Commonwealth Of Puerto Rico
Department of Natural and Environmental Resources
Fisheries and Wildlife Bureau
Fisheries Research Laboratory

Final Report
To the U.S. Fish and Wildlife Service
Federal Assistance Project F-48

Aspects of the Reproductive Biology of Recreationally Important Fish Species in Puerto Rico

Javier Vélez-Arocho
Secretary

Ernesto Diaz-Velázquez
Administrator

Mayra García-Pérez
Auxiliary Administrator

José M Berrios
Federal Assistance Coordinator

Aida Rosario-Jiménez
Director fisheries Research Laboratory

Prepared by: Miguel Figuerola-Fernández
Noemí Peña-Alvarado
Wilfredo Torres-Ruiz

February 2008

PROJECT: ASPECTS OF THE REPRODUCTIVE BIOLOGY OF RECREATIONALLY IMPORTANT FISH SPECIES IN PUERTO RICO

STUDY: MATURATION AND REPRODUCTIVE SEASONALITY OF THE WAHOO (*Acanthocybium solandri*), RED-EAR SARDINE (*Harengula humeralis*), FALSE PILCHARD (*Harengula clupeola*), THREAD HERRING (*Opisthonema oglinum*), CREVALLE JACK (*Caranx hippos*), HORSE-EYE JACK (*Caranx latus*), BLUE RUNNER (*Caranx crysos*), AND GREAT BARRACUDA (*Sphyraena barracuda*) IN PUERTO RICO

FINAL REPORT
TO THE U.S. FISH AND WILDLIFE SERVICE
FEDERAL AID PROJECT F-48

FEBRUARY, 2008

PUERTO RICO DEPARTMENT OF NATURAL AND ENVIRONMENTAL RESOURCES
FISH AND WILDLIFE BUREAU
FISHERIES RESEARCH LABORATORY

Prepared by: **Miguel Figuerola-Fernández**
Noemí Peña-Alvarado
Wilfredo Torres-Ruiz

Table of Contents

Final Report

State: Puerto Rico **Project Number:** F-48

Agency: Department of Natural and Environmental Resources
Fish and Wildlife Bureau
Fisheries Research Laboratory

Project Title: Aspects of the reproductive biology of recreational important fish species in Puerto Rico

Study Title: Maturation and reproductive seasonality of the wahoo (*Acanthocybium solandri*), red-ear sardine (*Harengula humeralis*), false pilchard (*Harengula clupeola*), thread herring (*Opisthonema oglinum*), crevalle jack (*Caranx hippos*), horse-eye jack (*Caranx latus*), blue runner (*Caranx crysos*), and great barracuda (*Sphyraena barracuda*) in Puerto Rico

Study Number: I

Objetives: To describe, through the use of histology, the annual reproductive cycle and minimum size of sexual maturation of the wahoo (*Acanthocybium solandri*), red-ear sardine (*Harengula humeralis*), false pilchard (*Harengula clupeola*), thread herring (*Opisthonema oglinum*), crevalle jack (*Caranx hippos*), horse-eye jack (*Caranx latus*), blue runner (*Caranx crysos*), and great barracuda (*Sphyraena barracuda*).

Period Covered: October 1, 2003 – September 30, 2007.

Summary

Observations on maturation stages and the annual reproductive cycle of eight species of recreationally important fish present around Puerto Rico were analyzed to examine relationships between fish size and maturity and to determine the duration of the spawning season. The samples for this study (n=3,208) were collected from October 2003 to October 2007. A summary of results is presented in the table below. In Puerto Rico, to our knowledge, this is the first study to provide size at maturity and spawning seasonality estimates of these recreationally important species based on histological methods to assess gonadal stages of development. The species reported here have extended spawning seasons (mainly from March-April through September-October), with one or two annual peaks generally extending 1-3 months and at least some spawning activity probably occurring year-round in some species.

Species	*A. solanderi*	*H. humeralis*	*H. clupeola*	*O. oglinum*	*C. hippos*	*C. latus*	*C. crysos*	*S. barracuda*
Total sample size range	670-1727	85-157	26-134	74-227	158-837	55-742	162-660	290-1347
Size range ♀	670-1727	86-157	50-134	93-227	186-827	257-742	162-660	290-1347
Size range ♂	680-1520	85-148	54-126	92-210	158-837	148-660	184-519	326-1220
Mature♀ minimum size	784	92	73	106	305	276	200	532
Mature ♂ minimum size	680	90	77	113	295	255	205	352
Mature 50% ♀	896	96	85	119	343	334	257	649
Mature 50% ♂	918	93	74	132	280	325	232	582
Total sample weight range	867-32931	10-65	0.18-38	5-190	98-11340	3.4-7428	78-3175	209-12712
Weight range ♀	867-32931	10-65	2-38	11-190	138-17443	371-7428	86-3175	209-9080
Weight range ♂	1831-21546	10-56	2-33	9-190	96-9534	69-4649	119-2497	242-12712
Reproductive activity	May-Sep*	Year round	Year roud	Apr-Sep	Apr-Nov	Year round	Mar-Oct	Year round
Peak reproductive activity	June*	Jan-Aug	Mar-Sep	Jun-Jul*	May-Jul	Apr; Aug*	May-Jun	Mar-Aug
GSI peak	June	May	Apr-May	Apr-Sep	July	Apr; Aug	Jun-Aug	Mar; Jun-Aug
% individuals captured below maturity size	50%	2%	24%	29%	7%	49%	8%	16%

*Insufficient data

As reported elsewhere, these trends represent a common reproductive strategy among fish species living in subtropical and tropical waters. The duration of the spawning period has been mainly related to subtle changes in water temperature and/or photoperiod. Decreases in average length and size-at-maturity have been associated with increased fishing pressure. Maturity assessments should be conducted on a periodic basis in the future to ensure that the management measures enacted by the PRDNER, to limit fishing on the spawning stocks and reduce fishing pressure on the immature fish continue to receive representative estimates of mean length at maturity and timing of spawning for other species in need of protection. Special attention should be given to wahoo and horse-eye jack, since our data indicate that a significant proportion of these species were captured before reaching sexual maturity.

Acknowledgements

We are grateful to all the anglers that provided many of the fish for this project, especially Pedro Silva, Rafael “Pipo” Ríos, Manuel “Neco” Román, Fred Lentz, and Francisco “Pochy” Rosario. Thanks to the Fisheries Research Laboratory personnel, in particular Aida Rosario, Daniel Matos, Luis A. Padilla, Héctor López, Yamitza Rodríguez, Verónica Seda, Miguel Román, Ana L. Rivera, and Juan Rosado. A special note of thanks goes to Grisel Rodríguez for its help and support during various phases of this study. Gratitude is also expressed to the Fisheries and Wildlife Bureau (PRDENR) personnel, in particular to José M. Berríos and Aitza Pabón for their help and suggestions. This research was funded by the Federal Aid for Sportfish Restoration Program, U.S. Fish and Wildlife Service, Department of the Interior.

List of Figures

Wahoo

Red-ear sardine

False pilchard

Thread herring

Crevalle jack

List of Tables

Blue runner

Great barracuda

List of Appendixes

Wahoo (*Acanthocybium solandri*)

Introduction

The wahoo, *Acanthocybium solandri,*(Cuvier, 1832*)* (family Scombridae) is an epipelagic, highly migratory fish occupying tropical and subtropical waters of the Atlantic (including the Mediterranean and Caribbean seas), Pacific and Indian oceans and extending seasonally into temperate latitudes (Collette, 2002; Hogarth, 1976). In the Western Central Atlantic, wahoo occurs from northeastern Brazil to Rhode Island, including Bermuda and the Bahamas. This species is present year-round throughout much of the Caribbean and Gulf of Mexico, although its presence appears to be seasonal in most places. In North Carolina and Bermuda some wahoo are present year-round, but the fish are far more abundant during warmer months (Oxenford et al., 2003; SAFMC, 1998). In the Caribbean the peak of abundance occurs from the fall through spring. In Puerto Rico wahoo appears to be present year-round, with peak catches between October and April and the lowest abundance reported during summer months. Wahoo are frequently encountered far offshore and also near drop-offs and seamount tops surrounded by deep water. Larger wahoo (>40 pounds) tend to be solitary, while smaller individuals sometimes form small, loose aggregations. In some areas, probably for feeding or spawning purposes, wahoo of all sizes aggregate during some months. In general, they congregate near drifting objects and are frequently associated with floating debris*,* current edges and temperature breaks. Wahoo are capable of long range movements, as was demonstrated by a fish that was recaptured 6.5 months and 1,707 miles away after being tagged and released (WRP, 2007).

The wahoo has a streamlined body with a sharp pointed head. Jaws are elongated and the large mouth has numerous closely set, triangular and finely serrated teeth. The upper jaw is movable which an unusual characteristic in fishes is. Gill rakers are absent. The caudal peduncle is narrow and contains three sets of keels. Body color is dark blue or green above, with a series of 24 to 30 irregular cobalt blue vertical bars on its sides. The belly and lower sides are pale blue to silvery. While other members of the Scombridae, such as tunas and mackerels, exist as several species, there is only one species of wahoo recognized worldwide (Collete, 2002).

The official record for the largest wahoo caught with hook and line is 158 pounds (IGFA, 2001). A commercial longliner once reported a wahoo weighting 218 pounds. According to the records of the Puerto Rico Sport Fishing Association the largest wahoo reported locally was 121 pounds.

Adult wahoo are high trophic level predators. Its morphology is well adapted to this oceanic predatory existence. The body is stiff and propulsion is provided by movements of the caudal portion of the body only, reducing drag to a minimum (Murray and Moore, 1999). When attacking prey wahoo are capable of reaching speeds up to60 mph (WRP, 2007). Wahoo feeds primarily on fishes. Hogarth (1976) found that fishes accounted for

97.4 of all food item collected, mainly mackerels, butterfish, porcupinefish, and round herrings.

Wahoo appear to grow very fast in their first year, attaining a size of over 39 inches (Hogarth, 1976). After that, individuals grow at a rate of 1.2 to 1.5 inches per month. One tagged/recaptured fish grew from 11 to 33 pounds in 10 months (WRP, 2007). Latitude appears to influence size, with average weight increasing with distance from the equator, apparently correlated to cooler temperatures. Age and growth studies indicate that it is a fast-growing species, has high mortality and longevity is probably 5-6 years (see Oxenford et al., 2003). Wahoo reach maturity between 1 and 2 years of age (roughly 1000 mm of length), depending upon location and sex (Hogarth, 1976; Brown-Peterson et al., 2000). From relatively limited studies of reproduction, wahoo appears to have an extended spawning season (May-October) (see Oxenford et al., 2003). In North Carolina, Northern Gulf of Mexico and the Bahamas the reproductive season occur between May-June and August, with a peak in June and July (Hogarth, 1976; Brown-Peterson et al., 2000; Maki and McBride, 2007). Females are multiple batch spawners and have high fecundity, but most of the reproductive parameter estimates are from very small sample sizes and should be treated as preliminary.

In the western central Atlantic wahoo is a target species for both commercial and recreational fisheries and annual landings have increased steadily over the last decades in excess of 4.4 million pounds (Murray and Joseph, 1996; Oxenford et al., 2003).

Recent genetic studies showed no evidence of more than one wahoo stock within the western central Atlantic and between the western central Atlantic and central Pacific. At present coordinated management on broad geographic scales appears warranted for wahoo (Garber et al., 2005).

Despite its importance as a gamefish, no studies on wahoo basic biology had been made in Puerto Rico until present. However, a bag limit of 5 wahoo/person/day or 20 wahoo/boat/day was implemented under the Puerto Rico Fishing Law #278, Regulation 6768, 2004 based on the best available scientific information.

Materials and Methods

Data for this study were collected between October 2003 and October 2007. Crevalle jack, horse-eye jack, blue runner, thread herring, false pilchard, red-ear sardine, great barracuda and wahoo were sampled monthly by project personnel. Additional samples were obtained from cooperating recreational (in fishing tournaments) and commercial fishermen, and other personnel of the Fisheries Research Laboratory and the Marine Resources Division (Project F-42) of the Puerto Rico Department of Natural and Environmental Resources. Gear used to collect the samples consisted of hook and line, trammel nets, cast nets, monofilament gillnets, fish traps, and a beach seine. The total number of samples and the samples collected by month is presented in Appendix II. Samples were obtained from all around the Island, but most of them were collected in western Puerto Rico. Locations sampled during the study are presented in Appendix I.

Each fish collected was measured to the nearest millimeter (mm) fork length (FL) and whole weight (W) was taken to the nearest gram (g). To establish the TL/FL relationship a subsample of all species was measured to the nearest mm total length (TL). Except when noted otherwise, all measurements reported in the text are fork length in mm. The gonadal tissues were removed and weighed to the nearest 0.01 g. One lobe, or a portion of it, was placed in Davidson's fixative (Yevich and Barszcz, 1981) for histological processing. Gonads were preserved for 48 hours, washed for 24 hrs and then stored in 70% ethanol until further processing. A sample from the central portion of one lobe of each gonad was dehydrated, embedded in paraffin (Paraplast) and sectioned to 8 µm, stained with hematoxylin and eosin, and mounted for microscopic examination. Appendix III shows gonads classification according to the stage of maturation for males and females (de Sylva, 1963; García–Cagide, 1988; Hunter and Macewicz, 1985; Maki and McBride, 2007). The gonad conditions described for males are immature and mature. For females, they are immature, mature inactive, mature active, ripe and spent. A summary of the data compiled and analyzed during the study is presented in Appendix IV. Approximately 240 slides were examined to compare cellular development throughout both gonad lobules of the eight species under study. Transverse sections from three gonad areas (anterior, central, and posterior), for each lobule, were prepared. No differences were detected between the lobules or sections.

Spawning seasonality are usually based solely on the assessment of ovaries because males are generally more difficult to stage than females, often do not show marked changes in gonad weight with time, and therefore could give less well defined estimate of the spawning season (see West, 1990). We determined reproductive seasonality by calculating the percentage of each maturity class in each month and by the average gonadosomatic index (GSI) plotted against month of collection. GSI was calculated to show differences in development of the gonads with respect to body weight using the relationship described by Maddock amd Burton (1998), GSI = 100*(GW / FW), where GW = gonad weight (g) FW = fish weight (g).

The estimate mean length at first maturity (L_{50}) for males and females was determined by fitting the logistic curve to the percentage of mature individuals (maturity classes ≥2). The logistic curve was fitted by using a routine statistical method provided in the graphing software SigmaPlot ver. 10.0 (Systat Software Inc.) (see Appendices V-XX). L_{50} was defined as the smallest size class in which 50% of the individuals were sexually mature. Data were entered and analyzed using Microsoft Excel. The Kolmogorov-Smirnov two-sample test and the t-test were used to compare size frequency distributions and mean size. Sex ratios were tested statistically for significant deviations from the expected 1:1 with a chi-square test (α=0.05) (Sokal and Rolhf, 1981).

Results

Sampling , size-frequency distribution, and sex ratio

Two hundred and ninety nine wahoo were collected from November 2003 to October 2007 (Appendix II). Seventy six percent were fish sampled in tournaments while the remaining 24% were captured by commercial fishermen and DNER personnel. The total samples sizes ranged from 670-1727 mm FL (mean=1119; sd=196) (Fig. 1-1). Almost all samples were sexed, resulting in 157 males and 141 females thus the sex ratio of our sample was 1♂:0.9♀ (X^2=0.85906, p>0.05, NS). Size-frequency distributions of males and females are not significantly different (Kolmogorov-Smirnov, D=0.0885, p>0.01) (Fig. 1-2). Males ranged in size from 680-1520 mm FL (mean=1128; sd=190) and females from 670-1727 mm FL (mean=1109; sd=202). The four individuals larger than 1600 mm FL we collected were all females (Fig. 1-2). The larger fish in our sampling was a tournament female of 72.6 pounds and 1631 mm FL. Relationships between total length-fork length and weight-fork length are presented in figures 1-3 and 1-4, respectively.

Size at maturity

Male and female wahoo mature at about the same size. Smallest mature male measured 680 mm while the smallest mature female was 670 mm (Appendix IV). Estimated mean length at first maturity was 918 and 896 mm for males and females, respectively. All males larger than 1100 and all females larger than 1200 mm were mature (Figs. 1-5 and 1-6; Tables 1-1 and 1-2).

Spawning seasonality

Wahoo abundance drops significantly during the summer months around Puerto Rico. The scarcity of samples collected from May to September precludes any definite conclusion regarding spawning dynamics of this species in local waters. However, our data suggest a clear tendency for spawning occurring between April and October, as the GSI and monthly distribution of gonadal development stages suggests (Figs. 1-7 and 1-8; Tables 1-3 and 1-4). Females with gonads in stages 3 and 4 were present from March to October. The two females collected in June had ripe ovaries, one of them with hydrated oocytes. Although the number of samples is very low (n=6), all females collected between May and July had gonads in stages 3-5, suggesting that reproductive activity has a maximum around these months (Fig. 1-8; Table 1-4). Imminent spawning, as indicated by the presence of hydrated oocytes, were found in seven females (April 30 and Sept. 24, 2005; April 22 and Sept. 29, 2006; April 29, 2007(two samples) and June 14, 2007). On the other hand, all the females sampled from November to February had inactive ovaries or were classified as immature. The monthly variation in the GSI show a very similar trend, being at its minimum from October to March and starting to increase in April, reaching a peak in June (Fig. 1-7; Table 1-3).

Discussion

Sampling, size-frequency distribution, and sex ratio

Our wahoo collection is likely a representation of what recreational anglers catch in Puerto Rico, since 76 % of the samples were obtained from tournaments. The remaining 24 % came from commercial fishermen and DNER personnel sampling trips. The size-frequency distribution reported here is similar to those reported from south Florida (Beardsley and Richards, 1970), Bermuda (Luckhurst and Troot, 2000), and Florida and Bahamas (McBride et al., 2007), except that the largest wahoo in our study (a 72.6 pounds female that measured 1631 mm) was significantly smaller than the largest individuals reported by the mentioned studies and the official record of Puerto Rico of 121 pounds. Size overlapped extensively between the sexes and the size-frequency distribution between males and females are not significantly different, but the largest fish in our collection were females. Similar results were reported by McBride et al., 2007. Contrary to the results reported by McBride et al (2007) and Hogarth (1976) we found no statistical difference in the overall sex ratio, probably due to the lack of very large wahoo (>75 pounds) in our samples. Hogarth (1976) suggested that the female biased sex ratio he found (1♂:3♀) could be explained by different migration patterns between the sexes, a greater catchability of females resulting from differences between the sexes in habitat preference, or differential mortality (shorter lifespan in males) such that there are fewer males in the size range taken by the fishery.

Size at maturity

Our estimated mean length at first maturity of 896 mm for females is smaller than sizes reported from previous studies in northern localities. In North Carolina, the size at first maturation was 970 mm FL (Hogarth, 1976). In the northern Gulf of Mexico, size at 50% maturity for female wahoo is 1020 mm FL (Brown-Peterson et al., 2000). Maki and McBride (2007) reported a 50% maturity size of 925 mm FL. For male wahoo, Hogarth (1976) reported a size of first maturity of 822 mm FL. From the northern Gulf of Mexico, preliminary estimates by Brown-Peterson et al. (2000) indicated that males reach maturity at one year of age and that 50% maturity is reached at < 935 mm FL. Maki and McBride (2007) did not estimated maturity size for male wahoo. In Bermuda, preliminary data for wahoo suggest that size at maturity is around 1020 mm FL for males and 950 mm FL for females, a trend similar to the estimates reported in this study (SAFMC, 1998). It is worth noting that the smallest male collected by Maki and McBride (2007) (631 mm FL) and Brown-Peterson et al. (2000) (935 mm FL) were mature. When we pooled all wahoo length data available from Puerto Rico (sexes combined) 50% of 988 wahoo measured were collected before reaching 50 % maturity size (data sources: Matos, unpublished data Fisheries Research Laboratory; Project F-42, unpublished data, and this study). Most immature wahoo were captured by commercial fishermen, mainly during fishing trips targeting dolphinfish (*Coryphaena hippurus*). We recommend some attention must be given to this figure and, if confirmed, the possibility of establishing size limits for wahoo should be considered.

Spawning seasonality

Relative abundance of wahoo around Puerto Rico is low during the summer months. Although the number of wahoo samples we were able to analyze between May-September is small, our data shows a tendency for spawning to occur during these months in local waters. Several studies of wahoo reproduction indicate that this species appears to have an extended spawning season, mainly from May to October in the Western Central Atlantic (WCA) (Oxenford et al., 2003). To our knowledge, this study is the first one regarding the reproductive biology of this species in the southerly part of its range in the WCA (see Oxenford et al., 2003). Off North Carolina, Hogarth (1976) concluded that wahoo spawns from late June through August with peak activity occurring in June and July. The monthly GSI progression presented by this author is very similar to our findings (see Oxenford et al., 2003). In Bermuda, based on macroscopic examination of gonads, females appear to spawn from May to August (see Oxenford et al., 2003). In the northern Gulf of Mexico, Brown-Peterson et al. (2000) concluded from GSI and histological examination of gonads that wahoo females spawn from May-August, with a peak in June. Based on very limited larval collections, wahoo from Florida and the Straits of Yucatán have a spawning season extending from May to October (Wollam, 1969). In the Atlantic coast of Florida and northern Bahamas Maki and McBride (2007), with year-round samples, found that the GSI and the percent frequency of mature, active females were elevated from May to August. Brown-Peterson et al., (2000) and Maki and McBride (2007) reported some regressed females during peak spawning months, suggesting skip spawning and /or the possibility that not all females are spawning at the same time during the spawning period (two temporarily different spawning groups of female wahoo). We found six out of seven hydrated ovaries by the end of April (n=3) and by the end of September (n=3), but since we only collected six females from May to August it is not possible for us to draw any conclusion regarding the processes behind these patterns. Brown-Peterson et al. (2000) noted the presence of maturing females in the Bahamas in November, speculating that there may be a spring spawning somewhere, yet to be discovered. Although not histologically processed, during a wahoo tournament held in December 1-2, 2007 in Puerto Rico, we collected a very large ovary weighing 720 g which macroscopically corresponded to a ripe female. As Maki and McBride (2007) point out, researchers should be open to geographical variation in reproductive seasonality by wahoo. As examples, in the central Pacific Ocean, Iversen and Yoshida (1957) report that wahoo are in spawning condition in spring (March) and winter (November-December), and Matsumoto (1967) collected wahoo larvae year-round.

References

Beardsley, G.L.,Jr. and W.J. Richards. 1970. Size seasonal abundance and length-weight relation of some Scombrid fishes from southeast Florida. United States Fish and Wildlife Service, Special Scientific report-Fisheries 595, Washington DC, USA, 6p.

Brown-Peterson, N.J., J.S. Franks and A.M. Burke. 2000. Preliminary observations on the reproductive biology of wahoo, *Acanthocybium solandri,* from the northern Gulf of Mexico and Bimini, Bahamas. Proceedings of the Gulf and Caribbean Fisheries Institute 51:414-427.

Collete, B.B. 2002. Scombridae. *In* The living marine resources of the Western Central Atlantic. Volume 2: Bony fishes part 1 (Acipenseridae to Grammatidae). FAO Species Indentification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Special Publication No. 5. (K.E. Carpenter, ed.), p.1701-1722. Food Agric. Organization, Rome.

de Sylva, D.P. 1963. Systematics and life history of the great barracuda, *Sphyraena barracuda* (Walbaum). University of Miami Press, Institute of Marine Science, vii, 179p.

Garber, A.F., M.D. Tringali, and J.S. Franks. 2005. Population genetic and phylogeographic structure of wahoo, *Acanthocybium solandri* from the western Atlantic and central Pacific Ocean. Marine Biology 147:205-214.

García-Cagide, A. 1988. Particularidades de la reproducción de la sardina de ley, *Harengula humeralis* (Cuvier 1829), en la región oriental del Golfo de Batabano, Cuba. Rep. Invest. Inst. Oceanol. Acad. Cienc. Cuba. 12: 1-15.

Hogarth, W.T. 1976. Life history aspects of the wahoo *Acanthocybium solandri* (Cuvier and Valenciennis) from the coast of North Carolina. PhD Dissertation. North Carolina State. Raleigh, N.C. 100 p.

Hunter, J.R., and B.J. Macewicz. 1985. Measurements of spawning frequency in multiple spawning fishes. *In* Lasker, R (ed) An egg production method for estimating spawning biomass of pelagic fishes: applications to the northern anchovy, *Engraulis mordax*. NOAA Technical Report NMFS 36:79-94.

IGFA. 2001. Database of IGFA angling records until 2001. IFGA, Fort Lauderdale, USA.

Iversen, E.S. and H.O. Yoshida. 1957. Notes on the biology of the wahoo in the Line Islands. Pacific Science 11:370-379.

Luckhurst, B.E. and T. Troot. 2000. Bermuda's commercial fishery for wahoo and dolphinfish: landings seasonality and catch per unit effort trends. Proceedings of the Gulf and Caribbean Fisheries Institute 51:404-413.

Maddock, D.M. and M.P. Burton. 1998. Gross and histological of ovarian development and related conditions changes in American plaice. Journal of Fish Biology 53: 928-944.

Maki, K.L. and R.S. McBride. 2007. Reproductive biology of wahoo, *Acanthocybium solandri*, from the Atlantic coast of Florida and the Bahamas. Part of a final report for the MARFIN-funded proposal:"Fishery and population characteristics of wahoo, *Acanthocybium solandri,* in Florida and adjacent waters of the western North Atlantic Ocean" (NOAA Award Number NA17FF2882).

Matsumoto, W.M. 1967. Morphology and distribution of larval wahoo *Acanthocybium solandri* (Cuvier) in the central Pacific Ocean. Fisheries Bulletin, U.S. 66:299-322.

McBride, R.S., A.K. Richardson and K.L. Maki. 2007. Age, growth and mortality of wahoo, *Acanthocybium solandri,* from the Atlantic coast of Florida and the Bahamas. Part of a final report for the MARFIN-funded proposal:"Fishery and population characteristics of wahoo, *Acanthocybium solandri,* in Florida and adjacent waters of the western North Atlantic Ocean" (NOAA Award Number NA17FF2882).

Murray, P.A. and W.B. Joseph, 1996. Trends in the exploitation of the wahoo, *Acanthocybium solandri*, by the St. Lucian pelagic fishery. Proceedings of the Gulf and Caribbean Fisheries Institute 44: pp 730-746.

Murray, P.A. and E.A. Moore. 1999. Morphometric relationships in wahoo, *Acanthocybium solandri*, landed in St. Lucia. Proceedings of the Gulf and Caribbean Fisheries Institute 45: pp 552-556.

Oxenford, H.A., P.A. Murray, and B.E. Luckhurst. 2003. The biology of the wahoo in the western central Atlantic. Gulf and Caribbean Research 15:33-49.

SAFMC, 1998. Proceedings of the South Atlantic Fishery Management Council dolphin/wahoo workshop, Charleston, SC, USA, May 6-9, 1998. South Atlantic Fishery Management Council, Charleston, SC, USA, unpag.

Sokal, R.R. y F. J. Rohlf. 1981. Biometry. W.H. Freeman and Company, San Francisco, Cal. 859 p.

West, G. 1990. Methods of assessing ovarian development in fishes: a review. Aust. J. Mar. Freshwater Res.,41, 199-222.

Wollam, M.B. 1969. Larval wahoo, *Acanthocybium solandri* (Cuvier), (Scombridae) from the strait of Yucatan and Florida. Florida Department of Natural Resources Leaflet Series 4 (12):1-7.

WRP, 2007. Wahoo Research Project at Florida Atlantic University. www.wahooproject.org

Yevich, P.R. y C.A. Barszcz. 1981. Preparation of aquatic animals for histopathological examination. Aquat. Biol. Sect., Biol. Methods Br., Environ. Monit. and Support Lab., U.S. Environ. Protect. Agcy, Cincinnati, 81 pp.

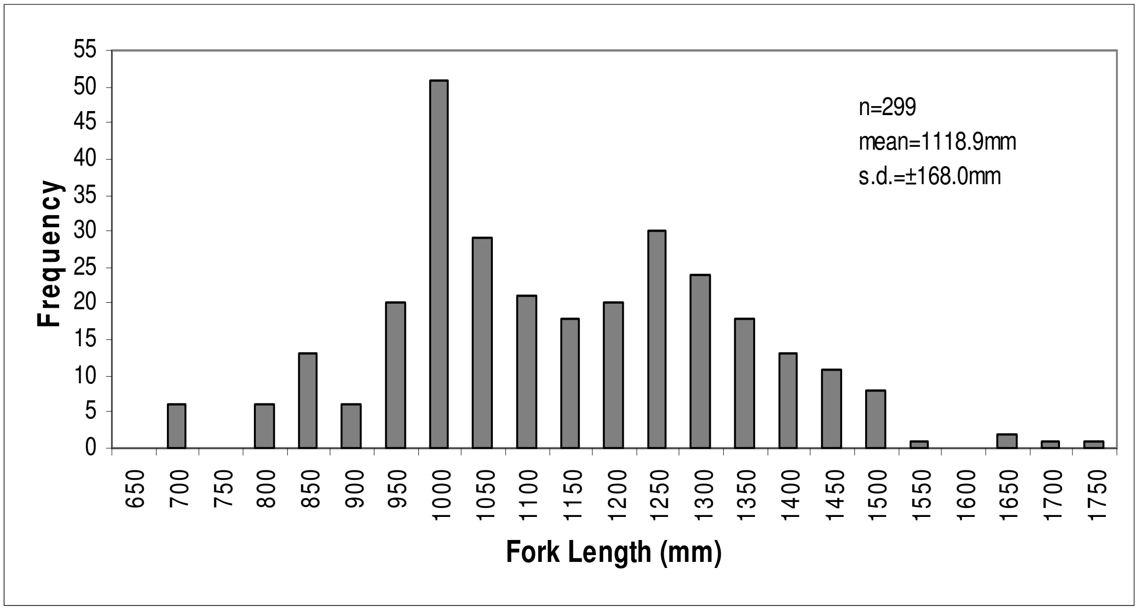


Figure 1-1. Size-frequency distribution of wahoo (*Acanthocybium solandri*) collected between November 2003 and October 2007.

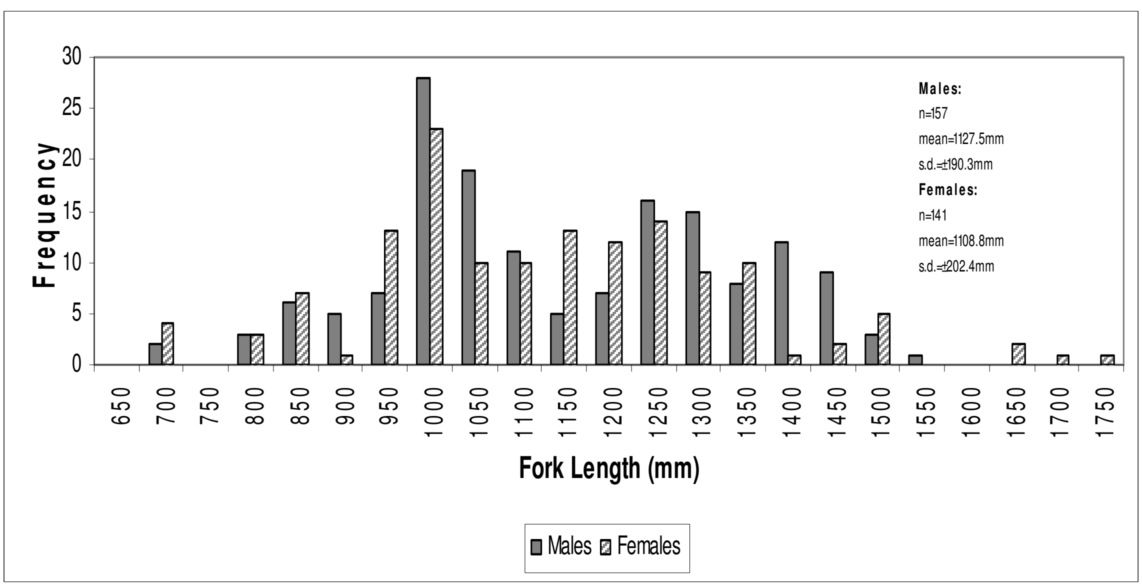


Figure 1-2. Size-frequency distribution of male and female wahoo (*Acanthocybium solandri*) collected between November 2003 and October 2007.

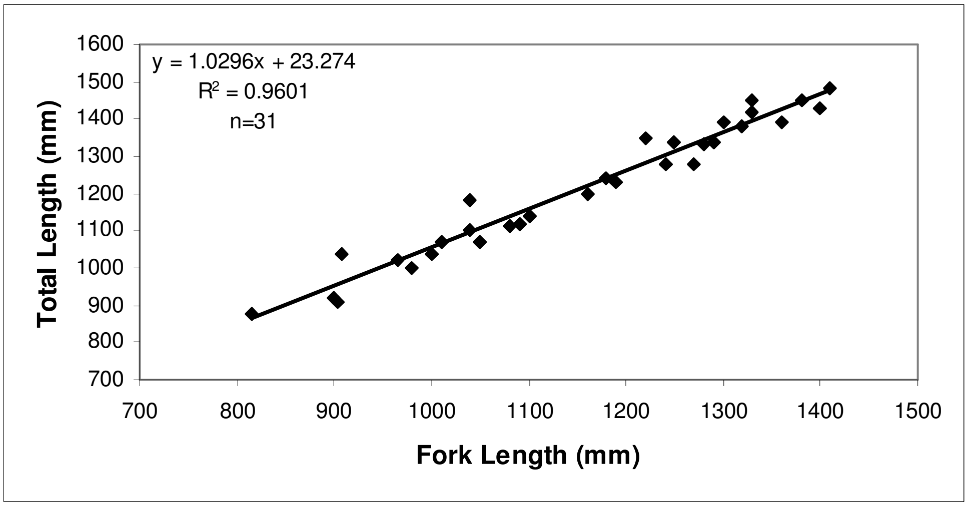


Figure 1-3. Relationship between total length and fork length for wahoo (*Acanthocybium solandri)*.

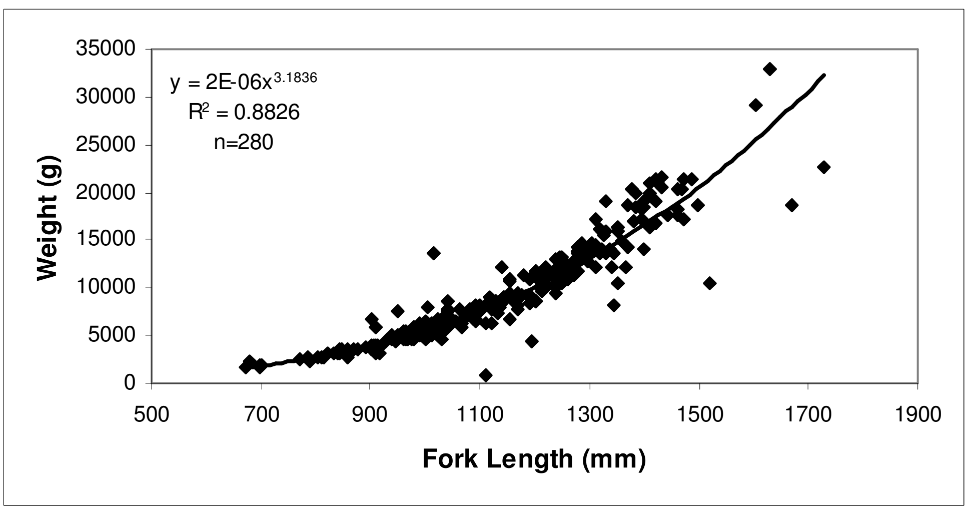


Figure 1-4. Relationship between weight and fork length for wahoo (*Acanthocybium solandri)*.

