PROJECT: HABITAT DEPENDENCY AND MARINE GAMEFISH POPULATION DYNAMICS

STUDY I: JUVENILE SNOOK AND TARPON POPULATION ABUNDANCE, DISTRIBUTION, AND SURVIVAL IN PUERTO RICO ESTUARIES

STUDY II: ADULT SNOOK AND TARPON ABUNDANCE, AGE, GROWTH, AND REPRODUCTION IN PUERTO RICO ESTUARIES AND COASTAL WATERS

SPORT FISH RESTORATION

FINAL REPORT
TO THE U.S. FISH AND WILDLIFE SERVICE
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Final Report

State: Puerto Rico **Project Number:** F-33

Agency: Department of Natural and Environmental Resources
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Project Title: Habitat dependency and marine gamefish population dynamics

Study Title: Adult snook and tarpon abundance, age, growth, and reproduction in Puerto Rico estuaries and coastal waters

Study Number: II

Objectives: To estimate the relative abundance of snook and tarpon in two Puerto Rico estuaries. To determine the age, growth, and mortality of snook and tarpon. To establish the annual reproductive cycle, size of sexual maturation, sexual pattern, batch fecundity, and spawning frequency of both species.

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Abstract

Common snook and tarpon are highly esteemed as sportfish and also exploited commercially in Puerto Rico. Evident signs of overfishing have been observed during the past decade. This study presents part of the life history information required to properly manage these fisheries. Relative abundance of juvenile snook and tarpon is high in mangrove-fringed bays and lagoons. Snook adults tend to concentrate close to river mouths and adjacent areas during the spawning season. Growth marks of both species were validated as annual. Marginal increment analysis showed that annuli are formed between April-July for snook and April-June for tarpon. In both species females attained larger sizes and ages than did males. Maximum ages for snook male and female were 16 and 17 years, respectively. The oldest tarpon male and female found during this study were 10 and 21 years, respectively. The largest male snook measured 898 mm FL while the largest female measured 1075 mm FL. Maximum sizes for tarpon were 1020 mm FL for males and 1740 mm FL for females. Snook female have higher total annual mortality rate than males. Tarpon females have lower total annual mortality than males. Sizes and ages at 50% maturity for male and female snook and male and female tarpon, respectively, are 350 mm FL (age 2-3), 610 mm FL (age 5), 785 mm FL (age 5), and 850 mm FL (age 5-6). No evidence of protandric hermaphroditism was found for snook during this study. Snook spawning season is from mid-April to mid-November. The reproductive season of tarpon extends from April to early August. Batch fecundity estimates ranged from 360,000 to

1,643,122 oocytes and from 127,935 to 8,402,788 oocytes for snook and tarpon, respectively. Spawning frequency of female snook averaged one spawning every 18 days (range 11-30 days). Female tarpon averaged one spawning every 30 days (range 15-60 days). Snook preferred spawning sites are mouths of rivers and nearby areas. Tarpon spawn within 2 Km from the shore but specific spawning locations are yet to be determined. Management is needed for both species in Puerto Rico.

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Introduction

Snook

The commom snook, Centropomus undecimalis (Bloch), a member of the family Centropomidae, is a euryhaline and diadromous species inhabiting tropical and subtropical coastal areas in the western Atlantic Ocean (Rivas, 1986). Intolerance to temperatures below 15 °C restricts its normal northern range to central Florida and southern Texas (Shafland and Foote, 1983; Howells et al. 1990). From Texas, the range extends continous southward to Río de Janeiro, Brazil (Rivas, 1986). Common snook also occur in the Caribbean islands having permanent freshwater sources communicating with the sea (Rivas, 1986). Adult common snook are found in rivers, mangrove-fringed bays and estuaries, coastal lagoons connected with the sea, along sandy beaches close to river mouths, and on the outer shores of barrier islands, whereas juveniles are generally restricted to the freshwaters and brackish waters of estuaries and rivers where they live for at least the first year (Marshall, 1958; Volpe, 1959; Fore and Schmidt, 1973; Carvajal, 1975; Alvarez-Lajonchere et al., 1982; Gilmore et al., 1983; Seaman and Collins, 1983). Common snook are non-migratory, but during summer, adults move from rivers and inland waterways where they stay during the winter months, to estuarine and saline waters to spawn (Bruger, 1982; Taylor et al., 1993b). In Florida, female and male snook attain ages of 19 and 13 years respectively (Taylor et al., 1993a). C. undecimalis is a carnivorous species at the top of the food web, its diet being composed mainly of fishes and crustaceans

(Vasconcelos et al., 1980).

Due to its fighting ability and culinary value common snook is recognized as a valuable resource to the recreational fishermen along its geographic range (Marshall, 1958; Tucker et al., 1985; Matlock and Osburn, 1987). In Puerto Rico, snook is considered one of the most important marine shoreline recreational species (Nieves-Figueroa, 1987; ; Berríos et al., 1989; Berríos et al., 1992). On the other hand, common snook is heavily exploited by commercial fishermen in Puerto Rico, mainly during the summer months. The number of large individuals has declined during the last 20 years. No fishing regulations exist concerning this species and conflicts between commercial and recreational fishermen have increased over the past decade. Under similar conditions, snook populations were overfished and severely reduced in Florida during the 1940's and the early 1950's (Bruger, 1982).

Despite the importance and potentially precarious situation of the common snook in Puerto Rico, very little is known of the biology or population dynamics of this species. Although various studies concerning the ecology and natural history of the common snook have been carried out in Florida (Marshall, 1958; Volpe, 1959; Fore and Schmidt, 1973; Thue et al., 1982; Gilmore et al., 1983; Tucker and Campbell, 1988; Taylor et al. 1993a,b) the applicability of these studies to management in Puerto Rico or any other location is not advisable (see Allendorf et al., 1987).

This study was aimed to provide basic information needed for effective development and management of the common snook fishery in Puerto Rico. The objectives of this study were: 1. To estimate the relative abundance of adult common snook in two Puerto Rico estuaries; 2. To determine the age, growth, and total mortality, and; 3. To establish the annual reproductive cycle, size of sexual maturation, sexual pattern, fecundity, and spawning frequency.

Tarpon

The tarpon, _Megalops atlanticus_ (Valenciennes), has a relatively cosmopolitan distribution within the tropical to subtropical Atlantic Ocean. In the western Atlantic, tarpon is found from Nova Scotia to Argentina, but regularly occurs from Virginia's eastern shore to Central Brazil and throughout the Caribbean and the Gulf of Mexico (Wade, 1962; Hildebrand, 1963; de Menezes and Paiva, 1966; Zale and Merrifield, 1989). In the eastern Atlantic, tarpon have been recorded from Ireland (Twomey and Byrne, 1985) to Angola (Roux, 1960; Costa Pereira and Saldanha, 1977). Tarpon have also ben reported from the Pacific Ocean side of the Panama Canal (Hildebrand, 1939), but there is no recorded evidence that a spawning population exists there (Cyr, 1991). Tarpon are found in a variety of habitats ranging from freshwater lakes and rivers to offshore marine waters (Crabtree et al., 1995). Adults are most abundant in estuarine and coastal waters. Juveniles up to a year old live in stagnant pools of various salinities, which may have only intermittant contact with areas of tidal flow (Breeder, 1933; Harrington, 1958; Wade, 1969; Chacón, 1989; Chacón and McLarney, 1992). In Florida, _M. atlanticus_ spawns between May and July (Cyr, 1991; Crabtree et al., 1992). In the eastern Gulf of

Mexico, tarpon seems to make extensive spawning migrations from inshore areas to offshore spawning grounds (Crabtree et al., 1992). Crabtree (1995) presents evidence that relates spawning activity of tarpon with lunar phase. According to Crabtree et al. (1995), in Florida, female and male tarpon can reach an age of 55 and 43 years, respectively. Tarpon is a strictly carnivorous species and feeds primarily on fishes and crustaceans (Zale and Merrifield, 1989).

The tarpon is probably the most popular inshore big-game fish throught its range. In South Florida, parts of Central and South America, and the Caribbean, tarpon support economically important recreational fisheries. Large seasonal aggregations of tarpon form the basis of sportfisheries in North and South Carolina, Florida, Louisiana, Mexico, Belize, Costa Rica, and Venezuela (Wade, 1973). Together with jacks and snooks, tarpon is considered one of the most important marine shoreline recreational species in Puerto Rico (Nieves-Figueroa, 1987; Berríos et al., 1989; Berríos et al., 1992). Due mainly to its large size and the lack of fishing regulations, tarpon is also commercially exploited in Puerto Rico, specially in certain localities where medium-sized and some large individuals tend to aggregate during the spring and summer. Tarpon over approximately 70 pounds, relatively common twenty years ago, are now very scarce.

Critical information needed to understand tarpon's biology and develop management measures to protect this resource is lacking. Again, studies done in Florida or other countries are not necessarily applicable to Puerto Rico. In this study we sought to determine: 1. The relative abundance of adult tarpon in two Puerto Rico estuaries; 2. The age, growth, and total mortality, and; 3. The annual reproductive cycle, size of sexual maturation, fecundity, and spawning frequency.

Materials and Methods

Snook and Tarpon Sampling

Common snook and tarpon were sampled monthly by study personnel from May, 1992 through December, 1995. Additional samples were obtained from study I (North Carolina State University, NCSU) personnel, cooperating recreational and commercial fishermen, and other personnel of the Puerto Rico Department of Natural and Environmental Resources. Gear used to collect the samples consisted of hook and line, trammel nets (one of 300 x 3 m small mesh #18, 44 mm stretched mesh inside wall, #24, 305 mm stretched mesh outside wall, two of 90 x 2 m #177, 56 mm stretched mesh inside wall, #208, 203 mm stretched mesh outside wall), monofilament gillnets of 25, 65, 87, 100, 125, 150, 170 mm stretched mesh, and a beach seine (250 x 2.5 m, #18, 56 mm stretched bag mesh). With the exception of March, a minimum of 50 samples of both species were collected for each month. Sampling sites visited during the study are presented in Figure 1.

Each fish collected was measured to the nearest mm fork length (FL) and total length (TL) and whole weight (W) was taken to the nearest gram. All measurements reported in the text are fork length in mm. Gonads were dissected and weighed to the nearest 0.01 g. One lobe was placed in Davidson's fixative (Yevich and Barszcz, 1981) for histological processing and the other was frozen for fecundity and spawning frequency analyses. Otoliths (sagittae), scales, and dorsal spines were collected from 20 individuals of each species in a preliminary evaluation of their utility in determining age. Sagittal otoliths were found to have marks best suitable for age determination. Both otoliths were extracted, washed, and stored dry in envelopes.

Estimation of Relative Abundance

Study Areas

Relative abundance of snook and tarpon was estimated in Caño Boquerón and Caño Boquilla (Figures 2 and 3). These systems are important for the recreational fishermen of the area and are subjected to relatively intense fishing activity (Carrera and Lugo, 1978). Besides that, habitat degradation has increased substantially in the past few years in both locations.

Caño Boquerón, also known as Laguna Rincón, is located near Boquerón, Cabo Rojo, in southwestern Puerto Rico. The lagoon has an area of 74 ha and is surrounded by red mangrove. A channel 0.1 Km wide connects the lagoon with the Boquerón Bay. A detailed description of the system is given in Negrón (1988). Caño Boquilla is located about 5 Km north of Mayagüez, in western Puerto Rico. It is also bordered by red mangrove and has an area of 25 ha (Carrera and Lugo, 1978). Caño Boquilla has a narrow mouth (maximum width of 15 m) that opens into the La Puente Beach only during the rainy season (May to October). As far as we know, a detailed description of Caño Boquilla has never been done.

Collection Techniques and Data Analysis

Three sampling sites were established in Caño Boquerón covering the perimeter and interior of the lagoon (Figure 2). One trammel net 90 x 2 m #177, 56 mm stretched mesh inside wall, #208, 203 mm stretched mesh outside wall) and three 90 m monofilament gillnets (65, 87, and 170 mm stretched mesh) were deployed at each station at least twice a month between 9:00 am and 1:00 pm. Samples were collected from September, 1994 through December, 1995 (in October, 1994 only one sampling trip was given). Due to the small area and relatively homogeneous habitat, Caño Boquilla was treated as one station. All fish collected were returned to the laboratory for identification, weight, and measurement. Fish relative abundance was expressed as catch per unit effort (CPUE). This index was calculated as the total number of fish captured divided by the total number of sampling hours.

The Margalef index of diversity ($D = (S-1)/\ln N$, where S = number of species in the sample, and N = total number of individuals) was used to summarize simultaneous changes in abundance and species richness (Hook, 1991; Decker and Erman, 1992).

Age, Growth, and Mortality

Generally, the left sagitta was used for age determination. If the left otolith was lost or broken, the right otolith was sectioned. For sectioning, otoliths were mounted on a small card with glue, using a hot glue gun, and sectioned through the core with a 7.2 cm diameter low-concentration diamond blade on a Buehler Isomet low-speed saw. From each otolith, three sections of 0.35-0.45 mm were mounted on glass slides using Pro-Texx mounting medium. Sections were read under a dissecting microscope (10-70X) with trasmitted light. Only sexed fish were used for age determination. Terminology follows that of Wilson et al. (1983).

For snook, otolith width (OW) of a sample of unsectioned otoliths from a wide size range of fish was measured to describe the OW/FL relationship. In sectioned samples, otolith radius (OR) and the radius of each opaque zone was measured from the focus along the anterior axis of the dorsoventral plane adjacent to the sulcus (Taylor, 1993a). Measurements were also made from the distal edge of the outermost opaque zone to the dorsal margin for marginal increment analysis. Total number of opaque zones was noted. All measurements were made with an ocular micrometer. Each otolith was read twice. If readings disagreed, a third reading was made to reconcile the differences. A subsample of 200 otoliths were read by an experienced independent researcher in Florida.

For tarpon, otolith weight (OWt) was measured to describe the OWt/FL relationship. Aging was accomplished by counting the number of opaque zones from the core to the otolith edge (Cyr, 1991). Measurements were done for marginal increment analysis. Each otolith was read twice and a third reading was done if necessary.

Marginal increment analysis was performed to determine if opaque zones were annual and when they are formed. To validate the temporal significance of opaque zones, snook and tarpon were captured and doubled tagged (Floy dorsal anchor tags and a small piece of numbered stainless steel tubing attached to the anal spine in the snooks and to the edge of the lower jaw in the tarpon). All fish were measured (FL to the nearest mm), injected with with oxytetracycline (OTC) at a dosage of 50 mg/kg of body weight, and released into the wild. Most fishes were marked and released at Caño Boquilla.

The von Bertalanffy growth function (VBGF) was fitted to the observed age-length data by using the nonlinear regression fitting method of FISHPARM (Saila et al., 1988). The VBGF (Ricker, 1975) is

$$L_t = L_\infty(1-\exp[-K(t-t_0)]),$$

where L_t = length at age t (mm FL)

L_∞ = asymptote of the growth-in-length curve (mm FL)

K = Brody growth coefficient

t = age of the fish (years)

t_0 = the hypothetical age at which a fish would have zero length

Back-calculation of body length from prior growth marks was made for snook using the Body Proportional Hypothesis (BPH) formula (Francis, 1990 and 1995). This method requires knowledge of the relationship between otlith radius (OR) and FL. The BPH formula is:

$$L_i = [\ (a + b\ O_i)\ /\ (a + b\ OR)]\ L_c,$$

where L_i = length at time of ith growth mark formation (mm FL)

a,b = obtained from the regression of L on OR

O_i = otolith radius at time of ith growth mark formation

OR = otolith radius at time of capture

L_c = length at time of capture (mm FL)

Estimates of instantaneous total annual mortality (Z) were made by anlysis of catch curves (Ricker, 1975). Mortality estimates may be obtained from catch curves if the age distribution is known by plotting the ln of the age frequency on age. The absolute value of the slope of the linear descending right limb of the curve estimates Z. Annual survival rates (S) were determined using the relationship $S = e^{-z}$. Total annual mortality rates (A) were calculated using the formula $A = 1 - S$ (Ricker, 1975).

Linear regression analysis was performed to describe the relationship between FL and TL. Log_{10}-transformed data was used to calculate the regression between weight and FL.

Reproduction

To describe the spawning dynamics of snook and tarpon, gonads were preserved for at least two days, washed for 24 hrs., and then stored in 70% ethanol. A sample from the central portion of one lobe of each gonad was embedded in paraffin, sectioned to 8 µm, stained with haematoxylin and eosin, and mounted for microscopic examination. Five classes of maturity were distinguished based on the histological criteria of Moe (1969), Wallace and Selman (1981), Grier (1981), and Hunter and Macewicz (1985).

The duration of the spawning season was defined by the percentage of each maturity class in each month and by the average gonadosomatic index (GSI) plotted against month of collection. GSI were calculated using the relationship described by de Vlaming et al. (1982),

$$GSI = GW \times 100/FW - GW,$$

where GW = gonad weight (g)

FW = fish weight (g)

To determine the smallest size class in which 50% of individuals were sexually mature (size-at-maturity), a maturity curve of the percent of fish of maturity classes ≥ 2 was developed.

Batch fecundity (F), defined as the number of eggs produced in a single spawning batch (Hunter et al., 1985), was estimated by counting all the oocytes in the most advanced stages of development (hydrated and migratory-nucleou-stage oocytes) in a gonad subsample (Macewicz and Hunter, 1993). Only class 4 (ripe) females were used to construct the oocyte size-frequency distributions. Oocytes were evenly distributed within the ovary in both species. Separation of oocytes was performed following the method of Lowerre-Barbieri and Barbieri (1993). A subsample of 0.1 - 0.2 g, weighed to the nearest 0.1 mg, was removed from each gonad and, using a dissecting microscope, all oocytes ≥ than 0.1 mm ϕ (for snook) and 0.25 mm ϕ (for tarpon) (these minimum sizes were chosen to include all vitellogenic oocytes) were measured to the nearest 0.05 mm. Since the migratory-nucleous-stage oocytes started at about 0.55 mm ϕ (for snook) and at 1.00 mm ϕ (for tarpon) all oocytes larger than 0.55 mm and 1.00 mm were counted. Batch fecundity was calculated as follows:

$$F = n \times GW/Gsw$$

where n = number of oocytes > 0.55 mm (snook); 1.00 mm (tarpon)

GW = gonad weight (g)

Gsw = subsample gonad weight (g)

The relation between female weight and batch fecundity was determined by linear regression analysis.

The oocyte diameter frequency distributions of 30 snook and 11 tarpon gonads were examined in order to determine the minimum spawning frequency for each species. To estimate how many batches of yolked oocytes an ovary contained, all the oocytes larger than 0.25 mm for the snook and 0.35 mm for the tarpon were counted. Histological criteria indicate these are the diameters of oocytes at the onset of vitellogenesis for each species. Assuming that the earliest vitellogenic oocytes will develop during the spawning season, by dividing the total number of oocytes larger than 0.25 mm and 0.35 mm, for snook and tarpon respectively, by their batch fecundity, an estimate of the number of batches is obtained (Macewicz and Hunter, 1993).

Taylor and Grier (1990) reported that Centropomus undecimalis is a protandric hermaphrodite species. In a sample of 1870 snook, they found 2 sex reversing individuals. Gonads from both fish contained ovigerous lamellae and dorsal remnants of ducts containing mature sperm. In this study we examined all snook gonads for evidence of sex change (Sadovy and Shapiro, 1987; Taylor and Grier, 1990). A sample of 200 gonads were examined by an independent researcher experienced in fish sex reversal.

Data were analized using the Basic Fishery Science Programs (Saila et al., 1988), Quattro Pro, and Statistix. The Kolmogorov-Smirnov two-sample test, t-test, and X^2 test were used to compare size frequency distributions, mean size, and sex ratios, respectively (Sokal and Rolhf, 1981).

Results

Snook Sampling

A total of 994 common snook were collected between May, 1992 and December, 1995. Size-frequency distribution of all fish collected during this study is shown in Figure 4. Size ranged from 97 to 1075 (mean=505; sd=195.4) mm FL. Size-frequency distributions of males and females are significantly different (Kolmogorov-Smirnov, $p<0.01$) (Figure 5). A total of 828 (83%) individuals were sexed (564 males and 264 females). Female snook attained larger sizes than did males. Males ranged from 224 to 898 (mean=426; sd=122.6) mm FL and females from 345 to 1075 (mean=707; sd=160.4) mm FL. These results are similar to the findings reported by Taylor et al. (1993a) in Florida. In Puerto Rico, recreational fishermen usually harvest small and medium-size snook whereas the majority of large fish are taken by commercial fishermen with beach seines and special gillnets.

Tarpon Sampling

Number of tarpon collected totaled 993. Size-frequency distribution of tarpon is presented in Figure 6. Size ranged from 124 to 1740 (mean=548; sd=235.5) mm FL. Size-frequency distributions are different for males and females (Kolmogorov-Smirnov, $p<0.01$) (Figure 7). A total of 251 (25%) individuals were sexed (118 males and 133 females). About 85% of all tarpon sampled were undifferentiated or inmature individuals. Female tarpon also attained larger sizes than males. Similar results were reported in Florida by Crabtree et al. (1995). The lack of males larger than 1020 mm FL in our samples is probably due to the small sample size of large tarpon collected in this study. Males ranged from 485 to 1020 (mean=826; sd=99.4) mm FL and females from 460 to 1740 (mean=825; sd=266.5) mm FL. Most tarpon over 1100 mm FL were collected by commercial fishermen using large beach seines. In general, tarpon sampling presented several difficult logistical problems whereas snook samples were relatively easy to obtain.

Estimation of Relative Abundance

Caño Boquerón

A total of 621 individuals of 37 species were collected at Caño Boquerón (Table 1, Figure 8). Seven species (Archosargus rhomboidalis, Bairdiella ronchus, Centropomus ensiferus, Centropomus undecimalis, Elops saurus, Eugerres brasilianus, and Megalops atlanticus, represented 62% of the total number of individuals. During the study, the most numerous species in the sampling was Megalops atlanticus (N=78), constituting 12.6% of the total sample. Centropomus undecimalis (N=40) represented 6.4%. When separated by month, the number of individuals was too small to permit any useful comparison (Table 2).

Table 3 summarizes data gathered by station. Station 2, adjacent to the Wildlife Refuge showed the maximum abundance and species richness, while Station 1, closer to the channel connecting with the Boquerón Bay, had the lowest values in both parameters.

During 1995, CPUE values for all stations combined ranged from 1.94 fish/hour in March to 0.13 fish/hour in November. Abundance stayed relatively constant from January to September, then dropped abruptly in October and remained very low (less than 0.3 fish/hour) until December (Table 4; Figure 9). Diversity (stations pooled) varied greatly by month, ranging from 0 in November to 5.25 in February (Table 4; Figure 9). However, a trend towards lower values progressing from January to December is apparent (Figure 9).

Size-frequency distributions of the 7 most abundant species are shown in Figures 10-13. Tarpon collected in Caño Boquerón ranged in size from 345 to 1000 (mean=509; sd=117.3) mm FL. Snook sizes ranged from 227 to 938 (mean=442; sd=174.2) mm FL. Large tarpon, probably over 50 pounds, were seen several times close to station 2 but never captured. Several ripe snook females were captured at stations 1 and 2 during the sampling period.

Caño Boquilla

During the 12-month collection period, 567 individuals of 14 species were collected at Caño Boquilla (Table 5; Figure 14). Three species (Centropomus undecimalis, Megalops atlanticus, and Tilapia mossambica, represented 88% of the total number of individuals. The most abundant species in the sampling was Tilapia mossambica (N=303), contituting 53.4% of the total sample. The second most abundant species was Megalops atlanticus (N=164), with 28.9%

Centropomus undecimalis (N=34), represented 6.0% of the total sample.

CPUE values for tarpon (January to December, 1995) showed a peak during January and December, reaching their lowest values in February and March (Table 6). CPUE values for all fish combined ranged from 6.88 fish/hour in January to 1.25 fish/hour in July. Abundance varied greatly showing no clear seasonal pattern. However, highest values were also observed in January and December (Table 7, Figure 15). Diversity ranged from 0.71 in May to 2.18 in October, with a defined peak in September-October (Table 7; Figure 15).

Size-frequency distributions of the 3 most abundant species are presented in Figures 16-17. In Caño Boquilla, tarpon ranged in size from 283 to 780 (mean=385; sd=71.4) mm FL. Range for snook was from 271 to 487 (mean=340; sd=39.7) mm FL. According to local fishermen, large snook ocassionally enter Boquilla, mainly after heavy rains but none were seen or captured during this study. Apparently, large tarpon very seldom enter Boquilla (only one large individual was seen between May, 1994 to December, 1995).

Age, Growth, and Mortality

Snook

Of 994 common snook collected during this study, 825 otoliths were prepared for examination. Opaque and translucent zones were detectable in most otolith sections. When zones lacked sufficient definition for focus-to-opaque zone measurements, the otoliths were not used for age determination. Otolith radius showed a linear relationship with FL (males, N=303, r^2=0.82; females, N=211, r^2=0.80) (Figure 18). A total of 514 (303 males and 211 females) otoliths sections were used to count growth rings and for focus-to-ring measurements. Otolith width and FL (Figure 19) were linearly related (N=147; r^2=0.97; sexes combined).

Mean marginal increments were plotted for ages II-V and ages VI-XI combined (Table 8; Figure 20). These data indicate that the growth marks are deposited annually. For annuli II-V, opaque zones are formed between about April and June. For annuli VI-XI, the minimum marginal increments occur between May and July.

During the field validation study, April to August, 1994, 127 snook ranging 312 - 731 mm FL were double-tagged, injected with OTC, and released. Most fish were tagged and released in Caño Boquilla. A few tagged snook were seen by a diver several months after we finished tagging fish in Caño Boquilla. However, from 44 recapture trips done between January to December, 1995, no tagged snook were recaptured.

The oldest, and largest, snook found during this study was a 17 year old, 1075 mm FL (15.5 Kg) female. The oldest males (2) were 16 years old and measured 765 and 791 mm FL. The largest male was 898 mm FL and 13 years old.

Tables 9 and 10 show the average observed, back-calculated, and predicted sizes at age for male and female snook, respectively. Observed and predicted (von Bertalanffy) growth curves by sex are presented in Figure 21. Figures 22 and 23 show the observed, back-calculated, and predicted growth curves for males and females, respectively. In this study we found no snook males younger than age two (mean=289 mm FL) (Table 9). The youngest clearly defined female was three years old (mean=411 mm FL) (Table 10). Significant differences in mean observed lengths at age were found between the sexes from ages 3-14 (t-test; $P<0.01$) (Tables 9 and 10; Figure 21). Females are larger than males for all ages. Observed lengths at age showed a good fit to the von Bertalanffy growth model for both sexes (males $r^2=0.97$; females $r^2=0.98$) (Table 11; Figure 21). The mean back-calculated sizes for males are significantly smaller than the mean back-calculated sizes for females for all ages (t-test; $P<0.05$) (Tables 9 and 10; Figure 24). Comparison of back-calculated fork lengths (mm) at age for snook from Florida and this study is presented in Table 12.

Estimated growth model parameters are given in Table 11. Overall, females grew at a sligtly slower rate ($K=0.16$) than did males ($K=0.18$). Theoretical maximum sizes were larger for females ($L_\infty=1103$ mm FL) than for males (L_∞ =886 mm FL) (Table 11).

Instantaneous total annual mortality rate (Z) estimate of female snook ($Z_{female}=0.67$) was higher than that of male snook ($Z_{male}=$ 0.34) (Table 13). Males were completely recruited to the fishery at age 4 and females at age 7. Estimates of Z were based on fish ages 4-14 for males and ages 7-11 for females (Figures 25 and 26, respectively). Total annual mortality rates (A), was 0.49 ($S=0.51$) for females and 0.29 ($S=0.71$) for males (Table 13).

Relationships of TL:FL and FL:Wt were established for each sex. For males: $TL = 17.63 + 1.0372\ FL$ ($r^2=0.99$; $N=553$); for females

TL = 22.26 + 1.0291 FL (r^2=0.99; N=264). For males: Log FL = 1.713 + 0.312 Log Wt (r^2=0.96; N=526); for females: Log FL = 1.743 + 0.305 Log Wt (r^2=0.98; N=249) (Figures 27 and 28 for males and females, respectively).

Tarpon

Of 993 tarpon collected during this study, 801 otoliths were sectioned and mounted for examination. Tarpon otolith reading was difficult. Although growth marks were detectable in most otolith sections, the majority of them were not clear enough for focus-to-opaque zone measurements. The relationship between otolith radius and FL was very poor (r^2=0.25; sexes combined). Back-calculation was, therefore, not performed. Aging was accomplished by counting the number of growth marks. A total of 215 (105 males and 110 females) otoliths sections were used to count growth marks. Otolith weight and FL (Figure 29) were linearly related (N=215; r^2=0.93; sexes combined).

Due to the low sample size in some months, mean marginal increments were plotted against months for ages II - IX combined. Our data indicate that tarpon growth marks are formed once a year, between about April and June (Table 14; Figure 30).

During the snook-tarpon field validation study, 67 tarpon ranging 285 - 575 mm FL were double-tagged, injected with OTC, and released. Most fish were tagged and released in Caño Boquilla. From 44 recapture trips done between January to December 1995, three (4.5%) tagged tarpon were recaptured at Caño Boquilla after being at liberty for 302 - 496 days (Table 15). At the time of recapture, the 3 fish appeared to be in good condition. One growth mark was deposited between the OTC mark and the edge of the otolith for the two fish at liberty for more than 365 days. Growth rate ranged between 0.09 mm/day to 0.26 mm/day (mean=0.16 mm/day). Only the dorsal anchor tags were retained by the recaptured fish.

The oldest, and largest, tarpon collected during this study was a 21 year old, 1740 mm FL (56.3 Kg) female. The oldest, and also largest, male collected was only 10 years old and measured 1020 mm FL (8.2 Kg). Based on sizes attained by males reported in the literature, it is very probable that male tarpon can grow much older and larger in Puerto Rico than the numbers reported here. Our low values are probably a consequence of the low sample size of tarpon larger than about 1100 mm FL obtained during this study.

Tables 16 and 17 show the average observed and predicted sizes at age for male and female tarpon, respectively. Observed and predicted (von Bertalanffy) growth curves by sex are presented in Figure 31. The youngest male collected was age two (mean=493 mm FL) (Table 16). The youngest female was also two years old (mean=468 mm FL) (Table 17). Significant differences in mean observed lengths at age were found for ages 6-10, females being larger than males (t-test; $P<0.05$) (Tables 16 and 17; Figure 31). Observed lengths at age showed a good fit to the von Bertalanffy growth model for both sexes (males $r^2=0.99$; females $r^2=0.97$) (Table 18; Figure 31).

Estimated parameters of the von Bertalanffy function are given in Table 18. Growth coefficient of males (K=0.16) was larger than that of females (K=0.09). Theoretical maximum sizes were larger for females (L_∞=1,850 mm FL) than for males (L_∞=1,173 mm FL).

Instantaneous total annual mortality rate (Z) estimates of male tarpon (Z_{male}=0.79) were higher than those of female tarpon (Z_{female}= 0.40) (Table 19). Both sexes were completely recruited to the fishery at age 6. Estimates of Z were based on fish ages 6-10 for males and ages 6-12 for females (Figures 32 and 33, respectively). Total annual mortality rates (A), was 0.55 (S=0.45) for males and 0.33 (S=0.67) for females (Table 19).

Relationships of TL:FL and FL:Wt were established for males and females separately. For males: TL = 3.94 + 1.1293 FL (r^2=0.96; N=117); for females: TL = 19.91 + 1.1029 FL (r^2=0.99; N=130). For males: Log FL = 1.593 + 0.351 Log Wt (r^2=0.94; N=117); for females: Log FL = 1.656 + 0.332 L og Wt (r^2=0.97; N=129) (Figures 34 and 35 for males and females, respectively).

Reproduction

Snook

The spawning season for snook is protracted, extending approximately from April to early November (Tables 20 and 21; Figure 36). GSI suggests that increased reproductive activity may occur in May-June and in October (Table 22 ; Figure 36). Maximum oocyte diameters and the presence of eggs with yolk vesicles, globules, and migrating nuclei confirmed the extension of the protracted reproductive season. All individuals were classified according to five maturity classes (Tables 23 and 24).

Male snook mature earlier than female snook. The smallest mature male collected measured 231 mm FL (age 1). The smallest mature female measured 467 mm FL (age 3). On the basis of 50% maturity, male snook are mature at 350 mm FL (age 2-3) and female snook at 610 mm FL (age 5). All males were mature at about 610 mm FL (age 6) and females at about 760 mm FL (age 6-7) (Tables 25 and 26; Figures 37 and 38).

Batch fecundity estimates were performed for 30 ripe female snook. Batch fecundity varied markedly between fish of similar weight (Table 27; Figure 39). The relation between batch fecundity (F) and fish weight (W,g) was best described by the equation $F = 3650.74 + 0.0056W$ ($r^2=0.65$). Estimates of F ranged from 360,000 to 1,643,122 eggs for fish ranging in size from 730 mm FL (5221 g) to 1012 mm FL (13,874 g).

Oocyte size-frequency distributions of the snook females utilized for batch fecund ity estimation are shown in Figures 40-54. For each female, by dividing the total number of oocytes larger than 0.25 mm ϕ by its batch fecundity, assuming that most of the advanced-yolked oocytes are spawned in a single batch, estimates ranging from 3 batches for fish # 539 (captured Oct. 2, 1993) to 17 batches for fish # 723 (captured May, 13, 1994) were obtained (Table 27; Figures 48a and 49b). The average number of batches for females collected in May was 10.4. Since we do not have estimates from April (begining of the reproductive season) and considering that the spawning season lasts roughly until October, by dividing 10.4 batches/6 months, a estimate of 1.7 spawnings per month or 1 spawning event about every 18 days (range = 1 spawning every 11 to 30 days) was obtained.

No evidence for protandric hermaphroditism was found in 828 gonads examined histologically. Spermatogenic cysts were found in one female gonad (fish # 158).

The overall sex ratio was 2.1 M : 1.0 F (Table 28), significantly different from the expected 1 M :1 F ($X^{2;}$, $P<0.05$) Below 560 mm FL, males predominate at a ratio of 8.8 M : 1.0 F. On the other hand, females predominate over 760 mm FL at a ratio of 1.0 M : 5.0 F.

Tarpon

Tarpon reproductive season extends approximately from March to about early August, as suggested by the GSI and the percentage of ripe females collected by month (Tables 29 and 30; Figure 55). GSI suggests that increased reproductive activity occur in April-May (Table 31; Figure 55). Maximum oocyte diameters and the presence of eggs with yolk vesicles and globules confirmed the duration of the spawning season. Both sexes were classified according to five maturity classes (Tables 23 and 24).

Male and female tarpon mature at about the same size and age (males=770 mm FL, age 5; females=780 mm FL, age 5). On the basis of 50% maturity, male tarpon are mature at about 785 mm FL (age 5) and female tarpon at 850 mm FL (age 5-6). All males were mature at about 950 mm FL (age 9) and females at about 1000 mm FL (age 8) (Tables 32 and 33; Figures 56 and 57).

Batch fecundity was estimated for 11 ripe female tarpon (Table

34). Figure 58 shows the relationship between batch fecundity (F) and fish weight (W,g). The equation is $F = 8432.26 + 0.0058W$ ($r^2=0.89$). Estimates of F ranged from 127,935 to 8,402,788 eggs for fish ranging in size from 974 mm FL (9676 g) to 1740 mm FL (56,296 g).

Figures 59-64 show the oocyte size-frequency distributions of the 11 eleven tarpon females utilized for batch fecundity analysis. For each female, by dividing the total number of oocytes larger than 0.35 mm ϕ by its batch fecundity, assuming that most of the advanced-yolked oocytes are spawned in a single batch, we obtained estimates ranging from 1 batch for fish # 853 (collected Jun. 21, 1995) to 8 batches for fish # 595 (collected April 29, 1994) (Table 34; Figures 61a and 64). The average number of batches for females collected in April was 3.5. Since we do not have estimates from March (begining of the spawning season) and knowing that the spawning season lasts roughly until July, by dividing 3.5 batches/4 months, a estimate of 0.9 batch every 30 days, or about one spawning per month (range = 1 spawning every 15 to 60 days) was obtained.

The overall sex ratio was 1.0 M : 1.1 F (Table 35), not significantly different from the expected 1:1 (X^2; $P>0.05$). Below 750 mm FL, females predominate at a ratio of 1.0 M : 4.2 F. In size classes between 800 and 1050 mm FL males predominate (1.0 M : 0.6 F). All fish collected larger than 1020 mm FL were females.

Discussion

Snook and Tarpon Sampling

We obtained snook and tarpon samples from fishery-independent and fishery-dependent sources, covering the entire size range for both species. Most small and medium-sized fish were collected by project personnel, whereas a significant proportion of the larger fish came from the commercial fishery. Few fishes were collected by recreational fishermen. One limitation of the data obtained from commercial fisheries is that size frequency distributions are inherently biased by the sampling methods utilized. The same principle applies to the recreational fishery. In any case, it was difficult to obtain the minimum of 50 monthly samples of each species proposed for this study. Many sampling trips and several contracts with commercial fishermen were necessary to accomplish our objectives. This is the first study performed in Puerto Rico concerning the basic biology of these two very important gamefish species. We believe our data closely reflects the actual composition of the snook and tarpon local populations, and it is of great importance to understand the fishery trends of these species in Puerto Rico.

One aspect of the sampling worth noting is the absence of large male tarpon. As mentioned before, we think this was mainly the result of the low sample size of tarpon over 1100 mm FL. A possible alternative explanation would be a sex-related spatial segregation, since most tarpon over 1100 mm FL were collected by commercial fishermen along sandy beaches using beach seines. Maximum sizes reported here for male and female snook and female tarpon are similar to those reported from Florida and Venezuela (Osorio and González, 1986; Taylor et al., 1993a; Crabtree et al., 1995).

Estimation of Relative Abundance

Caño Boquerón

We observed temporal differences in species relative abundance and diversity in Caño Boquerón. In addition, fishes were not spread evenly throughout the area, since differences in both, relative abundance and diversity between stations were noted. Observed differences were due in part to habitat variation between stations. Maximum abundance and species richness were generally observed at Station 2. The most likely mechanism for this distribution pattern is the presence of freshwater coming from the adjacent Wildlife Refuge. The periodic input of freshwater lowers salinity levels relative to other areas. Since hypersaline conditions depress species richness (Gunter, 1967), this runoff is probably important in maintaining higher abundance and diversity in Station 2. A second factor, probably related to freshwater input, affecting this distribution pattern, might be the apparent higher heterogeneity of Station 2 due to the presence of oyster beds and seagrass beds not present at Station 3.

