THORNYHEADS--STOCK ASSESSMENT FOR 1990

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Larry D. Jacobson

National Marine Fisheries Service
Southwest Fisheries Center
P.O. Box 271
La Jolla, CA 92038

Abstract

The thornyhead market category supports an expanding fishery; coastwide landings during 1989 were almost 8,000 mt and landings during 1990 are expected to be in excess of 11,000 mt. Shortspine thornyhead account for the bulk of total landings (5,266 mt or 66% of total landings during 1989) although the proportion of longspine thornyhead in landings has increased during recent years. Concurrent with increases in landings and real exvessel prices, real revenues (1989 $) from the thornyhead fishery have increased and are currently in excess of $6,000,000 annually. Real revenues from thornyheads have also increased relative to total revenues from the deep water Dover complex (i.e. thornyheads, Dover sole and sablefish). In 1989, the thornyheads accounted for 21% of total revenues from the deep water Dover complex.

Length composition data for the Eureka Area suggest that mean length of longspine thornyheads decreased by 2 cm during 1978-1989. No decline in mean length of shortspine thornyheads is apparent.

CPUE data for thornyheads from bottom trawl tows are difficult to interpret due to probable changes in fishing practices and gear efficiency. The data suggest, however, that catch rates and abundance of thornyheads, particularly large (>= 40 cm) shortspine thornyheads, inhabiting the 285-305 fathom depth interval in the Eureka Area has decreased since 1978.

Yield and spawning biomass-per-recruit analyses suggest that optimal fishing mortality rates for shortspine thornyhead are very low (F_{max} in the range of 0.038-0.12 yr^{-1}, $F_{0.1}$ in the range of 0.023-0.045 yr^{-1} and $F_{0.35}$ in the range of 0.029-0.057 yr^{-1}). These results are due to apparently low natural mortality rates (0.03-0.06 yr^{-1}) and non-asymptotic growth in weight.

Comparison of landings during 1989 with biomass estimates by bottom trawl and camera surveys suggests that fishing mortality rates in some areas may exceed optimal values (e.g. $F_{0.35}$) determined by yield and spawning biomass-per-recruit analysis. Biomass estimates indicated that longspine thornyheads are more abundant than shortspine thornyheads and that both species are most abundant in the Columbia Area, followed by the Monterey and Eureka areas. Landings of shortspine thornyheads exceed those of longspine thornyheads, however, and landings of the thornyhead market category are greatest in the Eureka and Monterey areas.

Introduction

This document is an assessment of shortspine thornyhead (Sebastolobus alascanus) and longspine thornyhead (S. altivelis) stocks along the Pacific Coast. Shortspine thornyhead in the Eureka (INPFC areas 1C and 2A) area are emphasized but information regarding longspine thornyhead and shortspine thornyhead in other areas is also presented.

Data Availability

Landings and exvessel price data (by port, area, month, year, etc.) for 1981-1989 are available from the PACFIN database. PACFIN landings data do not, however, distinguish between shortspine and longspine thornyheads which are both included in the thornyhead market category.

Species composition data (based on port samples) for 1978-1989 are available from the California Department of Fish and Game (CDFG), Oregon Department of Fish and Wildlife (ODFW), and Washington Department of Fisheries (WDF). These data can be used to separate thornyhead market category landings into longspine and shortspine components although the information available for some ports, areas and years is scanty and possibly unreliable (see below). Length composition data for 1978-1989 (also based on port samples) are available for shortspine and longspine thornyheads landed in California.

Logbook data (including information about catch and fishing effort) are collected by all three states. Logbook data for bottom trawl fisherman based in California during 1978-1987 are readily available in computer readable form and were used in this analysis. The logbook data for 1987 used in this analysis were revised by CDFG during July 1990.

"Swept area" estimates of biomass (mt) and density (mt/km^2) are available for shortspine and longspine in the region from Coquille Point to Cape Falcon, Oregon during 1984 and 1988/89 (Raymore and Weinberg 1990; Raymore pers. comm.), from Point Conception to San Francisco, California during 1987 and 1988 (Butler et al. 1989) and near Point Sur, California during 1984-1985 (Wakefield 1990). Estimates of biomass and density based on photographs taken from a sled towed along the bottom off Point Sur during 1984-1985 are also available (Wakefield 1990).

Biological data for thornyheads (sex, length, weight, maturity, etc.) are available from four research cruises conducted during 1984 and 1988 by the National Marine Fisheries Service (NMFS) and seven research cruises conducted by Scripps Institute of Oceanography (SIO) during 1984-1985. Biological data collected during 1984 (lengths and sex only) are for shortspine and longspine thornyheads taken at depths of 60-500 fathoms in the region from Coquille Point to Cape Falcon, Oregon. Biological data collected during 1988 are for shortspine thornyheads captured at depths of 125-675 fathoms in the region from Point Conception to San Francisco during February-April and from Hecata Head to Cape Lookout, Oregon during November-December. Biological data collected by SIO are for shortspine and longspine thornyheads captured at depths of 109-875 fathoms near Point Sur, California (Wakefield 1990 and pers. comm.). Length composition and other biological data for shortspine and longspine thornyheads collected by observers onboard commercial fishing vessels are available from Pikitch et al. (1990) and Pikitch (pers. comm.). The data collected by observers are unique because: 1) commercial gear and fishing practices were used, 2) small fish usually discarded by the fishery are included, and 3) data for different dates, areas, depths, and meshsizes can be distinguished.

Age and size at age data for a large sample (994 fish) of shortspine thornyheads taken during NMFS research cruises are available and were used in this analysis. In addition, age and size at age data are available for a number of large shortspine thornyheads taken from commercial landings in Oregon by port samplers (J. Butler, pers. comm.). The age data are preliminary, however, because techniques used to assign ages have not been validated. Oregon data were used in this study to estimate natural mortality rates but were not included in growth and maturity analyses. No age data are available for longspine thornyhead at this time.

Information about growth, mortality, maturity, fecundity, diet, and yield-per-recruit for shortspine thornyhead captured off Cape Ommaney in southeastern Alaska is available (Miller 1985). Thornyhead stocks in Alaskan waters are assessed annually on the basis of CPUE from longline and trawl surveys, swept area biomass estimates, and yield-per-recruit analysis (Anon. 1989).

Information about early life history of shortspine and longspine thornyheads is available from Moser (1974).

Landings

Thornyhead landings coast wide have increased dramatically during recent years (Table 1 and Figure 1). Coastwide landings during 1981 were less than 2,000 mt and increased to almost 8,000 mt in 1989. Preliminary figures from PACFIN for 1990 (released on August 14) indicate that 5,613 mt of thornyheads had been landed by the end of June. If catch rates are maintained during the second half of 1990, then total landings of thornyheads will be about 11,200 mt for 1990 which is an increase of 3,000 mt (38%) over total landings for 1989.

Landings during 1981-1989 were greatest in the Eureka area, followed by the Monterey and Columbia areas. On average, 51% of annual coastwide landings are from the Eureka Area, 28% are from the Monterey Area, 17% are from the Columbia Area and 4% are from the Conception Area (Table 1 and Figure 1).

Shortspine thornyhead are the largest component of the total catch although the longspine component has increased as a proportion of the total during recent years (Table 1 and Figure 2). The proportion of longspine thornyhead in coastwide landings increased from 13% during 1981 to 33% during 1989. Thornyhead landings increased as a proportion of total landings for the deep water Dover complex (sablefish, Dover sole and thornyheads) from about 6% in 1981 to about 21% during 1989 (Figure 3).

There were some inconsistencies in the species composition data. For example, official reports suggest that only shortspine thornyhead were landed in Washington during 1981-1989. Reports for fish taken off the Washington coast but landed in Oregon during the same period, however, suggest that both shortspine and longspine thornyheads are available to fisherman along the Washington coast. Landings data for shortspine and longspine thornyheads in Table 1 should, because of the inconsistencies, be regarded as crude and possibly unreliable approximations.

Another problem in interpreting historical landings data stems from the possibility that discard rates for thornyhead have changed over time. Exvessel prices for thornyhead doubled during 1981-1980 (see below) as export demand increased. It is likely that discard rates changed in response to changes in demand and prices.

Prices and Value

As shown in the table below, exvessel prices for thornyheads (expressed in 1989 dollars) rose from $0.18 per pound in 1982 to

$0.37 per pound in 1989 while real revenues (the product of real exvessel prices and landings) for the thornyhead fishery rose from $865,000 in 1982 to $6,464,000 in 1989.

Year	Exvessel Price*	Value
1982	$0.18	$865,000
1983	$0.19	$1,029,000
1984	$0.21	$1,352,000
1985	$0.22	$1,973,000
1986	$0.25	$2,007,000
1987	$0.30	$2,430,000
1988	$0.34	$4,200,000
1989	$0.37	$6,464,000

*1989 dollars per pound.

Revenues from thornyheads have increased relative to revenues from fisheries for other members of the deep water Dover complex (Figure 4). Thornyhead revenues increased from 5% of the total in 1982 to 21% of the total in 1989.

Size at Age

Polynomial linear regressions were used to model relationships between weight, length and age because traditional Von Bertalanffy models did not fit the data. Models were fitted to mean weight and length at age data using weighted linear regression (the standard errors for mean weights and lengths at each age were used as weights). The model for weight at age was:

$$W = -36.71 + 7.204\,A + 0.4463\,A^2, \quad [1]$$

where W is wet weight in gm and A is age in years (Figure 5). The coefficient of determination for the model was 97% and all parameters were significantly different from zero. The model for length at age was:

$$L = 81.99 + 12.07\,A - 0.1071\,A^2 + 0.000460\,A^3, \quad [2]$$

where L is total length in mm (Figure 6). The coefficient of determination for the model was 99% and all parameters were significantly different from zero.

Predicted values of size at age from [1] and [2] indicate that growth is not asymptotic for shortspine thornyhead which appear to grow at a fairly constant rate up to about 101 years of age. In addition, growth of shortspine thornyhead appears to be faster off Oregon and California than in the waters of southeastern Alaska (Miller 1985).

Maturity

Logistic regression was used to model the relationship between maturity and age for shortspine thornyheads ages 5 to 101. There were no significant differences between males and females so the data for both sexes were combined and a single curve was fitted to the data:

$$P = 1 / [1 + e^{(0.9860 - 0.0985 A)}], \qquad [3]$$

where P is the proportion mature and A is age in years (Figure 7). The model [3] fit the data for fish age 12 and older but consistently predicted maturity levels that were too high for fish younger age 12 (Figure 7). Predicted values for maturity of young fish are important because they affect spawning biomass per recruit analyses (i.e. calculation of $F_{0.35}$) described below. In order to improve the model for young fish, a straight line ($P = -0.389 + 0.0778 A$) was fit by eye to the data for ages 5-11 (Figure 7). In the analyses that follow, predicted values from the straight line were used for maturity at ages 5-11 and predicted values from [3] were used for maturity at ages 12 and older. The models fit to the maturity data indicate that shortspine thornyhead are 50% mature by age 12 (21 cm TL, 114 gm) and 95% mature by age 40 (42 cm TL, 966 gm). Miller (1985) estimated that 50% of shortspine thornyhead in waters southeastern Alaska were sexually mature by age 12 (19 cm SL) and that maturity was nearly 100% by age 16 (20 cm SL).

Length-Weight Relationships

Length-weight relationships for shortspine and longspine thornyheads were used to compute mean weights and in connection with catch-per-unit-effort data as described below. Length and weight data for shortspine thornyhead were obtained on deck from fresh fish collected during NMFS research cruises. Length and weight data for frozen longspine thornyhead were provided by Waldo

Wakefield (pers. comm.).

The model used for length and weight was:

$$L = a\ W^b, \qquad [4]$$

where L is total length in millimeters, W is round weight in grams and a and b are parameters. Parameters in [4] were estimated by linear regression analysis of log transformed values for length and weight:

$$\log(L) = \log(a') + b\ \log(W), \qquad [5]$$

where all logarithms are natural logarithms. The estimate for a' in [5] was used to estimate a in [4]:

$$a = \exp(a' + s^2/2), \qquad [6]$$

where s^2 is the variance of residuals from the regression analysis. The factor $s^2/2$ is a correction for bias (Beauchamp and Olson 1973). Parameter estimates and other statistics are summarized in the table below.

	Shortspine	Longspine
a	2.651×10^{-6}	1.794×10^{-6}
b	3.264	3.352
s^2	0.01127	0.01779
r^2	0.99	0.99
N	1721	289
min-max L	24-740 mm	69-308 mm
min-max W	9-6662 g	3-377 g

Additional information about length-weight relationships for longspine thornyhead are available in Raymore and Weinberg (1990).

Length Composition Data

Length composition data for shortspine thornyhead are usually bimodal (Figure 8; see also Butler et al. 1989, Table 3) with the first mode at 24-27 cm and the second above 35 cm. Bimodal length compositions that persist from year to year may be due changes in mortality or growth rate that occur as fish become larger (Barry 1990). The mode at 24-27 cm, however, coincides with the mode typically seen in length composition data for longspine thornyhead (Figure 9). It seems possible, therefore, that a significant number of longspine thornyhead are misidentified as shortspine thornyhead during port sampling and research cruises (i.e. the mode at 24-27 cm in the length composition data for shortspine thornyhead may be due to misidentified longspine thornyheads).

Another explanation for the bimodal pattern typical of length composition data for shortspine thornyhead is that a relationship between size and depth may exist such that smaller fish are found in the shallowest water where fishing effort may be concentrated. Length composition data collected by observers for shortspine thornyhead taken in the Eureka Area with bottom trawls (3 inch mesh in the codends) during 1988-1989 are bimodal (Figure 10). Almost all of the small fish (<= 31 cm TL) were, however, taken at 200-299 fathoms (Figure 11) while most of the larger fish (> 31 cm TL) were taken at depths greater than 300 fathoms (Figure 12). Length composition data in Raymore and Weinberg (1990, Figure 80) show a similar pattern. In recent years, the distribution of fishing effort with depth in the Eureka Area has been bimodal with concentrations of fishing effort at about 285 and 500 fathoms (Figure 16). It seems possible, therefore, that a combination of fishing effort concentrated in shallow waters (where small fish may be numerous) with fishing effort concentrated in deep water (where large fish are numerous) could result in bimodal length composition data. Additional work is required to resolve these issues.

CDFG length composition data were used to calculate mean lengths for thornyheads taken in the Eureka Area during 1978-1989. In order to obtain sufficiently reliable data for each year, data for thornyheads landed at ports in Eureka and Fort Bragg during January-December were combined. In order to deal with the possibility that length composition data for shortspine thornyhead were contaminated by misidentified longspine thornyheads, mean lengths were computed for shortspine thornyhead >= 40 cm TL (longspine thornyhead seldom reach 40 cm TL) as well as for all shortspine and longspine thornyhead.

Mean lengths of shortspine thornyheads varied without pattern during 1978-1989 (see table below). Mean lengths of longspine thornyhead declined continuously from 28.6 cm in 1978 to 26.4 in 1989.

Year	Longspine[1]	Shortspine[1] all	Shortspine[1] >=40 cm
1978	28.6	42.3	48.2
1979	28.3	47.9	50.8
1980	27.8	38.9	49.1
1981	28.5	40.3	50.1
1982	27.5	43.0	48.7
1983	28.5	44.5	48.8
1984	27.3	43.5	48.9
1985	26.9	40.3	50.2
1986	26.7	40.4	49.8
1987	26.4	42.9	51.3
1988	28.4	50.4	50.8
1989	26.4	40.9	49.1

[1]All lengths are total lengths in cm.

CPUE Data

The feasibility of using commercial catch-per-unit-effort (CPUE) data from bottom trawls as an index of relative abundance for thornyhead was assessed using logbook data provided by CDFG for fishing during 1978-1987. The logbook data included information about location, depth, date, hours fished and catch by species or market category. Different types and sizes of bottom trawls could not, however, be distinguished. Catches were adjusted to agree with landing receipts prior to use in this analysis so that the data correspond to landings rather than actual catch (landings plus discards). Only data for trawl hauls in the Eureka Area at depths of 235-615 fathoms were used. Relatively few thornyheads are taken at depths less than 235 fathoms and greater than 615 fathoms (see below). CPUE was calculated as the ratio of total catch and total effort within a stratum and units are mt/hour. Raw CPUE data are catch rates for the thornyhead market category (shortspine and longspine thornyhead combined). CPUE data for shortspine thornyhead were derived as described below.

Interpretation of CPUE data for thornyheads is complicated by probable changes in fishing practices and gear efficiency over time. As the exvessel price and market demand for thornyheads increased, it is likely that fisherman changed fishing tactics and reduced discard of thornyheads. As fishing effort has increased in offshore areas, it is likely that fisherman have invested in gear designed for use in deep water. Changes in the proportion of thornyheads in individual tows due, presumably, to changes in fishing practices are evident in the logbook data. Distributions of proportion thornyheads (i.e. total weight of thornyheads divided by the total weight of all fish in bottom trawl tows) for 1978-1984 are unimodal with peaks in the range of 0% to 10%. During these years, few tows were more than 40% thornyheads by weight (Figure 13). Beginning in 1985, however, distributions of proportion thornyheads were more skewed to the right and often bimodal with peaks at 0%-5% and 50%-55% so that a significant fraction of tows were more than 40% thornyheads by weight (Figure 14). These data suggest that fishing effort beginning in 1985 was, relative to fishing effort during prior years, directed more strongly towards capture of thornyheads.

The distribution of fishing effort (total hours of fishing for tows where thornyheads were present) with depth shows a pattern that is similar to the proportion thornyhead in individual tows. During 1978-1983, relatively little effort was expended at depths greater than 450 fathoms (Figure 15). After 1984, however, the amount of effort at depths greater than 450 fathoms increased (Figure 16). Catch rates for thornyheads are highest in deep water (see below) so that variation in CPUE due to changes in abundance might be masked by higher catch rates in deeper water as the fishery moved farther off shore.

Three approaches to dealing with changes due to variation in directed fishing effort and depth of fishing were tried. Firstly, CPUE values were calculated using only tows in which the proportion of thornyheads by weight was less than 40%, less than 30% and less than 20%. Secondly, CPUE values were computed (using data from all tows) for three depth intervals: 285-305, 385-405 and 485-505 fathoms.

The third approach involved fitting a generalized linear model (GLM) with years and depth as main effects. The model was fitted to the CPUE data for all tows. Month of capture was not included in the model because preliminary analyses showed no differences among months within years. Prior to this analysis, CPUE data were transformed using:

$$C'_{y,m,d} = \log(C_{y,m,d} + 0.00008), \quad [7]$$

where $C_{y,m,d}$ is CPUE for tows in year y, month m and year d, $C'_{y,m,d}$ is the transformed value and the constant (0.00008) was used to allow log-transformation where $C_{y,m,d}$ was zero. The value of the constant is slightly smaller than half of the smallest observed CPUE value (0.00017). The model fitted to the data was:

$$C'_{y,m,d} = a_y + b_d + e_{y,m,d}, \quad [8]$$

where a_y is the effect for year y, b_d is the effect of depth d and $e_{y,m,d}$ is a normally distributed random error. The model explained 50% of the total variation in the transformed data and the effects of both year and depth were statistically significant (p-value < 0.001). Models including interaction terms for depths and years were not fitted because too much computer memory was required.

