THORNYHEADS--STOCK ASSESSMENT FOR 1991

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Abstract

Coastwide landings in the thornyhead market category during 1990 exceeded 10,000 mt during 1990 and were up from almost 8,000 mt in 1989. For the first time, longspine thornyheads accounted for the bulk of total landings (6000 mt or 60% of total landings during 1990). Concurrent with increases in landings and exvessel prices, revenues from the thornyhead fishery increased to $8.8 million (1989 dollars) during 1990. In 1990, thornyheads accounted for 31% of total revenues from the deep water Dover complex (thornyheads, Dover sole and sablefish).

Sufficient and reliable life history data are now available to calculate $F_{35\%}$, the assumed optimal fishing mortality rate, for shortspine thornyheads. Estimates of $F_{35\%}$ for shortspine thornyheads were 0.021 to 0.050 yr^{-1}, depending on the assumed rate of natural mortality; the best estimate was probably 0.021 yr^{-1}.

New age data were used to calculate optimal fishing mortality rates for longspine thornyheads. Estimates of $F_{35\%}$ for longspine thornyheads were 0.11 to 0.18 yr^{-1}, depending on the assumed rate of natural mortality; the best estimate was probably 0.11 yr^{-1}.

Introduction

This is an assessment of shortspine (Sebastolobus alascanus) and longspine thornyheads (S. altivelis) stocks along the Pacific Coast of Washington, Oregon and California. Shortspine and longspine thornyheads in the Eureka area (PMFC areas 1C and 2A) are emphasized but information applicable to other areas is also presented. This analysis extends and replaces that of Jacobson (1990).

Data Availability

Landings and exvessel price data (by port, area, month, year, etc.) for 1981 to 1990 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 to 1990 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 information available for some ports, areas and years is scanty and possibly unreliable (see below). Fortunately, sound management advice can be provided for the thornyhead market category on the basis of existing data. Length composition data for 1978 to 1990 (also based on port samples) are available from CDFG for shortspine and longspine thornyheads landed in California.

Logbook data (including information about catch and fishing effort) are collected by all three states. Although logbook data are useful for determining distribution of depths fished and other quantities, catch rates for thornyheads are difficult to interpret as indices of relative abundance or biomass (Jacobson 1990).

"Swept area" estimates of biomass, abundance and other biological data (i.e. sex, weight, maturity, etc.) are available for shortspine and longspine thornyheads from a number of research cruises conducted by the National Marine Fisheries Service (NMFS) and Scripps Institution of Oceanography (SIO) (Table 1). Estimates of biomass and abundance of thornyheads based on photographs taken from a sled equipped with cameras and towed along the bottom off Point Sur during 1984 to 1985 are also available (Table 1).

Length composition and other biological data for shortspine and longspine thornyheads collected by observers on board commercial fishing vessels are available from Pikitch et al. (1990) and Pikitch (pers. comm.). These data are unique because: i) commercial gear and fishing practices were used, ii) small fish usually discarded by the fishery are included, and ii) data for different dates, areas, depths, and mesh sizes can be distinguished.

Age and size at age data for shortspine thornyheads taken during a NMFS research cruise off California during 1988 as well as large specimens taken by port samplers from commercial landings in Oregon are available (see below). A preliminary subset of the data for shortspine thornyheads were used by Jacobson (1990). Preliminary age and size at age data for a modest number of longspine thornyheads are also available (see below).

Information about growth, mortality, maturity, fecundity, diet, and yield per recruit for shortspine thornyheads captured off Cape Ommaney in southeastern Alaska is available (Miller 1985). Thornyheads in Alaskan waters are assessed annually on the basis of catch rates 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 coastwide have increased five-fold since 1981 (Table 2 and Figure 1). Coastwide thornyhead landings during 1981 were less than 2,000 mt, increased to almost 8,000 mt in 1989 and exceeded 10,000 mt in 1990.

Landings during 1981 to 1990 were greatest in the Eureka area, followed by the Monterey and Columbia areas. On average, 48% of annual coastwide thornyhead landings are from the Eureka area, 27% are from the Monterey area, 22% are from the Columbia area, 2% are from the Conception area, 1% are from the Vancouver area and less than 1% are from unknown areas (Table 2 and Figure 1).

During 1990 and for the first time, longspine thornyheads were the largest component of the total catch (Table 2 and Figure 2). The proportion of longspine thornyheads in coastwide thornyhead landings increased from 13% during 1981 to 33% during 1989 and was 60% in 1990. 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 and 29% in 1990 (Figure 3).

There continues to be some inconsistencies in species composition data used to separate thornyhead landings into shortspine and longspine components. For example, official reports indicate that only shortspine thornyheads were landed in Washington during 1981 to 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 were available to fishermen along the Washington coast. Landings data for shortspine and longspine thornyheads (Table 2) should, because of the inconsistencies, be regarded as a useful but not completely reliable index of species composition for the thornyhead market category.

Additional problems with the interpretation of historical landings data exist. Exvessel prices for thornyheads have more than doubled since 1981 (see below) as export demand increased and it is likely discard rates changed as well. Effective January 1, 1991, the Pacific Fishery Management Council (PFMC) instituted a weekly trip limit of 27,500 lbs (12.5 mt) for the deep water complex (Dover sole, sablefish and thornyheads) of which more no more than 7,500 lbs (3.4 mt or 27%) may be thornyheads. It is likely that discard rates for thornyheads have increased as a result. A coastwide minimum size limit for thornyheads of 10 inches (25.4 cm) was imposed by processors during 1990 in response to preferences of overseas markets. The 10 inch lower size limit probably resulted in considerable discard of small fish (particularly longspine thornyheads) during 1990 and changed the relationship between actual catch and landings. On June 12, 1991, the 10 inch minimum size limit for thornyheads was replaced with a "two-tiered" price structure with the exvessel price paid for thornyheads smaller than 10 inches ($0.30 lb^{-1}) about 64% as large as that paid for thornyheads larger than 10 inches ($0.47 lb^{-1}) (P. Leipzig, pers. comm.).

Fortunately, yield and spawning biomass per recruit analyses do not require landings data so that estimates of optimal fishing mortality rates (e.g. $F_{35\%}$), which form the basis of this assessment, were not sensitive to uncertainties about the relationships between landings, actual catch and discard. The effects of the uncertainty about discard were limited to <u>underestimation</u> of the fishing mortality experienced by thornyheads in recent years and increased uncertainty about the magnitude of changes in fishing mortality over time.

Prices and Revenues

As shown in the table below, exvessel prices (in 1989 dollars) for the thornyhead market category (both species) rose from $0.17 per pound in 1981 to $0.40 per pound in 1990 and the exvessel price during January, 1991 was $0.45 per pound. Real revenues (the product of real exvessel prices and landings) for the thornyhead fishery rose from $670,000 in 1981 to $8,930,000 in 1990.

Year	Exvessel Price[1]	Revenue[1]
1981	$0.17	$670,000
1982	$0.18	$864,000
1983	$0.19	$1,029,000
1984	$0.21	$1,332,000
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
1990	$0.40	$8,930,000
1991	$0.45[2]	---

[1]1989 dollars
[2]Based on data for January only

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 6% of the total in 1981 to 31% of the total in 1990.

Biological Data for Shortspine Thornyheads

Potential problems in identification of shortspine and longspine thornyheads in landings, port samples and research cruises were noted by Jacobson (1990) who found that length composition data for shortspine thornyheads were often bimodal with one peak corresponding to the peak in length distribution data for longspine thornyheads. Fortunately, biological data for shortspine thornyheads used in this analysis (from the R/V David Starr Jordan cruise during 1988) were free from this potential problem. Length data for shortspine thornyheads from the R/V David Starr Jordan cruise during 1988 have a single mode and are typical of what one would expect for a large, long lived fish like shortspine thornyheads (Figure 5). In addition, Lu (1990) used relationships between length and weight of otoliths to independently validate the reliability of species identification for thornyheads taken during the 1988 cruise (Figure 6). There is no reason to believe that the management advice arising from this assessment was affected by problems in biological data for shortspine thornyheads due to misidentified longspine thornyheads.

Mean Length

Mean lengths of shortspine thornyheads taken commercially in the Eureka area varied without pattern during 1978 to 1990 while mean lengths of longspine thornyheads declined from 28.6 to 25.3 cm (CDFG port sampling data, see table below). In order to deal avoid potential problems with misidentification of longspine thornyheads, mean lengths were computed for shortspine thornyheads ≥ 40 cm TL (longspine thornyheads seldom reach 40 cm TL) and for all shortspine thornyheads.

		Shortspine[1]	
Year	Longspine[1]	all	>=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
1990	25.3	35.6	49.9

[1]All lengths are total lengths in cm.

Size at Age

Shortspine thornyheads

Age determinations for shortspine thornyheads used in this study were provided by J. Butler (Southwest Fishery Science Center, NMFS). These data were an expanded version of the data used by Jacobson (1990) and estimated from the mean of independent estimates of age obtained by two readers from otolith sections (Figure 7). A small number of shortspine thornyheads were also aged by a third reader of considerable experience (M. Yoklavich, Southwest Fisheries Science Center, Monterey, CA) who obtained estimates of age similar or older than the estimates provided by Butler.

Age Estimate By Yoklavich	Age Estimate This Study
19	15
32	19
42	41
64	59
42-49	41
82	79

Although no validated criteria for ageing shortspine thornyheads exist, general agreement among independent readers indicates that shortspine thornyheads are probably long lived and that our estimate of maximum longevity (147 yr) is plausible. Only data for fish taken during the 1988 R/V David Starr Jordan research cruise were used to describe size at age for shortspine thornyhead. Otoliths for thornyheads collected during other cruises have not been examined yet.

Longspine thornyheads

Age data for a small sample of longspine thornyheads from otolith sections (also provided by J. Butler) were used to estimate length at age for longspine thornyhead. The age data for longspine thornyheads were preliminary because criteria used for ageing longspine thornyheads have not been validated and because ages were obtained by a single reader. Longspine thornyheads were easier to age than shortspine thornyheads because of differences in apparent longevity (i.e. annual marks were fewer and widely spaced).

Von Bertalanffy growth models were fit to total length (TL) and age data for shortspine (Figure 8) and longspine thornyheads (Figure 9) by nonlinear regression.

	Males	Females	All	Units
Shortspine thornyheads:				
L_{max}	72.99	96.46	87.19	cm
SE for L_{max}	2.996	5.717	3.303	cm
K	0.01958	0.01246	0.01449	yr^{-1}
SE for K	0.001736	0.001327	0.001045	yr^{-1}
t_0	-4.083	-6.875	-6.053	yr
SE for t_0	1.001	1.102	0.7801	yr
r^2	98%	99%	99%	
N	490	628	1,118	fish
min-max age	7-109	7-115	7-115	yr
min-max TL	13-70	15-74	13-74	cm
Longspine thornyheads:				
L_{max}	33.77	33.22	33.86	cm
SE for L_{max}	1.824	2.265	1.223	cm
K	0.05856	0.05825	0.05846	yr^{-1}
SE for K	0.009582	0.01315	0.005744	yr^{-1}
t_0	-0.7260	-1.501	-0.3812	yr
SE for t_0	1.1417	1.800	0.5564	yr
r^2	99%	99%	99%	
N	73	81	192	fish
min-max age	3-45	6-39	3-45	yr
min-max TL	7-32	13-32	7-32	cm

Maturity

Shortspine thornyheads

Shortspine data taken during the 1988 cruise by the R/V David Starr Jordan were used to describe maturity at length for female shortspine thornyheads. Initially, logistic regression was used to describe the relationship between maturity and total length for female shortspine thornyheads but the resulting curve did not fit the data for young fish (i.e. predicted values were too high, see Figure 10). A better fit was obtained using a model similar to the Von Bertalanffy growth model:

where L is total length (in one centimeter increments), P_L is the proportion of female shortspine thornyheads that were mature length

$$P_L = 1 - e^{-C(L-15)} + \epsilon \quad [1]$$

at length L, C is a parameter and ϵ is a statistical error assumed, for convenience, to be normally distributed. The model [1] was fit by nonlinear regression (Figure 10).

C	0.1244 cm^{-1}
SE for C	0.009024 cm^{-1}
r^2	99%
N	58
min-max L	15-74 cm

The model indicates that 10% of female shortspine thornyheads are sexually mature at about 16 cm TL (age 8), 50% are mature at about 21 cm TL (age 13) and 90% are mature at about 34 cm TL (age 28).

Longspine thornyheads

Data from Wakefield (1990, and pers. comm.) were used to describe the relationship between maturity and total length for female longspine thornyhead.

Standard Length (cm)	Percent Mature	N
8-10	0.0000	3
10-12	0.0000	7
12-14	0.2857	14
14-16	0.4375	16
16-18	0.6250	16
18-20	1.0000	19
20-22	1.0000	19
22-24	1.0000	17
24-26	1.0000	7
26-28	1.0000	2

Standard lengths were converted to total lengths using a conversion formula (Wakefield 1990):

$$TL = 1.22\, SL + 0.204 \quad [2]$$

where TL is total length (cm) and SL is standard length in cm (N=363, r^2=99%).