Some of the principal species sampled (i.e. Archosargus rhomboidalis, Bairdiella ronchus, Centropomus ensiferus, and Eugerres brasilianus), had ripe gonads during the spring and summer months, suggesting that movements associated with the breeding season must have influence on the seasonal changes observed in relative abundance and diversity. As far as we know, no information on abundance had been obtained prior to this study. Therefore, we do not know if earlier conditions fit the pattern of seasonal changes in the relative abundance we observed during 1995.

Numbers of snook and tarpon sampled by month are too small to permit any useful comparison. Most snook and tarpon collected were juveniles. Several snook females with gonads in advanced stage of development were collected in Caño Boquerón, suggesting the possibility that some spawning activity may occur there. Adult tarpon collected in the same area during the spawning season showed no signs of gonad development. For both snook and tarpon, juveniles were found in the three stations, while adults were only present in stations 1 and 2.

In general, conditions in Caño Boquerón provide nursery grounds for juveniles of several marine species (including important gamefishes such as snooks, tarpon, jacks, bonefish, ladyfish, and barracudas) as well as habitat for adult fish of species normally associated with estuaries and mangrove-fringed shores. Alterations of the mangrove habitat will eventually result in changes in the fish populations which inhabit nearby reefs and coastal waters. Enclosed nursery areas, such as mangroves, are important as potential places to detect early signs of population changes (Austin, 1971).

Caño Boquilla

The relatively low number of species and high number of individuals of the principal species found in Caño Boquilla, when compared with Caño Boquerón, is probably a result of the differences in habitat complexity between the two areas. Caño Boquilla does not have connection with the sea during the dry season and lacks the mixed seagrass beds and algal flats present in Caño Boquerón.

Relative abundance and diversity indexes varied greatly in Caño Boquilla, probably due to the wide changes in salinity and temperature associated with freshwater runoff and strong tidal influence. The fact that Caño Boquilla has a narrow and short channel connecting with the sea only during the rainy season (roughly between May and October), undoubtedly has an effect on the fish assemblages present at a given time.

Caño Boquilla seems to be a critical location for juvenile tarpon in southwestern Puerto Rico. Among the 22 sampling sites we visited during this study, Caño Boquilla ranked number one in young tarpon. On the other hand, the coastal waters adjacent to it are one of the few areas were large tarpon are seen and fished with certain frequency. Like Caño Boquerón, Caño Boquilla has suffered, and is suffering, significant habitat deterioration. Both areas are critical for the survival of snook, tarpon, and other important species and must be protected in order to develop and mantain a healthy recreational fishery in Puerto Rico.

Age, Growth, and Mortality

Snook

Snook sagittal otolith sections showed hyaline and opaque bands clear enough to be used in age determination. Marginal increment analysis supported the hypothesis that the growth marks are formed annually between April and July. The possible cause, or causes, responsible for the formation of the growth marks remains unknown. During the field validation study 127 snook were tagged, injected, and released at Caño Boquilla, but no marked fish were obtained during the 12-month recapture sampling period. A local diver saw several tagged snook a few months after we finished the tagging job. We suspect most of the marked fish moved out to open areas along the coast, where recapture efforts were much less intense. Direct validation performed in Florida using OTC-injected fish, in addition to marginal increment analysis, also showed that growth marks in snook otoliths are true annuli (Taylor et al., 1993a).

Snook are relatively slow growing and long-lived. Males and females attaining ages of 16 and 17 years, respectively. Females reach larger sizes than males; the largest female collected measured 1,075 mm FL whereas the largest male measured 898 mm FL. In Puerto Rico, the maximum size reported for the common snook is 1,240 mm FL, suggesting that ages probably over 20 years can be reached by this species. Taylor (1993a) reported that in Florida males live 13 years and reach 925 mm FL and females live 19 years and reach 1105 mm FL.

Male snook grow at a slightly faster rate than females, although females are larger than males for all ages. Similar results were found by Taylor et al. (1993a) with the exception that for ages 1 and 2 males were larger than females.

Observed lengths-at-age were higher than back-calculated lengths for all ages in both sexes, except for age 3 in females. (Tables 9 and 10). The higher observed lengths are generally due to additional growth between last growth mark formation and time of capture.

In this study, the back-calculated size for age one snook, sexes combined, was 205 mm FL, which is 42 mm greater than Volpe's (1959) estimate of 163 mm FL. Thue et al. (1982) reported a back-calculated size of 375 mm FL at age one, which is 170 mm FL greater than our estimate (Table 12). These differences may be explained, at least partially, by the aging method utilized by these authors. Volpe (1959) used whole otoliths and Thue et al. (1982) used acetate impressions of scales (Taylor, 1993a; Ojeda, 1994). In our case, sectioned otoliths were found to be best suited for age determination. Taylor et al. (1993a), using sectioned otoliths, reported a back-calculated size of 216 mm FL at age one, much closer to our estimate of 205 mm FL (Table 12). Gear selectivity is probably an important factor explaining the differences in age between previous studies (Volpe, 1959; Thue et al., 1982) and the study realized by Taylor et al. (1993a) and this study. Hook and line was the principal sampling gear used in the older studies whereas seines and trammel nets, which are less selective, were used in Taylor et al. (1993a) and this study.

Growth rate of young-of-the-year (YOY) estimated from daily rings was 0.4 - 0.5 mm SL/day (study I, this report). This result is in agreement with growth rates calculated from annual marks in otoliths (this study). The average back-calculated sizes for age one snook were 175, 248, and 205 mm FL for males, females, and sexes combined, respectively (Table 12) which translates into daily growth rates of 0.50 mm/day for males, 0.70 mm/day for females, and 0.56 mm/day for sexes combined. Taylor et al. (1993a) found that size for YOY snook ranged 144-268 mm FL (mean=184 mm FL). All fish had already formed the first annulus on their otoliths. The estimated growth rates of these fish ranged 0.43-0.86 mm/day (mean=0.72 mm/day). These authors, based on daily ring counts of three snook of 219, 285, and 290 mm FL, found growth rates to 0.74, 0.71, and 0.68 mm/day, respectively. Growth rates ranging 0.5-1.2 mm SL/day were reported by McMichael et al. (1989) from Tampa Bay.

Total annual mortality rate (A) was higher for females than for males. This difference may be partially due to the probably very high fishing mortality rates within estuaries and the size sexual dimorphism, which renders females more susceptible to be captured than males. In Florida, annual mortality rate was reported to be greater for males than for females. Taylor et al. (1993a) proposed as a possible explanation the selectivity caused by the current size limits in the fishery. The upper size limit established (34 in.; 860 mm) allows capture of male snook throughout their entire size range. While a significant number of large females can avoid the fishery, less than 1% of the male population attains the 34 in. size limit. Therefore, fishing drastically impacts their already reduced numbers (Taylor et al., 1993a).

Tarpon

Tarpon otolith reading was difficult, mainly for fish older than 6-7 years where growth marks tend to be closely spaced and in many cases weakly defined. Many of the problems we faced with tarpon otoliths were also encountered and discussed by Cyr (1991). The relationship between otolith radius and fork length was very poor (r^2=0.25), but the otolith weight was strongly related (r^2=0.93) to fish length, indicating a good relationship between body length and otolith size. Although back-calculation of length from prior growth marks could not be performed, aging was possible by counting the number of opaque bands in otolith sections.

Growth marks in tarpon were validated as annual in this study, both by marginal increment analysis and by marking the otoliths with OTC. Annuli formation was validated for ages two to nine years but the possibility of bi- or multiannual growth bands (Deelder, 1981; Lee et al., 1983) for older fish needs further investigation (see Cyr, 1991). The causes for the formation of the annual bands are not known and also needs to be addressed.

Tarpon reach their large size growing slowly and are long-lived (Cyr, 1991). It has been pointed out that a significant negative correlation exists between growth rate and maximum size for most fish (Adams, 1980; Moreau, 1987). We found that male tarpon grow at a faster rate (K=0.16) than females (K=0.09). A similar trend was reported by Crabtree et al. (1995). L_∞ values for female tarpon in Puerto Rico (L_∞=1,850 mm FL) was found to be similar to the value (L_∞=1,818 mm FL) reported by Crabtree et al. (1995) in Florida. In this study the oldest and largest male attained only 10 years of age and 1020 mm FL. The oldest and also largest female was 21 years old and measured 1,740 mm FL. Much greater maximum sizes and ages have been reported for males in Florida and Brazil (de Menezes and Paiva, 1966; Crabtree et al., 1995). As mentioned earlier, we think this result is an artifact due to the low sample size of large tarpon we were able to collect during this study. In any case, it was unexpected that all fish larger than 1020 mm FL (N=22) were females. Crabtree et al. (1995) found that males reach 43 years and 1,884 mm FL and females 55 years and 2,045 mm FL. It is worth noting that although it seems possible that tarpon in Puerto Rico can attain maximum sizes and ages much greater than the ones we found in this study, our estimate of 21 years for a 1740 mm FL female is within the range for average observed length-at-age reported by Crabtree et al. (1995). According to data presented by these authors the variability in length-at-age exhibited by both sexes is very high (as an example, a female measuring between 1,656 and 1,684 mm FL can be 17 to 49 years old; a male measuring 1,448 to 1,480 mm FL can be 10 to 41 years old). Unfortunately, we lacked the samples necessary to confirm if the same pattern exists for tarpon in

Puerto Rico. A captive tarpon placed in the John G. Shedd Aquarium in Chicago in 1935 was still alive in 1994, having by then an age of 59 years (see Crabtree et al., 1995). The IGFA (1990) record for tarpon was 123.8 Kg. Unconfirmed reports offered by commercial fishermen establish the maximum size in Puerto Rico around 100 Kg. Therefore the potential exists for ages well in excess of 50 years (Cyr, 1991).

The average predicted sizes for age one tarpon were 379 and 261 mm FL for males and females, respectively (Tables 16 and 17) which translates into daily growth rates of 1.04 mm/day for males and 0.72 mm/day for females. Study I data (this report) suggest that tarpon juveniles 39 - 133 mm SL have an average growth rate of 0.98 mm SL/day. These growth rates of YOY tarpon are lower than the rates of 1.16 and 1.10 mm/day for males and females, respectively, estimated from Crabtree et al. (1995, Table 4) data. Growth rates estimated from otoliths of unsexed fish marked during this study ranged from 0.09 to 0.26 mm/day (N=3; mean=0.16 mm/day; age=2 years) (Table 15). It can not be ruled out that the OTC injection or any other aspect of the tagging procedure had a negative effect on the growth rates of the marked fish, principally during the period following marking. Besides that, habitat degradation observed in Caño Boquilla is probably responsible, at least partially, for the low growth rates of fish living there. In this study, tarpon growth rate estimates for the second year of life were 0.32 and 0.39 mm/day for males and females, respectively. In Florida, the estimated growth rates were 0.41 and 0.42 mm/day for males and females of the same age (from Crabtree et al., 1995,

Table 4).

Tarpon total annual mortality was higher for males than for females. This result should be interpreted with caution since our growth estimates for male tarpon are probably bias due to the low sample size problems mentioned earlier. On the other hand, information is needed concerning migration patterns, patterns of spatial distribution during and outside the spawning season, or any other factor that could be sex-related and would explain, at least in part, the observed results. As far as we know, no other estimates of total annual mortality have been published for adult tarpon.

Reproduction

Snook

Based on the GSIs, the seasonal distribution of maturity classes, and observations of oocyte development in the ovaries, the reproductive season for snook in Puerto Rico was found to be protracted, extending from April to November. GSI suggests increased spawning activity in May-June and October. Some spawning probably takes place every month as suggested by the presence of small juveniles and post-larvae collected by study I (this project) personnel through most part of the year.

In Venezuela (Osorio and González, 1986) showed that spawning takes place between April and September, with a peak in September. Carvajal (1975) reported a protracted spawning season in Mexico extending from April to September, with peaks in May and September. Taylor et al. (1993a) found that Florida east coast snook began to spawn in May, about a month later than west coast snook, and continued to spawn into October, about a month longer than west coast fish. These authors presented a summary of the results of previous studies carried out in Florida. Based on observations of running-ripe male snook, Fore and Schmidt (1973) reported the spawning season in SW Florida to be from May to about the middle of November. Gilmore et al. (1983) suggested a protracted spawning season from April to December along the east-central coast of Florida based on back-calculated hatching dates of recruiting juveniles, and noted two peaks in spawning activity (June-July and August to October). Tucker and Campbell (1988) showed that spawning along the east-central coast of Florida ocurred from early May until early October. McMichael et al. (1989) reported that the spawning season in Tampa Bay was from April to December based on back-calculated dates from juvenile otoliths. According to Taylor et al. (1993a) these temporal variations are related to natural changes in physical parameters, especially temperature, which appears to mediate spawning (Gilmore et al., 1983; Bye, 1984). Garrat (1985) proposed that while temperature may be a major limiting factor in temperate waters, photoperiod is probably more important in terms of the onset of spawning in warmer waters.

Our estimates of size and age at maturity (50% of males and females were mature at 350 (age 2) and 610 (age 5) mm FL, respectively) are similar to the values reported by Taylor et al. (1993a) for the east coast of Florida (50% of males and females were mature at 379 (age 2.3) and 644 (age 3.7) mm FL, respectively. Osorio and González (1986) estimated (50% criteria) that in Venezuela male snook mature at 520 mm and females at 600 mm TL. It should be noted, however, that comparisons between maturity studies should be interpreted with caution, since different observers, methods, and sampling times may have a significant effect on maturity estimates (Hunter et al., 1992). Considering that length at sexual maturity is related to exploited fish populations structure, we estimated (from our size frequency distributions for both sexes) that about 30% of males and 29% of females are recruited to the fishery before attaining sexual maturity. These figures suggest that recruitment overfishing of snook is probably not very intense in Puerto Rico. In any case, management criteria based on these estimates should be conservative, since they merely represent the length class in which 50% of the individuals are mature.

Batch fecundity was determined by analysis of oocyte size frequency distribution. Oocytes in all stages of development, as expected in species with an extended spawning season, were present in the mature ovaries of all snook females examined. Our estimates of batch fecundity ranged from 360,000 to 1,643,122 eggs per spawning event. The lack of published batch fecundity estimates from other locations precluded any comparison.

The snook spawning frequency estimated in this study averaged 1 spawning about every 18 days (range of 1 spawning every 11 to 30 days). Taylor et al. (1993a), using the hydrated oocyte method, found that the spawning frequency for snook in Tampa Bay is 1 spawning about every 6 days. The hydrate oocyte method is considered more accurate than the oocyte-frequency method but it requires discrete, single day samples of females containing hydrated eggs. Because of the small numbers of running-ripe females usually collected in a single day, we could not use the method utilized by Taylor et al. (1993a).

Taylor and Grier (1990) proposed that the snook is a protandric hermaphrodite species based on the gonads of two fish containing ovigerous lamellae and dorsal remnants of ducts containing mature sperm. We could not find any conclusive evidence of sex reversal in the snook after examination of 828 gonads, of which, 200 were examined by a recognized expert in the subject of sex reversal in fishes (see Acknowledgements). Spermatogenic cysts were found in one gonad classified originally as female but the occurence of these structures can be the result of hormonal changes not necessarily associated with sex change. Features of population structure, such a sex-related bimodal size frequency distributions or sex ratios differing from 1:1, are not reliable indicators of sexual pattern (see Sadovy and Shapiro, 1987).

Marshall (1958) reported, from collections of reproductive individuals, that the main spawning sites for snook are the mouths of passes, canals, rivers, and adjacent shorelines. Taylor et al. (1993a) confirmed Marshall's findings and documented that mouths of major secondary embayments and nearshore islands are additional spawning locations. In Puerto Rico, we found running-ripe females and ripe males at the same time only at the mouths of rivers and adjacent shorelines. Our data strongly suggest that although some spawning takes place at mangrove-lined bays and passes, river mouths and nearby areas are the preferred spawning locations for snook in Puerto Rico.

Tarpon

The reproductive season for tarpon in Puerto Rico is protracted, extending from March to early August, with increased activity during April and May, as indicated by the GSI and the histological examination of gonads.

In Caño Boquerón backwaters, tarpon leptocephali were collected from May to December (study I, this report). Erdman (1976) found tarpon leptocephali 24-26 mm in July and September in Puerto Rico. In Florida, back-calculation of hatching dates of larvae and observation of adult gonads suggest that the spawning season begins in May, with peak activity in June and July. By August most fish had spent or recovering gonads, with some larvae having hatching dates from that month (Crabtree et al., 1992; Crabtree, 1995). Cyr (1991) stated that duration of the spawning season appears to follow a latitudinal gradient, with length of season increasing as latitude decreases, tarpon being capable of spawning year-around in tropical regions. In Costa Rica, no evidence of seasonal spawning has been shown and mature fish are found year round (Crabtree and Cyr, unpub. data). Chacón (1989) reported capturing tarpon leptocephali (phases I and II) in Costa Rica in May, July, August, November, and December. In Colombia, Mercado and Ciardelli (1972) collected phase I and II leptocephali from September to November. Tarpon spawning season in Brazil was reported to occur from October to December (de Menezes and Paiva, 1966). The estimate of the reproductive season extension in Puerto Rico is about two months longer than Florida's, but our data does not support the year round season reported for the mentioned countries.

Male and female tarpon mature at a similar size and age in Puerto Rico. On the basis of 50% maturity, males are mature at about 785 mm FL (age 5) and females at about 850 mm FL (age 5-6). Total maturity is reached at about 950 mm FL (age 9) in males and at about 1000 mm FL (age 8) in females. Cyr (1991) could not determine the size-at-maturity for Florida tarpon because of the low number of samples of intermediate size (900-1200 mm FL) he was able to obtain. From our size frequency distributions for both sexes separately, we calculated that about 15% and 54% of males and females, respectively, are captured before they can make a contribution to the overall reproductive effort. Since our size frequency distribution by sex is probably bias, due mainly to the lack of large males, conclusions derived from these results should be taken with caution.

In ripe tarpon ovaries, oocytes in all stages of development were observed. Batch fecundity estimated in this study ranged from 127,935 to 8,402,788 eggs per batch. Cyr (1991) estimated total fecundity and obtained a range from 1,081,330 to 19,519,400 eggs oocytes per female. Babcock (1936) estimated total fecundity in a 2036 mm TL individual to be 12,202,000 ocytes. One problem that the estimation of total fecundity (defined as the standing stock of advanced oocytes in the ovary) presents is that it is meaningless if, during the spawning season, new oocytes are added to that stock (Hunter et al., 1992), as is the case of the snook and the tarpon. In any case, although these estimates are not comparable, both of them suggest that tarpon is a very prolific species.

Estimated tarpon spawning frequency averaged one spawning per month (range 15 to 60 days). The only published fecundity estimation of which we are aware was performed by Cyr (1991). This author, assuming that only the most developed group of oocytes are spawned during the reproductive season, stated that tarpon spawn only once during that time. Again, different approaches and assumptions made comparisons difficult, if not impossible. Hunter et al. (1992) pointed out the importance of thoroughly evaluating the assumptions underlying fecundity and sexual maturity estimates.

Crabtree et al. (1992) and Crabtree et al.(1993) reported that adult tarpon appear to move offshore over the continental shelf during the winter and presumably enter inshore waters during April-June to feed. These fish have developing gonads and form large aggregations of 25 to more than 200 individuals 2-5 Km offshore before moving again to offshore spawning grounds. By August, many spent and recovering fish have returned to nearshore and inshore waters where they remain until the first cold front arrives, at which time most fish move offshore (Crabtree et al., 1993). These authors suggest the possibility of a southern migration during the winter, although there is no evidence for such movement. Specific locations of spawning grounds have not been determined, but some tarpon in the eastern Gulf of Mexico appear to spawn beyond the 200 m isobath (Cyr, 1991). This author found that no female tarpon collected during his research (all of which came from inshore areas) contained mature oocytes. These results are in contrast with the patterns we observed in Puerto Rico during this study. We found several females (all of which also came from inshore waters) with hydrated oocytes. During the peak of the spawning season, tarpon aggregations of about 50-75 individuals formed 0.3-2 Km offshore close to the Culebrinas river in Aguada. Most fish in these schools were about 1000 mm FL and several ripe females were collected from them using beach seines. Several isolated females with mature eggs were collected by commercial fishermen close to shore about 1 Km south of Añasco River. The evidence we have gathered strongly suggests that tarpon spawn relatively close to shore in Puerto Rico, although specific locations could not be determined during this investigation, with the probable exception of the Aguada site. According to local fishermen, these groups tend to form around the full moon phase, but that would have to confirmed by direct sampling of spawning fish or by back-calculating the hatching dates of larvae. Crabtree (1995) found evidence that relates spawning activity of tarpon to lunar phase, finding that hatching-date frequencies showed distinct peaks associated with new or full moon phases.

Conclusions and Recommendations

Snook

In Puerto Rico, the common snook is heavily exploited around river mouths and adjacent areas where the species concentrates during the spawning season, mainly by commercial fishermen using beach seines and specialized gillnets. Most recreational fishermen, who consider the snook as one of the most important gamefish available in Puerto Rican inshore waters, fish for them only during that same period (roughly from May to October). Obviously, conflicts frequently arise between these two groups, recreational fishermen often demanding for the regulation of the fishery, which is nonexistent today in Puerto Rico.

The present situation of the snook in Puerto Rico is probably similar in various aspects to the one described by Marshall (1958) and Volpe (1959) in Florida during the 1950's. Although we do not have population size estimates, some classical signs of overfishing like reduced captures despite increased fishing effort, and maximum sizes much smaller than in the past, are evident today. Habitat conservation, specially nursery areas, is critical for the survival of the snook and other related species. Being basically a non-migratory species with a restricted habitat, snook is probably forced to endure adverse environmental conditions or heavy localized fishing pressure. Snook life-history characteristics reported here such as slow growth, late maturing females, and the tendency to form spawning aggregations, only worsen the described scenario. In view of the factors summarized above, we have to conclude that the present condition of the snook stock in Puerto Rico is likely to be precarious. On the positive side, since the snook has been shown to be a prolific spawner, the stock can hopefully recover and increase if sound management measures are taken and enforced.

It is tempting at this final stage of report writing to include a relatively extensive list of management measures based on the results of this study. But considering the three main components of fishery management: habitat, fish, and people, plus the difficulties associated with law enforcement, only three measures will be proposed here: 1. Protection of the spawning grounds by prohibiting any fishing in a perimeter of 1000 m around all major river mouths during the May-June peak of the spawning season. This prohibition would be in effect for 5 years, and would include regular reevaluation and monitoring of the fishery. Eventually some of these areas could became permanent estuarine reserves; 2. Establishment of a minimum mesh size for the bunt of the beach seine. A short study would have to be conducted to determine the appropiate bunt mesh size. Envolvement of the commercial and recreational fishermen in data gathering and discussion is necessary for this measure to be successful and, 3. Establish a maximum size limit of 915 mm FL (36 in). Snook larger than 915 mm FL are becoming rapidly scarcerer. Large fish are more vulnerable to fishing pressure. On the other hand, since fecundity increases exponentially with fish size, the contribution of the larger females to the overall reproductive effort is critical to mantain healthy population levels. Among the possible management alternatives available, these three are probably the most practical in terms of the impact on both the fish and the fishermen while requiring relative less effort from law enforcement officials. It is expected that the recreational fishermen would benefit from these measures in a short term whereas the fishery as a whole may hopefully grow strong within a few years.

Tarpon

Additional work on age and growth is needed, but the scarcity of large size fish makes that possibility very remote.

Commercial exploitation of tarpon was apparently very low in Puerto Rico 25 years ago. Large tarpon were common in traditional locations and were harvested only occasionally as trophies by recreational fishermen or as by-catch by commercial fishermen. However, as the commercial fish stocks decreased due mainly to habitat degradation and overfishing, less valuable species like tarpon, became the target of local commercial fishermen. Today, in January 1996, tarpon sold at $1.00 a pound in the Cataño area. Prices in other parts of the island fluctuate between 0.25 to 0.75 dollars/lb. Apparently as a result of the increased demand, the numbers of large tarpon have decreased dramatically over the past two decades. Only an average of 4 individuals per year over 100 pounds are seen in the San Juan Bay by Capt. Mike Verges (pers. comm.). Mr. Verges is a professional recreative fisherman who makes over 200 tarpon charter trips per year in the San Juan area. The observed tendency is that large tarpon are becoming scarcer. Fishing mortality is probably the principal reason for the low abundance of large individuals. In species like tarpon, natural mortality of these fish is probably low due to the lack of predators larger than themselves. In summary, tarpon's future in Puerto Rico seems to be obscure.

Tarpon have life-history characteristics, such as slow growing and high longevity, typical of fishes prone to overexplotaition. Cyr (1991) presents an excellent discussion of the issues concerning management of species like tarpon and summarizes the history of tarpon management in Florida, evaluating the various options available, some of which might be applicable to Puerto Rico.

As in the case of the snook, the extent to which overfishing and habitat loss have affected tarpon population in Puerto Rico has yet to be quantified. Maintaining low fishing mortality on adults is critical to manage species like tarpon. Given its life-history traits and the visible signs of overfishing, the following practical management measures are recommended: 1. Prohibition of tarpon commercial fishing and, 2. Study the viability of establishing a tarpon permit system similar to the one implemented in Florida in 1988 (see Cyr, 1991). That system requires the purchasing of a tarpon permit for any tarpon killed. The cost of the permit is important in determining the effectiveness of this measure. If the price is too low, the measure would probably not have any impact on the fish whereas if it is too high, the impact could be negative on the recreational fishermen. An additional benefit of the plan would be that it would allow to monitor catches and undertake constant evaluation of the stock. In this way alternative courses of action to protect and develop the fishery could be taken when considered necessary. Alternative management measures like size and/or bag limits or closing the fishery during the peak of the spawning season, although probably more difficult to implement, should be taken into account. Participation of all interested groups is essential for the success of any measure going to be considered.

Summary

1. Caño Boquerón and Caño Boquilla, as well as other similar locations around the island, are critical areas for the survival of juvenile snook, tarpon, and many other species. Snook and tarpon are among the principal species inhabiting these areas, as indicated by the estimated relative abundance indexes.

2. Common snook and tarpon were aged by counting the growth marks in otoliths. Growth marks were validated as annual. Formation of annuli occurs between April-July for snook and April-June for tarpon.

3. Females of both species attain larger maximum sizes and ages than do males. Maximum ages found during this study were 17 and 21 years for snook and tarpon, respectively. Additional work on age and growth of tarpon would be desirable, although admittedly very difficult.

4. Total annual mortality is higher in snook female than in male. The opposite result was found for tarpon.

5. Male snook mature about two years younger and at smaller sizes than do females. Male and female tarpon mature at about the same size and age.

6. The spawning season of snook is protracted, extending approximately from mid-April to mid-November. Tarpon reproductive season extends from March to early August.

7. Sizes and ages at 50% maturity for male and female snook and male and female tarpon, respectively, are 350 mm FL (age 2-3), 610 mm FL (age 5), 785 mm FL (age 5), and 850 mm FL (age 5-6).

8. No evidence of protandric hermaphroditism was found for snook during this study.

9. Batch fecundity estimates ranged 360,000 to 1,643,122 and from 127,935 to 8,402,788 eggs for snook and tarpon, respectively.

10. Spawning frequency of snook females averaged one spwaning every 18 days (range 11-30 days). Tarpon females averaged one spawning every 30 days (range 15-60 days).

11. River mouths and adjacent areas are the preferred spawning locations for snook in Puerto Rico. Tarpon spawn relatively close to shore in Puerto Rico, probably preferring areas relatively close to rivers, but that apparent tendency needs to be confirmed.

12. It is crucial to establish management measures for common snook and tarpon in Puerto Rico. Some of the available alternatives are recommended in this report.

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Table 1. Species listing and relative abundance of individuals collected at Caño Boquerón.

SPECIES	N	%
Megalops atlanticus	78	12.56
Archosargus rhomboidalis	70	11.27
Centropomus ensiferus	60	9.66
Bairdiella ronchus	48	7.73
Elops saurus	46	7.41
Eugerres brasilianus	44	7.09
Centropomus undecimalis	40	6.44
Cetengraulis edentulus	35	5.64
Caranx hippos	33	5.31
Tilapia mossambica	31	4.99
Eugerres plumieri	23	3.70
Mugil curema	22	3.54
Lutjanus jocu	14	2.25
Achirus lineatus	13	2.09
Aetobatus narinari	12	1.93
Gerres cinereus	8	1.29
Sphyraena barracuda	6	0.97
Caranx latus	5	0.81
Opisthonema oglinum	5	0.81
Polydactylus virginicus	4	0.64
Citharichthys spilopterus	3	0.48
Centropomus parallelus	3	0.48
Lutjanus griseus	2	0.32
Sphoeroides greeleyi	2	0.32
Oligoplites saurus	2	0.32
Anchoa lamprotaenia	1	0.16
Eucinostomus sp.	1	0.16
Anchoa lyolepis	1	0.16
Sphyraena guachancho	1	0.16
Dasyatis americana	1	0.16
Trachinotus falcatus	1	0.16
Umbrina coroides	1	0.16
Synodus foetens	1	0.16
Eleotris pisonis	1	0.16
Lutjanus cyanopterus	1	0.16
Chloroscombrus chrysurus	1	0.16
Mugil liza	1	0.16
Total	621	

Table 2. Number of individuals of each species collected by month at Caño Boquerón between September, 1994 - December, 1995.

		Month															
		1994				1995											
Species	**N**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	12			7			4		1								
2	70	4		2	3	1	5	7	4	9	6	13	12	2	1		1
3	48			4		2	2	5	6	3	2	6	16	1	1		
4	5				1		3						1				
5	33			6			2	2	5	6	1	5	3	1	1	1	
6	60				1	3	4	7	11	16	2	5	9		1		1
7	3			1			2										
8	40		1		8	2	1	3	5	6	4	2	6	2			
9	35			1				27	2	3		2					
10	-																
11	46			2	4	4	1	6	3	8	5	2	11				
12	44			3	3	2		7	3	7	1	3	6	9			
13	23							1	3	4	5	3	4	3			
14	0																
15	-																
16	1				1												
17	2			1						1							
18	78	1	13	41	13	2	3	1	1	1			1	1			
19	22				5.	2	1	1	2	4		4		3			
20	1				1												
21	5				1	1	1		1	1							
22	4			1			2				1						
23	31		9	1	2		1		2	11	3	1	1				
24	1					1											
25	2					2											
26	14					2	1	1		1		4	4		1		
27	8						7						1				
28	1								1								
29	2						1		1								
30	13					1	1	1	1	5	2		1		1		
31	6						1		2	1		1	1				
32	1						1										
33	1							1									
34	1								1								
35	1									1							
36	1									1							
37	1									1							
38	3						1		1	1							
39	1											1					
40	1											1					
41	0																
42	0																
Total	621	5	23	70	43	25	45	70	56	91	32	53	77	22	6	1	2

Species code	**Species name**	**Species code**	**Species name**
1	*Aetobatus narinari*	22	*Polydactylus virginicus*
2	*Archosargus rhomboidalis*	23	*Tilapia mossambica*
3	*Bairdiella ronchus*	24	*Eleotris pisonis*
4	*Caranx latus*	25	*Oligoplites saurus*
5	*Caranx hippos*	26	*Lutjanus jocu*
6	*Centropomus ensiferus*	27	*Gerres cinereus*
7	*Centropomus parallelus*	28	*Synodus foetens*
8	*Centropomus undecimalis*	29	*Sphoeroides greeleyi*
9	*Cetengraulis edentulus*	30	*Achirus lineatus*
11	*Elops saurus*	31	*Sphyraena barracuda*
10	-	32	*Chloroscombrus chrysurus*
12	*Eugerres brasilianus*	33	*Anchoa lamprotaenia*
13	*Eugerres plumieri*	34	*Anchoa lyolepis*
14	*Guavina guavina*	35	*Eucinostomus sp.*
15	-	36	*Trachinotus falcatus*
16	*Lutjanus cyanopterus*	37	*Umbrina coroides*
17	*Lutjanus griseus*	38	*Citharichthys spilopterus*
18	*Megalops atlanticus*	39	*Sphyraena guachancho*
19	*Mugil curema*	40	*Dasyatis americana*
20	*Mugil liza*	41	*Gobiomorus dormitor*
21	*Opisthonema oglinum*	42	*Albula vulpes*

Table 3. Species richness, species diversity, and relative abundance (catch-per-unit-effort) by station of species collected at Caño Boquerón from September, 1994 to December, 1995.

Station	Number of species	Number of fish	Diversity	sd	CPUE Fish/hr.	sd
1	26	208	4.68	0.82	1.63	0.94
2	28	288	4.77	0.68	2.25	1.11
3	17	125	3.31	0.59	1.36	1.46

Table 4. Species richness, species diversity, and relative abundance (catch-per-unit-effort) by month of species collected at Caño Boquerón from January to December, 1995.

Month	Number of species	Number of fish	Diversity	CPUE Fish/hr.
January	13	25	3.73	1.56
February	21	45	5.25	1.88
March	14	70	3.06	1.94
April	20	56	4.72	1.56
May	21	91	4.43	1.63
June	11	32	2.89	1.60
July	15	53	3.53	1.66
August	15	77	3.22	1.48
September	8	22	2.26	1.83
October	6	6	2.79	0.75
November	1	1		0.13
December	2	2	1.44	0.25

Table 5. Species listing and relative abundance of individuals collected at Caño Boquilla.

SPECIES	N	%
Tilapia mossambica	303	53.44
Megalops atlanticus	164	28.92
Centropomus undecimalis	34	6.00
Centropomus parallelus	16	2.82
Mugil curema	11	1.94
Caranx hippos	8	1.41
Eleotris pisonis	7	1.23
Eugerres brasilianus	7	1.23
Caranx latus	5	0.88
Eugerres plumieri	4	0.71
Mugil liza	3	0.53
Gobiomorus dormitor	3	0.53
Guavina guavina	1	0.18
Albula vulpes	1	0.18
Total	567	

Table 6. Number of individuals of each species collected by month at Caño Boquilla during 1995. Numbers in parentheses represent CPUE values for *Megalops atlanticus*.

		1995					Month						
Species	N	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0												
2	0												
3	0												
4	5									2	3		
5	8									4	1	3	
6	0												
7	16		1							7	2	5	1
8	34	6	4	1	4	3			1	7		5	3
9	0												
10	-												
11	0												
12	7					1			1	2	1	2	
13	4						1				1	2	
14	1				1								
15	-												
16	0												
17	0												
18	164	21(2.63)	1(0.13)	2(0.17)	12(1.00)	7(0.58)	4(0.50)	13(1.08)	16(1.33)	30(0.94)	10(0.42)	17(0.61)	31(3.88)
19	11	1	2				1	1	1	2			3
20	3			1					1		1		
21	0												
22	0												
23	303	26	18	17	30	56	5	1	12	41	19	66	8
24	7	1								5	1		
25	0												
26	0												
27	0												
28	0												
29	0												
30	0												
31	0												
32	0												
33	0												
34	0												
35	0												
36	0												
37	0												
38	0												
39	0												
40	0												
41	3									3			
42	1									1			
Total	567	55	26	21	47	69	11	15	32	104	39	102	46

Species code	Species name	Species code	Species name
1	*Aetobatus narinari*	22	*Polydactylus virginicus*
2	*Archosargus rhomboidalis*	23	*Tilapia mossambica*
3	*Bairdiella ronchus*	24	*Eleotris pisonis*
4	*Caranx latus*	25	*Oligoplites saurus*
5	*Caranx hippos*	26	*Lutjanus jocu*
6	*Centropomus ensiferus*	27	*Gerres cinereus*
7	*Centropomus parallelus*	28	*Synodus foetens*
8	*Centropomus undecimalis*	29	*Sphoeroides greeleyi*
9	*Cetengraulis edentulus*	30	*Achirus lineatus*
11	*Elops saurus*	31	*Sphyraena barracuda*
10	-	32	*Chloroscombrus chrysurus*
12	*Eugerres brasilianus*	33	*Anchoa lamprotaenia*
13	*Eugerres plumieri*	34	*Anchoa lyolepis*
14	*Guavina guavina*	35	*Eucinostomus sp.*
15	-	36	*Trachinotus falcatus*
16	*Lutjanus cyanopterus*	37	*Umbrina coroides*
17	*Lutjanus griseus*	38	*Citharichthys spilopterus*
18	*Megalops atlanticus*	39	*Sphyraena guachancho*
19	*Mugil curema*	40	*Dasyatis americana*
20	*Mugil liza*	41	*Gobiomorus dormitor*
21	*Opisthonema oglinum*	42	*Albula vulpes*

Table 7. Species richness, species diversity, and relative abundance (catch-per-unit-effort) by month of species collected at Caño Boquilla from January to December, 1995.

Month	Number of species	Number of fish	Diversity	CPUE Fish/hr.
January	5	55	1.00	6.88
February	5	26	1.23	3.25
March	4	21	0.99	1.75
April	4	47	0.78	3.92
May	4	69	0.71	5.75
June	4	11	1.25	1.38
July	3	15	0.74	1.25
August	6	32	1.44	2.67
September	11	104	2.15	3.25
October	9	39	2.18	1.63
November	7	102	1.30	3.64
December	5	46	1.04	5.75

Table 8. Monthly mean marginal increments for age groups II - V and VI - XI for Centropomus undecimalis (sexes combined).

	Ages II - V			Ages VI - XI		
Month	Mean MI	N	sd	Mean MI	N	sd
January	5.24	17	0.88		0	
February	4.82	28	1.44	4.00	1	
March	5.00	6	0.58	3.50	2	0.50
April	3.43	21	0.90	3.00	6	0.82
May	1.78	9	0.79	1.92	37	0.82
June	2.33	3	0.47	1.47	38	0.82
July	4.43	7	0.90	2.18	28	0.85
August	4.00	2	1.00	3.13	16	1.05
September	4.50	4	0.50	3.04	27	1.07
October	4.38	13	1.21	4.11	9	1.10
November	4.78	9	1.23	4.00	3	0.82
December	5.25	4	1.09		0	
Total		123			167	

Table 9. Average observed, back-calculated, and predicted size-at-age for male Centropomus undecimalis.