Standardized estimates of CPUE in each year for the thornyhead market category were obtained as:

$$I_y = \exp(a_y + s^2/2), \qquad [9]$$

where $s^2 = 0.5722$ is the variance of residuals (mean square error) for the model (Table 2). The term $s^2/2$ corrects for bias (Beauchamp and Olson 1973).

The CPUE indices derived above are for the thornyhead market category (shortspine and longspine thornyheads). CPUE indices for large (>= 40 cm) shortspine thornyheads were obtained by: 1) calculating, for each species, wet weights corresponding to each length group in the length composition data, 2) combining the length composition data (with wet weights) for shortspine and longspine thornyheads to obtain length composition and weight data for the thornyhead market category, 3) calculating, from the length composition and weight data, the relative weights of all thornyheads landed (T_y) and all thornyheads landed that were >= 40 cm TL (U_y). Since thornyheads larger >= 40 cm TL are always shortspine thornyheads, the ratio $R_y = T_y/U_y$ is the fraction of total landings and total CPUE for the thornyhead market category that is due to large (>= 40 cm TL) shortspine thornyheads (Table 2). CPUE for large shortspine thornyheads can then be calculated as the product of two terms:

$$I'_y = R_y I_y, \qquad [10]$$

where I'_y is the CPUE for large shortspine thornyheads and I_y, for example, is from [9]. This approach to partitioning total CPUE into species and size specific components is equivalent to the approach used by Schnute (1987) and Schnute et al. (1989a and 1989b) to partition CPUE into components for newly and previously recruited fish.

The effects of depth on CPUE were quantified by:

$$B_y = \exp(b_y + s^2/2), \qquad [11]$$

where B_y is a multiplicative depth effect (see table below), b_y is from [8] and s^2 = 0.5722 is the same as in [9].

Depth	B_y	Depth	B_y
245	0.19	425	1.6
265	0.33	445	1.7
285	0.50	465	2.0
305	0.79	485	2.5
325	0.89	505	2.2
345	1.2	525	2.5
365	1.1	545	2.4
385	1.3	565	2.0
405	1.4	585	1.8

The results indicate that catch rates increase with depth to 485-545 fathoms and then decline as depth increases.

Results for CPUE data

Three CPUE series for the thornyhead market category (i.e. CPUE for tows less than 20% and less than 30% thornyhead by weight and CPUE for tows in the 285-305 fathom depth interval) declined during 1978-1987 (Figure 17). One CPUE series (i.e. CPUE for tows less than 40% thornyhead by weight) showed little variation during 1978-1987. Four CPUE series (i.e. CPUE from the general linear model, CPUE for all tows and CPUE for tows in the 385-405 and 485-505 fathom depth intervals) increased during 1984-1987. CPUE for tows in the 485-505 fathom depth interval were highly variable from year to year.

Four CPUE series for shortspine thornyheads >= 40 cm TL (i.e. CPUE for tows less than 20%, 30% and 40% thornyhead by weight as well as CPUE for tows in the 285-305 fathom depth stratum) declined during 1978-1987 (Figure 18). Three CPUE series (i.e. CPUE for tows in the 385-405 and 485-505 depth intervals, and CPUE from the general linear model) were variable from year to year but show no trend over time. One CPUE series (i.e. CPUE for all tows) increased during 1978-1987.

Although it is difficult to interpret trends in the various CPUE series the data suggest that abundance of thornyheads, particularly large shortspine thornyheads, may have decreased during 1978-1987 in relatively shallow waters (285-305 fathoms) where thornyheads are available to many trawlers but not naturally abundant. The erratic but relatively high CPUE series for tows from 485-505 fathoms may be due to relatively little effort in deep water where thornyheads are abundant but variation in catch rates is high. Problems in this analysis with interpreting CPUE data are similar to problems discussed by Anon (1989) where thornyhead CPUE data derived from longline and trawl surveys showed different trends.

Yield and Spawning Biomass-Per-Recruit

Yield and spawning biomass-per-recruit as a function of fishing mortality rates were evaluated for shortspine thornyhead by simulation (Thompson and Bell 1934). The fishing mortality rate that maximizes yield per recruit (F_{max}), the fishing mortality rate that corresponds to the point on the yield-per-recruit curve where the slope is one tenth as large as the slope at the origin ($F_{0.1}$) and the fishing mortality rate that results in a level of spawning biomass-per-recruit that is 35% of the maximum value obtained with no fishing ($F_{0.35}$) were calculated. Clark (in press) describes each of these biological reference points.

Yield-per-recruit analysis requires specification of weight at age, maturity at age, spawning season, recruitment to the fishery (on a relative basis) by age and the natural mortality rate. Predicted weights at age from [1] and predicted fraction mature at age from [3] were used in this analysis (Table 3). The month of peak spawning for shortspine thornyheads is thought to be April (Moser 1974) so spawning was assumed to occur after one third of the total fishing and natural mortality in each year.

<u>Recruitment</u>

There is little information available about age specific recruitment of shortspine thornyheads to the fishery. It is usually possible to obtain information about recruitment by examining age composition data from the principal fisheries. Age composition data were not, however, available for shortspine thorneyhead.

In lieu of age composition data, length composition data collected by observers during commercial fishing trips in the Eureka Area during 1988-1989 were used to infer recruitment patterns. Although the observer data were collected aboard vessels participating in a research project, fishing was conducted on typical fishing grounds and commercial fishing gear was used. In addition, the data collected by observers include small fish that are normally discarded but do not survive (Pikitch et al. 1990). Data used for this analysis were for bottom trawls (3, 4.5 and 5.5 inch mesh in the codends) fished at depths greater than 200 fathoms (figures 10 and 19-20).

At present, bottom trawls with meshsize in the codend >= 3 inch are allowed in the Eureka, Columbia and Vancouver areas. Bottom trawls actually used by the deep water fishery off Eureka typically have 3 inch mesh in the codends (Larry Quirollo, pers. comm.). Bottom trawls with mesh >= 4.5 inch are allowed in the Monterey and Conception areas.

As discussed above, the length composition data for 3 inch mesh collected by observers (Figure 10) are bimodal and difficult to interpret. In order to avoid this difficulty, only length composition data for 4.5 inch mesh were used to infer age at full recruitment to the commercial fishery for yield and spawner biomass per recruit analyses.

The length composition data for shortspine thornyheads captured in the Eureka Area by bottom trawls with 4.5 inch mesh suggests that fish are fully recruited at about 36 cm TL (Figure 19) which, from [2], corresponds to an age of about 30 years. There is considerable variation in the ages of fish that are 36 cm TL, however, and it appears that a fish of this length could be anywhere between 20 and 50 years old (Figure 6). It is also apparent that some thornyheads recruit to the fishery at 18 cm TL (Figure 19) which, from [2], corresponds to an age of about 9 years. Once again, there is considerable variation in the ages of fish that are 18 cm TL; a fish of this size could be anywhere between 7 and 15 years old (Figure 6). In this analysis, it was assumed that fish began to recruit to the fishery at age 9 and that the fraction recruited increased in a sigmoidal fashion with age until fish became fully recruited at age 30 (Table 3). A preliminary analysis revealed that results were sensitive to assumptions about recruitment but no other assumptions were formally evaluated because specific information about recruitment of shortspine thornyhead was scarce. Miller (1985) used age 16 for full recruitment of shortspine thornyheads while Anon (1989) used ages 10 and 16. Neither Miller (1985) nor Anon (1989) considered partial recruitment of younger age groups.

Natural Mortality

A linear regression model relating oldest observed age and mortality described by Hoenig (1983) was used to estimate M, the natural mortality rate. The oldest estimated age for a shortspine thornyhead is 157 years (John Butler, pers. comm.) which corresponds to a natural mortality of about 0.03 yr^{-1}. The oldest estimated age in the data used in this analysis was 102 years which corresponds to a natural mortality rate of about 0.045 yr^{-1}. The criteria used to estimate the age of these fish have not, however, been validated and it is possible that the age estimates are too large. If we assume that the age estimates are twice the actual age, then the fish whose age was estimated to be 157 years old may have been only 78 years old. The natural mortality rate corresponding to a maximum age of 78 years is about 0.06 yr^{-1}. Due to the uncertainty about the true natural mortality rate, three values (0.03, 0.045 and 0.06 yr^{-1}) were used in this analysis. Miller's (1985) estimate of the natural mortality rate for shortspine thornyhead (M=0.07) from a catch curve analysis is larger than the largest value used here. The oldest age observed in Miller's samples was only 62 years, however.

The number of age groups (N_a) that should be included in a yield per recruit analysis is a function of the natural mortality rate. The "95%" rule (Anon 1985; Gabriel et al. 1989) states that the terminal age (N_a) should be set large enough so that, in the absence of fishing, at least 95% of all recruits would die prior to reaching the terminal age (i.e. set $N_a = -\log(0.05)/M = 3/M$, where M is the natural mortality rate). The number of age groups included in this analysis (N_a = 103) was slightly larger than the minimum value (i.e. 3 / 0.03 = 100) specified by the 95% rule. The first age group in included in the analysis was age seven.

Results of Yield and Spawner Biomass per Recruit Analyses

Results of the analyses are summarized in the table below. Plots of yield and spawning biomass-per-recruit for each level of natural mortality are given in figures 21-23. The results suggest that low fishing mortality rates (< 0.12 yr^{-1}) are optimal, from the perspective of yield and spawning biomass-per-recruit, for managing shortspine thornyhead fisheries. The low values obtained for F_{max}, $F_{0.1}$ and $F_{0.35}$ are due to the non-asymptotic growth pattern and low natural mortality rates used in the analysis.

		Natural Mortality Rate		
		0.03	0.045	0.06
F_{max}		0.038	0.065	0.12
	Yield	0.29	0.17	0.12
	Spawning Biomass	7.9	3.0	1.3
$F_{0.1}$		0.023	0.032	0.045
	Yield	0.27	0.16	0.11
	Spawning Biomass	12.	5.3	2.7
$F_{0.35}$		0.029	0.040	0.057
	Yield	0.28	0.17	0.11
	Spawning Biomass	9.9	4.5	2.3

The estimate F_{max} = 0.29 from Anon (1989) for full recruitment at age 16 is much higher than the values obtained in this analysis. Values of $F_{0.1}$ = 0.075 and $F_{0.35}$ = 0.075 (for full recruitment at ages 10 and 16) are slightly larger than those obtained here. These differences are due primarily to differences in assumptions about growth, recruitment and natural mortality (i.e. lower natural mortality, partial recruitment of young fish and faster growth were assumed in this study).

When interpreting the results of yield and spawner biomass per recruit analyses for shortspine thornyhead, it is important to remember that there was considerable uncertainty regarding age specific recruitment to the fishery. In particular, recruitment of young fish was probably underestimated because the age specific recruitment vector was estimated from length composition data for trawls with 4.5 inch mesh, rather than 3 inch mesh, in the codends. If length composition data for trawls with 3 inch mesh had been used, then higher recruitment rates for young fish and smaller values of F_{max}, $F_{0.1}$ and $F_{0.35}$ would probably have been obtained.

Biomass

Density estimates (mt/km^2) from seven sources were used to estimate total biomass of shortspine and longspine thornyheads in the Columbia, Eureka and Monterey areas (Table 4). Density estimates from bottom trawl surveys conducted by NMFS during 1984 (F/V Half Moon Bay) and 1988/1989 (R/V Miller Freeman and F/V Golden Fleece) between Coquille Point and Cape Falcon, Oregon were provided by Paul Raymore (pers. comm.). The 1984 survey extended from 100-550 fathoms (Raymore and Weinberg 1990) so densities at depths beyond 500 fathoms were assumed equal to the survey estimates of density at 500-550 fathoms. The 1988/1989 surveys extended from 100-700 fathoms. Butler et al. 1989 give swept area density estimates from bottom trawl tows that were conducted during research fishing in 1987 and 1988 (R/V David Starr Jordan) between Point Conception and San Francisco at depths of 30-700 fathoms. The data in Butler et al. (1989) were corrected for errors in the planar area of strata. In addition, densities given in Butler et al. (1989) for each stratum were recomputed as the ratio of total catch and total area swept rather than as the simple mean of catch per area swept for individual tows. Wakefield (1990) gives estimates based on bottom trawl and camera sled tows that were conducted at depths of 109-875 fathoms during research fishing by Scripps Institute of Oceanography in 1984-1985 off Pt. Sur, California. Where necessary, survey data were retabulated using the following depth intervals as strata: 30-250, 250-550 and 550-700 fathoms.

As discussed by Wakefield (1990), density and biomass estimates based on the camera sled data are usually larger than estimates based on bottom trawl data. These differences may be due to fish that avoid bottom trawls by escaping under the footrope, through the meshes or over the top of the trawl. It is likely that camera sleds elicit less avoidance behavior than bottom trawls and, consequently, result in biomass estimates that are larger and more accurate than estimates based on bottom trawl data. Procedures for estimating biomass from observational data are new and relatively unproven, however, and it is also possible that estimates from camera sled data are too high. The planar area for depth strata was estimated by digitizing contour lines on bathymetric maps and numerically integrating between strata boundaries (Figure 24).

Minimum and maximum biomass estimates for shortspine thornyhead in the Columbia, Eureka and Monterey areas were 6,784-54,916 mt, 3,913-19,538 mt and 5,979-36,002 mt, respectively. Biomass estimates for longspine thornyhead in the Columbia, Eureka and Monterey areas were 8,973-63,995 mt, 5,819-41,239 mt and 8,332-58,381 mt, respectively. The results suggest that abundance of shortspine and longspine thornyheads is greatest in the Columbia Area, intermediate in the Monterey Area and least in the Eureka Area. Differences in the estimated abundance of thornyheads among areas are due to differences in the amount of habitat among areas since densities from each survey were used to estimate abundance in each area (i.e. there are 33,064 km^2 of habitat between at depths of 30-700 fathoms in the Columbia Area, 23,037 km^2 in the Monterey Area and 12,366 km^2 in the Eureka Area). It is interesting to note that abundance is inversely related to landings which are greatest in the Eureka Area, intermediate in the Monterey Area and least in the Columbia Area.

Estimates of total abundance for shortspine and longspine thornyheads in the Columbia, Eureka and Monterey areas were 16,676-110,268 mt and 23,124-163,616 mt, respectively. Longspine thornyheads appear to be the most abundant species overall. It is important to remember, however, that these figures are estimates of thornyhead biomass at depths less than 700 fathoms. It is likely that considerable numbers and biomass of thornyheads exist in deeper water.

Crude estimates of fishing mortality rates can be obtained from the ratio of landings during 1989 and estimated biomass. On this basis, estimates of the total fishing mortality rates in the

Columbia, Eureka and Monterey areas during 1989 for shortspine and longspine thornyheads are 0.05-0.31 yr^{-1} and 0.02-0.11 yr^{-1} (Table 4). Estimates of fishing mortality for shortspine and longspine thornyheads in the Eureka Area during 1989 are, for example, 0.12-0.60 yr^{-1} and 0.05-0.35 yr^{-1}, respectively. Uncertainties in the estimates of fishing mortality rates during 1989 are due primarily to uncertainty in the underlying biomass estimates. It is clear, however, that fishing mortality rates in some areas (e.g. the Eureka Area) probably exceed optimal values (i.e. F_{max}, $F_{0.1}$ and $F_{0.35}$) obtained from yield and spawning biomass-per-recruit analyses. It is also interesting to note that shortspine thornyheads, though apparently less abundant than longspine thornyheads, support the highest landings and experience the highest estimated fishing mortality rates.

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	Q	R	S	T	U	V	W	X
62	Table 1.	Landings for shortspine thornyheads and longspine thornyheads						
63		by area, 1981-1989.						
64						VANCOUVER AREA		
65	YEAR	UNKNOWN PFMC AREA				(INPFC 3B & 3C)		
66		SHORTSPINE	LONGSPINE	TOTAL		SHORTSPINE	LONGSPINE	TOTAL
67								
68	1981	0.00	0.00	0.00		0.00	0.00	0.00
69	1982	0.00	0.00	0.00		0.00	0.00	0.00
70	1983	0.00	0.90	0.90		29.18	2.52	31.70
71	1984	0.00	0.00	0.00		19.91	22.59	42.50
72	1985	0.00	0.00	0.00		64.30	0.00	64.30
73	1986	0.00	1.20	1.20		53.90	0.00	53.90
74	1987	0.00	14.00	14.00		30.10	0.00	30.10
75	1988	0.00	0.00	0.00		66.10	0.00	66.10
76	1989	0.00	12.50	12.50		102.68	8.52	111.20
77								
78		COLUMBIA AREA				EUREKA AREA		
79	YEAR	(INPFC 2B,2C & 3A)				(INPFC 1C & 2A)		
80		SHORTSPINE	LONGSPINE	TOTAL		SHORTSPINE	LONGSPINE	TOTAL
81								
82	1981	21.90	1.00	22.90		886.50	222.10	1108.60
83	1982	17.40	148.40	165.80		680.61	457.49	1138.10
84	1983	499.27	157.03	656.30		955.12	44.68	999.80
85	1984	463.82	163.88	627.70		822.48	247.22	1069.70
86	1985	694.50	160.80	855.30		1109.65	392.35	1502.00
87	1986	460.88	44.52	505.40		1133.70	536.30	1670.00
88	1987	461.83	104.07	565.90		982.43	676.97	1659.40
89	1988	582.05	139.95	722.00		1398.97	2452.33	3851.30
90	1989	1127.87	583.63	1711.50		2363.54	2029.56	4393.10
91								

	Q	R	S	T	U	V	W	X
92	Table 1 (continued)							
93								
94			MONTEREY AREA				CONCEPTION AREA	
95	YEAR		(INPFC 1B)				(INPFC 1A)	
96		SHORTSPINE	LONGSPINE	TOTAL		SHORTSPINE	LONGSPINE	TOTAL
97								
98	1981	644.09	6.71	650.80		5.40	0.00	5.40
99	1982	710.90	167.80	878.70		9.20	0.00	9.20
100	1983	661.69	64.11	725.80		95.70	0.00	95.70
101	1984	709.02	157.88	866.90		312.40	0.00	312.40
102	1985	1029.97	217.43	1247.40		398.60	0.00	398.60
103	1986	1028.33	256.07	1284.40		97.60	0.00	97.60
104	1987	926.53	446.77	1373.30		0.00	44.30	44.30
105	1988	979.50	0.00	979.50		0.74	0.06	0.80
106	1989	1666.78	8.32	1675.10		5.09	5.41	10.50
107								
108	YEAR		ALL AREAS					
109		SHORTSPINE	LONGSPINE	TOTAL				
110								
111	1981	1557.88	229.82	1787.70				
112	1982	1418.11	773.69	2191.80				
113	1983	2240.95	269.25	2510.20				
114	1984	2327.63	591.57	2919.20				
115	1985	3297.02	770.58	4067.60				
116	1986	2774.41	838.09	3612.50				
117	1987	2400.89	1286.11	3687.00				
118	1988	3027.37	2592.33	5619.70				
119	1989	5265.96	2647.94	7913.90				
120								

Table 2. CPUE data (mt / hour fished) for thornyheads in the Eureka Area during 1978-1987 (from CDFG logbook data). Data for the thornyhead market category (shortspine and longspine thornyheads, top panel) as well as shortspine thornyhead >= 40 cm TL (bottom panel) are presented.
CPUE values were computed as the ratio of total catch divided by total effort for each stratum.
The column labeled 'All tows' holds CPUE values computed from all tows at depths of 245-605 fathoms.
The columns labeled '20%', '30%', and '40%' hold CPUE values computed from tows that were 20%, 30% and 40% thornyheads by weight, respectively. The columns labeled '285-305', '385-405' and '485-505' hold CPUE data for tows in different depth strata. The column labeled 'GLM' holds CPUE data from a general linear model. The column labeled '% Shortspine >= 40 cm TL' holds the percentage (by weight) of shortspine thoryhead larger than 40 cm TL in landings during each year.