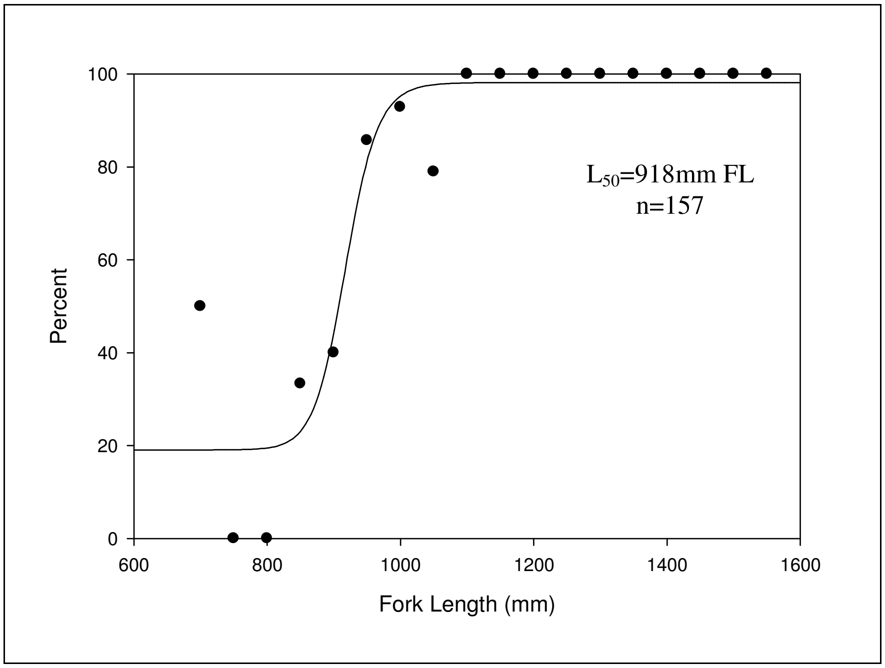


Figure 1-5. Percent of sexually mature male wahoo (*Acanthocybium solandri*) as a function of fork length (see Appendix V).

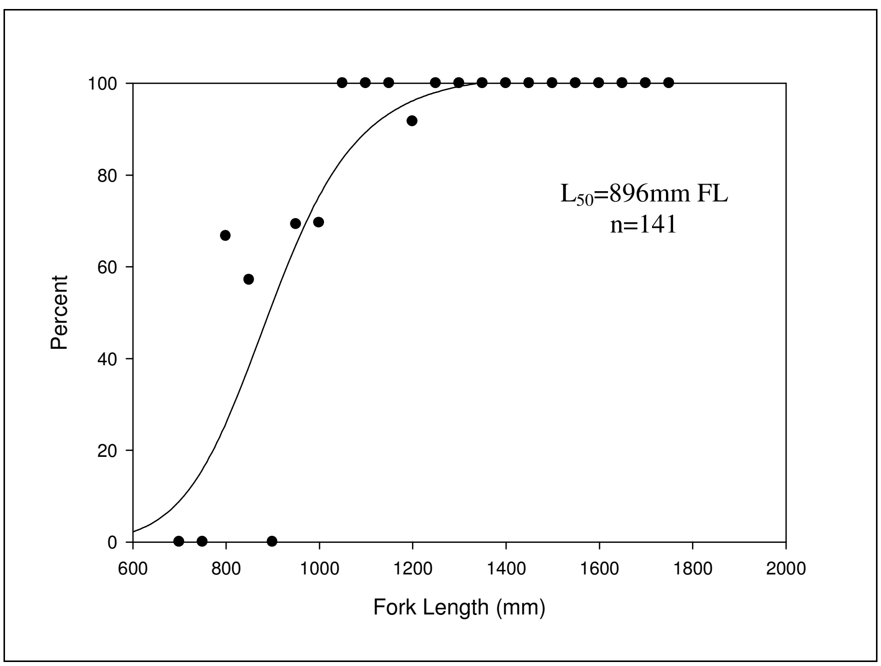


Figure 1-6. Percent of sexually mature female wahoo (*Acanthocybium solandri*) as a function of fork length (see Appendix VI).

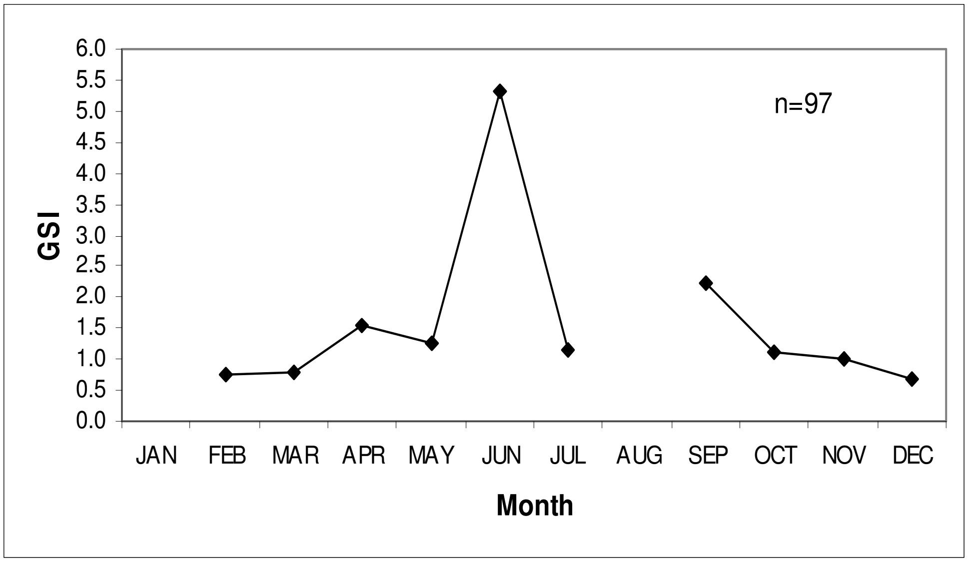


Figure 1-7. Monthly mean gonadosomatic index (GSI) for female wahoo (*Acanthocybium solandri*).

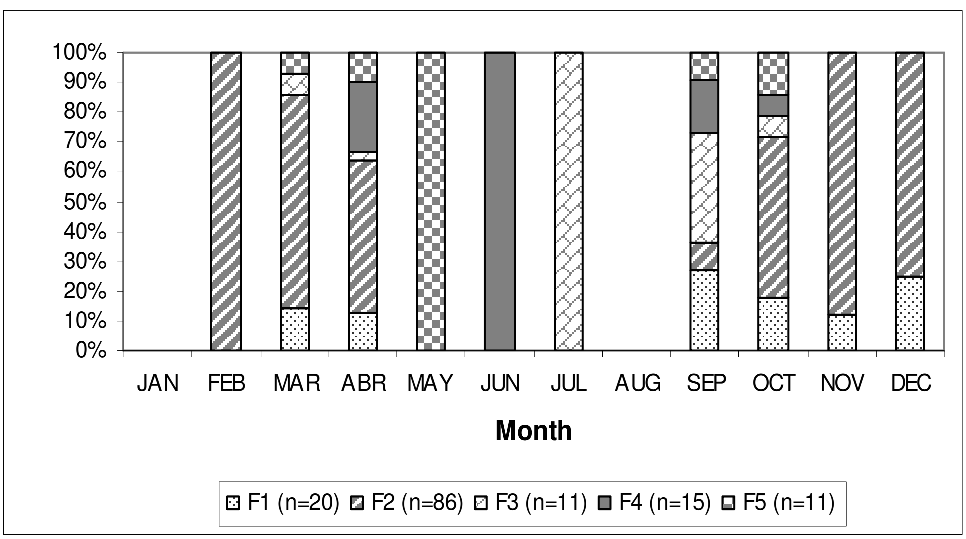


Figure 1-8. Monthly percentages of reproductive classes for female wahoo (*Acanthocybium solandri*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5=Spent).

FL (mm)	N total	N mature	% mature
700	2	1	50
750	0	0	
800	3	0	0
850	6	2	33
900	5	2	40
950	7	6	86
1000	28	26	93
1050	19	15	79
1100	11	11	100
1150	5	5	100
1200	7	7	100
1250	16	16	100
1300	15	15	100
1350	8	8	100
1400	12	12	100
1450	9	9	100
1500	3	3	100
1550	1	1	100
Total	157	139	

Table 1-1. Maturity schedule by size for male wahoo (*Acanthocybium solandri*).

FL (mm)	N total	N mature	% mature
700	4	0	0
750	0	0	
800	3	2	67
850	7	4	57
900	1	0	0
950	13	9	69
1000	23	16	70
1050	10	10	100
1100	10	10	100
1150	13	13	100
1200	12	11	92
1250	14	14	100
1300	9	9	100
1350	10	10	100
1400	1	1	100
1450	2	2	100
1500	5	5	100
1550	0	0	
1600	0	0	
1650	2	2	100
1700	1	1	100
1750	1	1	100
Total	141	120	

Table 1-2. Maturity schedule by size for female wahoo (*Acanthocybium solandri*).

Month	GSI	N	Sd
January		0	
February	0.738	8	0.176
March	0.774	10	0.152
April	1.544	20	1.583
May	1.250	1	
June	5.302	2	4.629
July	1.146	3	0.221
August		0	
September	2.211	4	2.255
October	1.104	22	0.624
November	1.004	24	1.365
December	0.673	3	0.172
Total		97	

Table 1-3. Monthly mean gonadosomatic index (GSI) of female wahoo (*Acanthocybium solandri*).

		Stage of gonad development									
		F1		**F2**		**F3**		**F4**		**F5**	
Month	**N**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
January	0	0	0	0	0	0	0	0	0	0	0
February	8	0	0	8	100.0	0	0	0	0	0	0
March	14	2	14.3	10	71.4	1	7.1	0	0	1	7.1
April	39	5	12.8	20	51.3	1	2.6	9	23.1	4	10.2
May	1	0	0	0	0	0	0	0	0	1	100.0
June	2	0	0	0	0	0	0	2	100.0	0	0
July	3	0	0	0	0	3	100.0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0
September	11	3	27.3	1	9.1	4	36.4	2	18.2	1	9.1
October	28	5	17.8	15	53.6	2	7.1	2	7.1	4	14.2
November	33	4	12.1	29	87.9	0	0	0	0	0	0
December	4	1	25.0	3	75.0	0	0	0	0	0	0
Total	143	20		86		11		15		11	

Table 1-4. Monthly percentages of reproductive classes for female wahoo (*Acanthocybium solandri*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5= Spent).

Red-ear sardine (*Harengula humeralis*)

Introduction

In Puerto Rico several species of clupeids are among the principal prey items for many important reef and pelagic fish, and therefore, are essential as bait in our commercial and recreational fisheries. An understanding of the life history and ecology of the forage base is important for an adequate management of the island fisheries (Beets and La Place, 1991).

The red-ear sardine (*Harengula humeralis*, Cuvier, 1829) is one of the most important baitfishes in Puerto Rico (Kimmel, 1991; LeGore, 2007). *H. humeralis* is pelagic and can be found near coral-reefs, sand beaches, estuaries and seagrass beds. When compared with *H. clupeola* in terms of habitat preferences, *H. humeralis* apparently prefers clear waters and coral-reef areas (Crevigón et al, 1993). Red-ear sardines fed mainly at night and are planktivorous, feeding mainly on copepods, larvae of decapods and fishes and stomatopods (Sierra, 1987; Sierra et al., 1994; Ortaz et al., 1996). The red-ear sardine can be found in Bermuda, Florida, Bahamas, Caribbean and West Indies (not Gulf of Mexico or Brazil) (Munroe and Nizinski, 2002). The red-ear sardine is easily distinguishable from the false pilchard by the presence of a prominent orange spot at upper end of gill opening and horizontal stripes on upper part of body. *H. humeralis* possesses a series of abdominal scutes forming a distinct keel and has no lateral line. Teeth are small but gill rakers are long and numerous for sieving plankton. This species reaches a maximum size of about 22 cm, being common to 12 cm (Whitehead, 1985). The flesh of *H. humeralis* has been reported to occasionally be deadly poisonous (Brody, 1972).

Materials and Methods

See Materials and Methods in Wahoo section, page 17.

Results

Sampling, size frequency distribution and sex ratio

Four hundred and twenty one *H. humeralis* were collected from November 2003 to October 2007. Size range was 85-157 (mean=119; sd=±13.6) (Fig. 2-1). Four hundred and eighteen were sexed (184 males and 234 females). Sex ratio was 1♂:1.37♀ (χ^2=5.98, $p<0.05$, significantly different). Size-frequency distribution of males and females are significantly different (Kolmogorov-Smirnov, D=0.243, $p<0.05$) (Fig.2-2). Males ranged in size from 85-148 mm FL (mean=115; sd=±13) and females ranged from 86-157 mm FL (mean=123; sd=±13). Following a trend similar to the one observed in *H. clupeola* females were predominant in all the size classes larger than 120 mm while males predominate in the size classes <110 mm (Fig. 2-2). Individuals smaller than 100 mm were difficult to locate and collect and only 28 were sampled during the study, 25 were sexed (16 males and 9 females). Relationships between total length-fork length and weight-fork length are presented in figures 2-3 and 2-4, respectively.

Size at maturity

Male and female *H. humeralis* mature at about the same size. Males started to mature at 90 mm FL while the smallest mature female was 92 mm FL (Appendix IV). Estimated mean length at first maturity was 93 and 96 mm for males and females, respectively. All males larger than 115 and all females larger than 110 mm FL were mature (Figs. 2-5 and 2-6; Tables 2-1 and 2-2).

Spawning seasonality

Ripe females were present in all months, indicating that *H. humeralis* reproduces year-round in Puerto Rico (Fig. 2-8; Table 2-4). Reproductive activity is more intense from January through August. The percentage of ripe females during these months ranged from 59 % in February to 100 % in May. During the period September-December the number of inactive mature females increased while the number of ripe females decreased. The percentage of ripe females during that period ranged from 7 % in October to 42 % in December. Both the monthly distribution of gonadal development stages and the GSI shown maximum values in May (n=2, both fish with hydrated oocytes) (Figs. 2-8 and 2-7; Tables 2-4 and 2-3).

Discussion

Sampling, size-frequency distribution, and sex ratio

As in the case of the false pilchard, the red-ear sardine samples were captured inshore with castnets. *H. humeralis* reaches a larger size than *H. clupeola*. In this study, the largest *H. humeralis* measured 157 mm FL. In Venezuela, Posada et al. (1988) reported a maximum size of 173 mm SL, while Rivas (1963) working with many specimens from Florida, Bermuda, West Indies and Central America reported a maximum size of 172 mm SL. Cervigón (1991) after examining several localities in Venezuela, reported a maximum size of 192 mm TL for this species. García-Cagide (1988), in a study concerning the reproductive biology of *H. humeralis* in eastern Cuba, reports results similar to this study. This author found that females predominate in the larger size classes (130-170 mm FL) and report a sex ratio of 1♂:2.3♀. Posada et al. (1988) observed sex ratio was not different from 1♂:1♀ in *H. humeralis*.

Size at maturity

Our 50 % maturity estimates were 93 and 96 mm for males and females, respectively. Males started to mature at 90 mm while the smallest mature female measured 92 mm. In eastern Cuba, García-Cagide (1988) states that the smallest individual with mature gonad measured 110 mm FL (sex not specified) and that more than 45 % of males were 110-130 mm FL while more than 45 % of females were 120-140 mm FL. On the other hand, in southwestern Cuba, García-Cagide et al. (1994) reported a minimum maturation size of 80-90 mm FL for males and 90-100 mm FL for females. The same report mentions a

50 % maturity value of 100 mm FL for males and 110 mm FL for females. Posada et al (1988) estimated mean length at first maturity was 124 mm TL for males and 128 mm TL for females. The minimum maturation size reported by these authors was 103 mm and 93 mm TL for males and females, respectively. In the very similar species, *H. jaguana,* both sexes mature for the first time between 78-85 mm SL (Martínez and Houde, 1975). It is interesting to note that, as in the case of the false pilchard, our 50% maturity estimates are smaller than the ones reported elsewhere. Females with hydrated oocytes were collected, in shallow water, in several sampling trips, although they were less common than in the case of false pilchard (see Discussion for *H. clupeola*). The two *Harengula* studied here frequently form mixed schools and their habits are very similar (see Posada et al, 1988). Our comments regarding possible management recommendations definitely apply to both species. Based on our estimated mean length at first maturity and the size-frequency distribution, about 98 % of the 467 fish measured were mature (data sources: Daniel Matos, unpublished data, Fisheries Research Laboratory and this study).

Spawning seasonality

According to the data we compiled, the red-ear sardine reproduces to some degree year-round, being January-August the period with more intense reproductive activity. Very similar results were reported by García-Cagide (1988) who found fish in spawning condition virtually year-round with an increment of reproductive activity from February until May, being April and May the peak months. Mester et al. (1974), in northern Cuba, noted that *H. humeralis* presented a maximum frequency of mature oocytes from April to May, but they only examined samples collected between February-July. In Venezuela (Posada et al. 1988) reported two spawning periods for the red-ear sardine (October-December and April-June).

References

Beets, J. and J.A. LaPlace. 1991. Virgin Islands baitfish survey: October to December 1986. Gulf & Carib. Fisheries Inst. 40: 55-63.

Brody, R.W. 1972. Fish poisoning in the Eastern Caribbean. Proceedings of the Gula and Caribbean Fisheries Institute 24: 100-116.

Cervigón, F. 1991. Los peces marinos de Venezuela. Vol. 1, Segunda edición, Cromotip, Caracas, 425p.

Cervigón, F., R. Cipriani, W. Fischer, L. Garibaldi, M. Hendrickx, A.J. Lemus, R. Márquez, J.M. Poutiers, G. Robaina, and B. Rodriguez. 1993. Fichas FAO de identificación de especies para los fines de la pesca. Guía de campo de las especies comerciales marinas y de aguas salobres de la costa septentrional de Sur América. FAO, Rome. 513 p. Preparado con el financiamiento de la Comisión de Comunidades Europeas y de NORAD.

García-Cagide, A. 1988. Particularidades de la reproducción de la sardina de ley, *Harengula humeralis* (Cuvier 1829), en la región oriental del Golfo de Batabano, Cuba. Rep. Invest. Inst. Oceanol. Acad. Cienc. Cuba. 12: 1-15.

García-Cagide, A., R. Claro and B.V. Koshelev. 1994. Reproducción. P 187-262 *In*: R. Claro (ed.). Ecología de los peces marinos de Cuba. Inst. Oceanol. Acad. Cienc. Cuba and Cen. Invest. Quintana Roo, (CIQPRO), México.

Kimmel, J.J. 1991. A fisheries dependent survey of baitfishes in Puerto Rico. Proceedings of the Gulf and Caribbean Fisheries Institute 40: -64-81.

LeGore, S. 2007. Bait fisheries serving the marine recreational fisheries of Puerto Rico. Technical Report No.06-113F. 127p

Martinez, S. and E.D. Houde. 1975. Fecundity, sexual maturation, and spawning of scaled sardine (*Harengula jaguana* Poey). Bulletin of Marine Science 25:35-45.

Mester, R.; Ros, R.M.; Mester, L. Jun. 1974. Estudio histológico de las gónadas de dos especies de sardinas, *Harengula clupeola* (Cuvier) y *Harengula humeralis* (Cuvier). Ciencias (Invest.Mar.). No. 8.

Munroe, T.A. and M.S. Nizinski. 2002. Clupeidae. *In* The living marine resources of the Western Central Atlantic. Volume 2: Bony fishes part 1 (Acipenseridae to Grammitidae), sea turtles and marine mammals. FAO Species Indentification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Special Publication No. 5. (K.E. Carpenter, ed.), p.804-820. Food Agric. Organization, Rome.

Ortaz, M., M.E. Rocha and J.M. Posada. 1996. Food habits of the sympatric fishes *Harengula humeralis* and *H. clupeola* (Clupeidae) in the Archipiélago de Los Roques National Park, Venezuela. Caribb. J. Sci. 32(1): 26-32.

Posada, J.M., B. Alvarez, y J.A. Marval. 1988. Algunos aspectos de la biología reproductiva de las sardinas, Harengula humeralis (Cuvier) y Harengula clupeola Cuvier (Pisces: Clupeidae) en el Parque Nacional Archipiélago de Los Roques. Mem. Soc. Cien. Nat. La Salle 48(3): 237-258.

Randall, J.E. 1996. Caribbean Reef Fishes. Third Edition – revised and enlarged. T.F.H. Pubs., Inc., Ltd. Hong Kong. 368 p.

Rivas, L.R. 1963. Genus *Harengula* Cuvier and Valenciennes 1847. *In* Fishes of the Western North Atlantic. Mem. Sears Fdn Mar. Res. 1(3):386-396.

Sierra, L.M. 1987. Peculiaridades de la alimentación de la sardina de ley, *Harengula humeralis* (Cuvier, 1829), en la región oriental del Golfo de Batabanó Cuba. Cuba. Rep. Invest. Inst. Oceanol. Acad. Cienc. Cuba. No. 69: 19p.

Sierra, L.M., R. Claro and O.A. Popova. 1994. Alimentación relaciones tróficas. P. 263-284 *In:* R. Claro (ed.). Ecología de los Peces Marinos de Cuba. Inst. de Oceanología Acad. De Cienc. De Cuba y Centro de Invest. De Quintna Roo, México.

Whitehead, P.J.P. 1985. FAO Species Catalogue. Vol. 7. Clupeoid fishes of the world (suborder Clupeioidei). An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf herrings. Part1 – Chirocentridae, Clupeidae and Pristigasteridae. FAO Fish Synop. 125(7/1): 1-303.

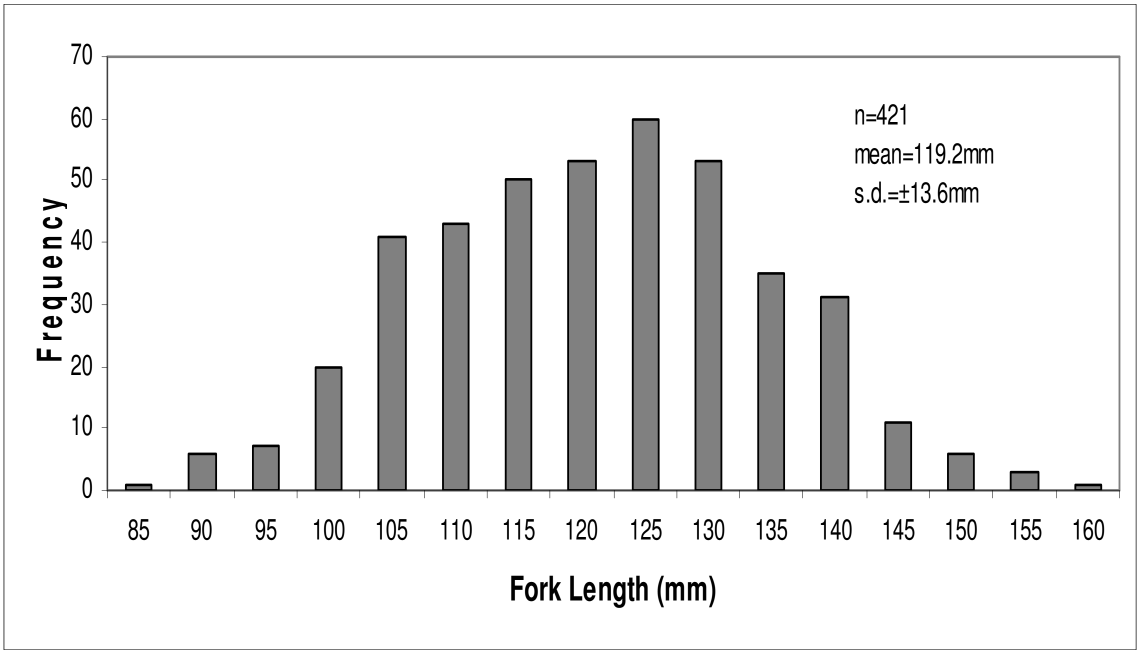


Figure 2-1. Size-frequency distribution of red-ear sardine (*Harengula humeralis*) collected between November 2003 and October 2007.

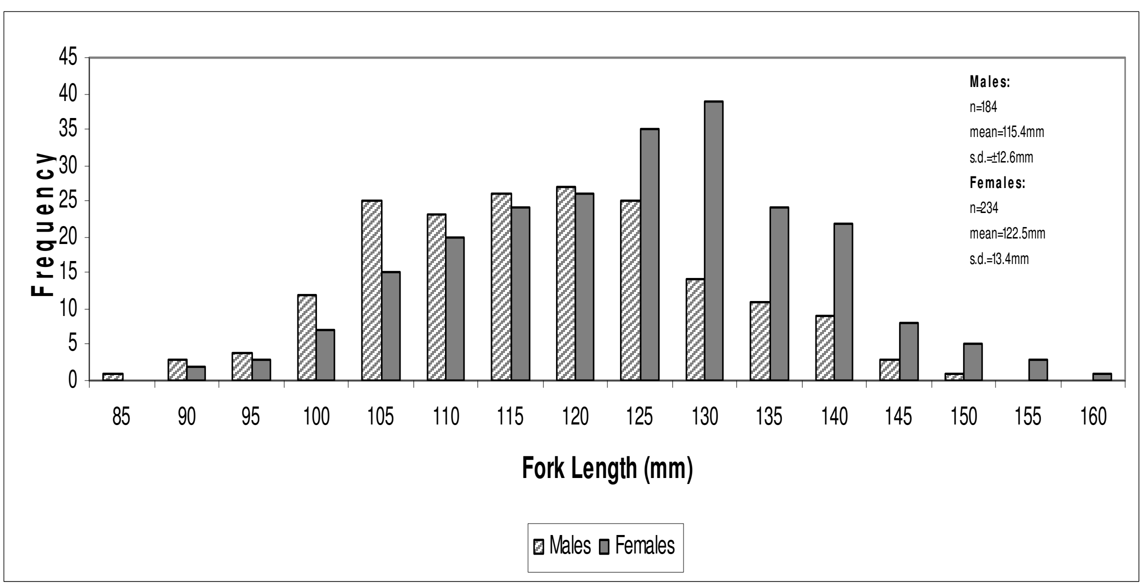


Figure 2-2. Size-frequency distribution of male and female red-ear sardine (*Harengula humeralis*) collected between November 2003 and October 2007.

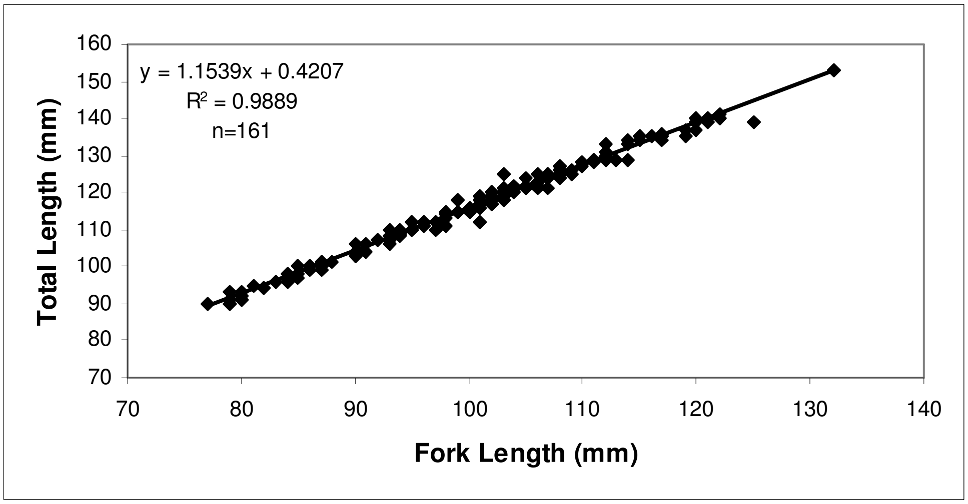


Figure 2-3. Relationship between total length and fork length for red-ear sardine (*Harengula humeralis*).

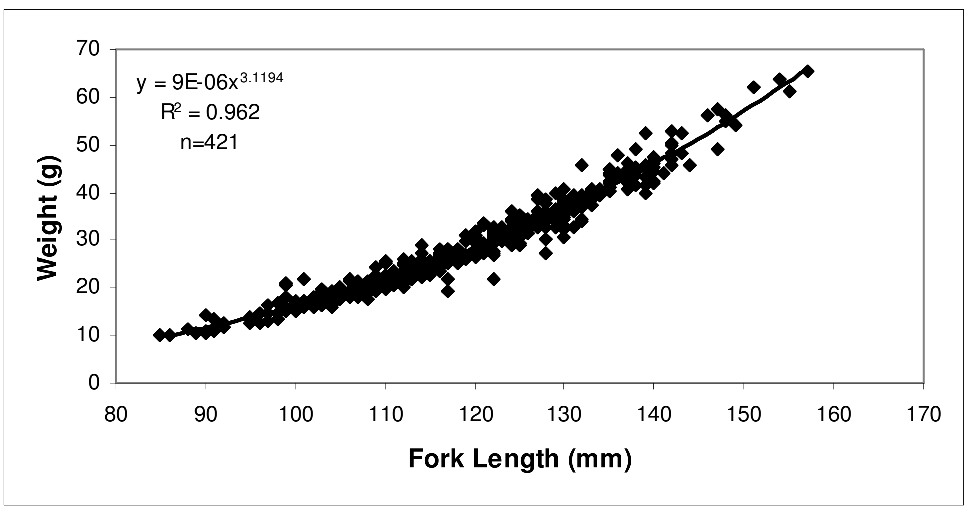


Figure 2-4. Relationship between weight and fork length for red-ear sardine (*Harengula humeralis*).

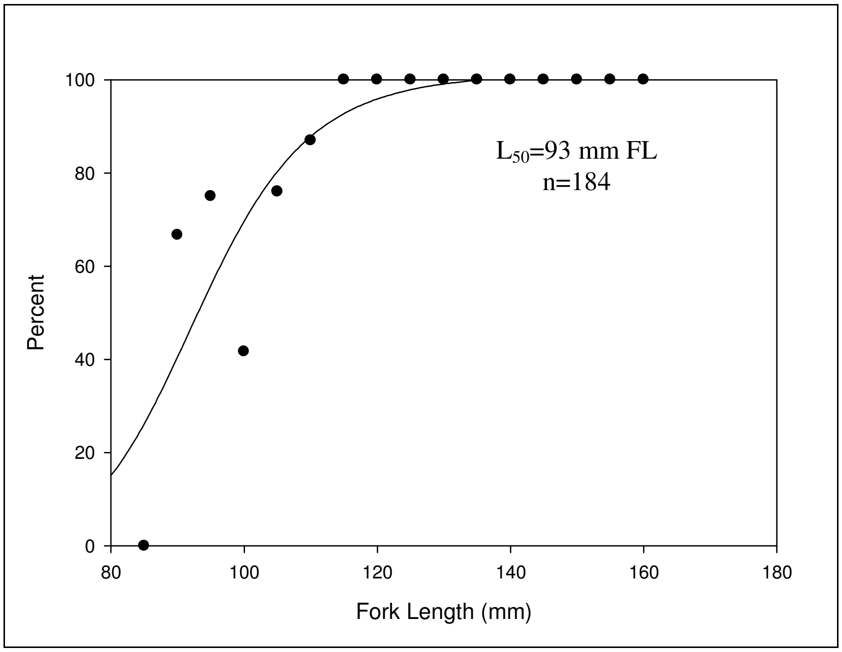


Figure 2-5. Percent of sexually mature male red-ear sardine (*Harengula humeralis*) as a function of fork length (see Appendix VII).

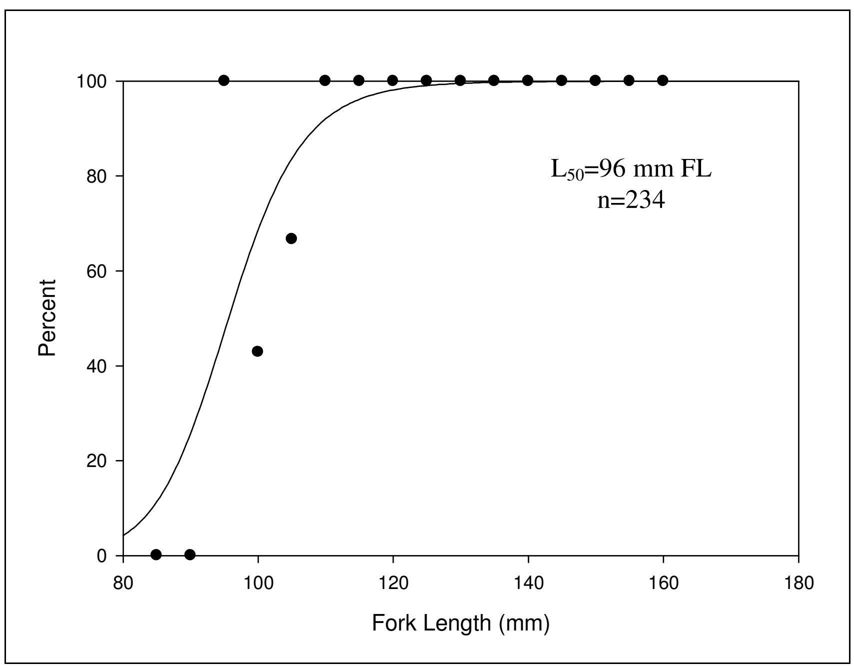


Figure 2-6. Percent of sexually mature female red-ear sardine (*Harengula humeralis*) as a function of fork length (see Appendix VIII).

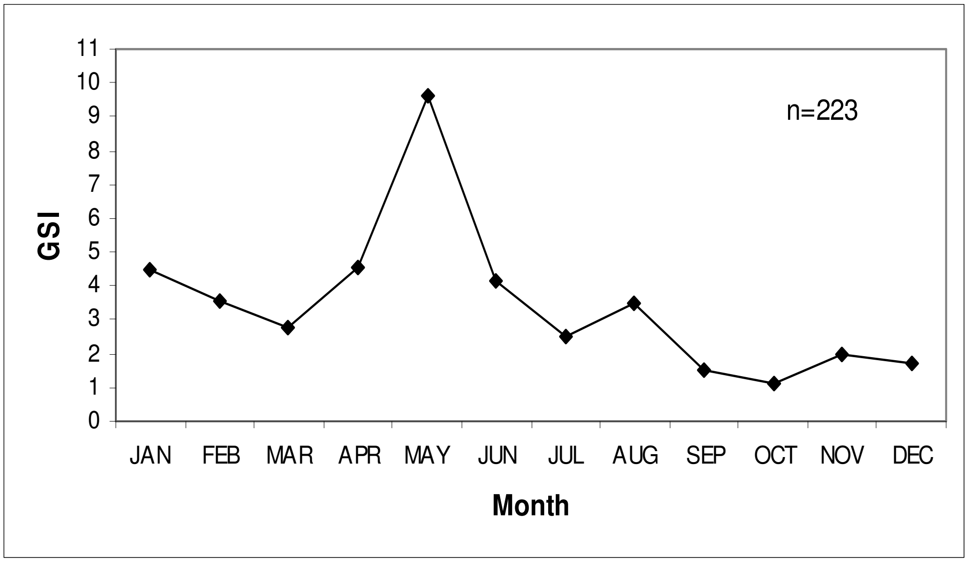


Figure 2-7. Monthly mean gonadosomatic index (GSI) for female red-ear sardine (*Harengula humeralis*).

