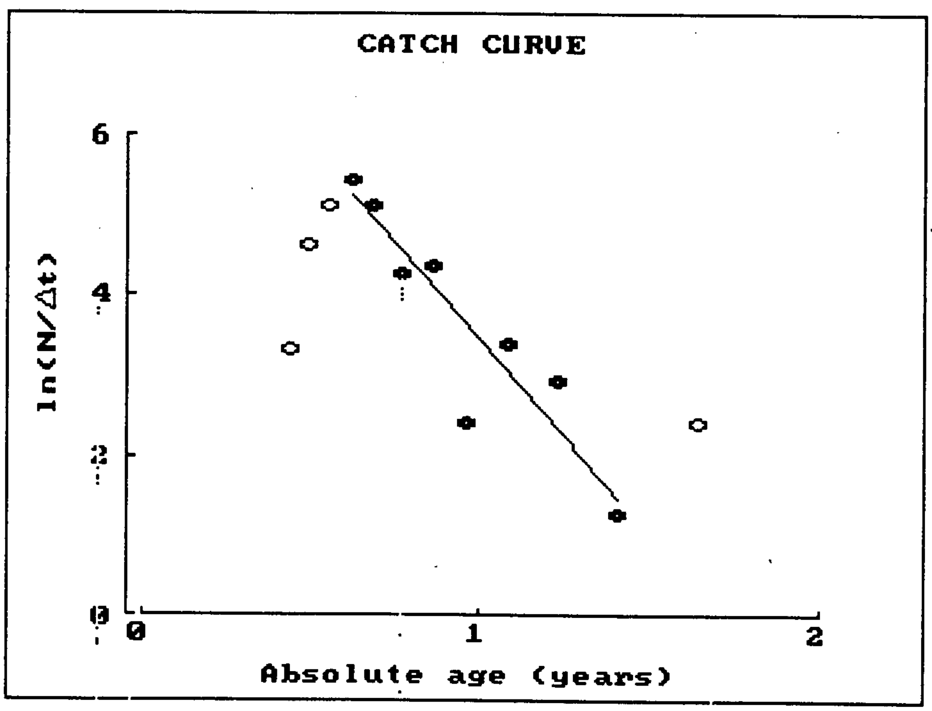


Figure 20. Length converted-catch curve of *R. argentea* from, a) Nyanza Gulf, b) open waters. Length was converted to age by inverse von Bertalanffy equation as outlined in the text.

- ● Points included in analysis
- ○ Points not included

Points to be used were established using Pauly 1984c method (Appendix 4).

Table 6. Mortality estimated (Z) of juvenile *R. argentea,* 95 % confidence interval (95% C.I.) and coefficient of determination (r^2) from age-catch curve.

Site	Z (yr^{-1})	Z (day^{-1})	95% C.I	r^2
Nyanza				
January	13.8	0.038	0.019-0.057	0.84
February	11.3	0.031	0.018-0.044	0.85
March	15.0	0.041	0.0083-0.073	0.75
Average	13.4	0.037		
Open waters				
February	9.5	0.026	0.0095-0.042	0.83
March	29.9	0.082	0.0412-0.123	0.99
Average	19.7	0.054		

Table 7. Total mortality (Z) of adult *R. argentea*, 95% confidence interval (95% C.I.) and coefficient of determination (r^2) from length-converted catch curve.

Site	Z	95% C.I	r^2
Nyanza	4.0	3.45-4.62	0.95
Open waters	4.8	1.4-8.1	0.72

Recruitment pattern

As indicated by the analysis *R. argentea* recruitment goes on throughout the year with two peaks in both Nyanza Gulf and open waters (Figure 21). In Nyanza Gulf there is one prolonged major recruitment period from January to September with a peak around May, and the minor starts in September to November peaking in late October. In open waters the two peaks occur in similar months like those in Nyanza Gulf, with peaks in May and late November. Months with high recruitment in Nyanza Gulf are January, May, September and November and in the open waters January, June and December (Table 8).

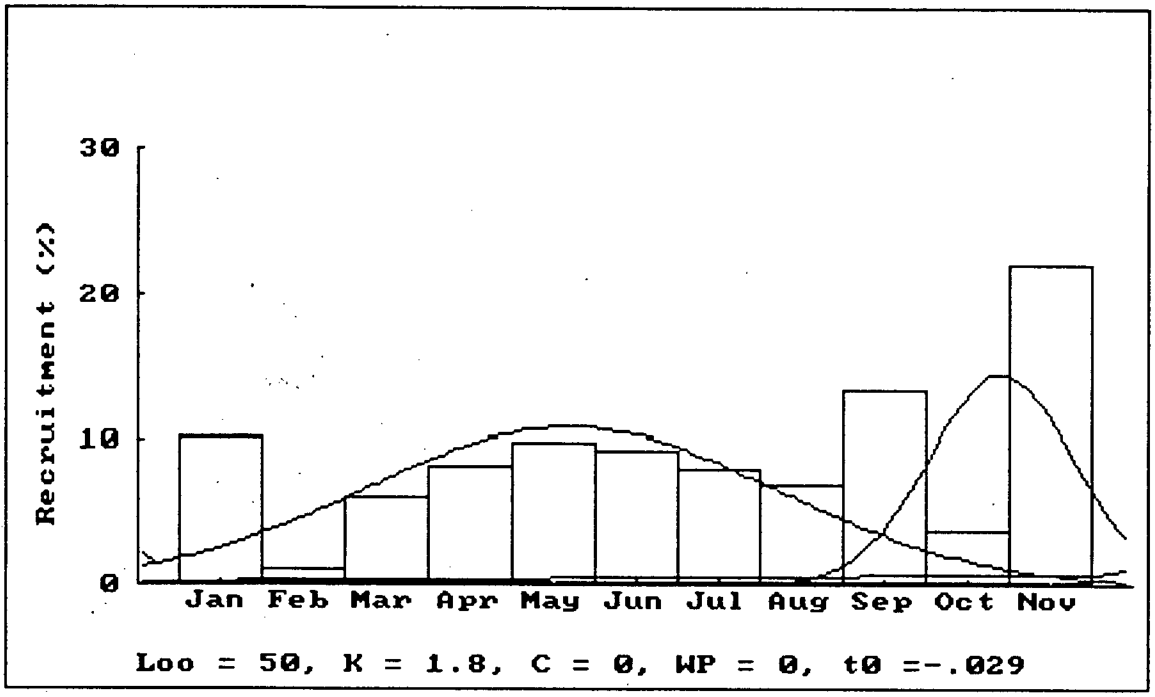
Estimation of selection and probability of capture

Figures 22 shows estimation of selection ogive from length-converted catch curve by extrapolation of juvenile total mortality. Figure 23 and table 10 shows 25 % of the *R. argentea* enters the fishery at 8.9 mm, 50 % at 11.6 mm and 75 % at 14.0 mm in Nyanza Gulf. In open waters, 25% of *R. argentea* enters the fishery at 32.1 mm, 50 % at 34.5 mm and 75 % at 36.7 mm.

