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Biological Research in Support of Swordfish Stock Assessment[1]

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BIOLOGICAL RESEARCH IN SUPPORT OF SWORDFISH STOCK ASSESSMENT

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Biological data for swordfish (Xiphias gladius) have been developed on the following topics of direct relevance to the January 1999 stock assessment for the Interim Scientific Committee: length-weight relationships; sex-specific body size (length) at sexual maturity; sex ratio and size composition; sex-specific size-at-age relationships; and genetics and movements (tag-recaptures) related to stock structure. Swordfish genetics has been evaluated by academic institutions using body tissue samples provided by the National Marine Fisheries Service (NMFS), Honolulu Laboratory, and other, including international agencies. The first four topics have been subjects of intensive study at the Honolulu Laboratory since 1994. Conventional tag-recapture studies have been initiated by the NMFS, Honolulu Laboratory. This white paper summarizes major findings to date for each of the five topics.

Length-weight relationships. Swordfish caught by the Hawaii-based longline fishery, like swordfish in fisheries elsewhere, are marketed in several dressed conditions (with versus without caudal peduncle versus in the round) that vary with fish size. Several different metrics have been used to describe body length of swordfish in Pacific (eye-to-fork length, EFL, versus cleithrum-to-keel length, CKL) and Atlantic fisheries (lower jaw-to-fork length, LJFL). The likely dynamic nature of length-weight relationships and the frequent use of alternative length and weight metrics has required the development of conversion factors using data collected in all seasons of multiple years. A pending NMFS Technical Memorandum (Uchiyama et al., in prep.) describes various length-length, length-weight, and weight-weight relationships for swordfish in the central North Pacific using fish caught on research and commercial longline cruises.

The body condition (weight-at-length) of swordfish in the central North Pacific varied among-months during 1994-97, with condition peaking about 15% higher in February (just prior to the start of its March-July spawning season in the central North Pacific) than in August-September (nadir in condition following spawning). Sexual differences in weight-at-length have been relatively minor--males average 2-3% heavier-at-length than females. Fig. 1 illustrates key length-weight relations (spanning round through fully dressed weights) as an example.

Body size at sexual maturity. Observers aboard Hawaii-based longline fishing vessels have been identifying the sex of swordfish based on macroscopic appearance of gonads revealed while fish are dressed at sea. Sexual identity has been confirmed (<1% error rate) and gonadal maturation state classified by histological tissue staining for over 1,300 fish caught during March 1994 - June 1997. Estimated body size (eye-to-fork length, EFL) at median (50%) sexual maturity differs appreciably between male and female swordfish in the central North Pacific (males: 102 ± 3(95% CI) cm EFL; females: 144 ± 3 cm EFL; Fig. 2). Patterns of sexual difference in size-at-maturity of central North Pacific swordfish are similar to those described by Taylor and Murphy (1992) for swordfish in the Straits of Florida and western Atlantic.

Sex ratio and size composition. The sex and size composition of swordfish caught by the Hawaii-based longline fishery has been examined for >6,500 fish sampled by observers-at-sea during March 1994 - June 1997. The sex ratio of catches during this period has varied with the body size of swordfish caught: fish less than 140 cm EFL have been predominantly (0.55) male, fish greater than 150 cm EFL have been mostly (0.64) female, and catches of each sex have been equal for fish between 140 and 150 cm EFL (Fig. 3). The proportion of female to total swordfish in fact can be adequately (r^2 = 0.87, P<0.001) predicted using length data partitioned into 5-cm classes (Fig. 4). The central North Pacific relationship resembles that described by Scott and Porter (1997, Fig. 2b) for swordfish in the North Atlantic. The relationship between sex ratio and body length class for swordfish catches in the central North Pacific appears to be sufficiently precise to warrant its use to estimate the magnitude of landings by sex, based on size composition, in a later-generation, age-structured stock assessment.

Size-at-age relations. Size-age relations of swordfish in the central North Pacific have been evaluated at the NMFS, Honolulu Laboratory, since 1991 using otoliths (sagittae) and anal fin rays; since 1994, otoliths and fin rays have been matched (within fish) whenever possible. Size-at-age studies are described and a preliminary estimate of size-at-age is provided by Uchiyama et al. (in press). To date, nearly 300 otoliths and more than 1,200 second rays of first anal fins have been sectioned and read by one or more readers. In addition, daily growth increments (DGIs) have been successfully examined using scanning electron microscopy of the etched rostral surfaces of sagittae for about three dozen fish of sizes spanning those of young-of-year (YOY) through age-1+ fish.