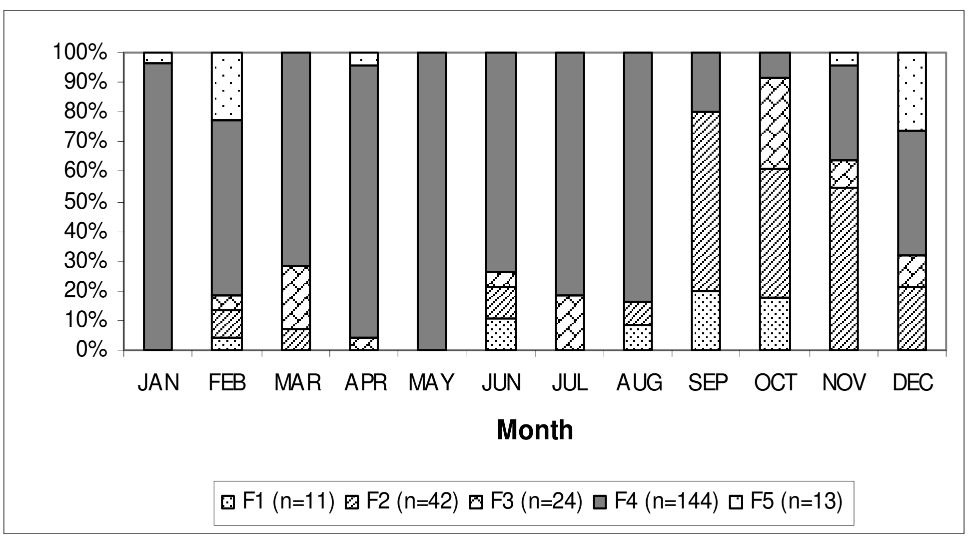


Figure 2-8. Monthly percentages of reproductive classes for female red-ear sardine (*Harengula humeralis*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5= Spent).

FL (mm)	N total	N mature	% mature
85	1	0	0
90	3	2	67
95	4	3	75
100	12	5	42
105	25	19	76
110	23	20	87
115	26	26	100
120	27	27	100
125	25	25	100
130	14	14	100
135	11	11	100
140	9	9	100
145	3	3	100
150	1	1	100
Total	184	165	

Table 2-1. Maturity schedule by size for male red-ear sardine (*Harengula humeralis*).

FL (mm)	N total	N mature	% mature
90	2	0	0
95	3	3	100
100	7	3	43
105	15	10	67
110	20	20	100
115	24	24	100
120	26	26	100
125	35	35	100
130	39	39	100
135	24	24	100
140	22	22	100
145	8	8	100
150	5	5	100
155	3	3	100
160	1	1	100
Total	234	223	

Table 2-2. Maturity schedule by size for female red-ear sardine (*Harengula humeralis*).

Month	**GSI**	**N**	**sd**
January	4.452	27	2.154
February	3.557	21	2.038
March	2.767	28	1.261
April	4.517	23	1.494
May	9.607	2	6.673
June	4.121	17	3.361
July	2.500	22	1.072
August	3.465	11	1.367
September	1.524	12	1.647
October	1.096	19	1.275
November	1.981	22	3.097
December	1.686	19	1.217
Total		223	

Table 2-3. Monthly mean gonadosomatic index (GSI) of female red-ear sardine (*Harengula humeralis*).

		Stage of gonad development									
		F1		**F2**		**F3**		**F4**		**F5**	
Month	**N**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
January	27	0	0	0	0	0	0	26	96.3	1	3.7
February	22	1	4.5	2	9.1	1	4.5	13	59.1	5	22.7
March	28	0	0	2	7.1	6	21.4	20	71.4	0	0
April	23	0	0	0	0	1	4.3	21	91.3	1	4.3
May	2	0	0	0	0	0	0	2	100.0	0	0
June	19	2	10.5	2	10.5	1	5.3	14	73.7	0	0
July	22	0	0	0	0	4	18.2	18	91.8	0	0
August	12	1	8.3	1	8.3	0	0	10	83.3	0	0
September	15	3	20.0	9	60.0	0	0	3	20.0	0	0
October	23	4	17.4	10	43.5	7	30.4	2	8.7	0	0
November	22	0	0	12	54.5	2	9.1	7	31.8	1	4.5
December	19	0	0	4	21.1	2	10.5	8	42.1	5	26.3
Total	234	11		42		24		144		13	

Table 2-4. Monthly percentages of reproductive classes for female red-ear sardine (*Harengula humeralis*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5= Spent).

False pilchard (*Harengula clupeola*)

Introduction

The false pilchard (or false herring), (*Harengula clupeola*) is one of the most important baitfishes in Puerto Rico (Kimmel, 1991; LeGore, 2007). This species appear to have similar behavior and frequently form mixed schools with *H. humeralis* (Randall, 1996). *H. clupeola* is pelagic and it is distributed in coastal marine areas, including coral-reefs, sand beaches, estuaries and seagrass beds (Cervigón et al, 1993). False pilchards are nocturnal predators and planktivorous, feeding mainly on copepods, larvae of decapods and fishes and stomatopods (Sierra, 1987; Sierra et al., 1994; Ortaz et al., 1996). The false pilchard ranges from the Gulf of Mexico to Brazil, including the Bahamas, entire Caribbean, West Indies, and southeastern Florida (not north Florida) (Munroe and Nizinski, 2002). The false pilchard has a faint black spot on side posterior to opercular margin. This species possess a series of abdominal scutes forming a distinct keel and have no lateral line. Teeth are small but gill rakers are long and numerous for sieving plankton. The false pilchard can attain about 17 cm, being common to 9 cm (Whitehead, 1985).

Materials and Methods

See Materials and Methods in Wahoo Section, page 17.

Results

Sampling, size-frequency distribution, and sex ratio

Five hundred and fifteen *H. clupeola* were collected from November 2003 to October 2007. Size range was 26-134 mm FL (mean=93; sd=±21) (Fig.3-1). Four hundred and sixty six were sexed (178 males and 288 females). Sex ratio was 1♂:1.6♀ (χ^2=20.82, $p < 0.05$, significantly different). Size-frequency distribution of males and females are significantly different (Kolmogorov-Smirnov, D=0.1828, $p<0.05$) (Fig. 3-2). Males ranged in size from 54-126 mm FL (mean=95; sd=±14) and females ranged from 50-134 mm FL (mean=99; sd=±14). Females were clearly predominant in virtually all the size classes larger than 85 mm while males were slightly predominant in the smaller size classes (Fig. 3-2). Individuals smaller than 75 mm were difficult to locate and collect and only 57 were sampled during the study, from which 19 were sexed (11 males and 8 females). Relationships between total length-fork length and weight-fork length are presented in figures 3-3 and 3-4, respectively.

Size at Maturity

Estimated median length at maturity was 74 mm FL for males and 85 mm FL for females. Smallest mature male measured 77 mm FL while the smallest mature female was 73 mm FL (Appendix IV). The discrepancy between the 50% maturity estimate and the smaller observed mature can be explained to the sharp decline of the maturity curve (Fig. 3-5; Table 3-1). All males larger than 100 and all females larger than 105 mm were mature (Figs. 3-5 and 3-6; Tables 3-1 and 3-2).

Spawning seasonality

Ripe females were found in all months except October and December, suggesting that at least some spawning occurs probably year-round (Fig. 4-8; Table 3-4). The GSI values were highest in March, June and September, reaching its minimum value in December (Fig. 4-7, Table 3-3). The percentage of ripe females was higher in March-April and June-September (Fig. 4-8; Table 3-4). March was the month with highest GSI. Eight of the 24 females examined in that month had ovaries with hydrated oocytes, indicating imminent spawning. In summary, our data indicates an extended spawning season more active from March to September, with reduced reproductive activity between October and February.

Discussion

Sampling, size-frequency distribution, and sex ratio

All the *H. clupeola* samples were captured inshore with castnets by cooperating fishermen and project personnel. The largest false pilchard we collected measured 134 mm FL. In Venezuela, Posada et al. (1988) reported a maximum size of 109 mm SL, while Rivas (1963) working with many specimens from Florida, Bermuda, West Indies and Central America reported a maximum size of 142 mm SL. Cervigón (1991), after examining several localities in Venezuela, reported a maximum size of 166 mm TL for this species. Posada et al. (1988) observed sex ratio was not different from 1♂:1♀.

Size at maturity

Estimated mean length at first maturity was 74 mm for males and 85 mm for females. The smallest mature male was 77 mm, while the smallest mature female was 73 mm. Posada et al. (1988) estimated 50 % maturity at 104 mm TL for males and 111 mm TL for females. They reported a minimum maturation size of 93 mm and 83 mm TL for males and females, respectively. García-Cagide et al. (1994) reported a minimum maturation size of 70 mm FL for females and a 50 % maturity value of 90-100 mm FL for males in southwestern Cuba. Our maturity estimates are smaller than those reported by previous studies. Although we do not have evidence suggesting a reduction in the maturity size of *H. clupeola* in Puerto Rico during the last decades, that is a possibility that can not be ruled out. Size at maturity can decrease as a consequence of increased fishing pressure (see Hood and Johnson, 2000). Clupeids in general and *Harengula* spp. in particular are one the most important baitfish species in local waters (LeGore, 2007). Kimmel (1991) carried out a baitfish survey in Puerto Rico in 1986 and his data suggested that baitfish landings (including *Harengula* spp.) were lower than any of the previous three years examined. Beets and LaPlace (1991) noted that complete aggregations of baitfish in bays may be eliminated through fishing. These authors mention that this has been observed on several occasions around St. Thomas and St. John (U.S. Virgin Islands). They also point out that if inshore migrations coincide with reproductive activity, heavy fishing pressure may severely impact reproductive success. García-Cagide (1988) states that spawning in *H. humeralis,* which frequently form mixed schools with *H. clupeola,* probably takes place at night and close to shore. During a sampling trip we did in March 26, 2006, 8 out of 24 (33%) of the females captured with cast net close to shore, had ovaries with hydrated oocytes. During this study we sporadically captured females in spawning condition in very shallow water, showing that at least some spawning takes place during the inshore movements, rendering this species and other clupeids that show similar habits, very vulnerable to intense fishing pressure. We agree with the recommendation made by Beets and LaPlace (1991) in that baitfish population should be monitored in selected areas to assess the need for management. Based on our estimated mean length at first maturity and the size-frequency distribution, about 76% of the 515 fish measured were mature (data sources: this study).

Spawning seasonality

Our data suggest that some spawning takes place year-round with a more active period occurring between March-September. These results, in general terms, agree with the findings reported by other investigators in the Caribbean region. Mester et al. (1974), in northern Cuba, noted that *H. clupeola* presented a maximum frequency of mature oocytes in April-May, but they did not examine the annual reproductive cycle. García-Cagide et al.(1994) found ripe females from April-June and in October and December. In Venezuela (Posada et al. 1988) reported two spawning periods for the false pilchard (February-June and October-December). In the close related species *H. jaguana* in the south Florida area, GSI indicated that spawning begins in February, peaks in April and May, ant terminates by August; plankton collections supported these results (Martínez and Houde, 1975).

References

Beets, J. and J.A. LaPlace. 1991. Virgin Islands baitfish survey: October to December 1986. Gulf & Carib. Fisheries Inst. 40: 55-63.

Cervigón, F. 1991. Los peces marinos de Venezuela. Vol. 1, Segunda edición, Cromotip, Caracas, 425p.

Cervigón, F., R. Cipriani, W. Fischer, L. Garibaldi, M. Hendrickx, A.J. Lemus, R. Márquez, J.M. Poutiers, G. Robaina, and B. Rodriguez. 1993. Fichas FAO de identificación de especies para los fines de la pesca. Guía de campo de las especies comerciales marinas y de aguas salobres de la costa septentrional de Sur América. FAO, Rome. 513 p. Preparado con el financiamiento de la Comisión de Comunidades Europeas y de NORAD.

García-Cagide, A. 1988. Particularidades de la reproducción de la sardina de ley, *Harengula humeralis* (Cuvier 1829), en la región oriental del Golfo de Batabano, Cuba. Rep. Invest. Inst. Oceanol. Acad. Cienc. Cuba. 12: 1-15.

García-Cagide, A., R. Claro and B.V. Koshelev. 1994. Reproducción. P 187-262 *In*: R. Claro (ed.). Ecología de los peces marinos de Cuba. Inst. Oceanol. Acad. Cienc. Cuba and Cen. Invest. Quintana Roo, (CIQPRO), México.

Hood, P.B. and A.K. Johnson. 2000. Age, growth, mortality, and reproduction of red porgy, *Pagrus pagrus*, from the eastern Gulf of Mexico. Fishery bulletin 98:723-735.

Kimmel, J.J. 1991. A fisheries dependent survey of baitfishes in Puerto Rico. Proceedings of the Gulf and Caribbean Fisheries Institute 40: -64-81.

LeGore, S. 2007. Bait fisheries serving the marine recreational fisheries of Puerto Rico. Technical Report No.06-113F. 127p

Martinez, S. and E.D. Houde. 1975. Fecundity, sexual maturation, and spawning of scaled sardine (*Harengula jaguana* Poey). Bulletin of Marine Science 25:35-45.

Mester, R.; Ros, R.M.; Mester, L. Jun. 1974. Estudio histológico de las gónadas de dos especies de sardinas, *Harengula clupeola* (Cuvier) y *Harengula humeralis* (Cuvier). Ciencias (Invest.Mar.). No. 8.

Munroe, T.A. and M.S. Nizinski. 2002. Clupeidae. *In* The living marine resources of the Western Central Atlantic. Volume 2: Bony fishes part 1 (Acipenseridae to Grammitidae), sea turtles and marine mammals. FAO Species Indentification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Special Publication No. 5. (K.E. Carpenter, ed.), p.804-820. Food Agric. Organization, Rome.

Ortaz, M., M.E. Rocha and J.M. Posada. 1996. Food habits of the sympatric fishes *Harengula humeralis* and *H. clupeola* (Clupeidae) in the Archipiélago de Los Roques National Park, Venezuela. Caribb. J. Sci. 32(1): 26-32.

Posada, J.M., B. Alvarez, y J.A. Marval. 1988. Algunos aspectos de la biología reproductiva de las sardinas, Harengula humeralis (Cuvier) y Harengula clupeola Cuvier (Pisces: Clupeidae) en el Parque Nacional Archipiélago de Los Roques. Mem. Soc. Cien. Nat. La Salle 48(3): 237-258.

Randall, J.E. 1996. Caribbean Reef Fishes. Third Edition – revised and enlarged. T.F.H. Pubs., Inc., Ltd. Hong Kong. 368 p.

Rivas, L.R. 1963. Genus *Harengula* Cuvier and Valenciennes 1847. *In* Fishes of the Western North Atlantic. Mem. Sears Fdn Mar. Res. 1(3):386-396.

Sierra, L.M. 1987. Peculiaridades de la alimentación de la sardina de ley, *Harengula humeralis* (Cuvier, 1829), en la región oriental del Golfo de Batabanó Cuba. Cuba. Rep. Invest. Inst. Oceanol. Acad. Cienc. Cuba. No. 69: 19p.

Sierra, L.M., R. Claro and O.A. Popova. 1994. Alimentación relaciones tróficas. P. 263-284 *In:* R. Claro (ed.). Ecología de los Peces Marinos de Cuba. Inst. de Oceanología Acad. De Cienc. De Cuba y Centro de Invest. De Quintna Roo, México.

Whitehead, P.J.P. 1985. FAO Species Catalogue. Vol. 7. Clupeoid fishes of the world (suborder Clupeioidei). An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf herrings. Part1 – Chirocentridae, Clupeidae and Pristigasteridae. FAO Fish Synop. 125(7/1): 1-303.

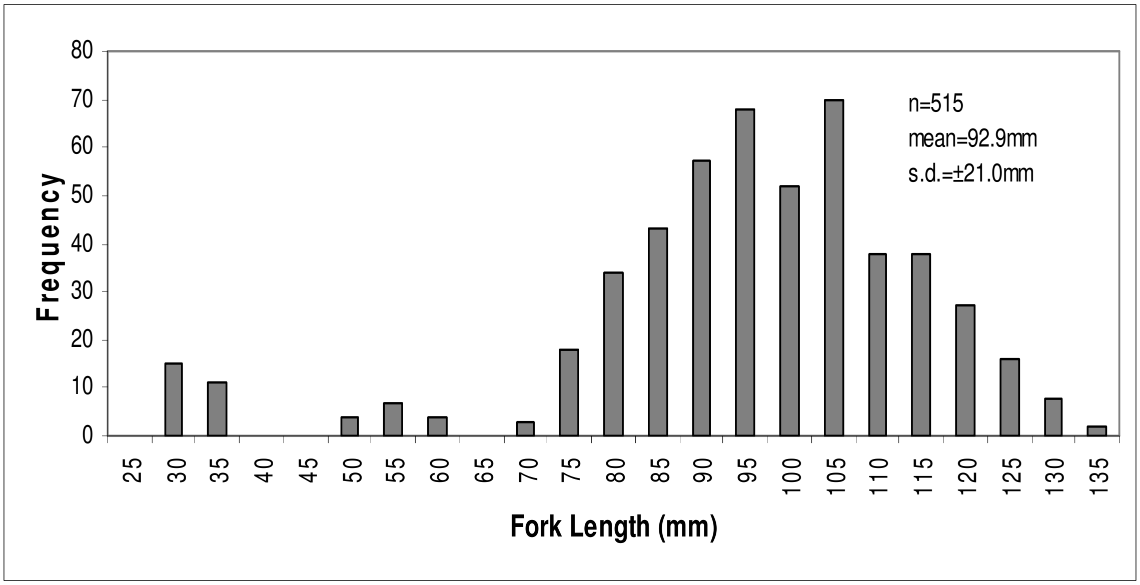


Figure 3-1. Size-frequency distribution of false pilchard (*Harengula clupeola*) collected between November 2003 and October 2007.

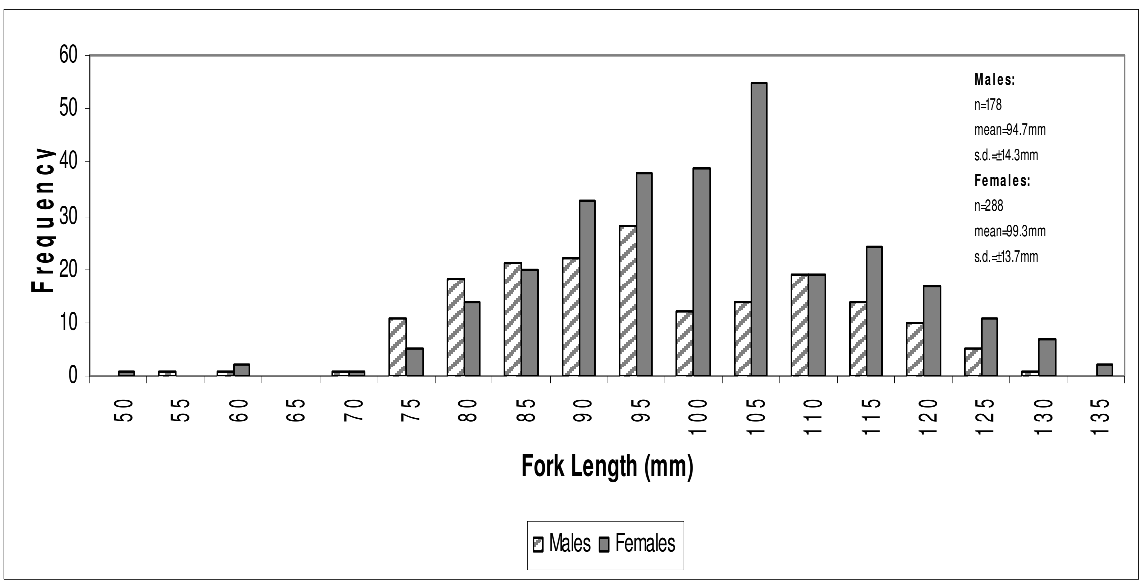


Figure 3-2. Size-frequency distribution of male and female false pilchard (*Harengula clupeola*) collected between November 2003 and October 2007.

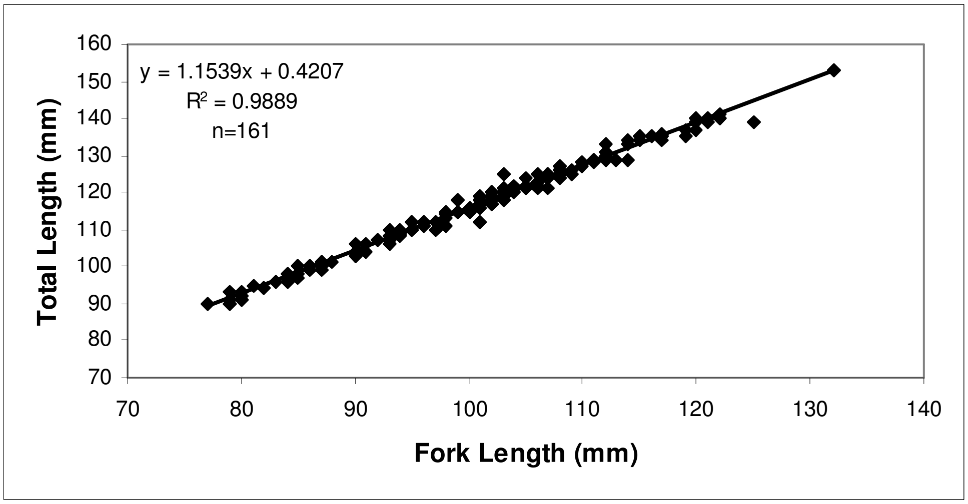


Figure 3-3. Relationship between total length and fork length for false pilchard (*Harengula clupeola*).

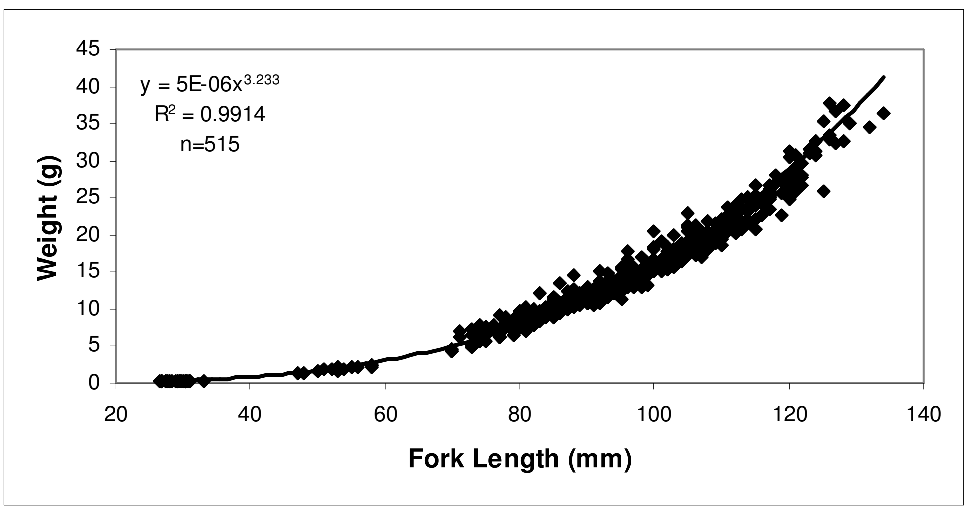


Figure 3-4. Relationship between weight and fork length for false pilchard (*Harengula clupeola*).

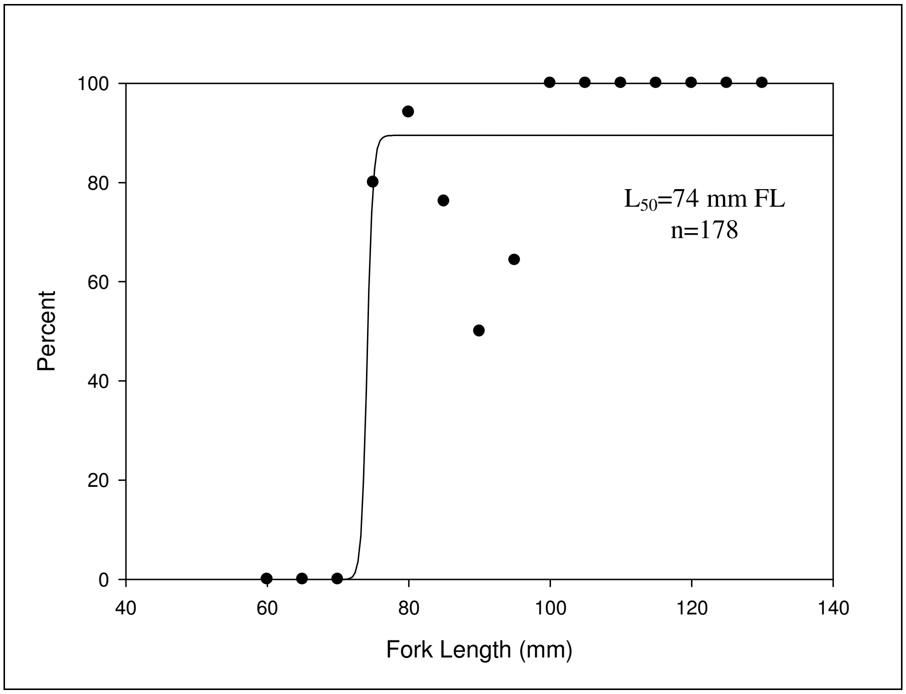


Figure 3-5. Percent of sexually mature male false pilchard (*Harengula clupeola*) as a function of fork length (see Appendix IX).

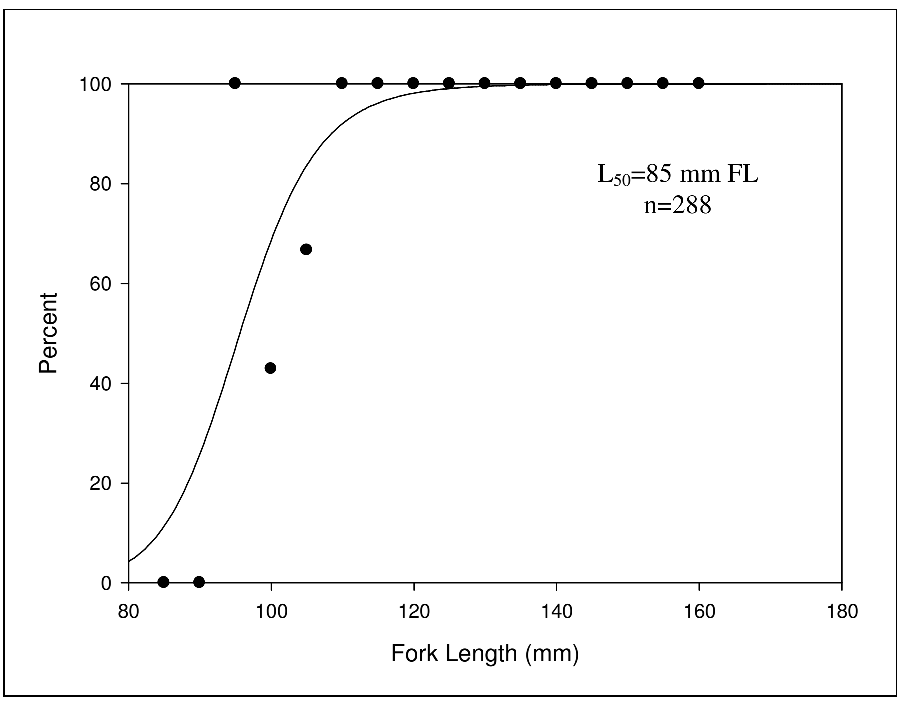


Figure 3-6. Percent of sexually mature female false pilchard (*Harengula clupeola*) as a function of fork length (see Appendix X).

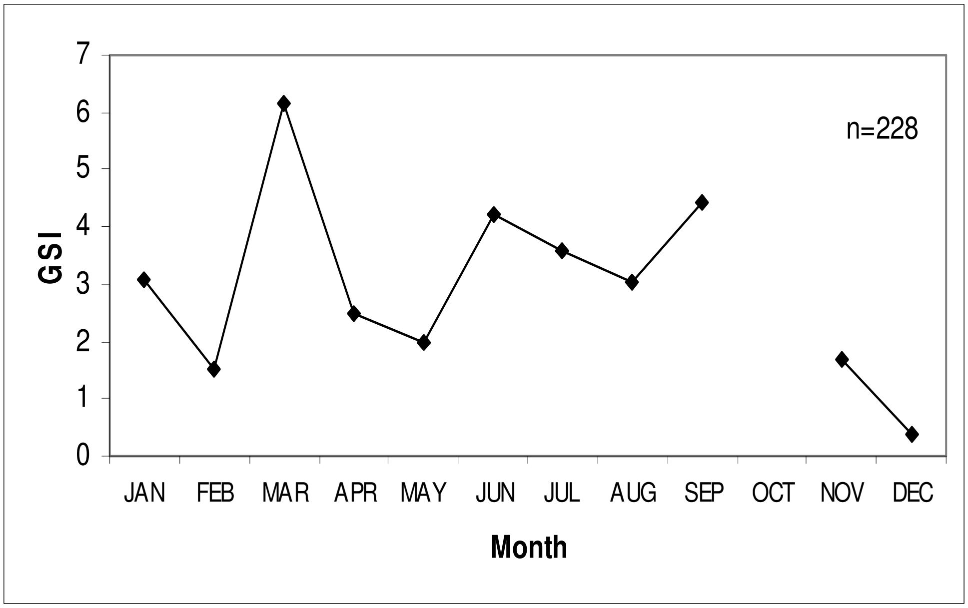


Figure 3-7. Monthly mean gonadosomatic index (GSI) for female false pilchard (*Harengula clupeola*).

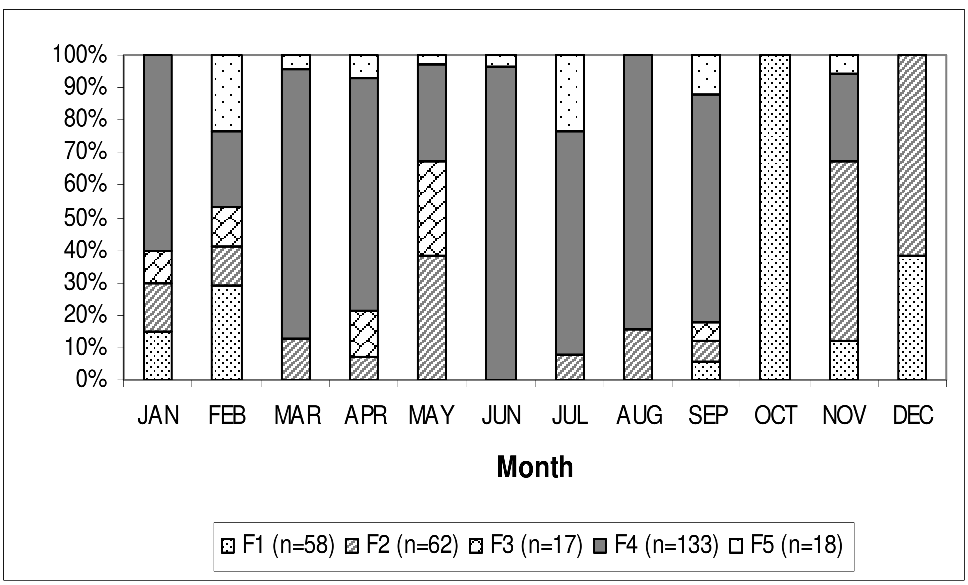


Figure 3-8. Monthly percentages of reproductive classes for female false pilchard (*Harengula clupeola*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5= Spent).

FL (mm)	N total	N mature	% mature
55	1	0	0
60	1	0	0
65	0	0	
70	1	0	0
75	11	8	73
80	18	15	83
85	21	16	76
90	22	11	50
95	28	18	64
100	12	12	100
105	14	14	100
110	19	19	100
115	14	14	100
120	10	10	100
125	5	5	100
130	1	1	100
Total	178	143	

Table 3-1. Maturity schedule by size for male false pilchard (*Harengula clupeola*).

FL (mm)	N total	N mature	% mature
50	1	0	0
55	0	0	
60	2	0	0
65	0	0	
70	1	0	0
75	5	0	0
80	14	7	50
85	20	12	60
90	33	23	70
95	38	23	61
100	39	31	79
105	55	55	100
110	19	19	100
115	24	24	100
120	17	17	100
125	11	10	91
130	7	7	100
135	2	2	100
Total	288	230	

Table 3-2. Maturity schedule by size for female false pilchard (*Harengula clupeola*).

Month	GSI	N	sd
January	3.075	17	2.526
February	1.537	12	0.767
March	6.144	23	3.696
April	2.469	14	0.854
May	2.000	34	0.960
June	4.230	27	1.266
July	3.586	26	1.467
August	3.039	13	2.347
September	4.447	16	2.608
October		0	
November	1.704	30	1.688
December	0.370	16	0.176
Total		228	

Table 3-3. Monthly mean gonadosomatic index (GSI) of female false pilchard (*Harengula clupeola*).

		Stage of gonad development									
		F1		**F2**		**F3**		**F4**		**F5**	
Month	**N**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
January	20	3	15.0	3	15.0	2	10.0	12	60.0	0	0
February	13	5	38.5	2	15.4	2	15.4	4	30.8	4	30.8
March	24	0	0	3	12.5	0	0	20	83.3	1	4.2
April	14	0	0	1	7.1	2	14.3	10	71.4	1	7.1
May	34	0	0	13	38.2	10	29.4	10	29.4	1	2.9
June	28	0	0	0	0	0	0	27	96.4	1	3.6
July	26	0	0	2	7.7	0	0	18	69.2	6	23.1
August	13	0	0	2	15.4	0	0	11	84.6	0	0
September	17	1	5.9	1	5.9	1	5.9	12	70.6	2	11.8
October	35	35	100.0	0	0	0	0	0	0	0	0
November	34	4	11.8	19	55.9	0	0	9	26.5	2	5.9
December	26	10	38.5	16	61.5	0	0	0	0	0	0
Total	284	58		62		17		133		18	

Table 3-4. Monthly percentages of reproductive classes for female false pilchard (*Harengula clupeola*) (F1= Immature; F2= Inactive mature; F3=Active mature; F4= Ripe; F5= Spent).

Thread herring (*Opisthonema oglinum*)

Introduction

The thread herring (or Atlantic thread herring) (*Opisthonema oglinum*, LeSueur, 1818) is a tropical and subtropical pelagic clupeoid widely distributed in the western Atlantic from the Gulf of Maine to Bermuda and throughout the Gulf of Mexico and West Indies southward to northern Argentina (Cervigón and Bastida, 1974). Schools of *O. oglinum* are especially common in shallow coastal waters and in the mouths of rivers, which are used as nursery and growth areas (Funicane and Vaught, 1986). This species occurs most frequently in the upper 3 meters of the water column, although in some seasons it may be found very near to the bottom, especially the larger individuals (LeGore 2007; Cervigón et al., 1993).

The body of *O. oglinum* is fusiform and compressed, with lower profile deeply curved and a keeled belly. The back an upper sides are blue-green, with 6-7 dark horizontal lines. It has a dark spot above opercle and a larger dark spot behind opercle. The last ray of the dorsal fin is filamentous. The lower sides and abdomen are silvery. Maximum size reported is 38 cm (exceptional); common to 20 cm.

Thread herring feeds on a variety of phytoplankton and zooplankton, including copepods, gastropods, plant detritus and sediments. Adults also take small fishes, crabs and shrimps (Carr and Adams, 1973; Whitehead, 1985; Sierra et al., 1994).

This species is targeted commercially by artisanal and moderately sized seine fisheries off the coasts of several countries of south and Central America, Caribbean, Gulf of Mexico and the Greater Antilles and along the southeastern coast of the United States (Reintjes, 1978; Smith, 1994). In Puerto Rico, together with *Harengula spp*. the thread herring is important mainly as bait in both commercial and recreational fisheries but minor quantities are used for human consumption (LeGore, 2007).

Due to it's relatively high economic importance, the life history and fisheries of the thread herring has been the subject of numerous studies through its range (Fuss et al., 1969; Valdés and Sotolongo, 1983; Smith, 1994; González-Cabellos and Mangual-Izquierdo, 1995; Mexicano-Cíntora et al., 1996; Vega-Candejas et al., 1997; García-Abad et al., 1998; Harvey et al., 2003; see LeGore, 2007).