Estimation of age at recruitment

Estimation of age at recruitment using t_0 of - 0.029 and - 0.027 for Nyanza Gulf and open waters respectively are presented in table 10. In Nyanza Gulf 25% of *R. argentea* enters the fishery at 29 days, 50% at 44 days and 75 % at 54 days. In open waters 25% of *R. argentea* enters the fishery at 160 days, 50% at 175 days and 75 % at 194 days.

a)



b)

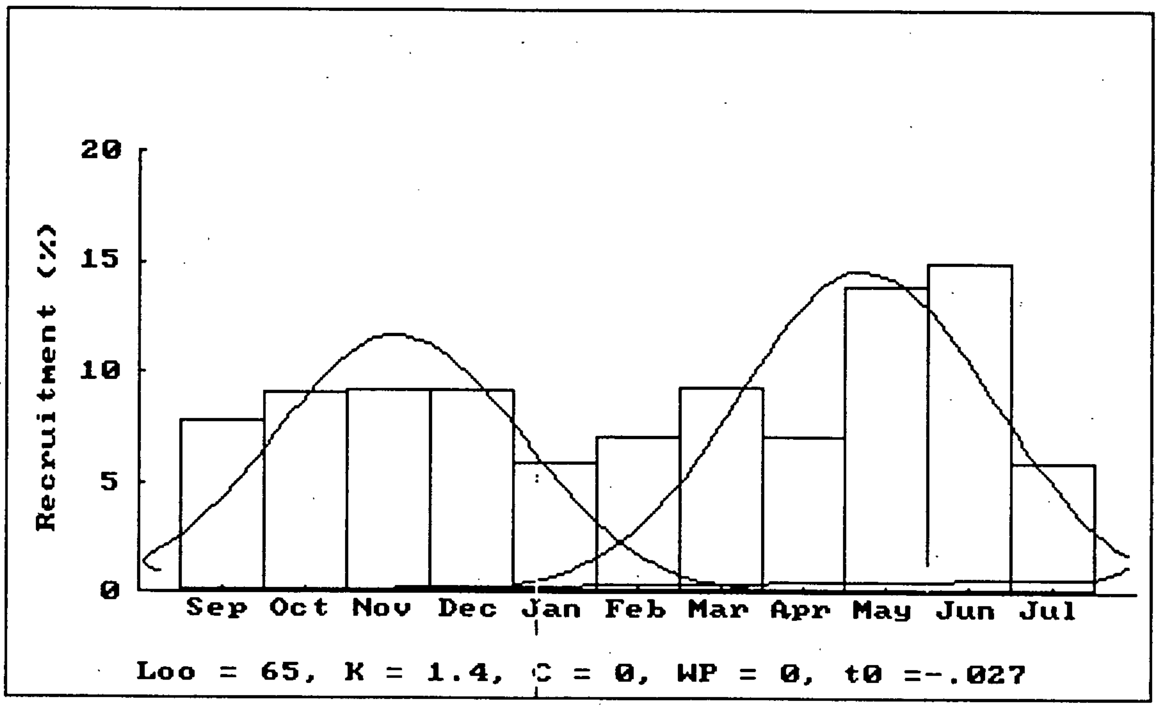


Figure 21. Recruitment pattern of *R. argentea* from, a) Nyanza Gulf, b) open waters.

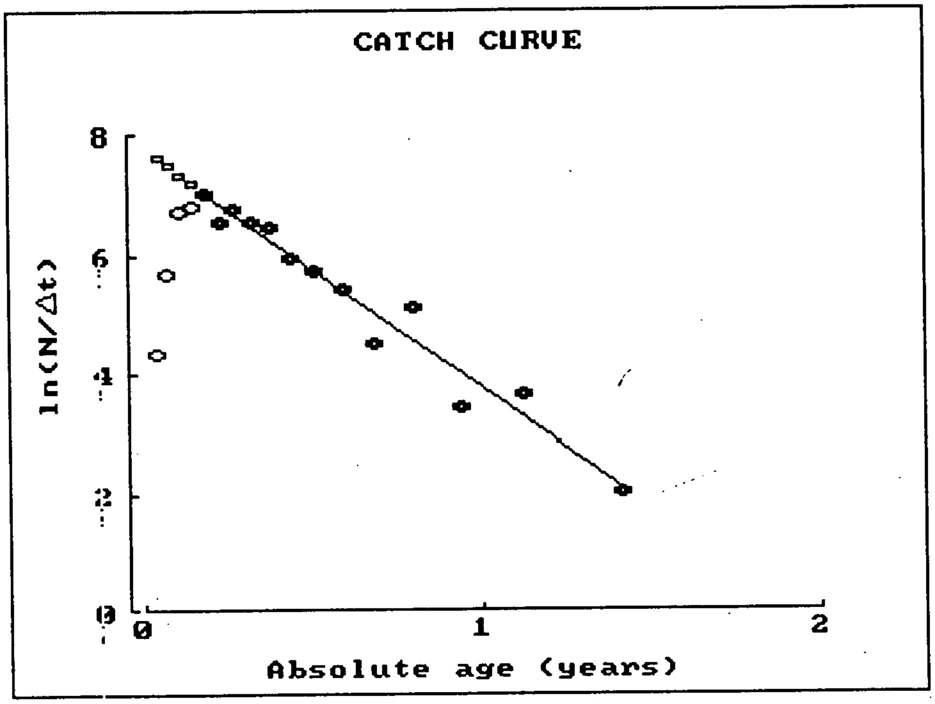
Table 8. Month and percent of recruitment of *R. argentea*.

Absolute time (months)	Percent Recruitment Nyanza Gulf	Open waters
January	10.0	9.3
February	1.2	5.6
March	6.1	8.2
April	8.3	7.7
May	9.9	9.1
June	9.4	17.2
July	8.2	9.4
August	7.8	0.0
September	13.5	7.6
October	3.4	7.6
November	22.3	9.0
December	0.0	9.2

Table 9. Probability of capture of *R. argentea*.

Probability (%) of capture	Length (mm)	
	Nyanza Gulf	Open waters
25	8.9	32.1
50	11.6	34.5
75	14.0	36.7

a)



b)