CPUE Data for Thornyhead Market Category (shortspine and longspine):

		Tows <= % Thornyhead (by weight)			Tows in Depth Intervals (fathoms)				% Shortspine
Year	All Tows	20%	30%	40%	285-305	385-405	485-505	GLM	>= 40 cm TL
1978	0.049	0.040	0.045	0.048	0.043	0.056	0.052	0.058	78%
1979	0.060	0.042	0.051	0.056	0.049	0.059	0.115	0.090	90%
1980	0.056	0.035	0.046	0.051	0.039	0.061	0.118	0.082	71%
1981	0.071	0.039	0.052	0.061	0.042	0.080	0.206	0.116	66%
1982	0.077	0.042	0.055	0.066	0.028	0.087	0.173	0.111	72%
1983	0.062	0.032	0.048	0.056	0.027	0.076	0.153	0.091	86%
1984	0.060	0.031	0.042	0.050	0.026	0.056	0.114	0.086	71%
1985	0.082	0.034	0.049	0.061	0.040	0.071	0.105	0.097	66%
1986	0.096	0.033	0.045	0.053	0.035	0.081	0.169	0.116	67%
1987	0.113	0.031	0.044	0.057	0.033	0.098	0.167	0.108	57%

CPUE Data for Shortspine Thornyheads >= 40 cm TL:

		Tows <= % Thornyhead (by weight)			Tows in Depth Intervals			
Year	All Tows	20%	30%	40%	285-305	385-405	485-505	GLM
1978	0.038	0.031	0.036	0.037	0.034	0.044	0.041	0.046
1979	0.054	0.037	0.046	0.050	0.044	0.053	0.104	0.081
1980	0.040	0.024	0.032	0.036	0.028	0.043	0.084	0.058
1981	0.047	0.025	0.034	0.040	0.027	0.052	0.135	0.076
1982	0.055	0.030	0.039	0.047	0.020	0.063	0.125	0.080
1983	0.054	0.028	0.041	0.048	0.024	0.065	0.131	0.078
1984	0.043	0.022	0.030	0.036	0.018	0.040	0.082	0.061
1985	0.054	0.022	0.032	0.040	0.026	0.047	0.069	0.064
1986	0.065	0.022	0.030	0.036	0.023	0.054	0.114	0.078
1987	0.064	0.018	0.025	0.032	0.019	0.056	0.095	0.061

Table 3. Input data for yield-per-recruit analyses.

TITLE:
SHRTSPN4.DAT:SHORTSPINE,1ST RECR @ 9,FULL RECR @ 30,LINEAR MAT,SPAWN APRIL
FIRST AGE GROUP: LAST AGE GROUP: LAST GROUP IS PLUS:
6 103 NO
PROPORTION OF F MORTALITY BEFORE SPAWNING SEASON:
.3333
PROPORTION OF M MORTALITY BEFORE SPAWNING SEASON:
.3333

AGE	FPATTERN	MPATTERN	MATURITY	WEIGHT IN THE CATCH	WEIGHT IN THE STOCK
1	0.0000	0.000	0.0000	0.0000	0.0000
2	0.0000	0.000	0.0000	0.0000	0.0000
3	0.0000	0.000	0.0000	0.0000	0.0000
4	0.0000	0.000	0.0000	0.0000	0.0000
5	0.0000	0.000	0.0000	0.0000	0.0000
6	0.0000	1.000	0.0800	0.0240	0.0240
7	0.0000	1.000	0.1600	0.0360	0.0360
8	0.0000	1.000	0.2300	0.0490	0.0490
9	0.0060	1.000	0.3100	0.0640	0.0640
10	0.0200	1.000	0.3900	0.0800	0.0800
11	0.0460	1.000	0.4700	0.0970	0.0970
12	0.0800	1.000	0.5490	0.1140	0.1140
13	0.1200	1.000	0.5730	0.1320	0.1320
14	0.1720	1.000	0.5970	0.1520	0.1520
15	0.2400	1.000	0.6210	0.1720	0.1720
16	0.3000	1.000	0.6430	0.1930	0.1930
17	0.3600	1.000	0.6660	0.2150	0.2150
18	0.4300	1.000	0.6870	0.2380	0.2380
19	0.5000	1.000	0.7080	0.2610	0.2610
20	0.5700	1.000	0.7280	0.2860	0.2860
21	0.6400	1.000	0.7470	0.3110	0.3110
22	0.7000	1.000	0.7650	0.3380	0.3380
23	0.7600	1.000	0.7820	0.3650	0.3650
24	0.8280	1.000	0.7990	0.3930	0.3930
25	0.8800	1.000	0.8140	0.4220	0.4220
26	0.9200	1.000	0.8280	0.4520	0.4520
27	0.9540	1.000	0.8420	0.4830	0.4830
28	0.9800	1.000	0.8550	0.5150	0.5150
29	0.9940	1.000	0.8670	0.5480	0.5480
30	1.0000	1.000	0.8780	0.5810	0.5810
31	1.0000	1.000	0.8880	0.6160	0.6160
32	1.0000	1.000	0.8970	0.6510	0.6510
33	1.0000	1.000	0.9060	0.6870	0.6870
34	1.0000	1.000	0.9140	0.7240	0.7240
35	1.0000	1.000	0.9210	0.7620	0.7620
36	1.0000	1.000	0.9280	0.8010	0.8010
37	1.0000	1.000	0.9350	0.8410	0.8410
38	1.0000	1.000	0.9400	0.8810	0.8810
39	1.0000	1.000	0.9460	0.9230	0.9230
40	1.0000	1.000	0.9500	0.9660	0.9660
41	1.0000	1.000	0.9550	1.0090	1.0090
42	1.0000	1.000	0.9590	1.0530	1.0530
43	1.0000	1.000	0.9630	1.0980	1.0980
44	1.0000	1.000	0.9660	1.1440	1.1440
45	1.0000	1.000	0.9690	1.1910	1.1910
46	1.0000	1.000	0.9720	1.2390	1.2390
47	1.0000	1.000	0.9750	1.2880	1.2880
48	1.0000	1.000	0.9770	1.3370	1.3370
49	1.0000	1.000	0.9790	1.3880	1.3880
50	1.0000	1.000	0.9810	1.4390	1.4390
51	1.0000	1.000	0.9830	1.4920	1.4920
52	1.0000	1.000	0.9840	1.5450	1.5450
53	1.0000	1.000	0.9860	1.5990	1.5990
54	1.0000	1.000	0.9870	1.6540	1.6540
55	1.0000	1.000	0.9880	1.7100	1.7100
56	1.0000	1.000	0.9890	1.7660	1.7660
57	1.0000	1.000	0.9900	1.8240	1.8240
58	1.0000	1.000	0.9910	1.8820	1.8820
59	1.0000	1.000	0.9920	1.9420	1.9420
60	1.0000	1.000	0.9930	2.0020	2.0020

61	1.0000	1.000	0.9930	2.0630	2.0630
62	1.0000	1.000	0.9940	2.1260	2.1260
63	1.0000	1.000	0.9950	2.1890	2.1890
64	1.0000	1.000	0.9950	2.2520	2.2520
65	1.0000	1.000	0.9960	2.3170	2.3170
66	1.0000	1.000	0.9960	2.3830	2.3830
67	1.0000	1.000	0.9960	2.4490	2.4490
68	1.0000	1.000	0.9970	2.5170	2.5170
69	1.0000	1.000	0.9970	2.5850	2.5850
70	1.0000	1.000	0.9970	2.6540	2.6540
71	1.0000	1.000	0.9980	2.7250	2.7250
72	1.0000	1.000	0.9980	2.7960	2.7960
73	1.0000	1.000	0.9980	2.8680	2.8680
74	1.0000	1.000	0.9980	2.9400	2.9400
75	1.0000	1.000	0.9980	3.0140	3.0140
76	1.0000	1.000	0.9980	3.0890	3.0890
77	1.0000	1.000	0.9990	3.1640	3.1640
78	1.0000	1.000	0.9990	3.2400	3.2400
79	1.0000	1.000	0.9990	3.3180	3.3180
80	1.0000	1.000	0.9990	3.3960	3.3960
81	1.0000	1.000	0.9990	3.4750	3.4750
82	1.0000	1.000	0.9990	3.5550	3.5550
83	1.0000	1.000	0.9990	3.6360	3.6360
84	1.0000	1.000	0.9990	3.7180	3.7180
85	1.0000	1.000	0.9990	3.8000	3.8000
86	1.0000	1.000	0.9990	3.8840	3.8840
87	1.0000	1.000	0.9990	3.9680	3.9680
88	1.0000	1.000	1.0000	4.0530	4.0530
89	1.0000	1.000	1.0000	4.1400	4.1400
90	1.0000	1.000	1.0000	4.2270	4.2270
91	1.0000	1.000	1.0000	4.3150	4.3150
92	1.0000	1.000	1.0000	4.4040	4.4040
93	1.0000	1.000	1.0000	4.4930	4.4930
94	1.0000	1.000	1.0000	4.5840	4.5840
95	1.0000	1.000	1.0000	4.6760	4.6760
96	1.0000	1.000	1.0000	4.7680	4.7680
97	1.0000	1.000	1.0000	4.8610	4.8610
98	1.0000	1.000	1.0000	4.9560	4.9560
99	1.0000	1.000	1.0000	5.0510	5.0510
100	1.0000	1.000	1.0000	5.1470	5.1470
101	1.0000	1.000	1.0000	5.2440	5.2440
102	1.0000	1.000	1.0000	5.3410	5.3410
103	1.0000	1.000	1.0000	5.4400	5.4400

Table 4. Area (km^2), density (mt/km^2), biomass (mt) and estimated fishing mortality rates during 1989 (yr^{-1}) for shortspine and longspine thornyheads at depths of 30-700 fathoms in the Columbia, Eureka and Monterey areas. Input data are given on the first page, calculations and results on the second. The heading "NMFS HMB-1984" is used for the 1984 bottom trawl survey (F/V Half Moon Bay) conducted at depths of 100-550 fathoms between Coquille Point and Cape Falcon, Oregon by NMFS. Densities of shortspine and longspine thornyheads for NMFS HMB-1984 at depths beyond 500 fathoms were assumed equal to the survey estimates of density at 500-550 fathoms. The headings "NMFS DSJ-1987" and "NMFS DSJ-1988" are used for bottom trawl surveys (R/V David Starr Jordan) conducted at depths of 30-700 fathoms during 1987 and 1988 between Point Conception and San Francisco, California by NMFS. Data for NMFS DSJ-1987 and NMFS-DSJ-1988 were revised as described in the text. The headings "NMFS MF-88/89" and "NMFS GF-88/89" are used for bottom trawl surveys (R/V Miller Freeman and F/V Golden Fleece) conducted at depths of 100-700 fathoms between Coquille Point and Cape Falcon, by NMFS. The 1987-1989 NMFS surveys extended from 100-700 fathoms. The headings "SIO TRAWL" and "SIO CAM. SLED" are used for bottom trawl and camera sled surveys conducted off Point Sur, California at depths of 109-875 fathoms during 1984-1985 by Scripps Institute of Oceanography. Fishing mortality rates for 1989 (rows labeled "1989 F for Area") were estimated from the ratio of landings during 1989 and estimated biomass.

Table 4 (page 1)

Planar Area (km^2) for Depth Intervals (fathoms):

Depth Interval	Columbia Area	Eureka Area	Monterey Area	Totals by Interval
30-250	21,898	5,176	11,843	38,917
250-550	7,590	4,934	6,853	19,377
550-700	3,576	2,256	4,341	10,173
Totals for areas:	33,064	12,366	23,037	
			Grand Total	68,467

Landings (mt) during 1989 by species and area:

Area	Shortspine	Longspine
Columbia	1,128	584
Eureka	2,364	2,030
Monterey	1,667	8
Total	5,159	2,622

Density of shortspine thornyheads (mt/km^2) by survey and depth interval:

Depth Interval	NMFS HMB-1984	NMFS DSJ-1987	NMFS DSJ-1988	NMFS MF-88/89	NMFS GF-88/89	SIO TRAWL	SIO CAM. SLED
30-250	1.160	0.036	0.099	1.800	1.840	0.053	0.093
250-550	0.940	0.842	0.703	1.750	1.100	0.625	2.947
550-700	0.250	0.158	0.161	0.620	0.720	0.246	2.002

Density of longspine thornyheads (mt/km^2) by survey and depth interval:

Depth Interval	NMFS HMB-1984	NMFS DSJ-1987	NMFS DSJ-1988	NMFS MF-88/89	NMFS GF-88/89	SIO TRAWL	SIO CAM. SLED
30-250	0.000	0.000	0.001	0.010	0.010	0.053	0.034
250-550	1.620	1.085	1.745	5.050	5.910	5.093	7.965
550-700	0.890	0.207	0.207	2.590	2.420	0.596	0.782

Table 4 (page 2)

Biomass (mt) of shortspine thornyhead by area, survey and depth interval:

	NMFS HMB-1984	NMFS DSJ-1987	NMFS DSJ-1988	NMFS MF-88/89	NMFS GF-88/89	SIO TRAWL	SIO CAM. SLED
Columbia							
50-250	25,402	782	2,170	39,416	40,292	1,161	2,037
250-550	7,135	6,388	5,336	13,283	8,349	4,744	22,368
550-700	894	566	576	2,217	2,575	880	7,159
Total for Area	33,430	7,736	8,082	54,916	51,216	6,784	31,563
1989 F for Area	0.03	0.15	0.14	0.02	0.02	0.17	0.04
Eureka							
50-250	6,004	185	513	9,317	9,524	274	481
250-550	4,638	4,152	3,469	8,635	5,427	3,084	14,540
550-700	564	357	363	1,399	1,624	555	4,517
Total for Area	11,206	4,694	4,345	19,350	16,576	3,913	19,538
1989 F for Area	0.21	0.50	0.54	0.12	0.14	0.60	0.12
Monterey							
50-250	13,738	423	1,174	21,317	21,791	628	1,101
250-550	6,442	5,767	4,818	11,993	7,538	4,283	20,196
550-700	1,085	687	699	2,691	3,126	1,068	8,691
Total for Area	21,265	6,877	6,690	36,002	32,455	5,979	29,988
1989 F for Area	0.08	0.24	0.25	0.05	0.05	0.28	0.06
All Areas:							
Grand Total Biomass	65,901	19,307	19,117	110,268	100,247	16,676	81,090
1989 F for Area	0.08	0.27	0.27	0.05	0.05	0.31	0.06

Biomass (mt) of longspine thornyhead by area, survey and depth interval:

	NMFS HMB-1984	NMFS DSJ-1987	NMFS DSJ-1988	NMFS MF-88/89	NMFS GF-88/89	SIO TRAWL	SIO CAM. SLED
Columbia							
50-250		0	28	219	219	1,161	745
250-550	12,296	8,233	13,245	38,330	44,857	38,656	60,454
550-700	3,183	740	740	9,262	8,654	2,131	2,796
Total for Area	15,478	8,973	14,013	47,810	53,730	41,948	63,995
1989 F for Area	0.04	0.07	0.04	0.01	0.01	0.01	0.01
Eureka							
50-250		0	7	52	52	274	176
250-550	7,993	5,352	8,610	24,917	29,160	25,129	39,299
550-700	2,008	467	467	5,843	5,460	1,345	1,764
Total for Area	10,001	5,819	9,083	30,812	34,671	26,748	41,239
1989 F for Area	0.20	0.35	0.22	0.07	0.06	0.08	0.05
Monterey							
50-250		0	15	118	118	628	403
250-550	11,102	7,433	11,958	34,608	40,501	34,902	54,584
550-700	3,863	899	898	11,243	10,505	2,587	3,395
Total for Area	14,965	8,332	12,872	45,969	51,125	38,117	58,381
1989 F for Area	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Areas:							
Grand Total Biomass	40,445	23,124	35,967	124,591	139,526	106,813	163,616
1989 F for Area	0.06	0.11	0.07	0.02	0.02	0.02	0.02

Figure 1. Landings data (mt) by area for the thornyhead market category, 1981-1989.