Thread herring can live up to 8 years of age (Smith, 1994; Arce and Sánchez, 1991). In most regions the species reaches maturity at an age of 1 or 2 years and about 12-15 cm length (Fuss et al., 1969; Reintjes, 1979; Houde et al., 1983; Berkeley and Houde, 1984. A study performed in Mexico found that *O. oglinum* matures at about 10-11 cm fork length at an age of three years (Vega-Candejas et al., 1997). In this species, as in other clupeoids, an extended reproductive season was observed. In Florida, South Carolina and Venezuela spawning has been reported to take place in nearshore waters mainly between March-July or May-June (Bigelow, 1963; Prest, 1971; Whitehead, 1985). On the other hand, two studies performed in Mexico found the main reproductive season extending from July to December or May-October (Vega-Candejas et al., 1997; García-Abad et al., 1998). As in the case of *Harengula spp.* no previous work on the reproductive biology of this species has been done in Puerto Rico.

Materials and Methods

See Materials and Methods in Wahoo Section, page 17.

Results

Sampling, size frequency distribution and sex ratio

Five hundred and eight *O. oglinum* were collected from February 2004 to August 2007. Size range was 72-227 (mean=148; sd=±35) (Fig. 4-1). Three hundred and sixty six were sexed (119 males and 247 females). Sex ratio was 1♂:2.1♀ (χ^2=44.76, $p<0.05$, significantly different). Size-frequency distribution of males and females are significantly different (Kolmogorov-Smirnov, D=0.1607, $p<0.05$ (Fig. 4-2). Males ranged in size from 92-210 mm FL (mean=147; sd=±27) and females ranged from 93-227 mm FL (mean=160; sd=±31). Females were predominant in all the size classes except the smallest individuals collected (<110 mm; n=8). A total of 54 individuals of threadfin herring were larger of 190 mm FL, of which 89 % (n=48) were females (Fig. 4-2). Relationships between total length-fork length and weight-fork length are presented in figures 4-3 and 4-4, respectively.

Size at maturity

Male and female thread herring mature at about the same size. Estimated mean length at first maturity was 132 and 119 mm FL for males and females, respectively. Smallest mature male measured 113 mm FL and the smallest mature female was 106 mm FL (Appendix IV). All males and females larger than 190 mm FL were mature (Figs. 4-5 and 4-6; Tables 4-1 and 4-2).

Spawning seasonality

In contrast to *Harengula spp*., histological data and the GSI show that *O. oglinum* have a 6 month spawning season. Ripe females were found from April through September. Mature active females were also only found in the same period. From October to March only immature and mature inactive females were collected (Fig. 4-8; Table 4-4). The GSI shows the same pattern, being <0.5 between October –March, increasing significantly in April and remaining relatively high until September (Fig. 4-7; Table 4-3). Individuals collected during the no-spawning period had regressed gonads so small that many of them could not be sexed. The higher frequency of ovaries with hydrated oocytes was found in June and July.

Discussion

Sampling, size-frequency distribution, and sex ratio

The main fishing gears used to capture thread herrings were beach seines, hook and line and cast nets. The largest individual in our samples measured 227 mm. This value is similar to others reports in the literature. García-Abad et al. (1998) reported a maximum size of 205 mm TL in the southern Gulf of Mexico. Also in Mexico (Yucatán), Mexicano-Cíntora et al. (1996) estimated a maximum size of 227 mm FL. The maximum estimated length calculated by Vega-Cendejas et al.(1997) was 223 mm TL. The largest fish measured by Valdés and Sotolongo (1983) was 200 mm FL, while Guitart (1974) states that *O. oglinum* reaches a size of 300 mm FL in cuban waters. Harvey et al. (2003) noted a maximum size of 190 mm TL captured by the beach seine fishery of Jamaica. Very similar sizes have been reported in the United States. Smith (1994) and FMRI (2003) mention that this species reaches a maximum size of 200 mm FL along the North Carolina and west central Florida coasts, respectively. According to Cervigón (1991), this species can reach a size of 380 mm TL. Gónzalez-Cabellos and Mangual-Izquierdo (1995) calculated a maximum size of 298 mm FL in Venezuela. Our size frequency distribution by sex and sex ratio results agree with Valdés and Sotolongo (1983); these authors also found that females tended to be larger and more abundant than males, reporting a sex ratio 1♂:1.43♀. A similar trend was observed by García-Abad et al (1998) who noted that females were more numerous in all months, except August. Smith (1994) also noted a sex ratio skewed toward females (1♂:1.67♀).

Size at maturity

Our estimated mean length at first maturity was 132 and 119 mm FL for males and females, respectively. Males started to mature at 113 mm while the smallest mature female measured 106 mm. In Campeche Bank, Vega-Cendejas et al. (1997) found that the smallest mature male was 115 mm FL; for females this corresponded with 106 mm FL. The size at 50% maturity was 151 mm FL and 155 mm FL for males and females, respectively. García-Abad et al. (1998) reported a size at first maturity of 135 mm TL in females of *O. oglinum.* Histological examination of thread herring gonads along the coast of the State of Ceara, Brazil, showed that size at first sexual maturity is 100 and 110 mm FL for males and females, respectively, while first maturity occurs in 50 % of the population (unsexed fish) at 110-115 mm FL (Alves and Sawaya, 1975). Berkeley and Houde (1984) reported that females first reached maturity at 145 mm FL and males at 125 mm FL in the northeastern Gulf of Mexico. Some south Florida females were sexually mature at 135 mm FL (Prest, 1971). Based on our estimated mean length at first maturity and the size-frequency distribution, about 71 % of 873 fish measured were mature (data sources: Daniel Matos, unpublished data, Fisheries Research Laboratory and this study).

Spawning seasonality

The results of this study indicate that the thread herring spawning season extends from April to September, with a possible peak in June-July. This is in agreement with several studies that have been published regarding spawning seasonality in this species. García-Abad et al. (1998) also detected a protracted spawning season extending from May to October, with peaks in May and August. In the eastern Gulf of Mexico Houde (1977), based on the abundance of eggs and larvae, proposed a spawning season extending from February to September with a peak from April to August (see Finucane and Vaught, 1986). Houde also reported that the primary spawning area was located in coastal waters from Tampa Bay to just south of Fort Myers (see Finucane and Vaught, 1986). Fuss et al. (1969) suggest a spawning period from March to August with a marked peak in June in Florida. A similar pattern was reported by Kemmerer (1977) in the northern Gulf of Mexico. According to Hildebrand (1963) *O. oglinum* spawns during May and June in North Carolina. Smith (1994) reported ripe and recently spawned females from a purse seine sampled in June in North Carolina. Prest (1971) indicated an April-July spawning season in the St. Petersburg area (Florida). Larvae were observed off south Texas during August and September (Finucane et al., 1978). Herrema et al. (1985) collected *O. oglinum* in spawning condition off St. Lucie, Florida, from February through May and in August. Whitehead (1985) suggests that *O. oglinum* spawns from March to July in Venezuela, while Bigelow et al. (1963) report spawning in may-June. Somewhat different findings were reported by Vega-Cendejas et al. (1997) from thre Campeche Bank, where *O. oglinum* apparently spawns from July to December and individuals with ripe gonads were found throughout the year. Spawning seems to takes place in nearshore shelf waters in depths between 10-30 meters ((Prest, 1971; Houde, 1977; Harvey et al., 2003). We collected females with hydrated ovocytes in depths ranging from 5-15 meters in locations between 0.5-1 miles from shore. In Puerto Rico, as in many other countries, clupeids are among the most important fishbait species and in many areas the beach seine is the main gear responsible for most of the landings reported. The vulnerability of the thread herring, red-ear sardine, false pilchard, and other clupeids and carangids to the beach seine was critical, mainly due to the nature of the inshore movements of their schools where the beach seine usually operated. The elimination of that fishing gear certainly was a crucial step towards the conservation of such an ecologically and economically important group of species.

References

Alves Mota, MI; Sawaya, P. 1975. Sobre a reproducao da sardina-bandeira, *Opisthonema oglinum* (Le Sueur), na costa do Estado do Ceara (Brasil) (On the reproduction of the thread herring, *Opisthonema oglinum* (Le Sueur), along the coast of the state of Ceara (Brazil)). Arq. Cienc. Mar. Vol. 15, no.1, pp. 19-28.

Arce, M. and J. Sanchez. 1991. Growth and mortality of the thread herring, (*Opisthonema oglinum* Le Sueur) Yucatán, México. (abstract) Amer. Fish. Soc. 121st Meeting, San Antonio, Texas, USA, p.56

Beets, J. and J.A. LaPlace. 1991. Virgin Islands baitfish survey: October to December 1986. Gulf & Carib. Fisheries Inst. 40: 55-63.

Berkeley, S.A. and Houde E.D. 1984. Age, growth and mortality of coastal herrings in the eastern Gulf of Mexico. Final Report of the Gulf and South Atlantic Fisheries Development Foundation, Project No. 21-12-32272, 11p.

Bigelow, H.B., M.B. Bradbury, J.R. Dymond, J.R. Greely, S.F. Hildebrand, G.W. Mead , R.R. Miller, L.R. Rivas, W.L. Schroeder, R.D., Suttkus, and V.D. Vladykov. 1963. Fishes of the Western North Atlantic. Part Three. New Haven sears Foundation. Marine Res., Yale University.

Carr, W.E.S. and C.A. Adams. 1973. Food habits of juvenile marine fishes occupuying seagrass beds in the estuarine zone near Crystal River, Florida. Trans. Amer. Fish. Soc. 102(3): 511-540.

Cervigón, F. 1991. Los peces marinos de Venezuela. Vol. 1, Segunda edicion, Cromotip, Caracas, 425p.

Cervigón, F. y Bastida, R. 1974. Contribución al conocimiento de la fauna ictiológica de la provincia de Buenos Aires. An. Soc. Cien., Argentina, CXCVII, pp.1-20.

Cervigón, F., R. Cipriani, W. Fischer, L. Garibaldi, M. Hendrickx, A.J. Lemus, R. Márquez, J.M. Poutiers, G. Robaina, and B. Rodriguez. 1993. Fichas FAO de identificación de especies para los fines de la pesca. Guía de campo de las especies comerciales marinas y de aguas salobres de la costa septentrional de Sur América. FAO, Rome. 513 p. Preparado con el financiamiento de la Comisión de Comunidades Europeas y de NORAD.

Claro, R. 1994. Características generales de la ictiofauna. p. 55-70. *In* R. Claro (ed.) Ecología de los peces marinos de Cuba. Instituto de Oceanología Academia de Ciencias de Cuba y Centro de Investigaciones de Quintana Roo.

Finucane, J.H. and R.N. Vaught. 1986. Species profile of Atlantic thread herring *Opisthonema oglinum* (Lessueur 1818). NOAA Tech. Mem. NMFS-SEFC-182. 30 p.

Finucane, J.H., L.A. Collins, L.E. Barrer and J.B. McEachran. 1978. Ichthyoplancton/mackerel eggs and larvae. NOAA final report to BLM, Environmental studies of the South Texas outer continental shelf, 1977. SEFC, Galveston Lab., 504p.

FMRI. 2003. Atlantic thread herring, *Opisthonema oglinum*. Species fact sheet. Florida Fish and Wildlife Conservation Commision. 5 p.

Fuss, C.M., Jr., J.A. Kelly, Jr., and K.W. Prest, Jr. 1969. Gulf Thread herring: aspect of the developing fishery and biological research. Proc. Gulf. Carib. Fish. Inst. 21: 111-125.

García-Abad MC; Yañez-Arancibia, A; Sánchez-Gil P; Tapia-García M. 1998. Distribución, abundancia y reproducción de *Opisthonema oglinum* (Pisces: Clupeidae) en la plataforma continental del Sur del Golfo de México. Revista de Biología Tropical. Vol. 46, no. 2, pp.257-266.

Gonzalez-Cabellos, L.W. and A. Mengual-Izquierdo. 1995. Edad y crecimiento del machelo, *Opisthonema oglinum* (Le Sueur, 1818)(Teleostei:Clupeidae), de la Isla Margarita, Venezuela. Ciencias Marinas, 21(4):387-399.

Guitart, D.J. 1974. Sinopsis de los peces marinos de Cuba. Tomo I, Academia de Ciencias de Cuba, Instituto de Oceanología, 136 pp.

Harvey, G.C.Mc.N., I. Goodbody and K.A. Aiken. 2003. The Artisanal thread herring fishery of Kingston Harbour: A review source. Bulletin of Marine Science 73 No.2:421-432.

Herrema, D.J., B.D. Peery, N. Williams-Walls and J.R. Wilcox. 1985. Spawning periods of common inshore fishes of the Florida east coast. Northeast Gulf Sci. &(2):153-155.

Hildebran, S.F. 1963. Family Clupeidae. *In*: Bigelow, H.B. Fishes of the western North atlantic. Seasrs Found. Mar. Res., Yale Univ., Mem. I, pt. III: 257-454.

Houde, E.D. 1977. Abundance and potential yield of the thread herring, Opisthonema oglinum, and aspects of its early life history in the eastern Gulf of Mexico. Fishery Bulletin 75:493-512.

Houde, E.D., Grall, C., and Berkeley, S. 1983. Population parameter estimates for three schoaling pelagic fishes in the eastern Gulf of Mexico. Int. Counc. Explor. Sea Pelagic Fish. Comm., CM 1983/H:43:11pp.

Kemmerer, R.J. 1977. LANDSAT menhaden and thread herring resources investigation. Southeast Fisheries Center Contrib. no. 77-16F; MARMAP Contrib. no. 145, pag. var.

LeGore, S. 2007. Bait fisheries serving the marine recreational fisheries of Puerto Rico. Technical Report No.06-113F. 127p

Mexicano-Cintora, G., Salas, S. and Cabrera M.A. 1996. La pesquería artesanal de sardina en Celestún, Yucatán. Jaina, 5(2):1011.

Prest, K.W. 1971. Fundamentals of sexual maturation, spawning and fecundity of thread herring (*Opisthonema oglinum*) in the eastern Gulf of Mexico. National Marine Fisheries Service, St. Petersburg, FL. (mimeo)

Reintjes, J.W. 1978. Pelagic clupeoid and carangid resources for fishery development in the Gulf of Mexico and Caribbean Sea. Proceedings of the Gulf and Caribbean Fisheries Institute 31:38-49.

Reintjes, J.W. 1979. Coastal herrings and associated species: a profile of species or groups of species, their biology, ecology, current exploitation with economic and social information. Rept Prepared for Gulf of Mexico Fisheries Management Council, SE Fish Sci Center, National Marine Fish Service, NOAA, Beaufort, NC USA. 170p.

Sierra, L.M., R. Claro and O.A. Popova. 1994. Alimentación relaciones tróficas. P. 263-284 *In:* R. Claro (ed.). Ecología de los Peces Marinos de Cuba. Inst. de Oceanología Acad. De Cienc. De Cuba y Centro de Invest. De Quintna Roo, México.

Smith, J.W. 1994. Biology and fishery for Atlantic threadfin herring, *Opisthonema oglinum*, along the North Caroline coast. Marine Fish Rev, Sept 22.

Valdés, E. and M. Sotolongo. 1983. Algunos aspectos de la biología y pesquería del machuelo (*Opisthonema oglinum*) de la plataforma sur-occidental cubana. Rev. Cubana Invest. Pesq. 8(1): 66-96.

Vega-Cendejas, M.E., G. Mexicano-Cíntora and A.M. Arce. 1997. Biology of the thread herring *Opisthonema oglinum* (Pisces:Clupeidae) from beach seine fishery of the Campeche Bank, Mexico. Fisheries Research 30:117-126.

Whitehead, P.J.P. 1985. FAO Species Catalogue. Vol. 7. Clupeoid fishes of the world (suborder Clupeioidei). An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf herrings. Part1 – Chirocentridae, Clupeidae and Pristigasteridae. FAO Fish Synop. 125(7/1): 1-303.

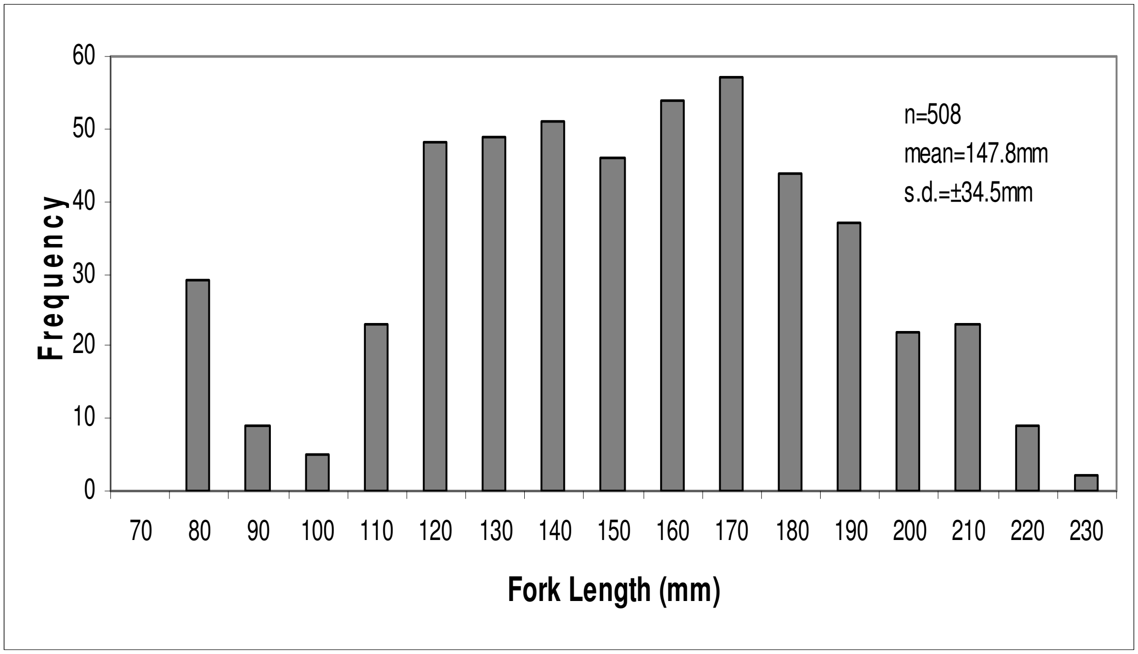


Figure 4-1. Size-frequency distribution of thread herring (*Opisthonema oglinum*) collected between February 2003 and August 2007.

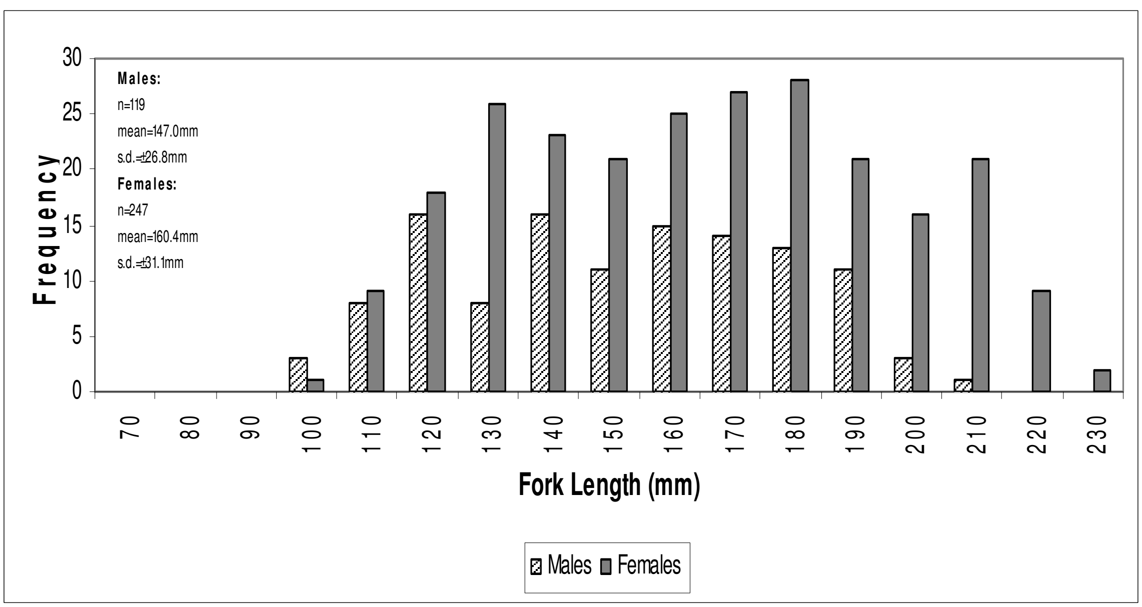


Figure 4-2. Size-frequency distribution of male and female thread herring (*Opisthonema oglinum*) collected between February 2003 and August 2007.

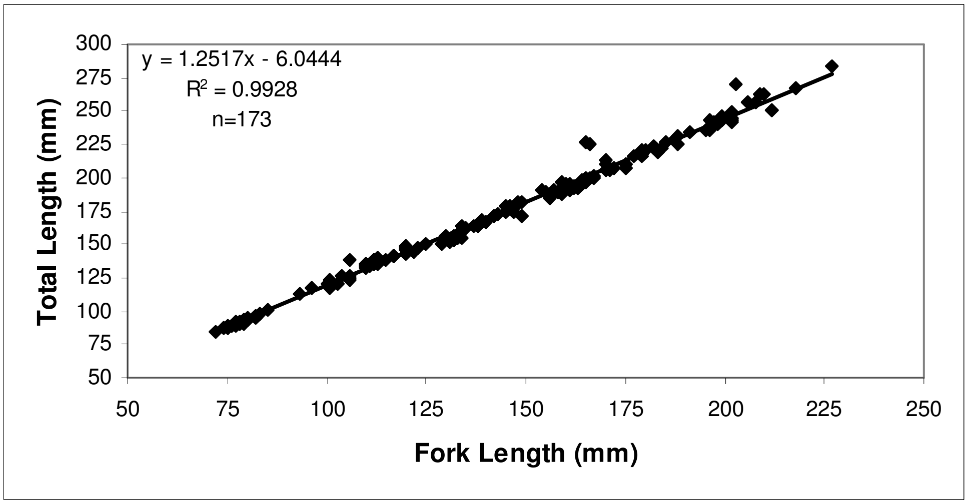


Figure 4-3. Relationship between total length and fork length for thread herring (*Opisthonema oglinum*).

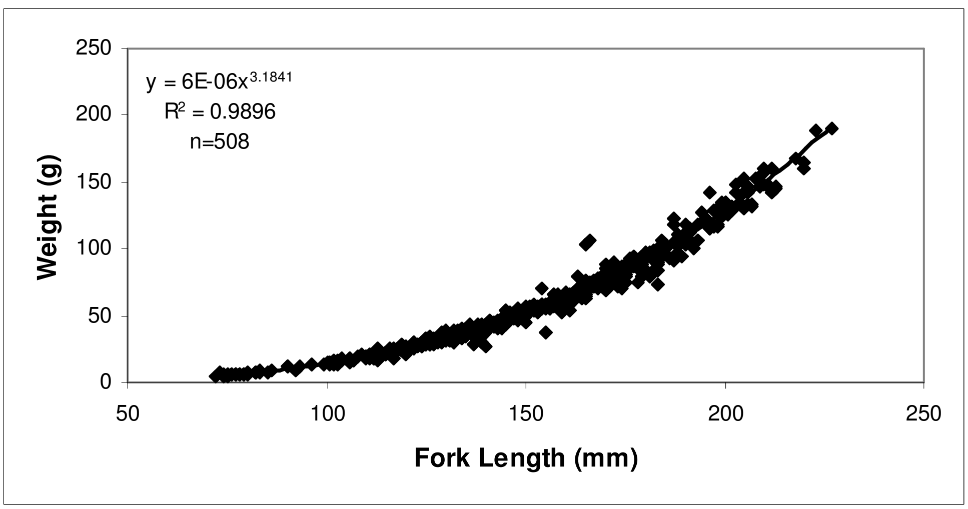


Figure 4-4. Relationship between weight and fork length for thread herring (*Opisthonema oglinum*).

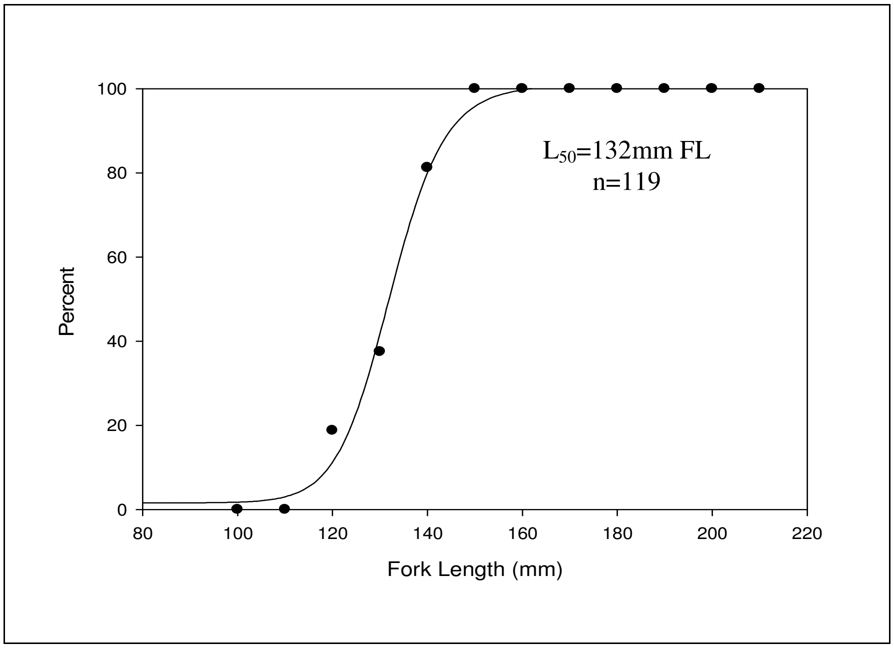


Figure 4-5. Percent of sexually mature male thread herring (*Opisthonema oglinum*) as a function of fork length (see Appendix XI).

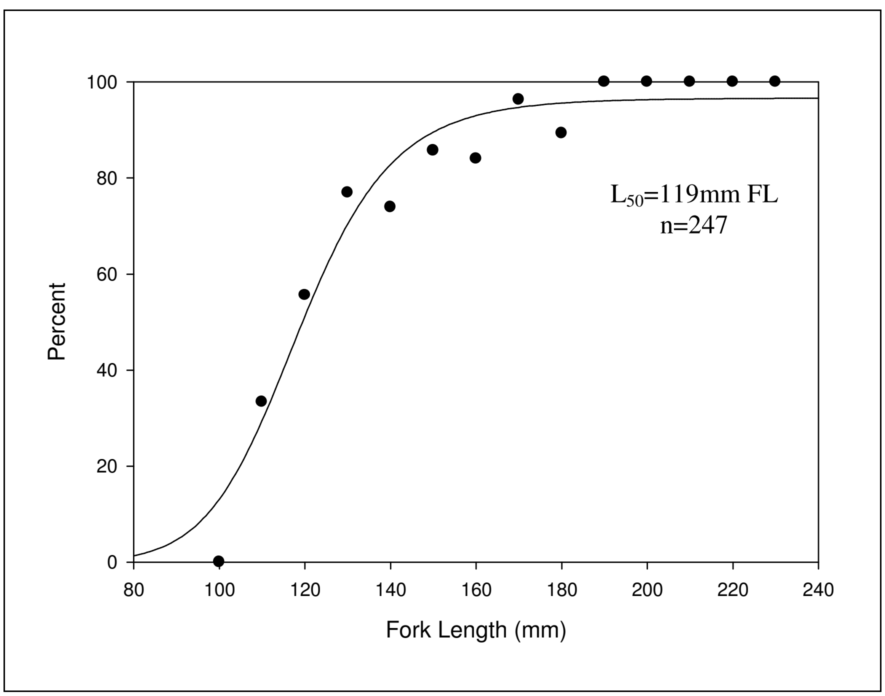


Figure 4-6. Percent of sexually mature female thread herring (*Opisthonema oglinum*) as a function of fork length (see Appendix XII).

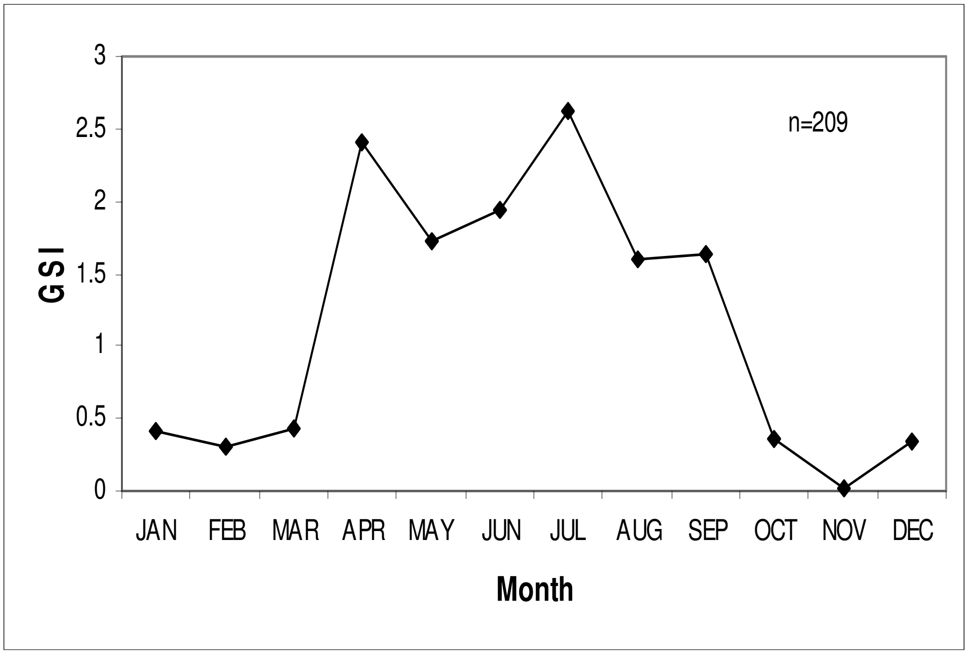


Figure 4-7. Monthly mean gonadosomatic index (GSI) for female thread herring (*Opisthonema oglinum*).

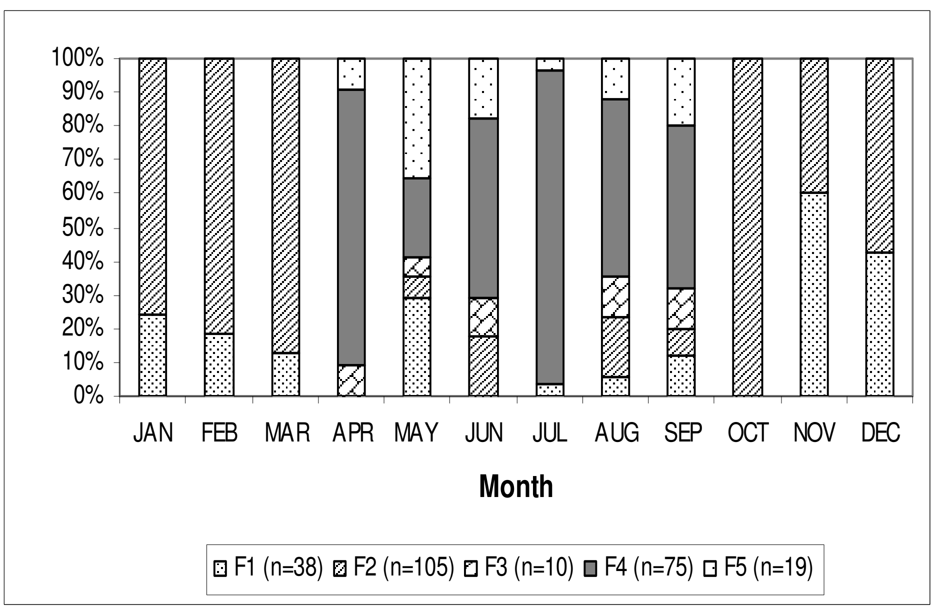


Figure 4-8. Monthly percentages of reproductive classes for female thread herring (*Opisthonema oglinum*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5=Spent).

FL (mm)	N total	N mature	% mature
100	3	0	0
110	8	0	0
120	16	3	19
130	8	3	38
140	16	7	44
150	11	7	64
160	15	6	40
170	14	11	79
180	13	11	85
190	11	11	100
200	3	3	100
210	1	1	100
Total	119	63	

Table 4-1. Maturity schedule by size for male thread herring (*Opisthonema oglinum*).

FL (mm)	N total	N mature	% mature
100	1	0	0
110	9	3	33
120	18	10	56
130	26	20	77
140	23	17	74
150	21	18	86
160	25	21	84
170	27	26	96
180	28	25	89
190	21	21	100
200	16	16	100
210	21	21	100
220	9	9	100
230	2	2	100
Total	247	209	

Table 4-2. Maturity schedule by size for female thread herring (*Opisthonema oglinum*).

Month	GSI	N	sd
January	0.416	17	0.795
February	1.297	26	0.126
March	0.433	21	0.122
April	2.413	21	1.264
May	1.733	12	0.911
June	1.948	17	1.543
July	2.626	25	0.886
August	1.599	16	0.871
September	1.637	22	0.857
October	0.364	16	0.103
November	0.010	2	0.003
December	0.336	14	0.144
Total		209	

Table 4-3. Monthly mean gonadosomatic index (GSI) of female thread herring (*Opisthonema oglinum*).

		Stage of gonad development									
		F1		**F2**		**F3**		**F4**		**F5**	
Month	**N**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
January	21	5	23.8	16	76.2	0	0	0	0	0	0
February	32	6	18.8	26	81.2	0	0	0	0	0	0
March	24	3	12.5	21	87.5	0	0	0	0	0	0
April	21	0	0	0	0	2	9.5	17	81.0	2	9.5
May	17	5	29.4	1	5.9	1	5.9	4	23.5	6	35.3
June	17	0	0	3	17.6	2	11.7	9	52.9	3	17.6
July	26	1	3.8	0	0	0	0	24	92.3	1	3.8
August	17	1	5.9	3	17.6	2	11.7	9	52.9	2	11.8
September	25	3	12.0	2	8.0	3	12	12	48.0	5	20.0
October	16	0	0	16	100.0	0	0	0	0	0	0
November	5	3	60.0	2	40.0	0	0	0	0	0	0
December	26	11	42.3	15	57.7	0	0	0	0	0	0
Total	247	38		105		10		75		19	

Table 4-4 Monthly percentage of reproductive classes for female thread herring (*Opisthonema oglinum*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5= Spent).

Crevalle jack (*Caranx hippos*)

Introduction

The crevalle jack *Caranx hippos* (family Carangidae) has an elongate, deep body. It has large eyes with strong adipose eyelid. The chest is scaleless except for a small patch in front of the pelvic fins, is the only one in the Atlantic that has this patch. Their body color is olivaceous to bluish green dorsally, silvery and brassy on the sides and yellowish caudal fin. There is a prominent black spot on the gill opening and another on the pectoral fin. They are in both sides of the Atlantic Ocean, in the eastern from Portugal to Angola including the Mediterranean Sea and in the western from Nova Scotia throughout the Gulf of Mexico, Caribbean and Uruguay. It is rare in the West Indies and Bahamas, absent in Bermuda (Smith-Vaniz, 2002). It is a pelagic fish found in oceanic, estuarine and riverine environments, depending on its life stage. Juveniles and larval stages are common in shallow brackish waters. Adults are found in upstream currents, reefs, offshore areas or shallow inshore areas (FLMH, 2007). Both adults and juveniles are usually found in schools, larger individuals may be found alone. Is a diurnal predator, feeding of fish, shrimp and invertebrates (Sierra et al., 1994). The maximum reported size is 124 cm TL (Cervigón et al., 1992). For Puerto Rico the maximum weight reported by the Sport Fishing Association is 32 pounds 5 ounces. Females are typically larger than males. Commercial catches of the species are made with haul seines and gill nets, also caught with purse seines, handlines and trolling lines (Smith-Vaniz, 2002). It is an important fish commercially and recreationally. The crevalle jack spawns at subtropical and tropical latitudes (Mc Bride and McKown, 2000). The spawning season is early March to early September; the spawning takes place offshore (FLMH, 2007). There have been some reports of ciguatera poisoning for the species (Halstead, et. al, 1990).