Logistic regression and maximum likelihood were used to fit the model:

$$P_L = \frac{1}{1 + e^{f + gL}} + \epsilon \quad [3]$$

to maturity data for female longspine thornyheads (Figure 11). The statistical error ϵ in [3] was assumed to be binomial.

f	11.14
SE for f	2.208
g	-0.593
SE for g	0.013

The model indicates that 10% of female longspine thornyheads are mature at about 15 cm TL (age 10), 50% are mature at about 19 cm TL (age 14) and 90% are mature at about 22 cm TL (age 18).

CPUE Data

The use of commercial catch rates (catch per unit-effort or CPUE) data as an index of relative biomass for thornyheads was assessed by Jacobson (1990) using bottom trawl logbook data provided by CDFG for fishing in the Eureka area during 1978 to 1987. It was difficult to interpret catch rates in terms of relative biomass but the results indicated that biomass of thornyheads, particularly large shortspine thornyheads, may have decreased during 1978 to 1987 in relatively shallow waters (285 to 305 fathoms). Shortspine thornyheads at these depths are available to trawlers but not naturally abundant. In addition, estimates of standardized relative catch rates (mt/hr) for thornyheads during 1978 to 1987 by depth interval were obtained from a general linear model:

Depth (fathoms)	Stand. CPUE	Depth (fathoms)	Stand. CPUE
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

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

Yield, Revenue and Spawning Biomass per Recruit

Yield, revenue and spawning biomass per recruit as a function of fishing mortality rates were evaluated for shortspine and longspine thornyheads by standard techniques (Thompson and Bell 1934). I used this approach to calculate: 1) the fishing mortality rate that maximizes yield per recruit (F_{max}), 2) 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 ($F_{0.1}$), 3) 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 ($F_{35\%}$), 4) the fishing mortality rate that results in a level of spawning biomass per recruit that is 20% of the maximum value obtained with no fishing ($F_{20\%}$) and 5) the fishing mortality rate that maximizes exvessel revenue per recruit received by fishermen ($F_{max\$}$). Clark (1991) describes F_{max}, $F_{0.1}$, $F_{20\%}$ and $F_{35\%}$. $F_{max\$}$ is described below and by Die et al. (1988) as "utility per recruit". $F_{35\%}$ is used, according to PFMC policy, as a target fishing mortality rate for groundfish while $F_{20\%}$ is used to define overfishing.

As described above, processors recently imposed a 10 inch (25.4 cm) TL minimum limit on thornyheads during 1990 that was later replaced by a two-tiered price structure. The two-tier price structure involves an exvessel price for small thornyheads (less than 10 inches TL) about 64% as large as the price paid for larger fish. Under the 10 inch minimum size limit, fish smaller than the size limit were discarded at sea by fishermen or sold for very low prices as animal food. Thornyheads taken in commercial trawls do not survive so the 10 inch minimum size limit resulted in waste as small fish were discarded dead and stock and spawning biomass was reduced without generating revenue for fishermen. In contrast, fishermen are expected to land their entire catch under the two tier price structure although their exvessel revenues from thornyheads will still not be proportional to total catch.

When the exvessel value of fish is not proportional to weight caught because of discard or size related price differences, it may make sense to make management decisions on the basis of revenue per recruit rather than other criteria such as $F_{35\%}$. For this analysis, revenue for thornyheads under the 10 inch minimum size limit was:

$$R_a = \begin{cases} 0 & \text{if } L_a < 25.4\,cm \\ W_a & \text{otherwise} \end{cases} \qquad [4]$$

where R_a is expected revenue for a fish age a and W_a is weight at age a (which is proportional to revenue for fish larger than 10 inches TL). Revenue under the two-tier price structure was:

$$R_a = \begin{cases} 0.6383\, W_a & \text{if } L_a < 25.4\,cm \\ W_a & \text{otherwise} \end{cases} \qquad [5]$$

$F_{max\$}$, the fishing mortality rate that maximized the measure ([4] or [5]) of expected exvessel revenue per recruit, was found using the same algorithm as used for F_{max}.

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 (tables

3 and 4). Weights at age were obtained by converting predicted mean lengths at age (for males and females combined) from Von Bertalanffy growth models for shortspine and longspine thornyheads using length-weight conversion formulas:

Parameter estimates in the model $W=aL^b$ (where W is round weight in grams and L is TL in mm) from Jacobson (1990).

	Shortspine	Longspine
a[1]	2.651×10^{-6}	1.794×10^{-6}
SE for ln(a)	0.04064	0.1051
b	3.264	3.352
SE for b	0.006993	0.02035
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

[1]Corrected for bias due to log transformation

Maturity at age (tables 3 and 4) was estimated from mean lengths at age and the maturity-length relationships for shortspine [1] and longspine [3] thornyheads described above. The month of peak spawning for shortspine thornyheads is thought to be April (Moser 1974) and the month of peak spawning for longspine thornyheads is thought to be February (Wakefield 1990).

Age specific recruitment rates for shortspine and longspine thornyheads are unknown because age composition data are unavailable. In lieu of age composition data, length composition data collected by observers during commercial fishing trips in the Eureka area during 1988 to 1989 were used to infer recruitment patterns (tables 3 and 4). Observer data were collected aboard commercial vessels that participated in a research project. Although normal fishing procedures were followed, measurements and catch were recorded for small fish that would normally be discarded (Pikitch et al. 1990). Age specific recruitment for shortspine and longspine thornyheads was estimated from length composition data collected by observers from catches in the Eureka area by bottom trawls that were fished with 4.5 inch (11 cm) mesh in the codends at depths greater than 200 fathoms (366 m).

Data from trawls with 4.5 inch mesh in codends was used because, after July 1, 1991, 4.5 inches will be the minimum legal meshsize for bottom trawls used to capture thornyheads off Washington, Oregon and California. A preliminary analysis revealed that results were moderately sensitive to assumptions about recruitment but no other assumptions were formally evaluated.

Recruitment-shortspine thornyheads

The length composition data for shortspine thornyheads indicates that fish are fully recruited at about 36 cm TL (Figure 12) which, from Figure 8 and the growth model, corresponds to an age of about 30 years. Some shortspine thornyheads recruit to the fishery at 17 cm TL (Figure 12) when they are about 9 years old. In this analysis, I assumed that shortspine thornyheads 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). Note that the length composition data for shortspine thornyheads (Figure 12) taken with 4.5 inch mesh have one mode near 40 cm TL which suggests that contamination by misidentified longspine thornyheads was not significant.

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. Jacobson (1990) made assumptions about recruitment of shortspine thornyheads similar to the assumptions made in this analysis.

Recruitment-longspine thornyheads

Length composition data for longspine thornyheads (Figure 13) suggest that fish are fully recruited at about 26 cm TL which, from Figure 9 and the growth model, corresponds to an age of about 25 years. Longspine thornyheads become vulnerable to the fishery at about 13 cm TL or 8 years of age. In this analysis, I assumed that longspine thornyheads began to recruit to the fishery at age 8 and that the fraction recruited increased in a sigmoidal fashion with age until fish became fully recruited at age 25 (Table 4).

Natural mortality-shortspine thornyheads

A linear regression model relating oldest observed age and mortality was used to estimate the natural mortality rate (M), for shortspine and longspine thornyheads (Hoenig 1983). The oldest estimated age for a shortspine thornyheads was 147 years for a large specimen (73 cm TL, 7.3 kg) taken in Oregon waters. A maximum age of 147 years corresponds to a natural mortality rate of about 0.03 yr^{-1}. It is possible that maximum age was overestimated since no independent validation of ageing criteria exist. If we assume that the age estimates are twice the actual age, then the fish estimated to be 147 years old may have been only about 75 years old. The natural mortality rate corresponding to a maximum age of 75 years is about 0.06 yr^{-1}. Owing to uncertainty about the true natural mortality rate, I used three values (0.03, 0.045 and 0.06 yr^{-1}) for natural mortality in this analysis. The estimate M=0.03 is probably the "best" estimate of natural mortality for shortspine thornyheads because the sample of fish aged were from populations that had already experienced considerable fishing mortality. If an unfished population had been sampled, older fish and smaller estimates of natural mortality would probably have been obtained.

Although the natural mortality rate of shortspine thornyheads is uncertain, the true value is almost certainly lower than values used for other groundfish. Low natural mortality rates lead inevitably to low optimal fishing mortality rates (e.g. $F_{35\%}$) so optimal fishing mortality rates and allowable biological catch levels for shortspine thornyheads will be low relative to those for other groundfish. This general result is a reflection of the pattern of growth and mortality for long lived species that typically grow slowly to large size.

Miller's (1985) estimate of the natural mortality rate for shortspine thornyheads (M = 0.07 yr^{-1}) from a catch curve analysis is slightly larger than the largest value used here. The oldest age observed in Miller's (1985) sample of shortspine thornyheads was 62 years. A maximum age of 62 years corresponds to a natural mortality rate of 0.07 yr^{-1} which is the equal to the value obtained by catch curve analysis. This result indicates that maximum age is a reasonable basis for estimating the natural mortality of shortspine thornyheads.

Natural mortality-longspine thornyheads

The oldest longspine thornyheads observed in the sample used for this analysis was 45 years which corresponds to a natural mortality rate of 0.1 yr^{-1}. In order to accommodate uncertainty in this estimate of natural mortality for longspine thornyhead, three values (0.08, 0.1 and 0.12 yr^{-1}) were used. The estimate M=0.08 (which corresponds to a maximum age of about 57 yr) is probably the "best" estimate of natural mortality for longspine thornyheads because the sample of fish aged was relatively small (192 fish) and was obtained from a population that had already experienced considerable fishing mortality. If a larger sample from an unfished population had been aged, older fish and smaller estimates of natural mortality would probably have been obtained.

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 for shortspine thornyheads ($N_a = 143$) was larger than the minimum value from the 95% rule (i.e. 3 / 0.03 = 100) as was the number of age groups included in the analysis for longspine thornyheads ($N_a = 45$ which is larger than 3 / 0.08 = 38). The first age group in included in yield per recruit analyses for shortspine and longspine thornyheads was age 6.

Results of yield, revenue and spawner biomass per recruit analyses for shortspine thornyheads

Results of yield and spawner biomass per recruit analyses indicate that the $F_{35\%}$ target fishing mortality rates for shortspine thornyheads are low (0.021 to 0.05 yr^{-1}, depending on the natural mortality rate, Table 5). The best estimate (according to assumptions about natural mortality discussed above) of $F_{35\%}$ is 0.021 yr^{-1} which corresponds to a natural mortality rate of M = 0.03 yr^{-1} (Figure 14). The corresponding best estimate of $F_{20\%}$ (used to define overfishing) for shortspine thornyheads is 0.039 yr^{-1}.

Yield per recruit at $F_{35\%}$ for shortspine thornyheads is very close to revenue per recruit generated at $F_{35\%}$ under the 10 inch minimum size limit (e.g. yield and revenue per recruit in Table 5 are both 0.29 kg for M = 0.03 and $F_{35\%}$ = 0.021 yr^{-1}). This result indicates that the $F_{35\%}$ harvest policy would result in little discard of shortspine thornyheads under a 10 inch minimum size limit. In addition, revenue per recruit generated by the $F_{35\%}$ harvest policy under either the 10 inch minimum size limit or two-tier price structure is very close to the maximum attainable (e.g. for M = 0.03 yr^{-1}, revenue per recruit at $F_{35\%}$ = 0.021 yr^{-1} is 0.29

kg while the maximum value attainable at $F_{max\$} = 0.03$ yr^{-1} is 0.30 kg). These results indicate that the $F_{35\%}$ harvest policy, current mesh size regulations (4.5 inch minimum mesh size in codends) and 10 inch minimum size limit/two-tier price structure set by the market are compatible for shortspine thornyheads.

The estimate $F_{max} = 0.29$ for shortspine thornyheads off Alaska from Anon (1989) for full recruitment at age 16 is much higher than the values obtained in this analysis (Table 5). Values of $F_{0.1}$ = 0.075 and $F_{35\%} = 0.075$ (for full recruitment at ages 10 and 16) are slightly larger than those obtained here. These differences were due to different 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). Despite the differences in underlying assumptions, the important general result from all studies to date is that $F_{35\%}$ is low (≤ 0.075 yr^{-1}) for shortspine thornyheads.

<u>Results of yield, revenue and spawner biomass per recruit analyses for longspine thornyheads</u>

Results of yield and spawner biomass per recruit analyses indicate that the $F_{35\%}$ target fishing mortality rates for longspine thornyheads are 0.11 to 0.18 yr^{-1}, depending on the natural mortality rate (Table 6). The best estimate (according to assumptions about natural mortality discussed above) of $F_{35\%}$ is 0.11 yr^{-1} which corresponds to a natural mortality rate of $M = 0.08$ yr^{-1} (Figure 15). The best estimate of $F_{20\%}$ (used to define overfishing) for longspine thornyheads is 0.22 yr^{-1}.