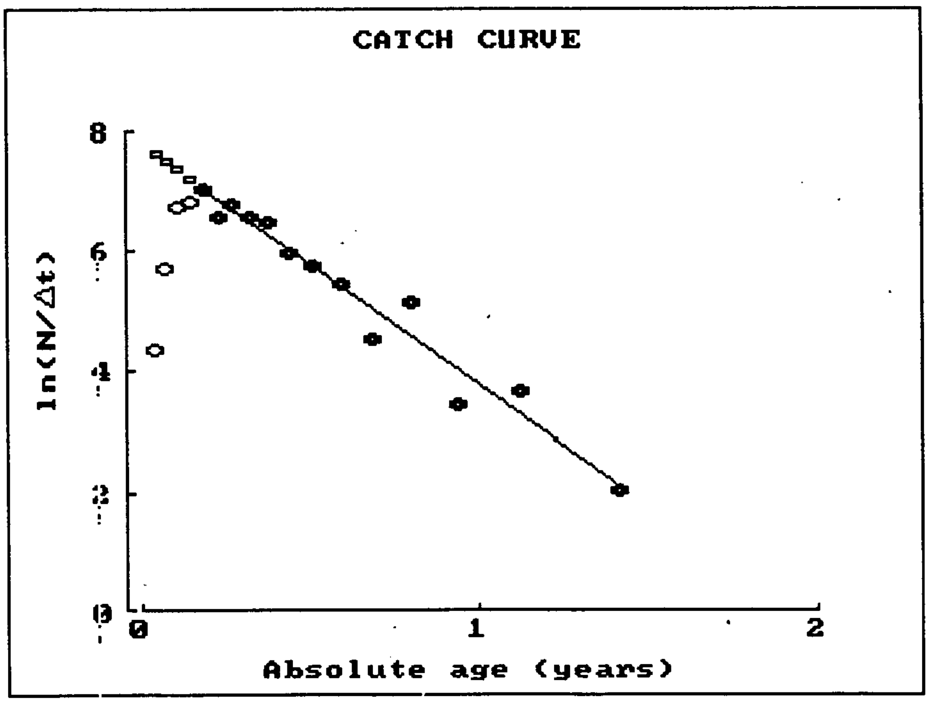
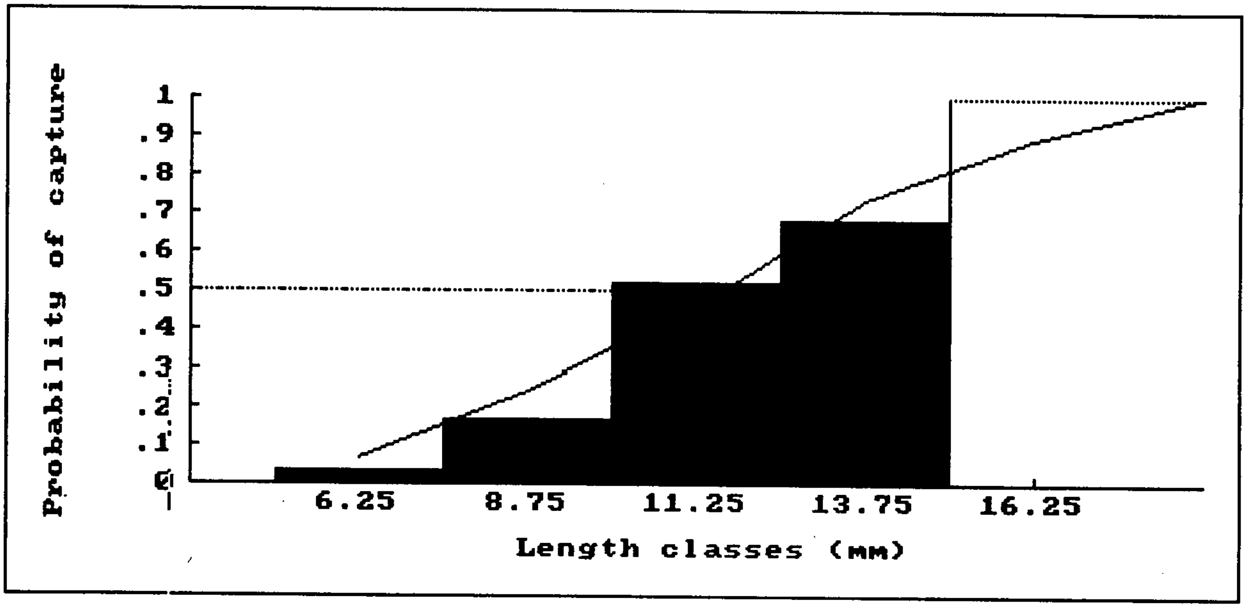


Figure 22. Estimation of selection ogive from length-converted catch curve for *R. argentea* from, a) Nyanza Gulf, b) open waters.

- ○ Points not used
- ● Points used
- ▭ Points showing extrapolation of juvenile total mortality (Z) from adult Z

a)



b)

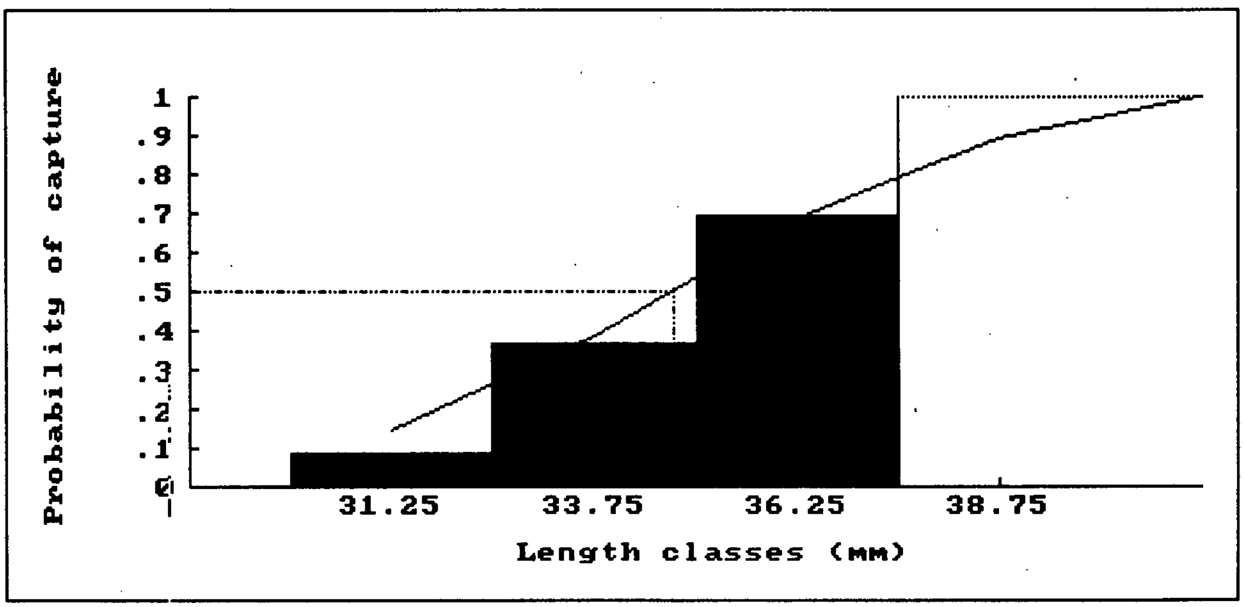


Figure 23. Selection curve of *R. argentea* from, a) Nyanza Gulf, b) open waters. Details in the text.

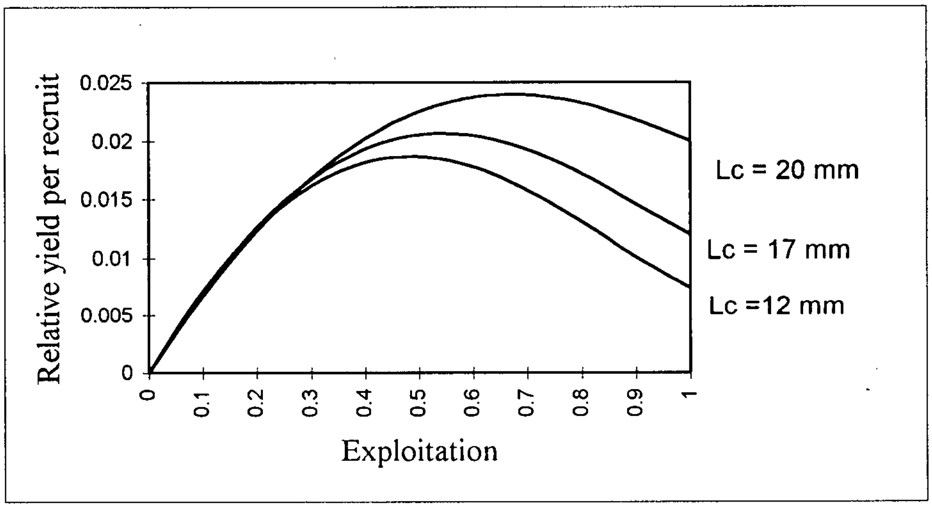
Table 10. Estimated age and length of *R. argentea* at 25, 50 and 75% recruitment

Recruitment (%)	Length (mm)	Age (years)
Nyanza Gulf		
25	8.9	0.029 (29 days)
50	11.6	0.12 (44 days)
75	14.0	0.15 (54 days)
Open waters		
25	32.1	0.43 (160 days)
50	34.5	0.48 (175 days)
75	36.7	0.53 (194 days)