TLAND90.XLC

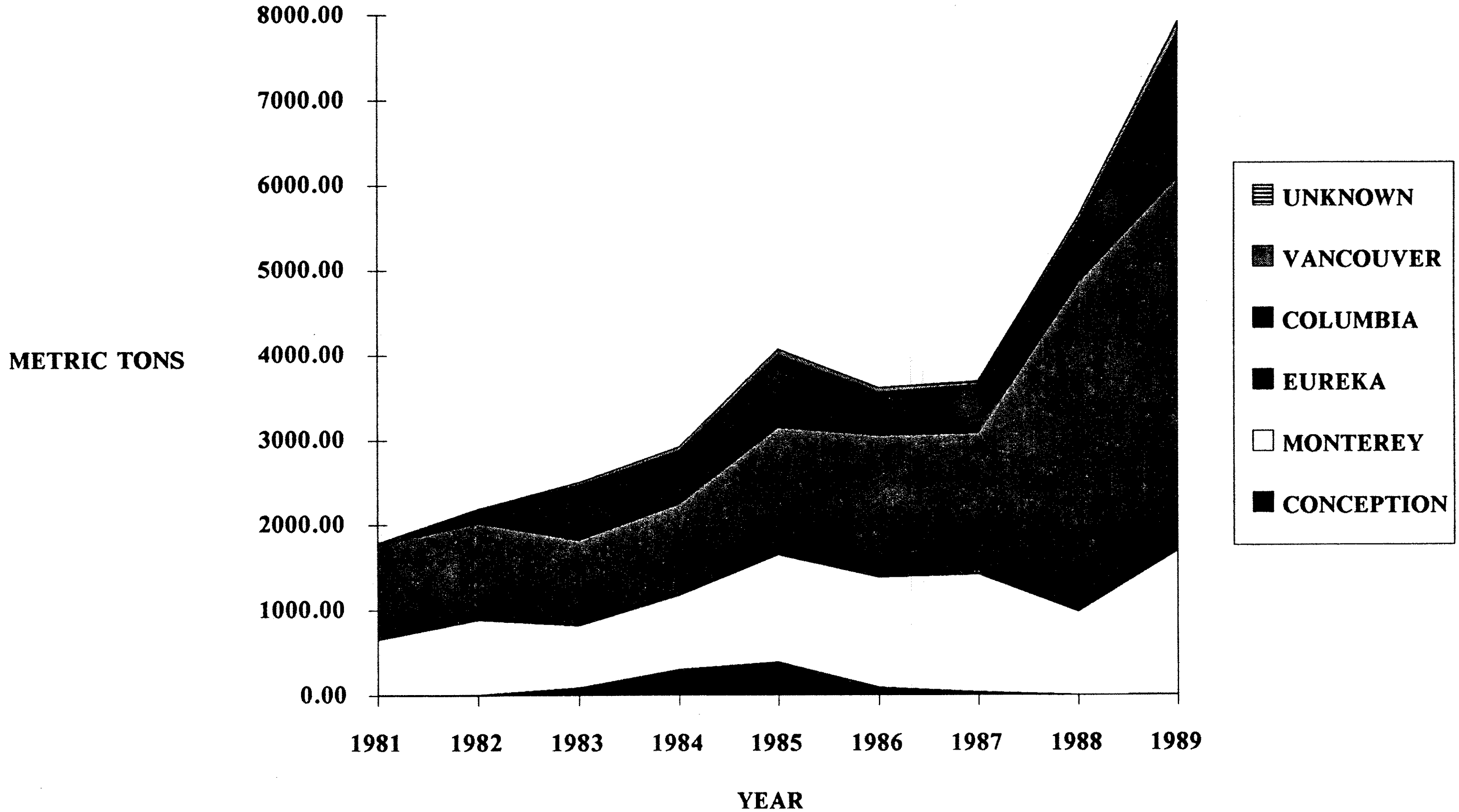

METRIC TONS
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
1981
1982
1983
1984
1985
1986
1987
1988
1989
YEAR
UNKNOWN
VANCOUVER
COLUMBIA
EUREKA
MONTEREY
CONCEPTION

Figure 2. Coastwide landings data (mt) by species for thornyheads, 1981-1989.

THORNY90.XLC

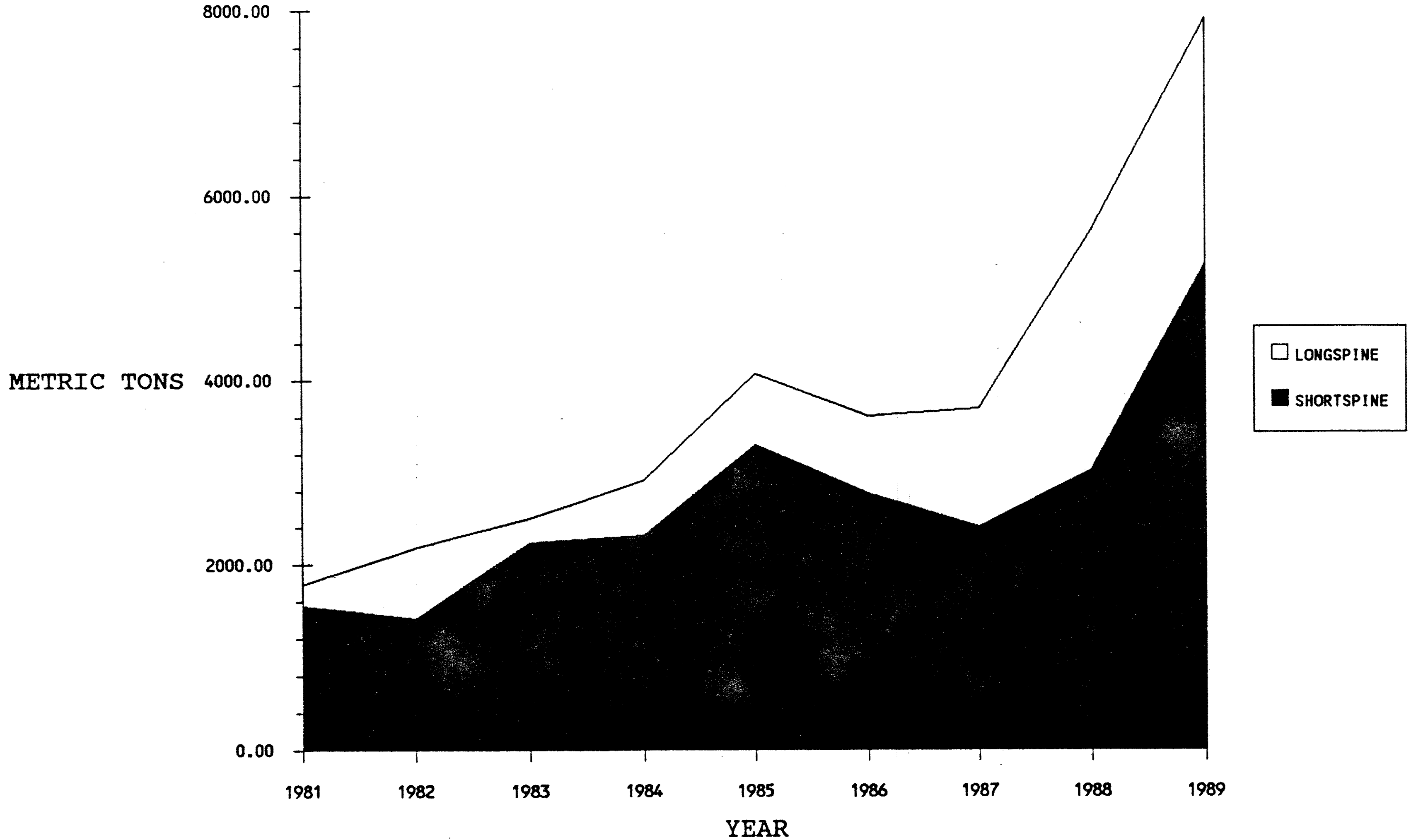


Figure 3. Landings (mt) by market categories for the deepwater dover complex, 1981-1989.

DWDCAT1.XLC

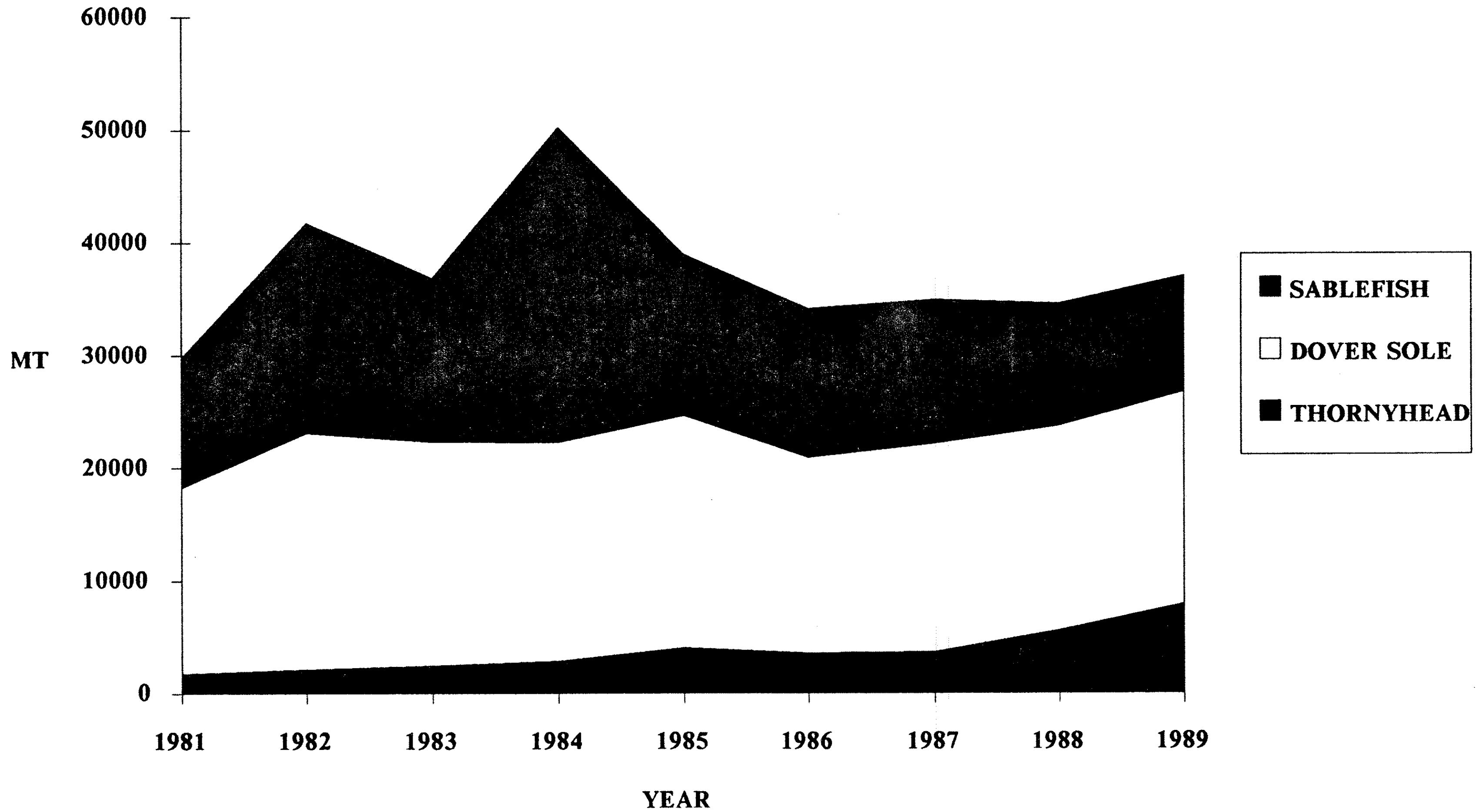

60000
50000
40000
30000
20000
10000
0
MT
1981
1982
1983
1984
1985
1986
1987
1988
1989
YEAR
SABLEFISH
DOVER SOLE
THORNYHEAD

Figure 4. Revenues (1989 $) by market categories for the deepwater dover complex.

DWDREVNU.XLC

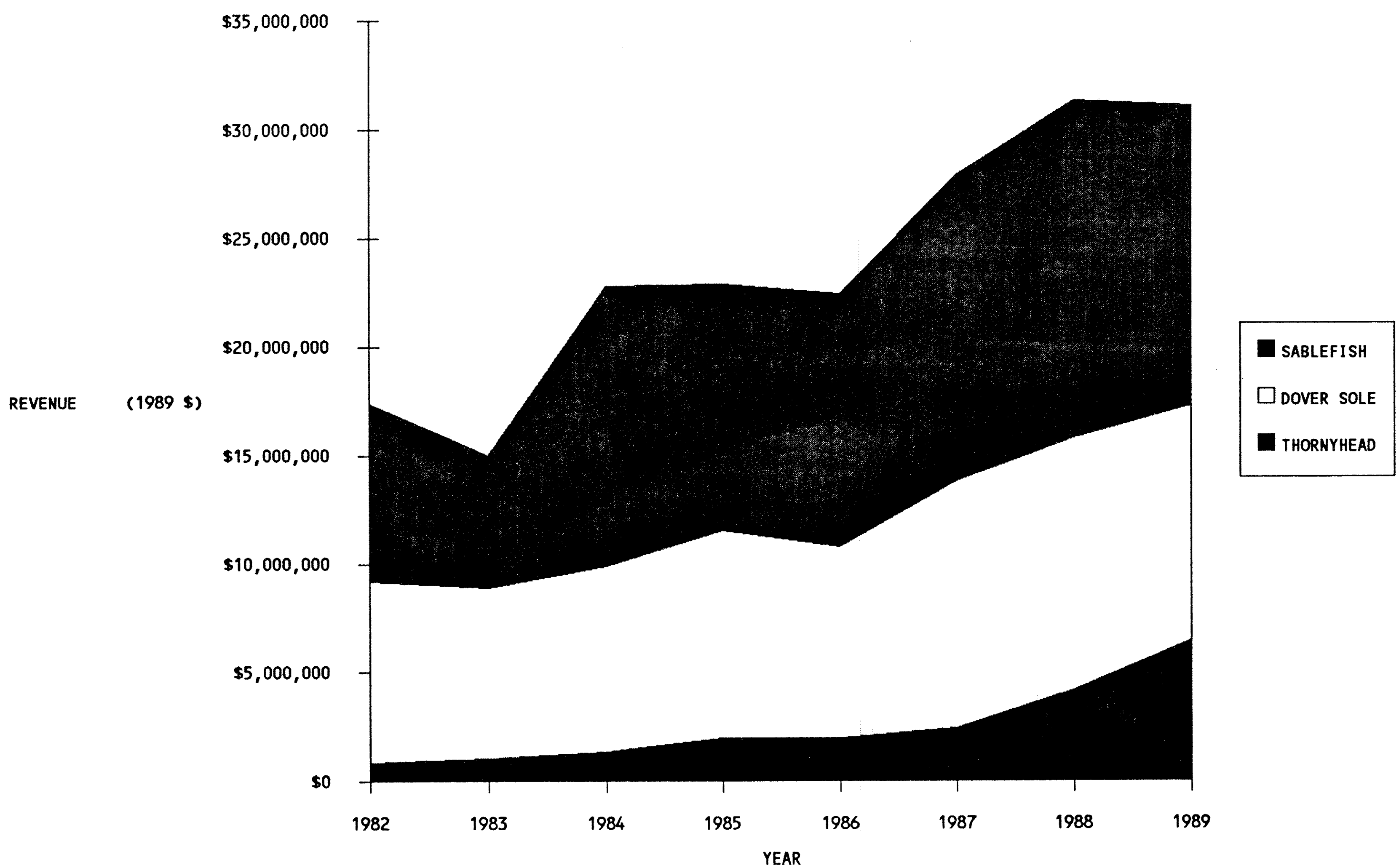
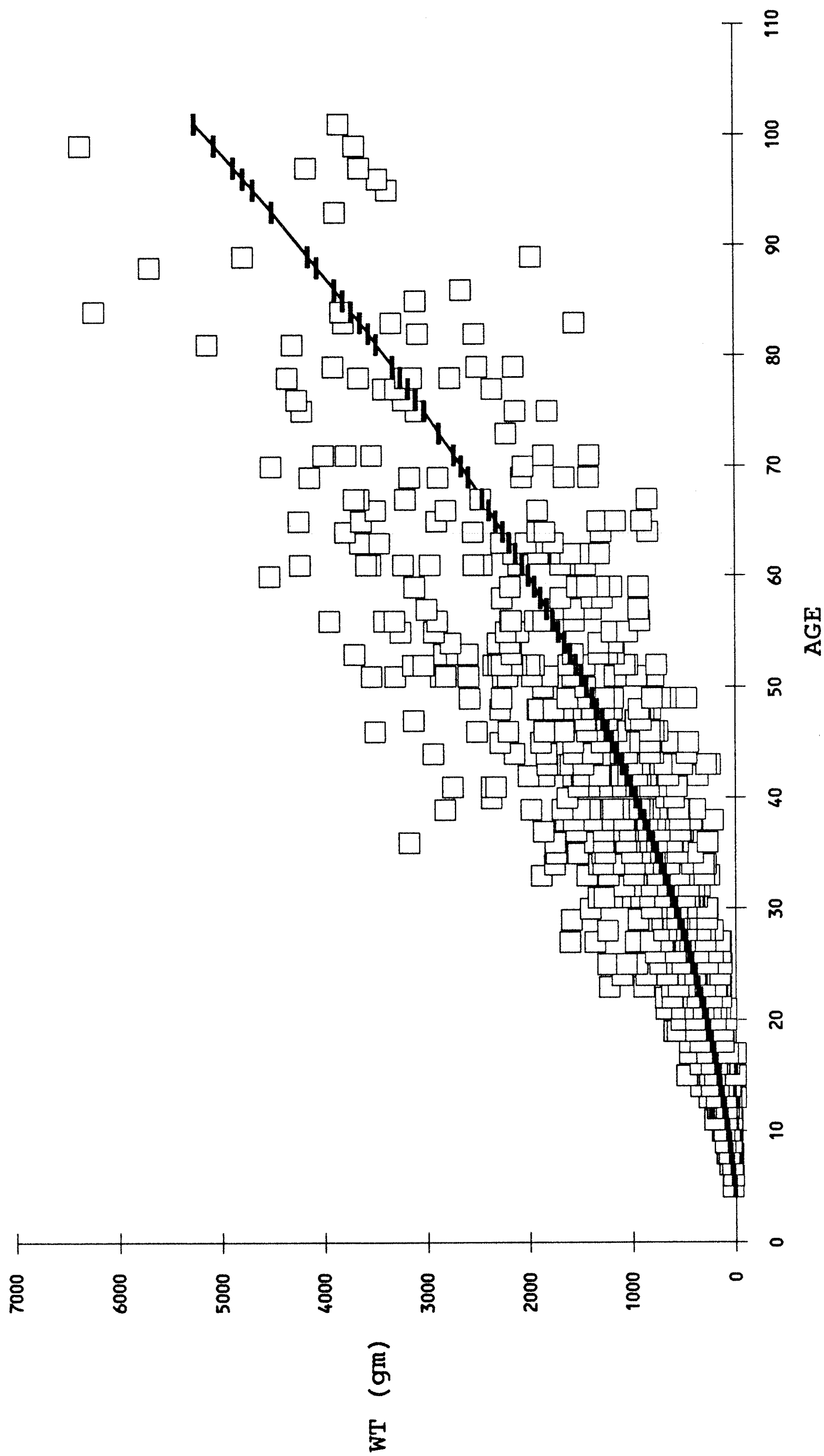


Figure 5. Observed and predicted round weights (gm) at age for shortspine thornyheads.

WTAGE.XLC



WT (gm)
AGE
0
1000
2000
3000
4000
5000
6000
7000
0
10
20
30
40
50
60
70
80
90
100
110

Figure 6. Observed and predicted total length (mm) at age for shortspine thornyheads.