Materials and Methods

See Materials and Methods in Wahoo Section, page 17.

Results

Sampling, size frequency distribution and sex ratio

A total of 304 samples of crevalle jack were collected during the study (Appendix II). Sizes ranged from 158-837 mm FL (mean=472; sd=±120) (Figure 5-1). The size frequency distributions of males and females are not significantly different (Kolmogorov-Smirnov, D=0.0819, $p<0.01$) (Figure 5-2). A total of 299 individuals were sexed (170 males; 129 females). The observed sex ratio was 1♂:0.76♀, significantly different from 1:1 ratio (χ^2=5.622; $p< 0.05$). Size for males ranged from 158-837 mm FL (mean=471; sd=±115) and females from 186-827 mm FL (mean=480; sd=±119)(Appendix IV). The largest fish collected was a male of 837 mm FL and 21 pounds. Relationships between total length-fork length and weight-fork length are presented in figures 5-3 and 5-4, respectively.

Size at maturity

Crevalle jack males mature at a smaller size than females. Males start maturity at 295 mm FL whether females do so at 305 mm FL. The estimated size of 50 % maturity in males was 280 mm FL and 343 mm FL in females. All males larger than 450 mm FL and all females larger than 390 mm FL were sexually mature (Figs. 5-5 and 5-6; Tables 5-1 and 5-2).

Spawning seasonality

Ovarian histological data and GSI from females suggest that the crevalle jack reproduces mainly from April-November, with a period of increased activity between May to July. Maximum GSI values and highest percentage of ripe females were found in July (Figs. 5-7 and 5-8; Tables 5-3 and 5-4).

Discussion

Sampling, size-frequency distribution, and sex ratio

Crevalle jacks captured for this study were taken largely from coastal waters and came from two sources. The main one were schooling fish that form large aggregations swimming several hundred yards off the beach weighing between 5-13 pounds, with some occasional specimens over 15 pounds. These jacks were collected by commercial fishermen using beach seines and accounted for 80 % of all the samples collected. The remaining fish were collected by PRDNER personnel using rod and reel and live bait. The heaviest specimen in our samples was 25 pounds female (827 mm FL). The official record for Puerto Rico is 32 pounds 5ounces, while the IGFA All-Tackle world record is 58 pounds 6 oz. (114 mm FL, Angola.) (Smith-Vaniz and Carpenter, 2007). We did not find any published report to which compare our *C. hippos* size frequency distribution and sex ratio results. The beach seine is the main commercial fishing gear targeting this species in Puerto Rico. This gear was finally prohibited by the Puerto Rico Fishing Law #278, Regulation 6768 in March 2007 and that action will be crucial in the conservation effort of this important gamefish in our coastal waters. Evaluation of the impact of the beach seine ban should be monitored in the future.

Size at maturity

In this study the estimated mean length at first maturity was 280 mm FL for males and 343 mm Fl for females. As far as we are aware, only two sizes at maturity estimates of *C. hippos* have been published until present. These studies report very different estimates, probably due in part to differences in sampling schedule; methodology and/or manipulation and interpretation of the data (see Hunter et al., 1992). Thompson and Munro (1974), in Jamaica, estimated maturation sizes of 550 and 660 mm FL for males and females, respectively. Reuben et al.(1992), in India, report a maturation size of 220 mm TL in unsexed fish.). Based on our estimated mean length at first maturity and the size-frequency distribution, about 93 % of the 340 fish measured were mature (data sources: Daniel Matos, unpublished data Fisheries Research Laboratory and this study).

Spawning seasonality

Our data indicates that *C. hippos* reproductive season extends from April through November, with increased activity during summer. These observations are in accordance with the findings reported by other authors in the Caribbean. Heyman (2001) mentions April-June as the apparent spawning season of *C. hippos* in Belize. Graham and Castellanos (2005) observed spawning behavior on crevalle jacks from April-September offshore Belize. In July, Munro et al. (1973) collected large numbers of ripe fish in Morant Bank (Jamaica). Noting the occurrence of smallest juveniles, Berry (1959) stated that in the southeastern Atlantic coast of the United States spawning probably occurs offshore from March to September. Kwei (1978) reported juveniles present in Ghanaian lagoons year-round. Large schools of jacks entered Ghanaian inshore waters from September to December, spawning appeared to be protracted, and peak spawning activity, determined from limited data, occurred from September to late January. McBride and KcKown (2000) reported young-of-the-year *C. hippos*, < 40 mm FL, present in estuaries from North Carolina to Florida from June to November. In Cuba, reproductive activity by crevalle jacks has been reported during April-May (García-Cagide et al. 1994). Erdman (1976) only mentions that *C. hippos* and other *Caranx* spp. has a protracted spawning season in Puerto Rico.

References

Berry, F.H. 1959. Young jacks crevalles (*Caranx* species) off the south eastern Atlantic coast of the United States. Fishery Bulletin 59:417-535.

Cervigón, F., R. Cipriani, W. Fischer, L. Garibaldi, M. Hendrickx, A.J. Lemus, R. Márquez, J.M. Poutiers, G. Robaina, and B. Rodriguez. 1992. Fichas FAO de identificación de especies para los fines de la pesca. Guía de campo de las especies comerciales marinas y de aguas salobres de la costa septentrional de Sur América. FAO, Rome. 513 p. Preparado con el financiamiento de la Comisión de Comunidades Europeas y de NORAD.

Erdman, D.S. 1976. Spawning patterns of fishes from the Northeast Caribbean. Puerto Rico Dept. Agric., Agric. and Fish. Contr. 8(2): 1-36.

García-Cagide, A., R. Claro and B.V. Koshelev. 1994. Reproducción. P 187-262 *In*: R. Claro (ed.). Ecología de los peces marinos de Cuba. Inst. Oceanol. Acad. Cienc. Cuba and Cen. Invest. Quintana Roo, (CIQPRO), México.

Graham, R.T. and D.W. Castellanos. 2005. Courtship and spawning behaviors of carangid species in Belize. Fishery Bulletin 103: 426-432.

FLMNH, 2007. Florida Museum of Natural History, Ichthyology Department, Bioprofiles. www.flmnh.ufl.edu/fish/education/bioprofile

Halstead, B.W., P.S. Auerbach and D.R. Campell, 1990. A colour atlas of dangerous marine animals. Wolfe Medical Publications Ltd., W.S. Cowell Ltd., Ipswich, England. 192p.

Heyman, W.D. 2001. Spawning aggregations in Belize. A report generated for the workshop, "Towards a sustainable management of Nassau Groupers in Belize". The Nature Conservancy.

Hunter, J.R., B.J. Macewicz, N.C.H. Lo, and C.A. Kimbrell. 1992. Fecundity, spawning, and maturity of female Dover sole, *Microstomus pacificus*, with an evaluation of assumptions and precision. Fishery Bulletin 90:101-128.

Kwei EA. 1978. Food and spawning activity of *Caranx hippos* off the coast of Ghana. Journal of natural history. 12 (2) 195-215.

Mc Bride, R. and K.A. McKown. 2000. Consequences of dispersal of subtropically spawned crevalle jacks, *Caranx hippos*, to temperate estuaries. Fishery Bulletin 98: 528-538.

Munro J.L., V.C. Gaut, R. Thompson, and P.H. Reeson. 1973. The spawning seasons of Caribbean reef fishes. J. Fish Biol. 5: 69-84.

Reuben, S., H.M. Kasim, S. Sivakami, P.N. Radhakrishnan, K.N. Kurup, M. Sivadas, A. Noble, K.V.S. Nair and S.G. Raje. 1992. Fishery, biology and stock assessment of carangid resources from the Indian seas. Indian Journal Fish. 39(3,4):195-234.

Sierra, L.M., R. Claro and O.A. Popova. 1994. Alimentación relaciones tróficas. P. 263-284 *In:* R. Claro (ed.). Ecología de los Peces Marinos de Cuba. Inst. de Oceanología Acad. De Cienc. De Cuba y Centro de Invest. De Quintana Roo, México.

Smith-Vaniz, W.F. 2002. Carangidae. *In* The living marine resources of the Western Central Atlantic. Volume 3: Bony fishes part 2 (Opisthograthidae to Molidae), sea turtles and marine mammals. FAO Species Indentification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Special Publication No. 5. (K.E. Carpenter, ed.), p.1426-1441. Food Agric. Organization, Rome.

Smith-Vaniz, W.F. and K. E. Carpenter. 2007. Review of the crevalle jacks, *Caranx hippos* complex (Teleostei:Carangidae), with a description of a new species from West Africa. Fishery Bulletin 105:207-233.

Thompson, R. and J.C. Munro. 1974. The biology, ecology and exploitation and management of the Caribbean reef fishes. Part V. Carangidae (jacks). Res. Rep. Zool. Dep. Univ. West Indies 3: 1-43.

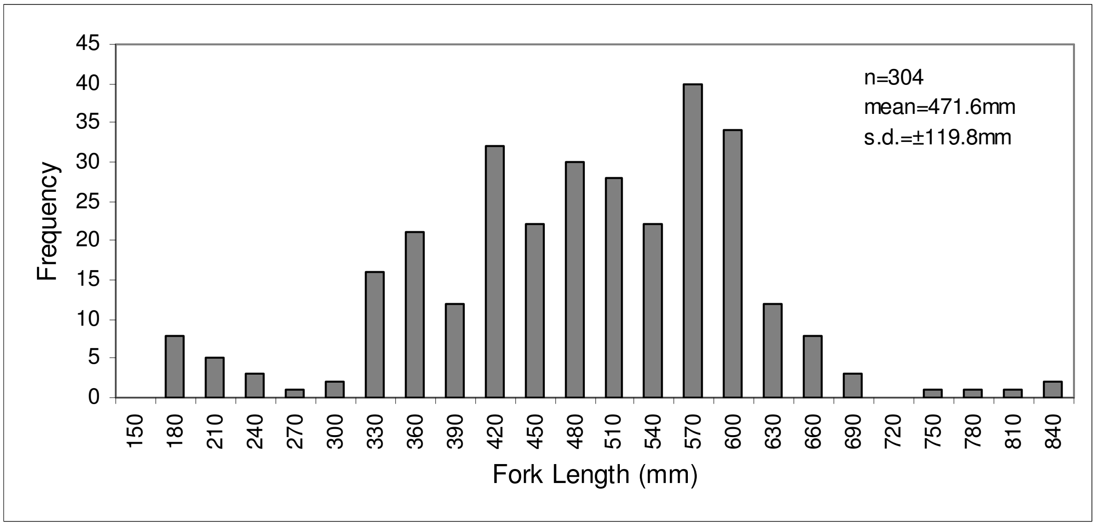


Figure 5-1. Size-frequency distribution of crevalle jack (*Caranx hippos*) collected between October 2003 and August 2007.

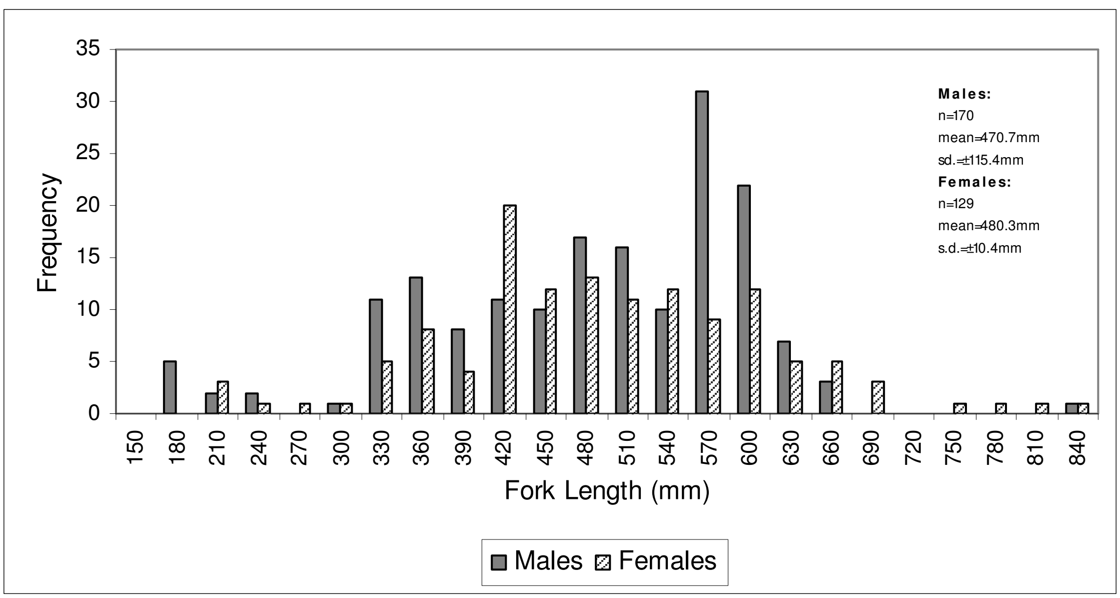


Figure 5-2. Size-frequency distribution of male and female crevalle jack (*Caranx hippos*) collected between October 2003 and August 2007.

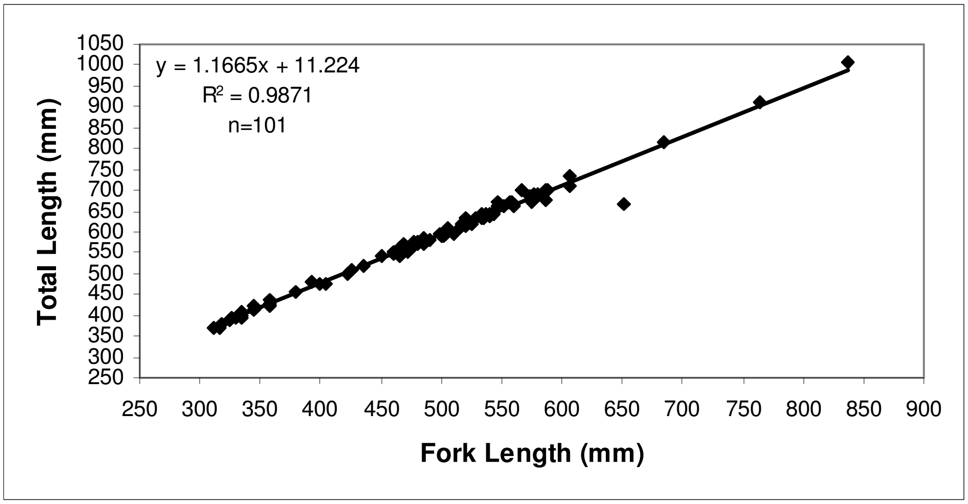


Figure 5-3. Relationship between total length and fork length for crevalle jack (*Caranx hippos*).

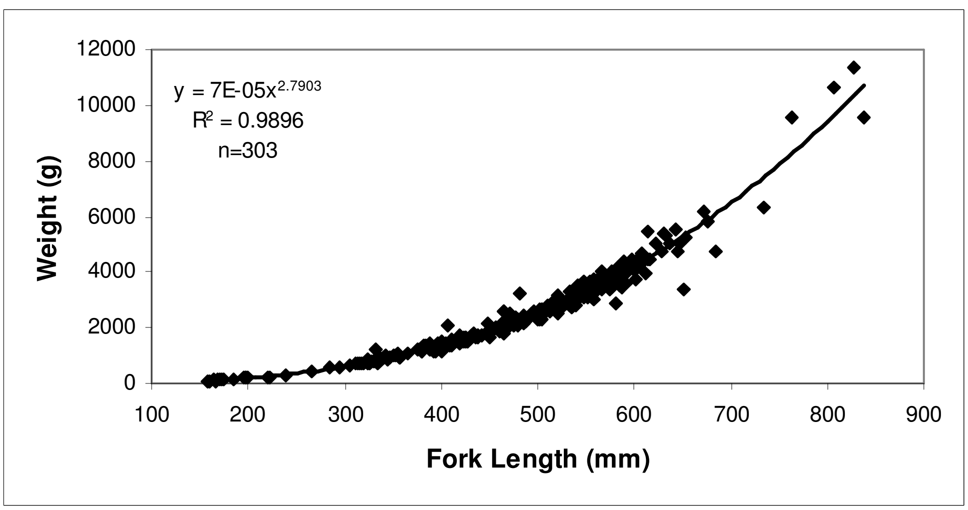


Figure 5-4. Relationship between weight and fork length for crevalle jack (*Caranx hippos*).

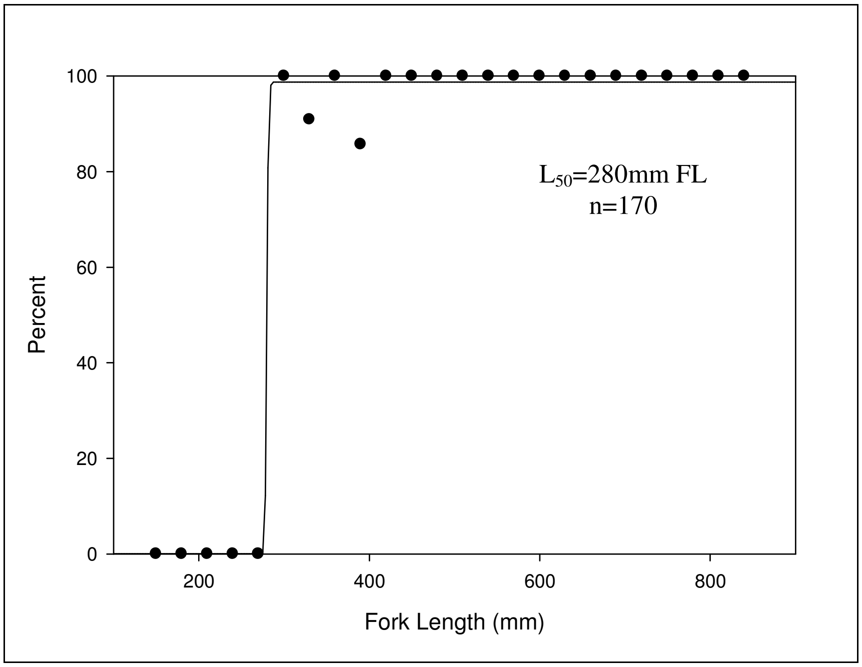


Figure 5-5. Percent of sexually mature male crevalle jack (*Caranx hippos*) as a function of fork length (see Appendix XIII).

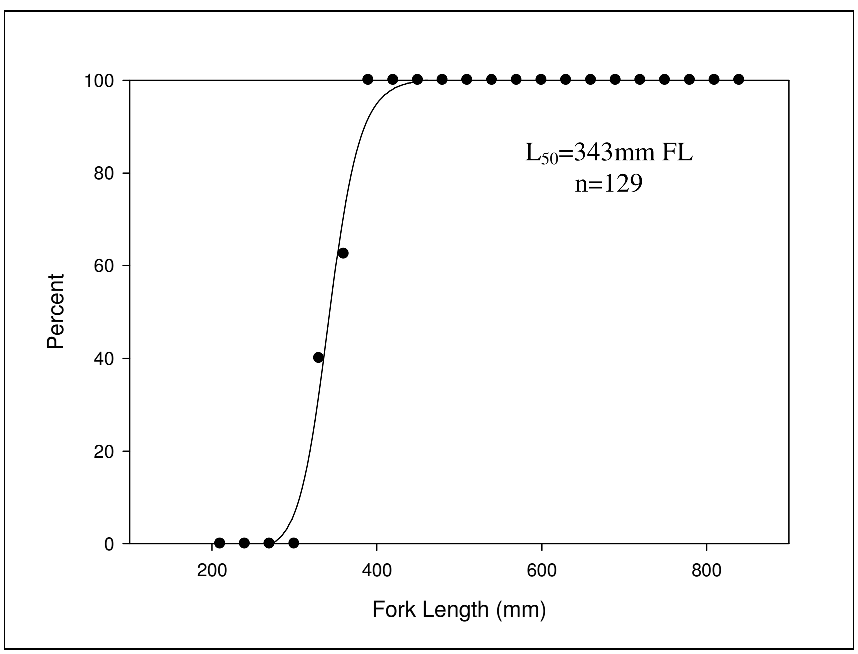


Figure 5-6. Percent of sexually mature female crevalle jack (*Caranx hippos*) as a function of fork length (see Appendix XIV).

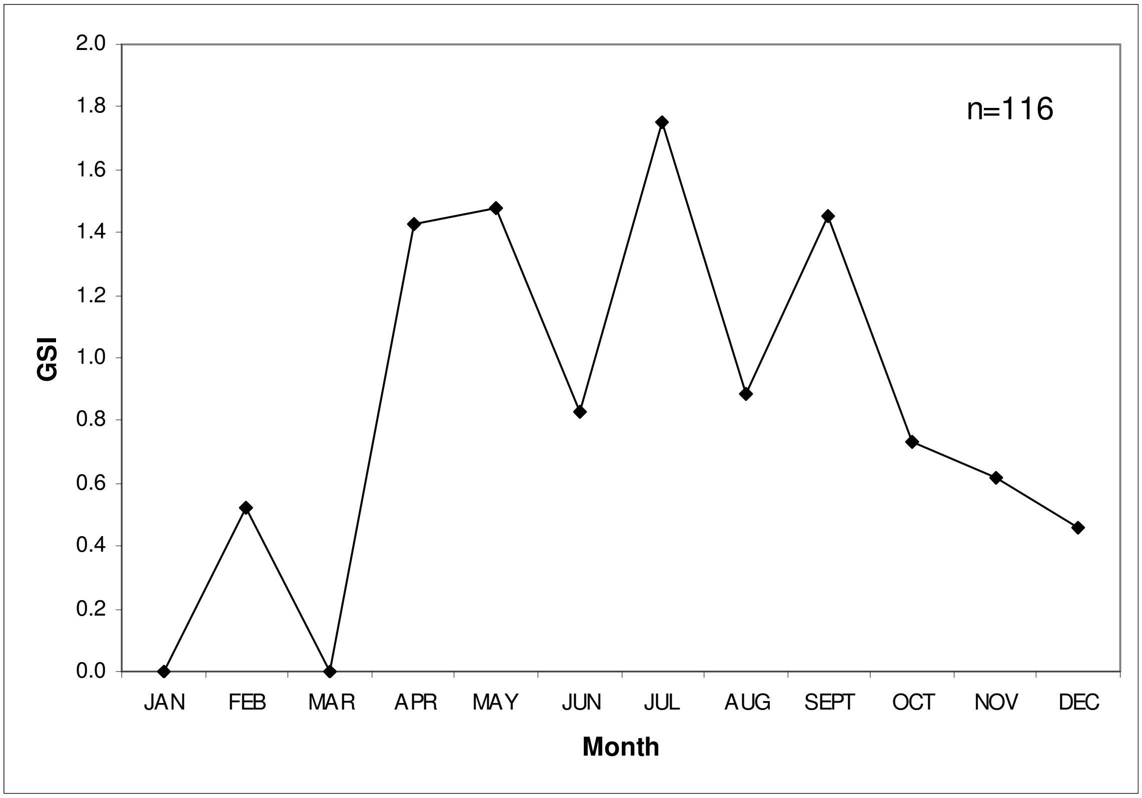


Figure 5-7. Monthly mean gonadosomatic index (GSI) for female crevalle jack (*Caranx hippos*).

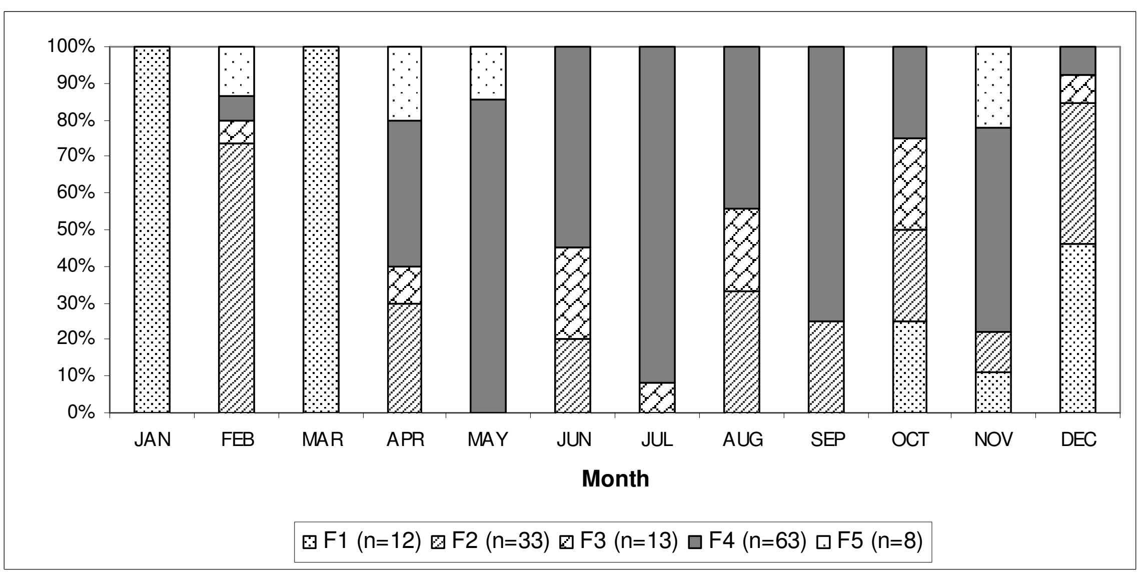


Figure 5-8. Monthly percentages of reproductive classes for female crevalle jack (*Caranx hippos*) (F1= Immature; F2= Inactive mature; F3=Active mature; F4= Ripe; F5=Spent).

FL (mm)	N total	N mature	% mature
180	5	0	0
210	2	0	0
240	2	0	0
270	0	0	
300	1	1	100
330	11	10	91
360	13	13	100
390	8	7	88
420	11	10	91
450	10	10	100
480	17	17	100
510	16	16	100
540	10	10	100
570	31	31	100
600	22	22	100
630	7	7	100
660	3	3	100
690	0	0	
720	0	0	
750	0	0	
780	0	0	
810	0	0	
840	1	1	100
Total	170	158	

Table 5-1. Maturity schedule by size for male crevalle jack (*Caranx hippos*).

FL (mm)	N total	N mature	% mature
210	3	0	0
240	1	0	0
270	1	0	0
300	1	0	0
330	5	2	40
360	8	5	62
390	4	4	100
420	20	20	100
450	12	12	100
480	13	13	100
510	11	11	100
540	12	12	100
570	9	9	100
600	12	12	100
630	5	5	100
660	5	5	100
690	3	3	100
720	0	0	
750	1	1	100
780	1	1	100
810	1	1	100
840	1	1	100
Total	129	117	

Table 5-2. Maturity schedule by size for female crevalle jack (*Caranx hippos*).

Month	GSI	N	sd
January		0	
February	0.521	15	0.449
March		0	
April	1.425	10	1.795
May	1.480	14	0.647
June	0.827	20	0624
July	1.750	12	0.712
August	0.887	9	0.870
September	1.450	16	1.338
October	0735	5	0.609
November	0.620	8	0.693
December	0.460	7	0.446
Total		116	

Table 5-3. Monthly mean gonadosomatic index (GSI) of female crevalle jack (*Caranx hippos*).

		Stage of gonad development									
		F1		**F2**		**F3**		**F4**		**F5**	
Month	**N**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
January	2	2	100.0	0	0	0	0	0	0	0	0
February	15	0	0	11	73.0	1	6.7	1	7.0	2	13.3
March	1	1	100.0	0	0.0	0	0	0	0	0	0
April	10	0	0	3	30.0	1	10.0	4	40.0	2	20.0
May	14	0	0	0	0	0	0	12	86.0	2	14.0
June	20	0	0	4	20.0	5	25.0	11	55.0	0	0
July	12	0	0	0	0	1	8.3	11	91.2	0	0
August	9	0	0	3	33.3	2	22.2	4	44.4	0	0
September	16	0	0	4	25.0	0	0	12	75.0	0	0
October	8	2	25.0	2	25.0	2	25.0	2	25.0	0	0
November	9	1	11.1	1	11.0	0	0	5	55.6	2	22.2
December	13	6	46.2	5	38.0	1	7.7	1	7.7	0	0
Total	129	12		33		13		63		8	

Table 5-4. Monthly percentages of reproductive classes for female crevalle jack (*Caranx hippos*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5= Spent).

Horse-eye jack (*Caranx latus*)

Introduction

The horse-eye jack (*Caranx latus*) (family Carangidae) has elongated, deep and compressed body, large eyes with strong adipose eyelid. Their chest is completely scaly and bilateral caudal keels are present. The body color is dark blue to bluish grey above, silvery white or golden below and no spots on pectoral fin (Smith-Vaniz, 2002). *C. latus* occurs in both sides of the Atlantic Ocean; in the Western Atlantic from New Jersey to Brazil, including the Gulf of Mexico and Caribbean. In the Eastern Atlantic it has been reported from St. Paul's Rocks, Ascension Island, and two confirmed records from the Gulf of Guinea. It is a pelagic schooling species usually found in offshore reefs (Claro, 1994). Juveniles are found along shore of sandy beaches and also over muddy bottoms (Cervigón, 1993). May enter brackish water and ascend rivers (Smith-Vaniz, 2002). Its diet consists primarily on small fish and crustaceans (Silvano, 2001). The maximum size reported is 101 cm FL and 29.5pounds of weight (IGFA, 2001). The maximum weight reported by the Puerto Rico Sport Fishing Association is 14 pounds 3 ounces. Horse-eye jacks are caught mainly with hook and line and beach seine (Smith-Vaniz, 2002). There are reports on ciguatera poisoning in *C. latus* (Larson and Rothman, 1967). Information about its ecology and reproductive biology is scant in the literature.

Materials and Methods

See Materials and Methods in Wahoo Section, page 17.

Results

Sampling, size-frequency distribution, and sex ratio

The length frequency distribution for all samples of *Caranx latus* is presented in Figure 6-1. A total of 398 individuals were collected from October 2003 through July 2007 (Appendix II). For this species, 191 males and 164 females were analyzed (n= 355). Sex ratio was 1♂: 0.7♀ (χ^2=2.05; p>0.05, NS). The size frequency distributions of males and females are not significantly different (Kolmogorov-Smirnov: D=0.0921; p<0.01; NS) (Figure 6-2). The size range was 148-660 mm FL for males and 257-742 mm FL for females. The biggest horse-eye jack collected was a female that measured 742 mm FL with a weigh of 16 pounds (Appendix IV). Relationships between total length-fork length and weight-fork length are presented in figures 6-3 and 6-4, respectively.

Size at maturity

The smallest mature male measured 255 mm FL and the smallest mature female measured 276 mm FL (Appendix IV). The estimated size for 50 % maturity in males was 325 mm FL; all males were mature at 450 mm FL (Figure 6-5; Table 6-1). Females mature at 334 mm FL, being all mature at 480 mm FL (Figure 6-6; Table 6-2).

Spawning seasonality

The monthly distribution of the gonadal development stages indicates at least some spawning occurs year-round in the horse-eye jack. Ripe females were found in every month, with no clear evidence of some period of increased reproductive activity (Fig. 6-8; Table 6-4). On the other hand, the GSI shows two peaks (April and August), reaching its lowest value in May (Fig 6-7; Table 6-3), suggesting the possibility of two periods of relative increased spawning activity during the year.

Discussion

Sampling, size-frequency distribution, and sex ratio

Around 82 % of *C. latus* samples were collected by commercial fishermen during night time fishing trips. In western Puerto Rico, horse-eye jack is mainly an incidental catch when targeting kingfish (*Scomberomorus cavalla*), mutton snapper (*Lutjanus analis*), and yellowtail snapper (*Ocyurus chrysurus*). Our largest specimen was a female of 742 mm FL and 16 pounds. The official record for Puerto Rico is 14 pounds 3 ounces. The IGFA All-Tackle world record is 30 pounds. As in the case of *C. hippos* we did not find any report to which compare our *C. latus* size frequency distribution and sex ratio results. Except for a few localized areas, the horse-eye jack is not a target species for neither commercial nor recreational fishermen in local waters. At the present time and with the data we have available, we think that the status of this species can be considered stable and not in imminent danger of overfishing.

Size at maturity

Our estimates of 50 % maturity were 325 and 334 mm FL for males and females, respectively. Thompson and Munro (1974), in Jamaica, estimated minimum maturation sizes of 350 mm FL for males and 340 mm FL for females, while the 50% maturity estimates were 420 and 370 for males and females, respectively. As far as we know, no other studies concerning sexual maturation in this species have been performed.). Based on our estimated mean length at first maturity and the size-frequency distributions examined, about 51 % of the 920 fish measured were mature, suggesting that this species could be a candidate to be regulated (data sources: Daniel Matos, unpublished data Fisheries Research Laboratory, and this study).

Spawning seasonality

We found that *C. latus* spawns year-round in Puerto Rico, with the possibility of the existence of two spawning peaks (April and August). In Cuba, reproductive activity by horse-eye jacks has been reported from June to August and in November (García-Cagide et al. (1994). Also in Cuba, Montolio (1978) found that several *Caranx* spp., including *C. latus, spawn* year-round with maximum activity peaks generally occurring between April-July. Munro et al. (1973) collected ripe horse-eye jacks in oceanic banks in Jamaica during February, May, and August. As in *C. hippos*, Heyman (2001), mentions April-

June as the apparent spawning season of C. *latus* in Belize. Graham and Castellanos (2005) observed courting and/or spawning behavior in horse-eye jacks from February to October offshore Belize. In Puerto Rico (Erdman, 1976) reported an extended spawning season for *C. latus* with no reference to specific months.

References

Cervigón, F. 1993. Los peces marinos de Venezuela. Volume 2. Fundación Científica Los Roques, Caracas, Venezuela. 497p.

Claro, R. 1994. Características generales de la ictiofauna. p. 55-70. *In* R. Claro (ed.) Ecología de los peces marinos de Cuba. Instituto de Oceanología Academia de Ciencias de Cuba y Centro de Investigaciones de Quintana Roo.

Erdman, D.S. 1976. Spawning patterns of fishes from the Northeast Caribbean. Puerto Rico Dept. Agric., Agric. and Fish. Contr. 8(2): 1-36.

García-Cagide, A., R. Claro and B.V. Koshelev. 1994. Reproducción. P 187-262 *In*: R. Claro (ed.). Ecología de los peces marinos de Cuba. Inst. Oceanol. Acad. Cienc. Cuba and Cen. Invest. Quintana Roo, (CIQPRO), México.

Graham, R.T. and D.W. Castellanos. 2005. Courtship and spawning behaviors of carangid species in Belize. Fishery Bulletin 103: 426-432.

Heyman, W.D. 2001. Spawning aggregations in Belize. A report generated for the workshop, "Towards a sustainable management of Nassau Groupers in Belize". The Nature Conservancy.

IGFA. 2001. Database of IGFA angling records until 2001. IFGA, Fort Lauderdale, USA.

Larson, E. and L. Rothman. 1967. Ciguatera poisoning by the horse-eye jack, *Caranx latus*, a carangid fish from the tropical Atlantic. Toxicon Vol. 5: 121-124.

Montolio, M. 1978. Algunos aspectos sobre el desove y las concentraciones larvarias de las especies de la familia Carangidae en el Mar Caribe. Revista cubana de Investigaciones Pesqueras 3:29-49.

Munro J.L., V.C. Gaut, R. Thompson, and P.H. Reeson. 1973. The spawning seasons of Caribbean reef fishes. J. Fish Biol. 5: 69-84.

Silvano R.A.M. 2001. Feeding habits and interspecific feeding associations of *Caranx latus* (Carangidae) in a subtropical reef. Environmental Biology of Fishes 60: 465-470.

Smith-Vaniz, W.F. 2002. Carangidae. *In* The living marine resources of the Western Central Atlantic. Volume 3: Bony fishes part 2 (Opisthograthidae to Molidae), sea turtles and marine mammals. FAO Species Indentification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Special Publication No. 5. (K.E. Carpenter, ed.), p.1426-1441. Food Agric. Organization, Rome.