Relative yield-per-recruit model

From the estimated parameters of L_{∞}, K, t_o and M the yield per recruit was calculated for different exploitation rates (E). Figure 24 and table 11 shows maximum exploitation rates (E_{max}) using different length at first capture (Lc) increases as Lc increases. When Lc is 12 mm in Nyanza Gulf, E_{max} which can sustain the fishery is at 0.48 and at Lc of 20 mm, E_{max} is at 0.67. In open waters at Lc of 32 mm, E_{max} is 0.83 and Lc of 40 mm has E_{max} of 1. Plot of relative-yield per-recruit against exploitation rate when assuming knife edge selection gives a higher E_{max} than in case of selection ogive (Figure 25 and Table 11b).

a)



b)

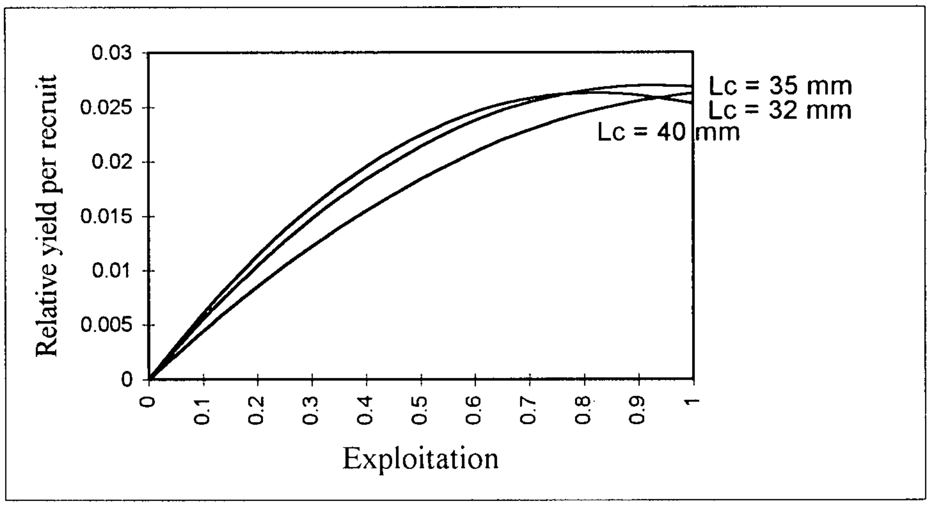
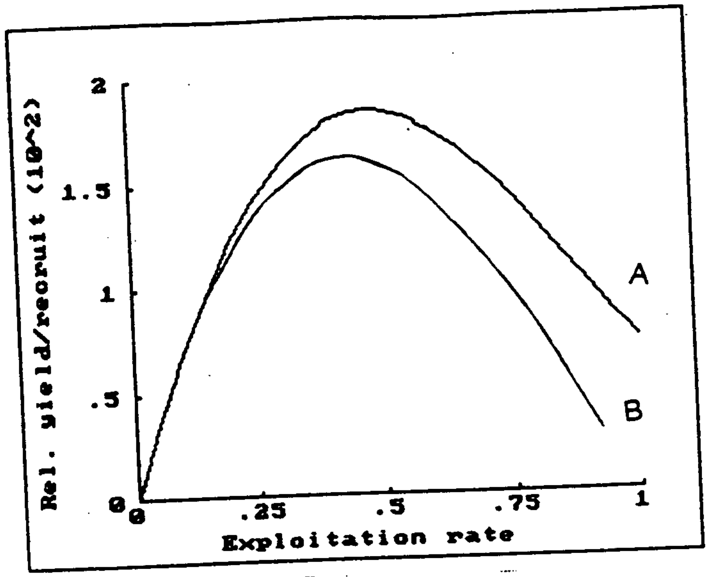


Figure 24. Relative yield-per-recruit as a fuction of exploitation rate for three values of mean length at first capture (Lc), a) Nyanza Gulf, b) open waters.

a)



b)

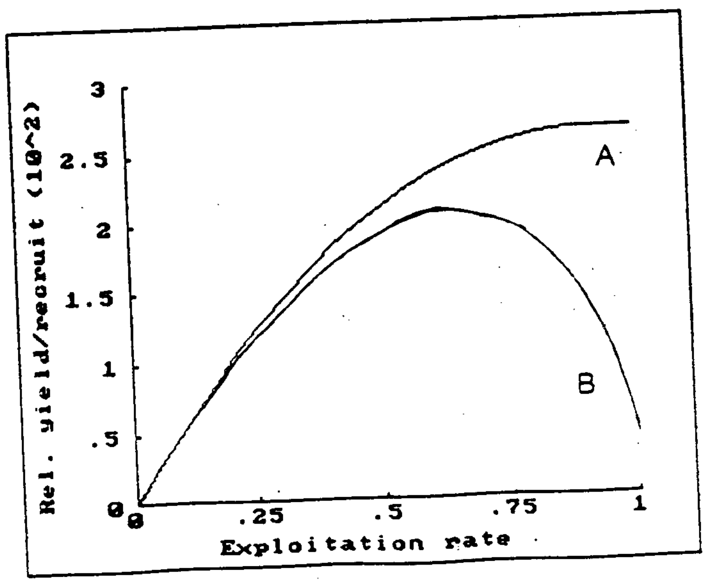


Figure 25. Relative yield-per-recruit showing the difference in exploitation rate when assuming knife-edge (A) and using selection ogive (B) for, a) Nyanza Gulf, b) open waters.

Table 11. Maximum exploitation (E_{max}) for *R. argentea*, a) assuming knife-edge

Lc (mm)	Lc/L∞	E_{max}
Nyanza Gulf		
12	0.24	0.48
17	0.34	0.59
20	0.40	0.67
Open waters		
32	0.49	0.83
40	0.54	0.94
43	0.62	1.00

b) Using selection ogive

	L∞(mm)	M/K	E_{max}
Nyanza Gulf	50	2.3	0.43
Open water	65	2.3	0.64

5. DISCUSSION

Clear growth increments consisting of alternating light and dark bands were visible in the lapillus of *R. argentea.* Studies on cyprinids have found that lapillus and sagitta otoliths are present in the first 4 days of development while the astericus developed in the third week (Victor and Brothers, 1982; Muth *et al.*, 1988), suggesting that growth increment on the lapillus provided the closest estimate of age in *R. argentea.*

Descriptions of growth and mortality during the juvenile life of *R. argentea* using otoliths have not been previously reported. In the present study growth was tested against three growth models, the von Bertalanffy, Gompertz, and Linear regression. The r^2 value derived from regression and total sums of squares from the least-squares regression was used as a criterion in choosing goodness of fit. For juvenile *R. argentea,* the Gompertz model was the best fit for Nyanza Gulf ($r^2 = 0.86$) and open waters ($r^2 = 0.93$), with estimated asymptotic length (L_∞) of 24.9 mm and 60.4 mm respectively. Linear regression had a better fit in both Nyanza Gulf ($r^2 = 0.84$) and open waters ($r^2 = 0.92$) compared to von Bertalanffy model ($r^2 = 0.82$ & 0.89). For the von Bertalanffy, L_∞ for open waters of 560.6 mm and K of 0.13 seems unrealistic. Larvae fish do not grow according to the von Bertalanffy model (Sparre and Venema, 1992) and hence these might not be a realistic estimate of growth parameters. Generally, fitting a model is not only a statistical procedure, but requires a decision about whether or not these particular data are suitable (Alhossaini, 1989).

Unfortunately there are no published growth estimates for juvenile *R. argentea* with which these data can be compared, but several studies have shown that Gompertz model and von Bertalanffy are equally suitable in describing growth of larval fish (Laroche *et al.*, 1982; Thorrold, 1988; Alhossaini, 1989), and selection of the appropriate growth model is generally based on goodness of fit (Ricker, 1979). The von-Bertalanffy growth model however, is generally used more to describe growth of adult fish (Ricker 1979).