The rate of growth of YOY-yearling swordfish in the central North Pacific is well described by DGIs on sagittae and compares favorably with analogous, but incomplete data for swordfish in the Mediterranean and western Atlantic (Fig. 5). Early growth characterized by otolith DGIs further agrees with early growth described using fin ray cross-sections (Fig. 6): size-at-age 1 based on otolith DGIs (98 ± 5[95% CI] cm EFL compares favorably with estimated size-at-age 1 based on fin ray cross-sections (95 ± 3 cm EFL). Body size increases exhibited by three, tagged yearling-sized fish, recaptured after periods at liberty of 1, 2 and 4 years, provide further incomplete validation of growth (Fig. 6). The results of an evaluation of the ages of very large (>200 cm EFL) swordfish using bomb carbon dating (Kalish et al., in prep.) have been equivocal because swordfish apparently do not live long enough (i.e., >30 years) for foolproof application of the method. Validation of the ages of larger swordfish will require growth-at-liberty data for fishery-sized fish (presently being tagged in the Hawaii-based longline fishery).

As described by Ehrhardt et al., (1995) and others for swordfish in the Atlantic, female swordfish in the central North Pacific initially grow faster and live longer than males. Size-at-age for fishery-sized swordfish in the central North Pacific is better described by a generalized growth function (see Ehrhardt et al. 1995) which allows for growth allometries, in contrast to a von Bertalanffy model with constant growth coefficient (Fig. 7). When size-at-maturity and size-at-age are cross-referenced, the resulting estimate of age at median sexual maturity of males (1+) is considerably less than the present tentative estimate for females (about 4 or 4+). These estimates are comparable to those of Taylor and Murphy (1992) for Atlantic swordfish.

Genetic evidence of stock structure. It is now well recognized that the circumglobal species *Xiphias gladius* consists of separate stocks in the Mediterranean, Atlantic, and Pacific (Alvarado-Bremer et al. 1996; Rosel and Block 1996; Chow et al. 1997; Reeb and Block 1997). Stock structuring within the Pacific is suggestive but as yet unresolved: swordfish caught off the Californias apparently comprise a mix of fish whose centers of distribution occur off of the western coast of South America and in the central-western North Pacific (Reeb et al. 1998). For swordfish in the Pacific, recent common ancestry, population expansion, and population overlap, combined with high levels of variability in slowly evolving haploid mtDNA require the additional use of diploid nuclear DNAs like microsatellites to evaluate stock mixing (Chow et al. 1997; Reeb et al. 1998). Chow and Takeyama (1998) recently describe the latest application of nuclear DNA technology for resolving stock structure issues for species like swordfish.

Tag-recapture studies. In 1990 the Honolulu Laboratory began encouraging the Hawaii based commercial longline fleet to voluntarily tag and release swordfish. Over 500 swordfish have since been tagged with 5 recaptures. In addition to their utility in growth studies (above) the recaptures suggest some movement of fish from the fishing grounds north of Hawaii towards the west coast of North America. Interestingly, the three fish that were recaptured at the same time of year as they were released were recaptured near the point of release. In contrast, the two recaptures that showed larger movements towards the west coast were recaptured at a different time of year, consistent with a hypothesis of cyclic seasonal migration.

Geoposition archiving tags can record daily positions from the point of release to recapture, not just start and end point data as provided by conventional tags and the first generation of pop-up satellite transmitting tags. The latter need not be recaptured since their position is determined by satellite when they pop-up. However, first generation pop-up tags do not provide a history of daily positions. Pop-up, geoposition archiving, satellite transmitting tags now under development will upload a history of daily positions when they pop up. Such tags will be the best means of determining the true migration patterns and stock structure of swordfish. The Honolulu Laboratory in cooperation with JIMAR and CSIRO are planning to deploy such tags on swordfish in 1999. Meanwhile, the Lab is deploying archival tags without the pop-up feature on bigeye tuna (which have five times the recapture rate of swordfish) to test the abilities of various position estimation algorithms on fish that descend very deep to avoid daylight. Most current archival tag geoposition algorithms are based on light measurement. However the Lab's analysis of archival tag data from a recaptured bigeye tuna suggests that in some circumstances, crepuscular dive behavior can be used to estimate latitude and longitude without light data.