Thompson, R. and J.C. Munro. 1974. The biology, ecology and exploitation and management of the Caribbean reef fishes. Part V. Carangidae (jacks). Res. Rep. Zool. Dep. Univ. West Indies 3: 1-43.

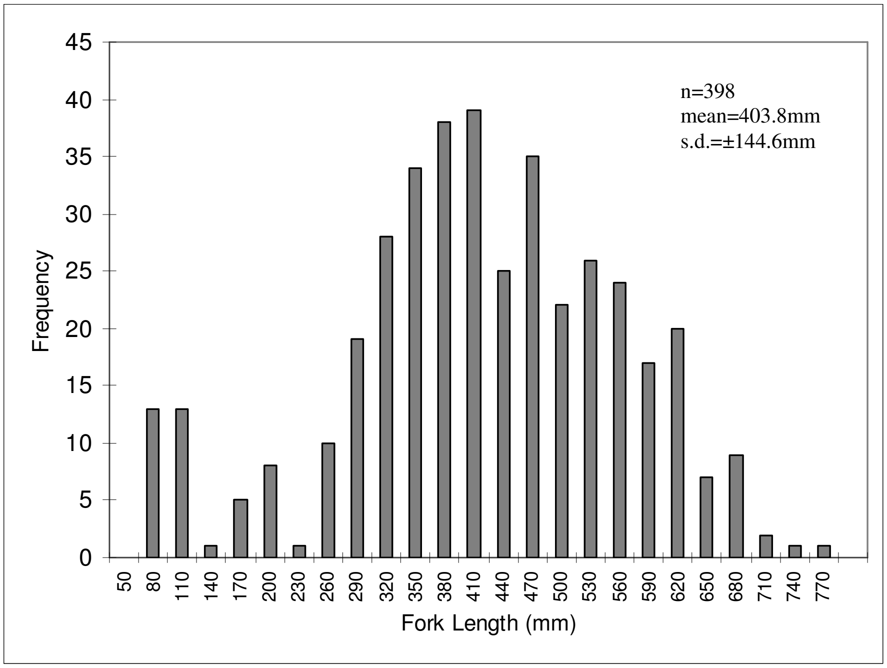


Figure 6-1. Size-frequency distribution of horse-eye jack (*Caranx latus*) collected between October 2003 and July 2007.

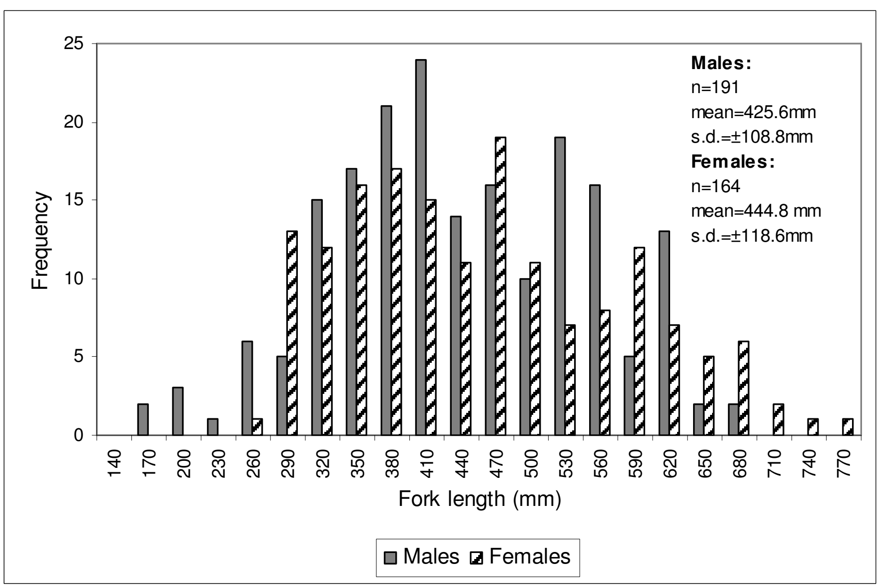


Figure 6-2. Size-frequency distribution of male and female horse-eye jack (*Caranx latus*) collected between October 2003 and July 2007.

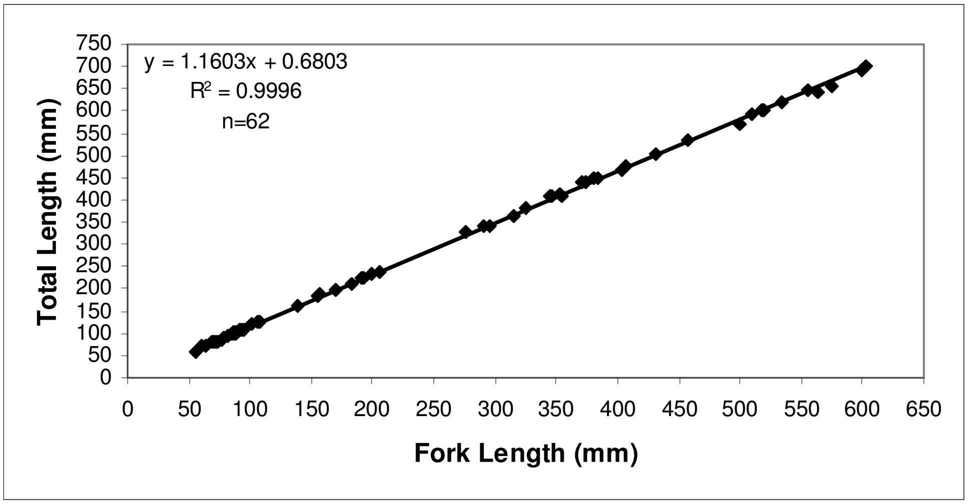


Figure 6-3 Relationship between total length and fork length for horse-eye jack (*Caranx latus*).

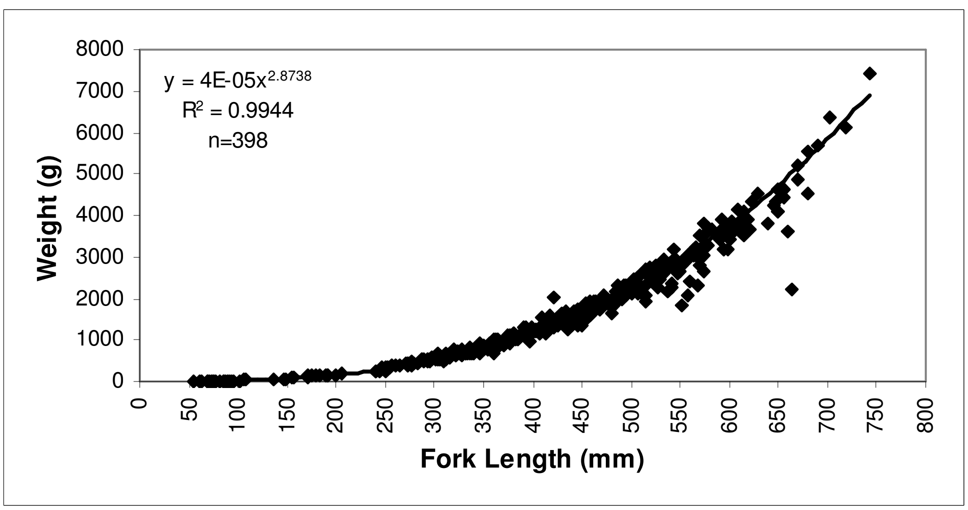


Figure 6-4. Relationship between weight and fork length for horse-eye jack (*Caranx latus*).

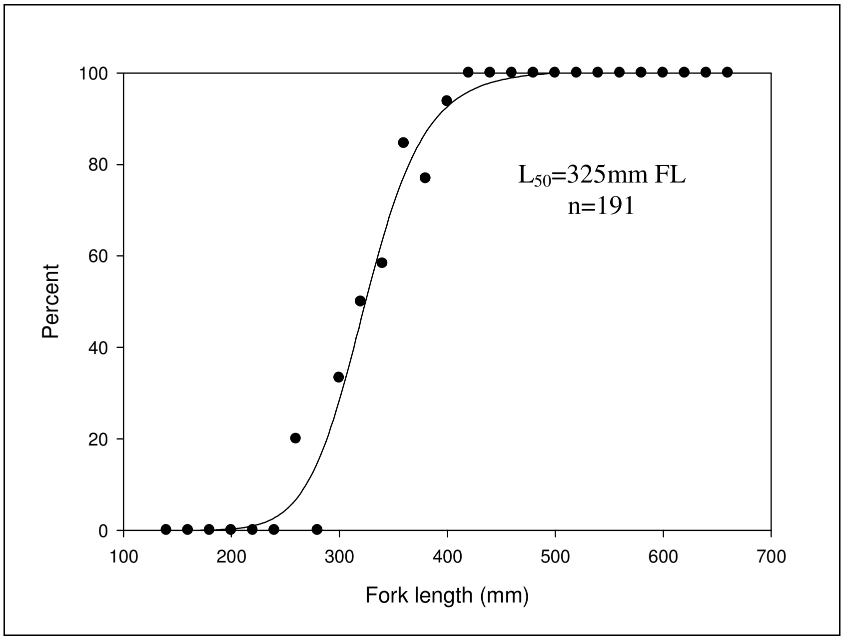


Figure 6-5. Percent of sexually mature male horse-eye jack (*Caranx latus*) as a function of fork length (see Appendix XV).

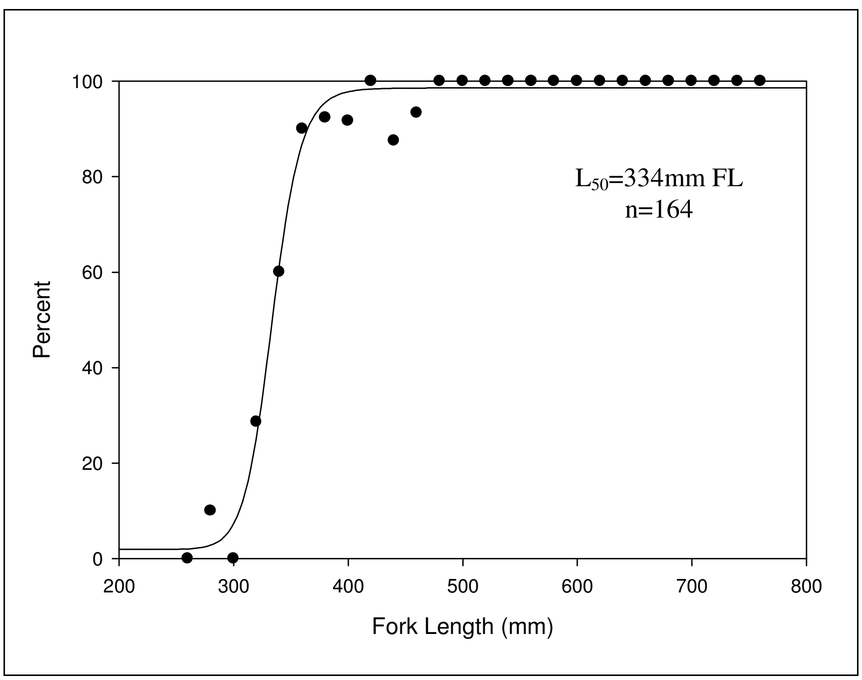


Figure 6-6. Percent of sexually mature female horse-eye jack (*Caranx latus*) as a function of fork length (see Appendix XVI).

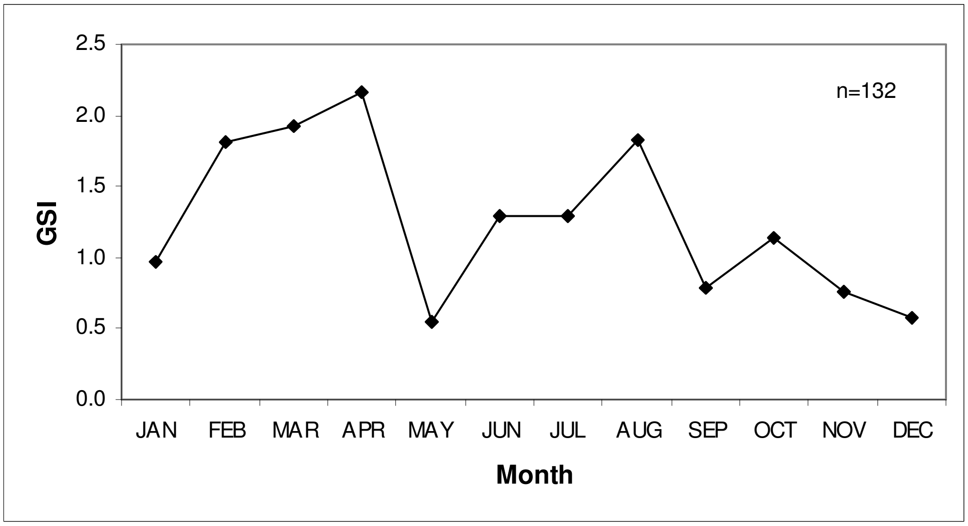


Figure 6-7. Monthly mean gonadosomatic index (GSI) for female horse-eye jack (*Caranx latus*).

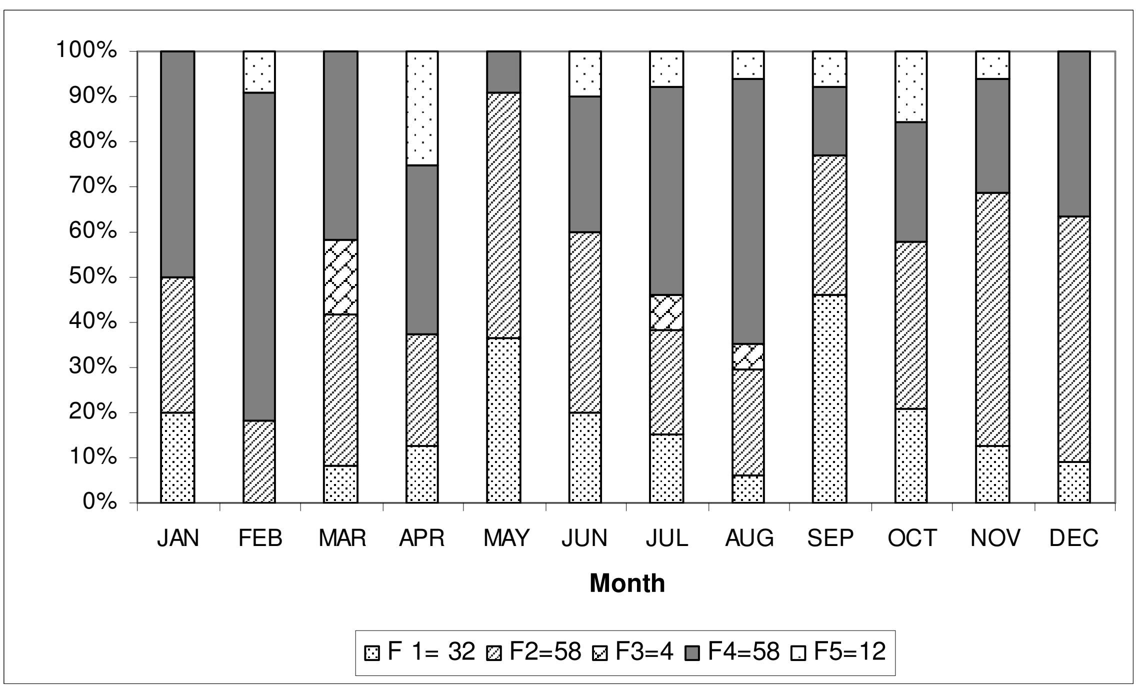


Figure 6-8. Monthly percentages of reproductive classes for female horse-eye jack (*Caranx latus*) (F1=Immature; F2= Inactive mature; F3=Active mature; F4= Ripe; F5= Spent).

FL (mm)	N total	N mature	% mature
160	1	0	0
180	3	0	0
200	1	0	0
220	1	0	0
240	1	0	0
260	5	1	20
280	2	0	0
300	6	2	33
320	12	6	50
340	12	7	58
360	13	11	85
380	13	10	77
400	16	15	94
420	12	12	100
440	10	10	100
460	11	11	100
480	8	8	100
500	7	7	100
520	16	16	100
540	7	7	100
560	12	12	100
580	5	5	100
600	8	8	100
620	5	5	100
640	1	1	100
660	3	3	100
Total	191	157	

Table 6-1. Maturity schedule by size for male horse-eye jack (*Caranx latus*).

FL (mm)	N total	N mature	% mature
260	1	0	0
280	10	1	10
300	8	0	0
320	7	2	29
340	10	6	60
360	10	9	90
380	13	12	92
400	12	11	92
420	6	6	100
440	8	7	88
460	15	14	93
480	6	6	100
500	9	9	100
520	3	3	100
540	7	7	100
560	5	5	100
580	10	10	100
600	4	4	100
620	5	5	100
640	2	2	100
660	5	5	100
680	4	4	100
700	1	1	100
720	2	2	100
740	0	0	
760	1	1	100
Total	164	132	

Table 6-2. Maturity schedule by size for female horse-eye jack (*Caranx latus*).

Month	GSI	N	sd
January	0.967	8	0.717
February	1.807	11	1.001
March	1.929	11	1.861
April	2.163	7	1.492
May	0.550	7	0.725
June	1.287	8	1.190
July	1.299	11	1.050
August	1.826	16	1.265
September	0.780	14	0.717
October	1.140	15	1.041
November	0.759	14	0.733
December	0.579	10	0.554
Total		132	

Table 6-3. Monthly mean gonadosomatic index (GSI) of female horse-eye jack (*Caranx latus*).

		Stage of gonad development									
		F1		**F2**		**F3**		**F4**		**F5**	
Month	**N**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
January	10	2	20.0	3	30.0	0	0	5	50.0	0	0
February	11	0	0	2	18.0	0	0	8	73.0	1	9.1
March	12	1	8.3	4	33.3	0	16.7	5	41.7	0	0
April	8	1	12.5	2	25.0	0	0	3	37.5	2	25.0
May	11	4	36.4	6	55.0	0	0	1	9.0	0	0
June	10	2	20.0	4	40.0	0	0	3	30.0	1	10.0
July	13	2	15.4	3	23.0	1	7.7	6	46.1	1	7.7
August	17	1	5.9	4	23.5	1	5.9	10	58.8	1	5.9
September	26	12	46.2	8	30.8	0	0	4	15.4	2	7.7
October	19	4	21.1	7	36.8	0	0	5	26.3	3	15.8
November	16	2	12.5	9	56.0	0	0	4	25.0	1	6.2
December	11	1	9.1	6	55.0	0	0	4	36.4	0	0
Total	155	32		58		4		58		12	

Table 6-4. Monthly percentages of reproductive classes for female horse-eye jack (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5=Spent).

Blue runner (*Caranx crysos*)

Introduction

The blue runner (*Caranx crysos*), family Carangidae, has elongate, moderately deep and compressed body. The color of the body is light olive to dark bluish green above, silvery grey to golden below (Smith-Vaniz, 2002). The species is distributed in both sides of the Atlantic Ocean, in the Western Atlantic from Nova Scotia, Canada to Brazil including Gulf of Mexico and Caribbean (Smith-Vaniz, 2002) and in the Eastern Atlantic from Senegal to Angola, including the Western Mediterranean, St Paul Rocks (Lubbock and Edwards, 1981) and Ascension Island. In the tropical eastern Pacific, it is replaced by *Caranx caballus*, which may be conspecific (Froese and Pauly, 2007). Is a schooling species, primarily inshore, not common around reefs and juveniles are often found associated with *Sargassum* (Smith-Vaniz, 2002). Feed on fish, shrimp and other invertebrates. The maximum size reported is 62 cm FL and maximum weight reported is 11.1pounds (IGFA, 2001). Blue runners are caught mainly with haul seines, lampara nets, purse seines, gill nets and handlines; also caught by anglers with rod and reel and used as bait (Smith-Vaniz, 2002). It is mentioned in some reports as an excellent food fish (Cervigón, 1993), although very large specimens have been implicated in ciguatera poisoning (Dammann, 1969). Like other carangids in the Caribbean, the spawning season usually extends from spring to autumn.

Materials and Methods

See Materials and Methods in Wahoo Section, page 17.

Results

Sampling, size-frequency distribution, and sex ratio

Length frequency distribution for *C. crysos* is presented in Figure 7-1. From 372 individuals analyzed, 170 were females and 202 males (Appendix II); the sex ratio was 1♂: 0.8♀ (χ^2=2.75; p<0.05, significantly different). There is no significant difference in the length frequency distribution between males and females (Kolmogorov-Smirnov: D=0.08346; p>0.01) (Figure 7-2). Size range was 184-519 mm FL for males and 162-660 mm FL for females (Appendix IV). Relationships between total length-fork length and weight-fork length are presented in figures 7-3 and 7-4, respectively.

Size at maturity

The smallest mature male measured 205 mm FL, while the smallest mature female measured 200 mm FL (Appendix IV). The estimate size for the 50 % of sexual maturity in males was 232mm FL. All males were mature at 340 mm FL (Figure 7-5; Table 7-1). In females the maturity size was 257 mm FL, been all mature at 360mm FL (Figure 7-6; Table 7-2). Using the length frequency distribution and the maturity estimates only 8 % (n=1227) of the blue runners measured were captured before reaching sexual maturity (data sources: Daniel Matos, unpublished data, Fisheries Research Laboratory; Aida Rosario, unpublished data, FRL; this study).

Spawning seasonality

The monthly variation of GSI females of *C. crysos* is presented in Figure 7-7 and Table 7-3. The GSI begins to increase on April, reaching their maximum from June-August, and then it starts to descend in September. The monthly distribution of the gonad development stages in females is presented in Figure 7-8 and Table 7-4. Ripe females (F4) were mostly found from March to October. The months with the highest percentage of ripe females were May and June with 82 % and 94 %, respectively (Fig. 7-8; Table 7-4). Fifty percent of the females examined in September were F5 (spent). This species has an extended reproductive season, showing an increase in spawning activity during the summer months.

Discussion

Sampling, size-frequency distribution, and sex ratio

Over 90% of the blue runner specimens were captured by cooperating commercial fishermen and PRDNER personnel using hook and line, beach seines, and gillnets, in that order of importance. Of the three species of *Caranx* we studied, C. *crysos* was the most frequently seen in both commercial and recreational catches. The largest specimen in our samples was a 7 pound female (660 mm FL). The IGFA All-Tackle world record is 11 pounds. Berry (1959) noted a maximum FL of 711 mm. We report here a sex ratio of 1♂:0.8♀. In contrast, Goodwin and Finucane (1985) found sex ratios of 1.15, 1.66, and 1.91♀:1♂ from three localities in the eastern Gulf of Mexico. As these authors postulate, numerical dominance of one particular sex may be an artifact of sampling methods. Also, spatial and/or temporal segregation by sex could cause artificially skewed sex ratios. As in the case of *C. hippos* and *C. latus* we did not find any report to which compare our *C. latus* size frequency distribution and sex ratio results. Although not significant, it is interesting to point out that in the three *Caranx* species presented here females tend to predominate in the larger size classes.

Size at maturity

Our estimated mean length at first maturity for *C. crysos* was 232 mm FL for males and 257 mm FL for females. These values are similar to other published estimates. In Jamaica the 50% maturity estimates reported were 260 and 280 for males and females, respectively (Thompson and Munro, 1974). In the eastern Gulf of Mexico, Goodwin and Finucane (1985) found that female blue runner 50% maturity estimate was 267 mm FL, while Berry (1959), offshore the southeastern Atlantic coast of the United States, reported a maturity value of 225-250 mm SL (standard length). Based on our estimated mean length at first maturity and the size-frequency distribution, about 92% of the 1227 fish measured were mature (data sources: Daniel Matos, unpublished data Fisheries Research Laboratory; Aida Rosario, unpublished data FRL; this study).

Spawning seasonality

According to our data, in Puerto Rico the blue runner spawning season extends probably from March to October with a peak during May and June. Erdman (1976) found blue runners (La Parguera, Puerto Rico) in spawning condition year-round with an increase in abundance from March through May. Estimation of the spawning cycle in *C. crysos* has been mainly based on the seasonal occurrence of larvae or young specimens in collections made by various researchers. Berry (1959) noted from larval size that spawning extended from April to September off the southeastern Atlantic coast of the United States. Peak abundance of juveniles was reported by Dooley (1972) during June and July off southeast Florida where they are associated with the *Sargassum* community. McKenney et al. (1958) and Fahay (1975) stated that spawning occurred year-round; however 75% of the postlarvae collected by McKenney et al. (1958) were taken from April through August. Munro et al. (1973) collected ripe females in Pedro Bank (Jamaica) in May. Montolio (1978) found two spawning peak based on larval collection from the south-central Gulf of Mexico, one in April-May, and the other in August-September. In the eastern Gulf of Mexico, GSI indicated that peak spawning occurred mainly in June, July, and August (Goodwin and Finucane, 1985). Through the direct observation of spawning/courtship behavior, Heyman (2001) reported April-May as the apparent spawning season of *C. crysos* in Belize. Other carangids have extended spawning seasons (March-April through September-October). A prolonged spawning season is a common reproductive strategy among fishes living in subtropical and tropical waters. The duration of the spawning period is probably related to the water temperature, which has a marked influence in the viability and development of spawned eggs. However, since spawning in many species diminish or ends when the temperature is still comparatively high, possibly a decrease in photoperiod in combination with a decrease in temperature provides the necessary stimuli for termination of spawning (Brown-Peterson et al. 1988). García-Cagide et al.(1994) stated that in tropical species, small seasonal fluctuations in temperature and photoperiod in conjunction with the lunar cycle, seem to be important as trigger mechanisms for the onset of spawning, but only when the individual fish is physiologically ready. Although many species have an extended spawning season, most or probably all, have a well defined (1-2 months) peak (Colin and Clavijo, 1988; Claro and Lindeman, 2003). Variations in spawning timing are not well understood but several factors have been proposed, among them the age of fish, local population size, intra and interannual climate and current changes, and shelf geomorphology (see Colin and Clavijo, 1988 and Claro and Lindeman, 2003).

References

Berry, F.H. 1959. Young jacks crevalles (*Caranx* species) off the south eastern Atlantic coast of the United States. Fishery Bulletin 59:417-535.

Brown-Peterson, N., P. Thomas and C.R. Arnold. 1988. Reproductive biology of the spotted seatrout, *Cynoscion nebulosus*, in south Texas. Fishery Bulletin: Vol 86, No. 2: 373-388.

Cervigón, F. 1993. Los peces marinos de Venezuela. Volume 2. Fundación Científica Los Roques, Caracas, Venezuela. 497p.

Claro, R. and K.C. Lindeman. 2003. Spawning aggregation sites of snapper and grouper species (Lutjanidae and Serranidae) on the insular shelf of Cuba. Gulf and Caribbean Research Vol 14(2): 91-106.

Colin, P.L. and I.E. Clavijo. 1988. Spawning activity of fishes producing pelagic eggs on a shelf edge coral reef, southwestern Puerto Rico. Bulletin of Marine Science, 43(2):249-279.

Dammann, A.E., 1969. Study of the fisheries potential of the Virgin Islands. Special Report. Contribution No. 1. Virgin Islands Ecological Research Station.

Dooley, J.K. 1972. Fishes associated with pelagic sargassum complex, with discussion of the sargassum community. Contribution Marine science 16:1-32.

Erdman, D.S. 1976. Spawning patterns of fishes from the Northeast Caribbean. Puerto Rico Dept. Agric., Agric. and Fish. Contr. 8(2): 1-36.

Fahay, M.P. 1975. An annotated list of larval and juvenile fishes captured with surface-towed meter net in the south Atlantic Bight during four R/V Dolphin cruises between May 1967 and February 1968. NOAA Technical Reports NMFS SSRF 685:39p

Froese, R. and D. Pauly. Editors. 2007. Fishbase. World Wide Web Electronic publication. www.fishbase.org

García-Cagide, A., R. Claro and B.V. Koshelev. 1994. Reproducción. P 187-262 *In*: R. Claro (ed.). Ecología de los peces marinos de Cuba. Inst. Oceanol. Acad. Cienc. Cuba and Cen. Invest. Quintana Roo, (CIQPRO), México.

Goodwin IV, J.M., and J.H. Finucane. 1985. Reproductive biology of blue runner (*Caranx crysos*) from the eastern Gulf of Mexico. Northeast Gulf Sci. 7(2): 139-146.

Heyman, W.D. 2001. Spawning aggregations in Belize. A report generated for the workshop, "Towards a sustainable management of Nassau Groupers in Belize". The Nature Conservancy.

IGFA. 2001. Database of IGFA angling records until 2001. IFGA, Fort Lauderdale, USA.

Lubbock, R. and A. Edwards. 1981. The fishes of Saint Paul's Rocks. J. Fish Biol. 18: 135-157.

McKenney, T.W., E.C. Alexander, and G.L. Voss. 1958. Early development and larval distribution of the carangid fish, *Caranx crysos* (Mitchill). Bulletin of Marine science Gulf and Caribbean 8(2):167-200.

Montolio, M. 1978. Algunos aspectos sobre el desove y las concentraciones larvarias de las especies de la familia Carangidae en el Mar Caribe. Revista cubana de Investigaciones Pesqueras 3:29-49.

Munro J.L., V.C. Gaut, R. Thompson, and P.H. Reeson. 1973. The spawning seasons of Caribbean reef fishes. J. Fish Biol. 5: 69-84.

Smith-Vaniz, W.F. 2002. Carangidae. *In* The living marine resources of the Western Central Atlantic. Volume 3: Bony fishes part 2 (Opisthograthidae to Molidae), sea turtles and marine mammals. FAO Species Indentification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Special Publication No. 5. (K.E. Carpenter, ed.), p.1426-1441. Food Agric. Organization, Rome.

Thompson, R. and J.C. Munro. 1974. The biology, ecology and exploitation and management of the Caribbean reef fishes. Part V. Carangidae (jacks). Res. Rep. Zool. Dep. Univ. West Indies 3: 1-43.

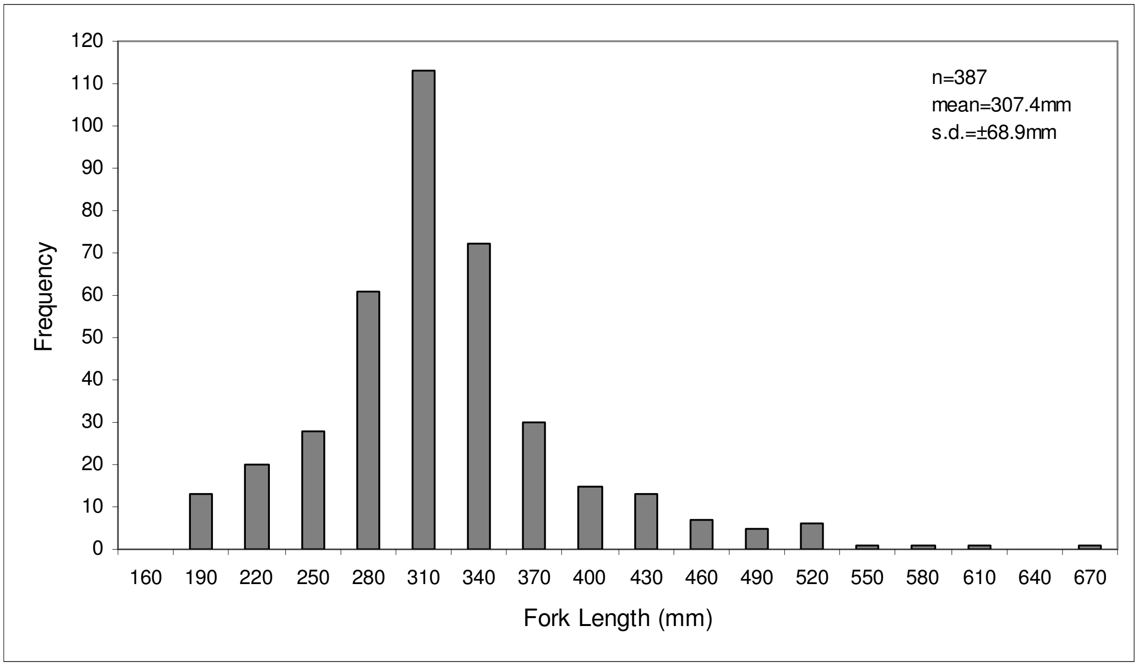


Figure 7-1. Size-frequency distribution of blue runner (*Caranx crysos*) collected between October 2003 and March 2007.

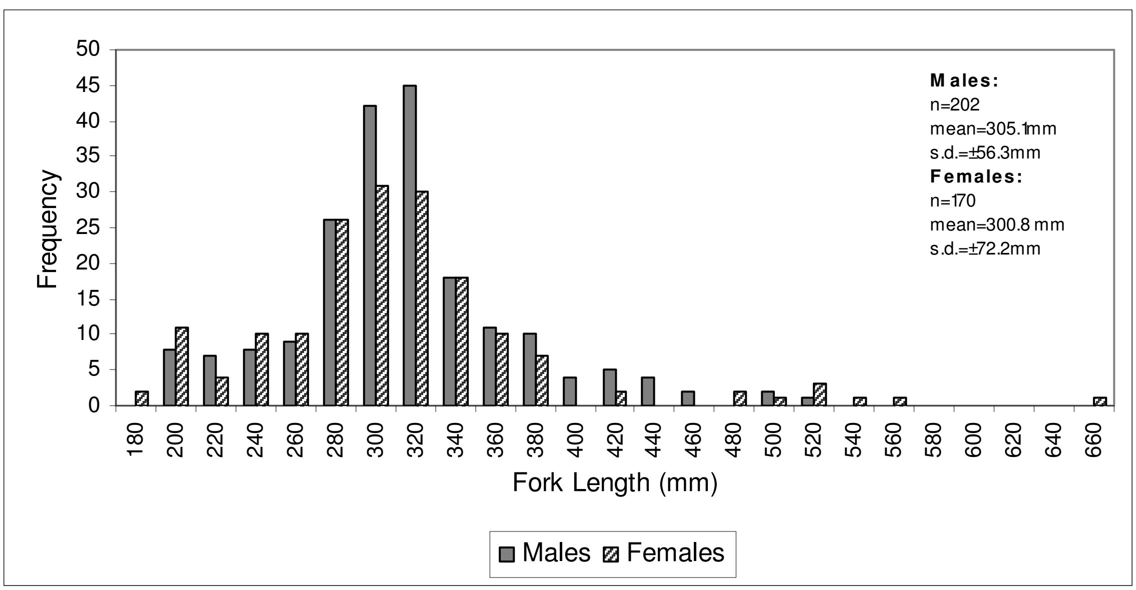


Figure 7-2. Size-frequency distribution of male and female blue runner (*Caranx crysos*) collected between October 2003 and March 2007.

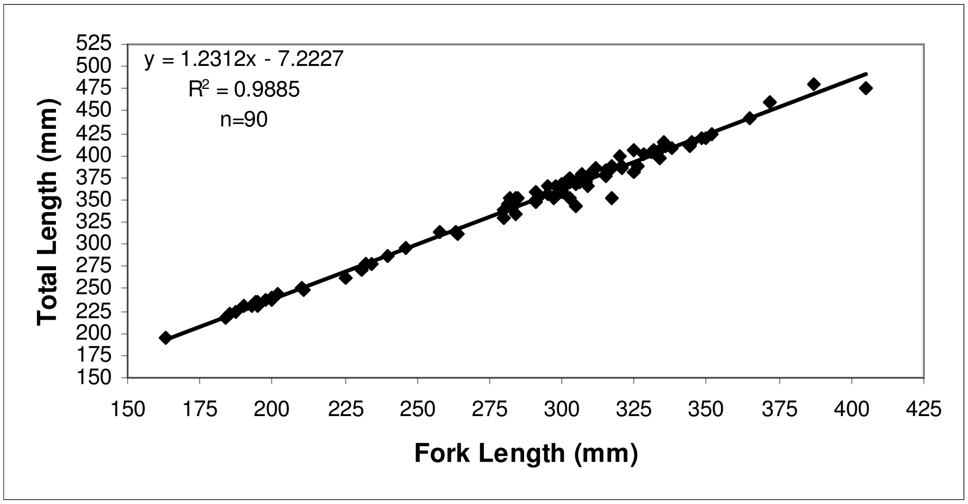


Figure 7-3. Relationship between total length and fork length for blue runner (*Caranx crysos*).