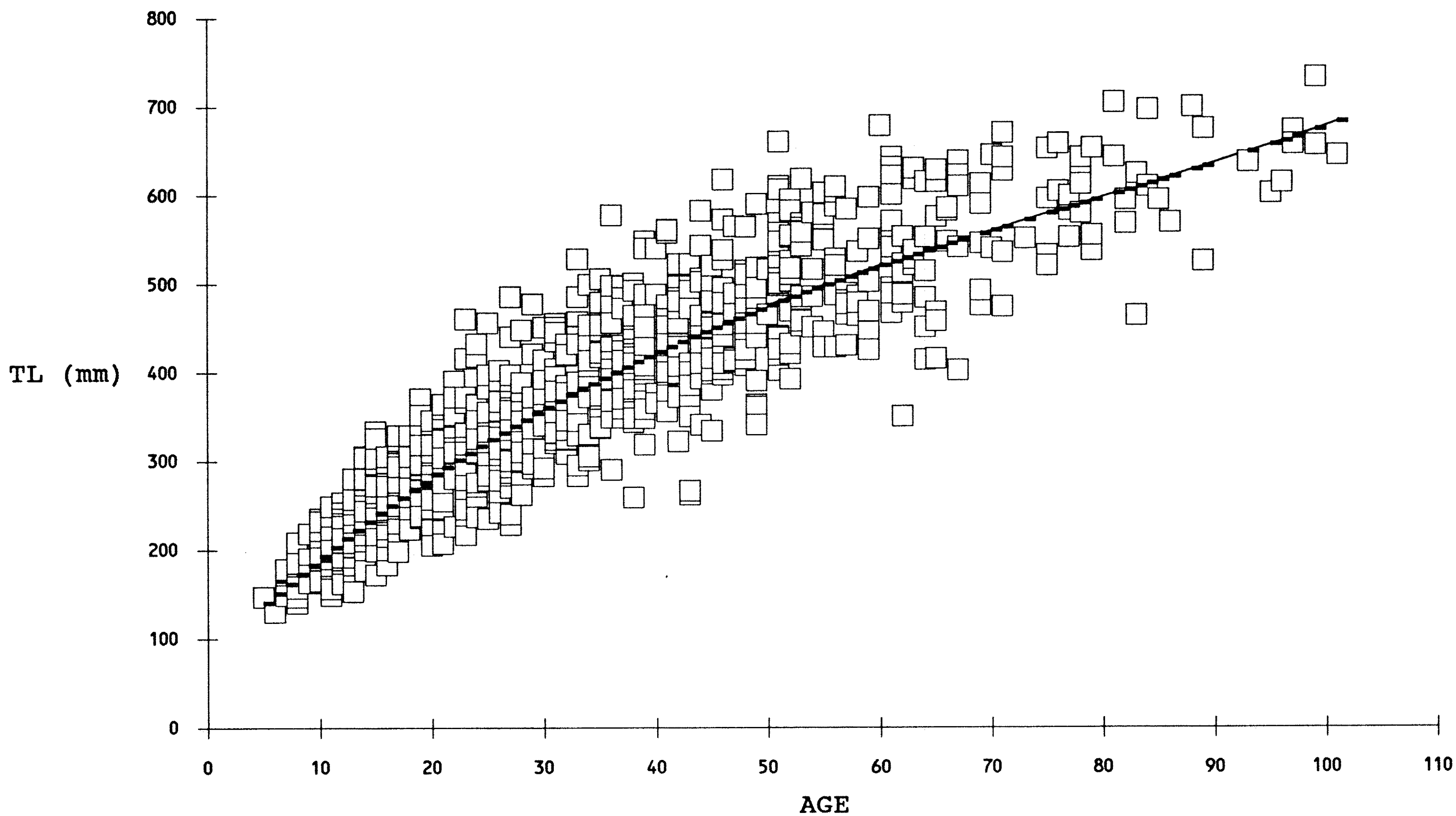

TL (mm)
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
110
AGE

Figure 7. Observed and predicted fraction mature at age for shortspine thornyheads.

MATURITY.XLC

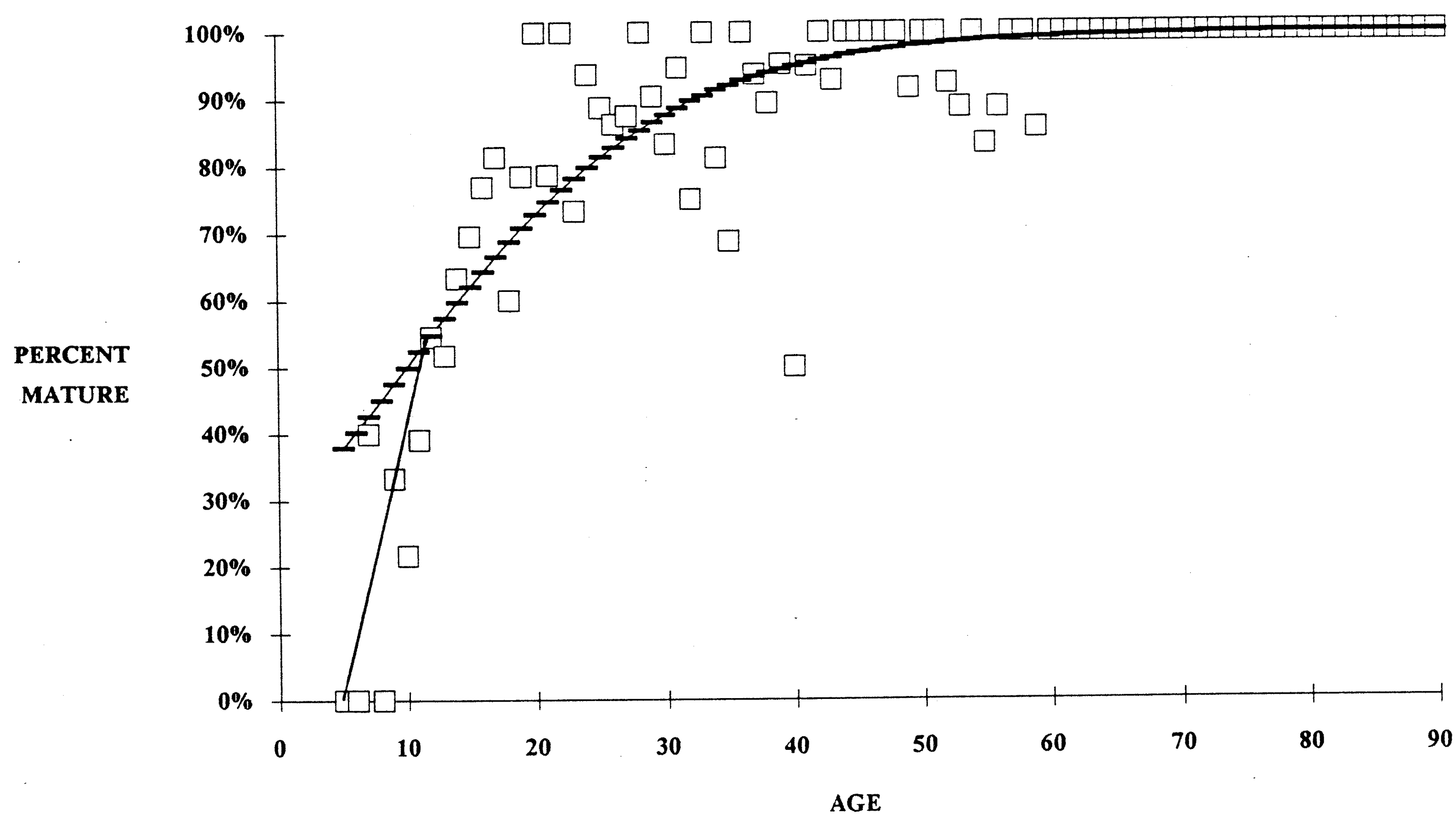


Figure 8. Length composition data for shortspine thornyhead landed at Eureka and Fort Bragg during 1978-1987 (from CDFG port samples).

SHORTLEN.XLC

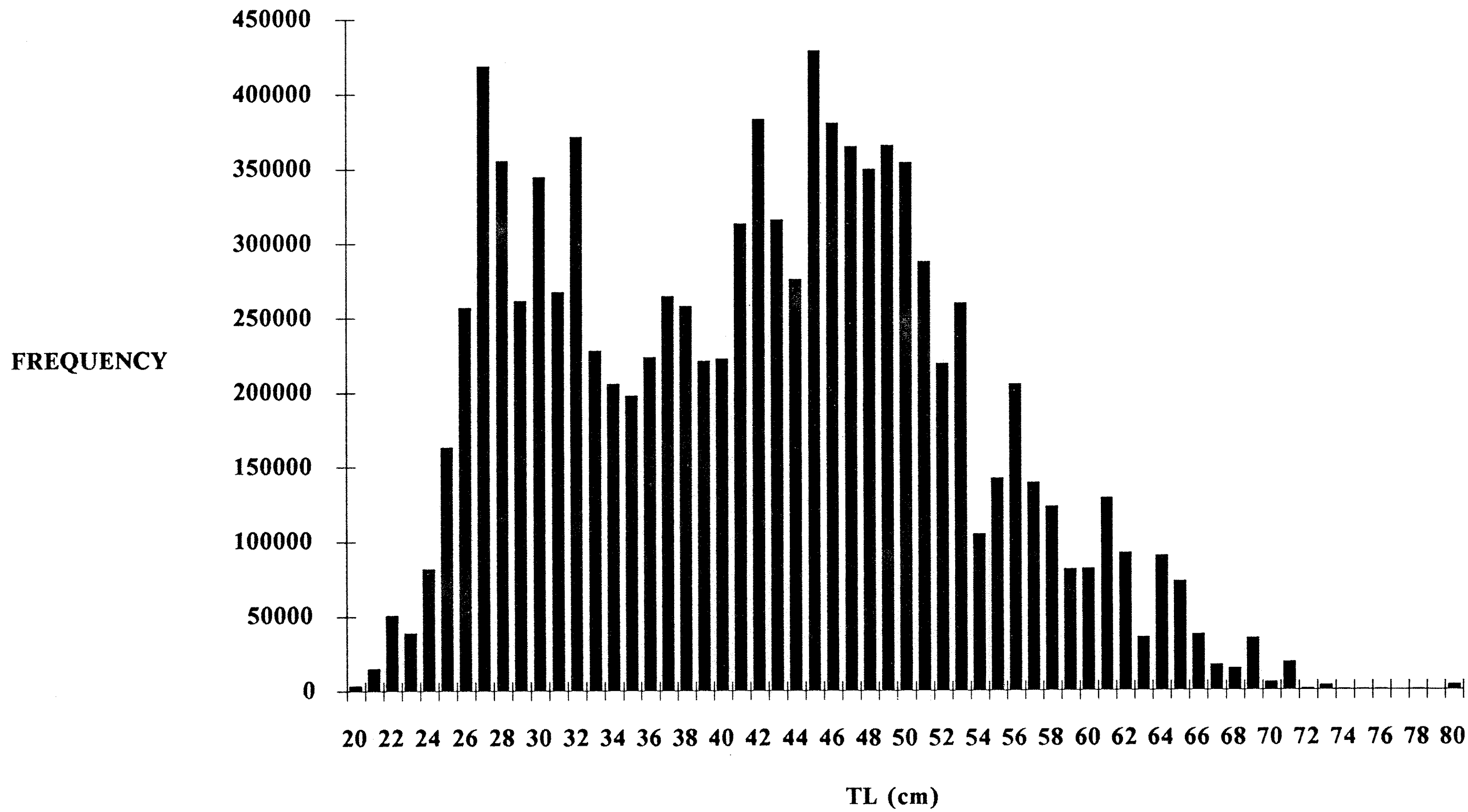
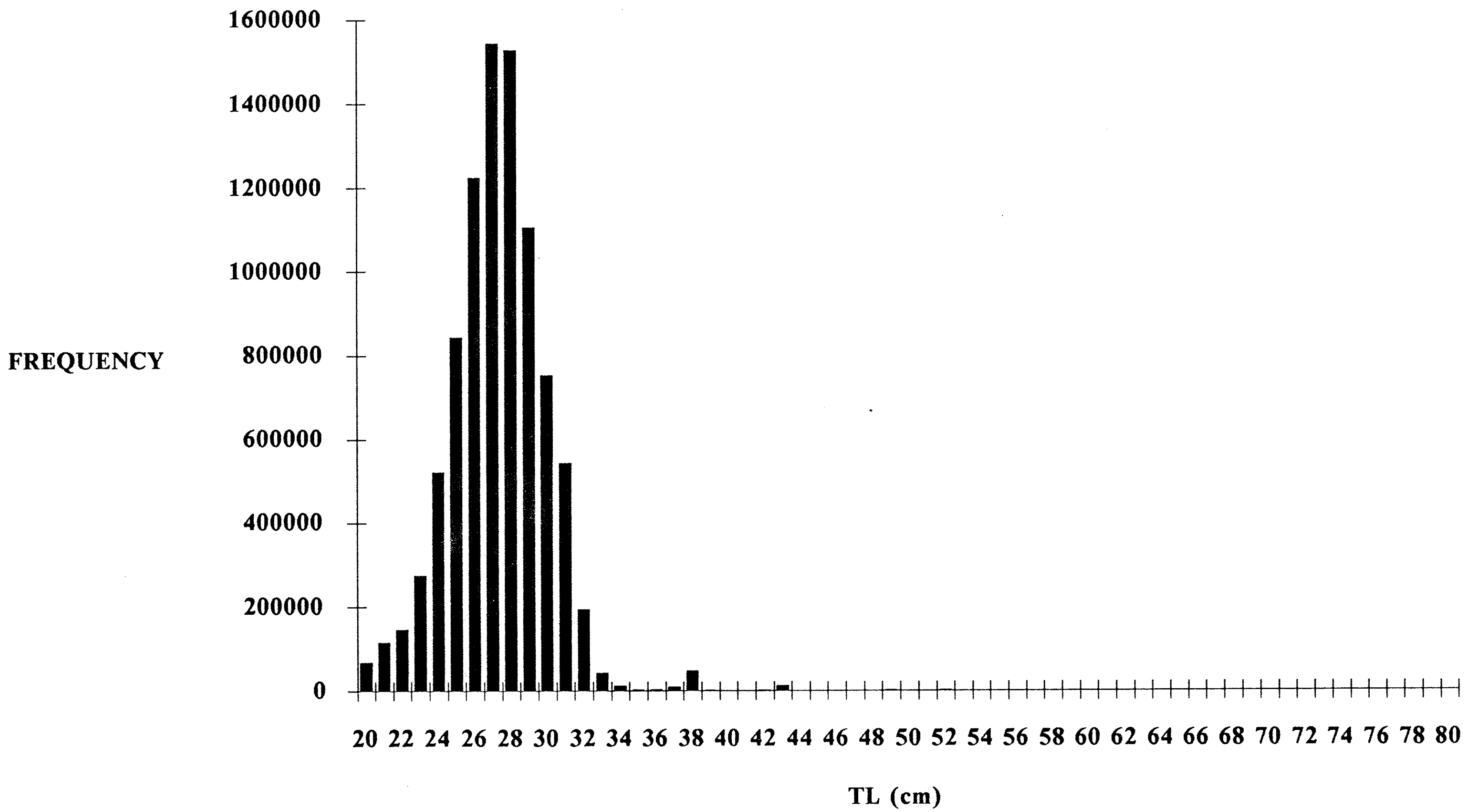


Figure 9. Length composition data for longspine thornyhead landed at Eureka and Fort Bragg during 1978-1987 (from CDFG port samples).

LONGLEN.XLC



FREQUENCY
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80
TL (cm)

Figure 10. Length composition data for shortspine thornyheads collected by observers onboard commercial fishing vessels. The data are for fish taken from the Eureka Area during 1988-1989 by bottom trawls with 3 inch mesh in the codends and at depths >= 200 fathoms.

3INCHALL.XLC

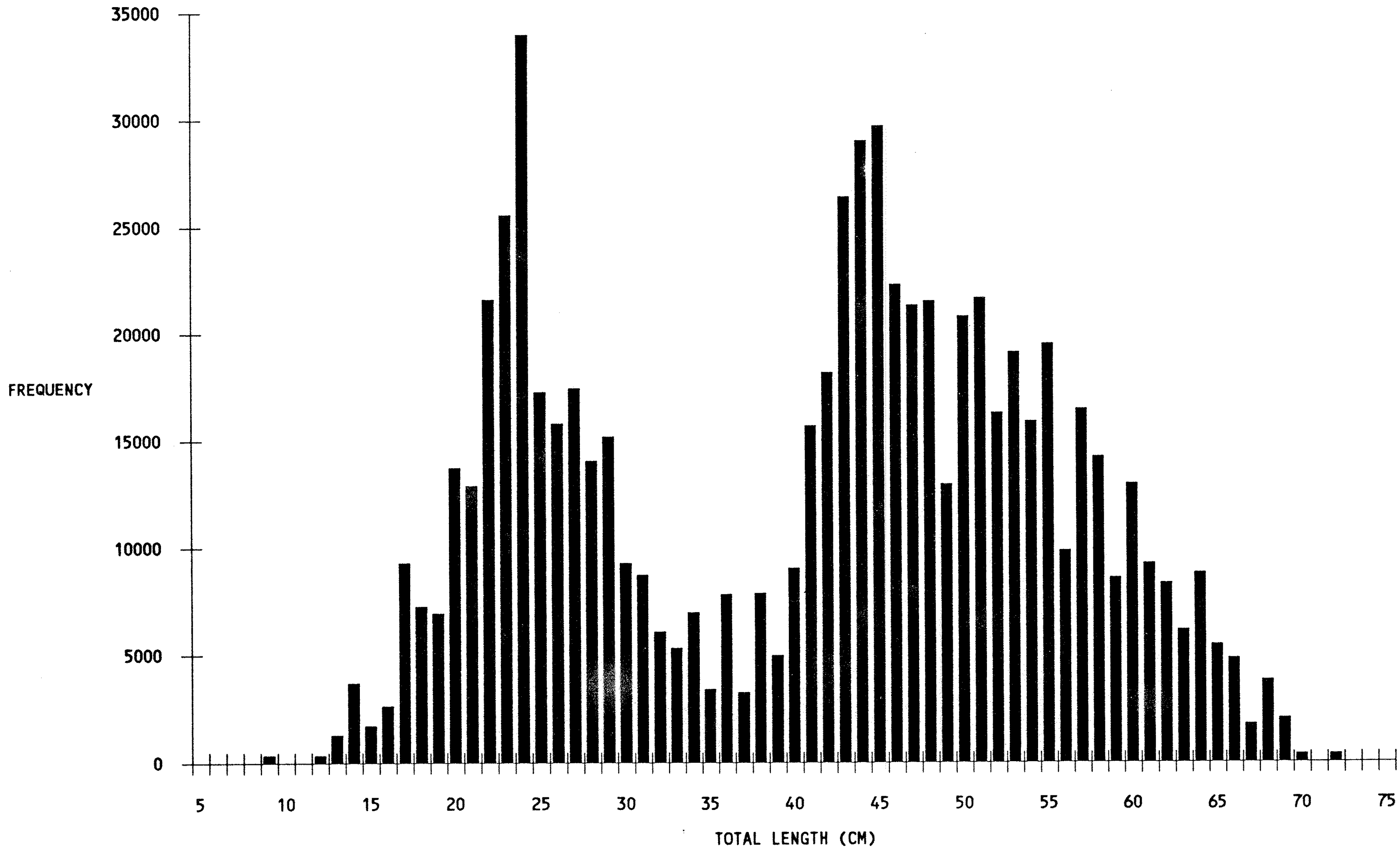


Figure 11. Length composition data for shortspine thornyheads collected by observers onboard commercial fishing vessels. The data are for fish taken from the Eureka Area during 1988-1989 by bottom trawls with 3 inch mesh in the codends and at depths between 200 and 299 fathoms.