Age	N	Observed FL (sd) (mm)	BC FL (mm)	Predicted FL (mm)
1	0		175	131
2	14	289 (27.60)	252	257
3	72	360 (39.34)	326	363
4	120	423 (38.30)	386	451
5	44	492 (40.70)	460	524
6	13	552 (47.20)	524	585
7	8	640 (54.65)	579	635
8	7	675 (42.47)	619	677
9	6	761 (42.69)	660	712
10	4	778 (28.18)	684	742
11	4	790 (33.79)	705	766
12	3	776 (9.79)	719	786
13	3	830 (51.56)	745	803
14	2	800 (15.89)	745	817
15	1	840	759	828
16	2	778 (13.36)	757	838
Total	303			

Table 10. Average observed, back-calculated, and predicted size-at-age for female *Centropomus undecimalis*.

Age	N	Observed FL (sd) (mm)	BC FL (mm)	Predicted FL (mm)
1	0		248	136
2	0		333	281
3	16	411 (30.67)	412	405
4	31	502 (46.87)	487	510
5	17	567 (51.21)	563	600
6	23	696 (65.62)	635	675
7	49	770 (48.69)	694	740
8	34	808 (43.95)	739	795
9	20	841 (41.13)	779	841
10	6	883 (37.35)	809	881
11	4	903 (26.62)	840	914
12	2	949 (11.46)	872	943
13	4	926 (67.89)	898	967
14	4	959 (52.63)	935	987
15	0		982	1005
16	0		1016	1020
17	1	1075	1050	1032
Total	211			

Table 11. Von Bertalanffy growth parameters for male and female *Centropomus undecimalis* (ase = asymptotic standard error).

	L_∞	ase	K	ase	t_0	ase	r^2	N
Male	885.9	36.8	0.184	0.029	0.133	0.414	0.97	303
Female	1,103.0	43.9	0.163	0.024	0.193	0.434	0.98	211

Table 12. Comparison of back-calculated fork lengths (mm) at age for *Centropomus undecimalis* (this study and the west coast of Florida). Data from existing literature.

Author	Volpe 1959	Thue et al. 1982	Bruger *	Taylor et al. 1993a			This Study 1996		
Method	Whole Otoliths	Scales	Otoliths ?	Sectioned Otoliths			Sectioned Otoliths		
Age	Sexes Combined	Sexes Combined	Sexes Combined	Sexes Combined	Male	Female	Sexes Combined	Male	Female
1	163	375	149	216	198	300	205	175	248
2	342	465	315	361	340	424	285	252	333
3	456	540	437	455	430	507	362	326	412
4	563	605	553	522	489	576	434	386	487
5	660	672	660	575	533	635	524	460	563
6	723	730	739	621	566	689	605	524	635
7	782	806	786	676	604	749	666	579	694
8		863	788	730	616	787	703	619	739
9				798	690	836	731	660	779
10				823	759	848	749	684	809
11				843	778	863	773	705	840
12				834	749	856	796	719	872
13				856	787	877	826	745	898
14				890		899	840	745	935
15				890		898	815	759	982
16				870		879	844	757	1016
17							1050		1050

* Cited by Taylor et al. (1993a) as pers. comm.

Table 13. Total instantaneous (Z) and annual (A) mortality rates, and annual survival rate (S) for male and female Centropomus undecimalis.

	Z	A	S
Male	0.34	0.29	0.71
Female	0.67	0.49	0.51

Table 14. Monthly mean marginal increments for age group II - IX for *Megalops atlanticus* (sexes combined).

	Ages II - IX		
Month	**Mean MI**	**N**	**sd**
January	4.11	9	0.87
February	3.67	3	0.94
March	2.50	2	0.50
April	3.17	12	1.14
May	1.62	37	0.82
June	2.18	28	0.97
July	2.13	15	1.02
August	2.97	38	1.20
September	3.33	12	1.03
October	4.60	5	1.02
November	4.28	18	1.24
December	4.53	17	1.19
Total		196	

Table 15. Mean growth rate and temporal significance of opaque growth marks in otoliths of Megalops atlanticus, based on OTC-marked/recaptured fish.

Tag number	Date capture recapture	FL (mm) capture recapture	Days in field	Mean growth (mm/day)	Age	Number of growth marks deposited
00176	June 1, 1994	373	395	0.09	2	1
	June 30, 1995	409				
00111	June 9, 1994	452	302	0.14	2	0
	April 6, 1995	493				
00088	July 7, 1994	346	496	0.26	3	1
	November 14, 1995	475				

Table 16. Average observed and predicted size-at-age for male Megalops atlanticus.

Age	N	Observed FL(sd) (mm)	Predicted FL (mm)
1	0		379
2	4	493(19.32)	494
3	5	583(97.12)	593
4	4	681(105.34)	677
5	10	779(37.12)	749
6	38	811(63.60)	811
7	23	847(66.87)	864
8	16	885(74.21)	909
9	3	947(15.47)	947
10	2	998(22.68)	980
Total	105		

Table 17. Average observed and predicted size-at-age for female Megalops atlanticus.

Age	N	Observed FL(sd) (mm)	Predicted FL (mm)
1	0		261
2	3	468(10.34)	402
3	20	534(33.50)	530
4	10	618(39.21)	647
5	11	765(39.35)	753
6	21	862(48.21)	851
7	16	931(63.11)	939
8	10	970(72.49)	1020
9	5	1037(55.27)	1093
10	4	1136(90.39)	1160
11	3	1156(32.25)	1221
12	2	1298(28.41)	1277
13	0		1328
14	1	1410	1374
15	2	1585(135.12)	1416
16	0		1454
17	1	1430	1489
18	0		1521
19	0		1550
20	0		1577
21	1	1740	1601
Total	110		

Table 18. Von Bertalanffy growth parameters for male and female *Megalops atlanticus* (ase = asymptotic standard error).

	L_∞	ase	K	ase	t_0	ase	r^2	N
Male	1,173.0	91.6	0.157	0.037	-1.480	0.059	0.99	118
Female	1,850.0	185.4	0.093	0.023	-0.643	0.730	0.97	133

Table 19. Total instantaneous (Z) and annual (A) mortality rates, and annual survival rate (S) for male and female *Megalops atlanticus*.

	Z	A	S
Male	0.79	0.55	0.45
Female	0.40	0.33	0.67

Table 20. Reproductive season of male Centropomus undecimalis as defined by the percentage of each maturity class present in each month (1 = Inmature; 2 = Inactive mature; 3 = active mature; 4 = ripe; 5 = spent).

		Stage of gonad development									
		1		2		3		4		5	
Month	N	N	%	N	%	N	%	N	%	N	%
January	54	39	72.2	7	13.0	3	5.6	5	9.3		
February	51	22	43.1	8	15.7	7	13.7	13	25.5	1	2.0
March	22	9	40.9	5	22.7	3	13.6	5	22.7		
April	41	10	24.4	10	24.4	8	19.5	12	29.3	1	2.4
May	62	7	11.3	6	9.7	14	22.6	33	53.2	2	3.2
June	59	11	18.6	7	11.9	5	8.5	35	59.3	1	1.7
July	52	14	26.9	6	11.5	12	23.1	20	38.5		
August	28	5	17.9	3	10.7	3	10.7	16	57.1	1	3.6
September	25	4	16.0	1	4.0	7	28.0	13	52.0		
October	50	15	30.0	5	10.0	9	18.0	21	42.0		
November	72	8	11.1	9	12.5	19	26.4	36	50.0		
December	48	12	25.0	11	22.9	10	20.8	15	31.3		
Total	564	156		78		100		224		6	

Table 21. Reproductive season of female Centropomus undecimalis as defined by the percentage of each maturity class present in each month (1 = Inmature; 2 = Inactive mature; 3 = active mature; 4 = ripe; 5 = spent).

		Stage of gonad development									
		1		2		3		4		5	
Month	N	N	%	N	%	N	%	N	%	N	%
January	6	6	100.0								
February	12	9	75.0	3	25.0						
March	7	1	14.3	3	42.9	1	14.3	2	28.6		
April	8	5	62.5	2	25.0			1	12.5		
May	47	11	23.4	1	2.1	1	2.1	34	72.3		
June	56	5	8.9	3	5.4	3	5.4	45	80.4		
July	36	8	22.2			2	5.6	26	72.2		
August	18	6	33.3					12	66.7		
September	30	3	10.0			2	6.7	25	83.3		
October	19	5	26.3	1	5.3			13	68.4		
November	16	10	62.5	2	12.5			3	18.8	1	6.3
December	9	6	66.7			1	11.1			2	22.2
Total	264	75		15		10		161		3	

Table 22. Monthly mean gonosomatic index (GSI) of female Centropomus undecimalis.

Month	GSI	N	sd
January	0.132	4	0.062
February	0.231	6	0.098
March	0.517	4	0.097
April	1.194	6	0.093
May	2.004	40	0.104
June	2.164	51	0.090
July	1.566	35	0.090
August	1.558	18	0.060
September	1.280	26	0.061
October	2.161	12	0.003
November	0.590	2	0.003
December	0.287	6	0.062
Total		210	

Table 23. Maturity classes of common snook and tarpon male gonads.

Class 1. Inmature

- Early stages of spermatogenesis predominate (spermatogonia and scattered cysts of primary spermatocytes).
- Small, clear, and compact testis.
- Spermatozoa absent.
- Lumen not developed.

Class 2. Inactive mature

- Early stages of spermatogenesis predominate, but all stages are present (spermatogonia, primary and secondary spermatocytes, spermatids, and spermatozoa).
- Few spermatids and spermatozoa.

Class 3. Active mature

- Late spermatogenesis.
- Secondary spermatocytes and spermatids predominate.
- Declining number of spermatogonia.
- Spermatozoa collecting in tubules and central lumen.

Class 4. Ripe

- Spermatids and spermatozoa predominate.
- Central lumen and efferent tubules filled with spermatozoa.
- Few spermatogonia and spermatocytes.
- Distal portions of a few efferent tubules empty and thickened.

Class 5. Spent

- Efferent tubules empty.
- Central lumen with few spermatozoa.
- Testis reduced in size.
- Abundant connective tissue. Only small crypts of spermatozoa present. Dark red and flaccid testes (this criteria applies only to tarpon).

Table 24. Maturity classes of common snook and tarpon female gonads.

Class 1. Inmature

- Early stages of oogenesis predominate (oocytes in stages 1 and 2).
- Stage 3 oocytes absent or very few.
- Compact gonad. Thin muscular tunica.
- No evidence of previous spawning (thick tunica, ovary with empty areas, and atretic oocytes).

Class 2. Inactive mature

- Early vitellogenesis.
- Oocytes in stages 1, 2, and 3 present, but stage 3 do not predominate.
- Oocytes in stage 4 absent or very few.
- Thin tunica, except in spent individuals.

Class 3. Active mature

- Late vitellogenesis.
- Oocytes in stages 2, 3, and 4 present, but stage 4 do not predominate.
- Advanced stage 4 oocytes absent.
- Thin tunica, except in spent individuals.

Class 4. Ripe

- Oocytes in stages 2, 3, 4, and rarely 5 present. Advanced stages predominate.
- Thin tunica, except in spent individuals.

Class 5. Spent

- Ovary with empty areas.
- Atretic oocytes scattered throughout.
- Tunica thickened and convoluted.

Table 25. Maturity schedule by size for male <u>Centropomus</u> <u>undecimalis</u>.

FL (mm)	N total	N mature	% mature
260	30	2	7
310	33	6	18
360	108	62	57
410	109	81	74
460	142	123	87
510	56	49	88
560	26	25	96
610	8	8	100
660	12	12	100
710	7	7	100
760	11	11	100
810	15	15	100
860	6	6	100
910	1	1	100
Total	564	408	

Table 26. Maturity schedule by size for female <u>Centropomus</u> <u>undecimalis</u>.

FL (mm)	N total	N mature	% mature
360	2	0	0
410	8	0	0
460	18	0	0
510	17	3	18
560	19	2	11
610	14	7	50
660	6	4	67
710	16	9	56
760	41	41	100
810	47	47	100
860	38	38	100
910	24	24	100
960	9	9	100
1010	2	2	100
1060	2	2	100
1110	1	1	100
Total	264	189	

Table 27. Batch fecundity (F, number of oocytes to be spawned in one batch) and number of batches of 30 *Centropomus undecimalis* females collected between May, 1993 and August, 1995).

Fish ID	Date	FL (mm)	Weight (g)	F	No. batches
CU385	May 03, 1993	880	11804	1169577	7
CU386	May 05, 1993	895	9112	705044	10
CU388	May 14, 1993	732	6470	513725	9
CU389	May 14, 1993	815	7491	845147	9
CU405	May 27, 1993	755	4994	398054	12
CU406	May 28, 1993	897	8172	593103	7
CU409	May 28, 1993	946	10215	1065287	6
CU410	May 28, 1993	902	9761	769524	13
CU441	Jun 23, 1993	865	7605	497486	6
CU443	Jun 23, 1993	730	5221	360000	11
CU489	Jul 31, 1993	1012	13874	1643122	5
CU507	Sep 10, 1993	765	5902	607750	4
CU508	Sep 10, 1993	776	7264	738804	4
CU521	Sep 29, 1993	843	7945	842888	6
CU528	Sep.30, 1993	875	9165	1027500	6
CU529	Sep 30, 1993	905	8910	796422	4
CU539	Oct 02, 1993	802	5675	932692	3
CU715	May 12, 1994	822	7832	490686	10
CU719	May 13, 1994	851	6810	392857	10
CU723	May 13, 1994	860	6810	408609	17
CU729	May 17, 1994	854	8740	726136	11
CU730	May 17, 1994	850	7718	762338	8
CU774	Jun 02, 1994	846	8285	1026802	8
CU798	Jun 15, 1994	862	8286	930275	8
CU816	Jun 29, 1994	837	7378	554816	8
CU822	Jun 30, 1994	795	5959	521606	10
CU834	Jul 01, 1994	951	11123	1218146	5
CU857	Jul 09, 1994	739	4200	474240	7
CU889	Sep 15, 1994	812	7264	1029126	5
CU985	Aug 04, 1995	857	7264	682410	5

Table 28. Sex ratios of *Centropomus undecimalis* collected from May, 1992 to December, 1995.

	Male		Female	
FL (mm)	N	%	N	%
260	30	3.6	0	0.0
310	33	4.0	0	0.0
360	108	13.0	2	0.2
410	109	13.2	8	1.0
460	142	17.1	18	2.2
510	56	6.8	17	2.1
560	26	3.1	19	2.3
610	8	1.0	14	1.7
660	12	1.4	6	0.7
710	7	0.8	16	1.9
760	11	1.3	41	5.0
810	15	1.8	47	5.7
860	6	0.7	38	4.6
910	1	0.1	24	2.9
960	0	0.0	9	1.1
1010	0	0.0	2	0.2
1060	0	0.00	2	0.2
1110	0	0.00	1	0.1
Total	564	68.1	264	31.9

Table 29. Reproductive season of male <u>Megalops</u> <u>atlanticus</u> as defined by the percentage of each maturity class present in each month (1 = Inmature; 2 = Inactive mature; 3 = active mature; 4 = ripe; 5 = spent).

		Stage of gonad development									
		1		2		3		4		5	
Month	N	N	%	N	%	N	%	N	%	N	%
January	4	3	75.0					1	25.0		
February	1					1	100.0				
March	0										
April	0										
May	21					3	14.3	15	71.4	3	14.3
June	18	2	11.1			3	16.7	12	66.7	1	5.6
July	16	3	18.8			1	6.3	12	75.0		
August	31	4	12.9	3	9.7	2	6.5	22	71.0		
September	7	6	85.7							1	14.3
October	3	1	33.3	1	33.3					1	33.3
November	3	3	100.0								
December	14	9	64.3	4	28.6					1	7.1
Total	118	31		8		10		62		7	

Table 30. Reproductive season of female *Megalops atlanticus* as defined by the percentage of each maturity class present in each month (1 = Inmature; 2 = Inactive mature; 3 = active mature; 4 = ripe; 5 = spent).

		Stage of gonad development									
		1		2		3		4		5	
Month	N	N	%	N	%	N	%	N	%	N	%
January	10	9	90.0	1	10.0						
February	4	4	100.0								
March	4	1	25.0	2	50.0			1	25.0		
April	10	5	50.0	2	20.0			3	30.0		
May	22	3	13.6	4	18.2	3	13.6	12	54.5		
June	13	7	53.8			1	7.7	3	23.1	2	15.4
July	14	5	35.7	3	21.4	2	14.3	3	21.4	1	7.1
August	13	4	30.8	4	30.8	4	30.8	1	7.7		
September	9	3	33.3	3	33.3	1	11.1			2	22.2
October	4	3	75.0							1	25.0
November	18	17	94.4	1	5.6						
December	12	9	75.0	1	8.3	2	16.7				
Total	133	70		21		13		23		6	

Table 31. Monthly mean gonosomatic index (GSI) of female *Megalops atlanticus*.

Month	GSI	N	sd
January	0.049	10	0.021
February	0.032	3	0.014
March	0.403	4	0.013
April	2.331	10	1.578
May	2.202	22	1.437
June	1.673	13	1.248
July	0.768	14	0.095
August	0.169	13	0.095
September	0.091	9	0.012
October	0.062	4	0.045
November	0.052	17	0.035
December	0.029	12	0.021
Total		131	

Table 32. Maturity schedule by size for male *Megalops atlanticus*.

FL (mm)	N total	N mature	% mature
500	3	0	0
550	4	0	0
600	0	0	0
650	2	0	0
700	2	0	0
750	1	0	0
800	12	7	58
850	45	34	76
900	32	29	91
950	12	12	100
1000	3	3	100
1050	2	2	100
Total	118	87	

Table 33. Maturity schedule by size for female Megalops atlanticus.

FL (mm)	N total	N mature	% mature
500	13	0	0
550	14	0	0
600	9	0	0
650	5	0	0
700	4	0	0
750	5	0	0
800	12	2	17
850	10	4	40
900	12	11	92
950	13	10	77
1000	12	12	100
1050	6	6	100
1100	1	1	100
1150	5	5	100
1200	1	1	100
1250	0	0	0
1300	3	3	100
1350	1	1	100
1400	0	0	0
1450	4	4	100
1500	1	1	100
1550	0	0	0
1600	0	0	0
1650	0	0	0
1700	0	0	0
1750	2	2	100
Total	133	63	

Table 34. Batch fecundity (F, number of oocytes to be spawned in one batch) and number of batches of 11 *Megalops atlanticus* females collected between June, 1993 and June, 1995).

Fish ID	Date	FL (mm)	Weight (g)	F	No. batches
MA226	Jun 25,93	978	10442	468180	4
MA258	Jul 01,93	960	9534	783723	4
MA591	Apr 24,94	1270	23608	2080723	2
MA592	Apr 27,94	1025	14074	2753823	2
MA595	Apr 29,94	1071	13620	323716	8
MA596	Apr 29,94	1575	39044	3483496	2
MA625	May 16,94	974	9676	127935	5
MA628	May 20,94	1052	11520	452746	2
MA641	May 29,94	993	11691	894864	3
MA654	Jun 02,94	922	9761	188927	4
MA853	Jun 21,95	1740	56296	8402788	1

Table 35. Sex ratios of *Megalops atlanticus* collected from May, 1992 to December, 1995.

	Male		Female	
FL (mm)	N	%	N	%
450	0	0.0	0	0.0
500	3	1.2	13	5.2
550	4	1.6	14	5.6
600	0	0.0	9	3.6
650	2	0.8	5	2.0
700	2	0.8	4	1.6
750	1	0.4	5	2.0
800	12	4.8	12	4.8
850	45	17.9	10	4.0
900	32	12.7	12	4.8
950	12	4.8	13	5.2
1000	3	1.2	12	4.8
1050	2	0.8	6	2.4
1100	0	0.0	1	0.4
1150	0	0.0	5	2.0
1200	0	0.0	1	0.4
1250	0	0.00	0	0.0
1300	0	0.00	3	1.2
1350	0	0.0	1	0.4
1400	0	0	0	0
1450	0	0	4	1.6
1500	0	0	1	0.4
1550	0	0	0	0
1600	0	0	0	0
1650	0	0	0	0
1700	0	0	0	0
1750	0	0	2	0.8
Total	118	47.0	133	53.0

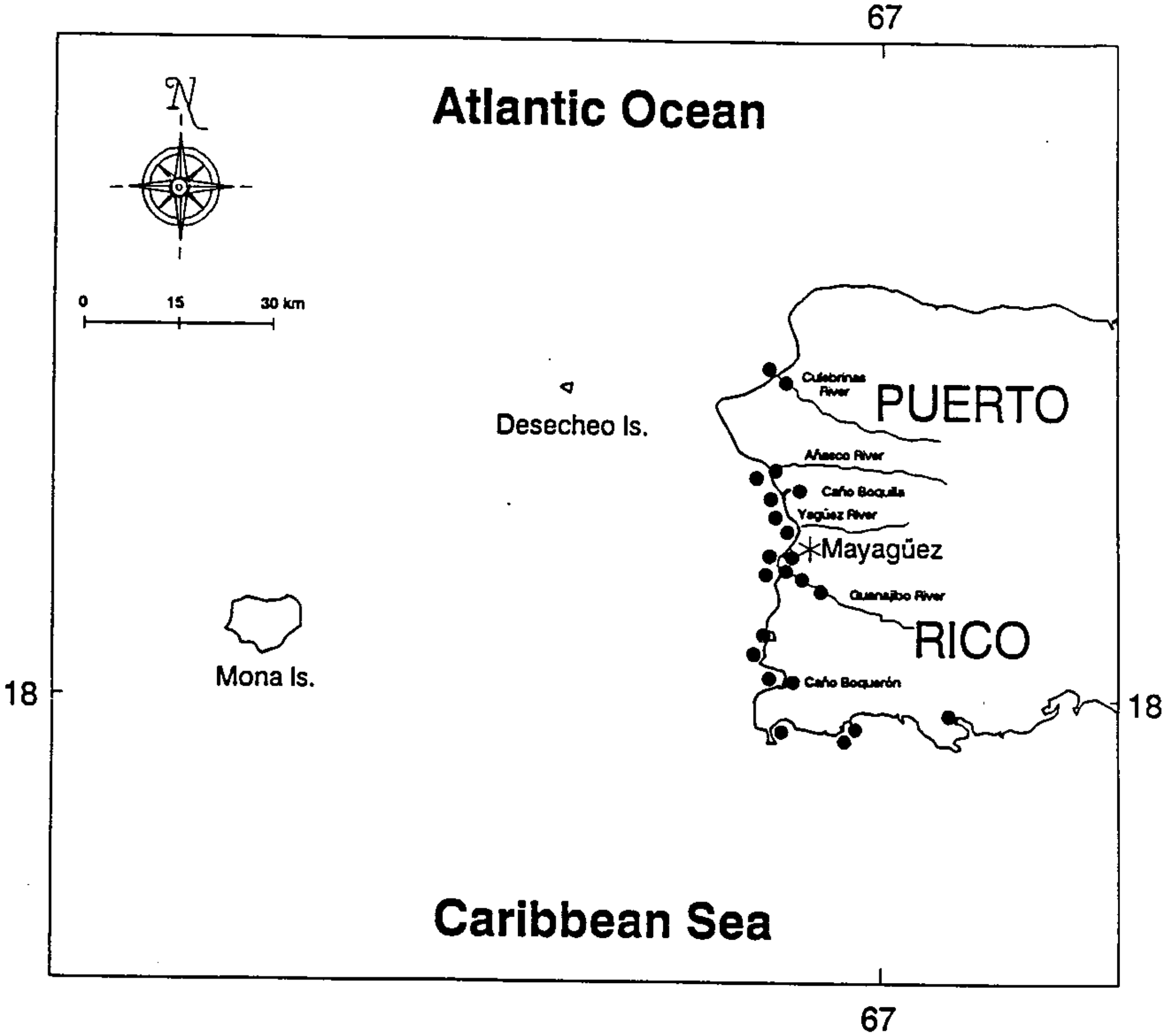


Figure 1. Map of western Puerto Rico showing the locations sampled from May, 1992 to December, 1995.

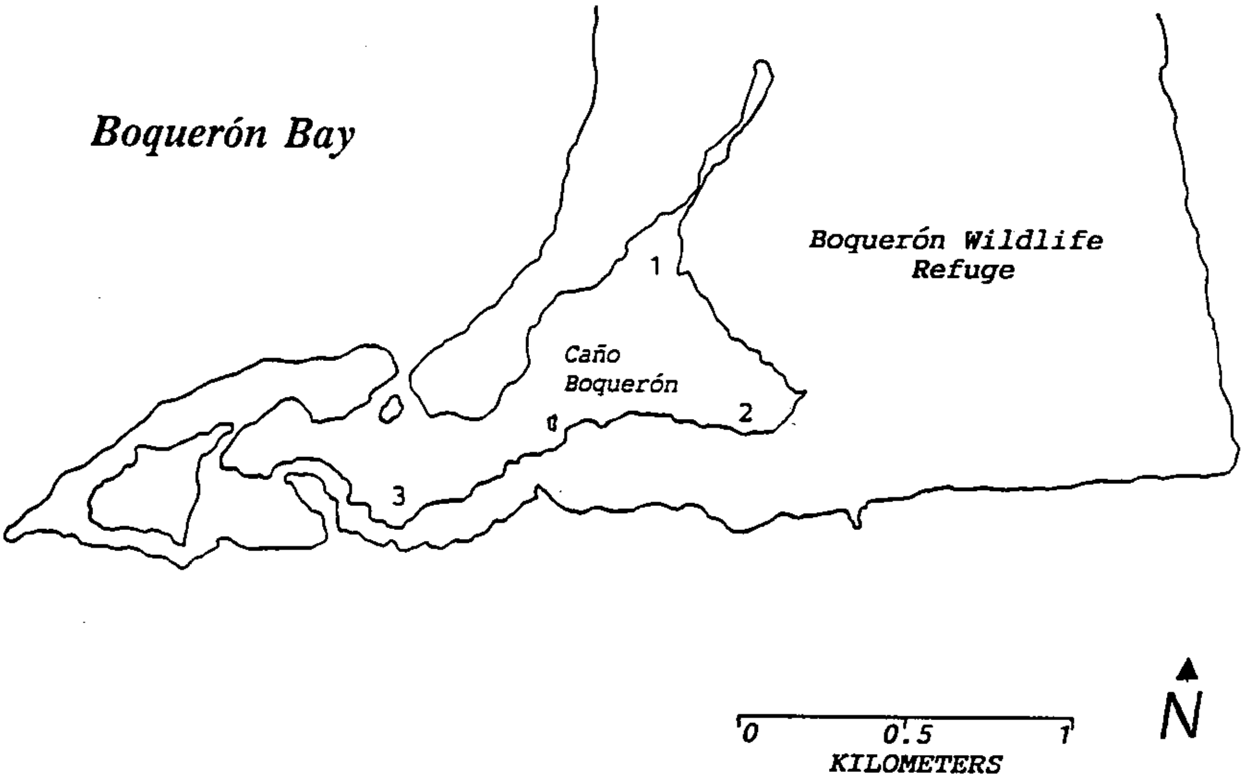


Figure 2. Map of Caño Boquerón area. Numbers indicate sampling stations.

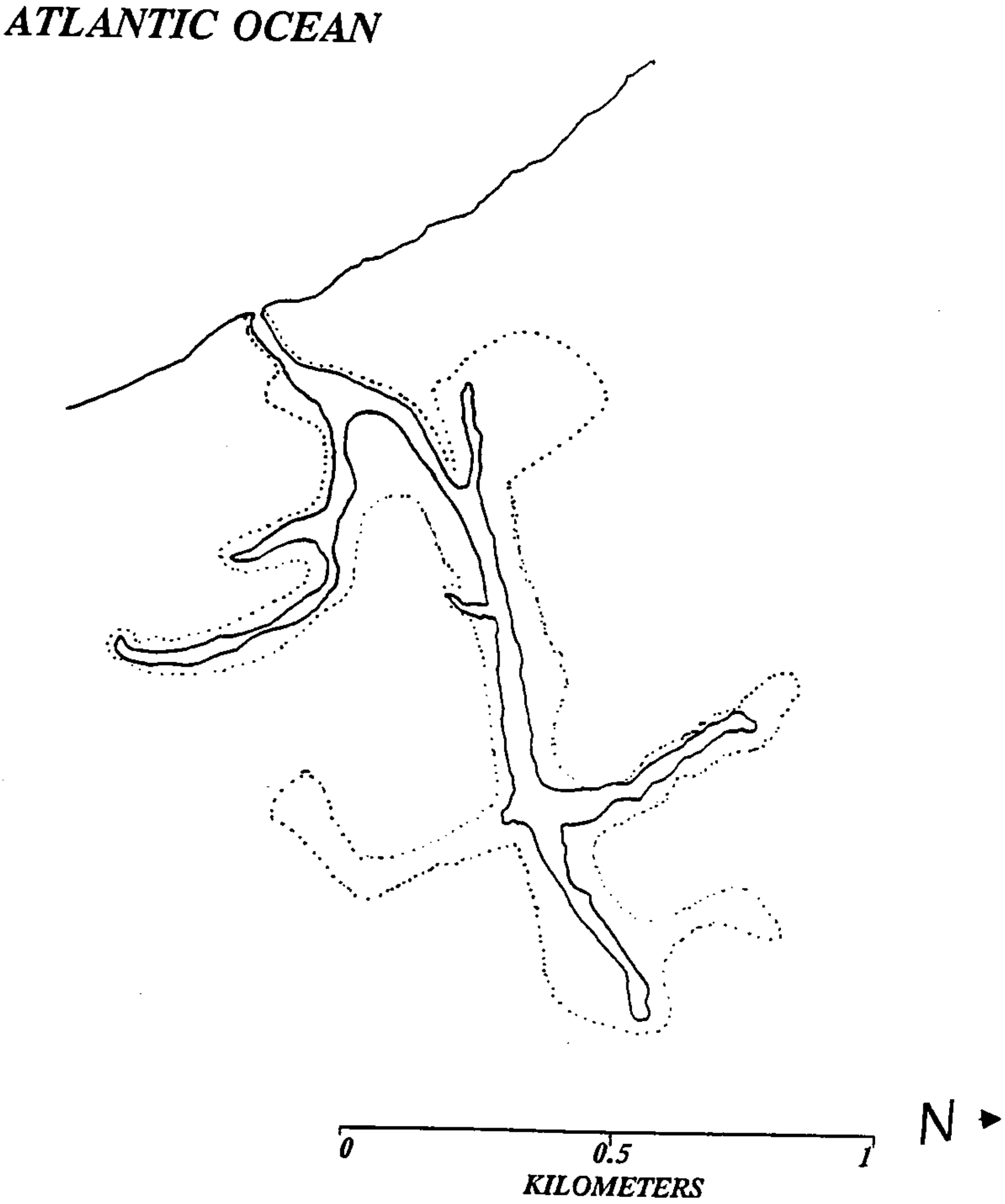


Figure 3. Map of Caño Boquilla.

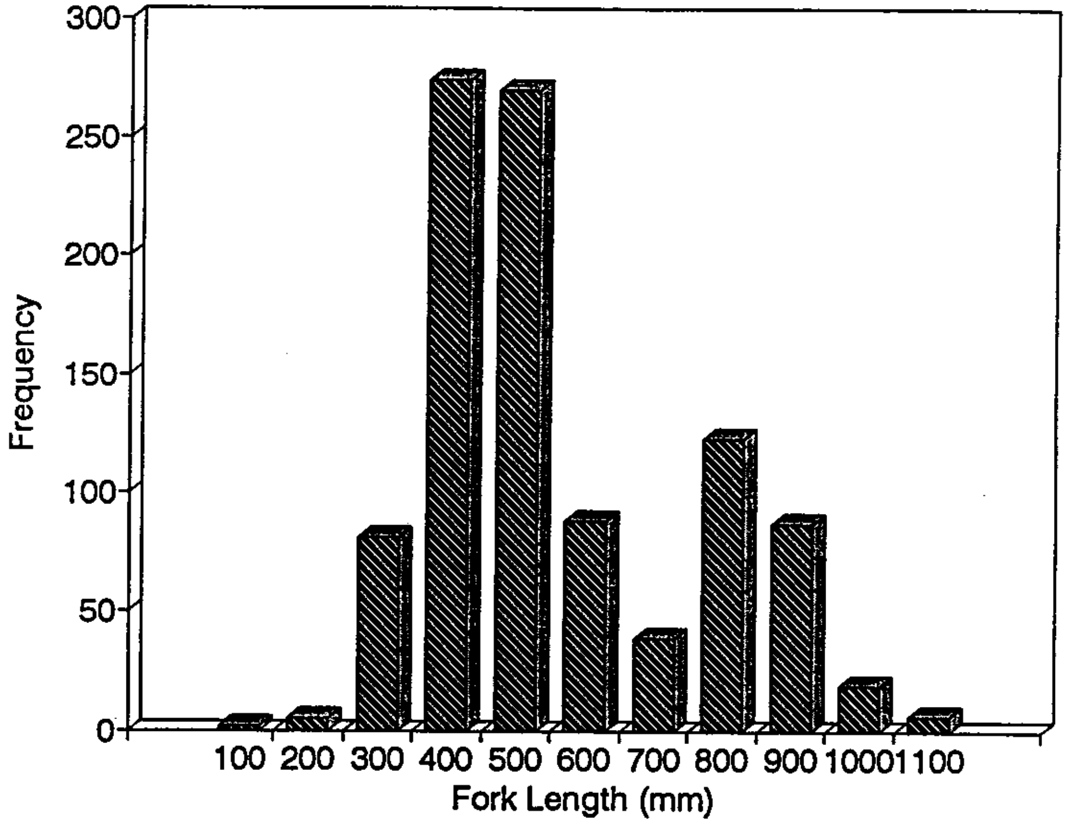


Figure 4. Size-frequency distribution of common snook collected between May, 1992 and December, 1995 (N = 994; mean = 505 mm FL; sd = 195.4).

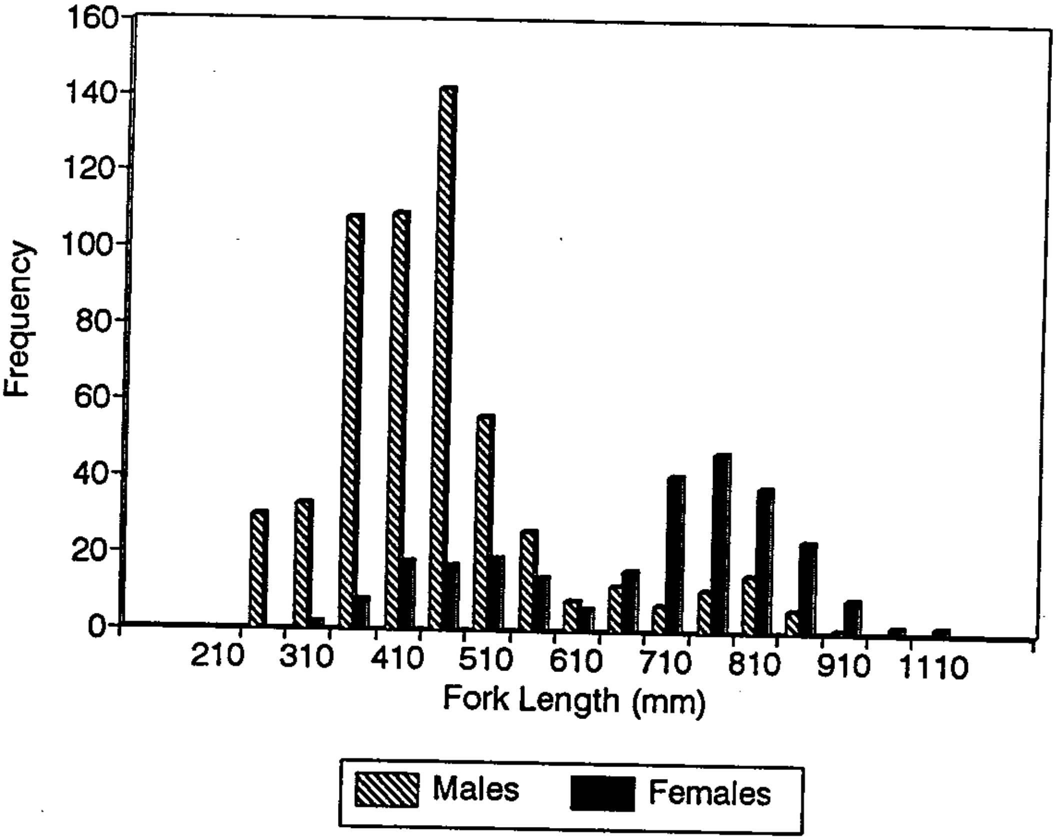


Figure 5. Size-frequency distribution of male (N = 564; mean = 426 mm FL; sd = 122.6) and female (N = 264; mean = 707 mm FL; sd = 160.4) common snook collected between May, 1992 and December, 1995.