This study obtained growth coefficient, K, of 1.5 and 1.8 yr^{-1} for commercial catch which is in agreement with published values of K for the species. Mannini (1992) reports a K of 0.57-1.1 yr^{-1}, while Wandera and Wanink (1995) from their studies got K of 1.0-1.2 yr^{-1}. One reason for their low K may be due to the authors converting length into age thereby underestimating growth of younger fish. Size is a poor indicator of cohort membership and age estimated from daily increments ageing technique is a better estimate of age for *R. argentea.*

Counts of daily increments provide more accurate estimates of *R. argentea* age and growth than has previously been available. This information allows computation of age-dependent mortality rates resulting in more accurate estimates of larval mortality in the lake. The most significant advantage of using otolith ageing technique is the ability to produce individual rather than population statistics which have not been available for *R. argentea.*

However, there are drawbacks to the use of otoliths increment data for estimating age and mortality. Most apparent is the extensive effort required to extract them, prepare and count growth increments. Increments are inherently difficult to locate and this problem increases with size of the fish, where increments disappear or are difficult to see on the edge and near the nucleus of otolith because of refraction of the transmitted light (Campana, 1992). Overgrinding of lapillus lead to loss of microstructure and inaccurate age determination may have been caused by nondaily deposition of rings, or failure to detect all rings within an otolith due to the resolution problem of light microscopy (Campana and Jones, 1992; Jones, 1992). Increment width in this study ranged from 1.3

μm near the nucleus to 4.5 μm towards the edge of the lapillus indicating that LM resolution was adequate for counting the increments. Theoretical resolution of a LM is 0.2 μm although for practical applications it is really close to 1 μm (Neilson, 1992). SEM micrographs allowed for an accurate increment width measurement because they were not subjected to refractive effects that distort an imagine under LM (Campana, 1992).

Chemical marking techniques commonly use compounds such as tetracycline (TC) or oxytetracycline (OTC) which is incorporated into growing calcified tissues within a day of application (Thorrold, 1988; Geffen, 1992). In this study TC was incorporated within 12 hours after *R. argentea* was immersed in TC. Incorporation occurred only in 600 mg/l TC and this was attributed to immersion instead of injection of TC. Geffen (1992) recommends juvenile and adult fish be marked by injection. In their studies Secor *et al* (1991) found that incorporation rates of OTC by immersion was low and time for exposure had to be increased up to 40 hours. Injection with TC was not possible because *R. argentea* were very fragile and a few minutes exposure lead to their death.

Of the two marked fish, the fish immersed in 600 mg/L TC for 21 hours and lived for 33 days had 30 countable increments, while the one immersed for 12 hours had no increment beyond the fluorescence band. This suggested that *R. argentea* likely deposits increments daily. If the assumption of a daily periodicity of increments is correct, one would expect a reasonable agreement between the values of the growth parameters derived from the present work and those given in the literature. This is in fact the case. The values of phi prime (Pauly, 1979a) from this study were 1.7 and are in agreement with 1.5,1.6 and 1.7 from Wanink (1989), Wandera (1992), Wandera and Wanink (1995) respectively. When daily increment are assumed to be deposited more than once per day phi prime does not lie within the calculated mean and standard deviation (1.62 +/- 0.084).

It would therefore be safe to conclude the increments seen were actually daily rings.

Tetracycline although most commonly used in marking otoliths (Thorrold, 1988; Geffen, 1992), is toxic, cause disorders in the digestive system, and inhibits protein synthesis affecting growth in animals (Winstein, 1975). It is possible that *R. argentea* immersed in 600 mg/L TC for 12 hours growth was affected and deposition of daily increments did occur, but they were beyond the resolution of light microscope. Yoklavich and Boehlert (1987) failed to observe daily rings in most otoliths of *Sebastes melanops* after injection with TC. Hetler (1984) failed to determine increment beyond the fluorescence band after immersion of fish in oxytetracycline hydrochloride (OTC).

The lapillus of fish immersed in TC showed low contrast between the continuous and discontinuous zones under a light microscope. The poor deposition of daily rings in *R. argentea* could be related to TC immersion or constant temperature. Such faint increments are a common phenomenon among several species in the laboratory, (Campana 1984b; Alhossaini and Pitcher, 1988) found fish reared in constant temperature in the laboratory were found to produce faint increments, whereas fish subjected to diel temperature cycle are characterized by more easily observed growth increments (Neilson and Geen, 1985).

While a given procedure may be preferred in certain situation, light microscopy (LM) and scanning electron microscope (SEM) will generally produce increments counts of similar accuracy and precision if increment are of sufficient width (>1 μm) (Campana, 1985). In this study increment ranged from 1.3-4.5 μm and structures confused with daily growth increments under LM, such as subdaily increments were also confused when viewed on SEM. Subdaily increments have been reported in several other species (Laroche *et al.,* 1982; Campana, 1984b; Alhossaini and Pitcher, 1988). In these studies, use of SEM provided no further confirmation on subdaily increments, proofing that LM was adequate and likely produced accurate number of increments as could have SEM.

A strong dose of TC usually results in mortality and in a wide diffuse band, whose central area, corresponding to the exact time of marking is difficult to locate. Small doses, on the other hand, result in rings that are difficult to detect (Geffen, 1992). In this study strong dose (600 mg/l TC) did not produce any diffuse bands and weaker doses (100-500 mg/l TC) produced no rings.

Instantaneous growth rate shows a general decreased with age. In the open waters there is more gradual decline whereas in Nyanza Gulf the decline is gradual. As a fish grows, the growth rate per unit length slows down.This a normal trend expected in fish as they grow (Ricker, 1975).

Mortality was estimated by age-catch curve and length-converted catch curve. The age-catch was applied to the juvenile population while length-converted catch curve to commercial catch. Age-catch curve gave high juvenile total mortality (Z) ranging from 7.3-26.2 yr^{-1}. The juveniles have not yet migrated to the fishing grounds and they are exposed only to natural mortality (M), while the adult population is exposed to both M and total mortality (Z).

Values of total mortality (Z) got for adult population with the length-converted catch curve of 4.0 yr^{-1} for Nyanza Gulf and 4.8 yr^{-1} for open waters were in agreement with what is published. Wandera and Wanink (1995) got a range of 3.9-4.4 yr^{-1}, Manyala *et al.* (1992), 3.1 yr^{-1}, and Wandera (1992), 3.6 yr^{-1}.

Pauly's formula (Pauly, 1980a) gave a natural mortality (M) of 4.1 and 3.4 yr^{-1} in Nyanza Gulf and open waters respectively. The value of M for Nyanza Gulf is more than Z which is not suppose to be the case and that of open waters is higher than published figures. Manyala (1991) and Mannini, (1992) reports that, *R. argentea* has an M ranging from 0.68-0.80 yr^{-1} and 1.8-2.9 yr^{-1} respectively. This study was carried out for only 3 months and the data may not be a true reflection of the status of the whole population of *R. argentea*. Direct measurements of M on the other hand is often impossible to obtain, and a method like Pauly's formula (1980a) is "qualified guess" (Sparre and Venema,1992), which is influenced by mean water temperature and asymptotic length (L_∞).