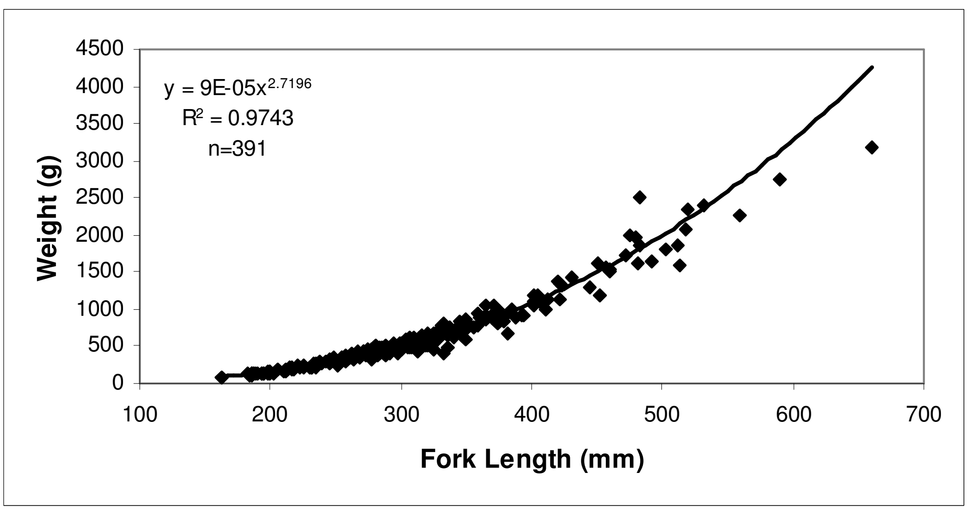


Figure 7-4. Relationship between weight and fork length for blue runner (*Caranx crysos*).

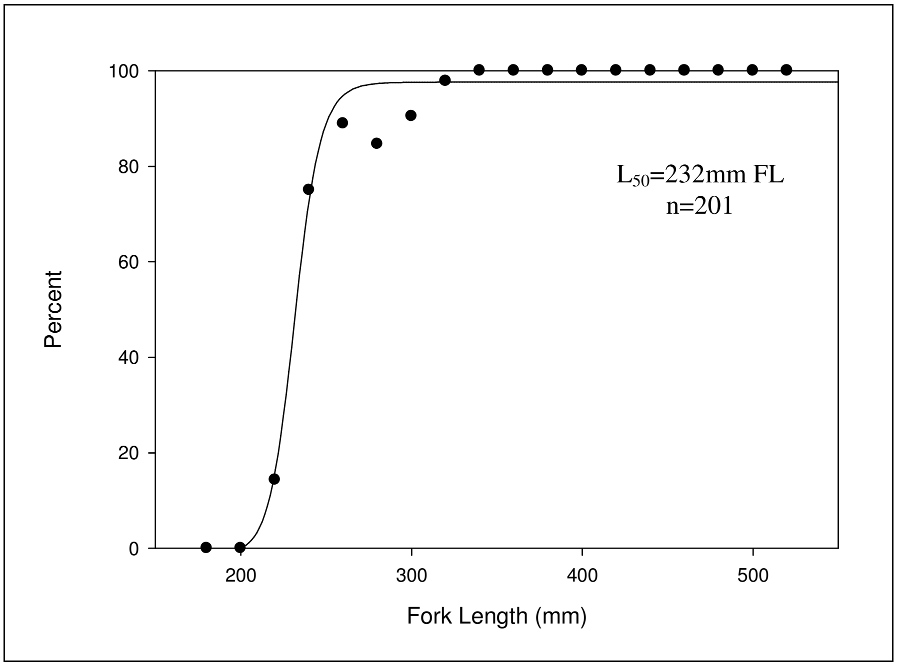


Figure 7-5. Percent of sexually mature male blue runner (*Caranx crysos*) as a function of fork length (see Appendix XVII).

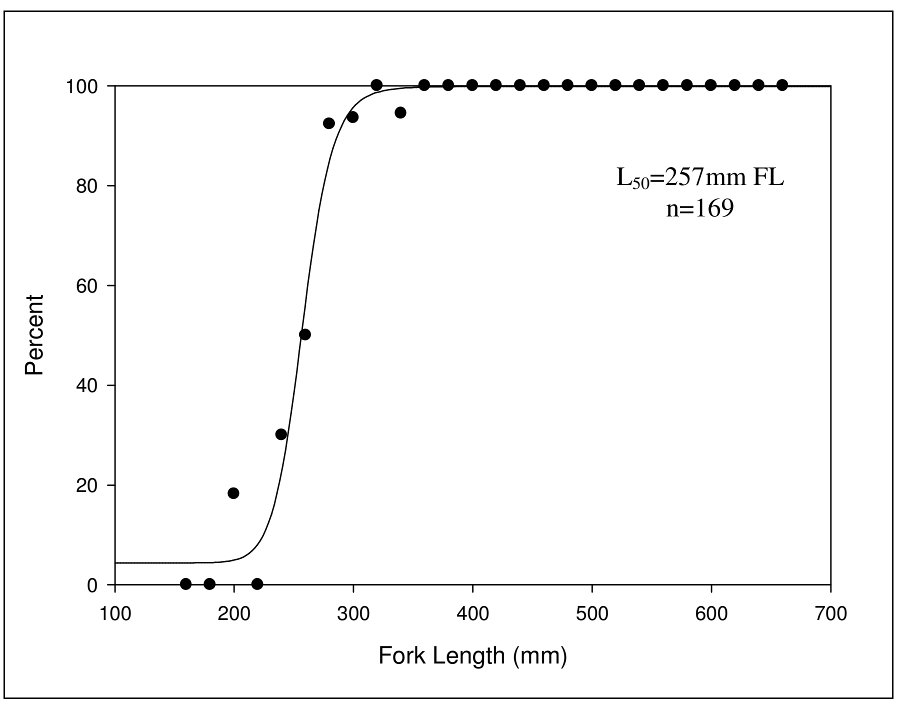


Figure 7-6. Percent of sexually mature female blue runner (*Caranx crysos*) as a function of fork length (see Appendix XVIII).

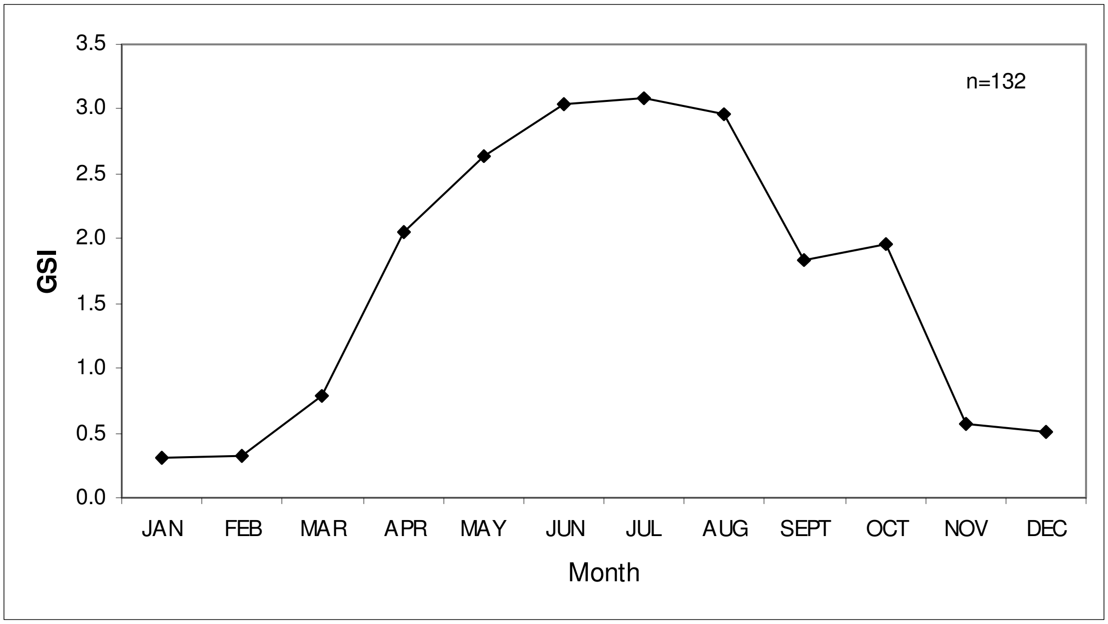


Figure 7-7. Monthly mean gonadosomatic index (GSI) for female blue runner (*Caranx crysos*).

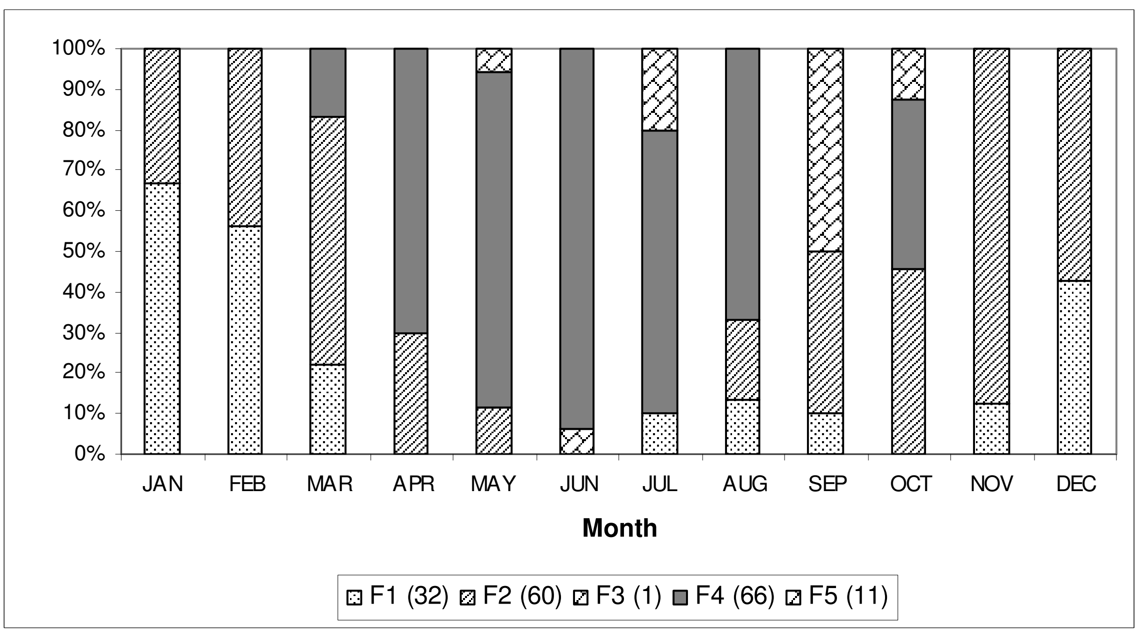


Figure 7-8. Monthly percentages of reproductive classes for female blue runner (*Caranx crysos*) (F1= Immature; F2= Inactive mature; F3=Active mature; F4= Ripe; F5= Spent).

FL (mm)	N total	N mature	% mature
200	8	0	0
220	7	1	14
240	8	6	75
260	9	8	89
280	26	22	85
300	42	38	90
320	45	44	98
340	18	18	100
360	11	11	100
380	9	9	100
400	4	4	100
420	5	5	100
440	4	4	100
460	2	2	100
480	0	0	
500	2	2	100
520	1	1	100
Total	201	175	

Table 7-1. Maturity schedule by size for male blue runner (*Caranx crysos*).

FL (mm)	N total	N mature	% mature
180	2	0	0
200	11	2	18
220	4	0	0
240	10	3	30
260	10	5	50
280	26	24	92
300	31	29	94
320	29	29	100
340	18	17	94
360	10	10	100
380	7	7	100
400	0	0	
420	2	2	100
440	0	0	
460	0	0	
480	2	2	100
500	1	1	100
520	3	3	100
540	1	1	100
560	1	1	100
580	0	0	
600	0	0	
620	0	0	
640	0	0	
660	1	1	100
Total	169	137	

Table 7-2. Maturity schedule by size for female blue runner (*Caranx crysos*).

Month	GSI	N	sd
January	0.314	4	0.158
February	0.328	7	0.141
March	0.784	14	0.744
April	2.053	10	1.489
May	2.637	17	1.139
June	3.045	16	1.093
July	3.091	9	1.049
August	2.954	13	1.852
September	1.830	9	1.460
October	1.963	20	1.434
November	0.567	7	0.178
December	0.505	6	0.077
Total		132	

Table 7-3. Monthly mean gonadosomatic index (GSI) of female blue runner (*Caranx crysos*).

		Stage of gonad development									
		F1		**F2**		**F3**		**F4**		**F5**	
Month	**N**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
January	12	8	66.7	4	33.3	0	0	0	0	0	0
February	16	9	56.2	7	43.8	0	0	0	0	0	0
March	18	4	22.2	11	61.1	0	0	3	16.7	0	0
April	10	0	0	3	30.0	0	0	7	70.0	0	0
May	17	0	0	2	11.8	0	0	14	82.4	1	6.0
June	16	0	0	0	0	1	6.0	15	93.8	0	0
July	10	1	10.0	0	0	0	0	7	70.0	2	20.0
August	15	2	13.3	3	20.0	0	0	10	66.7	0	0
September	10	1	10.0	4	40.0	0	0	0	0	5	50.0
October	24	0	0	11	45.8	0	0	10	41.7	3	12.5
November	8	1	12.5	7	87.5	0	0	0	0	0	0
December	14	6	42.7	8	57.1	0	0	0	0	0	0
Total	170	32		60		1		66		11	

Table 7-4. Monthly percentages of reproductive classes for female blue runner (*Caranx crysos*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5=Spent).

Great barracuda (*Sphyraena barracuda*)

Introduction

The great barracuda (*Sphyraena barracuda*) (Walbaum, 1792) is one of the largest of the 20 species comprising the genus *Sphyraena* (family Sphyraenidae). The barracuda has a slender, elongated body that is round in the mid-section. The mouth is large with a projecting lower jaw containing many triangular and flattened razor-sharp teeth. The body is colored dark green to grey along the back with sides mostly silvery, abruptly becoming white on ventral surface. Adults have 18-22 dark bars on upper sides of body, and usually, several scattered black spots on posterior part of lower sides (Fischer, 1978). Barracudas are large fish. The world record for a hook and line caught fish is 5.5 feet and 103 pounds (Randall, 1996) and the species is reported to reach a size slightly over 6.5 feet (Robbins and Ray, 1986) and 110 pounds (de Sylva, 1990). The maximum weight reported in Puerto Rico is 48 pounds. Its distribution is worldwide in tropical and subtropical seas, being common in the Western Atlantic Ocean from Massachusetts to Brazil, including the Gulf of Mexico and the Caribbean. It is also found in the eastern Atlantic, the Indo-Pacific, and the Red Sea, but absent or rare in some areas of the eastern Pacific. This species occur nearshore in coral reefs, seagrasses, mangroves and also in open waters, living predominantly at or near the surface, although it can be found at depths to 100 meters. The preferred habitat is high profile-bottom such as reefs and wrecks in waters that are 68 °F or warmer (FLMNH, 2007; Manooch, 1988). Small individuals occur mainly in shallow water over sandy bottoms and seagrass beds, often forming schools, while larger specimens (over 65 cm) are generally solitary. However, schools of adult barracuda have been observed occasionally and are probably connected to spawning behavior (Fischer, 1978). Great Barracudas are mainly piscivorous but feed occasionally on cephalopods and shrimps. Favorite foods are jacks, grunts, groupers, snappers, herrings, parrotfish and anchovies. This species is generally a diurnal top predator, and it is estimated that can reach speeds of about 36 mph. Shark, tuna, and goliath grouper have been known to feed on barracudas.

Adult barracuda is a frequently implicated fish species in ciguatera fish poisoning within certain areas of its range, particularly in the Caribbean (deSylva, 1963; Tosteson, 2004). For that reason, in countries were its capture is not prohibited, the species has little commercial value. In the more northern areas of their range they are safe to eat and their flesh is often considered of excellent quality. Although not considered a target species, the barracuda is a strong fish and therefore esteemed by some anglers as a gamefish. Up to 1996, about 30 cases were known of attacks on humans, most of them in murky water (Randall, 1996). Despite its ecological, and to a lesser extent, non-extractive commercial value, little is known about their ecology and behavior (Williams, 1965; Blaber,1982; Wilson et al., 2006).

Based on scale analysis in Florida, deSylva (1963) reported that juveniles attain 10-12 inches during the first year, while specimens measuring around 1260 mm were 13 years old. Males mature at an age of two or three years while females do so at three or four years of age. The spawning season extends from April until October in southern Florida (de Sylva, 1963). It is believed that spawning takes place in deeper, offshore waters.

(FLMNH, 2007).The larvae settle in shallow, vegetated areas and the juveniles spend the remainder of their first year within mangrove and seagrass habitats. During the second year they move to deep reef areas where they will spend their adult life.

In Puerto Rico, information on the reproductive biology is lacking. Erdman (1976) found juveniles of 25 mm every month of the year off La Parguera, though they were more numerous in summer and autumn. The same report also mentions that few adult barracuda contained ripe gonads in winter. In 1978 a trolling survey of pelagic species was carried out, in which barracuda was the main species captured (Erdman, 1978). As far as we are aware, no other studies concerning the Great Barracuda have been performed in local waters.

Materials and Methods

See Materials and Methods in Wahoo Section, page 17.

Results

Sampling, size-frequency distribution, and sex ratio

Three hundred and eighty barracuda were sampled during the study. Size ranged from 290-1347 mm (mean=747; sd=158) (Fig. 8-1). Size-frequency distributions of males and females are significantly different (Kolmogorov-Smirnov, D=0.2376, $p < 0.01$) (Fig. 8-2). A total of 375 were sexed (219 males; 156 females); sex ratio 1♂: 0.7♀ is significantly different (χ^2=10.584, $p<0.05$). Males ranged in size from 326-1220 mm (mean=714; sd=138) and females from 290-1347 mm (mean=794; sd=172) (Appendix IV). Females were more abundant in the larger size classes. Of 24 individuals collected larger than 1000 mm, only four were males. The largest fish in our sampling was a female measuring 1347 mm with a weight of 29 pounds. Relationships between total length-fork length and weight-fork length are presented in figures 8-3 and 8-4, respectively.

Size at Maturity

Barracuda males mature at a smaller size than females. Males started to mature at 352 mm and females at 532 mm. Estimated mean length at first maturity was 582 mm for males and 649 mm for females. All males and females larger than 880 and 840 mm were sexually mature, respectively (Figs. 8-5 and 8-6; Tables 8-1 and 8-2).

Spawning seasonality

Ovarian histological data and GSI for females indicated a potential 6 month main spawning season of great barracuda around Puerto Rico although some reproductive activity is present probably year-round (Figs. 8-7 and 8-8; Tables 8-3 and 8-4). Females with gonads in stages of development 3 and 4 (mature active and ripe, respectively) were found in all months except September and January (Fig. 8-8; Table 8-4). Most females appeared to spawn for about six months as indicated by the percentage of fully developed ovaries from March to August. Maximum number of ovaries containing late vitellogenic oocytes were observed in March-April and July-August. Minimal GSI values were found from September through January. Mean GSI values start increasing during January and February and remained relatively high until August with a minimum reached in May, indicating the possibility of two spawning periods occurring within the main reproductive season (Fig. 8-7; Table 8-3). In addition, males with large testis and running milt were more common during March-August.

Discussion

Sampling, size-frequency distribution, and sex ratio

The Puerto Rico Fishing Law #278 specifically prohibits the capture/selling of barracuda because the ciguatoxic condition of its flesh. For this study, virtually all the barracudas were obtained by Fisheries Research Laboratory personnel utilizing hook and line. One aspect of the sampling worth noting is the maximum size of the fish we were able to sample during the past four years. The largest fish in our samples weighed 28 pounds (53 inches TL).   The world record for this species is 103 pounds (66 inches TL) taken in the Bahamas in 1932. The official record for Puerto Rican is 48 pounds (no length available). According to de Sylva (1963) fish weighing 45 –50 pounds represented the maximum weight reported by local tournaments in Florida at the beginning of the 1960's. Despite the cooperation of some commercial fishermen who helped us during many sampling trips, we captured only 7 individuals over 15 lbs. (two of which were over 20 lbs.). Maximum size sampled by de Sylva (1963) in Florida was 39 pounds (55.5 inches TL). The largest barracuda caught during a study performed around Puerto Rico between 1976-1978 was 19 pounds (Erdman, 1978). Apparently this species does not reach very large sizes in local waters, and/or the abundance of large (>30-40 pounds) individuals is very low. Females tended to be dominant in the larger size classes and males were more abundant in the smaller ones. Wilson and Nieland (1994) found that in the red drum (*Sciaenops ocellatus)* males outnumbered females in the smaller size classes in offshore waters, suggesting a predisposition for emigration from estuarine habitats at younger age than females which is reflected in the smaller size at maturity seen in males. While males were dominant in our samples, with a sex ratio of 1♂:0.7♀, deSylva (1963) reported a ratio of 0.1♂:1.7♀ in Florida. These results are probably explained by the fact that most of our fish were collected by trolling near offshore reefs, while Florida barracudas were caught by anglers fishing from piers in the Miami area (de Sylva, 1963). Sex ratios can vary as a result of differential growth and mortality rates and/or distribution between the sexes. Similar to our findings, Starck (1971) reported that in *Lutjanus griseus* males were generally more abundant in offshore reefs than in waters closer to shore.

Size at Maturity

Our estimated mean length at first maturity was 582 and 649 mm FL for males and females, respectively. In Florida de Sylva (1963) found that males do not mature until they reach about 460 mm FL, and most males are mature at about 500 mm FL; some females first mature at 580 mm but most do not mature until a length of 660 mm.

Williams (1965) states that in *S. barracuda* maturity is reached between 540 and 670 mm standard length. The two studies mentioned here are the only ones we found in the literature where the maturation size of *S. barracuda* was estimated. Our estimates are similar to the ones reported in these previous studies, although it should be noted that comparison between maturity estimates are very sensitive to different methodologies and data manipulation procedures, hence results should be interpreted with caution (Hunter et al., 1992). Based on our estimated mean length at first maturity and the size-frequency distributions, about 84 % of the 614 fish measured were mature, suggesting that at the present time, the species is not confronting a recruitment overfishing condition (data sources: Matos, unpublished data Fisheries Research Laboratory; Project F-42, unpublished data, and this study).

Spawning seasonality

The analyses of the monthly variation in the GSI and the monthly distribution of the gonadal development stages, together with the histological observations of the gonads, indicates that the spawning season of the great barracuda in Puerto Rico is protracted, extending mainly from March to August. Individuals with mature active and ripe gonads were found in November, December and February, suggesting that some reproductive activity probably occurs throughout the year. These results are consistent with the findings of Erdman (1978) who reported "ripe and near-ripe fish as early as February 25 and as late as September 10". Erdman (1976) mentions the presence year-round of one inch juveniles in shallow waters at La Parguera, southwestern Puerto Rico. In Florida ripe *S. barracuda* were found from mid-April to mid-October, spawning ceasing when the water temperature dropped from a mean maximum temperature of 83.8 to 77°F (de Sylva, 1963). Around Puerto Rico, open sea surface water seldom reaches as low as 77°F (Erdman, 1978). The timing and location of spawning has not been well documented, but it is believed to occur offshore (FMNH, 2007). We have some evidence supporting this idea. We collected only two females with very advance vitellogenic oocytes (probably close to hydration) during this study (March and August). Both fish were captured by trolling along the shelf edge offshore western Puerto Rico. In addition, several mature males had spermatozoa filling the efferent duct of the testes, suggesting imminent spawning, were collected in the same area between May and August.

References

Blaber, SJM. 1982. The ecology of *Sphyraena barracuda* (Osteichthyes: Perciformes) in the Kosi with notes on the Sphyraenidae of other Natal estuaries. South African Journal of Zoology. Vol.17, no.4, pp. 171-176.

de Sylva, D.P. 1963. Systematics and life history of the great barracuda, *Sphyraena barracuda* (Walbaum). University of Miami Press, Institute of Marine Science, vii, 179p.

de Sylva, D.P., 1990 Sphyraenidae. p. 860-864. In J.C. Quero, J.C. Hureau, C. Karrer, A. Post and L. Saldanha (eds.) Check-list of the fishes of the eastern tropical Atlantic

(CLOFETA). JNICT, Lisbon; SEI, Paris; and UNESCO, Paris. Vol. 2.

Erdman, D.S. 1976. Spawning patterns of fishes from the Northeast Caribbean. Puerto Rico Dept. Agric., Agric. and Fish. Contr. 8(2): 1-36.

Erdman, D.S., 1978. Commercial pelagic fishing survey around Puerto Rico. PL 88-309 as amended, Project No. 2-258-R. 166 p.

Fischer, W. (Ed). 1978. FAO species identification sheets for fishery purposes. Western Central Atlantic (fishing area 31) Vol. 5.

FLMNH, 2007. Florida Museum of Natural History, Ichthyology Department, Bioprofiles. www.flmnh.ufl.edu/fish/education/bioprofile

Hunter, J.R., J.B. Macewicz, N.C.H. Lo and C.A. Kimbrell. 1992. Fecundity, spawning and maturity of female Dover sole, *Microstomus pacificus*, with an evaluation of assumptions and precision. Fishery Bulletin 90: 101-128.

Manooch, C.S. III. 1988. Fisherman's Guide. Fishes of the Southeastern United States. North Carolina State Museum of Natural History. 362p.

Randall, J.E. 1996. Caribbean Reef Fishes. Third Edition – revised and enlarged. T.F.H. Pubs., Inc., Ltd. Hong Kong. 368 p.

Robins, C.R. and G.C. Ray, 1986 A field guide to Atlantic coast fishes of North America. Houghton Mifflin Company, Boston, U.S.A. 354 p.

Starck, W.A. 1971. Biology of the grey snapper, *Lutjanus griseus* (Linnaeus) in the Florida Keys. Studies of Tropical Oceanography 10:12-150.

Tosteson, T.R. 2004. Caribbean ciguatera: a changing paradigm. Revista de Biología Tropical 52:109-113.

Williams, F. 1965. Further notes on the biology of East African pelagic fishes of the families Carangidae and Sphyraenidae. E. Afr. Agric. For. J. 31:141-168.

Wilson, C.A and D.L. Nieland. 1994. Reproductive biology of red drum, *Sciaenops ocellatus*, from the neritic waters of the northern Gulf of Mexico. Fishery Bulletin 92:841-850.

Wilson, S.K., D.T. Wilson, C. Lamont and M. Evans. 2006. Identifying individual great barracuda *Sphyraena barracuda* using natural body marks. Journal of Fish Biology (2006) 69: 928-932.

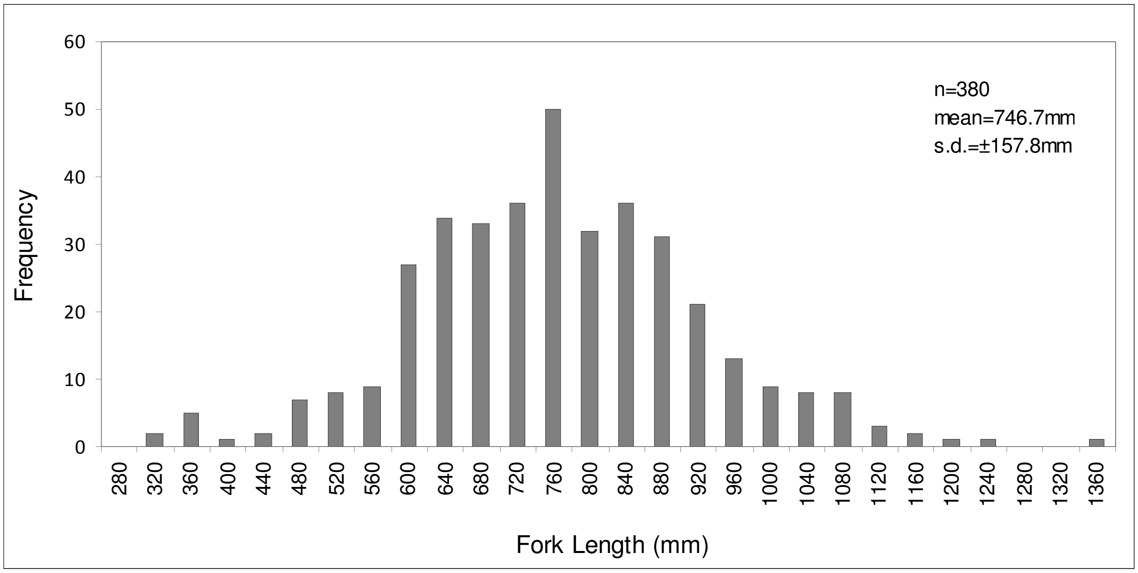


Figure 8-1. Size-frequency distribution of great barracuda (*Sphyraena barracuda*) collected between November 2003 and December 2006.

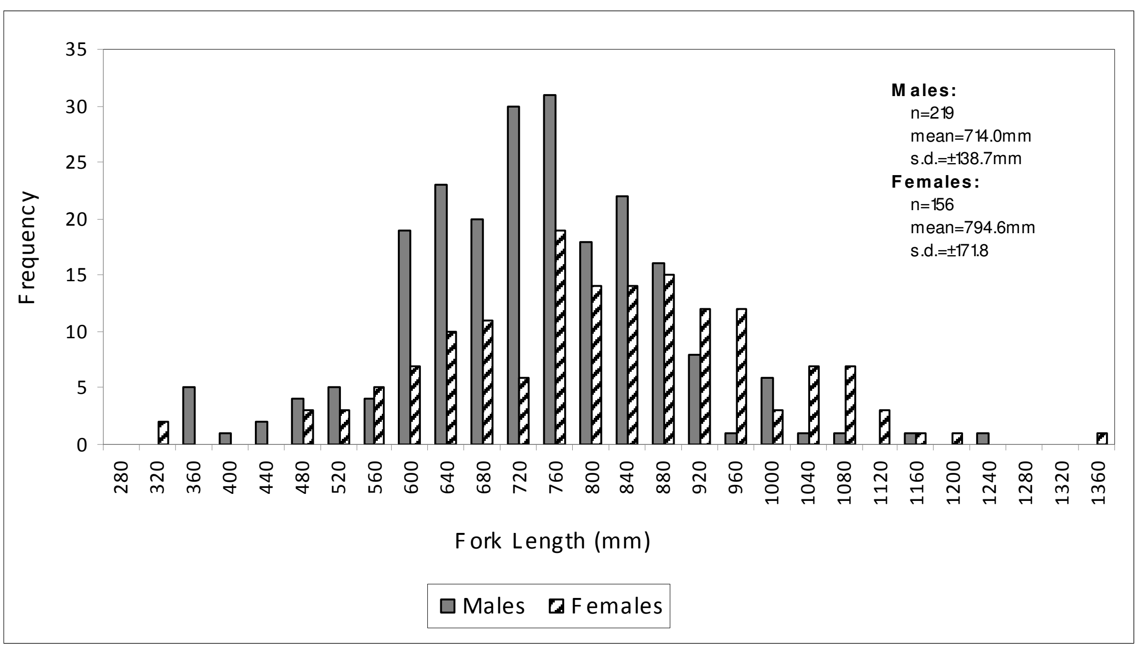


Figure 8-2. Size-frequency distribution of male and female great barracuda (*Sphyraena barracuda*) collected between November 2003 and December 2006.

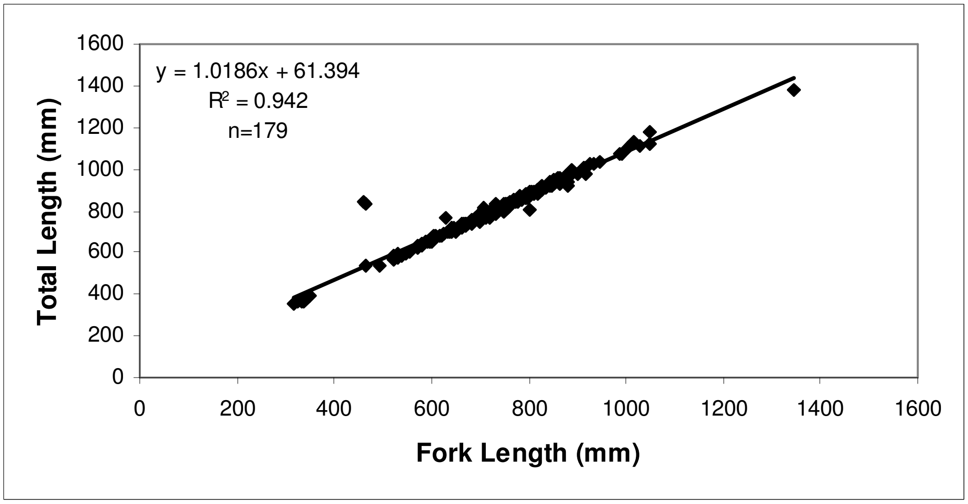


Figure 8-3. Relationship between total length and fork length for great barracuda (*Sphyraena barracuda*).

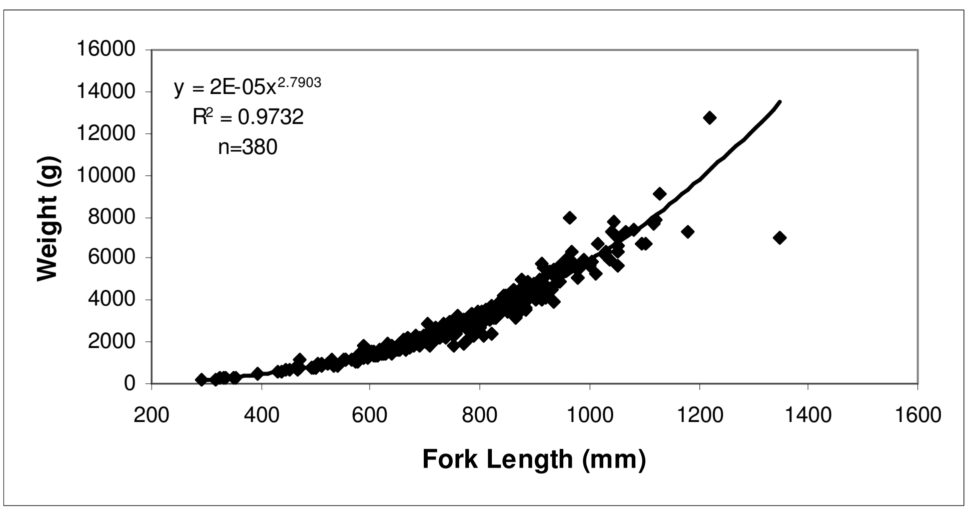


Figure 8-4. Relationship between weight and fork length for great barracuda (*Sphyraena barracuda*).

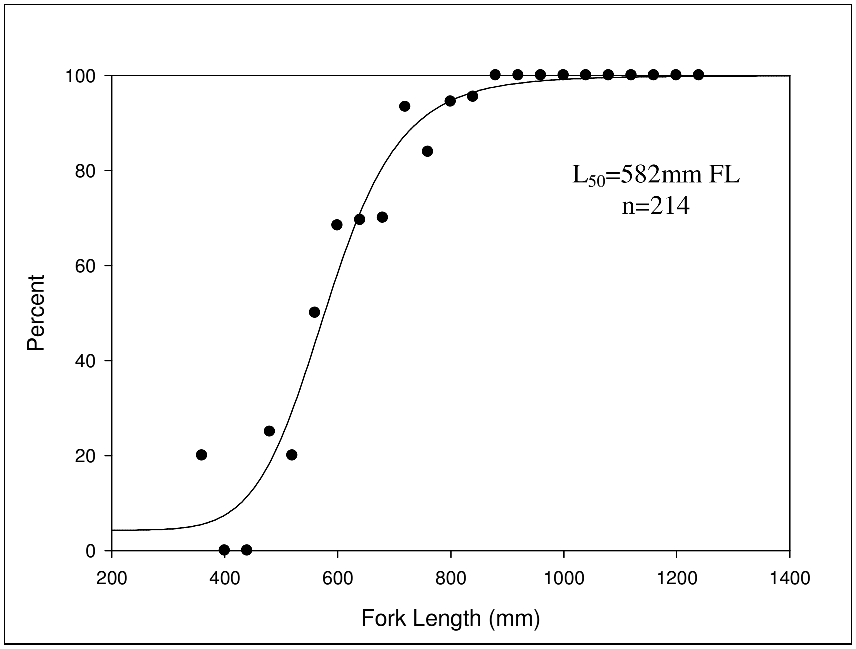


Figure 8-5. Percent of sexually mature male great barracuda (*Sphyraena barracuda*) as a function of fork length (see Appendix XIX).