Predictably, the $F_{35\%}$ harvest policy and 10 inch minimum size limit would generate substantial discard of longspine thornyheads and loss of potential revenue to fishermen. For example, the yield per recruit for longspine thornyheads at $F_{35\%} = 0.11$ yr^{-1} and M = 0.08 yr^{-1} was 0.042 kg while revenue per recruit was only 0.017 kg. The difference between yield and revenue per recruit means that 0.042 to 0.017 = 0.025 kg per recruit or 60% of total yield of longspine thornyheads would, on average, be discarded and go to waste under the $F_{35\%}$ harvest policy and 10 inch minimum size limit. This surprising result is due to fishing mortality on longspine thornyheads too small to be accepted by the market and inability of fishermen to target exclusively on either species. As mentioned above, however, the $F_{35\%}$ policy for longspine thornyheads would not result in discard under the two-tier price structure.

Confirmation that significant amounts of longspine thornyheads would be discarded under the 10 inch minimum size limit and prevailing fishing mortality rates can be obtained from length composition data collected by observers for longspine thornyheads taken with 4.5 inch mesh in the Eureka area (Figure 13). Fish smaller than 10 inch TL that would be discarded constitute 60% of the total number of fish caught and, assuming the length-weight conversion described above, 44% of the total catch in weight.

The fishing mortality rate that maximizes revenue per recruit ($F_{max\$}$) for 4.5 inch mesh under a 10 inch minimum size limit is much smaller than $F_{35\%}$. This means that fishing mortality rates substantially lower than $F_{35\%}$ would result in higher revenues to the fishery. For example, at M = 0.08 yr^{-1}, $F_{35\%}$ = 0.11 yr^{-1} and revenue per recruit is 0.017 kg while $F_{max\$}$ = 0.063 yr^{-1} and the corresponding revenue per recruit is 0.019 kg). This means that the $F_{35\%}$ harvest policy and 10 inch minimum size limit would result in a 12% loss of revenue to fishermen relative to the maximum attainable under the $F_{max\$}$ policy. The situation is reversed under the two-tier price structure since the fishing mortality rate that maximizes revenue per recruit is greater than $F_{35\%}$ (e.g. for M = 0.08 yr^{-1}, $F_{max\$}$ = 0.13 yr^{-1} and revenue per recruit is 0.033 kg while $F_{35\%}$ = 0.11 yr^{-1} and the corresponding revenue per recruit is 0.017 kg).

Biomass

Density estimates (mt/km^2) from eight sources were used to estimate total biomass of shortspine and longspine thornyheads in the Columbia, Eureka and Monterey areas (Table 1 and Jacobson 1990). Biomass estimates were calculated for each species separately and for both species combined (Table 7). Where necessary, survey data were retabulated using the following depth intervals as strata: 30 to 250, 250 to 550 and 550 to 700 fathoms. The biomass estimates may underestimate biomass available to trawls surveys somewhat since some fish may be found at depths greater than 700 fathoms.

Minimum and maximum biomass estimates for shortspine thornyheads in the Columbia, Eureka and Monterey areas were 6,900 to 55,000 mt, 3,900 to 19,000 mt and 5,300 to 34,000 mt. Biomass estimates for longspine thornyheads in the Columbia, Eureka and Monterey areas were 9,200 to 65,000 mt, 5,800 to 41,000 mt and 7,300 to 51,000 mt. Minimum and maximum estimates for the thornyhead species group in the Columbia, Eureka and Monterey areas were 17,000 to 106,000 mt, 10,000 to 61,000 mt and 17,000 to 77,000 mt. The results suggest that biomass 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 biomass of thornyheads among areas are due to differences among areas in the amount of area in each depth interval. It is interesting to note that biomass is inversely related to landings, with highest landings and lowest biomass in the Eureka area, intermediate landings and biomass in the Monterey area and lowest landings and highest biomass in the Columbia area.

Estimates of total biomass for shortspine, longspine and the thornyhead species group in the Columbia, Eureka and Monterey areas were 16,000 to 110,000 mt, 22,000 to 160,000 mt and 41,000 to 240,000 mt. Longspine thornyheads appear to be more abundant overall.

Crude estimates of fishing mortality rates can be obtained from the ratio of landings during 1990 and estimated biomass. Uncertainties in the estimates of fishing mortality rates during 1990 are due primarily to uncertainty in the underlying biomass estimates and possible errors in landings data. Estimates of fishing mortality for shortspine, longspine and the thornyhead species group in the Eureka area during 1990 were, for example, 0.03 to 0.13 yr^{-1}, 0.08 to 0.58 yr^{-1} and 0.08 to 0.38 yr^{-1} (Table 7). It appears that current fishing mortality rates for shortspine and longspine thornyheads in some areas (e.g. the Eureka area) may exceed optimal values.

Biomass available to fisheries

Estimates of allowable biological catch can be obtained from the product of the target fishing mortality rate (i.e. $F_{35\%}$) and fishable biomass (i.e. biomass available to the fishery). A simple conversion factor for converting research survey biomass estimates (Table 7) to estimates of fishable biomass was obtained by converting mean age at 50% recruitment to the fishery (tables 3 and 4) to mean length using Von Bertalanffy growth equations and then calculating the fraction of total survey biomass due to fish larger than the size at 50% recruitment. Conversion factors were obtained for shortspine and longspine thornyheads from research cruises conducted by NMFS between Point Conception and San Francisco (Monterey area) during 1988 and in the Eureka area during 1990.

The results (see below) indicated that about 94% of shortspine biomass available to research surveys was also available to the fishery while only 71% of longspine thornyhead biomass available to research surveys was available to the fishery.

Survey	Shortspine	Longspine
1988	0.94	0.74
1990	0.93	0.69
average	0.94	0.71

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Table 1. Research cruises from which biomass, density, length composition or other biological data are available for shortspine and longspine thornyheads. "NMFS" denotes the National Marine Fisheries Service, "SIO" denotes Scripps Institution of Oceanography, "BT" denotes a bottom trawl survey and "CS" denotes a camera sled survey. Identifiers used in Table 7 are underlined (e.g. "NMFS HMB-84-01").

Agency	Year	Months	Depth (fathoms)	Location; Survey Type; Reference
NMFS	1984	Apr-May Sep-Oct	60-300 60-500	Coquille Point to Cape Falcon, OR (Columbia area); BT; Raymore and Weinberg (1990); NMFS HMB-84-01
SIO	1984-85	7 cruises	100-875	Point Sur, CA (Monterey area); BT and CS; Wakefield (1990); SIO TRAWL and SIO CAM. SLED
NMFS	1987	Jan-Feb	100-700	Point Conception to San Francisco, CA (Monterey area); BT; Butler et al. (1989); NMFS DS-87-01
NMFS	1988	Feb-Apr	100-700	Point Conception to San Francisco, CA (Monterey area); BT; Butler et al. (1989); NMFS DS-88-03
NMFS	1988	Nov-Dec	100-700	Heceta Head to Cape Lookout, OR (Columbia area); BT; AFSC Cruise Report; NMFS MF-88-09

NMFS	1989	Sep-Oct	100-700	Coquille Point to Cape Falcon, OR (Columbia area); BT; AFSC Cruise Report; NMFS GF-89-02
NMFS	1989	Feb-Apr	100-700	Heceta Head, to Cape Lookout, OR (Columbia area); BT; SWFSC Cruise Report; NMFS DS-89-02; Swept area biomass estimates not used in Table 7 due to equipment problems
NMFS	1990	Oct-Nov	100-700	Cape Mendocino, CA to Cape Blanco, OR (Eureka area); BT; AFSC Cruise Report; NMFS MF-90-11

Table 2. Landings for shortspine thornyheads and longspine thornyheads by area, 1981-1990.

YEAR	UNKNOWN PFMC AREA SHORTSPINE	LONGSPINE	TOTAL	VANCOUVER AREA (INPFC 3B & 3C) SHORTSPINE	LONGSPINE	TOTAL
1981	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.90	0.90	29.18	2.52	31.70
1984	0.00	0.00	0.00	19.91	22.59	42.50
1985	0.00	0.00	0.00	64.30	0.00	64.30
1986	0.00	1.20	1.20	53.90	0.00	53.90
1987	0.00	14.00	14.00	30.10	0.00	30.10
1988	0.00	0.00	0.00	66.10	0.00	66.10
1989	0.00	12.50	12.50	102.68	8.52	111.20
1990	0.00	8.50	8.50	182.64	0.96	183.60

YEAR	COLUMBIA AREA (INPFC 2B,2C & 3A) SHORTSPINE	LONGSPINE	TOTAL	EUREKA AREA (INPFC 1C & 2A) SHORTSPINE	LONGSPINE	TOTAL
1981	21.90	1.00	22.90	886.50	222.10	1108.60
1982	17.40	148.40	165.80	680.61	457.49	1138.10
1983	499.27	157.03	656.30	955.12	44.68	999.80
1984	463.82	163.88	627.70	822.48	247.22	1069.70
1985	694.50	160.80	855.30	1109.65	392.35	1502.00
1986	460.88	44.52	505.40	1133.70	536.30	1670.00
1987	461.83	104.07	565.90	982.43	676.97	1659.40
1988	582.05	139.95	722.00	1398.97	2452.33	3851.30
1989	1127.87	583.63	1711.50	2363.54	2029.56	4393.10
1990	1513.37	2269.93	3783.30	570.12	3376.28	3946.40

YEAR	MONTEREY AREA (INPFC 1B) SHORTSPINE	LONGSPINE	TOTAL	CONCEPTION AREA (INPFC 1A) SHORTSPINE	LONGSPINE	TOTAL
1981	644.09	6.71	650.80	5.40	0.00	5.40
1982	710.90	167.80	878.70	9.20	0.00	9.20
1983	661.69	64.11	725.80	95.70	0.00	95.70
1984	709.02	157.88	866.90	312.40	0.00	312.40
1985	1029.97	217.43	1247.40	398.60	0.00	398.60
1986	1028.33	256.07	1284.40	97.60	0.00	97.60
1987	926.53	446.77	1373.30	0.00	44.30	44.30
1988	979.50	0.00	979.50	0.74	0.06	0.80
1989	1666.78	8.32	1675.10	5.09	5.41	10.50
1990	1823.03	375.77	2198.80	2.27	3.43	5.70

YEAR	ALL AREAS SHORTSPINE	LONGSPINE	TOTAL
1981	1,558	230	1,788
1982	1,418	774	2,192
1983	2,241	269	2,510
1984	2,328	592	2,919
1985	3,297	771	4,068
1986	2,774	838	3,613
1987	2,401	1,286	3,687
1988	3,027	2,592	5,620
1989	5,266	2,648	7,914
1990	4,091	6,035	10,126

Table 3. Input data for shortspine thornyheads yield per recruit analyses. The relative value of small fish (less than 10 inches) was 0.0000 under the 10 inch minimum size limit and 0.6383 under the two tier price structure.

TITLE:
SSYRDAT2.DAT,S.ALASCANUS,REVISED AGE/SIZE/MATUR,10" MARKET LIMIT,FEB SPAWN
FIRST AGE GROUP: LAST AGE GROUP: LAST GROUP IS PLUS:
6 143 YES
PROPORTION OF F MORTALITY BEFORE SPAWNING SEASON:
0.1667
PROPORTION OF M MORTALITY BEFORE SPAWNING SEASON:
0.1667