Results on mortality and growth indicate that adult *R. argentea* has high total mortality (Z) and growth performance (K). However, when Lake Victoria *R. argentea* Z and K are compared with other small pelagic species inhabiting African lakes they are found to be low (Mannini, 1992). *Limnothrissa miodon* from lake Tanganyika has Z of 4.4-7.4 yr^{-1} and K of 0.96-2.5 yr^{-1} and in Lake Kariba the species has Z of 8.6-13.8 yr^{-1} and K of 3.1 yr^{-1}. For *Stolothrissa tanganicae* in Lake Tanganyika Z is 5.2-5.5 yr^{-1} and K is 2.6-2.89 yr^{-1} (Mannini, 1992; Wandera and Wanink, 1995). Turner (1982) gave values of Z for *Engraulicypris sardella* in Lake Malawi ranging from 2.2-5.0 yr^{-1} and K of 2.6 yr^{-1}.

In most tropical fish stocks recruitment continues all year round with seasonal oscillations and small pelagics like *E. sardella* (Rufli and van Lissa,1982) and *Stolothrissa tanganicae* (Roest, 1978) have more than one spawning peak during a year. Using ELEFAN II (Electron Length Frequency Analysis, Pauly, 1987) this study shows *R.argentea* breeds throughout the year with two peaks which corresponds to the two rainy seasons from April-June and October-December. These findings are similar to those of Wandera (1992) who found *R. argentea* to breed from April-May and August-September, but differ from results of Wandera and Wanink (1995) who found only one major breeding period year in October-November. During rainy seasons Lake Victoria completely or partially mixes subsequently providing plenty of food resources and encourages *R. argentea* gamete production (Wandera, 1992).

Recruitment of fish to the fishing area is size dependent. Every size of fish is not fully represented at fishing grounds and the probability that it is retained by the fishing gear is a product probability of its presence in this fishing ground and its retention by the meshes (Sparre and Venema, 1992). In Nyanza Gulf and open waters, 50% of *R. argentea* of 11.6 mm (44 days) and 34.5 mm (175 days) can be retained by present commercial catch gears. Wanink (1989) reports that *R. argentea* can lives for 1-2 years, female mature at 43-44 mm and male at 40-41 mm (Wandera, 1992). Therefore, present commercial gear (5-8 mm mesh size) in Kenyan waters of Lake Victoria are catching immature *R. argentea*.

The fishing mortality (F) for *R. argentea* from Nyanza Gulf is 0.98 yr^{-1} and an exploitation rate (E) of 0.25, while F in the open waters is 1.4 yr^{-1} and E of 0.29. The plot of relative yield-per-recruit (Y/R)' against exploitation (E) shows the fishery can withstand more exploitation than this, and increase of mesh size and thus increase in length of fish at first capture (Lc) produces a higher exploitation rate (E_{max}). When assuming knife-edge selection, E_{max} is higher than in selection ogive. In knife-edge selection assumption that fish at Lc are suddenly exposed to fishing mortality does not apply in real life situation. This method tends to overestimate numbers of older fish and underestimate young fish retained by a net.

For management purposes, it is important to be able to determine changes in yield per recruit for different values of exploitation (E). The (Y/R)' can provide this information (Sparre and Venema, 1992). The model requires fewer parameters and is suitable for accessing the effects of mesh size. The model forms a direct link between fish stock assessment and fishery resource management.

However, the (Y/R)' model should be used with caution because the values of E producing maximum relative yield per recruit could also reduce the parental stock to a level at which no recruits are produced. In small tropical fish like *R. argentea* the value of E which maximize relative yield-per-recruit are generally high. Like in this study E of 0.7 (Lc = 20 mm) and 1.0 (Lc = 40 mm) in Nyanza Gulf and open waters respectively are quite high and therefore using only (Y/R)' analysis for management can be very misleading (Pauly 1979b; Pauly and Martosubroto 1980).

4. IMPLICATION OF STUDY FOR RASTRINEOBOLA FISHERY

The knowledge of more accurate age, growth and mortality of juvenile *R. argentea* is fundamental to sustainability of the present *Rastrineobola* fishery. Information on age structure can be used to clarify the effects of changes in the environment, growth and survival of the juveniles, resulting in improved understanding of factors affecting recruitment success. In adults the information can be used to determine the effects of fishing on the stocks, to understand life history events, and to maximize yield while ensuring future stocks of dagaa are maintained. If dagaa is to be cultured, knowledge of growth rates of cultured versus wild fish can be useful in determining the feasibility, potential, and profitability of rearing the fish in captivity.

Growth rate and maximum length of *R. argentea* in Lake Victoria has decreased significantly over the last 15 years (Manyala, 1991; Wandera and Wanink 1995). In Mwanza Gulf the modal length of dagaa decreased by 18% between 1982 and 1987 (Wanink,1988a). Unfortunately, the early work on growth of *R. argentea* had never been published for comparison. In Ugandan waters Rufli and van Lissa (1982) have cited a fork length of 105 mm (95 mm SL). The growth rate was said to resemble the values found for *E. sardella.* Wandera and Wanink (1995) assumed a K value of 2.74 yr^{-1} (the two mean value given for *E. sardella*) for the dagaa population studied by Proude and Stoneman (1973). This early study demonstrates that *R. argentea* had a very high growth rate and attained a greater length than reported by scientists working on the species from the late 1980s to present.

This reduction in growth rate and size could be due to a number of reasons. It could be due to overfishing, high predation, intra-specific competition for food or due to abrupt changes in the environment (Katunzi, 1992). In the current situation, overfishing, use of illegal gears and predation pressure by the Nile perch are considered to be the main cause of *Rastrineobola* stock reduction (Katunzi, 1992; Manyala *et al*., 1992). This study has demonstrated using Beverton and Holt relative yield-per-recruit model that fishing is a major factor in reduction in size of dagaa at first capture.

Fast growing species with high turn over rate are capable of reacting to higher fishing pressure (Katunzi, 1992). In consequence, there should be a stimulation of the reproductive output in order to sustain survival. This tends towards attaining reproductive maturity at a smaller adult body size shorter life span, smaller eggs and faster growth rates. These changes have not been reported in Lake Victoria *R. argentea* (Wanink,1989; Katunzi,1992). If such a scenario occurs the recovery of *R. argentea* could be hampered by heavy fishing pressure, use of illegal gears, Nile perch predation and pollution of the lake.

Studies have shown that the *Rastrineobola* fishery is shifting from 10 mm to 5 mm meshes (Manyala *et al*., 1992) and the latter captures immature individuals of the species. This study has shown there is 50% probability of *R. argentea* of 11.6 mm (44 days) aand 34.5 mm (175 days) in Nyanza Gulf and open waters respectively being retained by commercial gears. These are very immature fish for a species reported to mature between 40-43 mm and live for 1-2 years (Wandera, 1992). Therefore the present form of fishing is highly destructive to *R. argentea* recruitment success.

Continual use of smaller mesh sizes would lead to further reduction of *R. argentea* size/length at first capture (Lc) and consequently the fishermen would in turn reduce their mesh sizes to target the smaller dagaa. This will decrease the immediate and long-term catches of the species. Beverton (1959) had predicted a similar trend due to use of smaller mesh gill-nets to capture the dwindling stocks of *Oreochromis esculentus, Bagrus docmac*, .and *Barbus altianus*, once most cherished traditional species in Lake Victoria.

When this problem of small mesh sizes is compounded by the effects of Nile perch predation and pollution of the lake (Ochumba, 1988), it could spell doom to *Rastrineobola* fishery and the entire Lake Victoria fishery. Good estimation of growth and mortality is a vital management tool and implementation of findings (like increase in mesh sizes) which will save this species are long over due. The collapse of *Rastrineobola* would not only be disastrous to Lake Victoria ecosystem, but to the people and the economies of the three riparian states. Rhetoric speeches should cease and those empowered with authority should seek immediate solution.