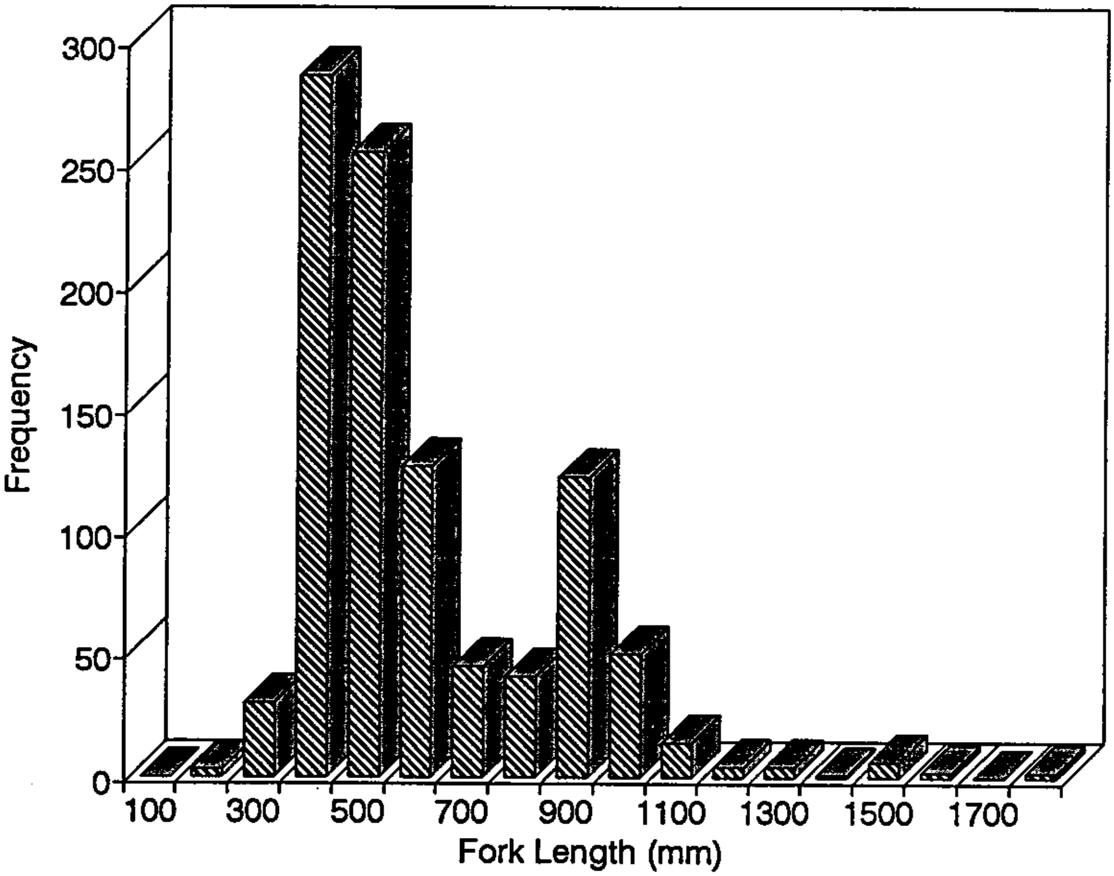


Figure 6. Size-frequency distribution of tarpon collected between May, 1992 and December, 1995 (N = 993; mean = 548 mm FL; sd = 235.5).

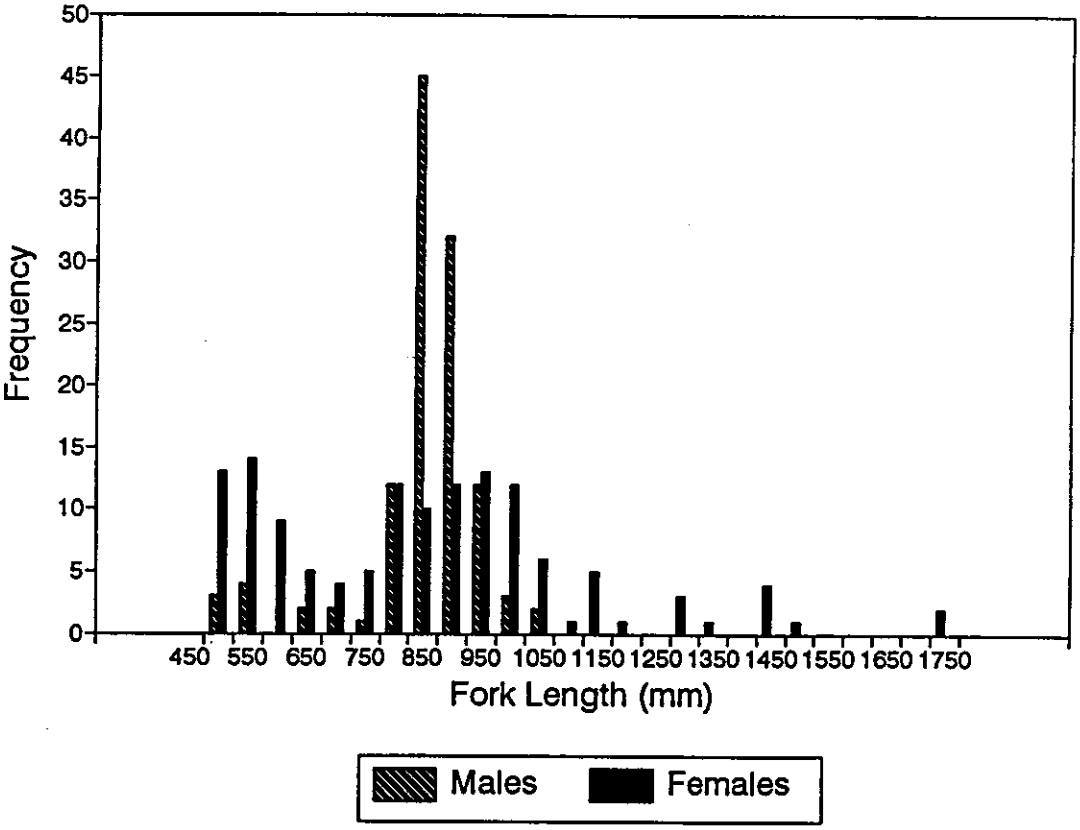


Figure 7. Size-frequency distribution of male (N = 118; mean = 826 mm FL; sd = 99.4) and female (N = 133; mean = 825 mm FL; sd = 266.5) tarpon collected between May, 1992 and December, 1995.

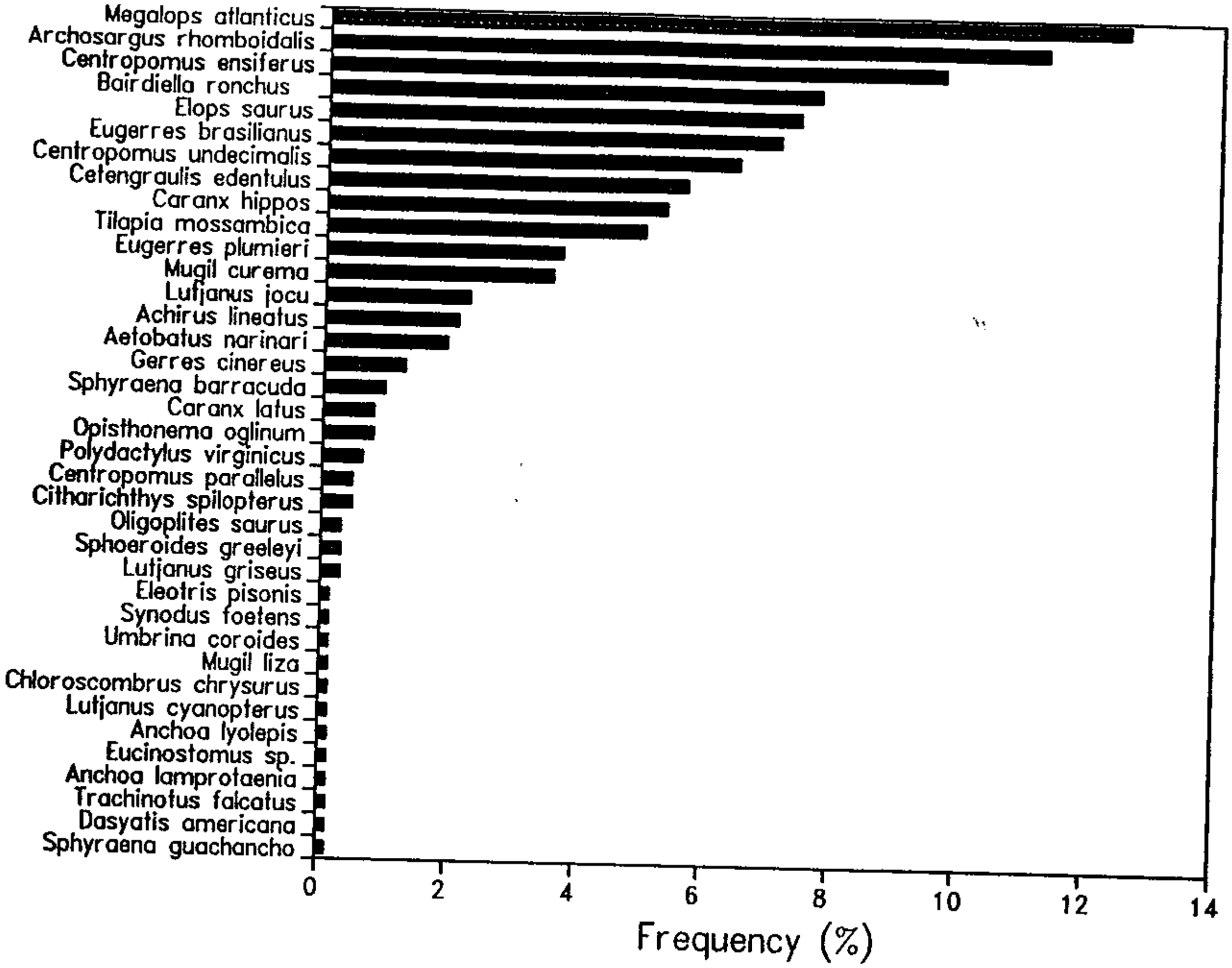


Figure 8. Relative abundance of species collected at Caño Boquerón.

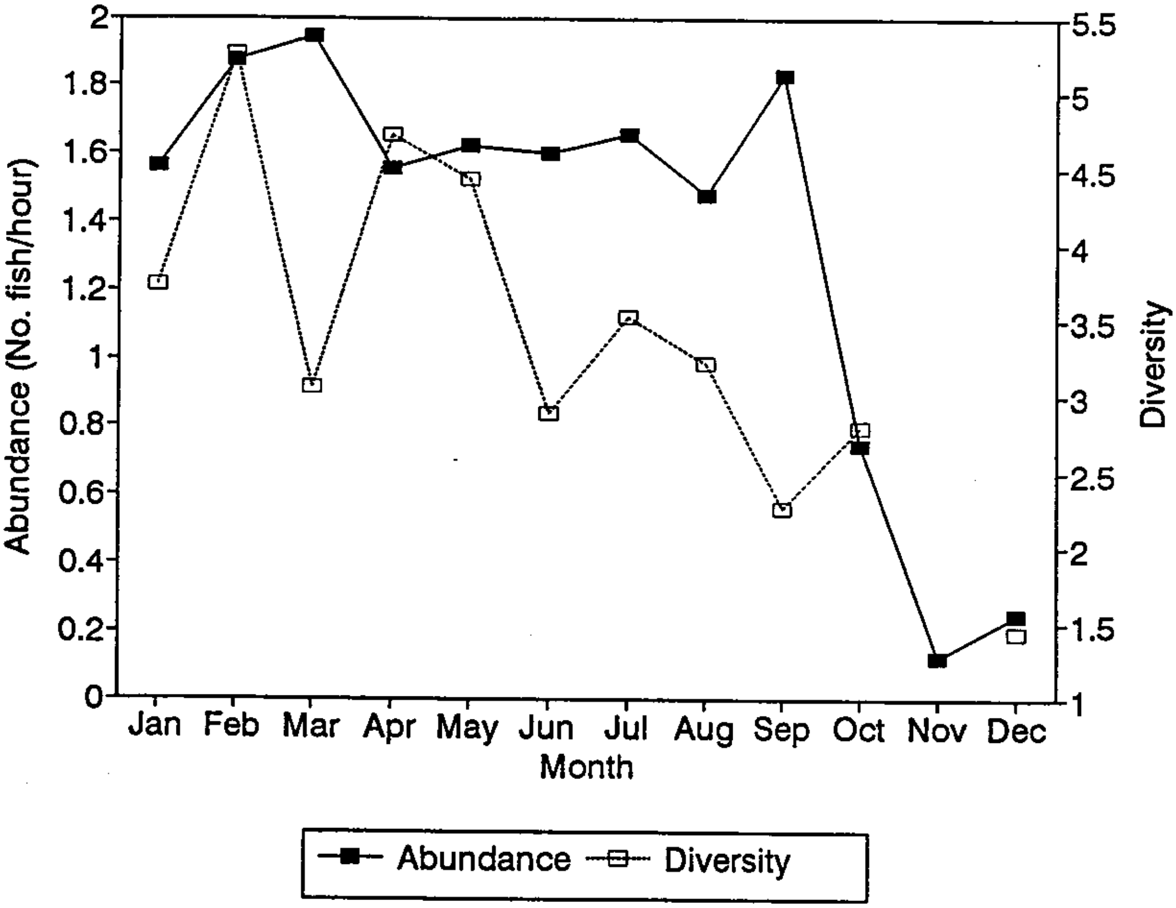
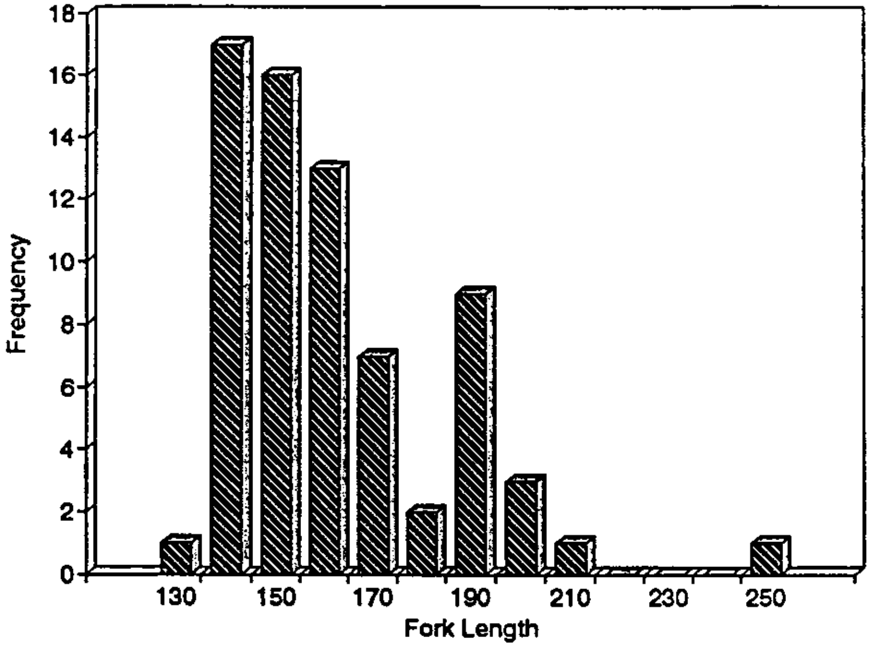
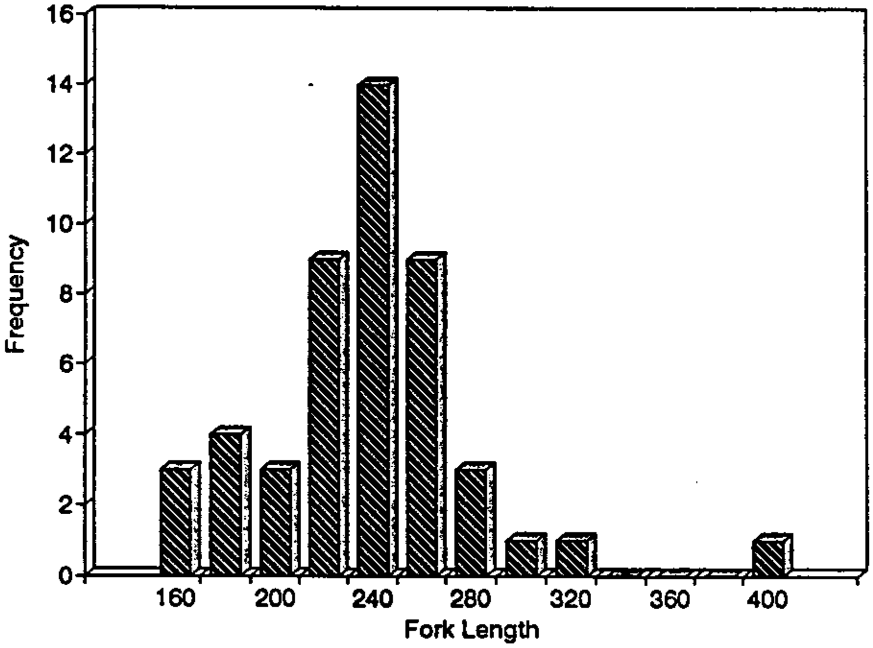


Figure 9. Seasonal variation in fish abundance and diversity at Caño Boquerón during 1995.

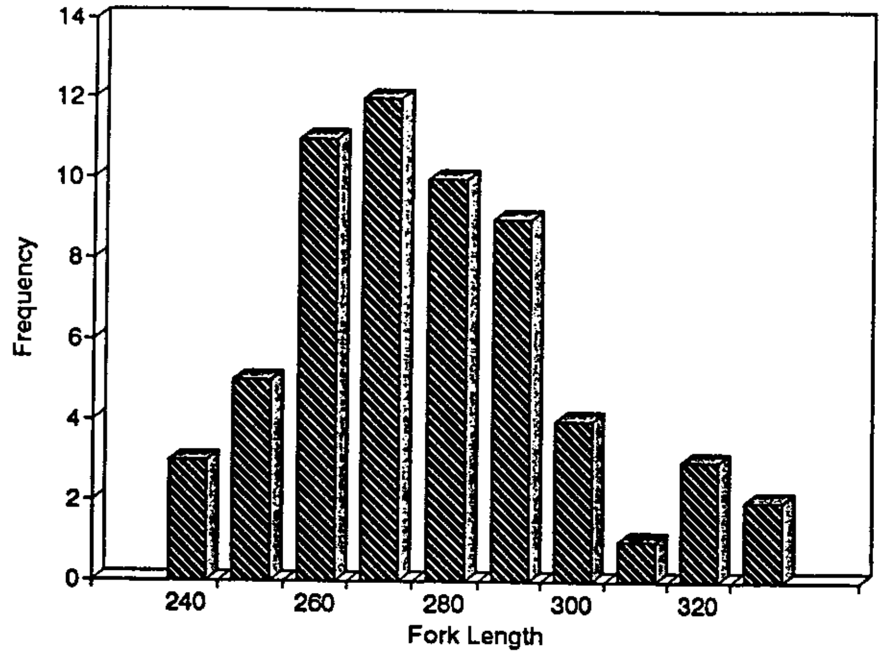


Archosargus rhomboidalis

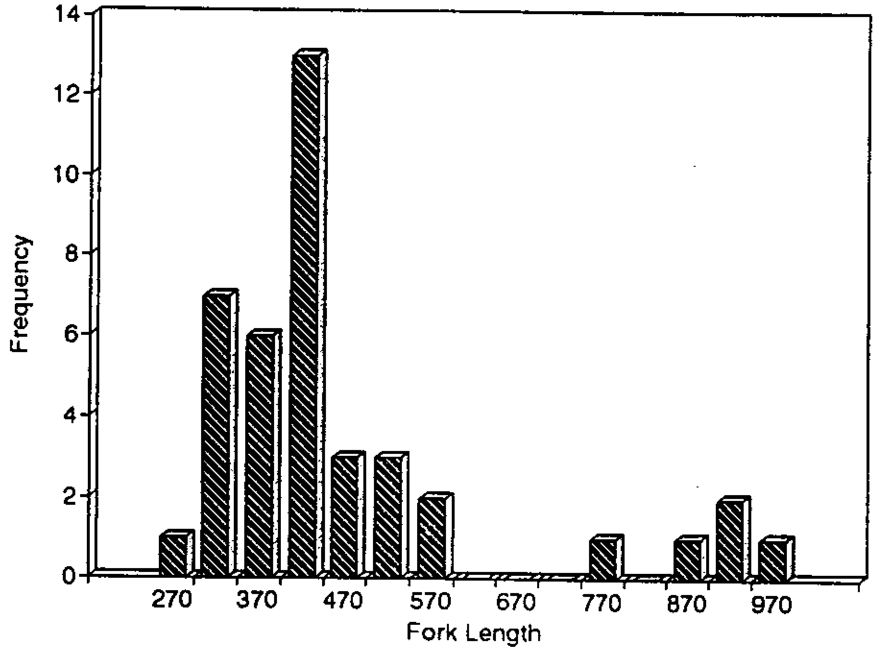


Bairdiella ronchus

Figure 10. Size-frequency distributions of Archosargus rhomboidalis (upper) and Bairdiella ronchus (lower) collected at Caño Boquerón.

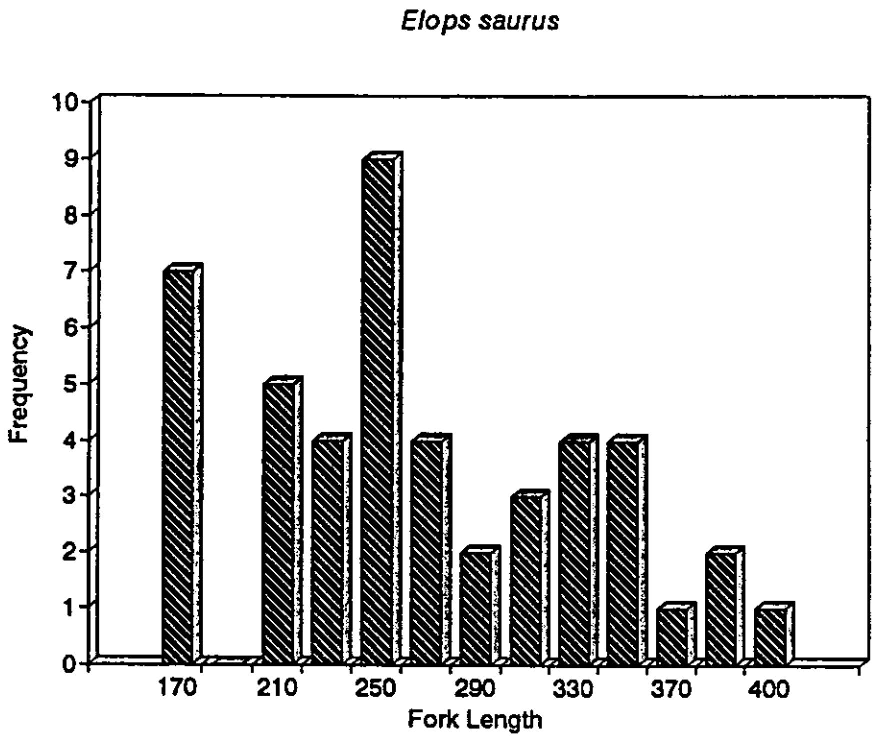


Centropomus ensiferus



Centropomus undecimalis

Figure 11. Size-frequency distributions of Centropomus ensiferus (upper) and Centropomus undecimalis (lower) collected at Caño Boquerón.



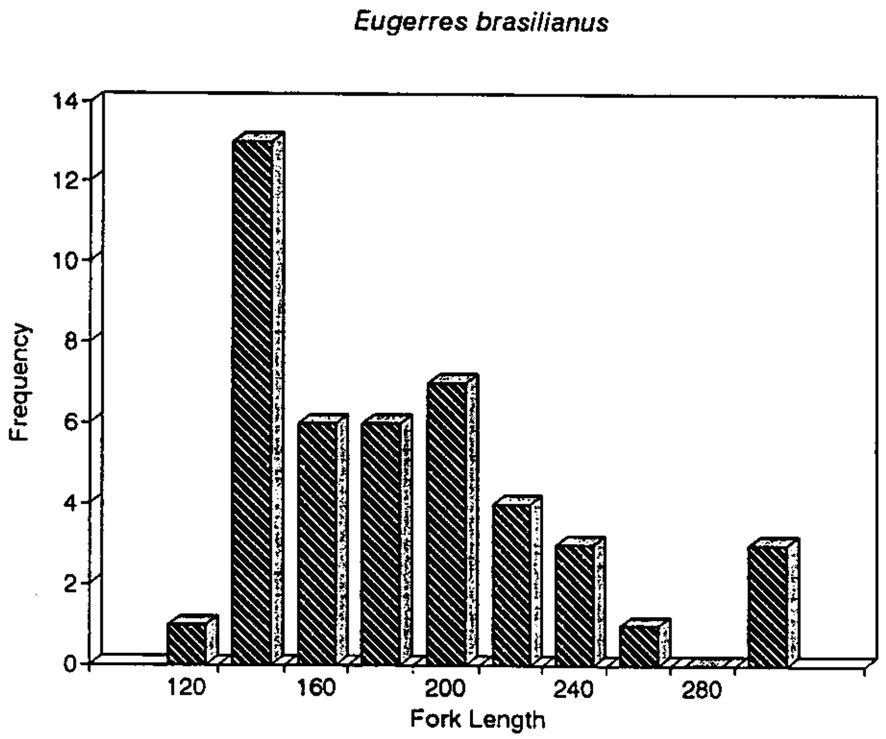


Figure 12. Size-frequency distributions of Elops saurus (upper) and Eugerres brasilianus (lower) collected at Caño Boquerón.

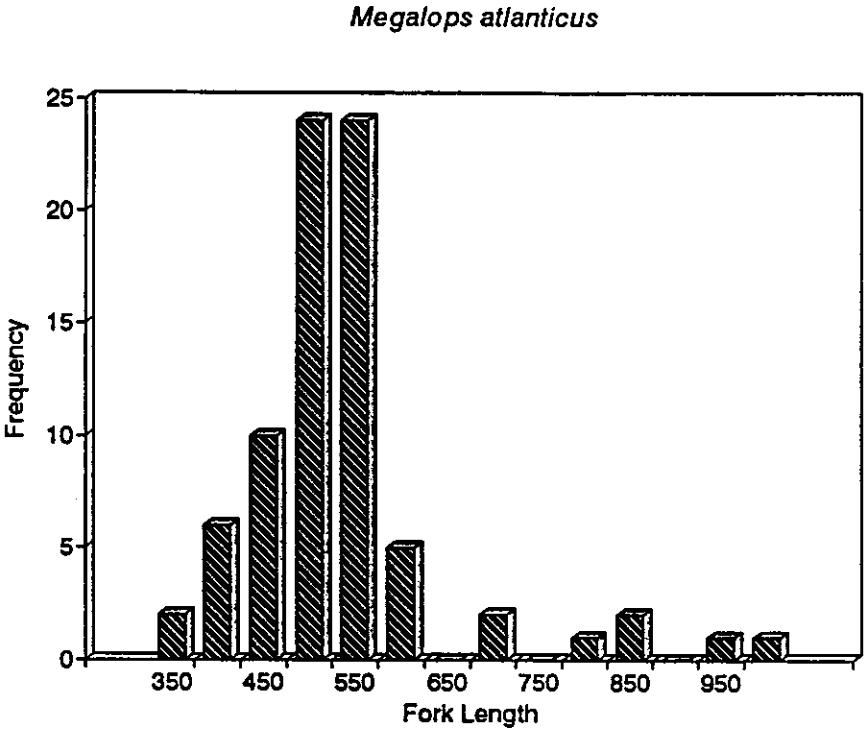


Figure 13. Size-frequency distribution of Megalops atlanticus collected at Caño Boquerón.

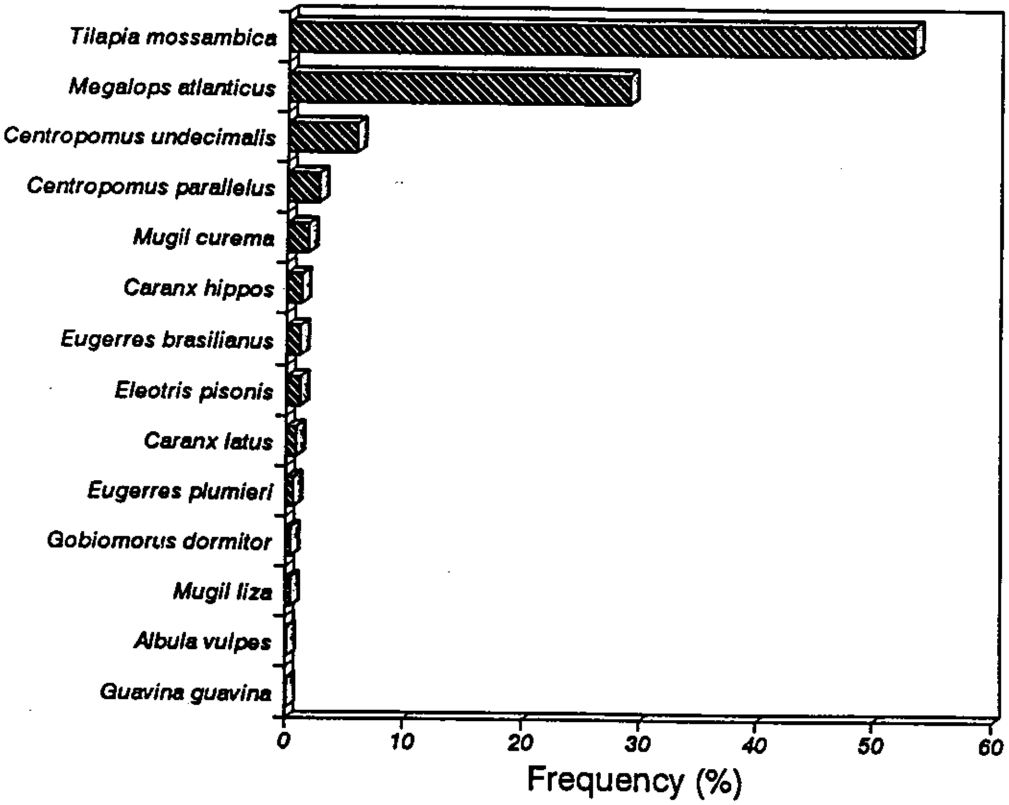


Figure 14. Relative abundance of species collected at Caño Boquilla.

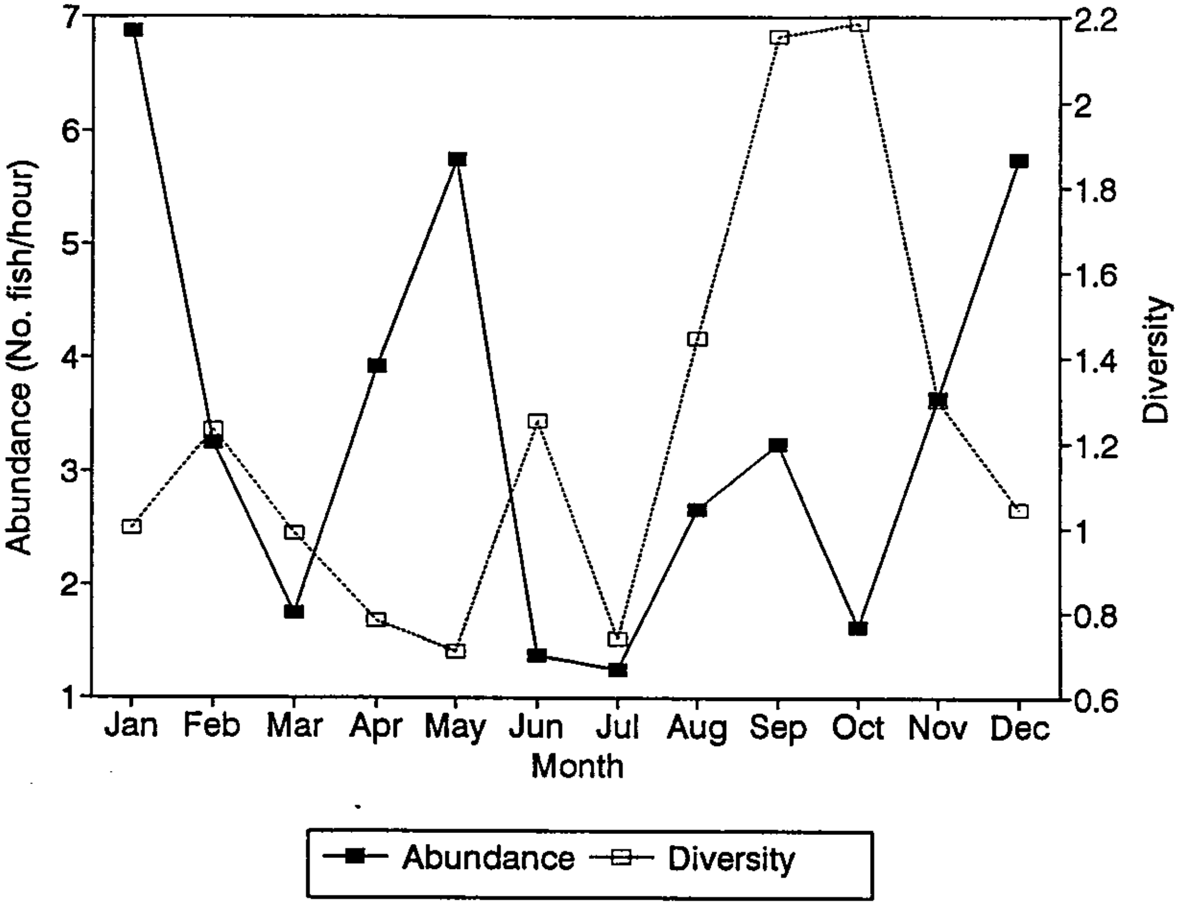
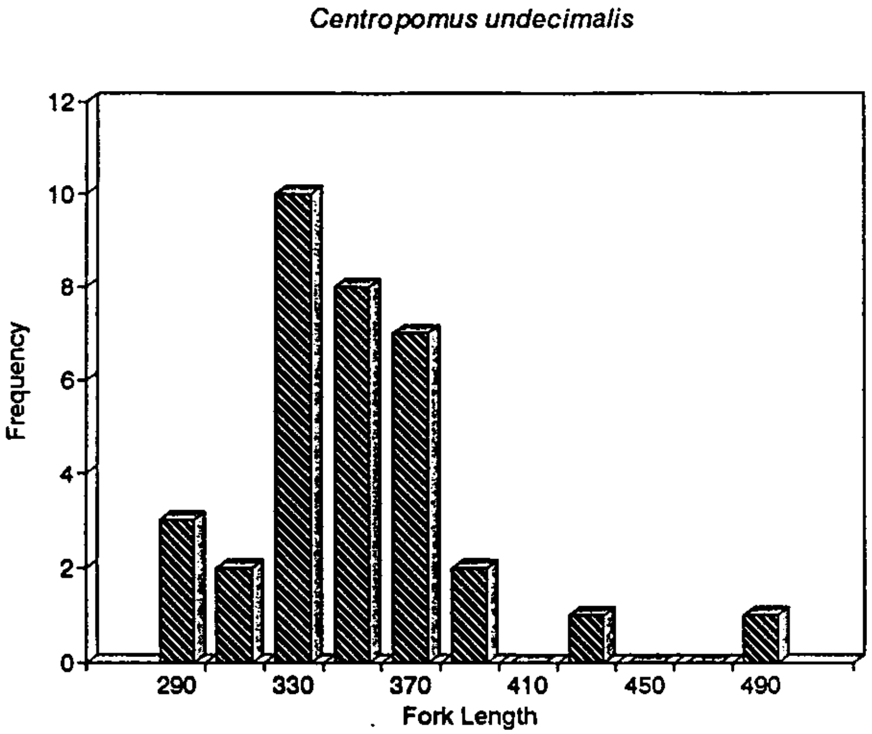


Figure 15. Seasonal variation in fish abundance and diversity at Caño Boquilla during 1995.



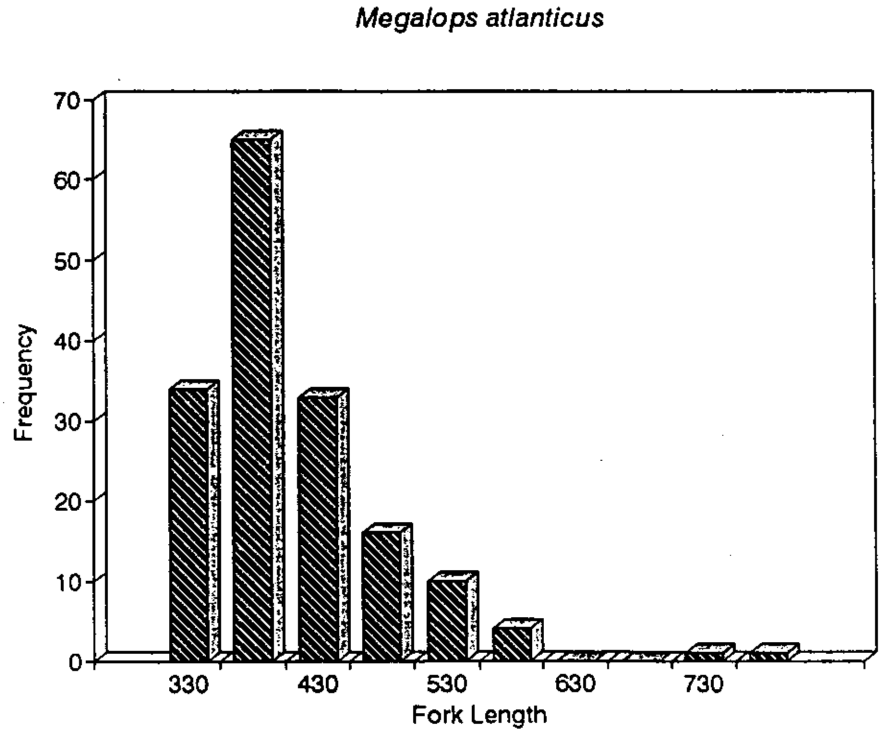


Figure 16. Size-frequency distributions of Centropomus undecimalis (upper) and Megalops atlanticus (lower) collected at Caño Boquilla.