AGE	FPATTERN	MPATTERN	MATURITY	WEIGHT IN THE CATCH	WEIGHT IN THE STOCK	relative value
1	0.0000	0.0000	0.0000	0.0052	0.0052	0.0000 or 0.6383
2	0.0000	0.0000	0.0000	0.0078	0.0078	0.0000 or 0.6383
3	0.0000	0.0000	0.0000	0.0112	0.0112	0.0000 or 0.6383
4	0.0000	0.0000	0.0000	0.0154	0.0154	0.0000 or 0.6383
5	0.0000	0.0000	0.0000	0.0205	0.0205	0.0000 or 0.6383
6	0.0000	1.0000	0.0000	0.0266	0.0266	0.0000 or 0.6383
7	0.0000	1.0000	0.0027	0.0337	0.0337	0.0000 or 0.6383
8	0.0000	1.0000	0.1236	0.0420	0.0420	0.0000 or 0.6383
9	0.0060	1.0000	0.2283	0.0513	0.0513	0.0000 or 0.6383
10	0.0200	1.0000	0.3193	0.0619	0.0619	0.0000 or 0.6383
11	0.0460	1.0000	0.3985	0.0737	0.0737	0.0000 or 0.6383
12	0.0800	1.0000	0.4675	0.0868	0.0868	0.0000 or 0.6383
13	0.1200	1.0000	0.5278	0.1012	0.1012	0.0000 or 0.6383
14	0.1720	1.0000	0.5806	0.1169	0.1169	0.0000 or 0.6383
15	0.2400	1.0000	0.6268	0.1340	0.1340	0.0000 or 0.6383
16	0.3000	1.0000	0.6673	0.1525	0.1525	0.0000 or 0.6383
17	0.3600	1.0000	0.7030	0.1723	0.1723	0.0000 or 0.6383
18	0.4300	1.0000	0.7344	0.1936	0.1936	1.0000
19	0.5000	1.0000	0.7621	0.2162	0.2162	1.0000
20	0.5700	1.0000	0.7866	0.2403	0.2403	1.0000
21	0.6400	1.0000	0.8082	0.2658	0.2658	1.0000
22	0.7000	1.0000	0.8274	0.2927	0.2927	1.0000
23	0.7600	1.0000	0.8444	0.3210	0.3210	1.0000
24	0.8280	1.0000	0.8596	0.3507	0.3507	1.0000
25	0.8800	1.0000	0.8731	0.3818	0.3818	1.0000
26	0.9200	1.0000	0.8851	0.4142	0.4142	1.0000
27	0.9540	1.0000	0.8958	0.4480	0.4480	1.0000
28	0.9800	1.0000	0.9054	0.4832	0.4832	1.0000
29	0.9940	1.0000	0.9140	0.5197	0.5197	1.0000
30	1.0000	1.0000	0.9217	0.5575	0.5575	1.0000
31	1.0000	1.0000	0.9287	0.5965	0.5965	1.0000
32	1.0000	1.0000	0.9349	0.6369	0.6369	1.0000
33	1.0000	1.0000	0.9405	0.6784	0.6784	1.0000
34	1.0000	1.0000	0.9455	0.7212	0.7212	1.0000
35	1.0000	1.0000	0.9501	0.7651	0.7651	1.0000
36	1.0000	1.0000	0.9542	0.8102	0.8102	1.0000
37	1.0000	1.0000	0.9579	0.8564	0.8564	1.0000
38	1.0000	1.0000	0.9613	0.9038	0.9038	1.0000
39	1.0000	1.0000	0.9644	0.9521	0.9521	1.0000
40	1.0000	1.0000	0.9671	1.0016	1.0016	1.0000
41	1.0000	1.0000	0.9697	1.0520	1.0520	1.0000
42	1.0000	1.0000	0.9720	1.1034	1.1034	1.0000
43	1.0000	1.0000	0.9741	1.1557	1.1557	1.0000
44	1.0000	1.0000	0.9760	1.2089	1.2089	1.0000
45	1.0000	1.0000	0.9777	1.2630	1.2630	1.0000
46	1.0000	1.0000	0.9793	1.3180	1.3180	1.0000
47	1.0000	1.0000	0.9808	1.3737	1.3737	1.0000
48	1.0000	1.0000	0.9821	1.4303	1.4303	1.0000
49	1.0000	1.0000	0.9834	1.4876	1.4876	1.0000
50	1.0000	1.0000	0.9845	1.5456	1.5456	1.0000
51	1.0000	1.0000	0.9855	1.6043	1.6043	1.0000
52	1.0000	1.0000	0.9865	1.6636	1.6636	1.0000
53	1.0000	1.0000	0.9874	1.7236	1.7236	1.0000
54	1.0000	1.0000	0.9882	1.7841	1.7841	1.0000
55	1.0000	1.0000	0.9889	1.8452	1.8452	1.0000

56	1.0000	1.0000	0.9896	1.9068	1.9068	1.0000
57	1.0000	1.0000	0.9903	1.9690	1.9690	1.0000
58	1.0000	1.0000	0.9908	2.0315	2.0315	1.0000
59	1.0000	1.0000	0.9914	2.0946	2.0946	1.0000
60	1.0000	1.0000	0.9919	2.1580	2.1580	1.0000
61	1.0000	1.0000	0.9924	2.2218	2.2218	1.0000
62	1.0000	1.0000	0.9928	2.2860	2.2860	1.0000
63	1.0000	1.0000	0.9932	2.3505	2.3505	1.0000
64	1.0000	1.0000	0.9936	2.4153	2.4153	1.0000
65	1.0000	1.0000	0.9939	2.4803	2.4803	1.0000
66	1.0000	1.0000	0.9943	2.5456	2.5456	1.0000
67	1.0000	1.0000	0.9946	2.6112	2.6112	1.0000
68	1.0000	1.0000	0.9949	2.6769	2.6769	1.0000
69	1.0000	1.0000	0.9951	2.7428	2.7428	1.0000
70	1.0000	1.0000	0.9954	2.8088	2.8088	1.0000
71	1.0000	1.0000	0.9956	2.8749	2.8749	1.0000
72	1.0000	1.0000	0.9958	2.9412	2.9412	1.0000
73	1.0000	1.0000	0.9960	3.0075	3.0075	1.0000
74	1.0000	1.0000	0.9962	3.0739	3.0739	1.0000
75	1.0000	1.0000	0.9964	3.1403	3.1403	1.0000
76	1.0000	1.0000	0.9966	3.2067	3.2067	1.0000
77	1.0000	1.0000	0.9967	3.2731	3.2731	1.0000
78	1.0000	1.0000	0.9969	3.3395	3.3395	1.0000
79	1.0000	1.0000	0.9970	3.4059	3.4059	1.0000
80	1.0000	1.0000	0.9972	3.4721	3.4721	1.0000
81	1.0000	1.0000	0.9973	3.5383	3.5383	1.0000
82	1.0000	1.0000	0.9974	3.6044	3.6044	1.0000
83	1.0000	1.0000	0.9975	3.6704	3.6704	1.0000
84	1.0000	1.0000	0.9976	3.7362	3.7362	1.0000
85	1.0000	1.0000	0.9977	3.8019	3.8019	1.0000
86	1.0000	1.0000	0.9978	3.8675	3.8675	1.0000
87	1.0000	1.0000	0.9979	3.9328	3.9328	1.0000
88	1.0000	1.0000	0.9980	3.9980	3.9980	1.0000
89	1.0000	1.0000	0.9981	4.0629	4.0629	1.0000
90	1.0000	1.0000	0.9981	4.1276	4.1276	1.0000
91	1.0000	1.0000	0.9982	4.1921	4.1921	1.0000
92	1.0000	1.0000	0.9983	4.2564	4.2564	1.0000
93	1.0000	1.0000	0.9983	4.3203	4.3203	1.0000
94	1.0000	1.0000	0.9984	4.3840	4.3840	1.0000
95	1.0000	1.0000	0.9985	4.4475	4.4475	1.0000
96	1.0000	1.0000	0.9985	4.5106	4.5106	1.0000
97	1.0000	1.0000	0.9986	4.5735	4.5735	1.0000
98	1.0000	1.0000	0.9986	4.6360	4.6360	1.0000
99	1.0000	1.0000	0.9987	4.6982	4.6982	1.0000
100	1.0000	1.0000	0.9987	4.7600	4.7600	1.0000
101	1.0000	1.0000	0.9987	4.8216	4.8216	1.0000
102	1.0000	1.0000	0.9988	4.8828	4.8828	1.0000
103	1.0000	1.0000	0.9988	4.9436	4.9436	1.0000
104	1.0000	1.0000	0.9989	5.0041	5.0041	1.0000
105	1.0000	1.0000	0.9989	5.0642	5.0642	1.0000
106	1.0000	1.0000	0.9989	5.1239	5.1239	1.0000
107	1.0000	1.0000	0.9990	5.1832	5.1832	1.0000
108	1.0000	1.0000	0.9990	5.2422	5.2422	1.0000
109	1.0000	1.0000	0.9990	5.3007	5.3007	1.0000
110	1.0000	1.0000	0.9991	5.3589	5.3589	1.0000
111	1.0000	1.0000	0.9991	5.4166	5.4166	1.0000
112	1.0000	1.0000	0.9991	5.4740	5.4740	1.0000
113	1.0000	1.0000	0.9991	5.5309	5.5309	1.0000
114	1.0000	1.0000	0.9992	5.5874	5.5874	1.0000
115	1.0000	1.0000	0.9992	5.6435	5.6435	1.0000
116	1.0000	1.0000	0.9992	5.6992	5.6992	1.0000
117	1.0000	1.0000	0.9992	5.7544	5.7544	1.0000
118	1.0000	1.0000	0.9992	5.8092	5.8092	1.0000
119	1.0000	1.0000	0.9993	5.8636	5.8636	1.0000
120	1.0000	1.0000	0.9993	5.9175	5.9175	1.0000
121	1.0000	1.0000	0.9993	5.9710	5.9710	1.0000
122	1.0000	1.0000	0.9993	6.0240	6.0240	1.0000
123	1.0000	1.0000	0.9993	6.0766	6.0766	1.0000
124	1.0000	1.0000	0.9993	6.1288	6.1288	1.0000
125	1.0000	1.0000	0.9994	6.1805	6.1805	1.0000
126	1.0000	1.0000	0.9994	6.2318	6.2318	1.0000
127	1.0000	1.0000	0.9994	6.2826	6.2826	1.0000
128	1.0000	1.0000	0.9994	6.3329	6.3329	1.0000

129	1.0000	1.0000	0.9994	6.3828	6.3828	1.0000
130	1.0000	1.0000	0.9994	6.4323	6.4323	1.0000
131	1.0000	1.0000	0.9994	6.4813	6.4813	1.0000
132	1.0000	1.0000	0.9995	6.5299	6.5299	1.0000
133	1.0000	1.0000	0.9995	6.5780	6.5780	1.0000
134	1.0000	1.0000	0.9995	6.6256	6.6256	1.0000
135	1.0000	1.0000	0.9995	6.6728	6.6728	1.0000
136	1.0000	1.0000	0.9995	6.7196	6.7196	1.0000
137	1.0000	1.0000	0.9995	6.7659	6.7659	1.0000
138	1.0000	1.0000	0.9995	6.8117	6.8117	1.0000
139	1.0000	1.0000	0.9995	6.8571	6.8571	1.0000
140	1.0000	1.0000	0.9995	6.9021	6.9021	1.0000
141	1.0000	1.0000	0.9995	6.9466	6.9466	1.0000
142	1.0000	1.0000	0.9996	6.9906	6.9906	1.0000
143	1.0000	1.0000	0.9996	7.0342	7.0342	1.0000

Table 4. Input data for longspine thornyheads yield per recruit analyses. The relative value of small fish (less than 10 inches) was 0.0000 under the 10 inch minimum size limit and 0.6383 under the two tier price structure.

TITLE:
yprdata3.dat,S.altivelis,JB's size/age,WW matur,10" market limit,mat ogv ok
FIRST AGE GROUP: LAST AGE GROUP: LAST GROUP IS PLUS:
6 45 YES
PROPORTION OF F MORTALITY BEFORE SPAWNING SEASON:
0.0000
PROPORTION OF M MORTALITY BEFORE SPAWNING SEASON:
0.0000

AGE	FPATTERN	MPATTERN	MATURITY	WEIGHT IN THE CATCH	WEIGHT IN THE STOCK	relative value
1	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000 or 0.6383
2	0.0000	0.0000	0.0002	0.0006	0.0006	0.0000 or 0.6383
3	0.0000	0.0000	0.0005	0.0017	0.0017	0.0000 or 0.6383
4	0.0000	0.0000	0.0013	0.0037	0.0037	0.0000 or 0.6383
5	0.0000	0.0000	0.0033	0.0067	0.0067	0.0000 or 0.6383
6	0.0000	1.0000	0.0075	0.0108	0.0108	0.0000 or 0.6383
7	0.0000	1.0000	0.0162	0.0161	0.0161	0.0000 or 0.6383
8	0.0100	1.0000	0.0334	0.0225	0.0225	0.0000 or 0.6383
9	0.0430	1.0000	0.0649	0.0300	0.0300	0.0000 or 0.6383
10	0.1100	1.0000	0.1182	0.0386	0.0386	0.0000 or 0.6383
11	0.1750	1.0000	0.1998	0.0481	0.0481	0.0000 or 0.6383
12	0.2400	1.0000	0.3097	0.0585	0.0585	0.0000 or 0.6383
13	0.3070	1.0000	0.4381	0.0697	0.0697	0.0000 or 0.6383
14	0.3720	1.0000	0.5677	0.0815	0.0815	0.0000 or 0.6383
15	0.4370	1.0000	0.6823	0.0939	0.0939	0.0000 or 0.6383
16	0.5000	1.0000	0.7735	0.1068	0.1068	0.0000 or 0.6383
17	0.5630	1.0000	0.8410	0.1199	0.1199	0.0000 or 0.6383
18	0.6280	1.0000	0.8888	0.1334	0.1334	0.0000 or 0.6383
19	0.6930	1.0000	0.9219	0.1470	0.1470	0.0000 or 0.6383
20	0.7600	1.0000	0.9445	0.1607	0.1607	0.0000 or 0.6383
21	0.8250	1.0000	0.9601	0.1745	0.1745	0.0000 or 0.6383
22	0.8900	1.0000	0.9709	0.1882	0.1882	0.0000 or 0.6383
23	0.9570	1.0000	0.9785	0.2018	0.2018	0.0000 or 0.6383
24	0.9900	1.0000	0.9838	0.2152	0.2152	1.0000
25	1.0000	1.0000	0.9876	0.2285	0.2285	1.0000
26	1.0000	1.0000	0.9904	0.2415	0.2415	1.0000
27	1.0000	1.0000	0.9925	0.2542	0.2542	1.0000
28	1.0000	1.0000	0.9940	0.2666	0.2666	1.0000
29	1.0000	1.0000	0.9952	0.2788	0.2788	1.0000
30	1.0000	1.0000	0.9961	0.2905	0.2905	1.0000
31	1.0000	1.0000	0.9968	0.3020	0.3020	1.0000
32	1.0000	1.0000	0.9973	0.3130	0.3130	1.0000
33	1.0000	1.0000	0.9977	0.3237	0.3237	1.0000
34	1.0000	1.0000	0.9981	0.3340	0.3340	1.0000
35	1.0000	1.0000	0.9983	0.3440	0.3440	1.0000
36	1.0000	1.0000	0.9986	0.3535	0.3535	1.0000
37	1.0000	1.0000	0.9987	0.3627	0.3627	1.0000
38	1.0000	1.0000	0.9989	0.3716	0.3716	1.0000
39	1.0000	1.0000	0.9990	0.3800	0.3800	1.0000
40	1.0000	1.0000	0.9991	0.3881	0.3881	1.0000
41	1.0000	1.0000	0.9992	0.3959	0.3959	1.0000
42	1.0000	1.0000	0.9993	0.4033	0.4033	1.0000
43	1.0000	1.0000	0.9994	0.4104	0.4104	1.0000
44	1.0000	1.0000	0.9994	0.4171	0.4171	1.0000
45	1.0000	1.0000	0.9995	0.4236	0.4236	1.0000

Table 5. Results of yield per recruit, spawning biomass per recruit and revenue per recruit analyses for shortspine thornyhead. Revenue per recruit is given for two price scenarios: a 10 inch minimum size limit (exvessel price zero for fish less than 10 inches TL) and a two-tier price structure (exvessel price for fish less than 10 inches 64% as large as that for fish larger than 10 inches). As explained in the text, the best estimate of natural mortality is probably 0.03 yr^{-1}.