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Appendix 1

Table A1.1. Length-frequency samples of juvenile *R. argentea* from Nyanza Gulf.

Length (mm)	January	February	March	April	May	Total
3	0	1	0	0	0	1
4	1	0	0	0	0	2
5	16	1	12	0	0	29
6	20	4	19	2	2	47
7	30	10	24	13	6	83
8	11	29	31	16	7	90
9	33	70	8	10	6	133
10	28	55	25	11	8	126
11	15	53	17	1	2	98
12	15	25	10	0	0	51
13	17	26	14	0	0	58
14	4	17	5	0	0	26
15	7	7	12	0	0	26
16	21	15	6	0	0	42
17	3	14	9	0	0	26
18	2	14	17	0	0	33
19	4	4	4	0	0	12
20	0	7	6	0	0	13
21	0	5	17	0	0	22
22	0	7	4	0	0	11
23	1	5	2	0	0	8
24	0	8	1	0	0	9
25	0	1	0	0	0	1
26	1	4	1	0	0	6
Total	229	382	244	66	31	952

Table A1.2. Length-frequency samples of juvenile *R. argentea* from open waters sampling site.

Length (mm)	February	March	April	May	Total
3	0	0	0	0	0
4	0	0	0	0	0
5	0	12	0	0	12
6	0	17	1	2	20
7	0	23	4	6	33
8	3	31	1	6	41
9	19	0	6	5	30
10	13	0	5	4	22
11	14	0	5	1	20
12	8	0	0	0	8
13	12	0	1	0	13
14	5	0	0	0	5
15	1	0	0	0	1
16	7	0	0	0	7
17	4	0	0	0	4
18	5	0	0	0	5
19	2	0	0	0	2
20	3	0	0	0	3
21	0	0	0	0	0
22	3	0	0	0	3
23	3	0	0	0	3
24	2	0	0	0	2
25	0	0	0	0	0
26	2	0	0	0	2
Total	106	83	23	24	236

Table A1.3. Length frequency samples of *R. argentea* commercial catch from Nyanza Gulf.

Length (mm)	January	February	March	Total
5	0	1	0	1
6	0	0	0	0
7	0	3	0	3
8	0	3	0	3
9	1	3	1	5
10	0	7	3	10
11	5	4	3	12
12	5	8	3	16
13	3	10	3	16
14	7	1	4	12
15	22	2	2	26
16	5	4	6	15
17	1	9	5	15
18	5	4	5	14
19	2	6	3	11
20	5	5	9	19
21	4	7	4	15
22	10	4	2	16
23	5	8	3	16
24	11	4	1	16
25	16	4	3	23
26	9	1	1	11
27	6	5	2	13
28	3	3	5	11
29	3	3	3	9
30	7	2	1	10
31	6	2	2	10
32	6	5	1	12
33	6	2	2	10
34	3	2	0	5
35	2	9	1	12
36	1	4	2	7
37	2	11	2	15
38	0	13	1	14
39	1	15	3	19
40	0	11	0	11
41	1	4	0	5

Table A1.3. Continual

Length (mm)	January	February	March	Total
42	1	3	1	5
43	1	1	1	2
44	0	6	4	10
45	1	4	1	6
46	0	4	0	4
47	0	0	0	0
48	0	0	0	0
49	0	0	0	0
50	0	1	0	1
51	0	2	0	1
52	0	2	0	2
53	0	2	0	2
54	0	0	0	0
55	0	0	0	0
56	0	0	0	0
57	0	1	0	1
58	0	3	0	3
Total	166	83	24	236

Table A1.4. Length frequency samples of *R. argentea* commercial catch from open waters.

Length (mm)	February (mm)	Length	February
37	5	48	0
38	7	49	0
39	7	50	1
40	9	51	2
41	3	52	2
42	3	53	2
43	0	54	0
44	5	55	0
45	3	56	0
46	4	57	1
47	0	58	1
Total			55

Appendix 2

Table A2. Age-frequency samples of juvenile *R. argentea* from Nyanza Gulf and open waters sampling site.

Nyanza Gulf				Open waters	
Age (days)	Frequency Jan	Feb	March	Feb	March
10	1	0	0	0	3
12	3	0	0	0	3
14	11	1	0	0	5
16	2	1	0	0	4
18	7	2	1	0	5
20	7	5	0	0	14
22	10	4	0	0	7
24	8	3	2	0	6
26	1	0	1	0	3
28	6	3	2	0	1
30	3	5	1	1	0
32	3	4	2	1	1
34	7	3	2	0	0
36	3	8	1	6	0
38	8	7	0	1	1
40	8	8	1	3	3
42	2	7	0	4	0
44	3	12	0	5	3
46	5	6	2	6	0
48	1	12	1	2	0
50	15	11	4	2	0
52	3	7	3	2	0
54	3	8	3	0	0
56	4	5	0	1	0
58	0	3	1	2	0
60	2	6	4	3	0
62	2	7	3	3	0
64	2	3	1	2	0
66	1	1	1	0	0
68	2	11	4	5	0
70	3	7	7	0	0
72	1	1	5	0	0

Table A2. Continual

Nyanza Gulf				Open waters	
Age	Frequency				
(days)	Jan.	Feb.	March	Feb.	March
74	0	0	2	0	1
76	0	3	1	0	0
78	0	4	0	0	0
80	2	3	4	1	0
82	0	0	2	2	0
84	3	3	1	1	0
86	0	0	1	0	0
88	0	2	0	0	0
90	2	8	3	3	0
92	0	0	0	0	0
94	0	1	0	0	0
96	1	3	0	3	0
98	0	4	0	0	0
100	3	4	2	0	0
102	0	0	0	0	0
104	0	0	0	2	0
106	0	0	3	2	0
108	0	1	1	0	0
110	1	3	1	0	0
112	0	1	0	0	0
114	0	0	0	0	0
116	0	3	1	0	0
118	0	2	0	0	0
120	0	1	1	0	0
122	0	0	0	0	0
124	0	0	0	0	0
126	0	0	0	0	0
128	0	0	0	0	0
130	0	1	0	0	0
132	0	0	0	0	0
134	0	1	0	0	0

Appendix 3

Data for estimation of L_∞ using the method of Powell-Wetherall
Table A3.1. Nyanza Gulf.

L(mean)-L'	L'
18.3	5.0
15.9	7.5
13.8	10.0
12.4	12.5
11.1	15.0
10.3	17.5
9.1	20.0
7.4	22.5
7.1	25.0***
6.3	27.5
5.6	30.0
4.9	32.5
3.3	35.0
3.4	37.5
1.8	40.0
1.8	40.2
1.2	45.0

Table A3.2. Open waters.

L(mean)-L'	L'
12.0	30.0
9.8	32.5
8.0	35.0
6.8	37.5
6.6	40.0
6.7	42.5***
5.9	45.0
6.4	47.5
4.4	50.0
3.8	52.5
3.2	55.5
1.2	57.5

***Regression line fitted from this point

Appendix 4

Robson and Chapman method (1961)

Its a least square method providing a statistical test whether the points lie on the same line. The method estimates Z from progressive subsets of the whole catch curve, dropping the youngest age from the analysis each time, until the test becomes non-significant.

1 On a scatter plot age is plotted against natural logarithm of number at age (Frequency).

2. Estimation of Mortality: Age which to start is coded zero, then the other subsequent ages coded *i* in order up to the maximum age (*i* max). The catches for each coded age are n_i .