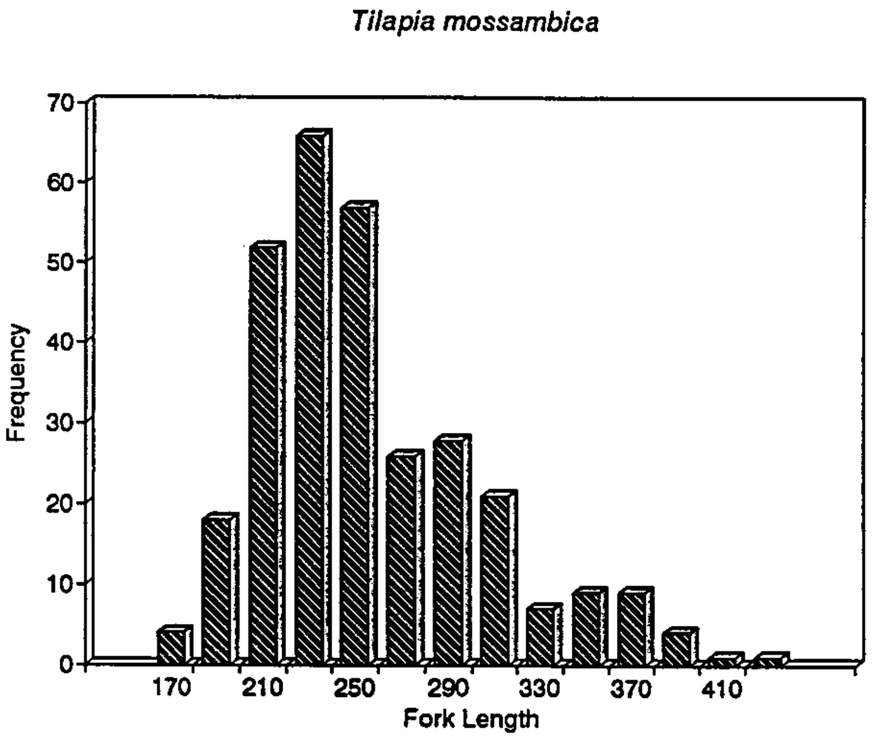
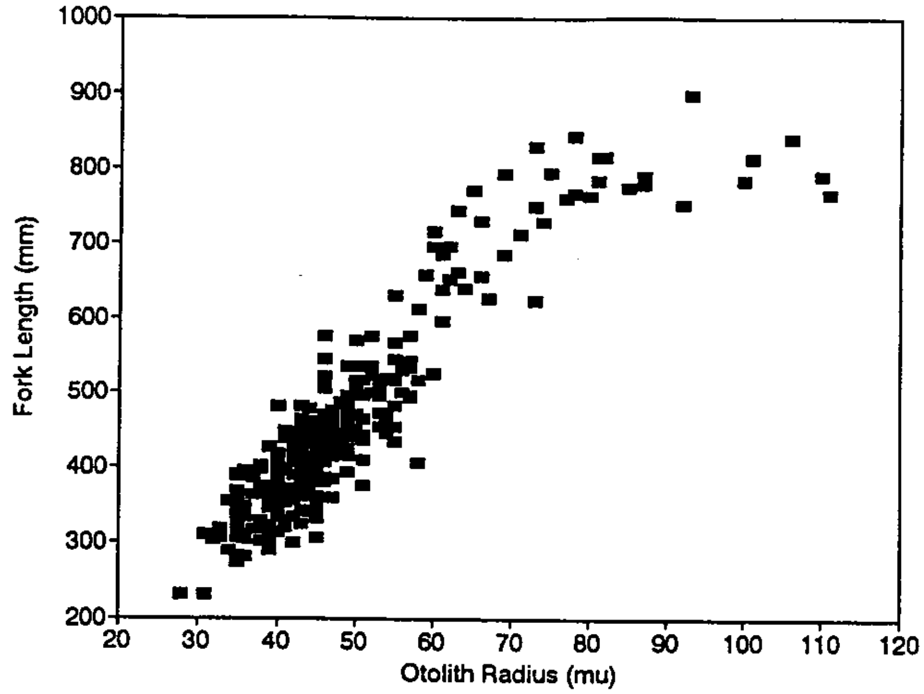


Figure 17. Size-frequency distribution of Tilapia mossambica collected at Caño Boquilla.



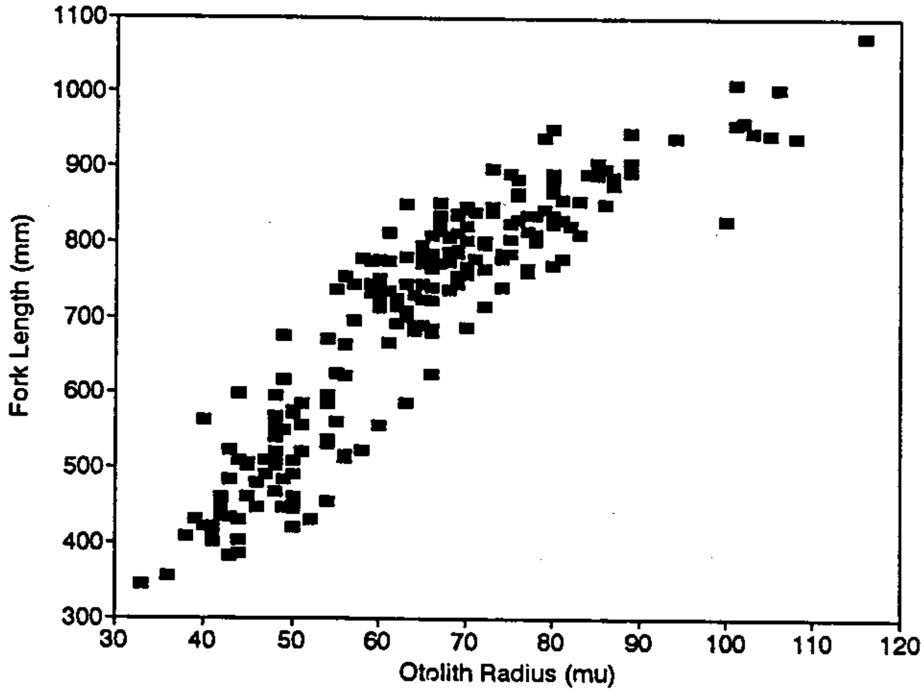


Figure 18. Relationships between otolith radius and fork length for male (upper) and female (lower) Centropomus undecimalis.

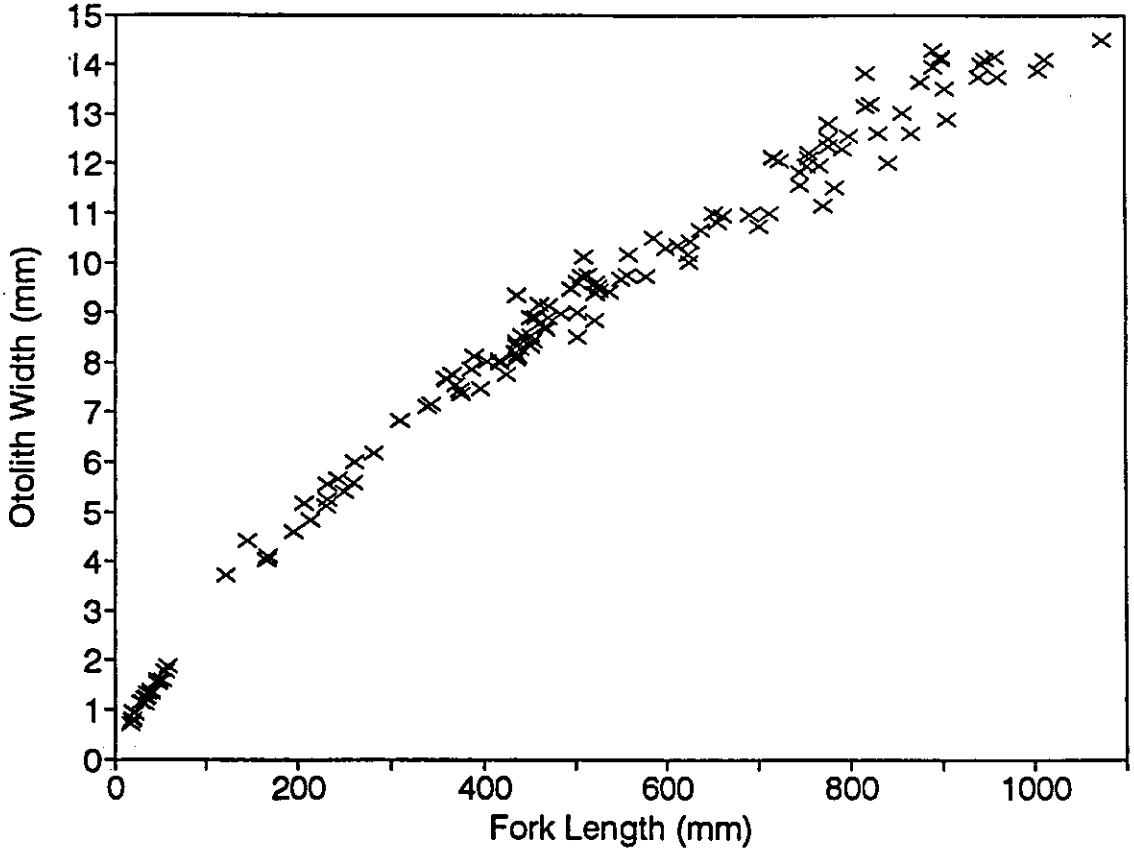


Figure 19. Relationship between unsectioned otolith width and fork length for Centropomus undecimalis (sexes combined).

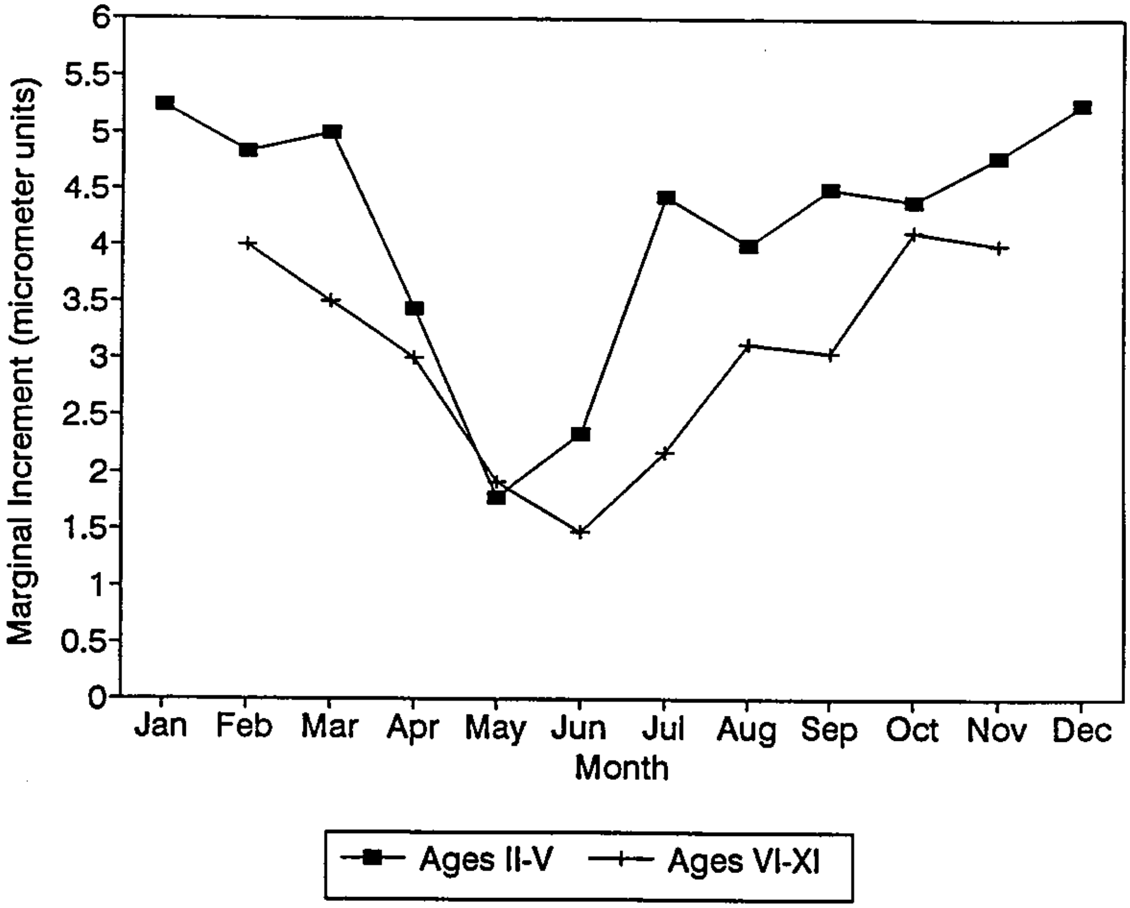


Figure 20. Marginal increment analysis for age groups II - V and VI - XI for Centropomus undecimalis (sexes combined).

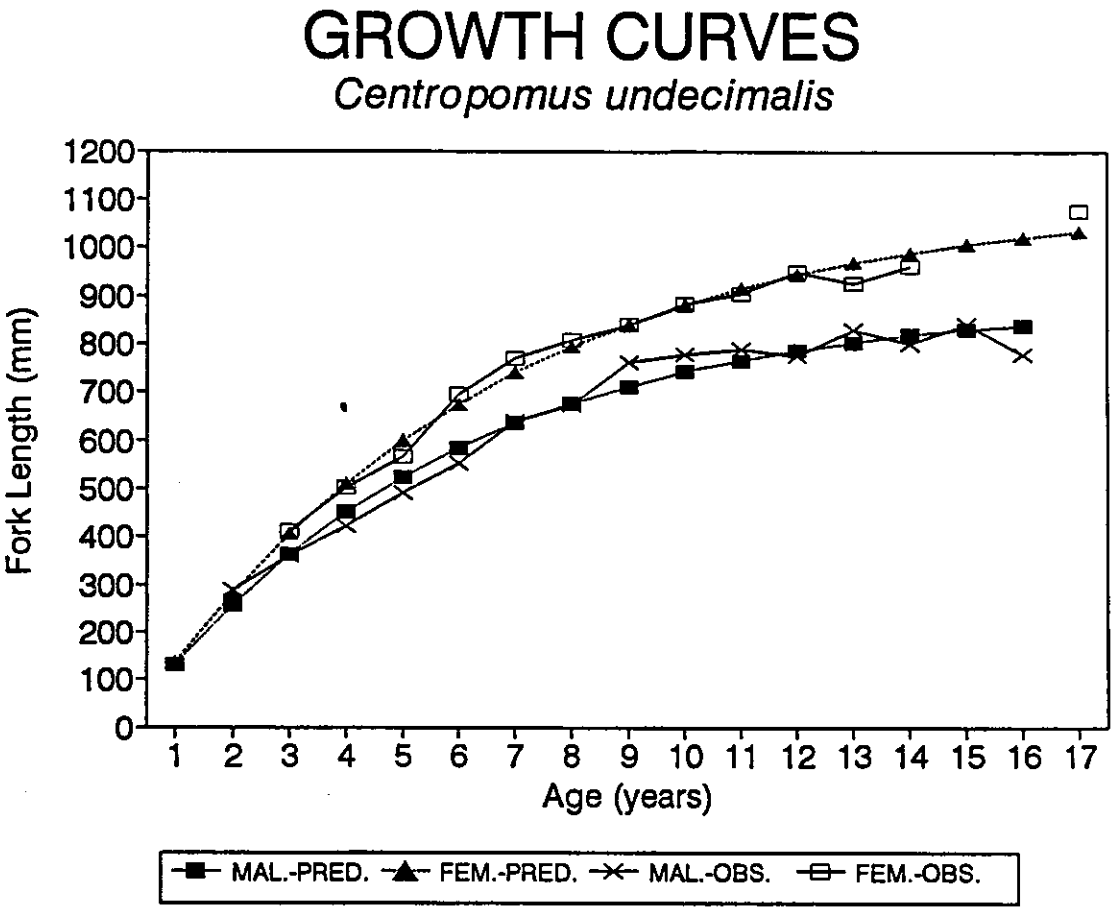


Figure 21. Observed and predicted (von Bertalanffy) growth curves for male and female Centropomus undecimalis.

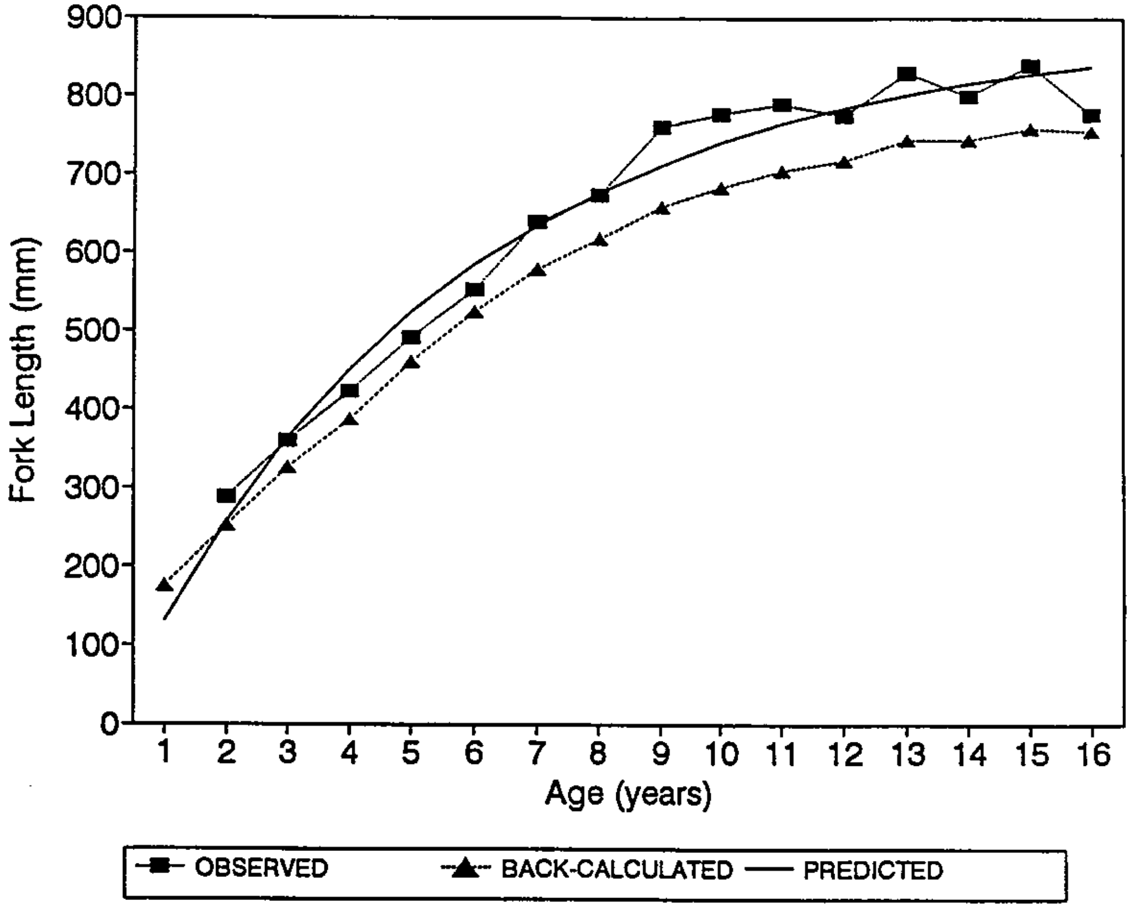


Figure 22. Observed, back-calculated, and predicted (von Bertalanffy) growth curves for male *Centropomus undecimalis*.

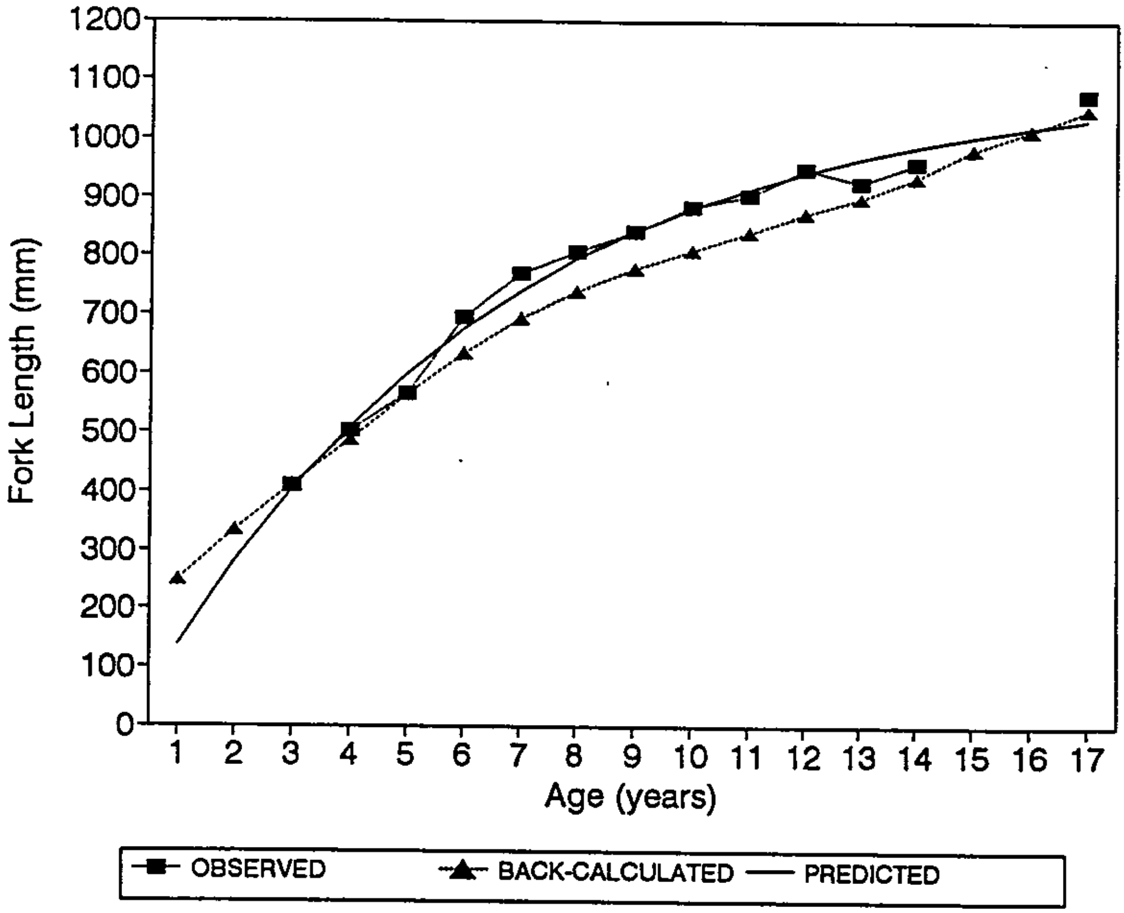


Figure 23. Observed, back-calculated, and predicted (von Bertalanffy) growth curves for female Centropomus undecimalis.

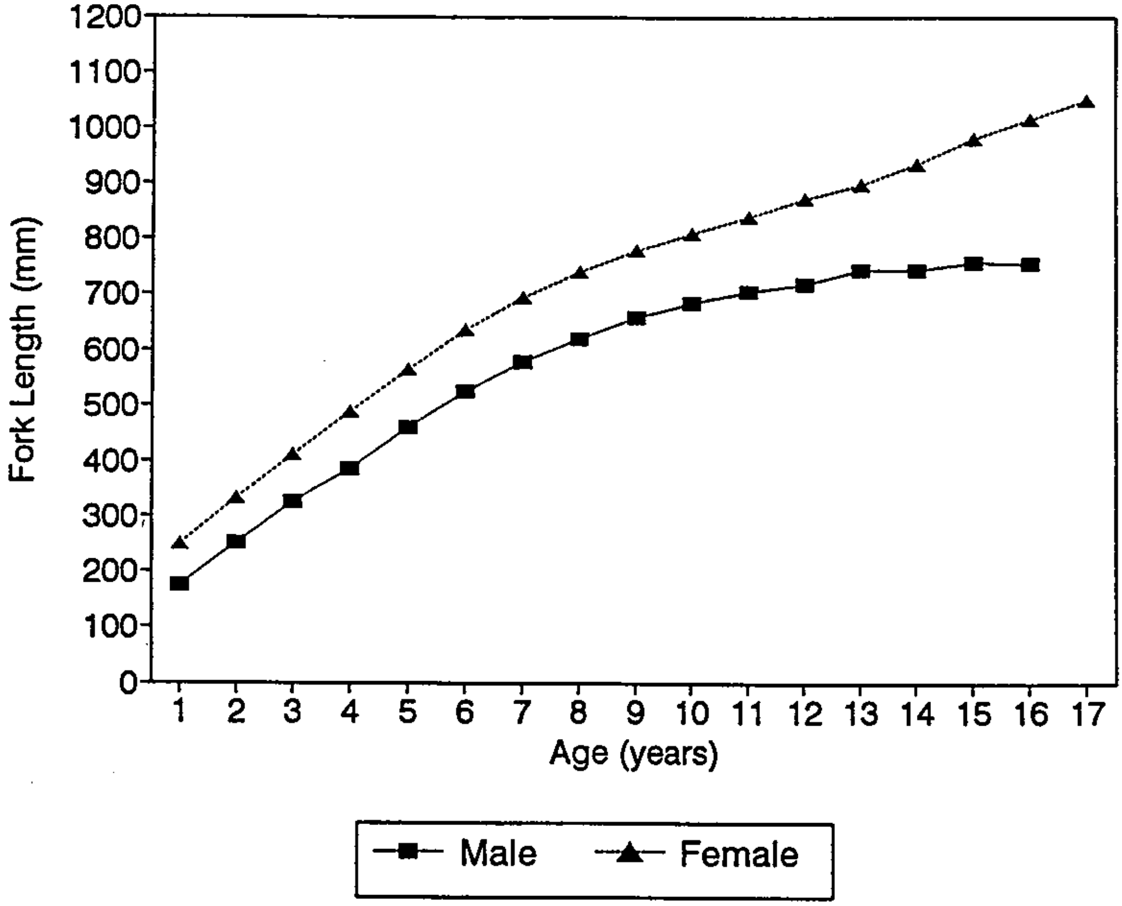


Figure 24. Back-calculated growth curves for male and female Centropomus undecimalis.

Figure 25. **Catch curve for male** **<u>Centropomus</u> <u>undecimalis</u>.** **Ages 4 - 14 included for Z estimation.**

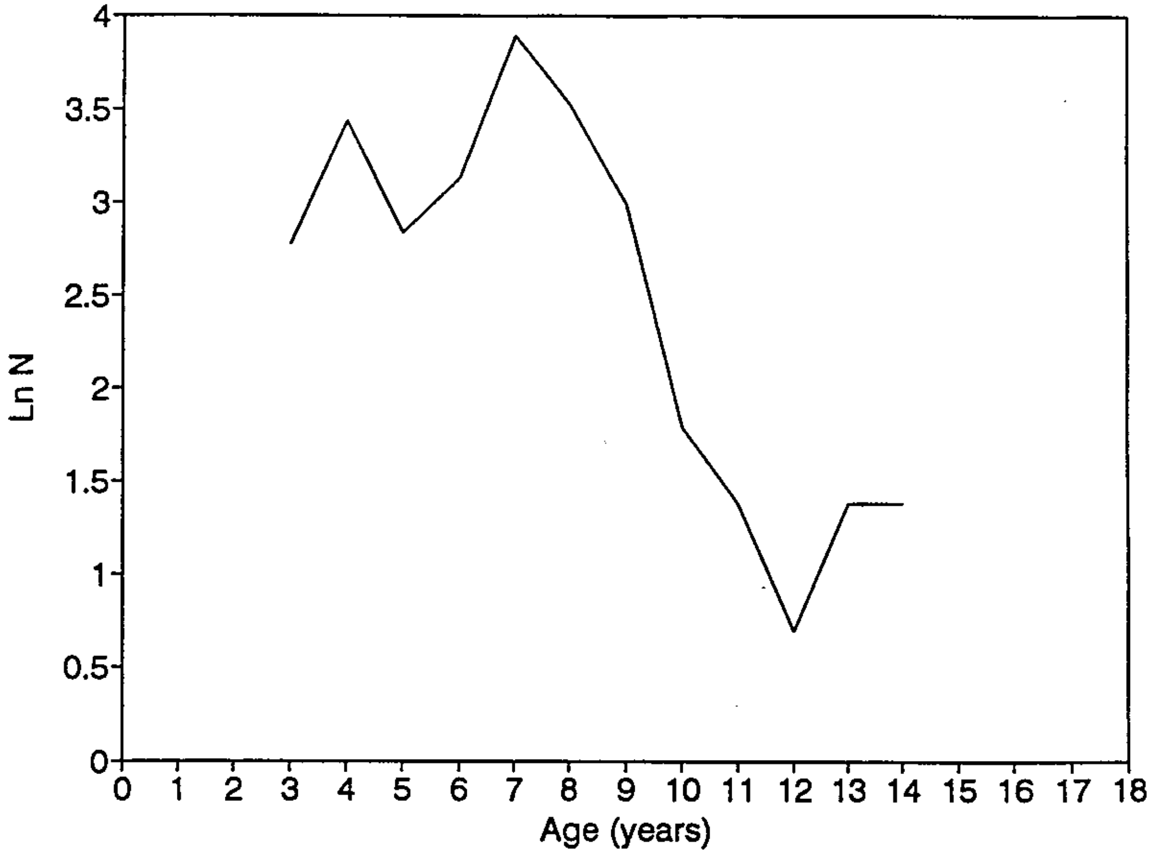


Figure 26. Catch curve for female Centropomus undecimalis. Ages 7 - 11 included for Z estimation.

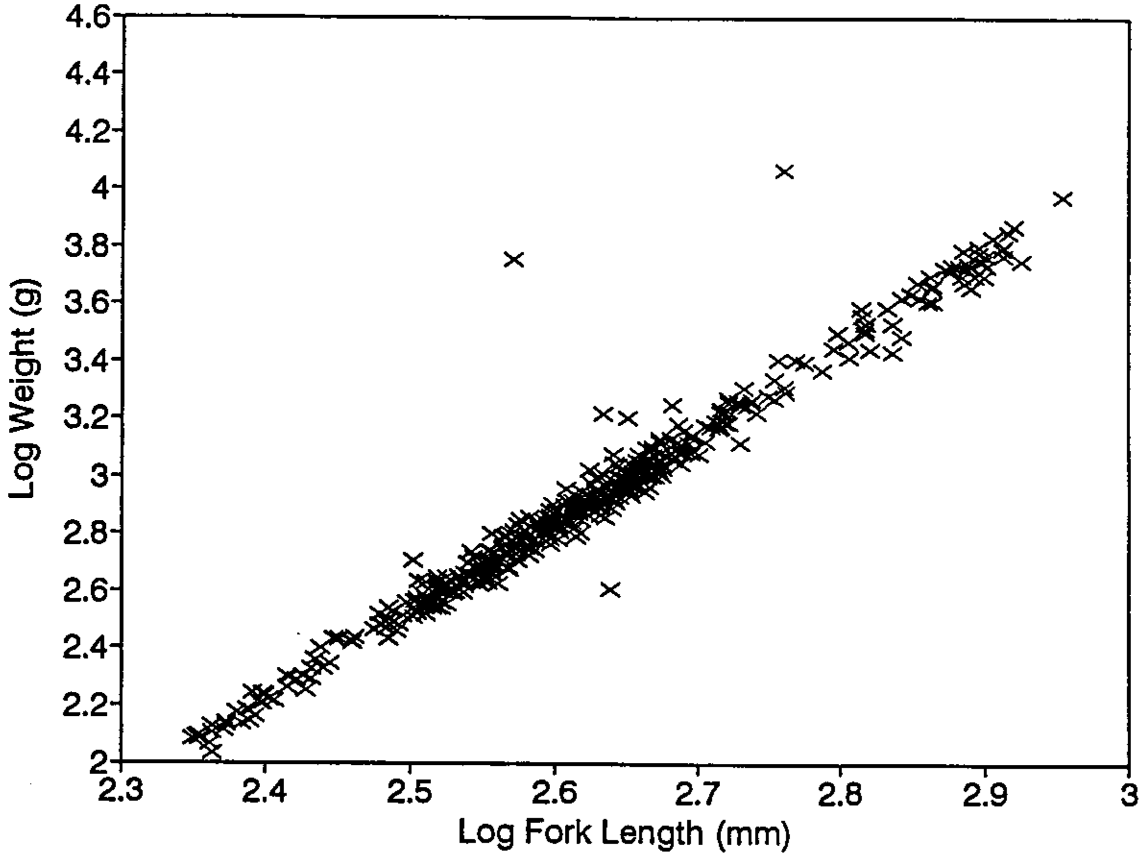


Figure 27. Relationship between log weight and log fork length for male Centropomus undecimalis.

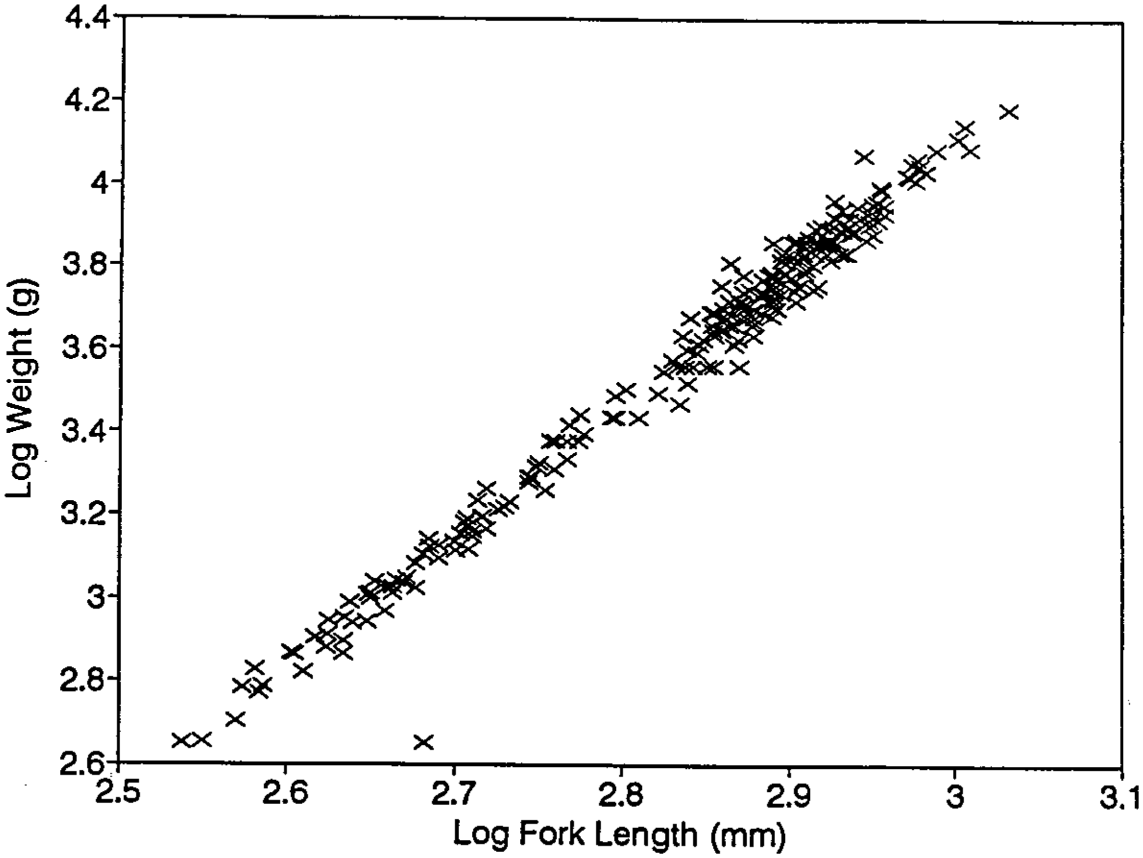


Figure 28. Relationship between log weight and log fork length for female Centropomus undecimalis.

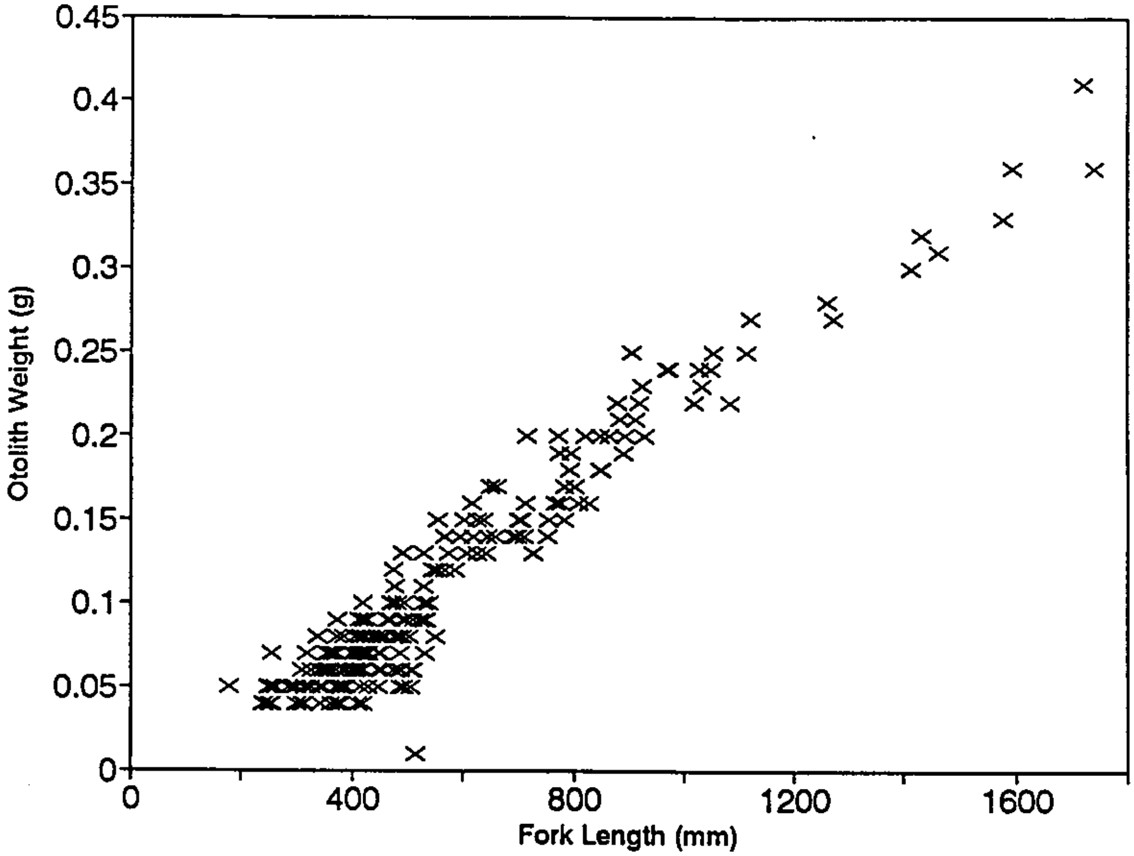


Figure 29. Relationship between otolith weight and fork length for *Megalops atlanticus* (sexes combined).