	Natural Mortality Rate		
	0.03	0.045	0.06
Maximum Spawning Biomass (at F = 0.0 yr^{-1})	40.	15.	7.0
F_{max}	0.030	0.053	0.088
Yield	0.30	0.17	0.11
Spawning Biomass	10.	3.5	1.6
Revenue	0.30	0.16	0.10
$F_{0.1}$	0.018	0.028	0.040
Yield	0.28	0.15	0.10
Spawning Biomass	16.	6.0	2.8
Revenue	0.28	0.15	0.097
$F_{20\%}$	0.039	0.064	0.10
Yield	0.30	0.17	0.11
Spawning Biomass	8.0	3.0	1.4
Revenue	0.29	0.16	0.10
$F_{35\%}$	0.021	0.034	0.050
Yield	0.29	0.16	0.11
Spawning Biomass	14.	5.2	2.4
Revenue	0.29	0.16	0.10
$F_{max\$}$ (10 in min size limit)	0.030	0.049	0.072
Yield	0.30	0.17	0.11
Spawning Biomass	11.	3.8	1.9
Revenue	0.30	0.16	0.10
$F_{max\$}$ (two tier prices)	0.030	0.051	0.081
Yield	0.30	0.17	0.11
Spawning Biomass	10.	3.6	1.7
Revenue	0.30	0.17	0.11

Table 6. Results of yield per recruit, spawning biomass per recruit and revenue per recruit analyses for longspine thornyhead. Revenue per recruit is given for two price scenarios: a 10 inch minimum size limit (exvessel price zero for fish less than 10 inches TL) and a two-tier price structure (exvessel price for fish less than 10 inches 64% as large as that for fish larger than 10 inches). As explained in the text, the best estimate of M is probably 0.08 yr^{-1}.

		Natural Mortality Rate	
	0.08	0.10	0.12
Maximum Spawning Biomass (at $F = 0.0\ yr^{-1}$)	1.4	0.90	0.59
F_{max}	0.21	0.33	0.52
Yield	0.044	0.035	0.028
Spawning Biomass	0.30	0.16	0.090
Revenue	0.0087	0.0026	0.0004
$F_{0.1}$	0.084	0.11	0.14
Yield	0.039	0.030	0.024
Spawning Biomass	0.59	0.37	0.24
Revenue	0.018	0.010	0.0056
$F_{20\%}$	0.22	0.29	0.38
Yield	0.044	0.035	0.028
Spawning Biomass	0.29	0.18	0.12
Revenue	0.0084	0.0033	0.0012
$F_{35\%}$	0.11	0.14	0.18
Yield	0.042	0.032	0.025
Spawning Biomass	0.51	0.31	0.21
Revenue	0.017	0.0088	0.0046
$F_{max\$}$ (10 in min size limit)	0.063	0.069	0.074
Yield	0.036	0.026	0.019
Spawning Biomass	0.70	0.47	0.33
Revenue	0.019	0.011	0.0068
$F_{max\$}$ (two tier prices)	0.13	0.18	0.30
Yield	0.043	0.033	0.027
Spawning Biomass	0.44	0.26	0.14
Revenue	0.033	0.024	0.018

Table 7. Area (km^2), density (mt/km^2), survey biomass estimates (mt) and estimated fishing mortality rates during 1990 (yr^{-1}) for shortspine thornyheads, longspine thornyheads and the thornyhead species group at depths of 30 to 700 fathoms in the Columbia, Eureka and Monterey areas. Input data are given on the first page, calculations and results are given separately for shortspine thornyheads and longspine thornyheads on the second page and for the thornyhead species group on the third page. Headings for cruises are given in Table 1. Fishing mortality rates for 1990 (rows labeled "1990 F for Area") were estimated from the ratio of landings during 1990 and estimated survey biomass. Multiply survey biomass estimates by 0.94 (shortspine thornyhead) or 0.71 (longspine thornyhead) to obtain estimates of fishable biomass.

Table 7 (page 1) (revised July 30, 1991)

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

Depth Interval	Columbia Area	Eureka Area	Monterey Area	Totals by Interval
30-250	21,671	5,127	11,556	38,354
250-550	7,739	4,913	6,028	18,679
550-700	3,679	2,250	3,579	9,507
Totals for areas:	33,089	12,289	21,163	
			Grand Total	66,541

Landings (mt) during 1990 by species and area:

Area	Shortspine	Longspine
Columbia	1,513	2,270
Eureka	570	3,376
Monterey	1,823	376
Total	3,906	6,022

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

Depth Interval	NMFS HMB-84-01	NMFS DS-87-01	NMFS DS-88-03	NMFS MF-88-09	NMFS GF-89-02	SIO TRAWL	SIO CAM. SLED	NMFS MF-90-11
30-250	1.160	0.036	0.099	1.800	1.840	0.053	0.093	0.327
250-550	0.940	0.842	0.703	1.750	1.100	0.625	2.947	0.663
550-700	0.250	0.158	0.161	0.620	0.720	0.246	2.002	1.539

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

Depth Interval	NMFS HMB-84-01	NMFS DS-87-01	NMFS DS-88-03	NMFS MF-88-09	NMFS GF-89-02	SIO TRAWL	SIO CAM. SLED	NMFS MF-90-11
30-250	0.000	0.000	0.001	0.010	0.010	0.053	0.034	0.016
250-550	1.620	1.085	1.745	5.050	5.910	5.093	7.965	3.767
550-700	0.890	0.207	0.207	2.590	2.420	0.596	0.782	4.631

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

		NMFS HMB-84-01	NMFS DS-87-01	NMFS DS-88-03	NMFS MF-88-09	NMFS GF-89-02	SIO TRAWL	SIO CAM. SLED	NMFS MF-90-11
Columbia									
	30-250	25,138	774	2,148	39,008	39,875	1,149	2,015	7,081
	250-550	7,275	6,513	5,440	13,543	8,513	4,837	22,807	5,131
	550-700	920	582	592	2,281	2,649	905	7,365	5,660
Total for Area		33,333	7,869	8,180	54,832	51,036	6,890	32,187	17,871
1990 F for Area		0.05	0.19	0.18	0.03	0.03	0.22	0.05	0.08
Eureka									
	30-250	5,947	183	508	9,228	9,433	272	477	1,675
	250-550	4,618	4,135	3,454	8,597	5,404	3,070	14,478	3,257
	550-700	562	356	362	1,395	1,620	553	4,504	3,462
Total for Area		11,127	4,674	4,324	19,220	16,457	3,896	19,459	8,394
1990 F for Area		0.05	0.12	0.13	0.03	0.03	0.15	0.03	0.07
Monterey									
	30-250	13,405	413	1,145	20,802	21,264	612	1,075	3,776
	250-550	5,666	5,073	4,238	10,549	6,631	3,767	17,764	3,996
	550-700	895	567	576	2,219	2,577	880	7,165	5,506
Total for Area		19,966	6,052	5,959	33,569	30,471	5,260	26,003	13,278
1990 F for Area		0.09	0.30	0.31	0.05	0.06	0.35	0.07	0.14
All Areas:									
Grand Total Biomass		64,426	18,595	18,463	107,621	97,964	16,046	77,649	39,544
1990 F for Area		0.06	0.21	0.21	0.04	0.04	0.24	0.05	0.10

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

		NMFS HMB-84-01	NMFS DS-87-01	NMFS DS-88-03	NMFS MF-88-09	NMFS GF-89-02	SIO TRAWL	SIO CAM. SLED	NMFS MF-90-11
Columbia									
	30-250	0	0	28	217	217	1,149	737	338
	250-550	12,537	8,394	13,504	39,081	45,737	39,414	61,640	29,155
	550-700	3,274	761	761	9,528	8,902	2,193	2,877	17,036
Total for Area		15,811	9,156	14,293	48,826	54,856	42,755	65,254	46,529
1990 F for Area		0.14	0.25	0.16	0.05	0.04	0.05	0.03	0.05
Eureka									
	30-250	0	0	7	51	51	272	174	80
	250-550	7,959	5,329	8,573	24,809	29,034	25,020	39,130	18,508
	550-700	2,002	466	465	5,827	5,445	1,341	1,759	10,419
Total for Area		9,961	5,795	9,045	30,688	34,530	26,633	41,063	29,007
1990 F for Area		0.34	0.58	0.37	0.11	0.10	0.13	0.08	0.12
Monterey									
	30-250	0	0	15	116	116	612	393	180
	250-550	9,765	6,538	10,519	30,440	35,624	30,700	48,011	22,709
	550-700	3,185	741	740	9,269	8,661	2,133	2,799	16,573
Total for Area		12,950	7,279	11,274	39,825	44,401	33,445	51,203	39,462
1989 F for Area		0.03	0.05	0.03	0.01	0.01	0.01	0.01	0.01
All Areas:									
Grand Total Biomass		38,722	22,230	34,612	119,339	133,787	102,833	157,520	114,998
1990 F for Area		0.16	0.27	0.17	0.05	0.05	0.06	0.04	0.05

Biomass (mt) of longspine and shortspine thornyhead by area, survey and depth interval:		NMFS HMB-84-01	NMFS DS-87-01	NMFS DS-88-03	NMFS MF-88-09	NMFS GF-89-02	SIO TRAWL	SIO CAM. SLED	NMFS MF-90-11
Columbia									
	30-250	25,138	774	2,176	39,225	40,091	2,297	2,752	7,419
	250-550	19,812	14,907	18,945	52,625	54,250	44,251	84,447	34,286
	550-700	4,194	1,344	1,353	11,809	11,551	3,097	10,242	22,695
Total for Area		49,144	17,025	22,474	103,658	105,892	49,646	97,441	64,401
1990 F for Area		0.08	0.22	0.17	0.04	0.04	0.08	0.04	0.06
Eureka									
	30-250	5,947	183	515	9,279	9,484	543	651	1,755
	250-550	12,577	9,463	12,026	33,406	34,438	28,091	53,607	21,765
	550-700	2,565	822	828	7,222	7,065	1,894	6,264	13,881
Total for Area		21,088	10,468	13,369	49,908	50,987	30,529	60,522	37,401
1990 F for Area		0.19	0.38	0.30	0.08	0.08	0.13	0.07	0.11
Monterey									
	30-250	13,405	413	1,160	20,917	21,379	1,225	1,468	3,956
	250-550	15,431	11,611	14,756	40,989	42,255	34,467	65,775	26,705
	550-700	4,080	1,307	1,316	11,488	11,237	3,013	9,963	22,079
Total for Area		32,916	13,331	17,233	73,394	74,872	38,705	77,206	52,741
1989 F for Area		0.07	0.03	0.04	0.01	0.01	0.01	0.00	0.01
All Areas (both species):									
Grand Total Biomass		103,148	40,824	53,075	226,959	231,751	118,880	235,169	154,542
1990 F for Area		0.10	0.24	0.19	0.04	0.04	0.08	0.04	0.06

Figure 1. Landings data (mt) by area for the thornyhead market category, 1981 to 1990.