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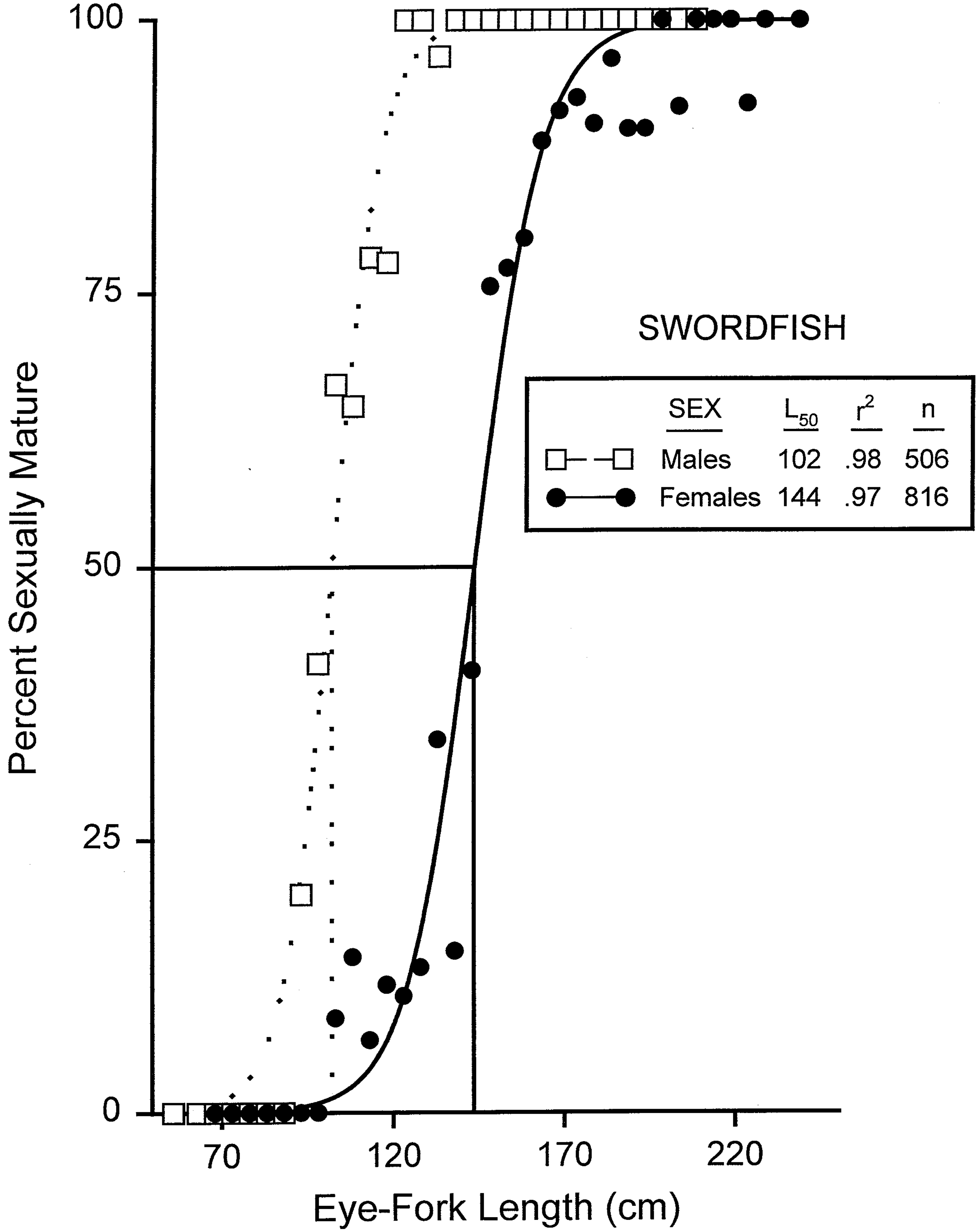
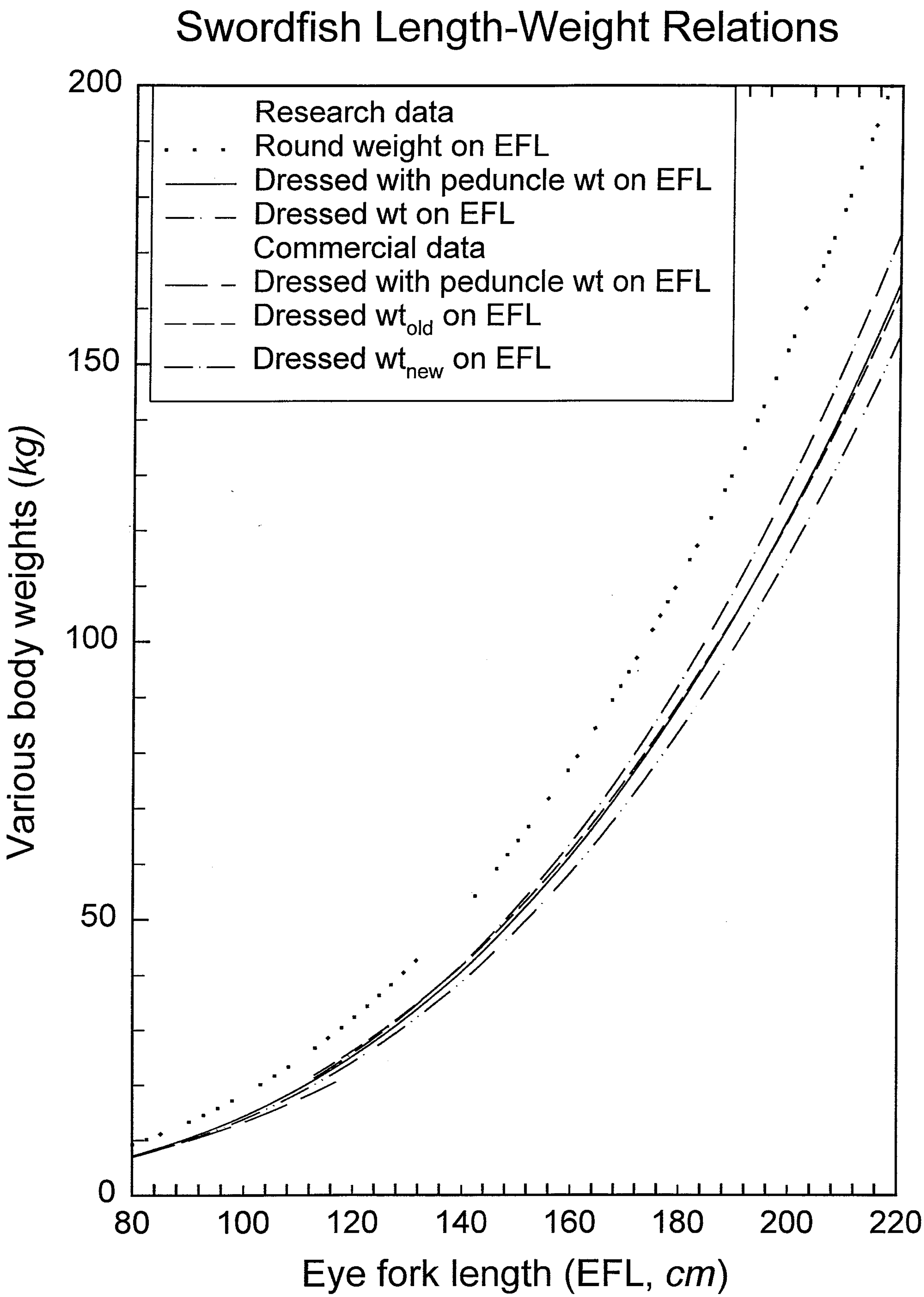
Fig. 2