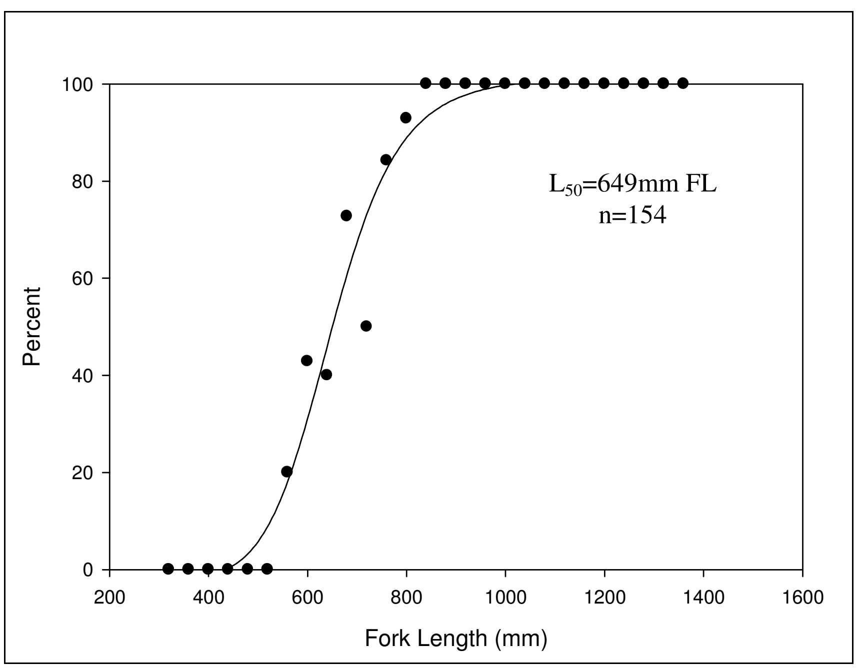


Figure 8-6. Percent of sexually mature female great barracuda (*Sphyraena barracuda*) as a function of fork length (see Appendix XX).

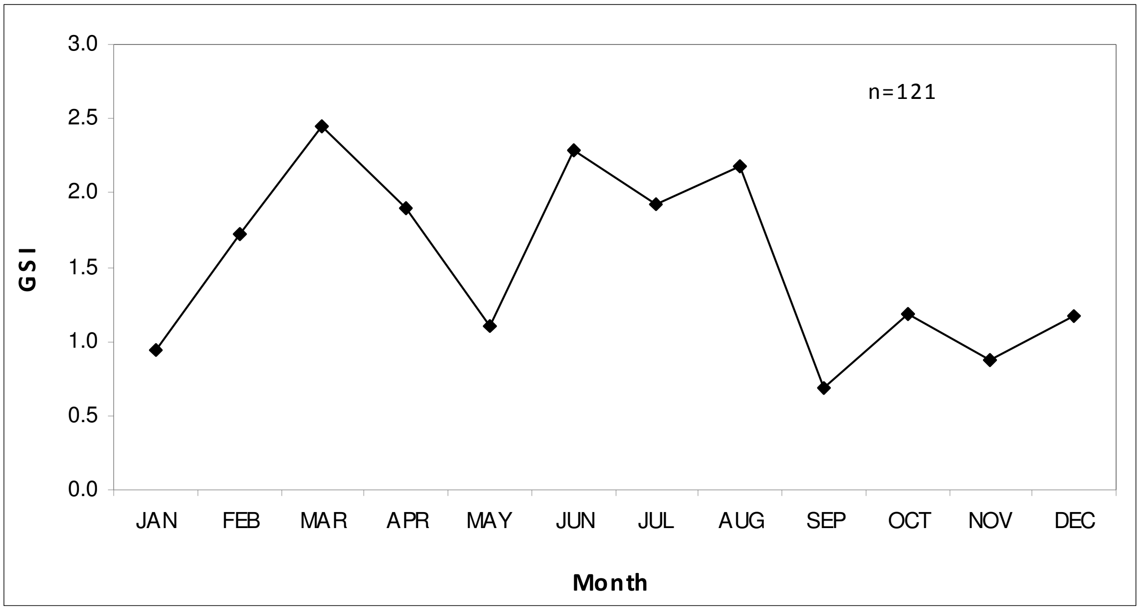


Figure 8-7. Monthly mean gonadosomatic index (GSI) for female great barracuda (*Sphyraena barracuda*).

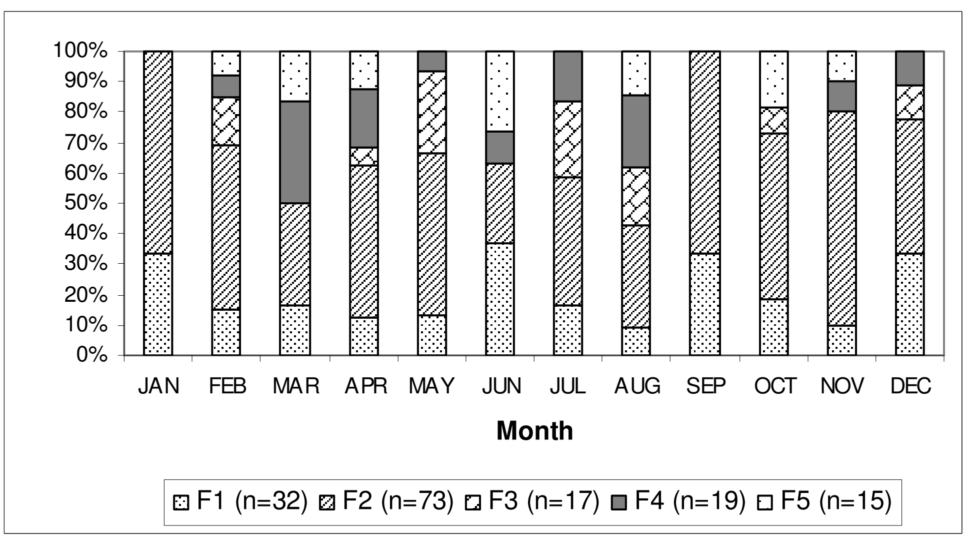


Figure 8-8. Monthly percentages of reproductive classes for female great barracuda (*Sphyraena barracuda*) (F1= Immature; F2= Inactive mature; F3= Active mature; F4= Ripe; F5= Spent).

FL (mm)	N total	N mature	% mature
360	5	1	20
400	1	0	0
440	2	0	0
480	4	1	25
520	5	1	20
560	4	2	50
600	19	13	68
640	23	16	70
680	20	14	70
720	30	28	93
760	31	26	84
800	18	17	94
840	22	21	95
880	16	16	100
920	8	8	100
960	1	1	100
1000	6	6	100
1040	1	1	100
1080	1	1	100
1120	0	0	
1160	1	1	100
1200	0	0	
1240	1	1	100
Total	214	174	

Table 8-1. Maturity schedule by size for male great barracuda (*Sphyraena barracuda*).

FL (mm)	N total	N mature	% mature
320	2	0	0
360	0	0	
400	0	0	
440	0	0	
480	3	0	0
520	3	0	0
560	5	1	20
600	7	3	43
640	10	4	40
680	11	8	73
720	6	3	50
760	19	16	84
800	14	13	93
840	14	14	100
880	15	15	100
920	12	12	100
960	12	12	100
1000	3	3	100
1040	7	7	100
1080	7	7	100
1120	3	3	100
1160	1	1	100
1200	1	1	100
1240	0	0	
1280	0	0	
1320	0	0	
1360	1	1	100
Total	154	124	

Table 8-2. Maturity schedule by size for female great barracuda (*Sphyraena barracuda*).

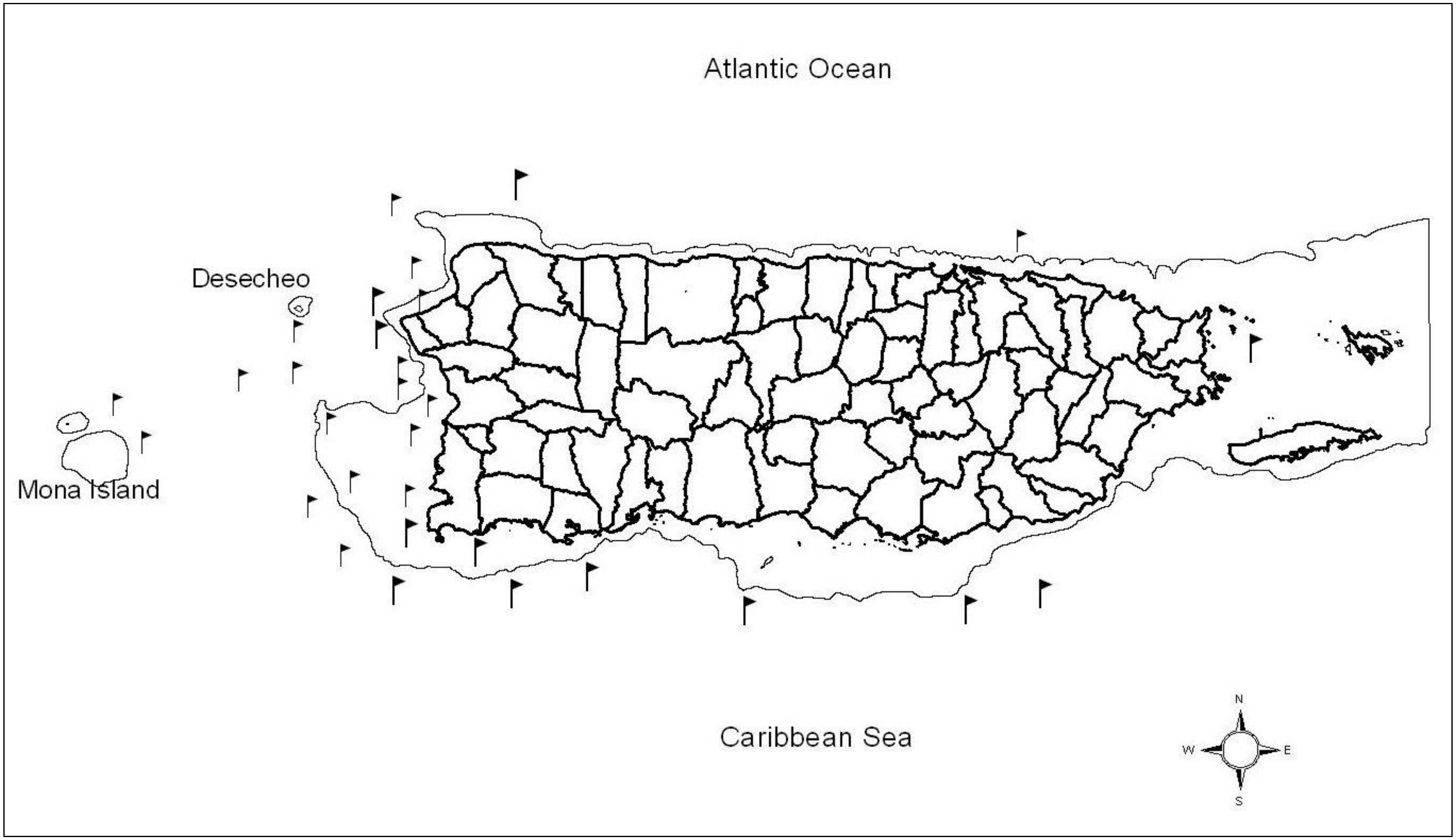
Month	GSI	N	sd
January	0.946	6	0.351
February	1.716	11	1.876
March	2.445	5	2.666
April	1.890	13	2.297
May	1.107	13	0.682
June	2.282	12	2.037
July	1.930	10	1.375
August	2.181	18	1.927
September	0.688	4	0.192
October	1.186	9	0.349
November	0.880	8	0.483
December	1.172	12	0.864
Total		121	

Table 8-3. Monthly mean gonadosomatic index (GSI) of female *Sphyraena barracuda*.

		Stage of gonad development									
		F1		**F2**		**F3**		**F4**		**F5**	
Month	**N**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
January	9	3	33.3	6	66.7	0	0	0	0	0	0
February	13	2	15.4	7	53.8	2	15.4	1	7.7	1	7.7
March	6	1	16.7	2	33.3	0	0	2	33.3	1	16.7
April	16	2	12.5	8	50.0	1	6.2	3	18.8	2	12.5
May	15	2	13.3	8	53.3	4	26.7	1	6.7	0	0
June	19	7	36.8	5	26.3	0	0	2	10.5	5	26.3
July	12	2	16.7	5	41.7	3	25.0	2	16.7	0	0
August	21	2	9.5	7	33.3	4	19.0	5	23.8	3	14.3
September	6	2	33.3	4	66.7	0	0	0	0	0	0
October	11	2	18.2	6	54.5	1	9.1	0	0	2	18.2
November	10	1	10.0	7	70.0	0	0	1	10.0	1	10.0
December	18	6	33.3	8	44.4	2	11.1	2	11.1	0	0
Total	156	32		73		17		19		15	

Table 8-4. Monthly percentages of reproductive classes for female great barracuda (*Sphyraena barracuda*) (1= Immature; 2= Inactive mature; 3= Active mature; 4= Ripe; 5= Spent).

Appendix I. Locations sampled from October 2003 to October 2007.



Appendix II. Summary of samples collected by month during the study. (October 2003 – October 2007).

Species	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Caranx hippos	5	30	1	27	40	30	22	24	34	31	18	42	304
Caranx latus	29	30	31	29	28	30	54	39	35	37	26	30	398
Caranx crysos	29	30	28	30	29	31	31	38	30	47	20	30	373
Opisthonema oglinum	80	55	45	25	35	36	35	54	36	29	30	48	508
Harengula humeralis	36	34	31	35	34	33	25	30	30	37	46	50	421
Harengula clupeola	38	35	37	35	35	60	35	41	31	75	51	42	515
Sphyraena barracuda	27	29	29	42	30	37	27	31	28	25	27	48	380
Acanthocybium solanderi	0	26	26	87	1	3	5	2	15	51	82	5	303
Total	244	269	228	310	232	260	234	265	239	332	300	295	3202
Sampling trips	46	42	43	50	37	45	24	55	44	61	40	30	525

Appendix III. Microscopic description of sexual maturation of male and female gonads.

Stage of maturation	Microscopic descriptions
Ovaries:	
F1 (Immature)	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, post-ovulatory follicles and atretic bodies present.
F2 (Inactive mature)	Oocytes in stages 1, 2, and 3 present, but stages 3 do not predominate. Oocytes in stage 4 absent or very few. Thin tunica, except in spent individuals.
F3 (active mature)	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.
F4 (ripe)	Oocytes in stages 2, 3, 4, and rarely 5 present. Advanced stages predominate. Thin tunica, except in spent individuals.
F5 (spent)	Post-ovulatory follicles and atretic bodies present. Thick tunica. Ovary with empty areas.
Testes:	
M1 (inactive)	Early stages of spermatogenesis, gonad small and compact with gonia and seminiferous tubules.
M2 (active)	All stages of spermatogenesis are equal, or later stages dominate. Post-spawning testes are disorganized with empty lumina.

.

Appendix IV. Summary of the data collected and analyzed from October 2003 to October 2007. All size measurements are in fork length (mm); all weight measurements are in grams.

Species	*A. solanderi*	*H. humeralis*	*H. clupeola*	*O. oglinum*	*C. hippos*	*C. latus*	*C. crysos*	*S. barracuda*
Total sample size range	670-1727	85-157	26-134	74-227	158-837	55-742	162-660	290-1347
Size range ♀	670-1727	86-157	50-134	93-227	186-827	257-742	162-660	290-1347
Size range ♂	680-1520	85-148	54-126	92-210	158-837	148-660	184-519	326-1220
Mature♀ minimum size	784	92	73	106	305	276	200	532
Mature ♂ minimum size	680	90	77	113	295	255	205	352
Mature 50% ♀	896	96	85	119	342	334	257	649
Mature 50% ♂	918	93	74	132	280	325	232	582
Total sample weight range	867-32931	10-65	0.18-38	5-190	98-11340	3.4-7428	78-3175	209-12712
Weight range ♀	867-32931	10-65	2-38	11-190	138-17443	371-7428	86-3175	209-9080
Weight range ♂	1831-21546	10-56	2-33	9-190	96-9534	69-4649	119-2497	242-12712
Reproductive activity	May-Sep*	Year round	Year round	Apr-Sep	Apr-Nov	Year round	Mar-Oct	Year round
Peak reproductive activity	June*	Jan-Aug	Mar-Sep	Jun-Jul*	May-Jul	Apr; Aug*	May-Jun	Mar-Aug
GSI peak	June	May	Apr-May	Apr-Sep	July	Apr; Aug	Jun-Aug	Mar; Jun-Aug
% individuals captured below maturity size	50%	2%	24%	29%	7%	49%	8%	16%

*Not enough data.

Appendix V. Summary statistics of the size at maturity analysis for male wahoo (*Acanthocybium solandri*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9465	0.8959	0.8736	12.6387

	Coefficient	Std. Error	t	P	VIF
min	19.0790	7.0154	2.7196	0.0166	1.3561
max	98.1689	3.7773	25.9890	<0.0001	1.1287
EC50	918.0840	15.4286	59.5055	<0.0001	1.2707
Hillslope	-38.1299	20.1556	-1.8918	0.0794	1.2035

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	125176.8706	31294.2177
Residual	14	2236.3152	159.7368
Total	18	127413.1858	7078.5103

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	19246.1703	6415.3901	40.1623	<0.0001
Residual	14	2236.3152	159.7368		
Total	17	21482.4855	1263.6756		

Statistical Tests:

PRESS 5670.6665

Durbin-Watson Statistic 1.9765 Passed

Normality Test Passed (P = 0.0863)

K-S Statistic = 0.2856 Significance Level = 0.0863

Constant Variance Test Failed (P = <0.0001)

Power of performed test with alpha = 0.0500: 1.0000

Appendix VI. Summary statistics of the size at maturity analysis for female wahoo (*Acanthocybium solandri*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.8856	0.7843	0.7483	17.6049

	Coefficient	Std. Error	t	P	VIF
min	0.0000	(NAN)	(-inf)	<0.0001	0.0000
max	102.2223	(NAN)	(+inf)	<0.0001	0.0000
EC50	896.2149	(NAN)	(+inf)	<0.0001	0.0000
Hillslope	-9.4801	(NAN)	(-inf)	<0.0001	0.0000

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	160165.9663	40041.4916
Residual	18	5578.7810	309.9323
Total	22	165744.7472	7533.8521

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	20280.9266	6760.3089	21.8122	<0.0001
Residual	18	5578.7810	309.9323		
Total	21	25859.7076	1231.4146		

Statistical Tests:

PRESS (NAN)

Durbin-Watson Statistic 2.2871 Passed

Normality Test Passed (P = 0.1962)

K-S Statistic = 0.2229 Significance Level = 0.1962

Constant Variance Test Failed (P = <0.0001)

Power of performed test with alpha = 0.0500: 1.0000

Appendix VII. Summary of the size at maturity analysis for male red-ear sardine (*Harengula humeralis*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.8828	0.7793	0.7241	14.7716

	Coefficient	Std. Error	t	P	VIF
min	0.0000	(NAN)	(-inf)	<0.0001	0.0000
max	101.4170	(NAN)	(+inf)	<0.0001	0.0000
EC50	93.2962	(NAN)	(+inf)	<0.0001	0.0000
Hillslope	-11.3273	(NAN)	(-inf)	<0.0001	0.0000

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	122524.6036	30631.1509
Residual	12	2618.3886	218.1991
Total	16	125142.9922	7821.4370

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	9243.5802	3081.1934	14.1210	0.0003
Residual	12	2618.3886	218.1991		
Total	15	11861.9689	790.7979		

Statistical Tests:

PRESS (NAN)

Durbin-Watson Statistic 2.1629 Passed

Normality Test Passed (P = 0.1440)

K-S Statistic = 0.2765 Significance Level = 0.1440

Constant Variance Test Failed (P = 0.0013)

Power of performed test with alpha = 0.0500: 0.9988

Appendix VIII. Summary statistics of the size at maturity analysis for female red-ear sardine (*Harengula humeralis*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	**Rsqr**	**Adj Rsqr**	**Standard Error of Estimate**
0.8707	0.7581	0.6977	19.6218

	Coefficient	**Std. Error**	**t**	**P**	**VIF**
min	0.0000	(NAN)	(-inf)	<0.0001	0.0000
max	99.9760	(NAN)	(+inf)	<0.0001	0.0000
EC50	95.6157	(NAN)	(+inf)	<0.0001	0.0000
Hillslope	-17.4796	(NAN)	(-inf)	<0.0001	0.0000

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	**SS**	**MS**
Regression	4	121660.9958	30415.2489
Residual	12	4620.1834	385.0153
Total	16	126281.1791	7892.5737

Corrected for the mean of the observations:

	DF	**SS**	**MS**	**F**	**P**
Regression	3	14482.7078	4827.5693	12.5386	0.0005
Residual	12	4620.1834	385.0153		
Total	15	19102.8912	1273.5261		

Statistical Tests:

PRESS (NAN)

Durbin-Watson Statistic 2.8759 Failed

Normality Test Passed (P = 0.1145)

K-S Statistic = 0.2883 Significance Level = 0.1145

Constant Variance Test Failed (P = <0.0001)

Power of performed test with alpha = 0.0500: 0.9979

Appendix IX. Summary statistics of the size at maturity analysis for male false pilchard (*Harengula clupeola*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9257	0.8570	0.8180	16.9658

	Coefficient	Std. Error	t	P	VIF
min	-0.0011	11.9943	-9.1480E-005	0.9999	1.5051
max	89.5086	5.1157	17.4969	<0.0001	1.0727
EC50	74.1172	478.5495	0.1549	0.8797	338509.6243<
Hillslope	-179.8826	98088.9797	-0.0018	0.9986	338462.5191<

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	94529.5468	23632.3867
Residual	11	3166.2264	287.8388
Total	15	97695.7732	6513.0515

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	18972.2109	6324.0703	21.9709	<0.0001
Residual	11	3166.2264	287.8388		
Total	14	22138.4373	1581.3169		

Statistical Tests:

PRESS 1.7462E+012

Durbin-Watson Statistic 0.7922 Failed

Normality Test Passed (P = 0.1089)

K-S Statistic = 0.2999 Significance Level = 0.1089

Constant Variance Test Failed (P = 0.0192)

Power of performed test with alpha = 0.0500: 0.9999

Appendix X. Summary statistics of the size at maturity analysis for female false pilchard (*Harengula clupeola*).

Nonlinear Regression

Data Source: Data 1 in HC females 2
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9430	0.8892	0.8523	11.6104

	Coefficient	Std. Error	t	P	VIF
min	0.0000	(NAN)	(-inf)	<0.0001	0.0000
max	101.7657	(NAN)	(+inf)	<0.0001	0.0000
EC50	85.0011	(NAN)	(+inf)	<0.0001	0.0000
Hillslope	-10.7319	(NAN)	(-inf)	<0.0001	0.0000

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	89726.1048	22431.5262
Residual	9	1213.2094	134.8010
Total	13	90939.3142	6995.3319

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	9740.7638	3246.9213	24.0868	0.0001
Residual	9	1213.2094	134.8010		
Total	12	10953.9732	912.8311		

Statistical Tests:

PRESS (NAN)

Durbin-Watson Statistic 1.7946 Passed

Normality Test Passed (P = 0.4602)

K-S Statistic = 0.2272 Significance Level = 0.4602

Constant Variance Test Failed (P = <0.0001)

Power of performed test with alpha = 0.0500: 0.9999

Appendix XI. Summary statistics of the size at maturity analysis for male thread herring (*Opisthonema oglinum*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9972	0.9945	0.9924	3.7064

	Coefficient	Std. Error	t	P	VIF
min	1.5963	2.7428	0.5820	0.5766	1.7445
max	100.9271	1.5363	65.6949	<0.0001	1.3165
EC50	132.2015	0.8597	153.7777	<0.0001	1.5492
Hillslope	-23.0352	2.9999	-7.6786	<0.0001	1.4892

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	78249.4750	19562.3687
Residual	8	109.9000	13.7375
Total	12	78359.3750	6529.9479

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	19798.9541	6599.6514	480.4112	<0.0001
Residual	8	109.9000	13.7375		
Total	11	19908.8542	1809.8958		

Statistical Tests:

PRESS 551.5453

Durbin-Watson Statistic 2.7935 Failed

Normality Test Passed (P = 0.4122)

K-S Statistic = 0.2451 Significance Level = 0.4122

Constant Variance Test Failed (P = 0.0285)

Power of performed test with alpha = 0.0500: 1.0000

Appendix XII. Summary statistics of the size at maturity analysis for female thread herring (*Opisthonema oglinum*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	**Rsqr**	**Adj Rsqr**	**Standard Error of Estimate**
0.9972	0.9945	0.9924	3.7064

	Coefficient	**Std. Error**	**t**	**P**	**VIF**
min	1.5963	2.7428	0.5820	0.5766	1.7445
max	100.9271	1.5363	65.6949	<0.0001	1.3165
EC50	132.2015	0.8597	153.7777	<0.0001	1.5492
Hillslope	-23.0352	2.9999	-7.6786	<0.0001	1.4892

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	**SS**	**MS**
Regression	4	78249.4750	19562.3687
Residual	8	109.9000	13.7375
Total	12	78359.3750	6529.9479

Corrected for the mean of the observations:

	DF	**SS**	**MS**	**F**	**P**
Regression	3	19798.9541	6599.6514	480.4112	<0.0001
Residual	8	109.9000	13.7375		
Total	11	19908.8542	1809.8958		

Statistical Tests:

PRESS 551.5453

Durbin-Watson Statistic 2.7935 Failed

Normality Test Passed (P = 0.4122)

K-S Statistic = 0.2451 Significance Level = 0.4122

Constant Variance Test Failed (P = 0.0285)

Power of performed test with alpha = 0.0500: 1.0000

Appendix XIII. Summary statistics of the size at maturity analysis for crevalle jack (*Caranx hippos*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9967	0.9934	0.9924	3.5914

	Coefficient	Std. Error	t	P	VIF
min	8.0477E-006	1.7924	4.4899E-006	1.0000	1.2559
max	98.7697	0.8306	118.9108	<0.0001	1.0163
EC50	279.8868131357	31.6648	2.1307E-005	1.0000	33665768.7858<
Hillslope	-309.7754404261	120.3201	-7.6628E-007	1.0000	33666237.8788<

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	185353.4367	46338.3592
Residual	20	257.9649	12.8982
Total	24	185611.4016	7733.8084

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	38615.2993	12871.7664	997.9472	<0.0001
Residual	20	257.9649	12.8982		
Total	23	38873.2642	1690.1419		

Statistical Tests:

PRESS 37426492960.8548

Durbin-Watson Statistic 2.2289 Passed

Normality Test Failed (P = 0.0003)

K-S Statistic = 0.4165 Significance Level = 0.0003

Constant Variance Test Failed (P = 0.0441)

Power of performed test with alpha = 0.0500: 1.0000

Appendix XIV. Summary statistics of the size at maturity analysis for female crevalle jack (*Caranx hippos*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9963	0.9925	0.9913	3.7423

	Coefficient	Std. Error	t	P	VIF
min	-1.4788	2.1854	-0.6767	0.5072	1.4836
max	100.4107	0.9858	101.8615	<0.0001	1.1384
EC50	342.4856	2.4767	138.2825	<0.0001	1.3624
Hillslope	-18.4786	2.0831	-8.8708	<0.0001	1.2736

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	165254.1630	41313.5407
Residual	18	252.0870	14.0048
Total	22	165506.2500	7523.0114

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	33503.8789	11167.9596	797.4360	<0.0001
Residual	18	252.0870	14.0048		
Total	21	33755.9659	1607.4269		

Statistical Tests:

PRESS 1576.2849

Durbin-Watson Statistic 3.3238 Failed

Normality Test Failed (P = 0.0044)

K-S Statistic = 0.3619 Significance Level = 0.0044

Constant Variance Test Passed (P = 0.4028)

Power of performed test with alpha = 0.0500: 1.0000

Appendix XV. Summary statistics of the size at maturity analysis for male horse-eye jack (*Caranx latus*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9935	0.9870	0.9854	5.3122

	Coefficient	Std. Error	t	P	VIF
min	-0.0547	2.2594	-0.0242	0.9809	1.5431
max	100.5893	1.6172	62.1979	<0.0001	1.4532
EC50	324.6373	3.7198	87.2727	<0.0001	1.5075
Hillslope	-11.7691	1.3774	-8.5447	<0.0001	1.4822

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	158630.8295	39657.7074
Residual	23	649.0449	28.2193
Total	27	159279.8745	5899.2546

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	49448.0550	16482.6850	584.0917	<0.0001
Residual	23	649.0449	28.2193		
Total	26	50097.0999	1926.8115		

Statistical Tests:

PRESS 1099.6455

Durbin-Watson Statistic 3.2522 Failed

Normality Test Failed (P = 0.0269)

K-S Statistic = 0.2751 Significance Level = 0.0269

Constant Variance Test Passed (P = 0.6506)

Power of performed test with alpha = 0.0500: 1.0000

Appendix XVI. Summary statistics of the size at maturity analysis for female horse-eye jack (*Caranx latus*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9935	0.9870	0.9852	4.0374

	Coefficient	Std. Error	t	P	VIF
min	1.9162	2.7958	0.6854	0.5003	1.7270
max	98.5548	0.9216	106.9382	<0.0001	1.1013
EC50	333.8686	1.9826	168.3993	<0.0001	1.4879
Hillslope	-26.5032	3.4931	-7.5874	<0.0001	1.3638

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	205548.5620	51387.1405
Residual	22	358.6135	16.3006
Total	26	205907.1755	7919.5067

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	27200.8067	9066.9356	556.2328	<0.0001
Residual	22	358.6135	16.3006		
Total	25	27559.4202	1102.3768		

Statistical Tests:

PRESS 662.1394

Durbin-Watson Statistic 2.1944 Passed

Normality Test Failed (P = 0.0007)

K-S Statistic = 0.3794 Significance Level = 0.0007

Constant Variance Test Failed (P = <0.0001)

Power of performed test with alpha = 0.0500: 1.0000

Appendix XVII. Summary statistics of the size at maturity analysis for male blue runner (*Caranx crysos*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9928	0.9856	0.9825	4.7252

	Coefficient	Std. Error	t	P	VIF
min	-1.0394	3.5857	-0.2899	0.7762	1.5710
max	97.6086	1.2884	75.7620	<0.0001	1.0799
EC50	231.6257	1.8266	126.8083	<0.0001	1.4373
Hillslope	-30.6071	5.1814	-5.9071	<0.0001	1.3026

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	138323.9272	34580.9818
Residual	14	312.5872	22.3277
Total	18	138636.5144	7702.0286

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	21350.1181	7116.7060	318.7395	<0.0001
Residual	14	312.5872	22.3277		
Total	17	21662.7054	1274.2768		

Statistical Tests:

PRESS 2820.1563

Durbin-Watson Statistic 0.7050 Failed

Normality Test Failed (P = 0.0463)

K-S Statistic = 0.3127 Significance Level = 0.0463

Constant Variance Test Passed (P = 0.5464)

Power of performed test with alpha = 0.0500: 1.0000

Appendix XVIII. Summary statistics of the size at maturity analysis for female blue runner (*Caranx crysos*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9931	0.9863	0.9844	4.5836

	Coefficient	Std. Error	t	P	VIF
min	4.3843	2.5278	1.7344	0.0968	1.4552
max	99.8563	1.0826	92.2349	<0.0001	1.1123
EC50	257.4316	2.1637	118.9792	<0.0001	1.3343
Hillslope	-20.2426	2.9441	-6.8756	<0.0001	1.2549

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	199460.1261	49865.0315
Residual	22	462.2163	21.0098
Total	26	199922.3424	7689.3209

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	33302.8628	11100.9543	528.3695	<0.0001
Residual	22	462.2163	21.0098		
Total	25	33765.0791	1350.6032		

Statistical Tests:

PRESS 1451.7757

Durbin-Watson Statistic 3.3830 Failed

Normality Test Failed (P = 0.0065)

K-S Statistic = 0.3229 Significance Level = 0.0065

Constant Variance Test Failed (P = <0.0001)

Power of performed test with alpha = 0.0500: 1.0000

Appendix XIX. Summary statistics of the size at maturity analysis for male great barracuda (*Sphyraena barracuda*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9838	0.9678	0.9627	6.8780

	Coefficient	Std. Error	t	P	VIF
min	4.3060	5.5181	0.7803	0.4448	3.0355
max	99.9387	2.3636	42.2831	<0.0001	1.7702
EC50	582.3269	14.0787	41.3622	<0.0001	2.4782
Hillslope	-8.9672	1.6458	-5.4486	<0.0001	2.3337

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	4	151223.7079	37805.9270
Residual	19	898.8257	47.3066
Total	23	152122.5336	6614.0232

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	3	27032.2851	9010.7617	190.4757	<0.0001
Residual	19	898.8257	47.3066		
Total	22	27931.1108	1269.5959		

Statistical Tests:

PRESS 1936.1482

Durbin-Watson Statistic 2.3378 Passed

Normality Test Passed (P = 0.4095)

K-S Statistic = 0.1798 Significance Level = 0.4095

Constant Variance Test Failed (P = <0.0001)

Power of performed test with alpha = 0.0500: 1.0000

Appendix XX. Summary statistics of the size at maturity analysis for female great barracuda (*Sphyraena barracuda*).

Nonlinear Regression

Data Source: Data 1 in Notebook1
Equation: Standard Curves, Four Parameter Logistic Curve
f1=min + (max-min)/(1 + abs(x/EC50)^Hillslope)
f2=min + (max-min)*(abs(x/EC50)^abs(Hillslope))/(1 + (abs(x/EC50)^abs(Hillslope)))
f = if(x<=0, if(Hillslope>0,max,min), if(Hillslope>0, f1, f2))

R	**Rsqr**	**Adj Rsqr**	**Standard Error of Estimate**
0.9887	0.9775	0.9745	6.7850

	Coefficient	**Std. Error**	**t**	**P**	**VIF**
min	-2.2419	3.5077	-0.6391	0.5290	1.9487
max	101.4050	2.1706	46.7172	<0.0001	1.6625
EC50	649.1198	11.1854	58.0330	<0.0001	1.7966
Hillslope	-9.5188	1.3625	-6.9864	<0.0001	1.7971

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	**SS**	**MS**
Regression	4	166281.0335	41570.2584
Residual	23	1058.8191	46.0356
Total	27	167339.8526	6197.7723

Corrected for the mean of the observations:

	DF	**SS**	**MS**	**F**	**P**
Regression	3	45927.1617	15309.0539	332.5481	<0.0001
Residual	23	1058.8191	46.0356		
Total	26	46985.9808	1807.1531		

Statistical Tests:

PRESS 1778.0567

Durbin-Watson Statistic 2.6317 Failed

Normality Test Failed (P = 0.0312)

K-S Statistic = 0.2703 Significance Level = 0.0312

Constant Variance Test Failed (P = 0.0387)

Power of performed test with alpha = 0.0500: 1.0000