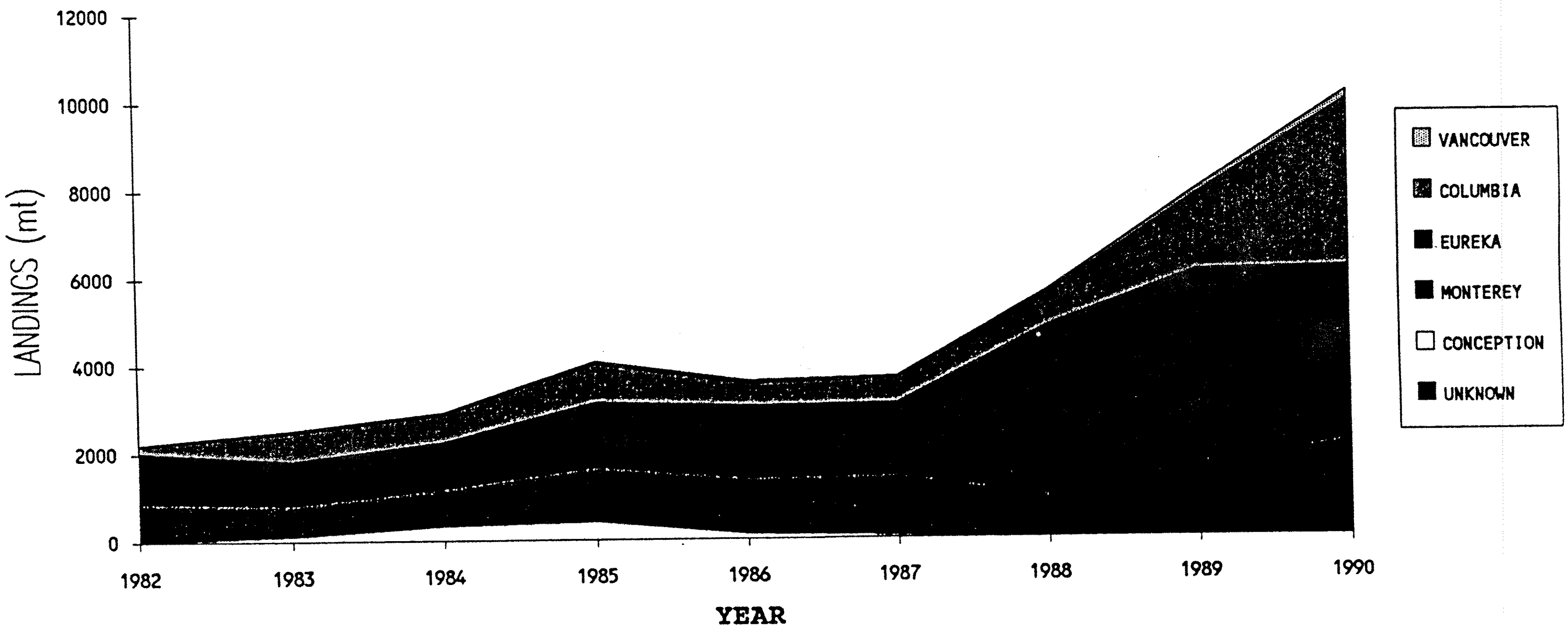
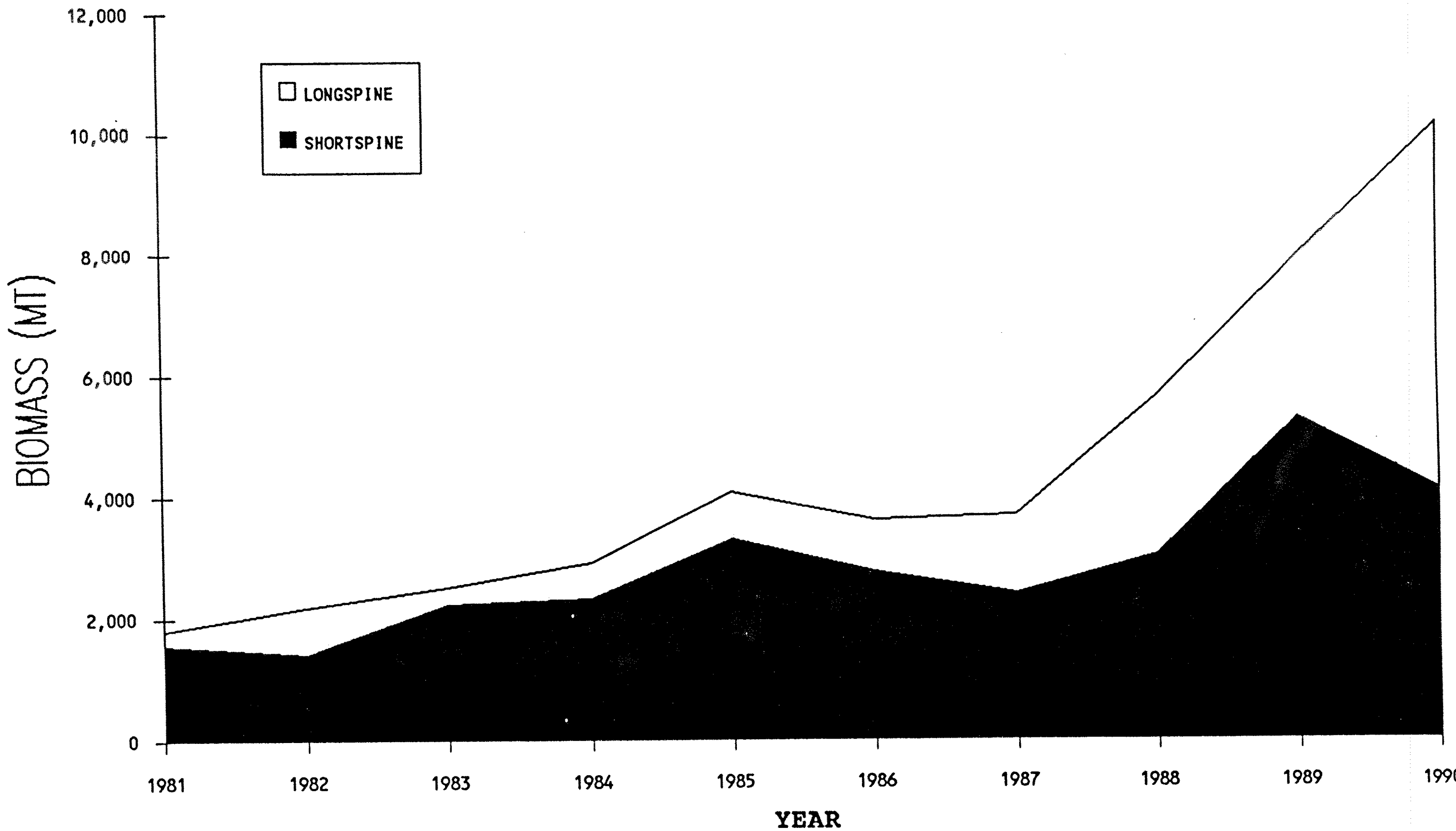

12000
10000
8000
6000
4000
2000
0
LANDINGS (mt)
1982
1983
1984
1985
1986
1987
1988
1989
1990
YEAR
VANCOUVER
COLUMBIA
EUREKA
MONTEREY
CONCEPTION
UNKNOWN

Figure 2. Coastwide landings data (mt) by species for thornyheads, 1981 to 1990.



LONGSPINE
SHORTSPINE
12,000
10,000
8,000
6,000
4,000
2,000
0
BIOMASS (MT)
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
YEAR

Figure 3. Landings (mt) by market categories for the deep water dover complex, 1981 to 1990.

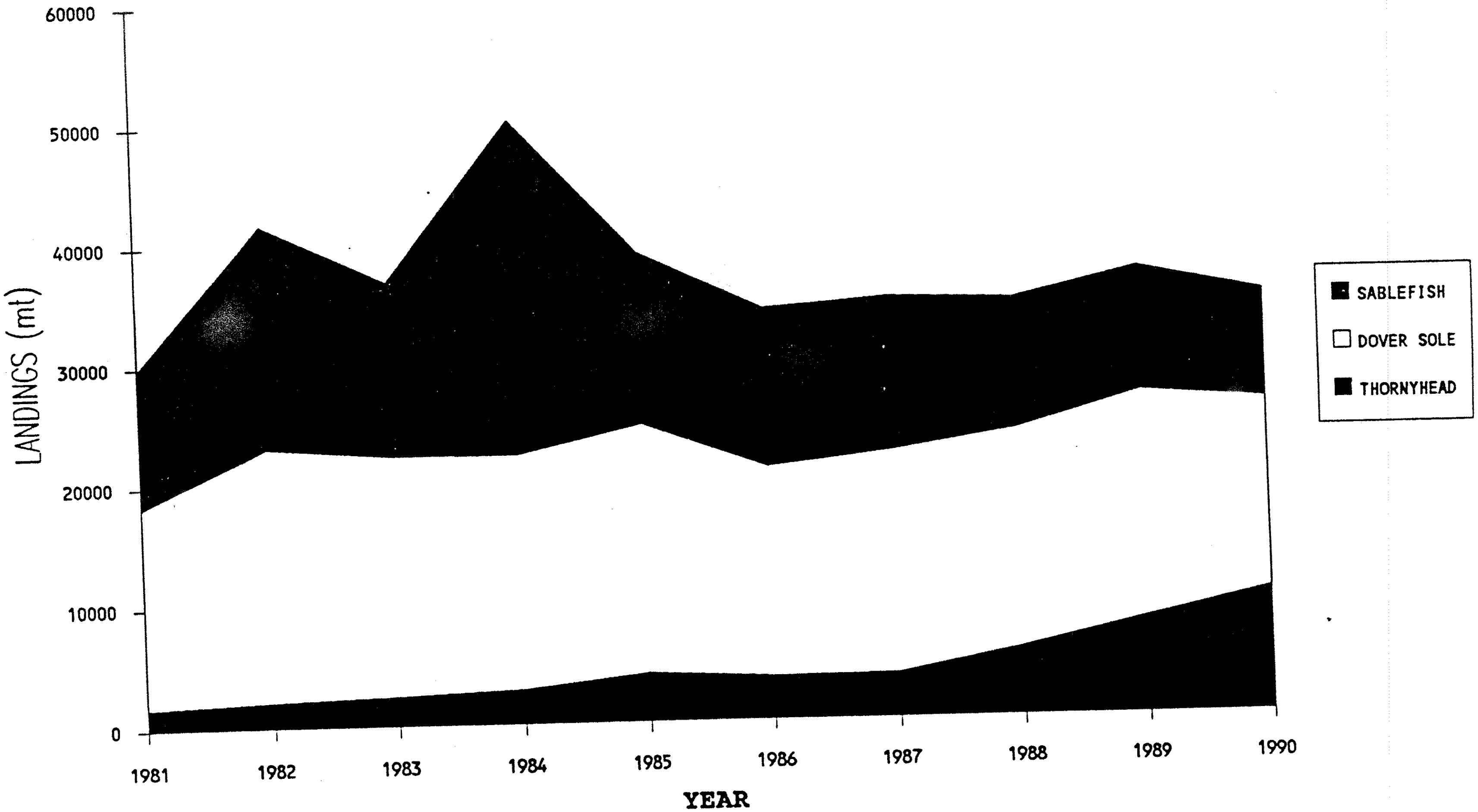

60000
50000
40000
30000
20000
10000
0
LANDINGS (mt)
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
YEAR
SABLEFISH
DOVER SOLE
THORNYHEAD

Figure 4. Revenues (1989 $) by market categories for the deep water dover complex during 1982 to 1990.

DWDREVN2.XLC

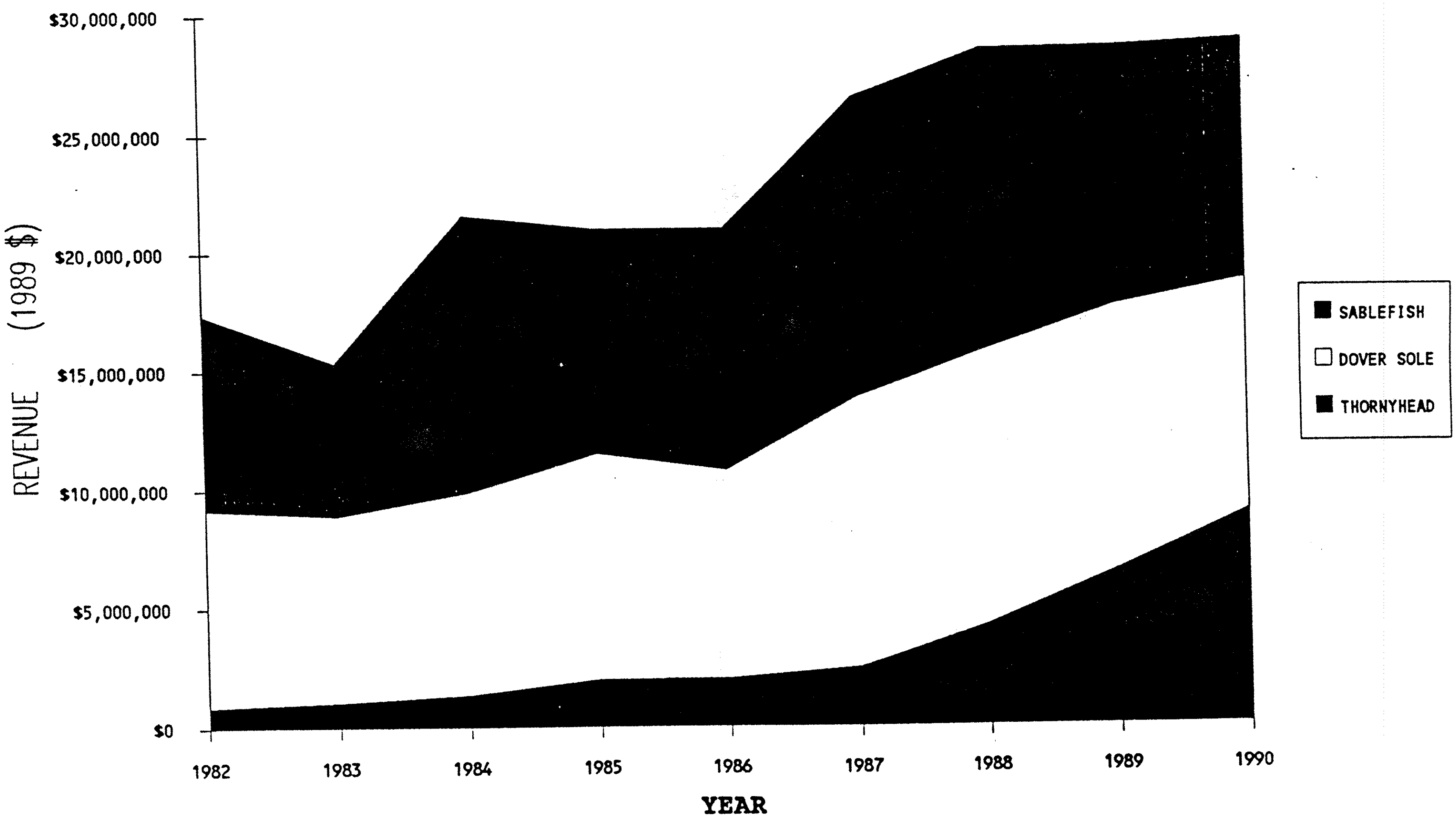


Figure 5. Length composition data for shortspine thornyheads taken during the R/V David Starr Jordan cruise conducted by NMFS during 1988 between Pt. Conception and Pt. Sur, California.