SS200300.XLC

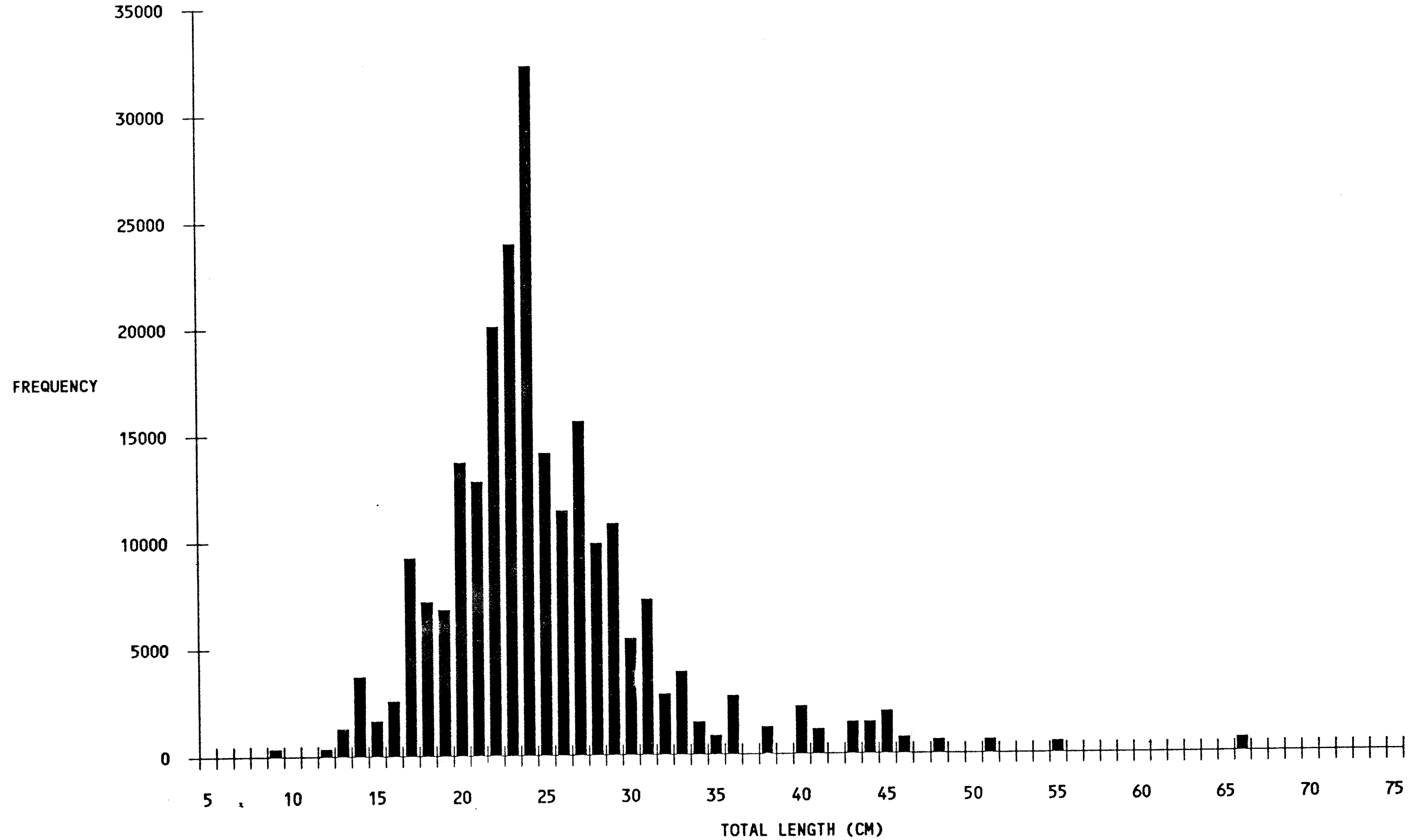


Figure 12. Length composition data for shortspine thornyheads collected by observers onboard commercial fishing vessels. The data are for fish taken from the Eureka Area during 1988-1989 by bottom trawls with 3 inch mesh in the codends and at depths >= 300 fathoms.

SS300PLS.XLC

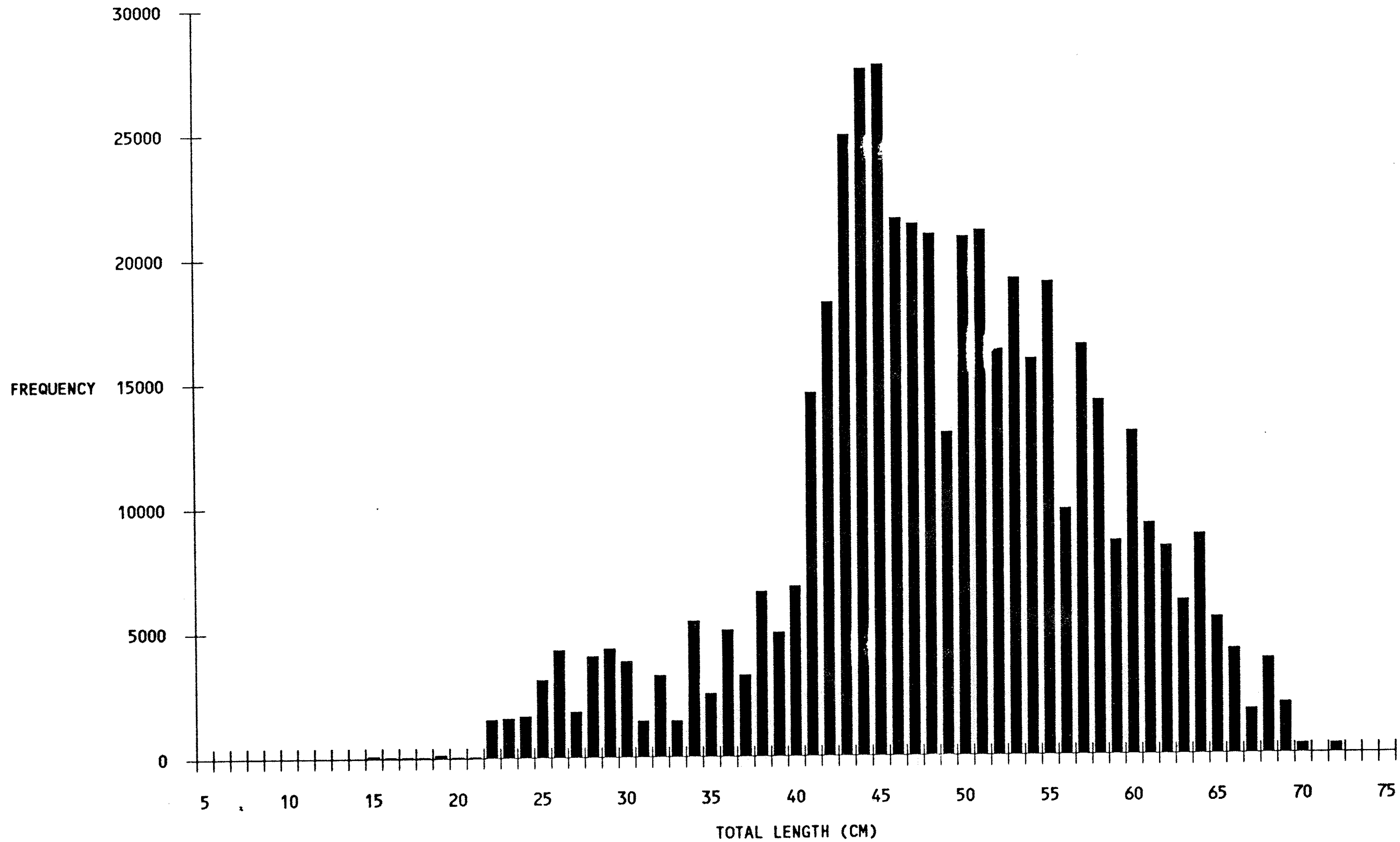


Figure 13. Percent thornyheads by weight for bottom trawl tows in the Eureka area during 1978-1984.

PERCENT1.XLC

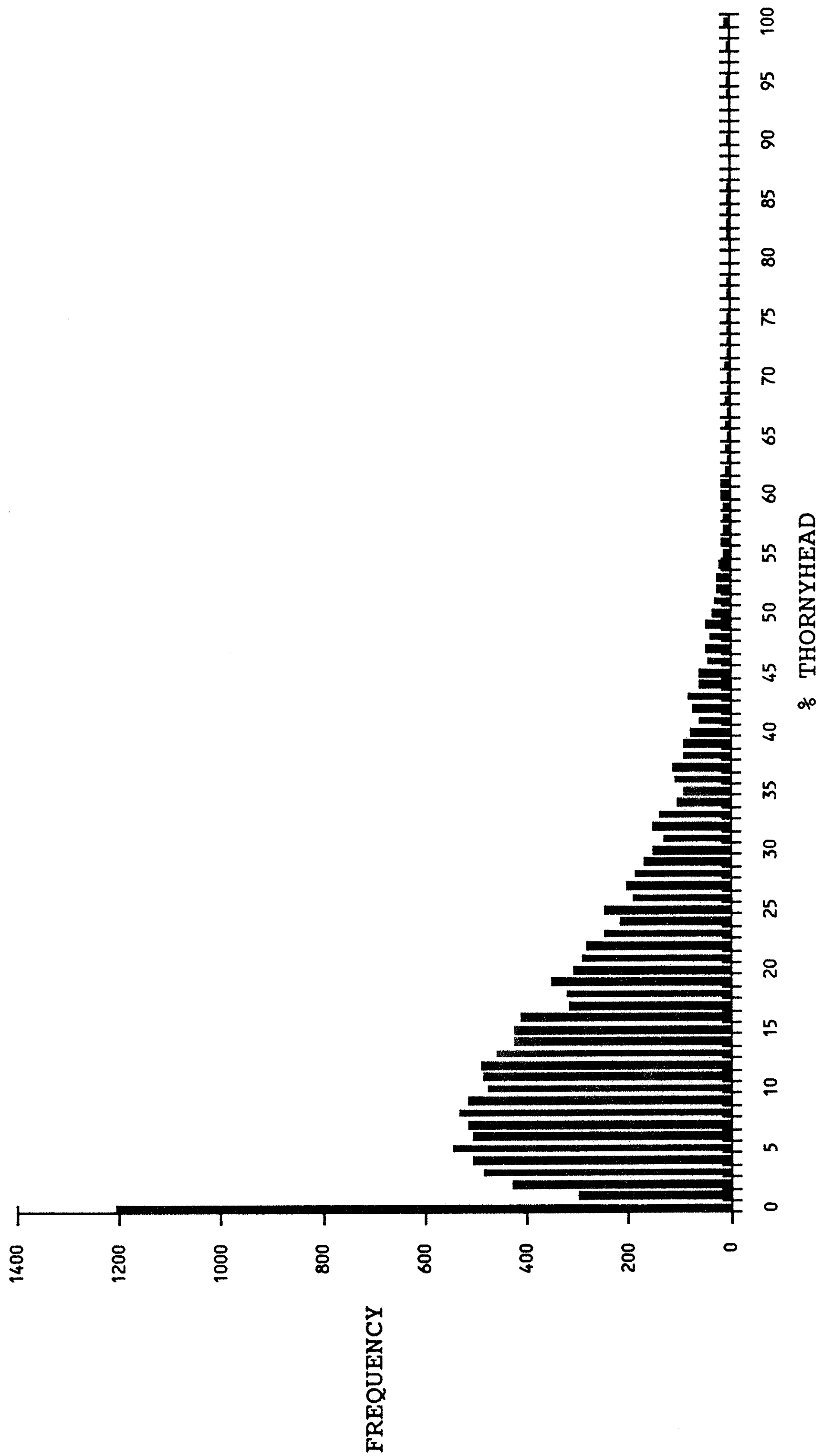


Figure 14. Percent thornyheads by weight for bottom trawl tows in the Eureka area during 1985-1987.

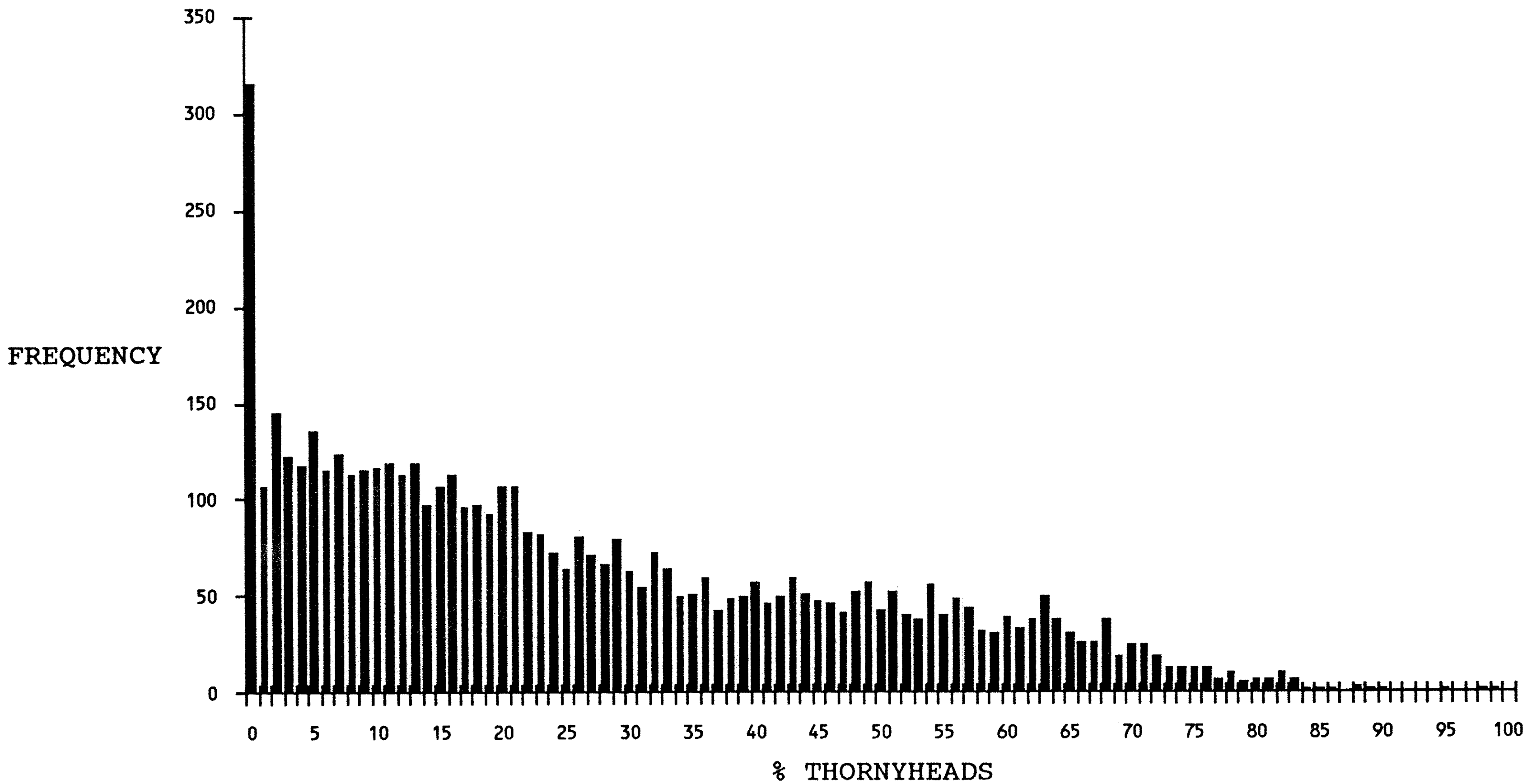
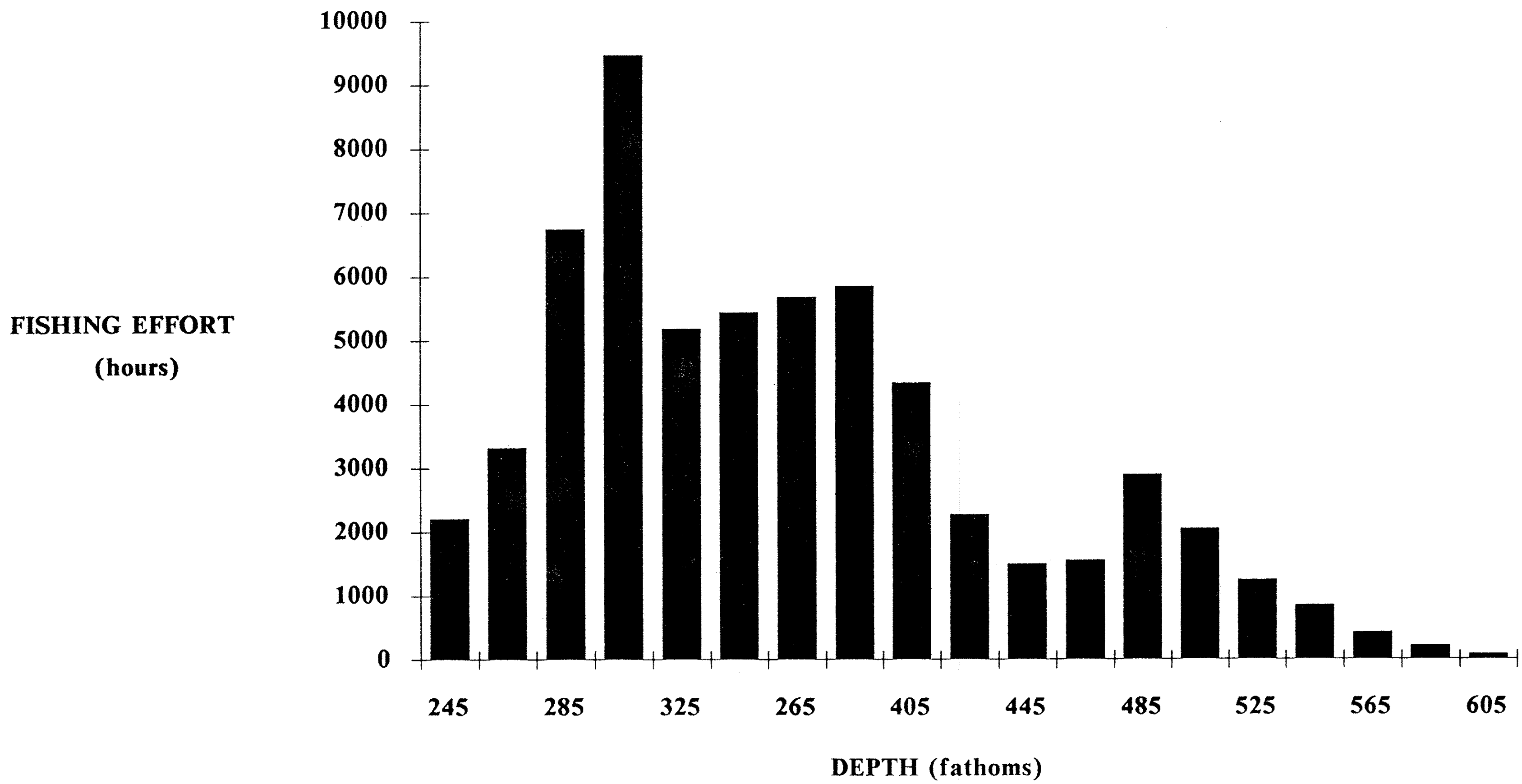

FREQUENCY
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
% THORNYHEADS

Figure 15. Fishing effort (hours fished) by depth for tows that caught thornyheads in the Eureka area during 1978-1984.