Calculate: $T = \sum i.n_i$ from i = 1 to *i* max

$N = \sum n_i$ from i = 0 to *i* max

Survival percentage (SV) is estimated as:

$$SV = T/(N+T-1)$$

So the instantaneous mortality rate (Z) is given by

$$Z = -Ln(survival)$$

Confidence limits may be attached by calculating the variance

$$S^2(SV) = SV\ (SV-\ [(T-1)/(N+T-2)]$$

and standard deviation

$$S(SV) = \sqrt{S^2(SV)}$$

which may be used with student's t for (N-1) d.f. to set confidence limit win the usual way.

3. The validity of the analysis on the current set of ages can be checked using chi-square which tests whether the first age group (n_0) fits with the rest of the curve.

Calculate:

$$h = (N-n_0)/N$$

and

$$b = [T(T-1)\ (N - 1)]/\ [\ (N(N+T-1)^2\ (N+T-2)]$$

then

$$\chi^2_{obs} = (SV-h)^2/b$$

which is checked with chi-square$_{crit}$ tables or chart with 1 d.f. (NB.95% value of chi-square$_{crit}$ is 3.841).

4. If the test gives a significant result, the whole analysis is moved on by one age and repeated (go back to (2) above) until the test becomes non-significant.

5. Regression is started from this non-significant point including all the other points after it.

Appendix 5

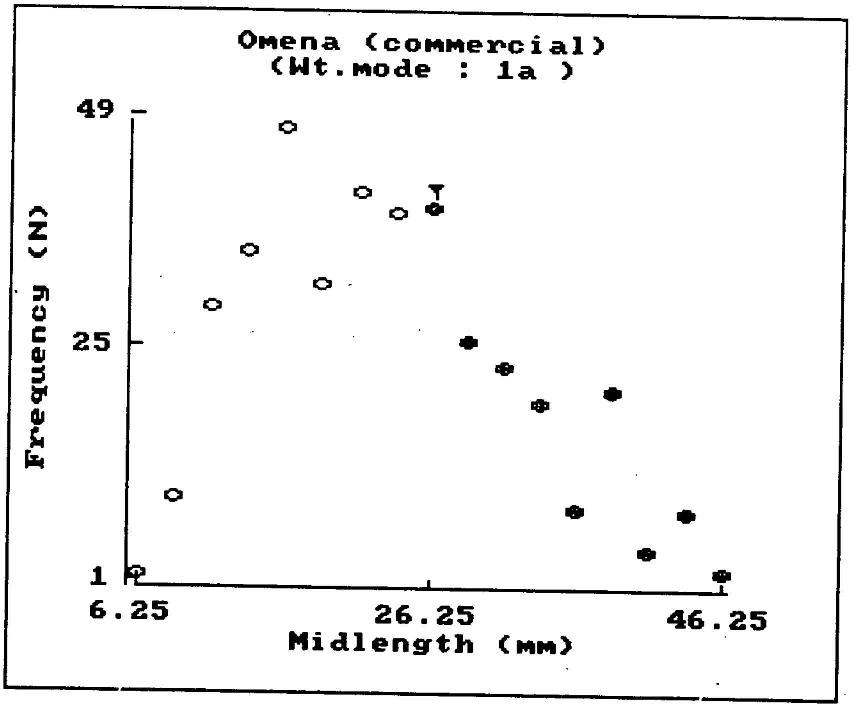
Table A5.1. Length-frequency from Nyanza Gulf used for length-converted catch curve.

Midlength (mm)	Jan.	Feb.	March
6.25		2.5	
8.75	1.0	7.5	2.0
11.25	7.5	15.0	7.5
13.75	12.5	15.0	8.5
16.25	27.5	10.5	10.5
18.75	7.5	14.5	10.5
21.25	14.0	14.0	14.5
23.75	21.0	14.0	5.0
26.25	28.0	7.5	5.0
28.75	9.0	8.5	9.0
31.25	16.0	4.5	3.5
33.75	12.0	5.5	2.5
36.25	4.0	1.5	4.0
38.75	2.0	14.5	5.0
41.25	1.5	3.0	0.5
43.25	1.5	2.0	1.0
46.25	1.0	1.0	

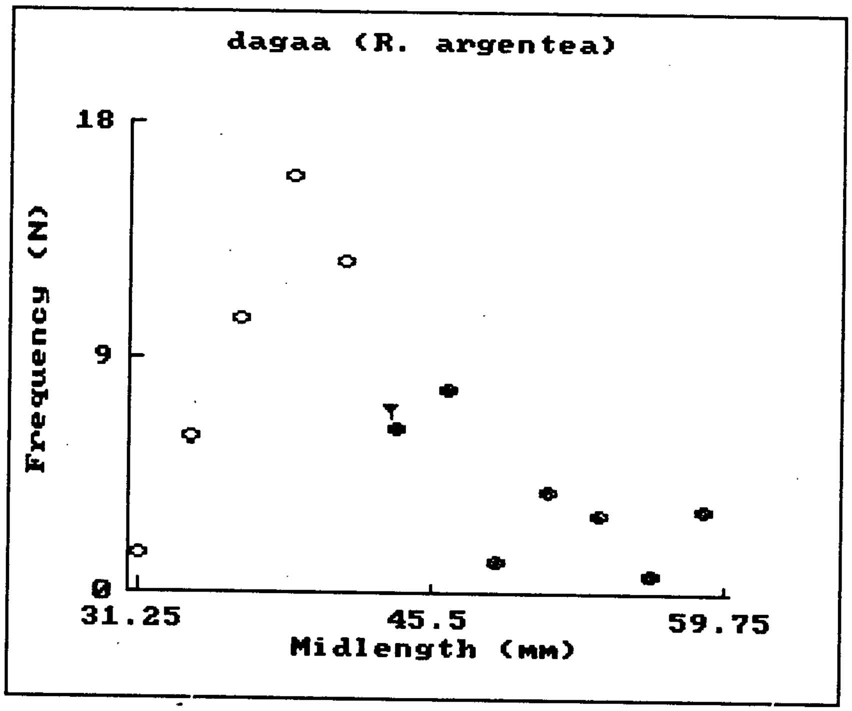
Table A5.2. Length-frequency from open waters used for length-converted catch curve.

Midlength (mm)	February
31.25	1.5
33.75	6.0
36.25	10.5
38.75	16.0
41.25	12.8
43.75	6.3
46.25	7.8
48.75	1.3
51.25	4.0
53.75	3.0
56.25	0.75
58.75	3.3

Data points used in regression
a)Nyanza Gulf



b) Open waters



• Used data points ○ Points not used

Selection of points to be used in the regression (Pauly, 1984c).

1. The first point in the regression should be the point immediately to the right of the highest point on the catch curve plot. Points were chosen by soft ware ELEFAN II.
2. Any point within 5 % of L_∞ should be discarded as these will generate unrealistically high age. 3. One single outlier may be rejected within the region where the straight line is to be fitted.

Appendix 6

Table A6. Annual estimates of total mortality (Z), fishing mortality (F), natural mortality (M) and exploitation rate (E) from age-catch curve, length-converted catch curve and ECOPATH II from Nyanza Gulf and open waters.

	age	len	ecop	Pauly	age	len	age	len
	Z1	Z2	Z3	M	F1	F2	E1	E2
Gulf	13.4	4.0	2.2	3.2	10.2	0.80	0.76	0.20
Open	19.7	4.8	2.2	2.7	17.0	2.10	0.86	0.44

age = estimates from age-catch curve.
len = estimates from length-converted catch curve.
eco = estimate from ECOPATH II model.
Pauly = estimate of M from Pauly equation.
Note in the above table Z = F-M.
M used to estimate F accounted for schooling behaviour (20% reduction). M = 3.2 yr^{-1} in Nyanza Gulf and 2.7 yr^{-1} in open waters.