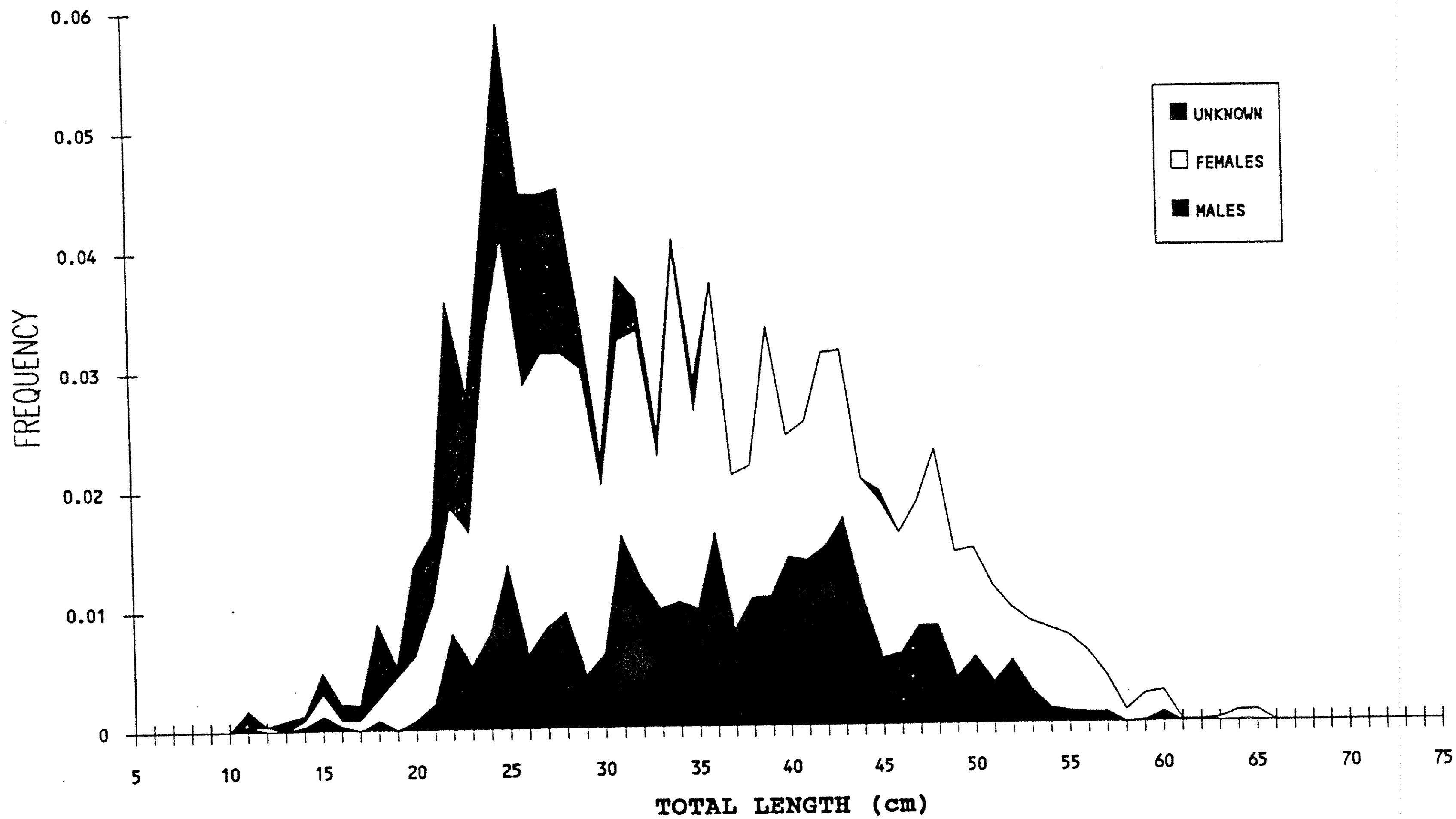
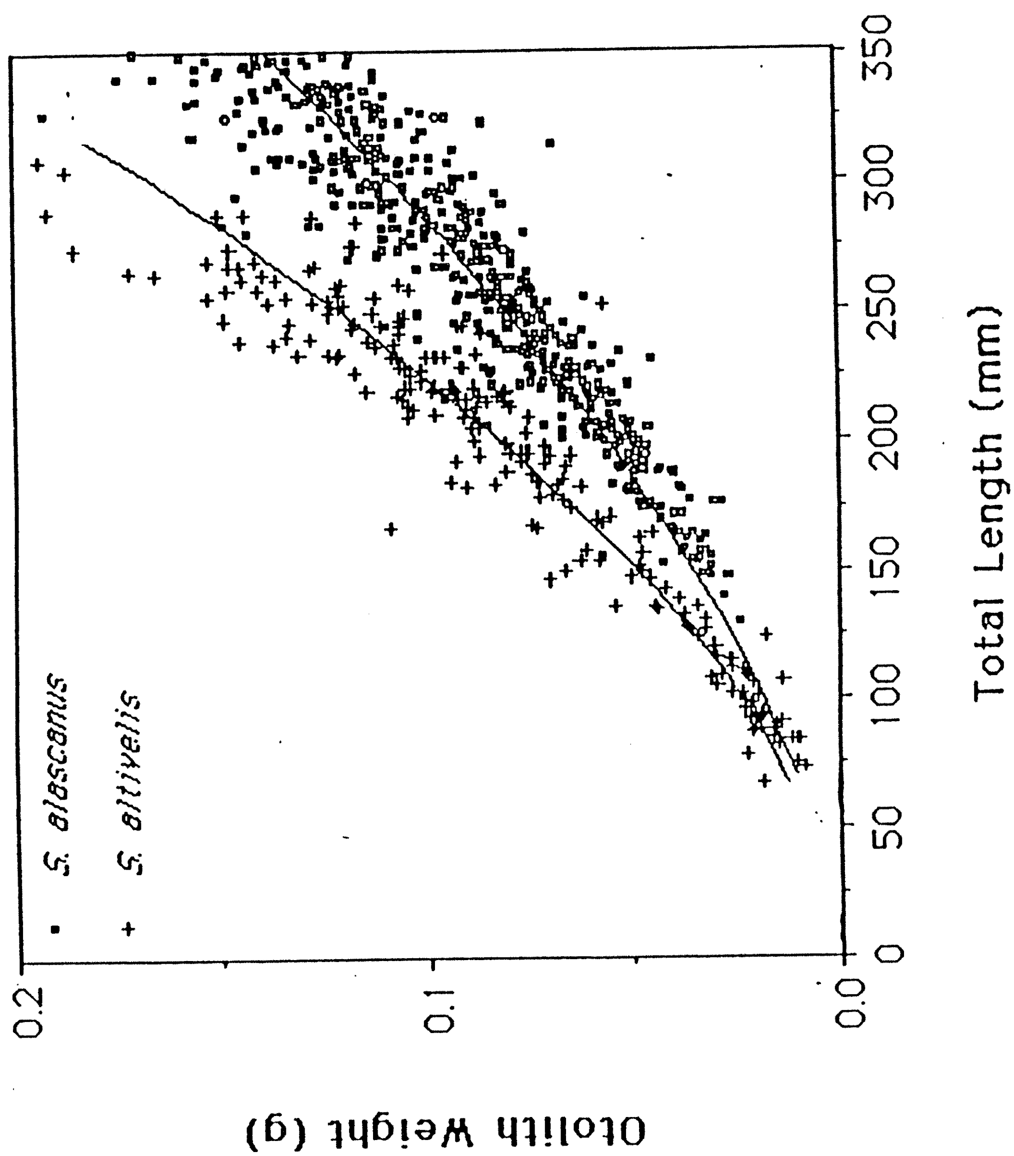

0.06
0.05
0.04
0.03
0.02
0.01
0
FREQUENCY
UNKNOWN
FEMALES
MALES
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
TOTAL LENGTH (cm)

Figure 6. The relationship between total length and otolith weight for shortspine and longspine thornyheads (from Lu 1990).



S. alascanus
S. altivelis
Otolith Weight (g)
0.2
0.1
0.0
0
50
100
150
200
250
300
350
Total Length (mm)

Figure 7. Age determinations for shortspine thornyheads from two readers.

SSAGELEN.XLS Chart 3

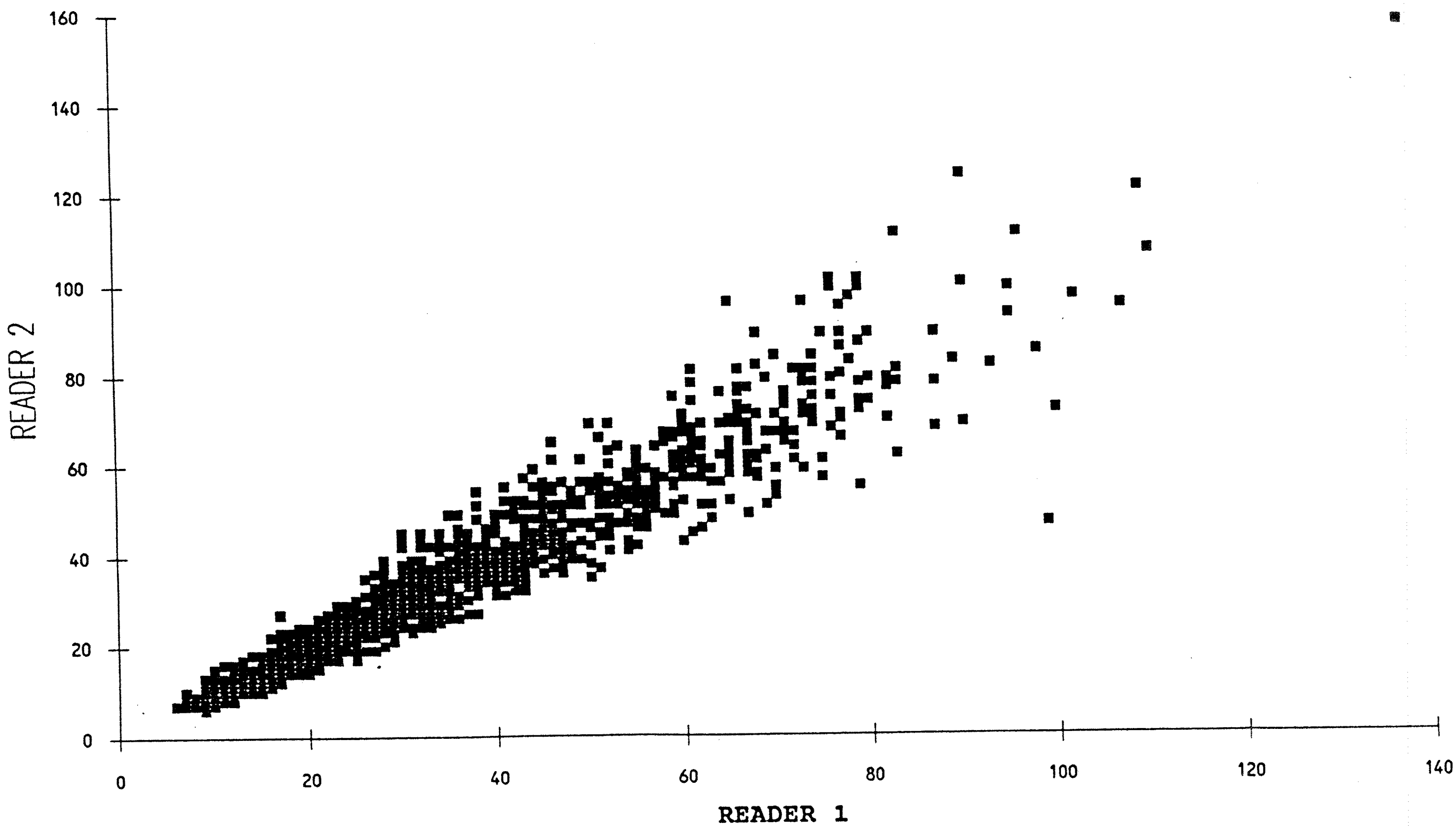


Figure 8. Observed and predicted total length (cm) at age for shortspine thornyheads.