DEPTH1.XLC



FISHING EFFORT
(hours)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
245
285
325
265
405
445
485
525
565
605
DEPTH (fathoms)

Figure 16. Fishing effort (hours fished) by depth for tows that caught thornyheads in the Eureka area during 1985-1987.

DEPT8587.XLC

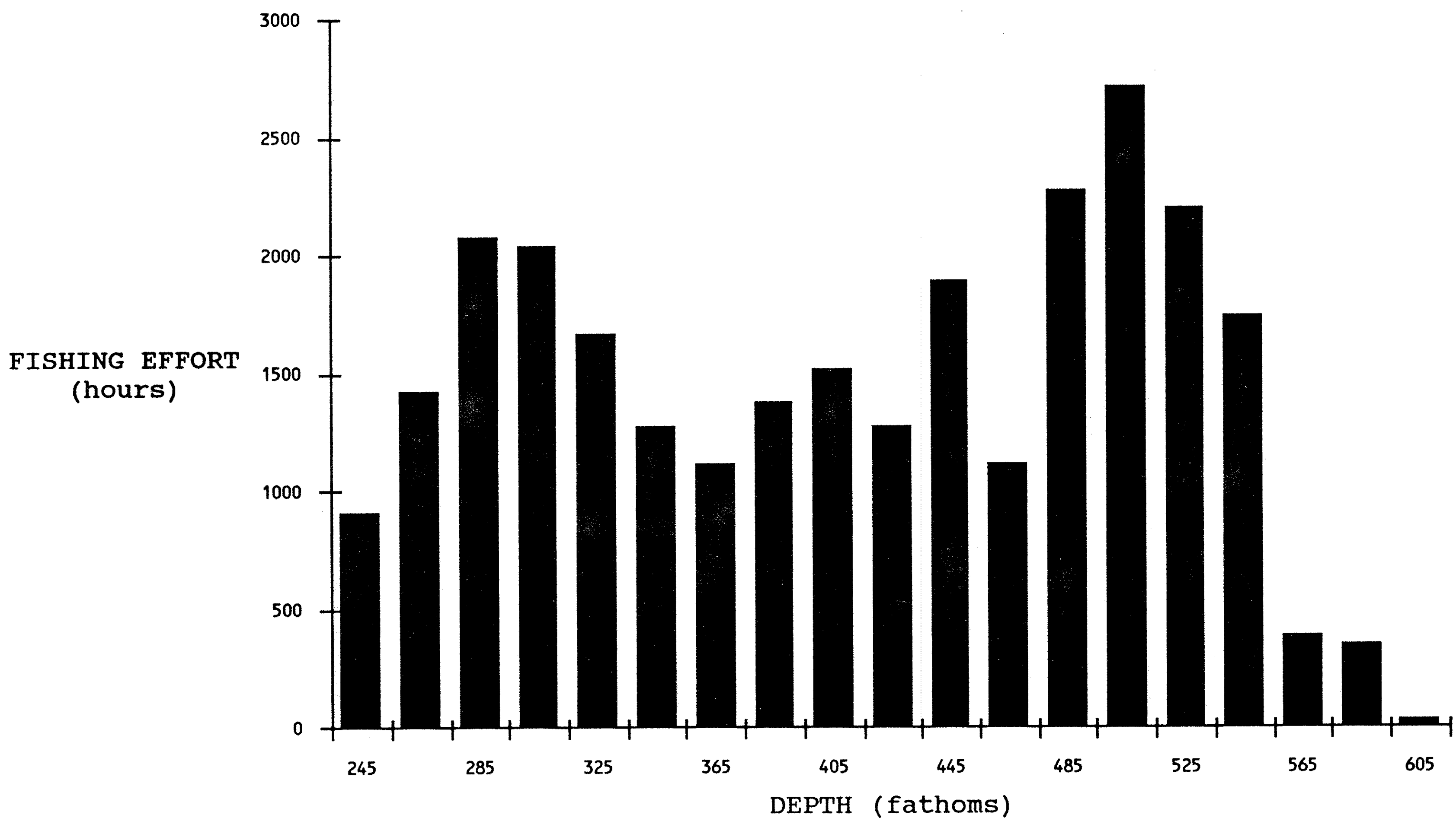


Figure 17. CPUE data (mt/hr) for the thornyhead market category during 1978-1987.

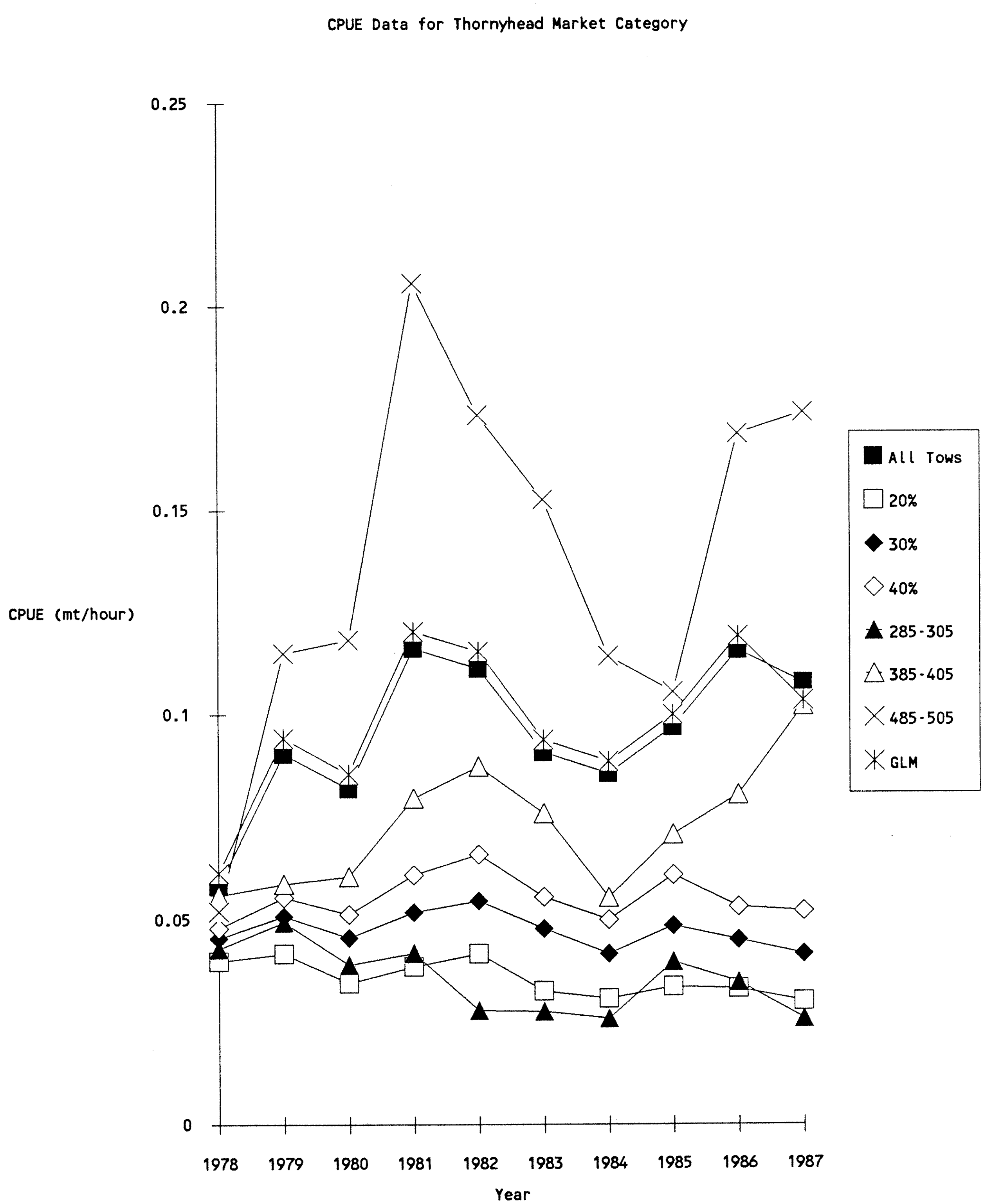

CPUE Data for Thornyhead Market Category
CPUE (mt/hour)
0.25
0.2
0.15
0.1
0.05
0
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
Year
All Tows
20%
30%
40%
285-305
385-405
485-505
GLM

Figure 18. CPUE data (mt/hr) for shortspine thornyhead >= 40 cm TL during 1978-1987.

CPUE Data for Shortspine Thornyheads (>= 40 cm TL)

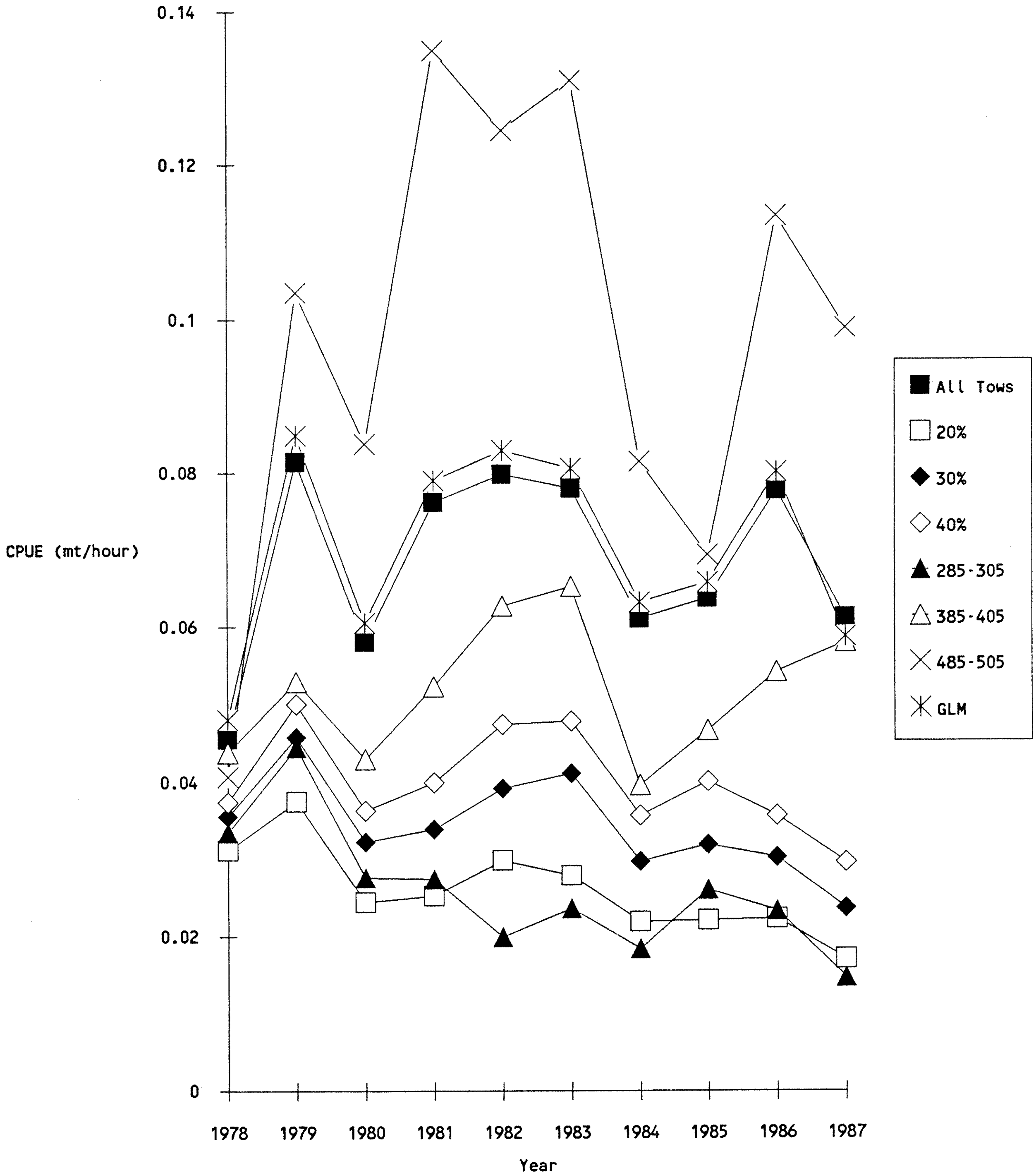


Figure 19. Length composition data for shortspine thornyheads collected by observers onboard commercial fishing vessels. The data are for fish taken from the Eureka Area during 1988-1989 by bottom trawls with 4.5 inch mesh in the codends and at depths >= 200 fathoms.

4INCHALL.XLC

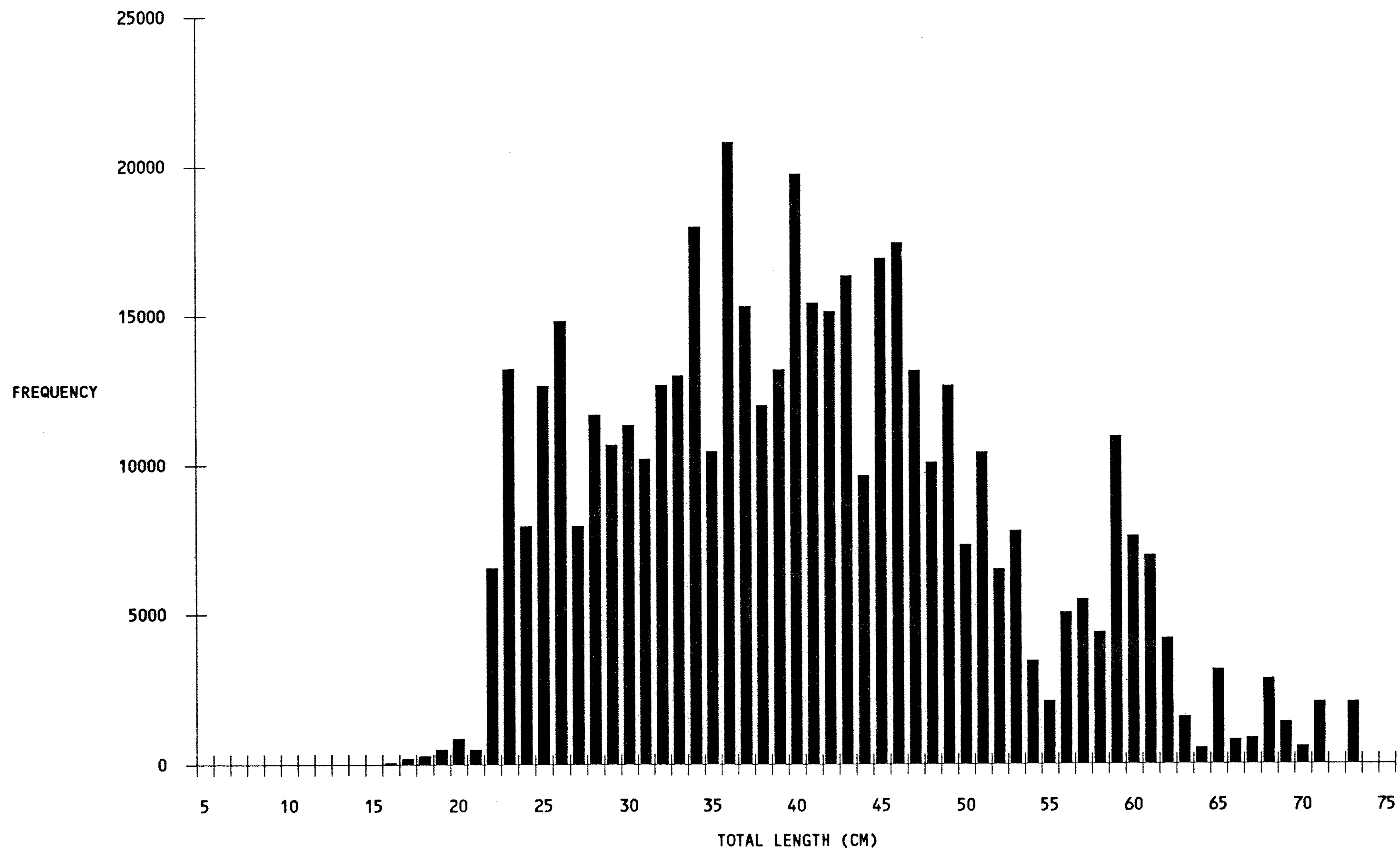


Figure 20. Length composition data for shortspine thornyheads collected by observers onboard commercial fishing vessels. The data are for fish taken from the Eureka Area during 1988-1989 by bottom trawls with 5.5 inch mesh in the codends and at depths >= 200 fathoms.