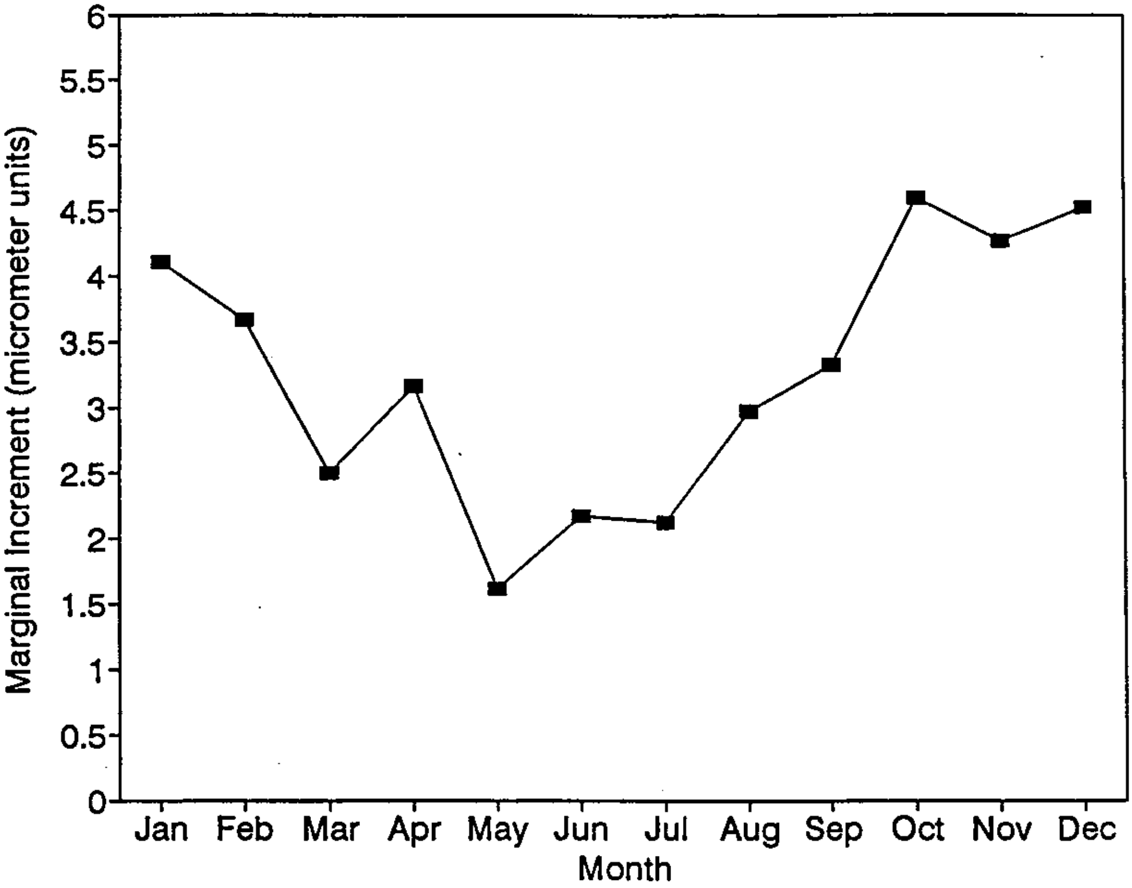


Figure 30. Marginal increment analysis for age group II - IX for Megalops atlanticus (sexes combined).

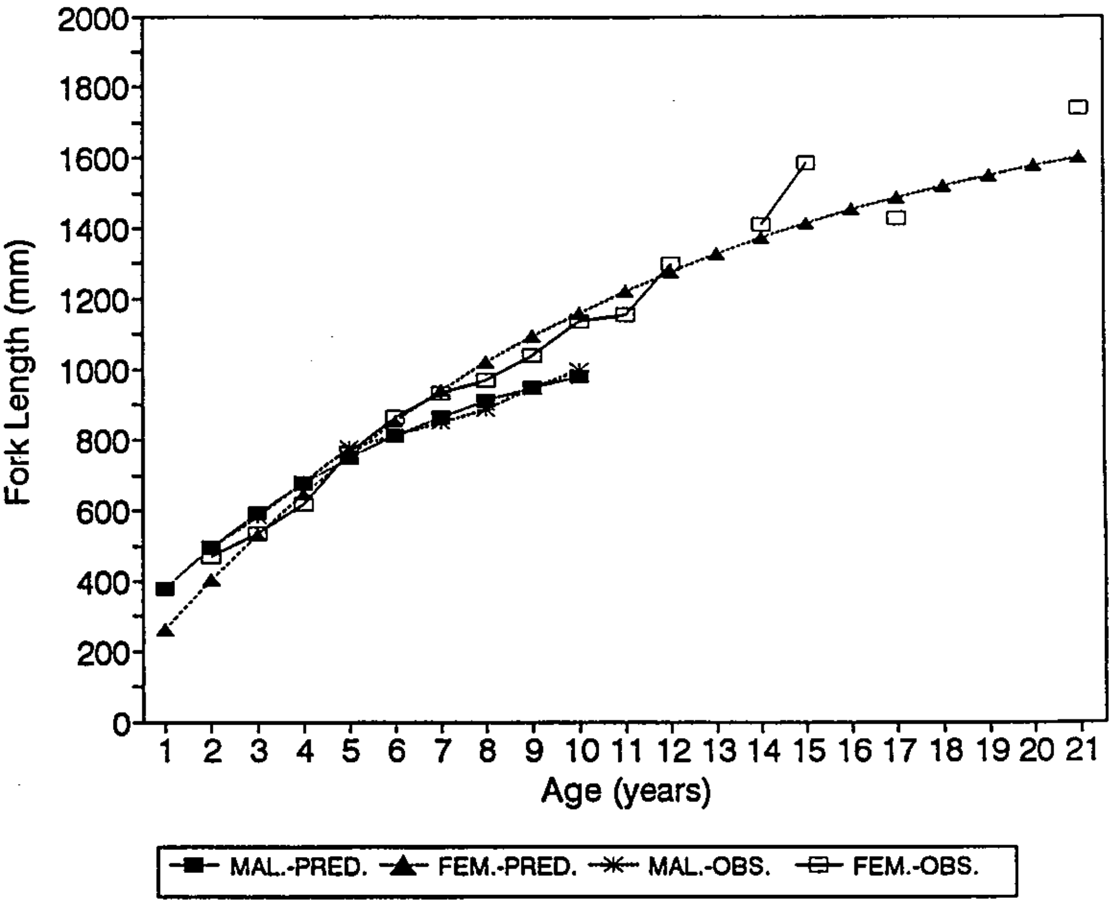


Figure 31. Observed and predicted (von Bertalanffy) growth curves for male and female Megalops atlanticus.

Figure 32. Catch curve for male Megalops atlanticus. Ages 6 - 10 included for Z estimation.

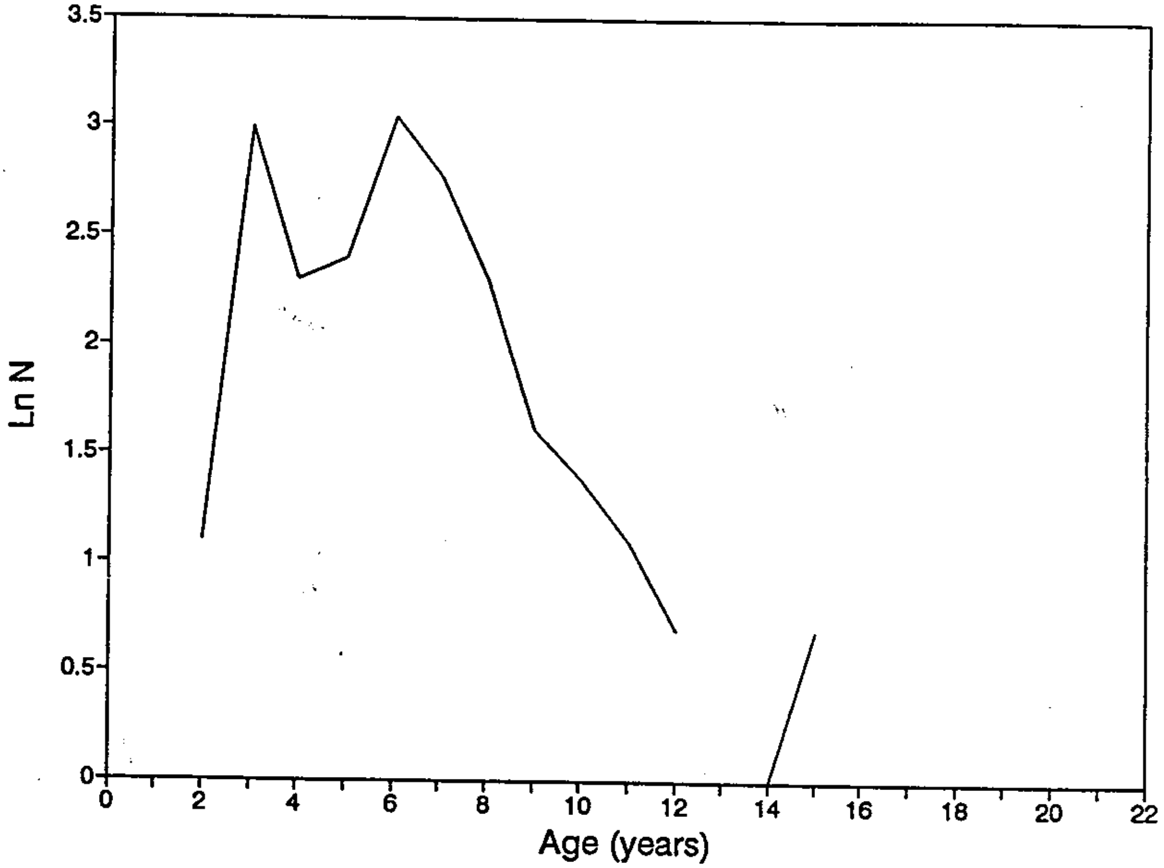


Figure 33. Catch curve for female Megalops atlanticus. Ages 6 - 12 included for Z estimation.

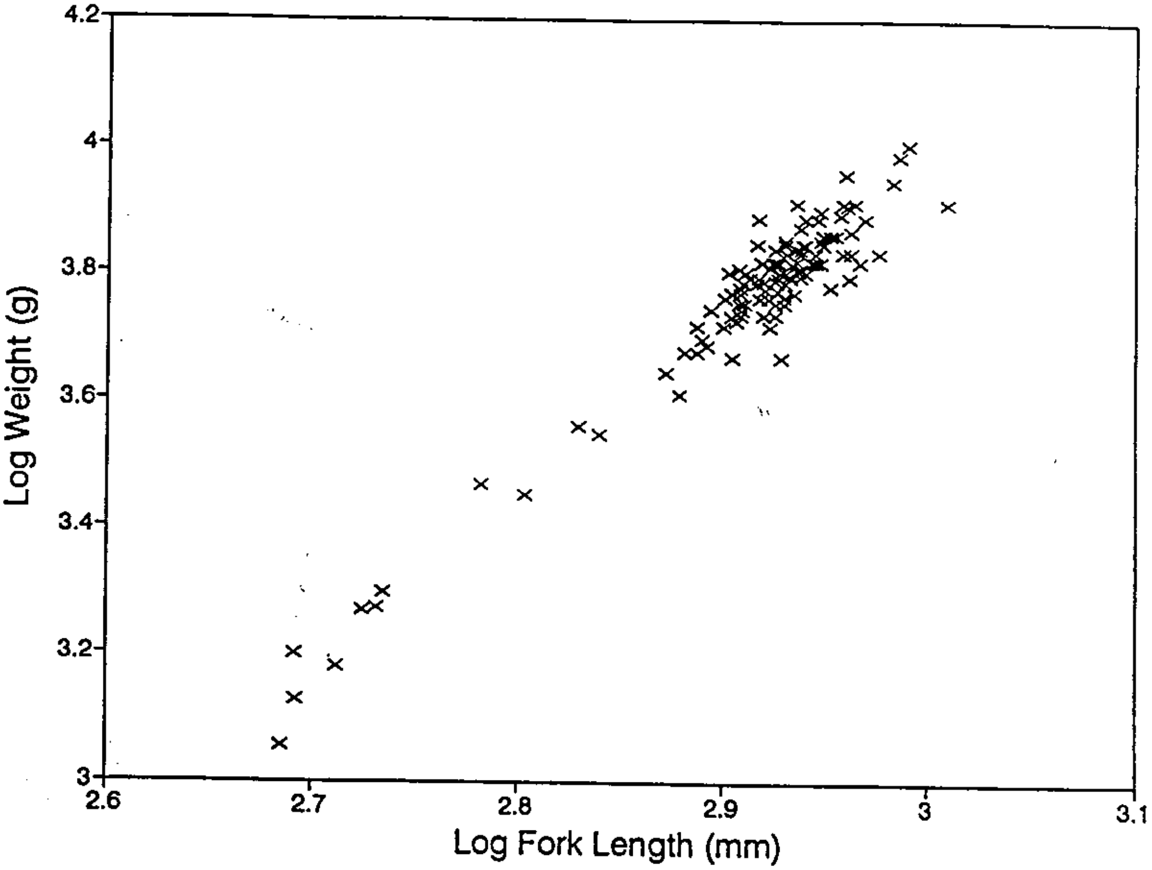


Figure 34. Relationship between log weight and log fork length for male Megalops atlantıcus.

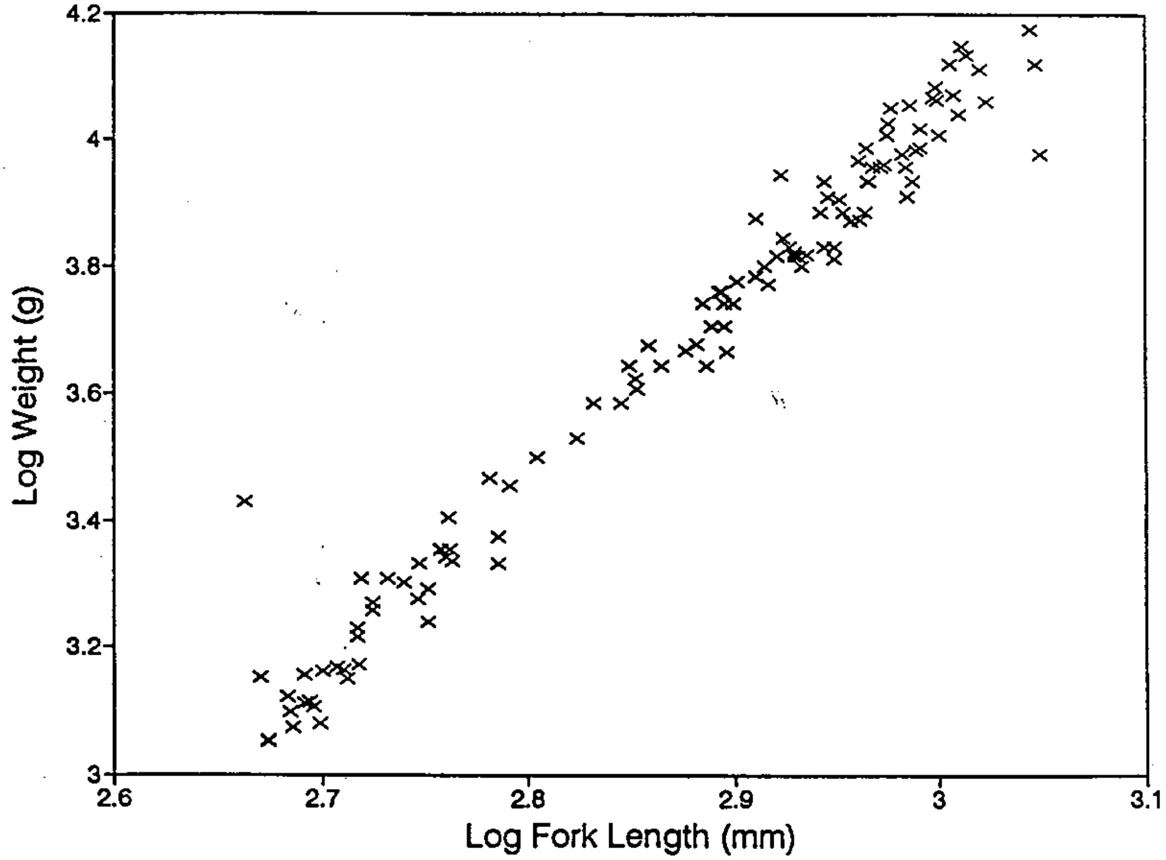


Figure 35. Relationship between log weight and log fork length for female Megalops atlanticus.

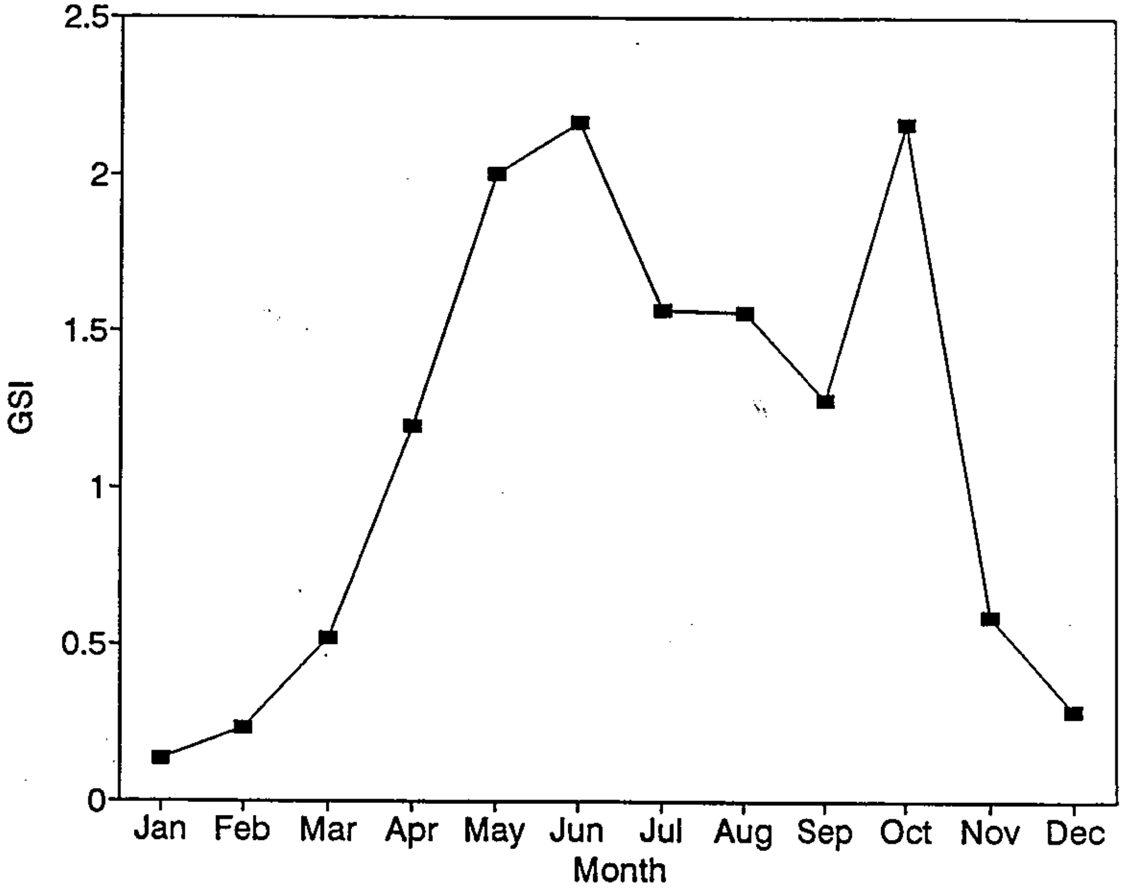


Figure 36. Mean gonosomatic index (GSI) per month for Centropomus undecimalis.

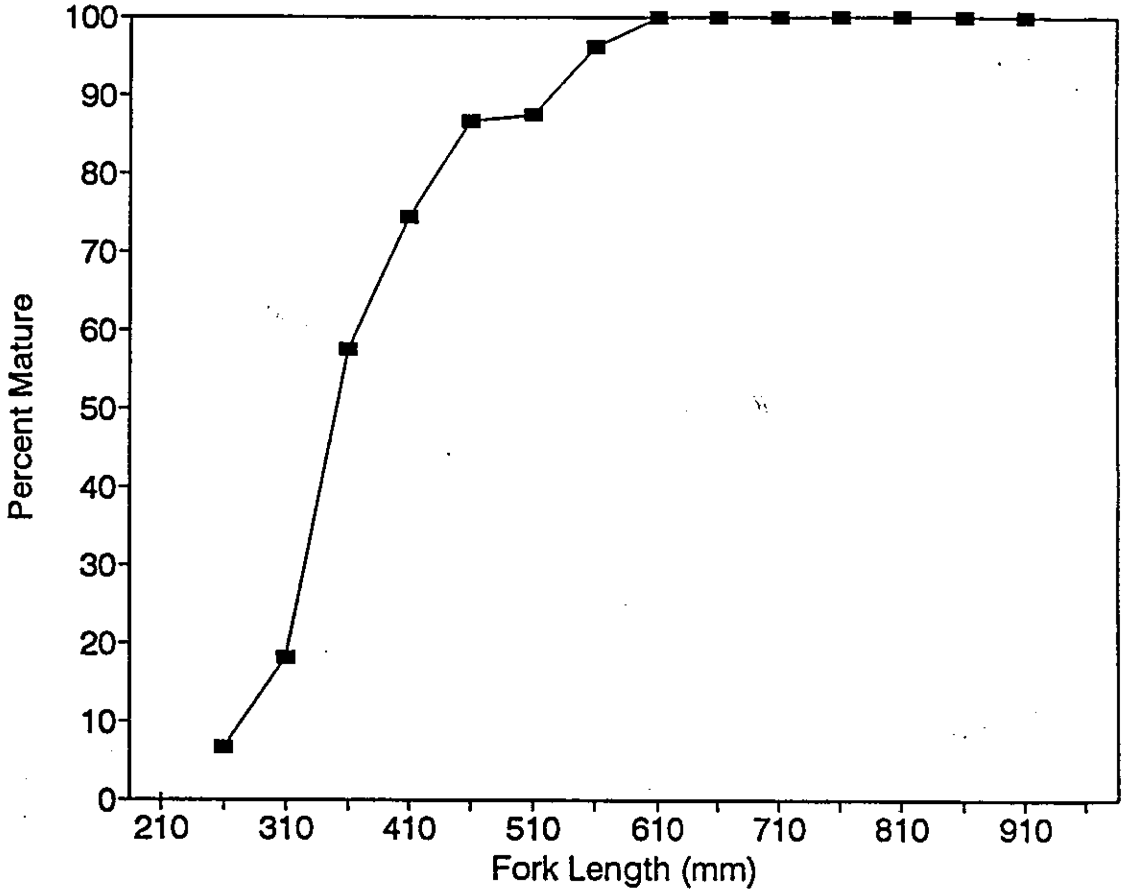


Figure 37. Maturity curve showing the percent of male Centropomus undecimalis of maturity classes 2, 3, 4, and 5 in 50 mm FL size classes.

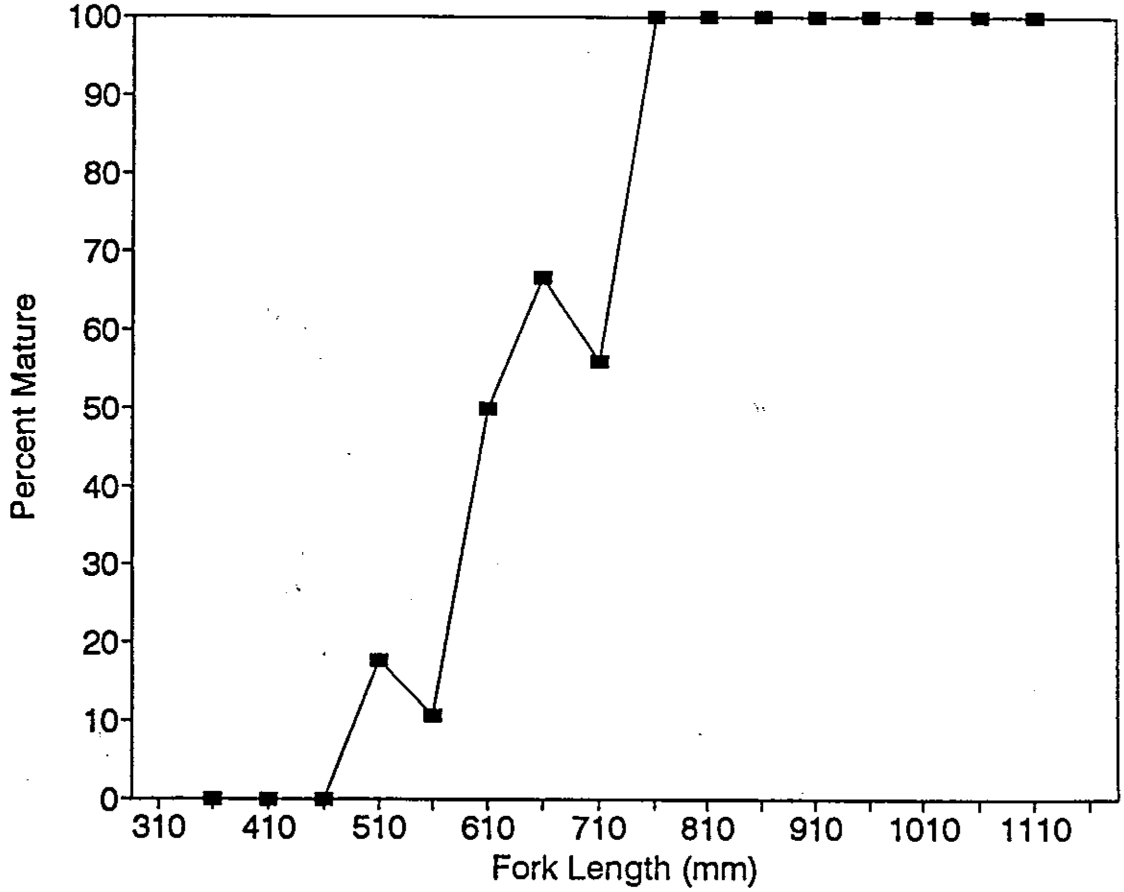


Figure 38. Maturity curve showing the percent of female Centropomus undecimalis of maturity classes 2, 3, 4, and 5 in 50 mm FL size classes.

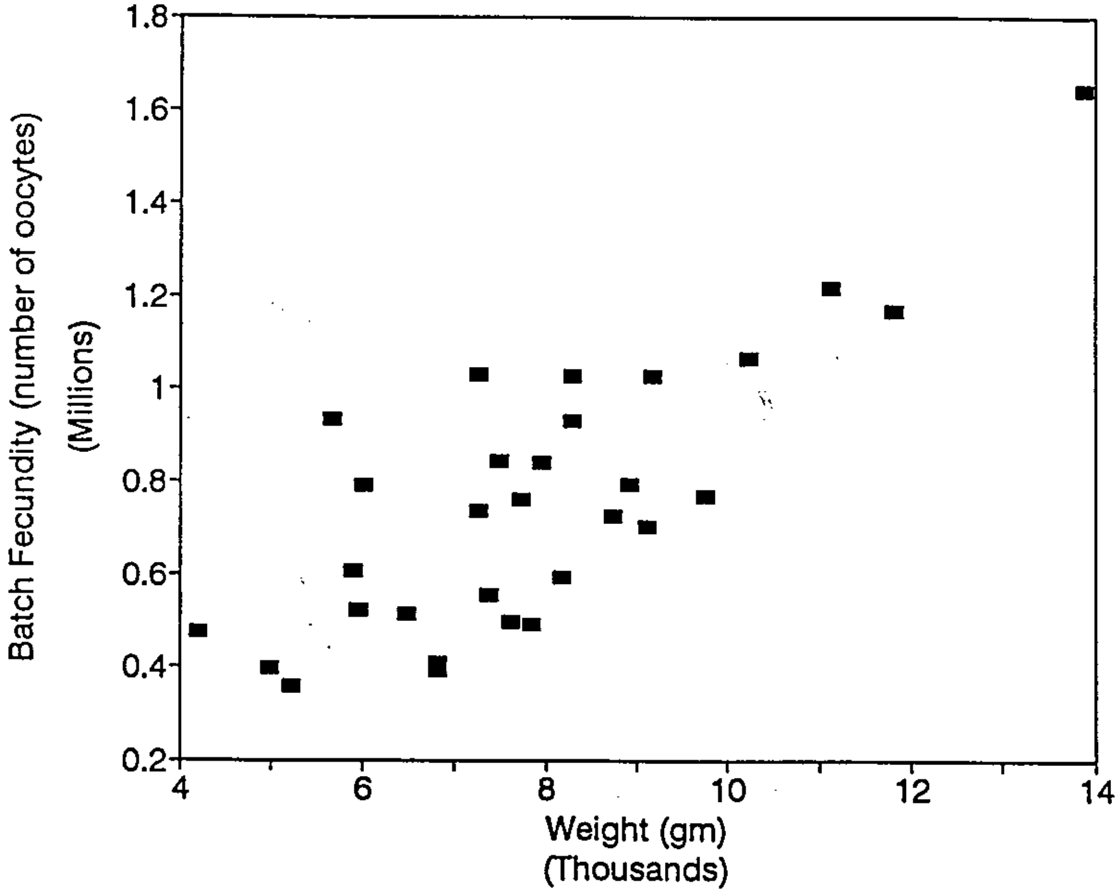
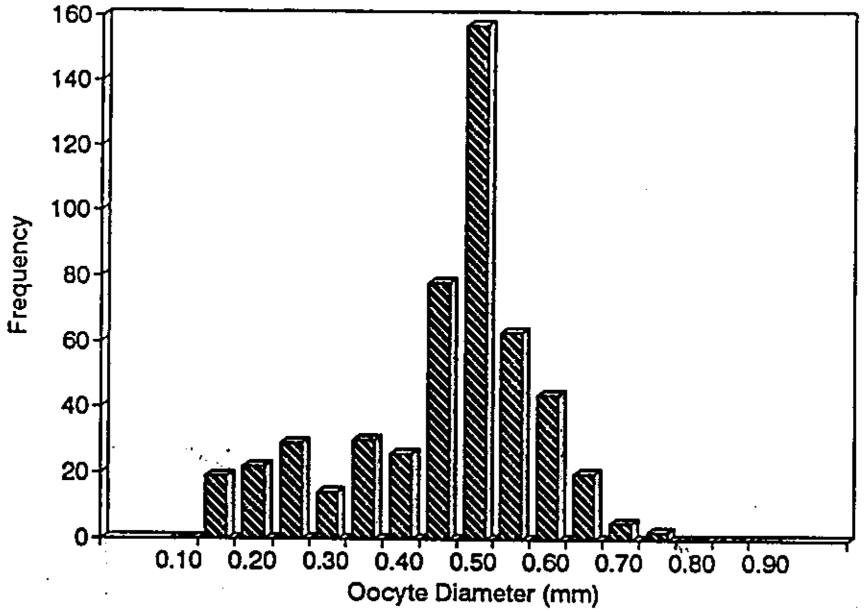


Figure 39. Batch fecundity of Centropomus undecimalis as a function of body weight.

CU 385, May 3, 1993
FL 880 mm (N=509)



CU 386, May 5, 1993
FL 895 mm (N=440)

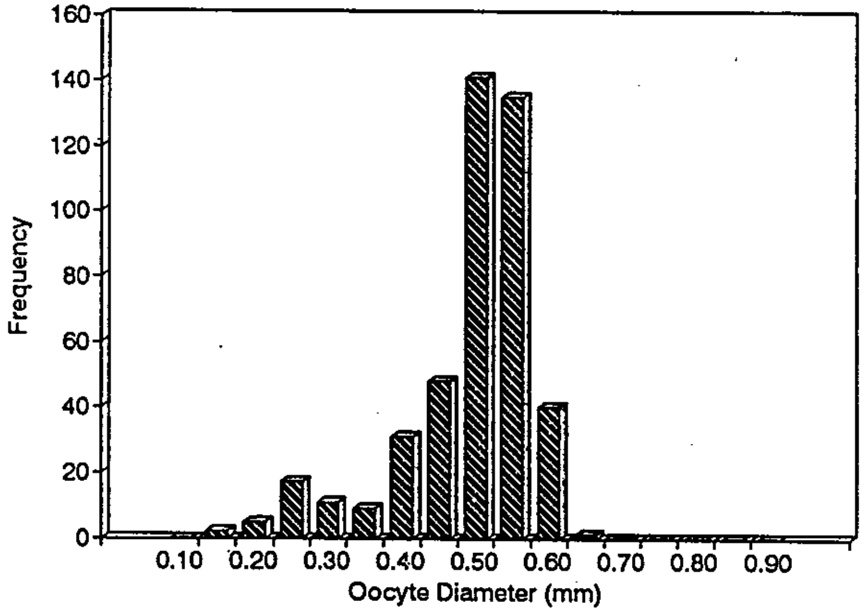
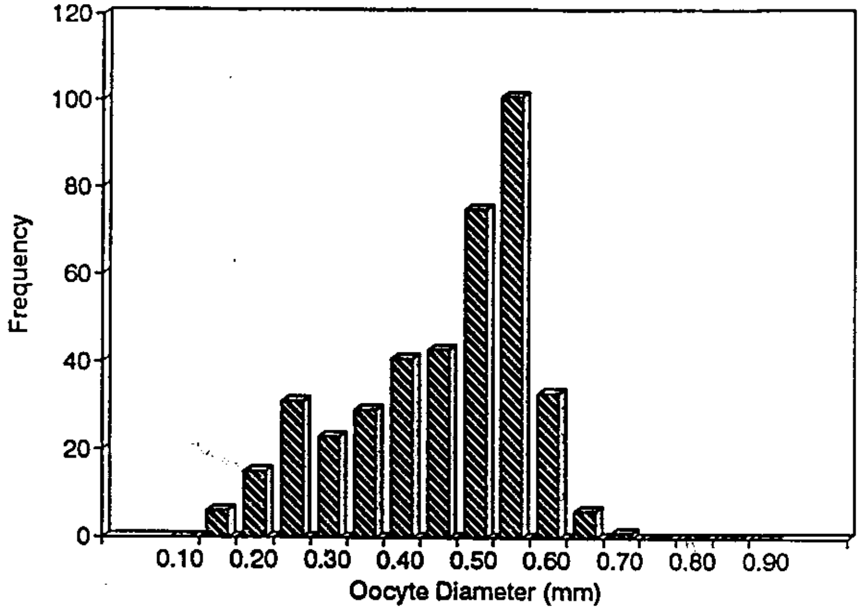


Figure 40. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.

CU 388, May 14, 1993
FL 732 mm (N=404)



CU 389, May 14, 1993
FL 815 mm (N=409)

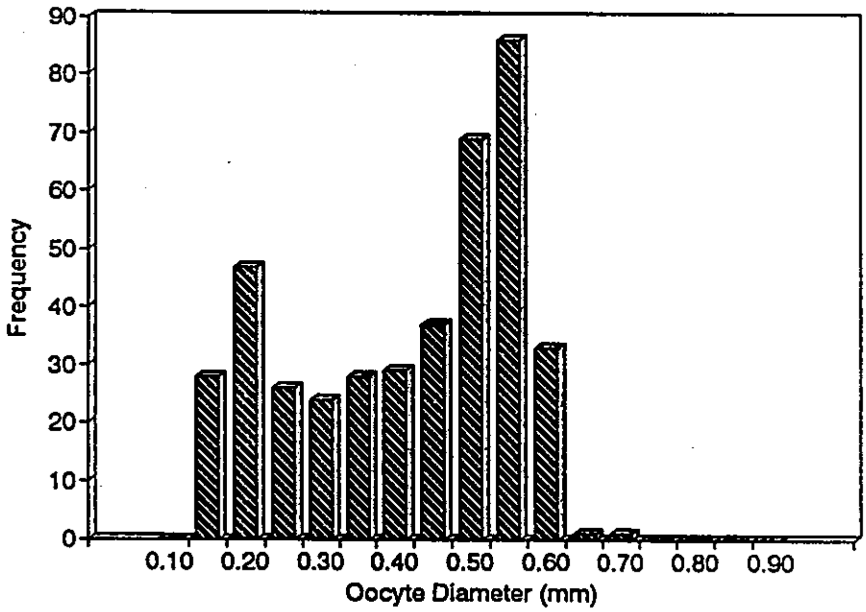


Figure 41. **Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.**

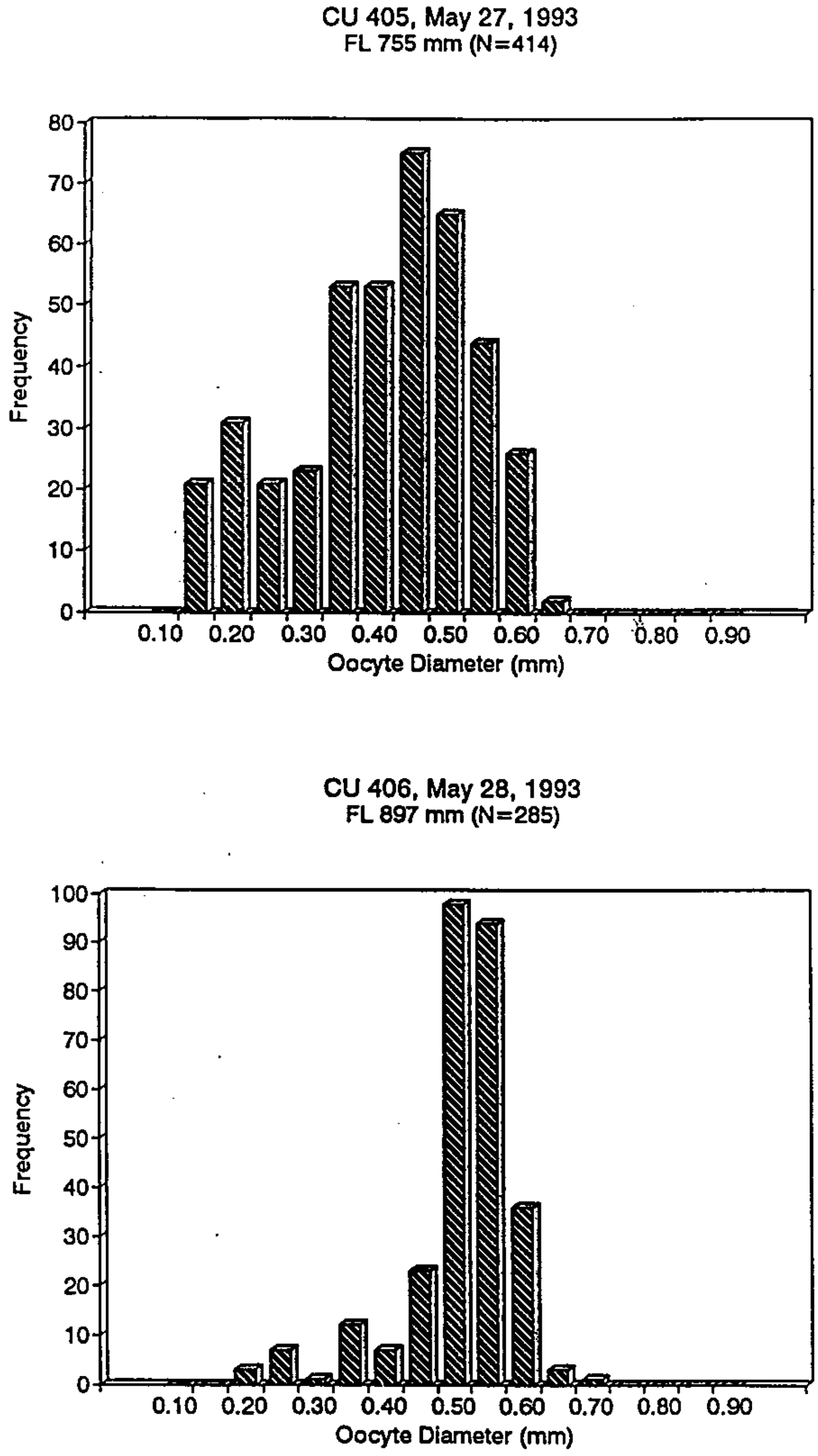
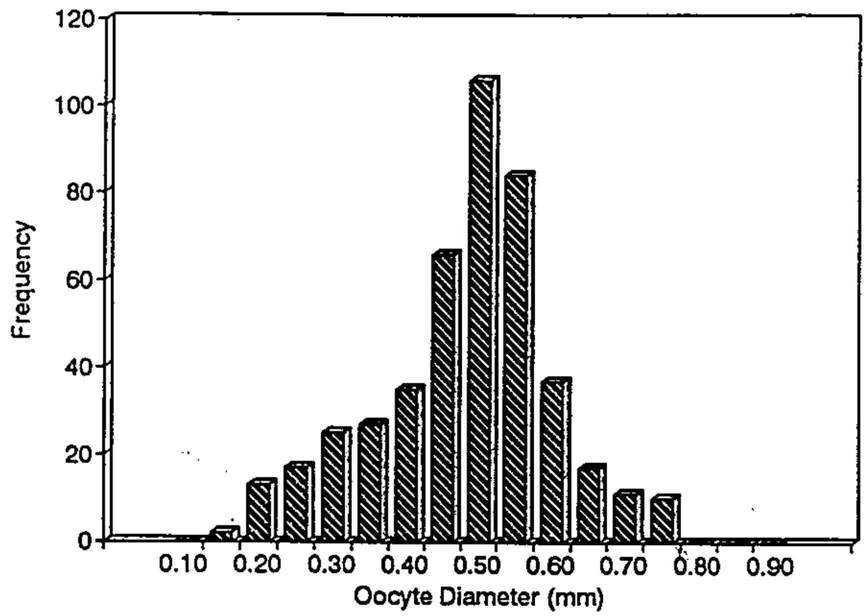


Figure 42. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.