SWORDFISH
SEX L50 r2 n
Males 102 .98 506
Females 144 .97 816
Percent Sexually Mature
100
75
50
25
0
70
120
170
220
Eye-Fork Length (cm)

Fig. 1



Swordfish Length-Weight Relations
Research data
Round weight on EFL
Dressed with peduncle wt on EFL
Dressed wt on EFL
Commercial data
Dressed with peduncle wt on EFL
Dressed wt$_{old}$ on EFL
Dressed wt$_{new}$ on EFL
Various body weights (*kg*)
0
50
100
150
200
80
100
120
140
160
180
200
220
Eye fork length (EFL, *cm*)

FIG. 3

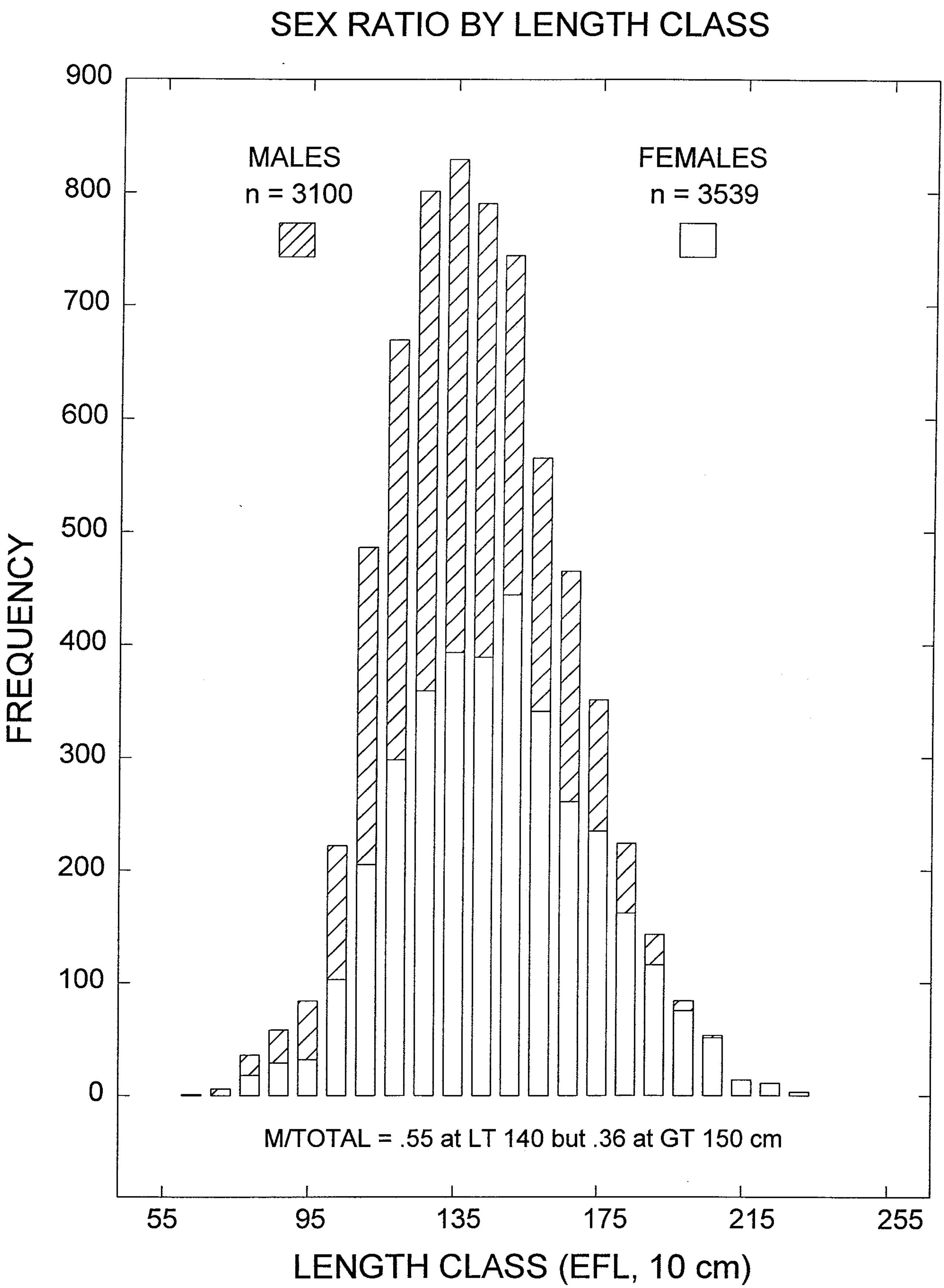
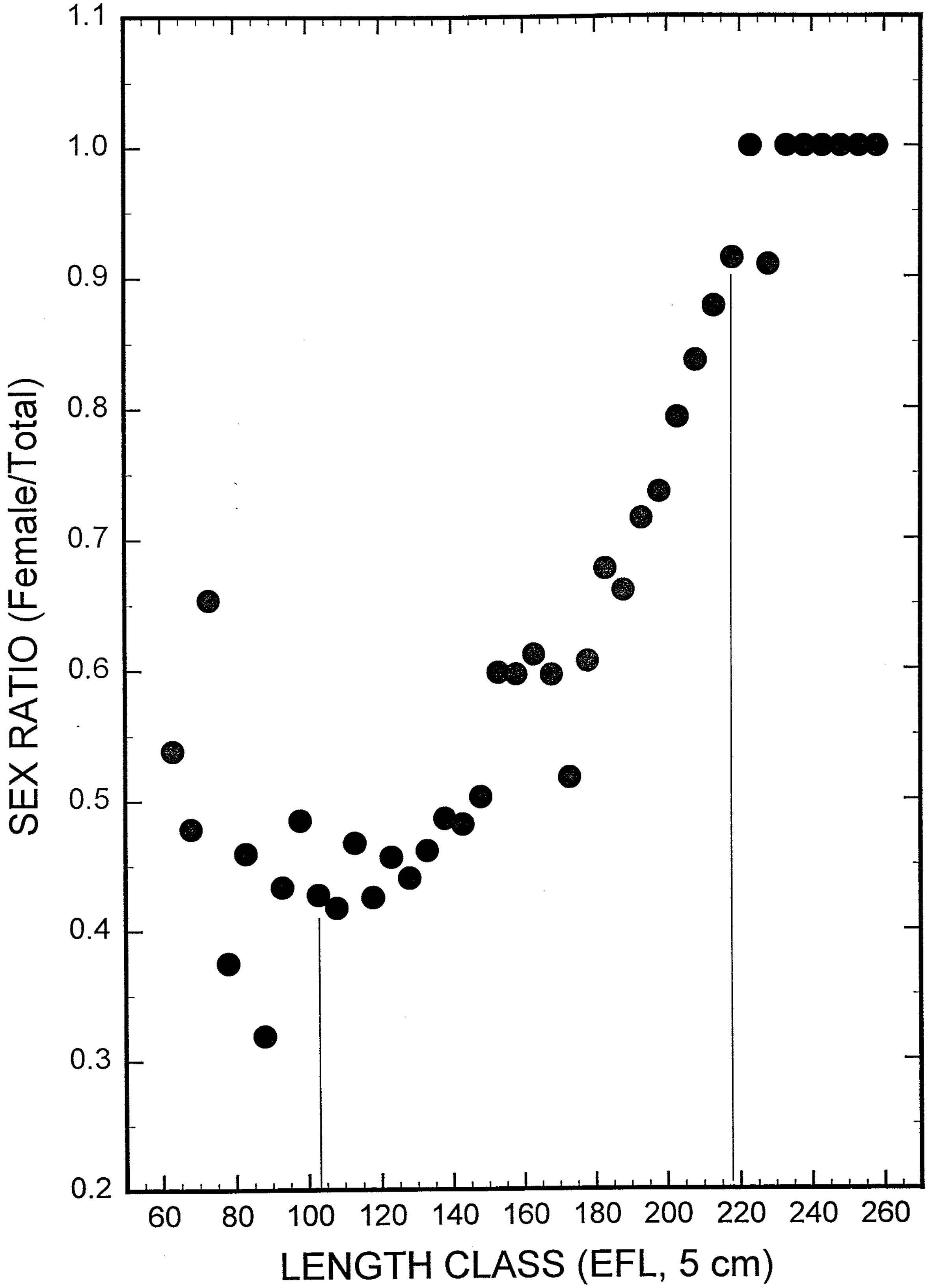