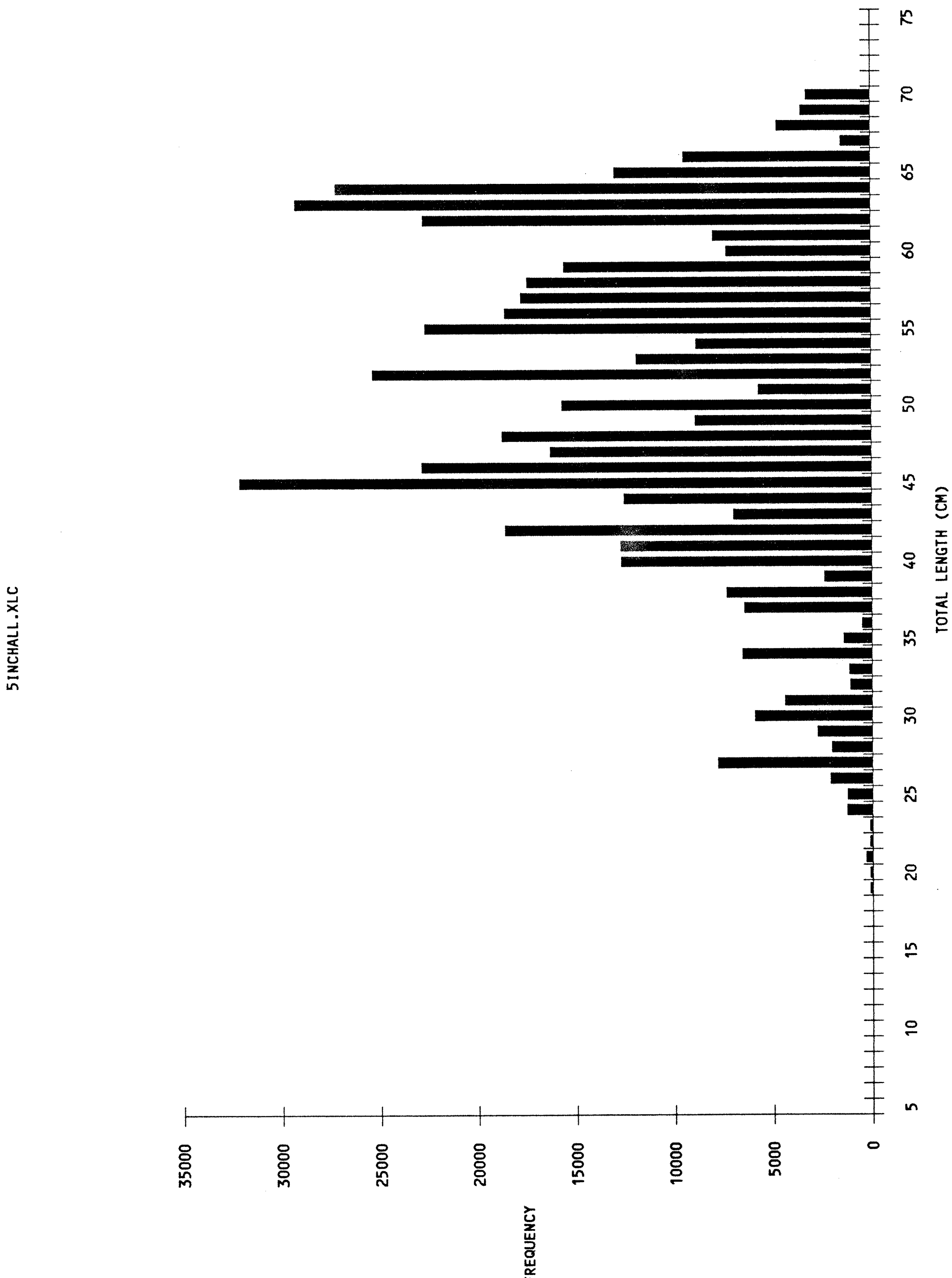

5INCHALL.XLC
FREQUENCY
35000
30000
25000
20000
15000
10000
5000
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
TOTAL LENGTH (CM)

Figure 21. Yield and spawning biomass per recruit for shortspine thornyhead ($M = 0.03\ yr^{-1}$).

Yield and Spawner Biomass Per Recruit, M=0.03

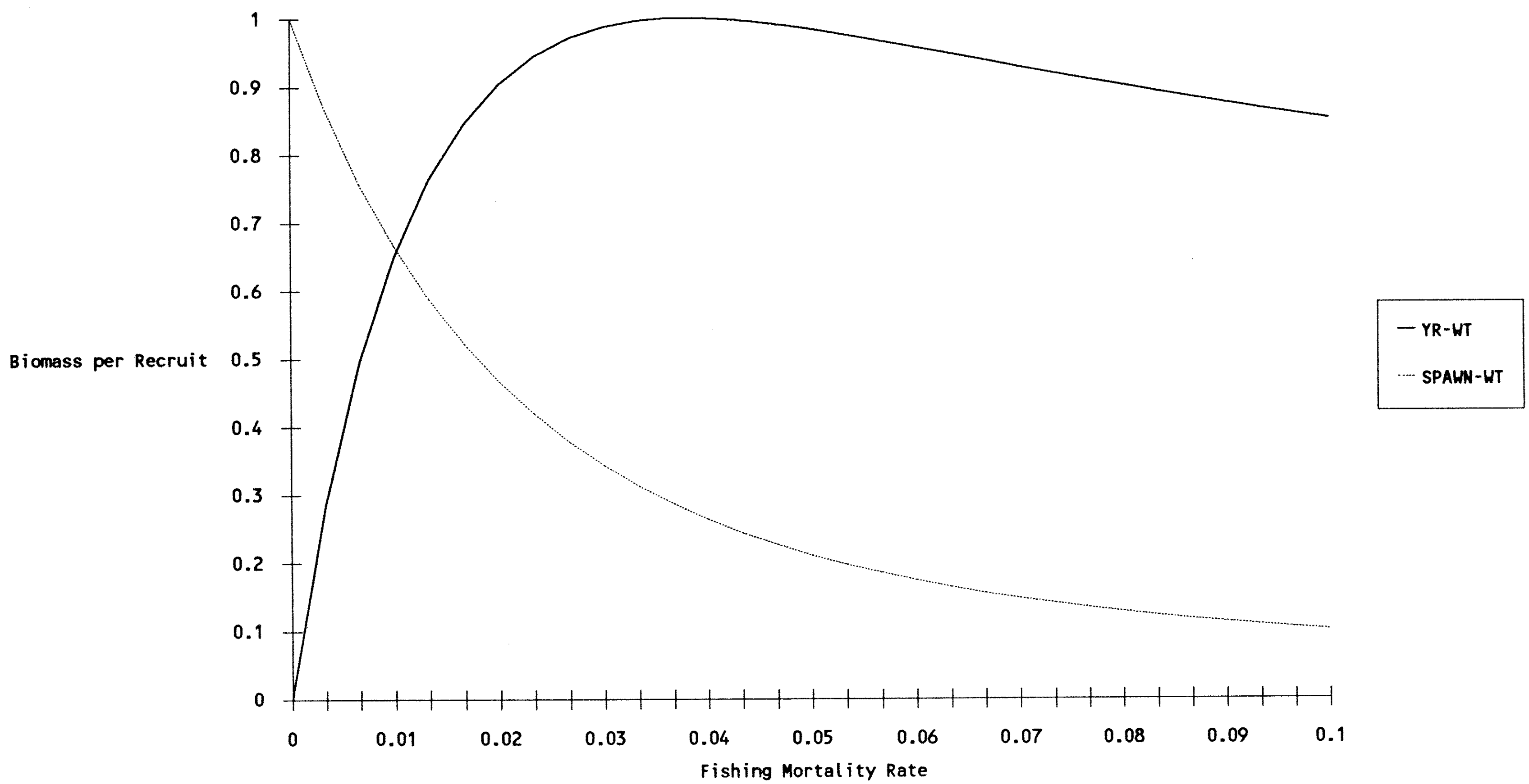


Figure 22. Yield and spawning biomass per recruit for shortspine thornyhead ($M = 0.045\ yr^{-1}$).

Yield and Spawner Biomass Per Recruit, M=0.045

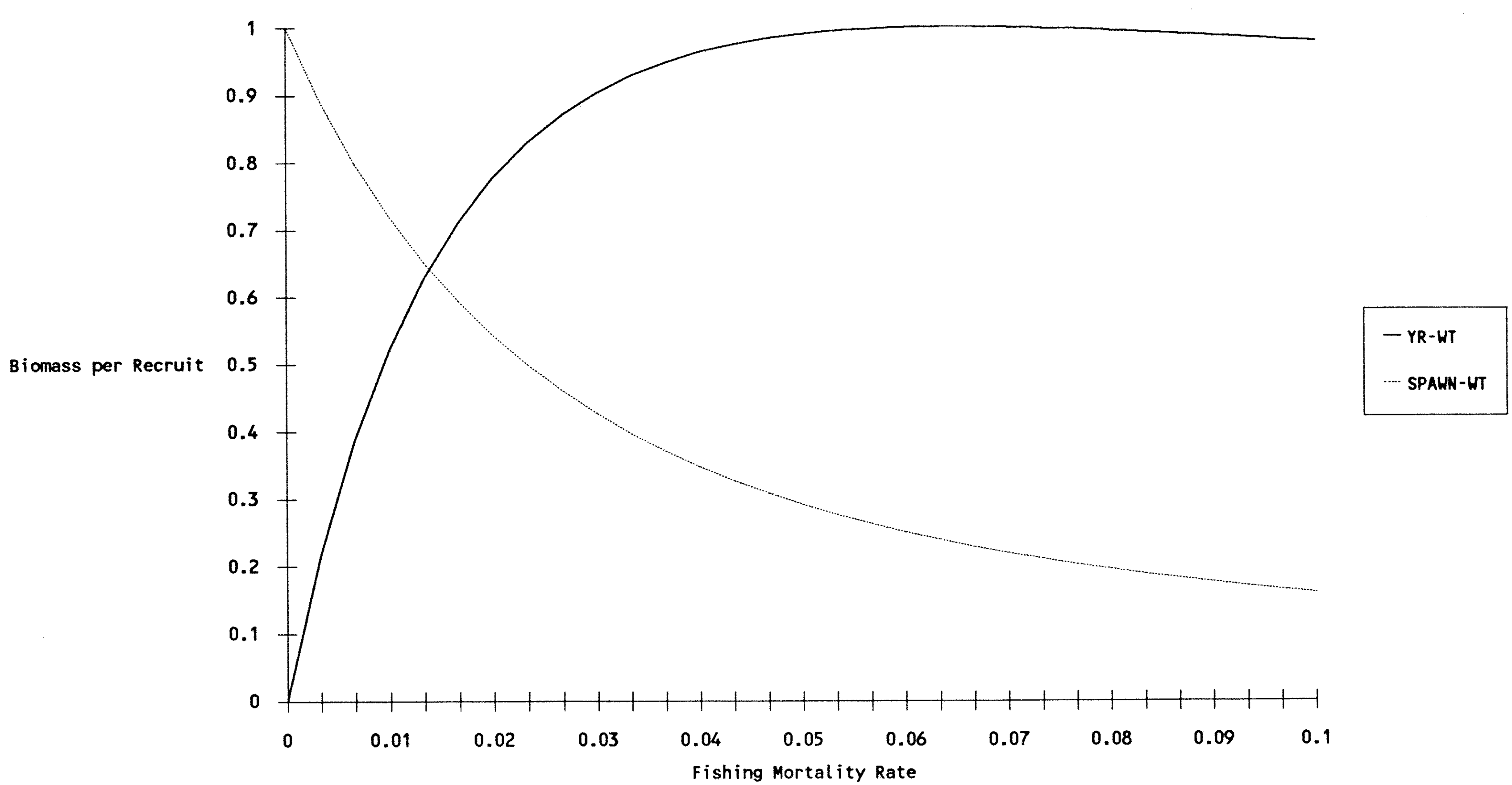


Figure 23. Yield and spawning biomass per recruit for shortspine thornyhead ($M = 0.06\ yr^{-1}$).

Yield and Spawner Biomass Per Recruit, M=0.06

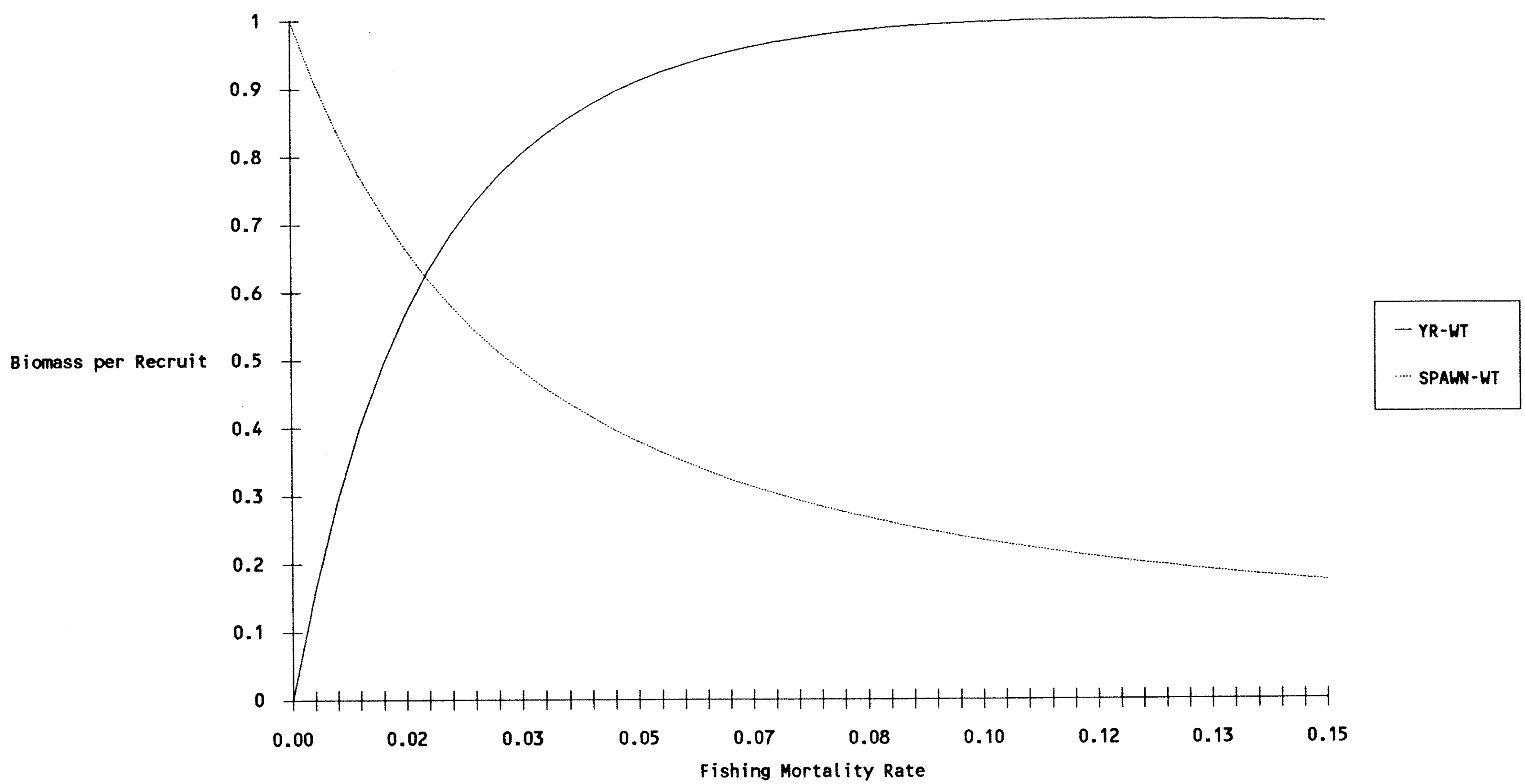
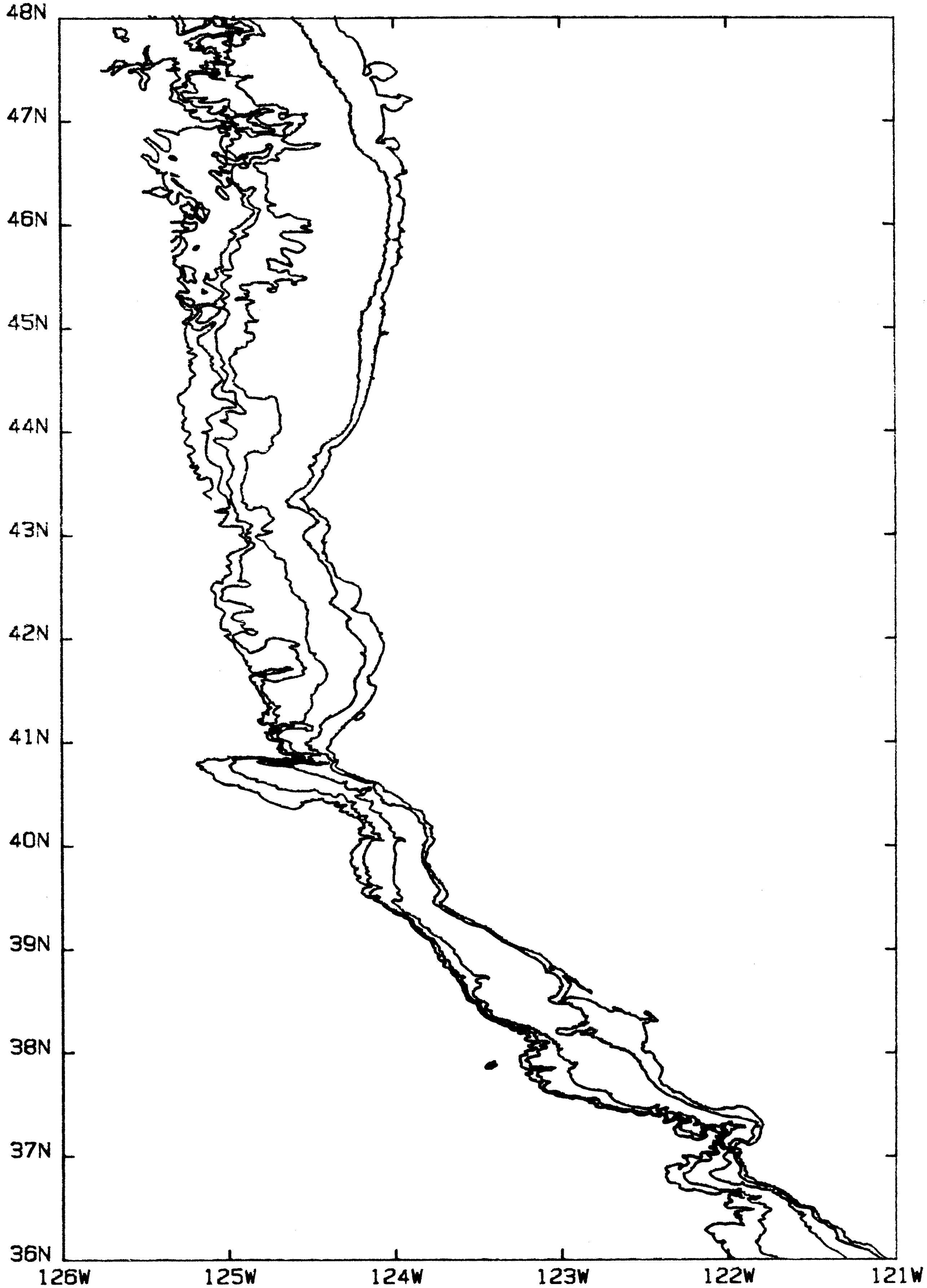


Figure 24. Thornyhead habitat along the coast of Washington, Oregon and California (contours at 0, 30, 250, 550, 700 and 1,000 fathoms).

Piedras Blancas - C. Elizabeth



STATUS OF THE PACIFIC COAST GROUNDFISH FISHERY THROUGH 1990 AND RECOMMENDED ACCEPTABLE BIOLOGICAL CATCHES FOR 1991

Stock Assessment and Fishery Evaluation

Pacific Fishery Management Council
Metro Center, Suite 420
2000 S.W. First Avenue
Portland, Oregon

October 1990