CU 409, May 28, 1993
FL 946 mm (N=450)



CU 410, May 28, 1993
FL 902 mm (N=425)

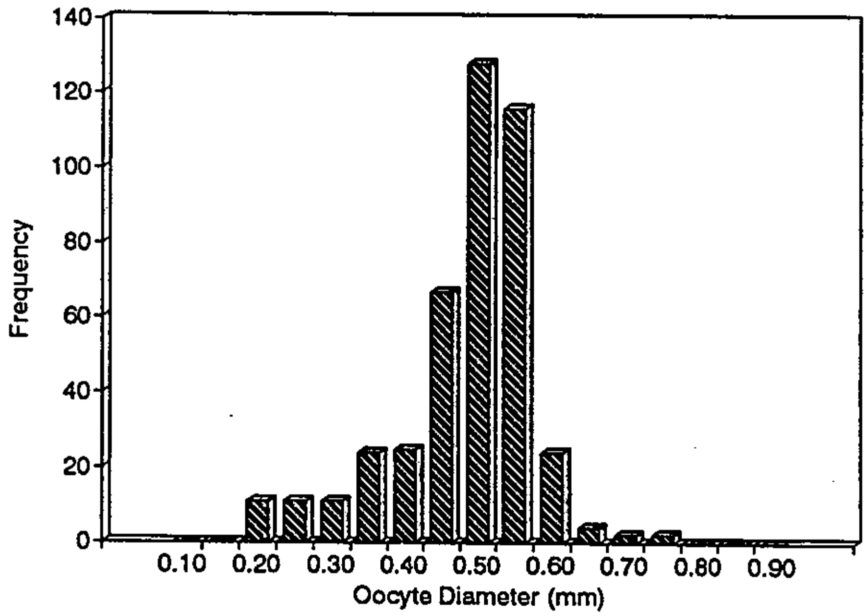
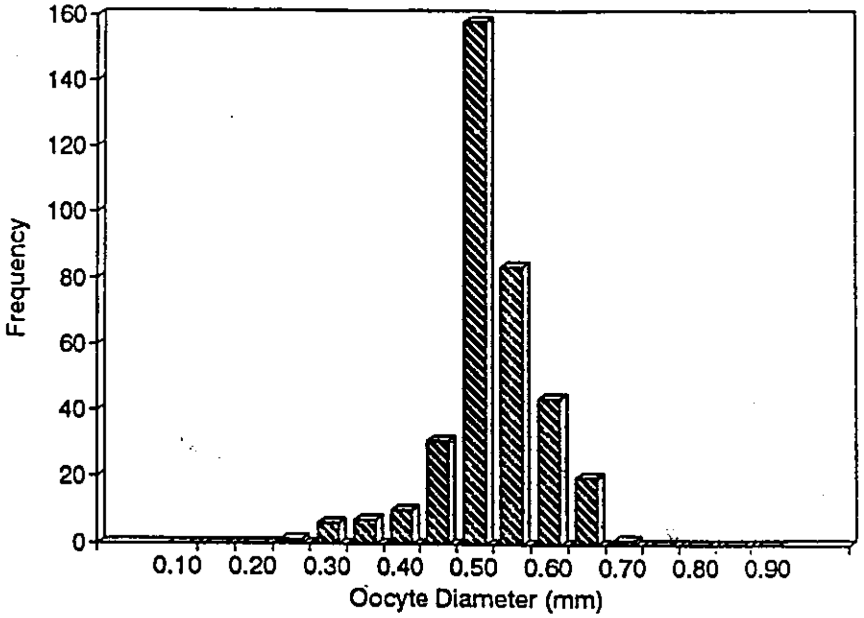


Figure 43. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.

CU 441, Jun. 23, 1993
FL 865 mm (N=362)



CU 443, Jun. 23, 1993
FL 730 mm (N=542)

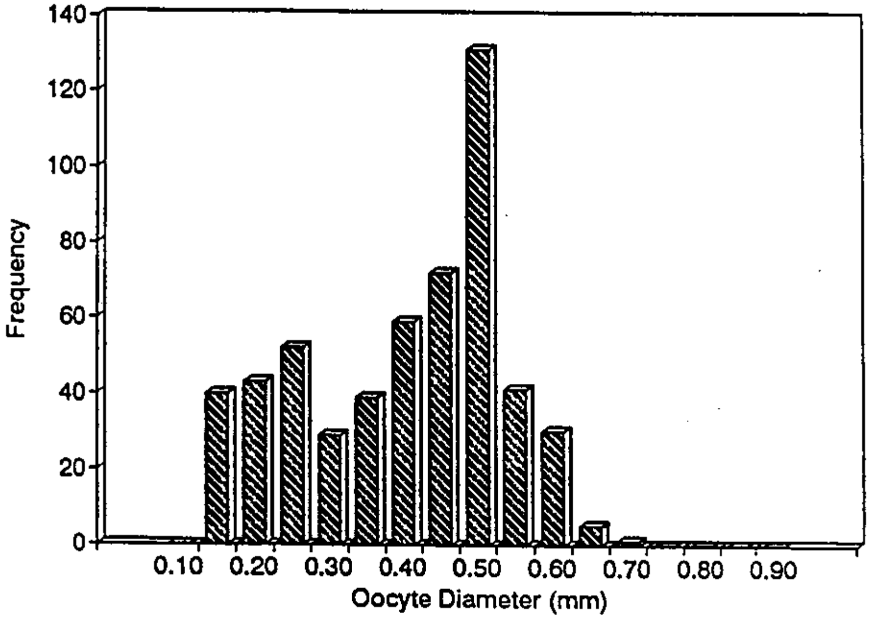
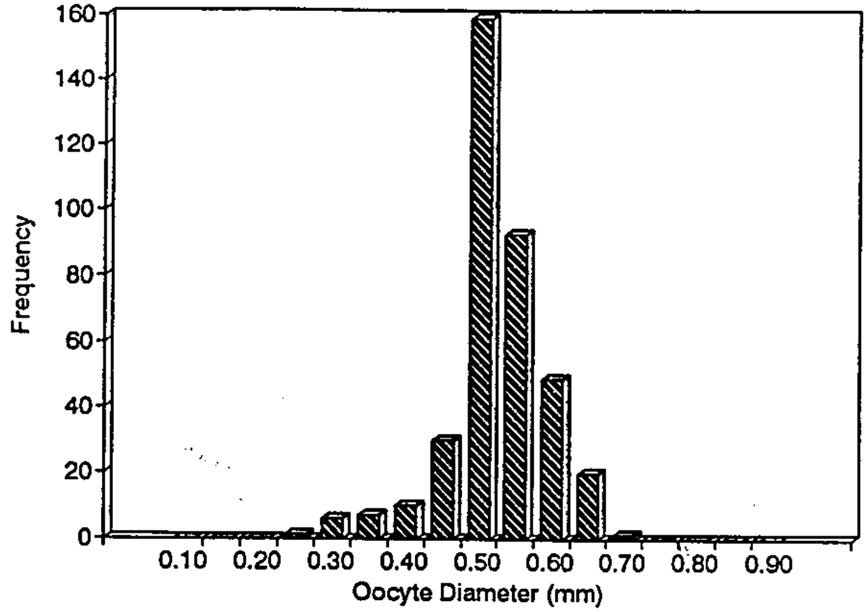


Figure 44. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.

CU 489, Jul. 31, 1993
FL 1012 mm (N=376)



CU 507, Sep. 10, 1993
FL 765 mm (N=435)

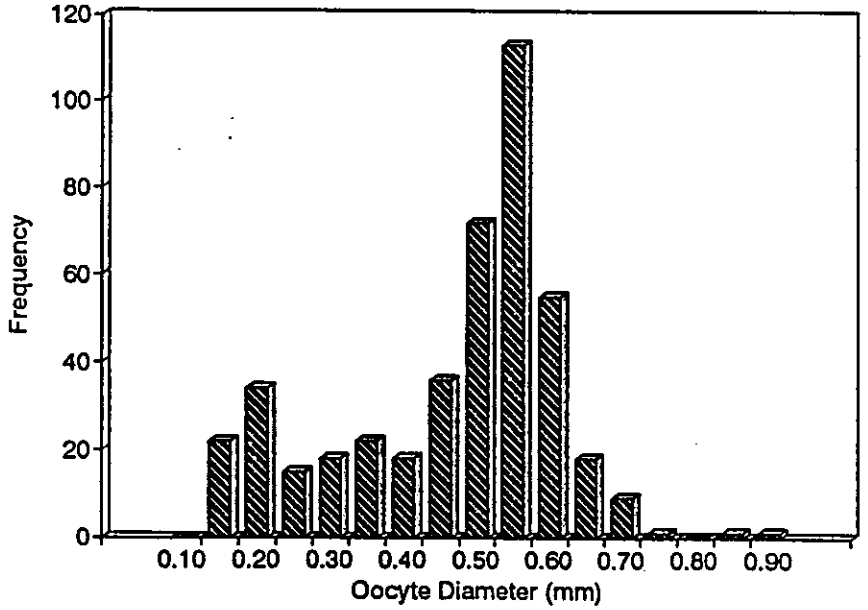
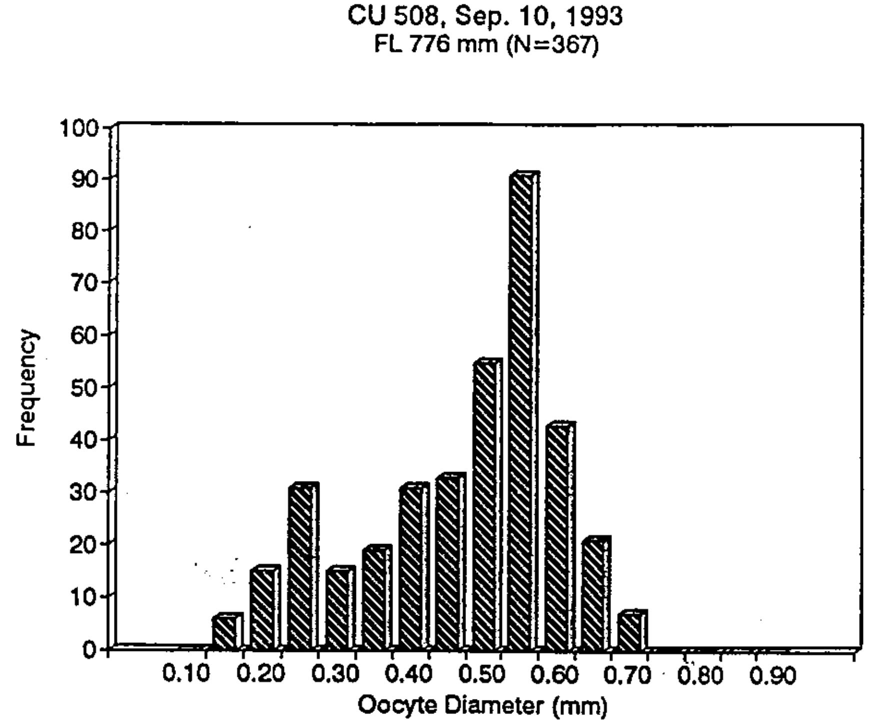


Figure 45. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.



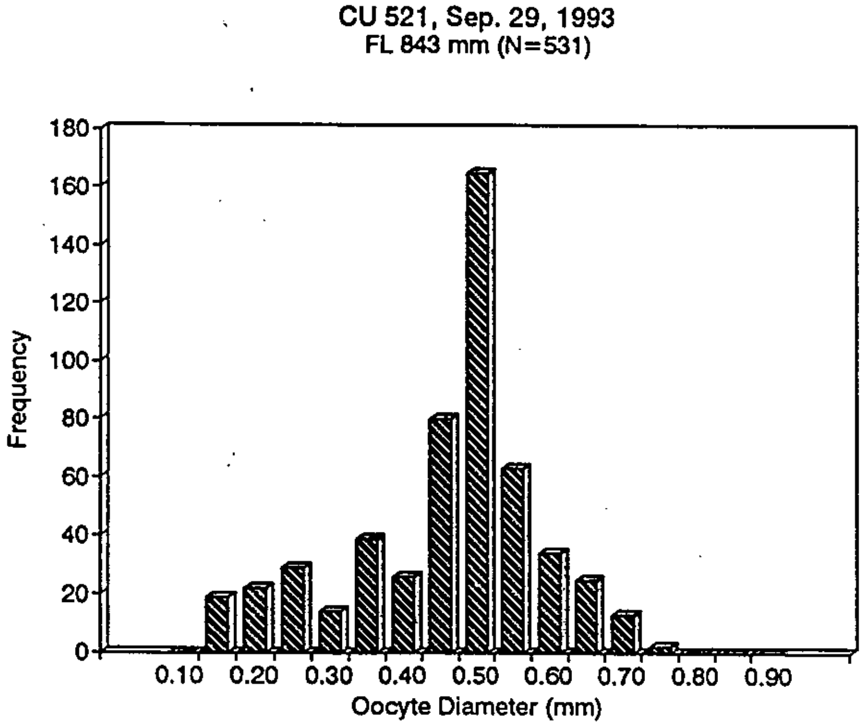
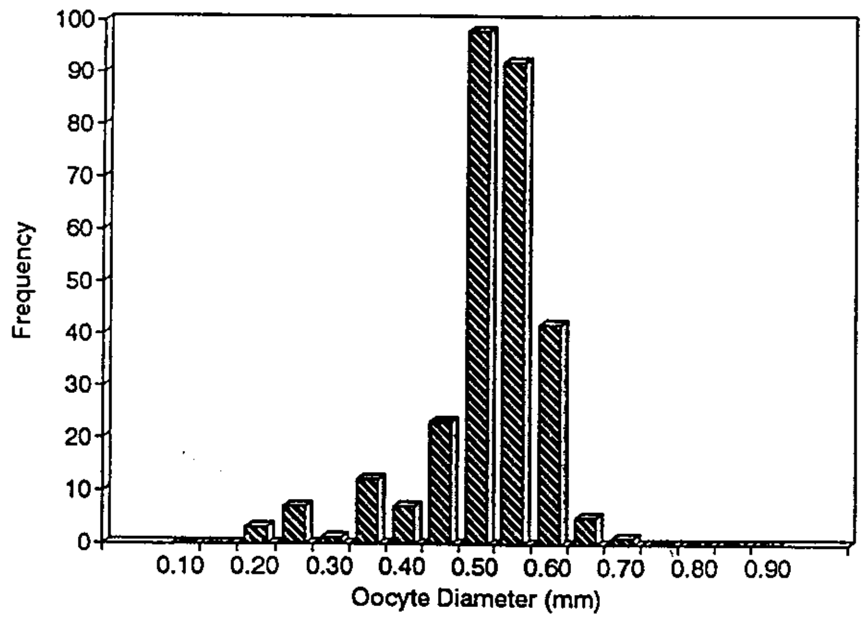


Figure 46. Oocyte size-frequency distributions of female <u>Centropomus</u> <u>undecimalis</u> utilized for the estimation of batch fecundity and spawning frequency.

CU 528, Sep. 30, 1993
FL 875 mm (N=291)



CU 529, Sep. 30, 1993
FL 905 mm (N=424)

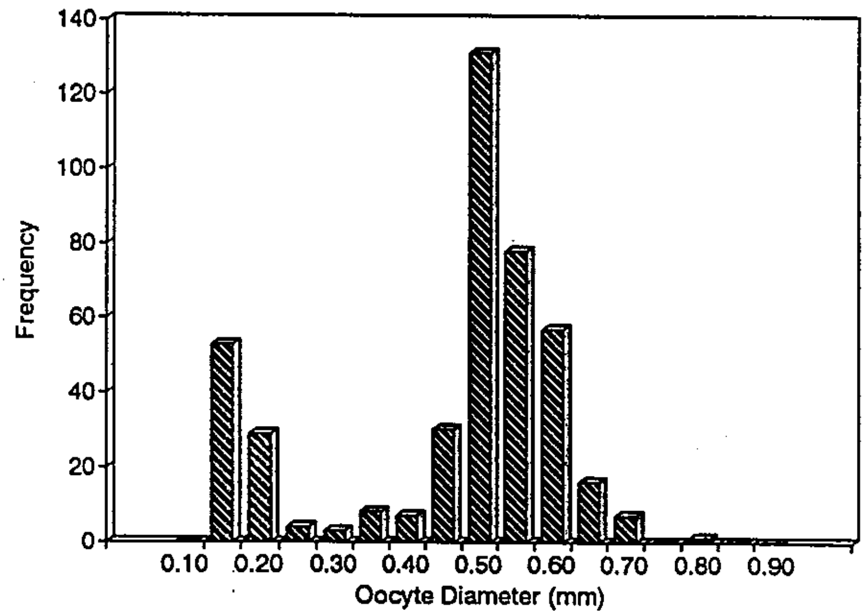
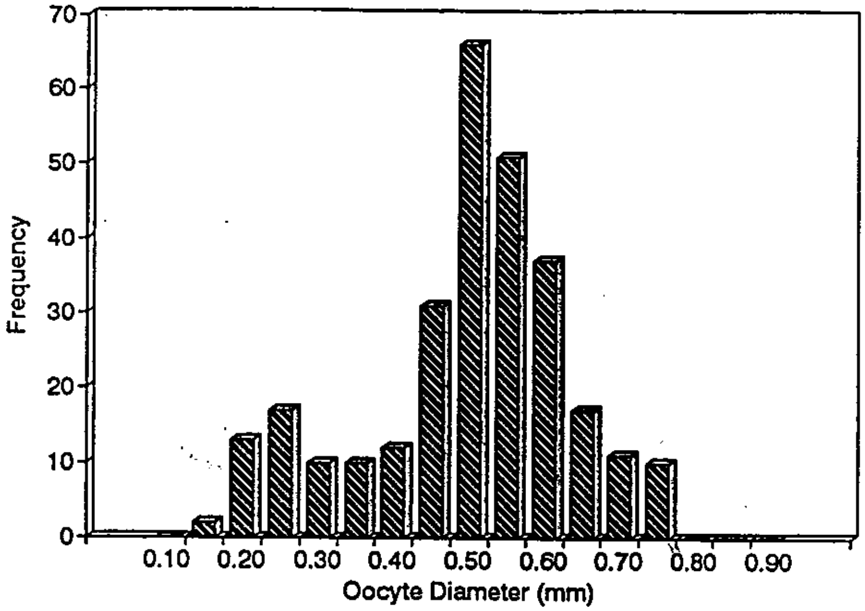


Figure 47. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.

CU 539, Oct. 2, 1993
FL 802 mm (N=287)



CU 715, May 12, 1994
FL 822 mm (N=413)

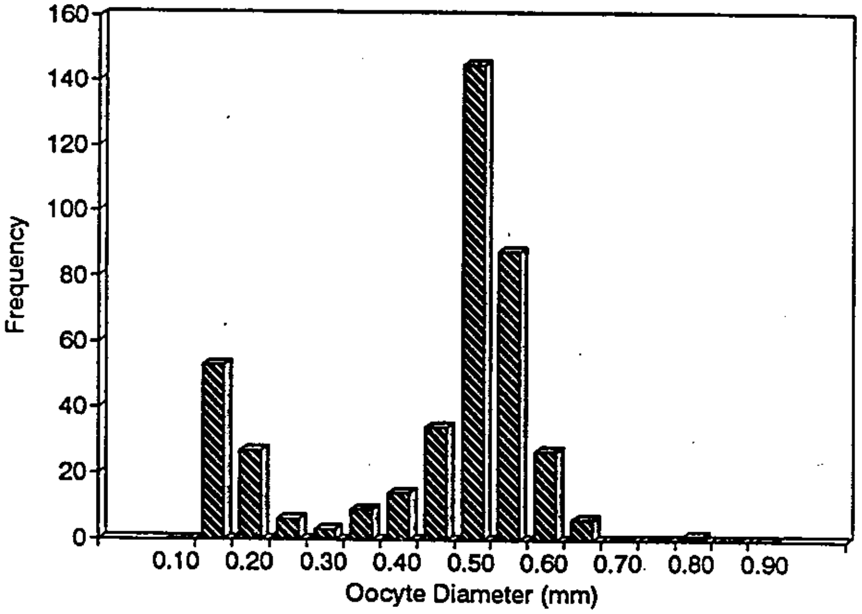
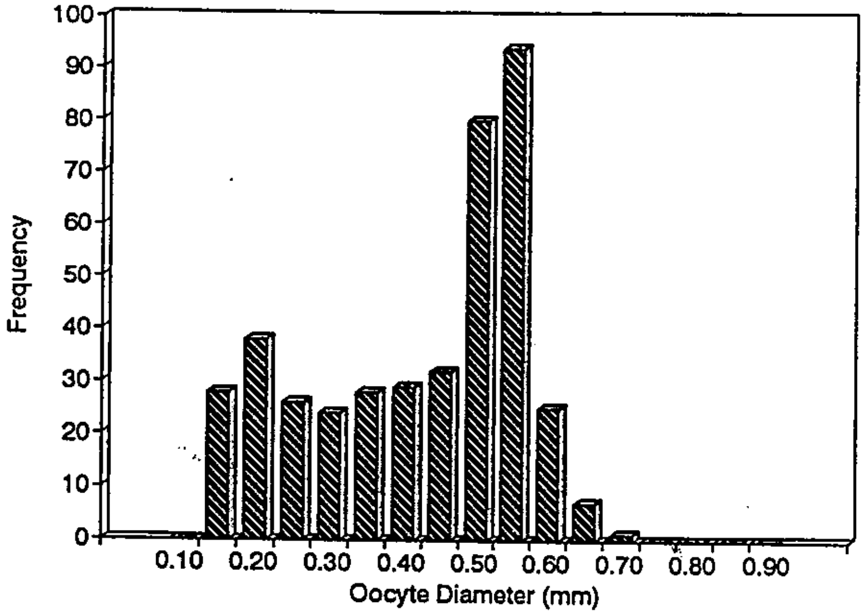
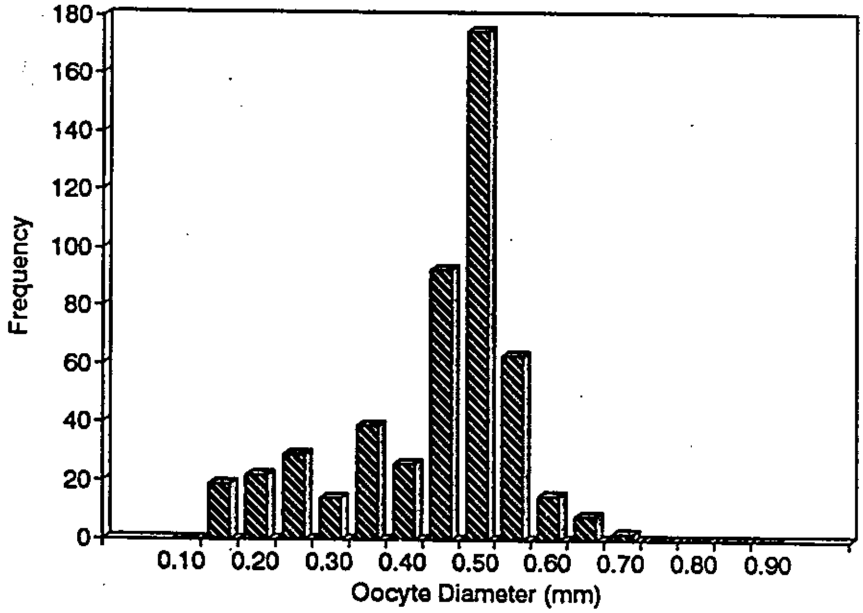


Figure 48. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.



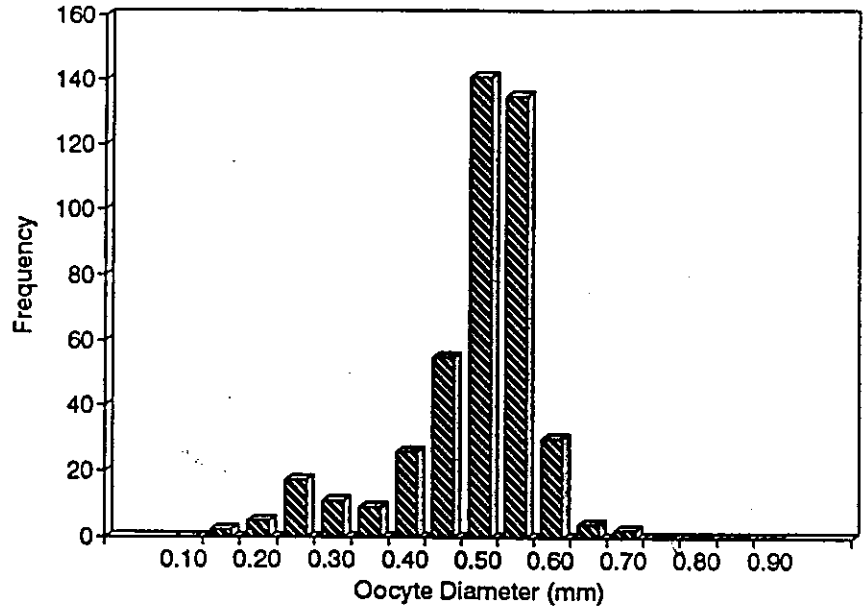
CU 719, May 13, 1994
FL 851 mm (N=412)



CU 723, May 13, 1994
FL 860 mm (N=505)

Figure 49. Oocyte size-frequency distributions of female <u>Centropomus</u> <u>undecimalis</u> utilized for the estimation of batch fecundity and spawning frequency.

CU 729, May 17, 1994
FL 854 mm (N=437)



CU 730, May 17, 1994
FL 850 mm (N=603)

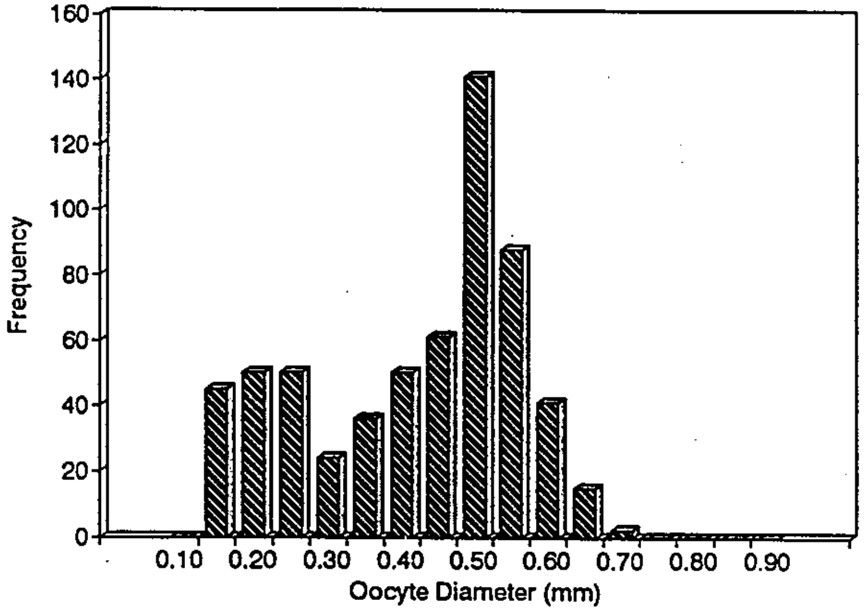
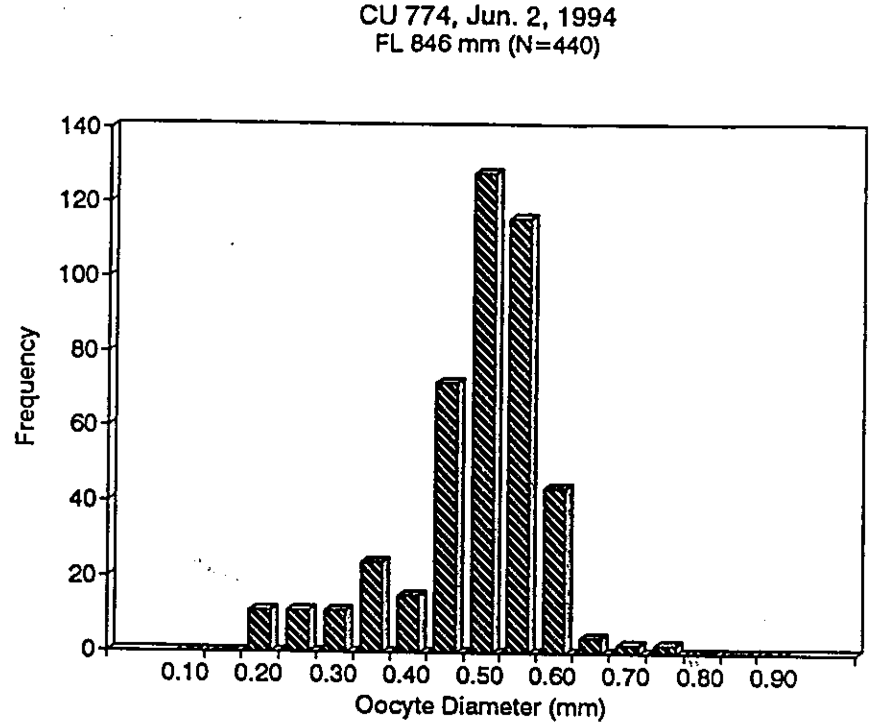
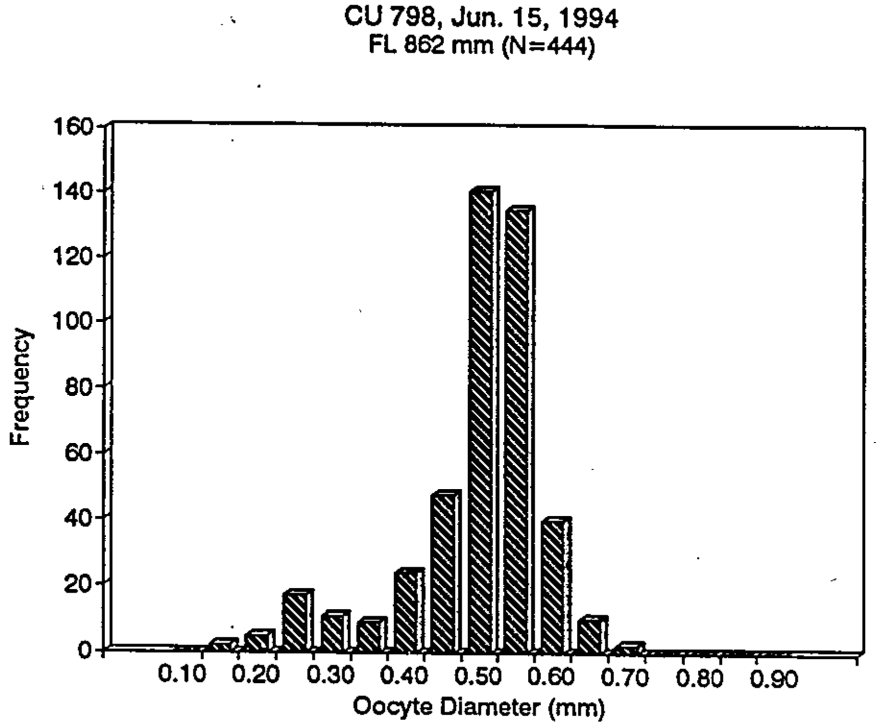


Figure 50. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.



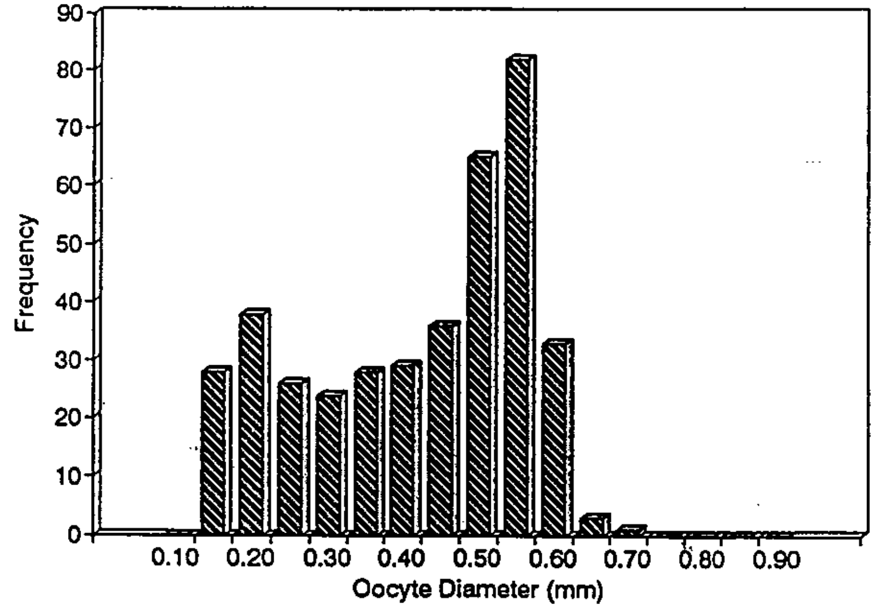
CU 774, Jun. 2, 1994
FL 846 mm (N=440)



CU 798, Jun. 15, 1994
FL 862 mm (N=444)

Figure 51. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.