SEX RATIO BY LENGTH CLASS
900
800
700
600
500
400
300
200
100
0
FREQUENCY
MALES
n = 3100
FEMALES
n = 3539
M/TOTAL = .55 at LT 140 but .36 at GT 150 cm
55
95
135
175
215
255
LENGTH CLASS (EFL, 10 cm)

FIG. 4



1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
SEX RATIO (Female/Total)
60
80
100
120
140
160
180
200
220
240
260
LENGTH CLASS (EFL, 5 cm)

FIG. 5

YOY-YEARLING SWORDFISH
Length-at-Age
Sexes Pooled

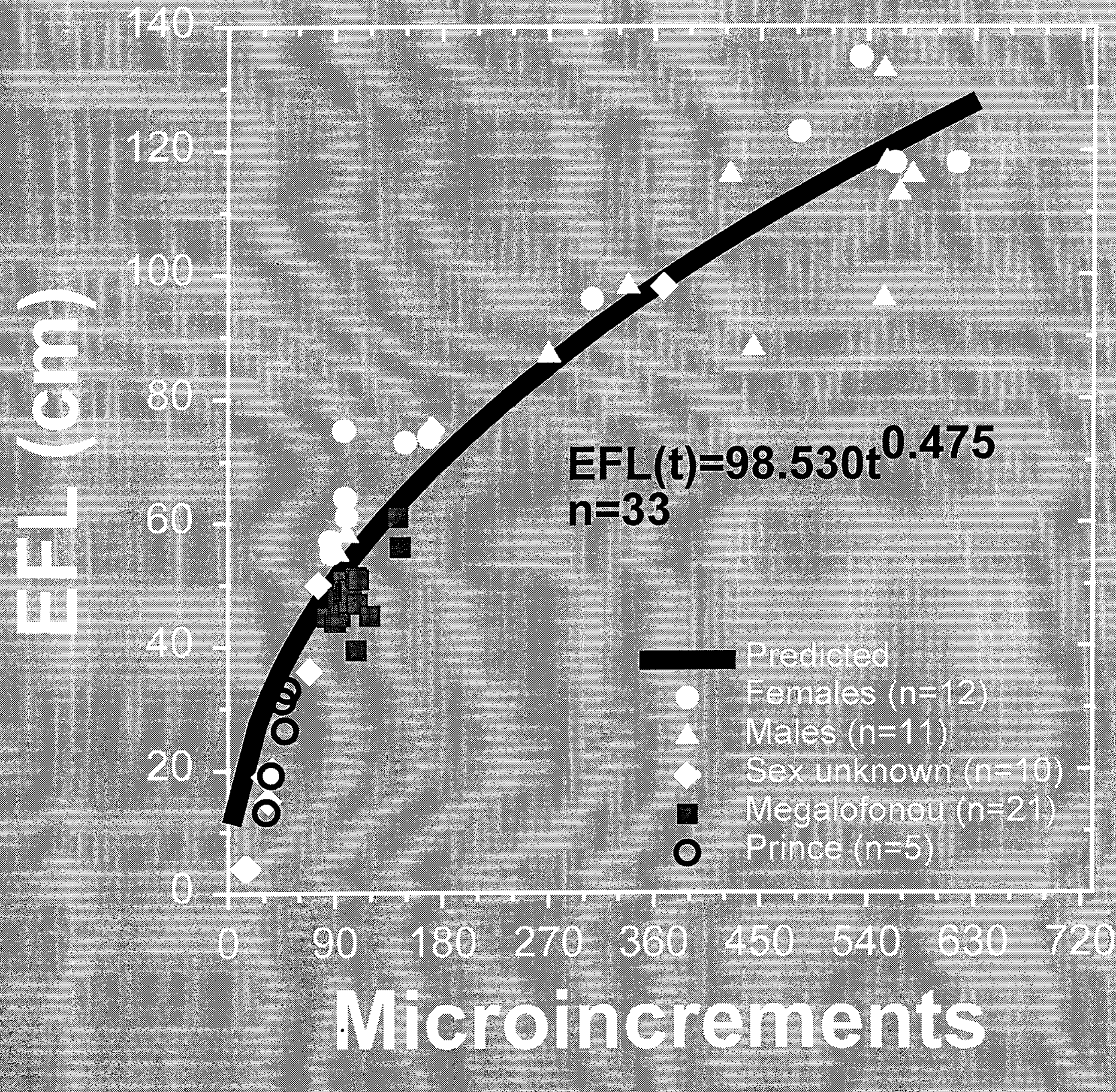


Fig. 6

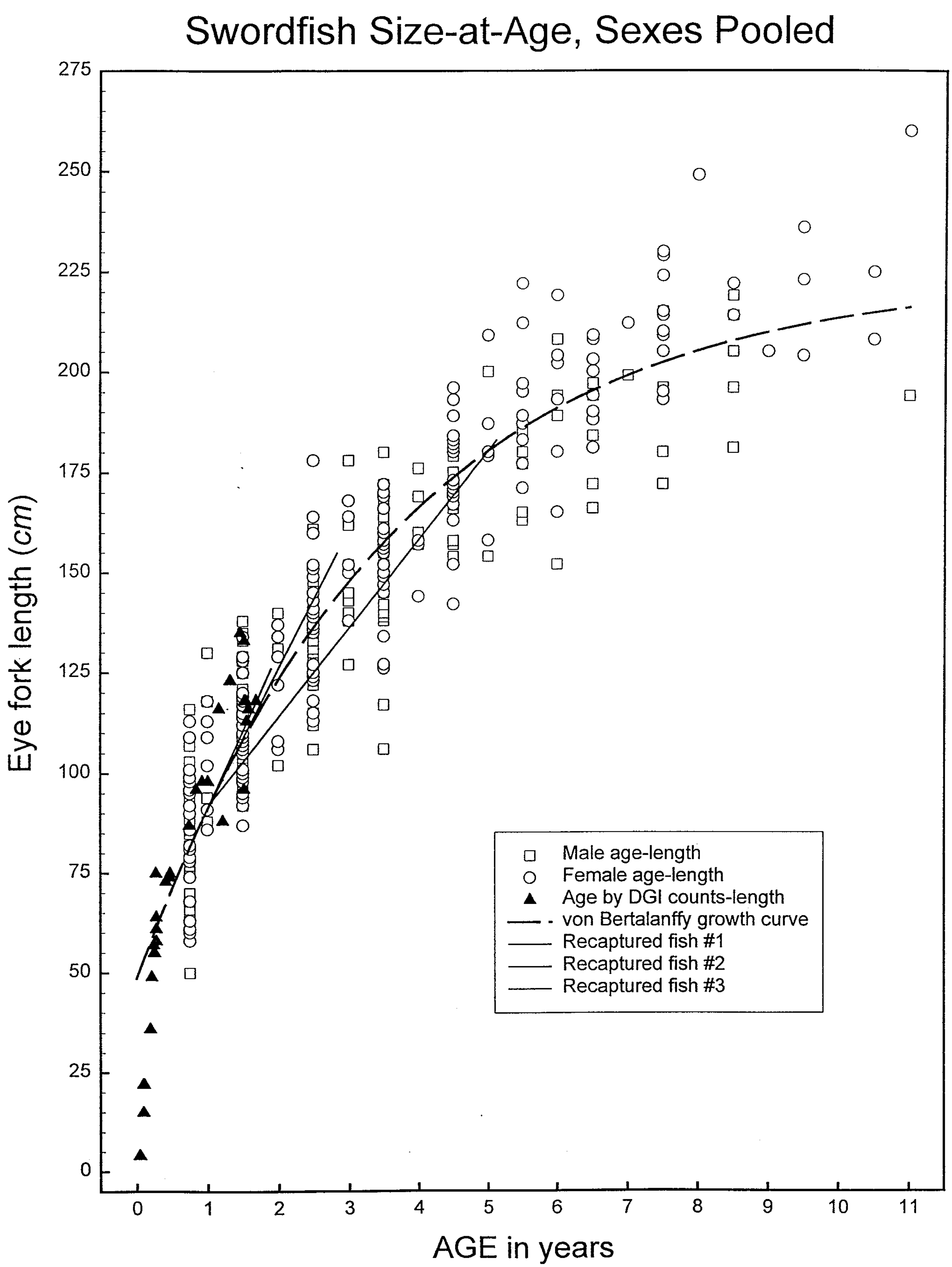
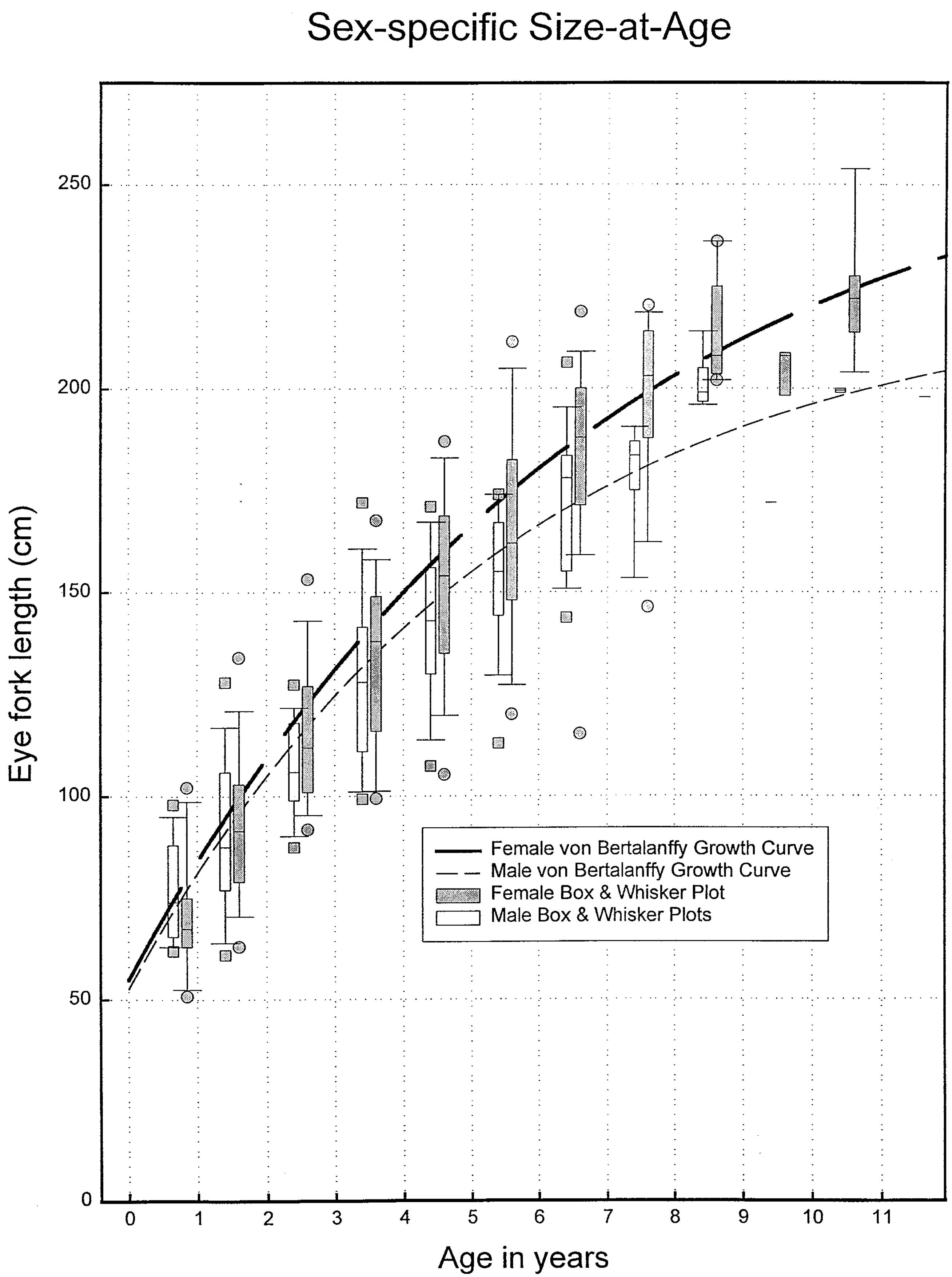

Swordfish Size-at-Age, Sexes Pooled
Eye fork length (cm)
AGE in years
275
250
225
200
175
150
125
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
Male age-length
Female age-length
Age by DGI counts-length
von Bertalanffy growth curve
Recaptured fish #1
Recaptured fish #2
Recaptured fish #3

FIG. 7


Sex-specific Size-at-Age
Eye fork length (cm)
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
11
Age in years
Female von Bertalanffy Growth Curve
Male von Bertalanffy Growth Curve
Female Box & Whisker Plot
Male Box & Whisker Plots