CU 816, Jun. 29, 1994
FL 837 mm (N=393)



CU 822, Jun. 30, 1994
FL 795 mm (N=441)

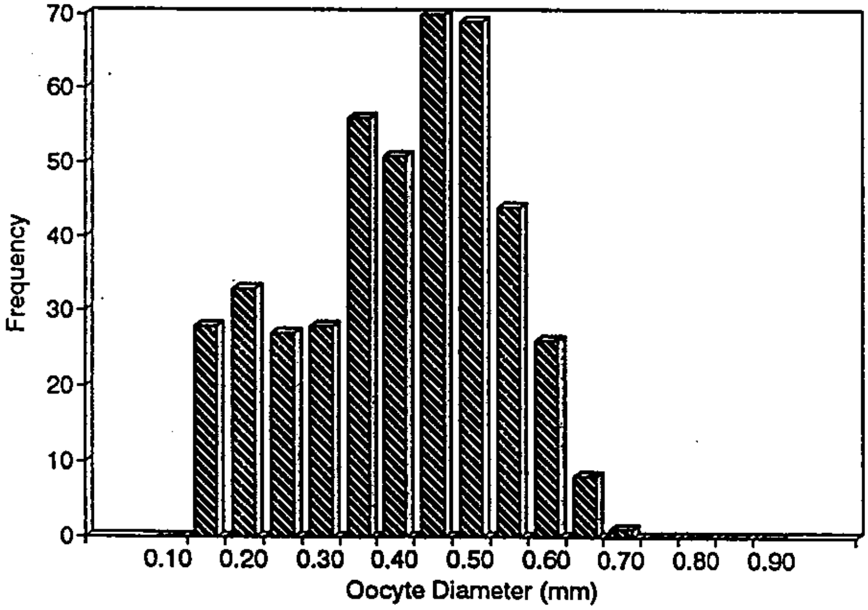
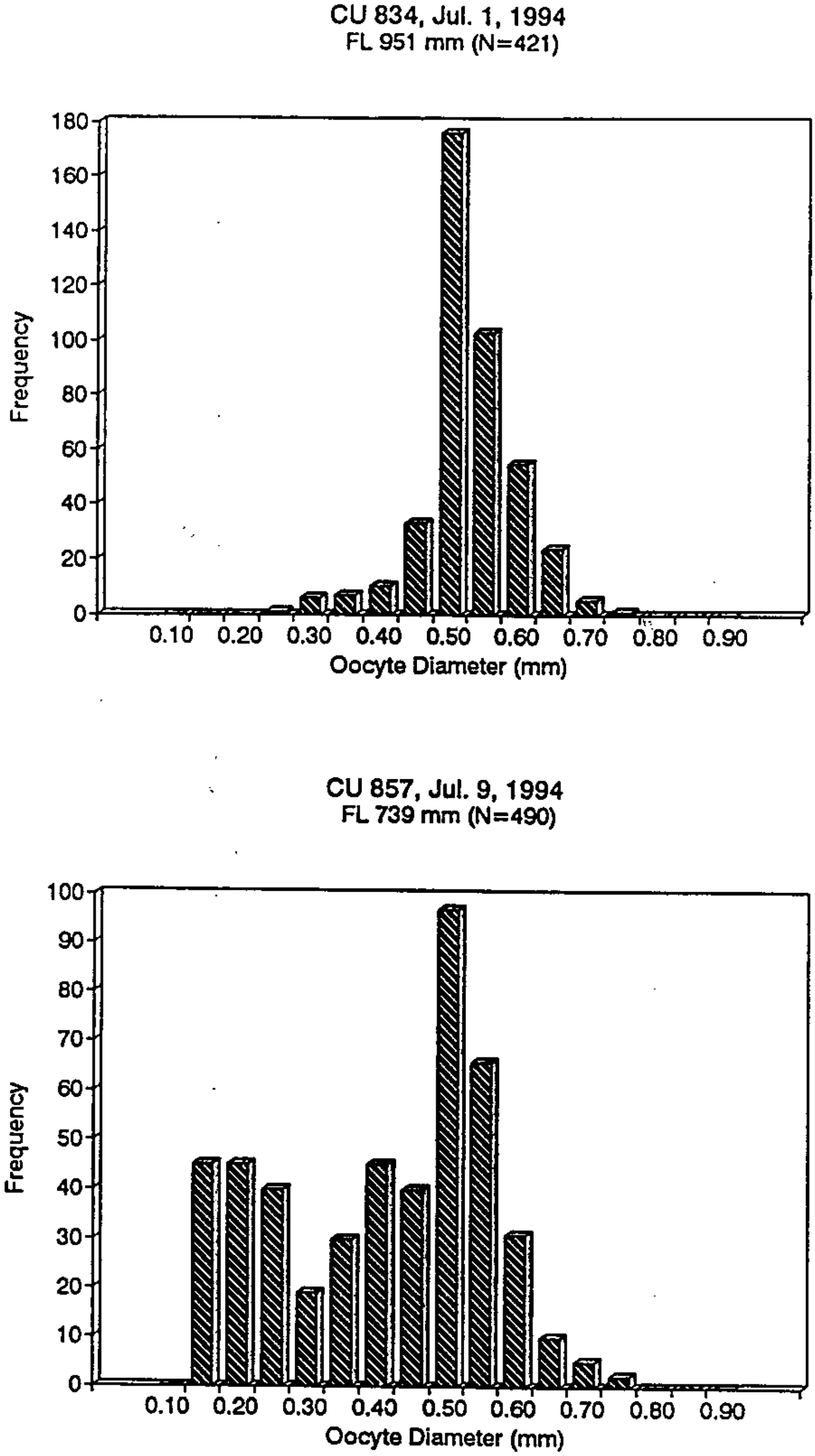


Figure 52. Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.

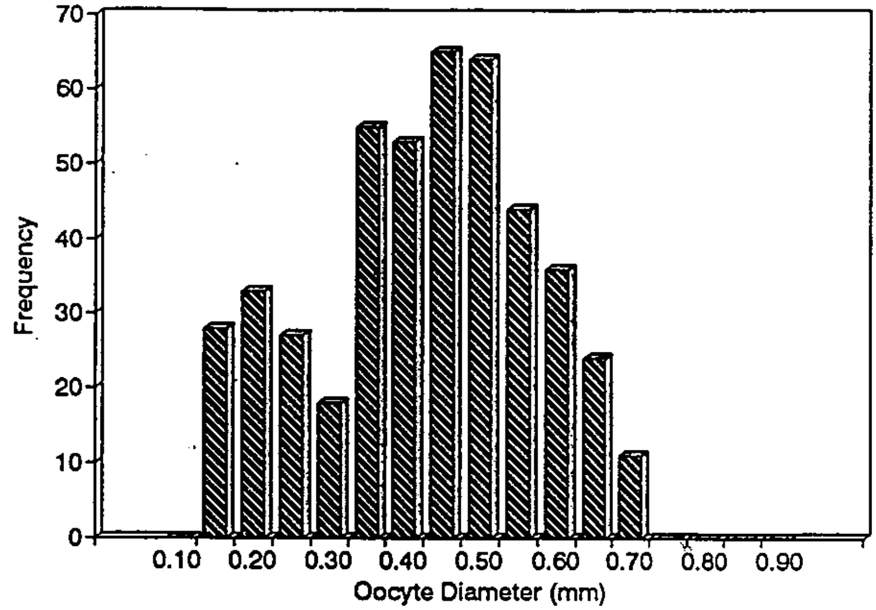


CU 834, Jul. 1, 1994
FL 951 mm (N=421)

CU 857, Jul. 9, 1994
FL 739 mm (N=490)

Figure 53. **Oocyte size-frequency distributions of female <u>Centropomus</u> <u>undecimalis</u> utilized for the estimation of batch fecundity and spawning frequency.**

CU 889, Sep. 15, 1994
FL 812 mm (N=458)



CU 985, Aug. 4, 1995
FL 857 mm (N=430)

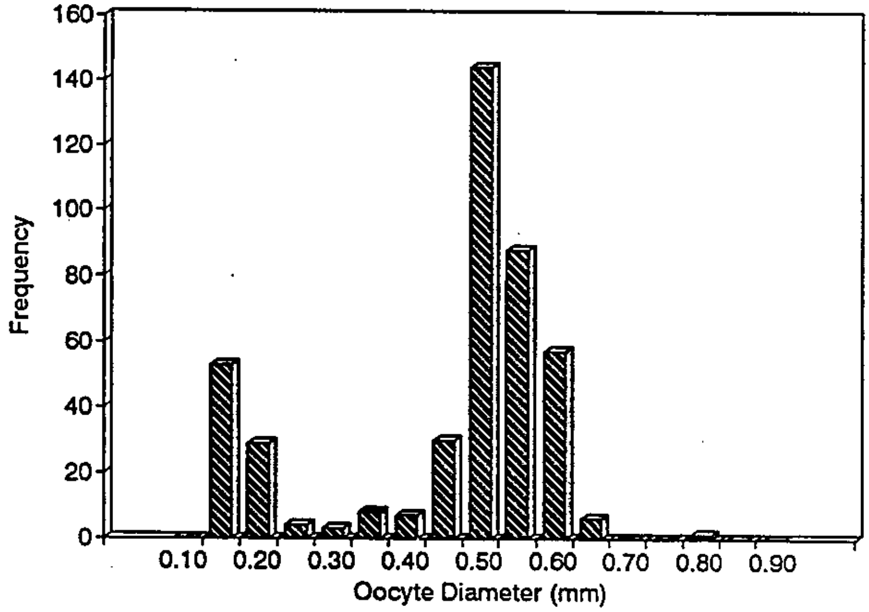


Figure 54. **Oocyte size-frequency distributions of female Centropomus undecimalis utilized for the estimation of batch fecundity and spawning frequency.**

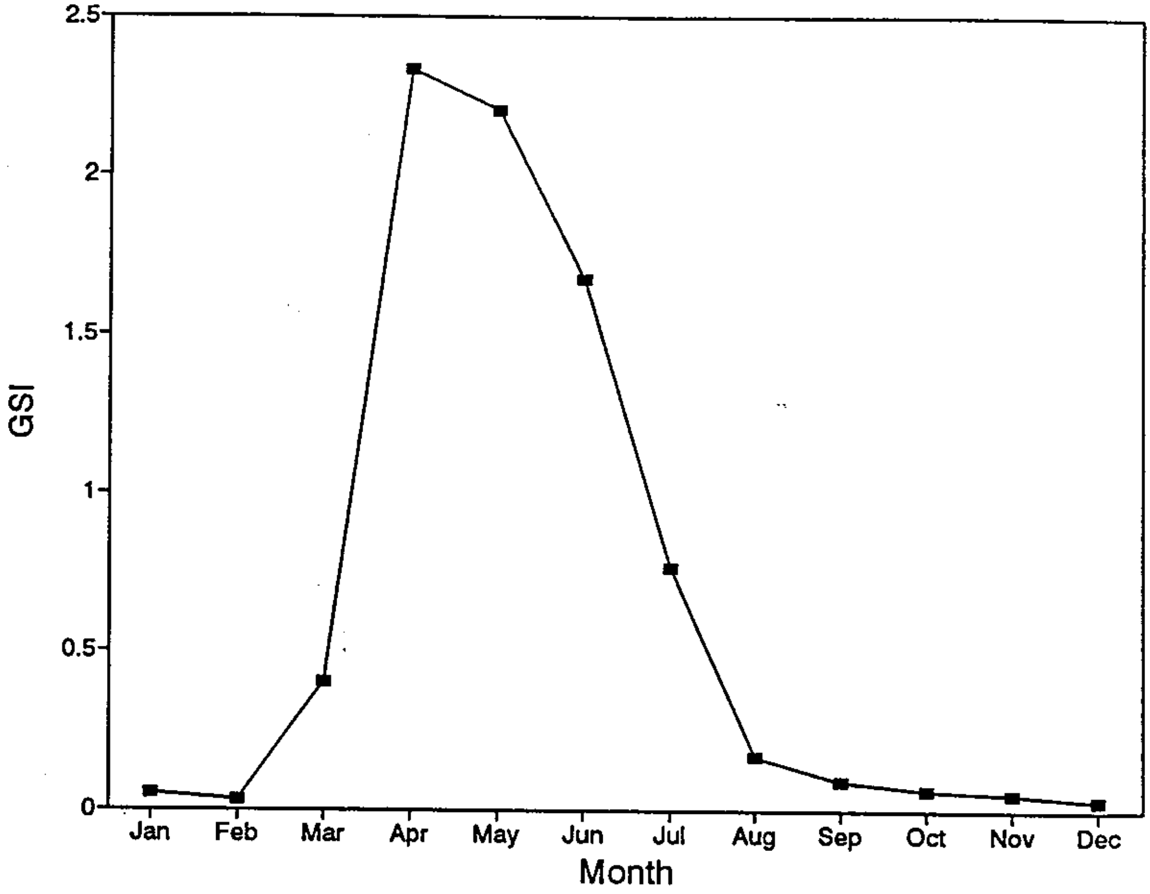


Figure 55. Mean gonosomatic index (GSI) per month for *Megalops atlanticus*.

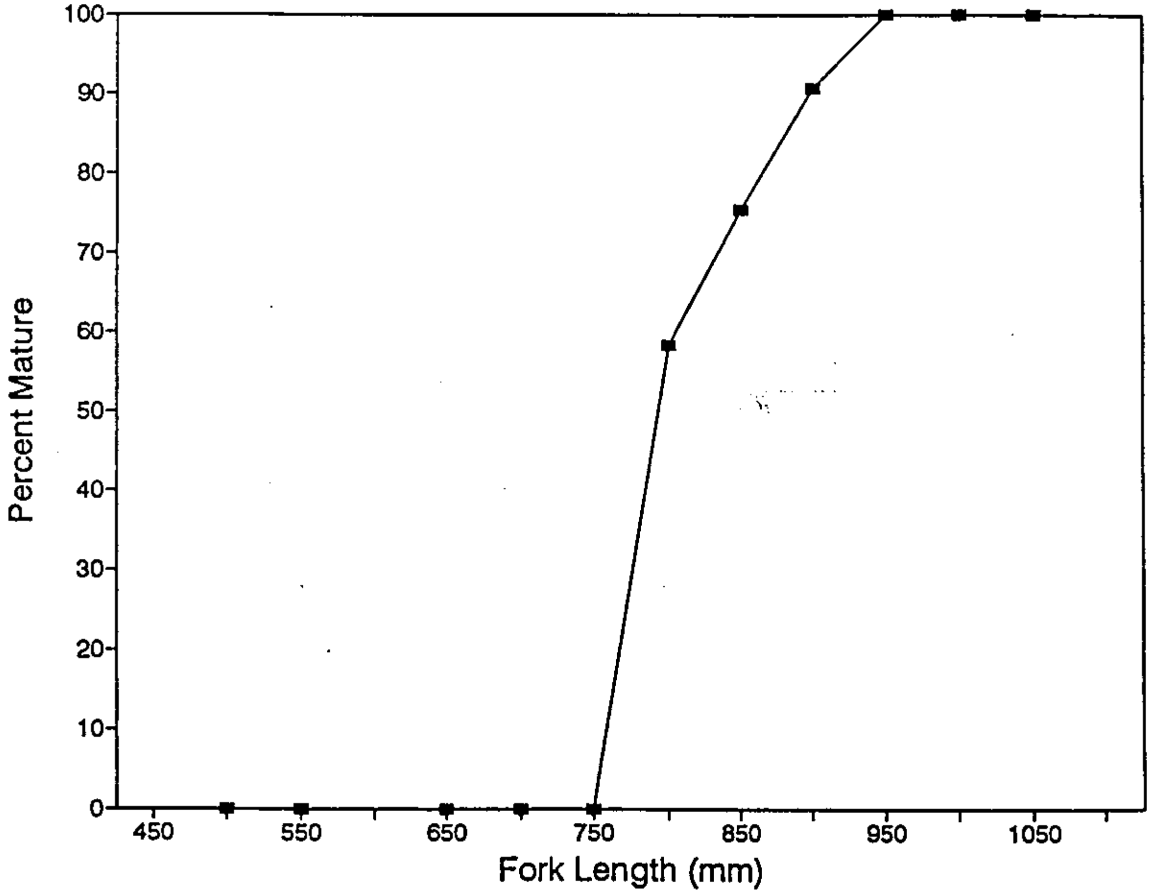


Figure 56. Maturity curve showing the percent of male Megalops atlanticus of maturity classes 2, 3, 4, and 5 in 50 mm FL size classes.

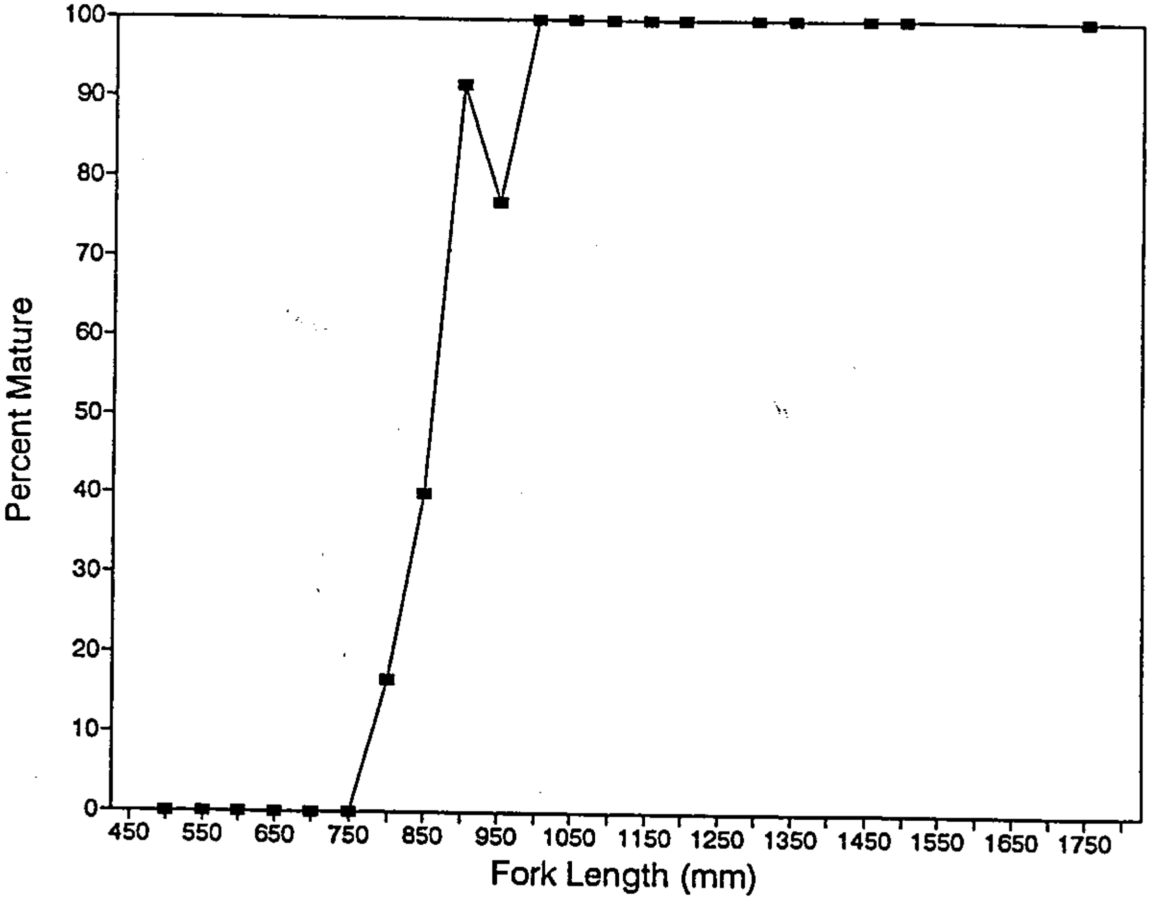


Figure 57. Maturity curve showing the percent of female Megalops atlanticus of maturity classes 2, 3, 4, and 5 in 50 mm FL size classes.

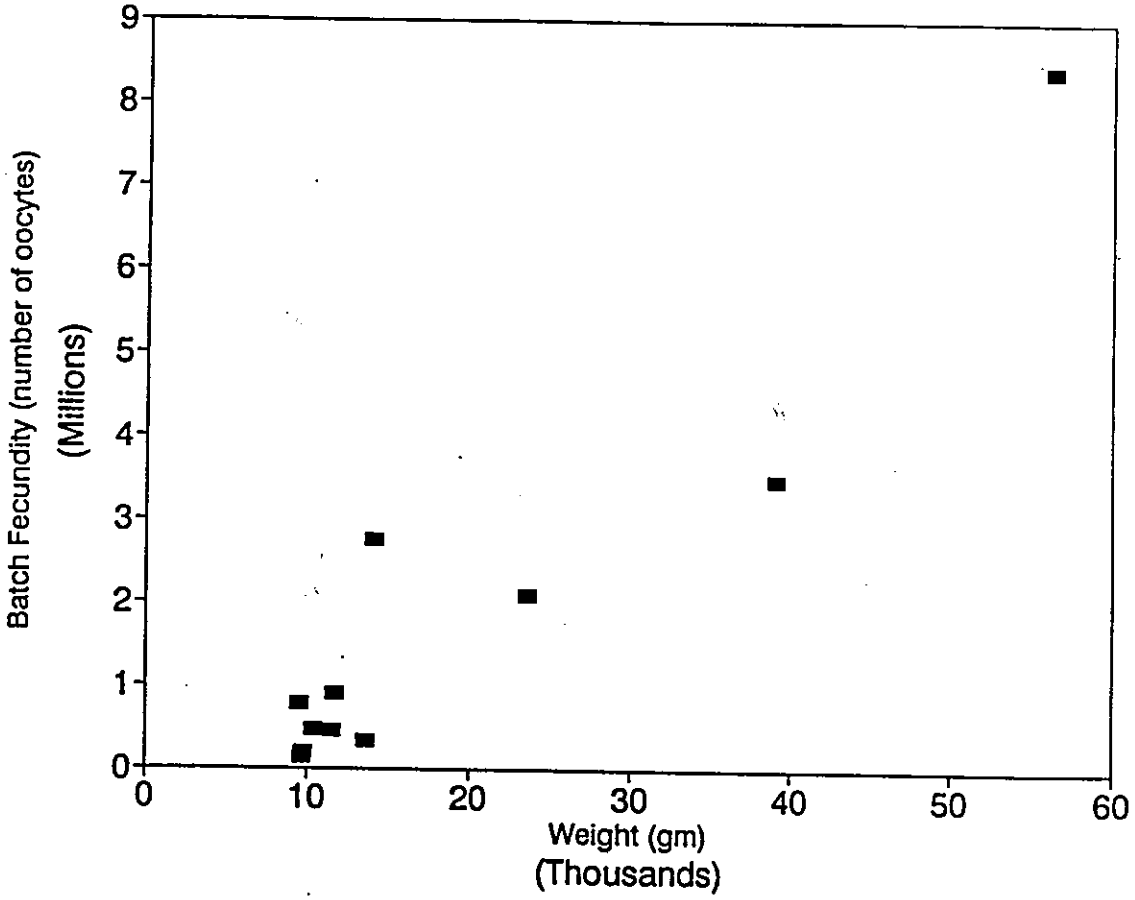
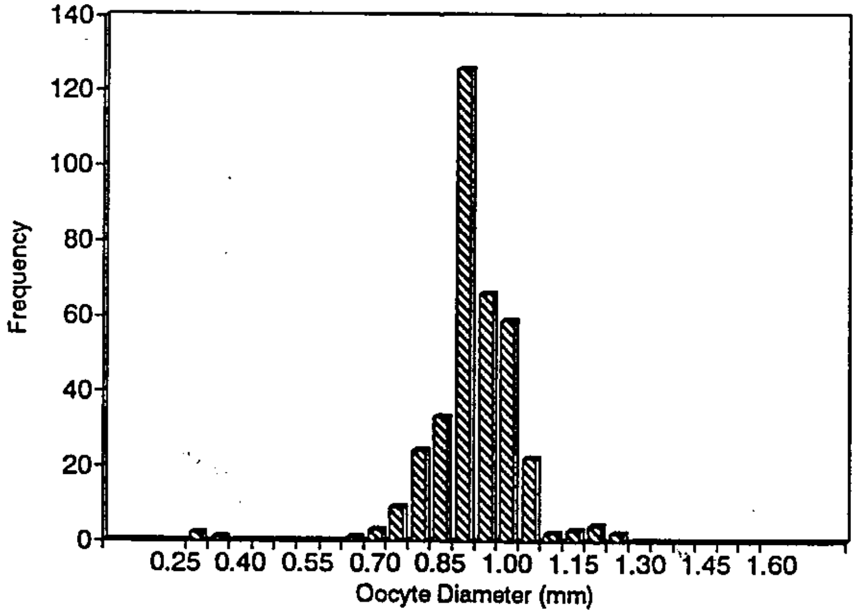


Figure 58. Batch fecundity of Megalops atlanticus as a function of body weight.

MA 226, Jun. 25, 1993
FL 978 mm (N=357)



MA 258, Jul. 1, 1993
FL 960 mm (N=384)

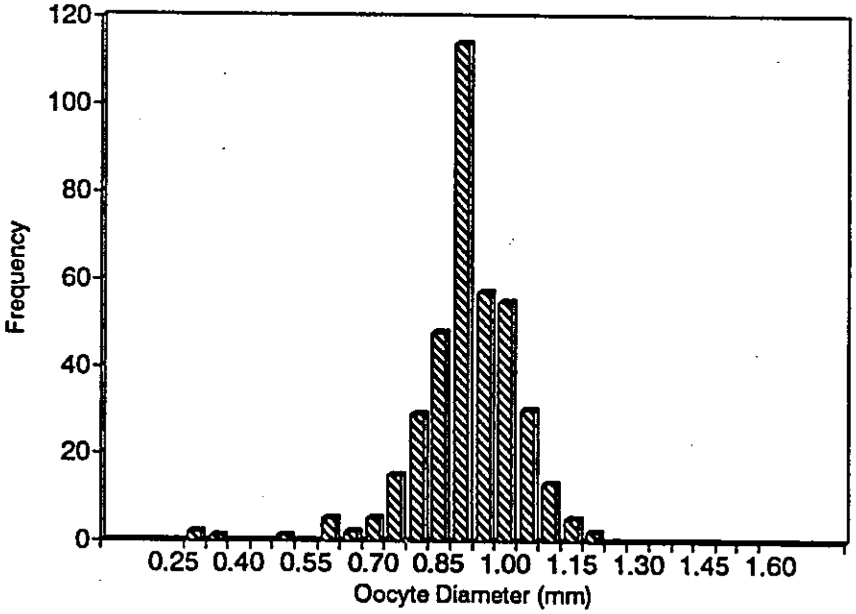
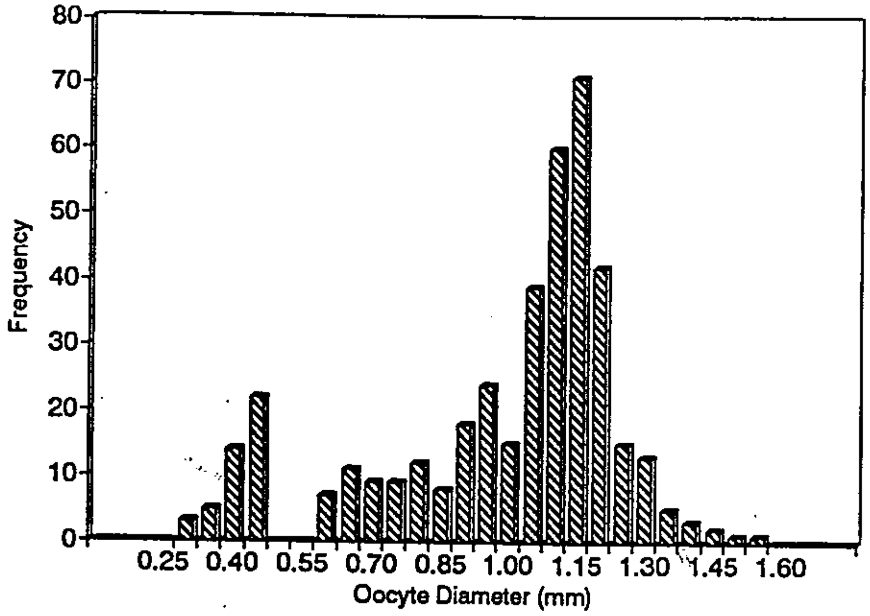


Figure 59. Oocyte size-frequency distributions of female Megalops atlanticus utilized for the estimation of batch fecundity and spawning frequency.


MA 591, Apr. 24, 1994
FL 1270 mm (N=423)

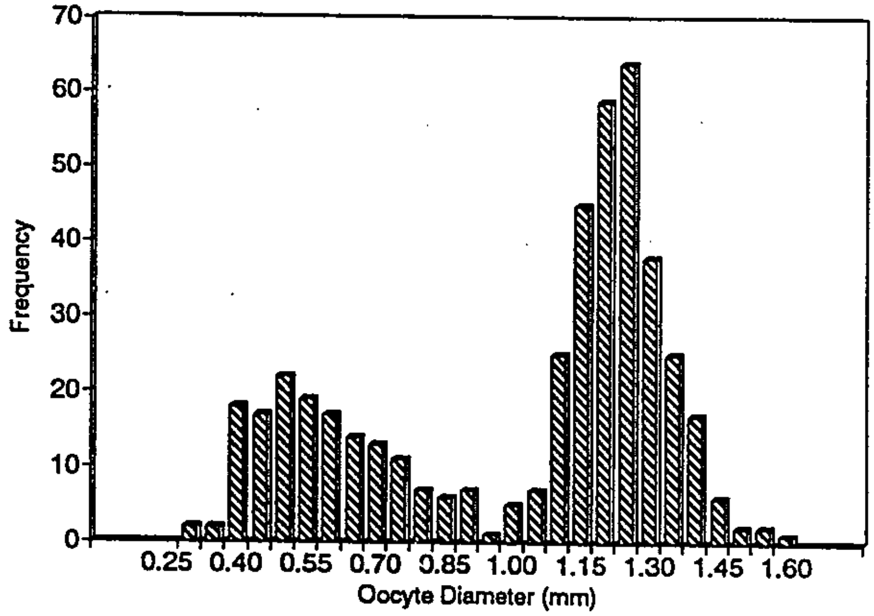
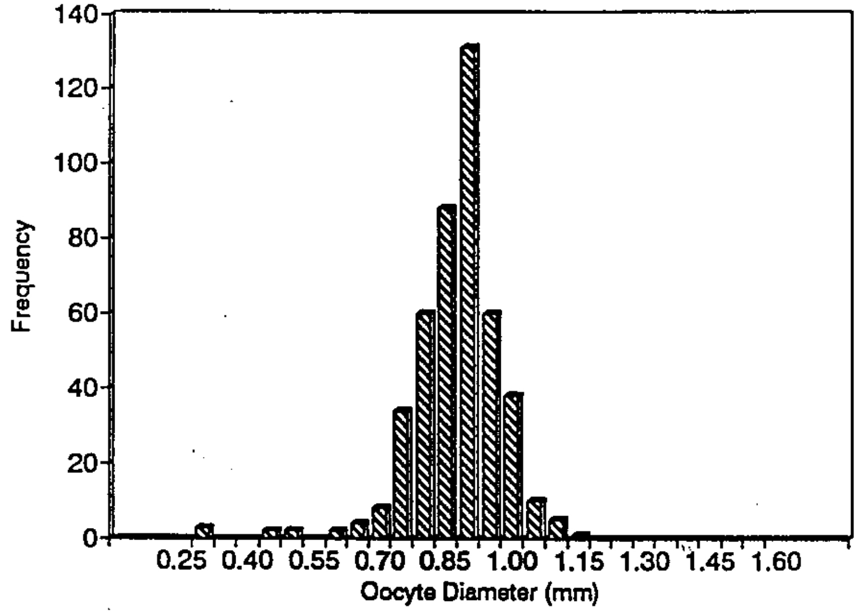
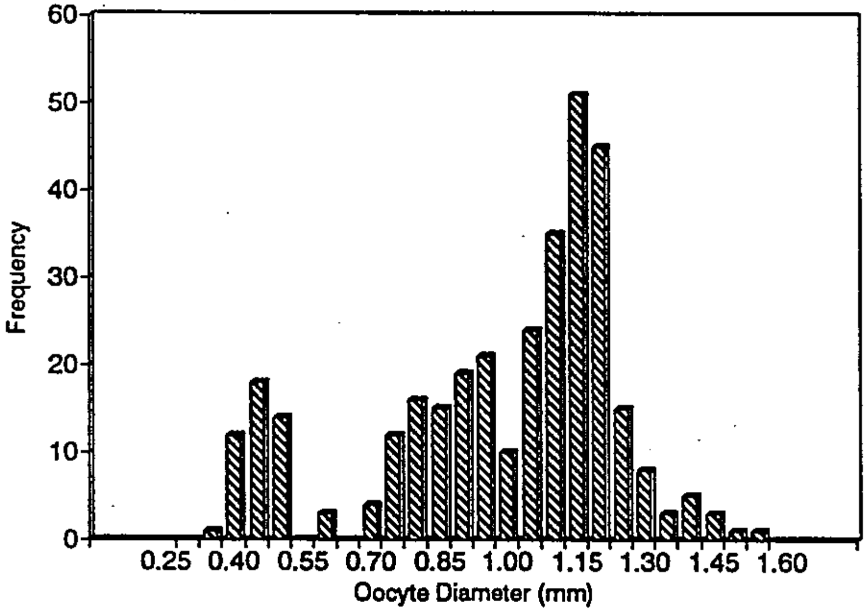

MA 592, Apr. 27, 1994
FL 1025 mm (N=452)

Figure 60. Oocyte size-frequency distributions of female Megalops atlanticus utilized for the estimation of batch fecundity and spawning frequency.



MA 595, Apr. 29, 1994
FL 1071 mm (N=448)



MA 596, Apr. 29, 1994
FL 1575 mm (N=336)

Figure 61. Oocyte size-frequency distributions of female Megalops atlanticus utilized for the estimation of batch fecundity and spawning frequency.

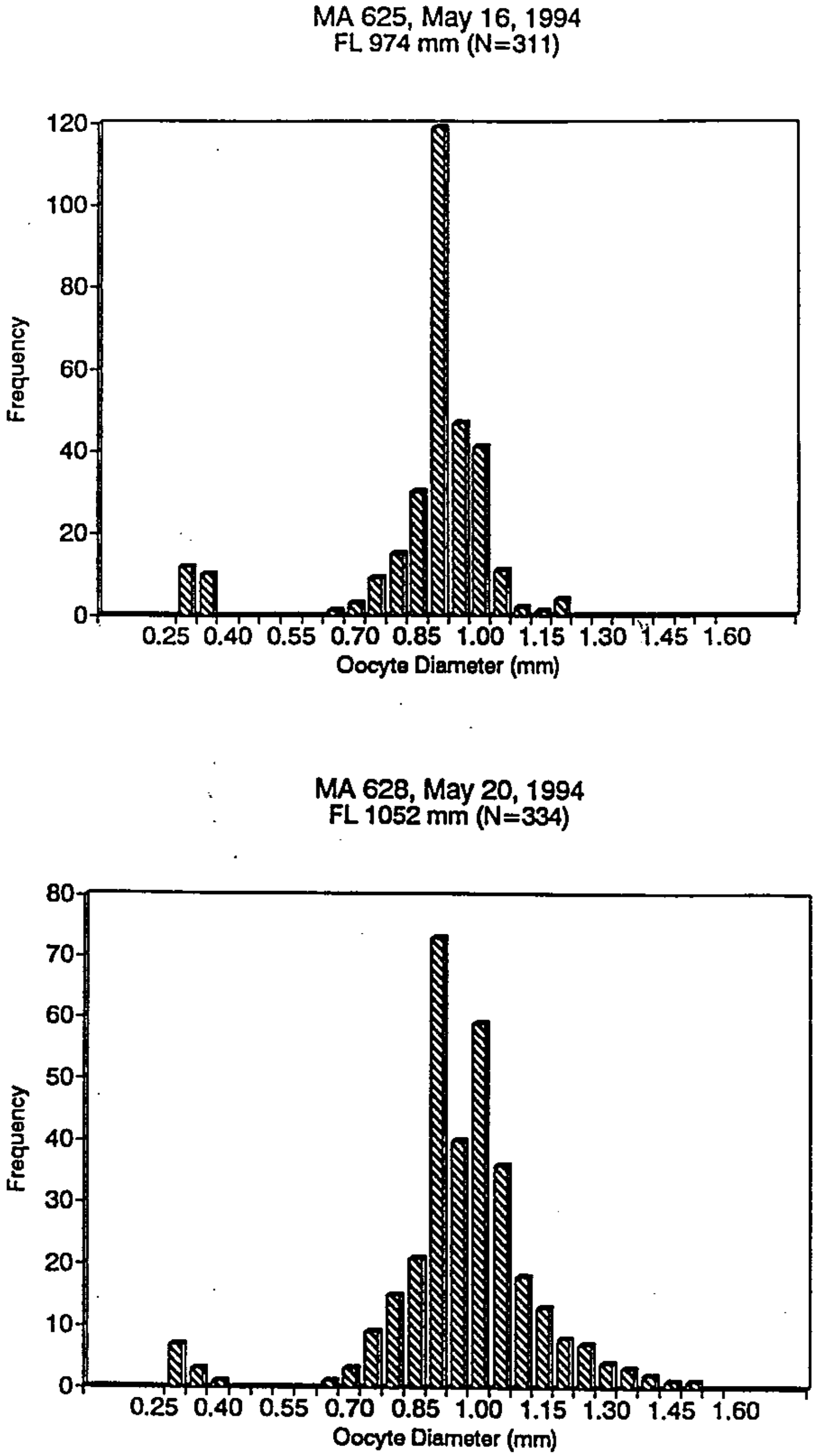


Figure 62. **Oocyte size-frequency distributions of female <u>Megalops</u> <u>atlanticus</u> utilized for the estimation of batch fecundity and spawning frequency.**

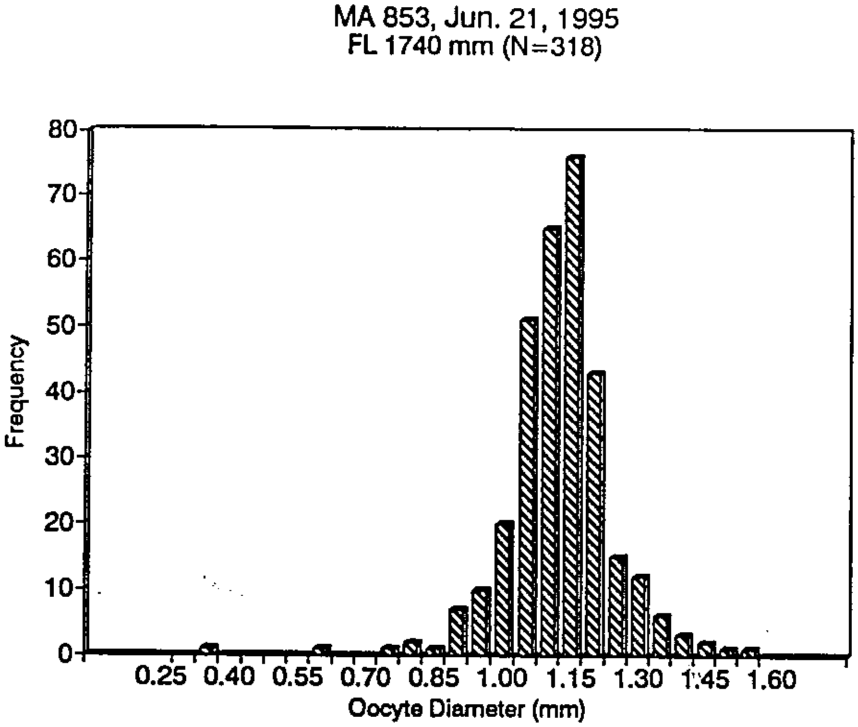


Figure 64. Oocyte size-frequency distribution of female Megalops atlanticus utilized for the estimation of batch fecundity and spawning frequency.