SSAGELEN.XLS Chart 2

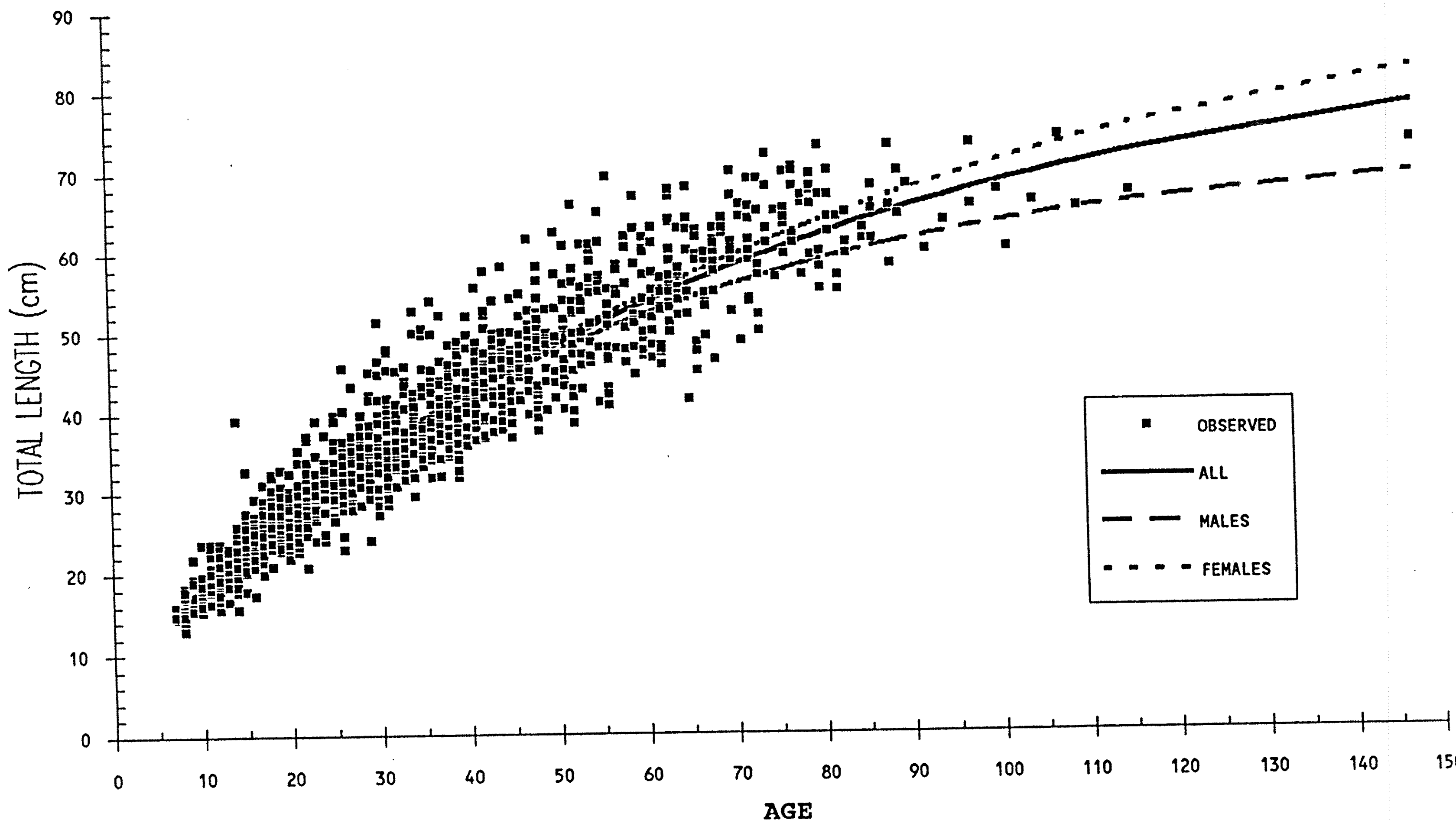


Figure 9. Observed and predicted total length (cm) at age for longspine thornyheads.

LSTOTOL2.XLS Chart 2

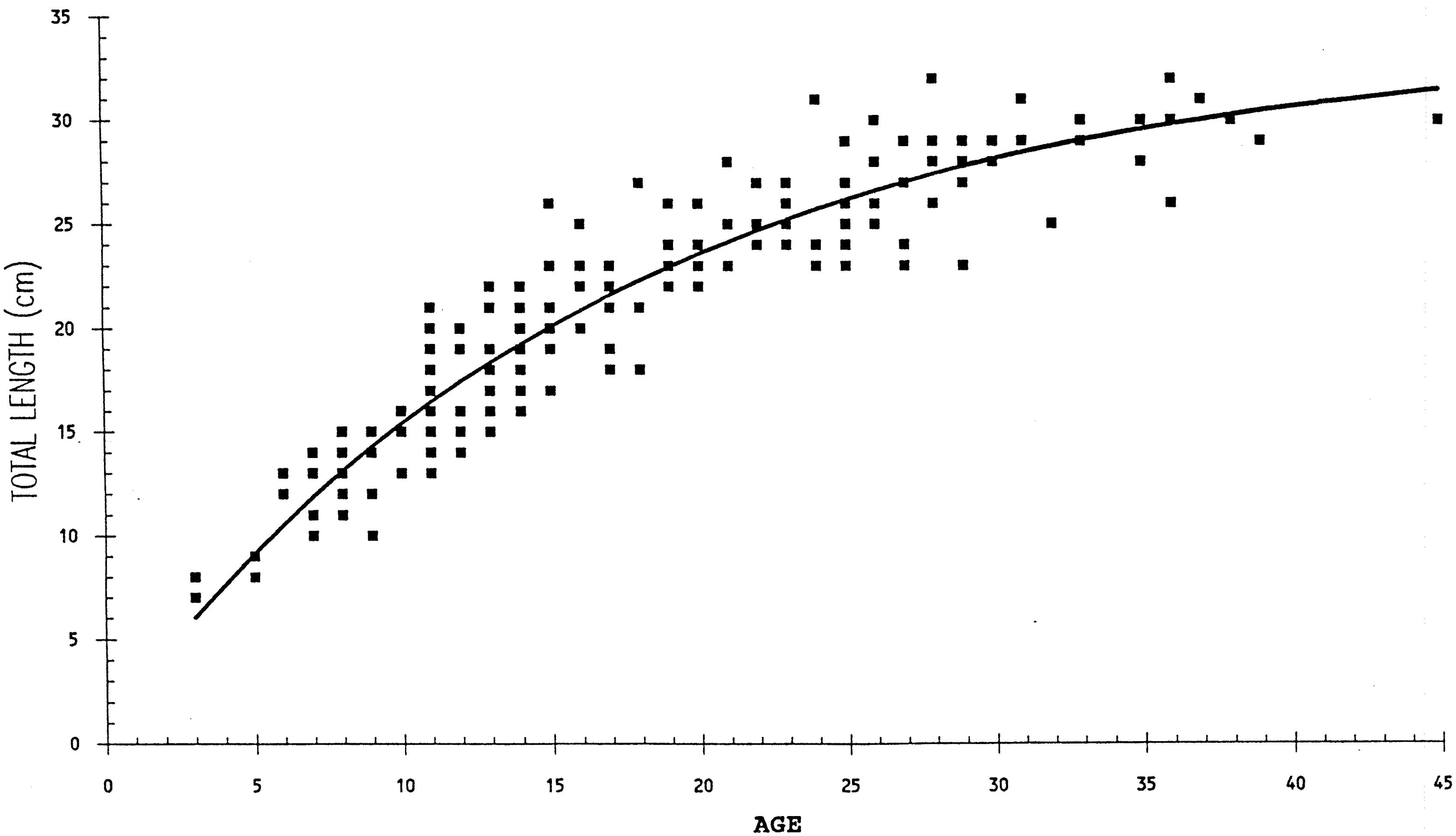


Figure 10. Observed and predicted fraction mature at length for female shortspine thornyheads. The line labeled "Logistic Fem %" was fit by logistic regression. The line labeled "Von Bert Fem %" was derived from a Von Bertalanffy growth model and fit by nonlinear least squares.

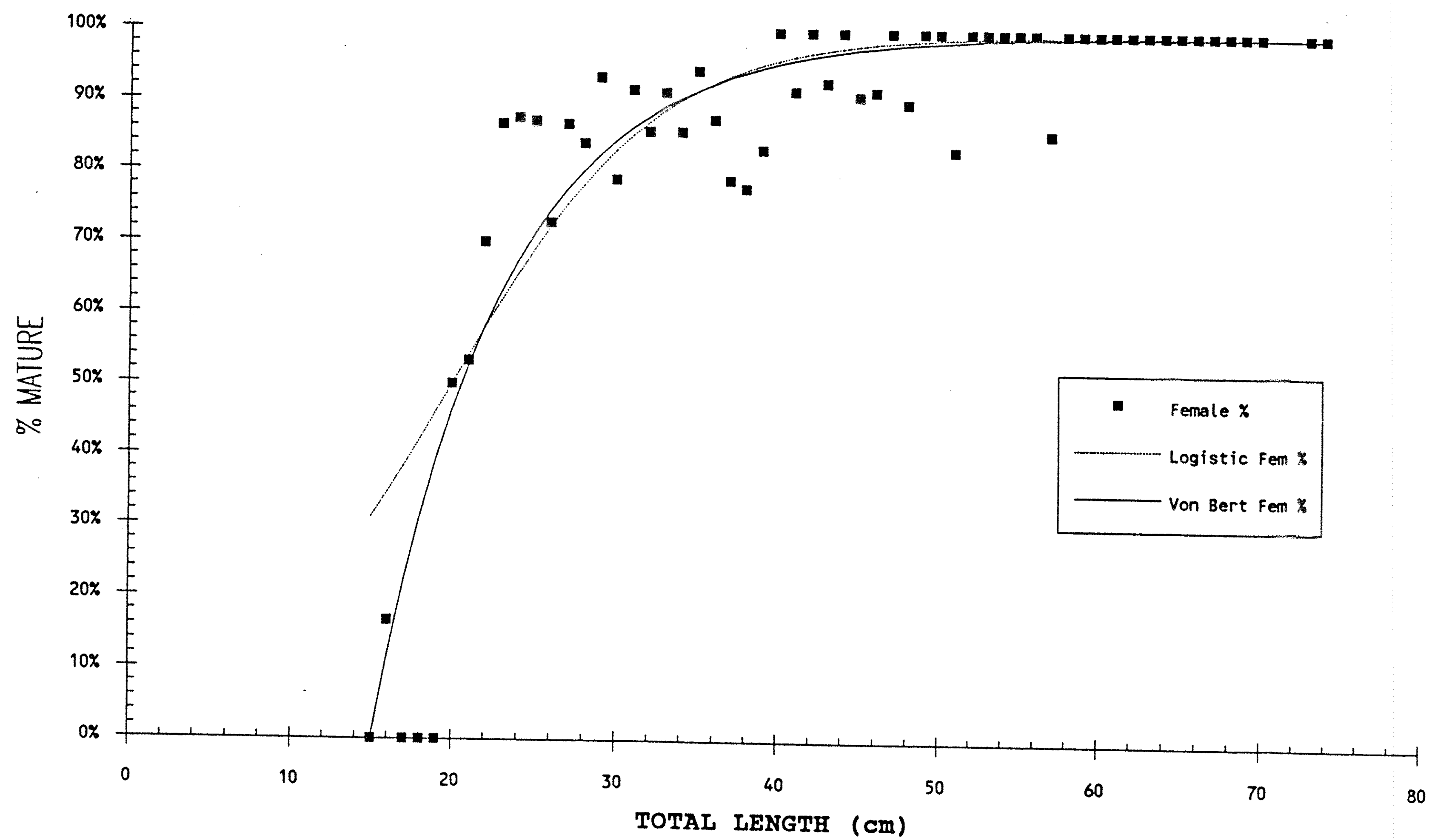

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% MATURE
0
10
20
30
40
50
60
70
80
TOTAL LENGTH (cm)
Female %
Logistic Fem %
Von Bert Fem %

Figure 11. Observed and predicted fraction mature at length for female longspine thornyheads.

PLTLSMAT.XLS Chart 1

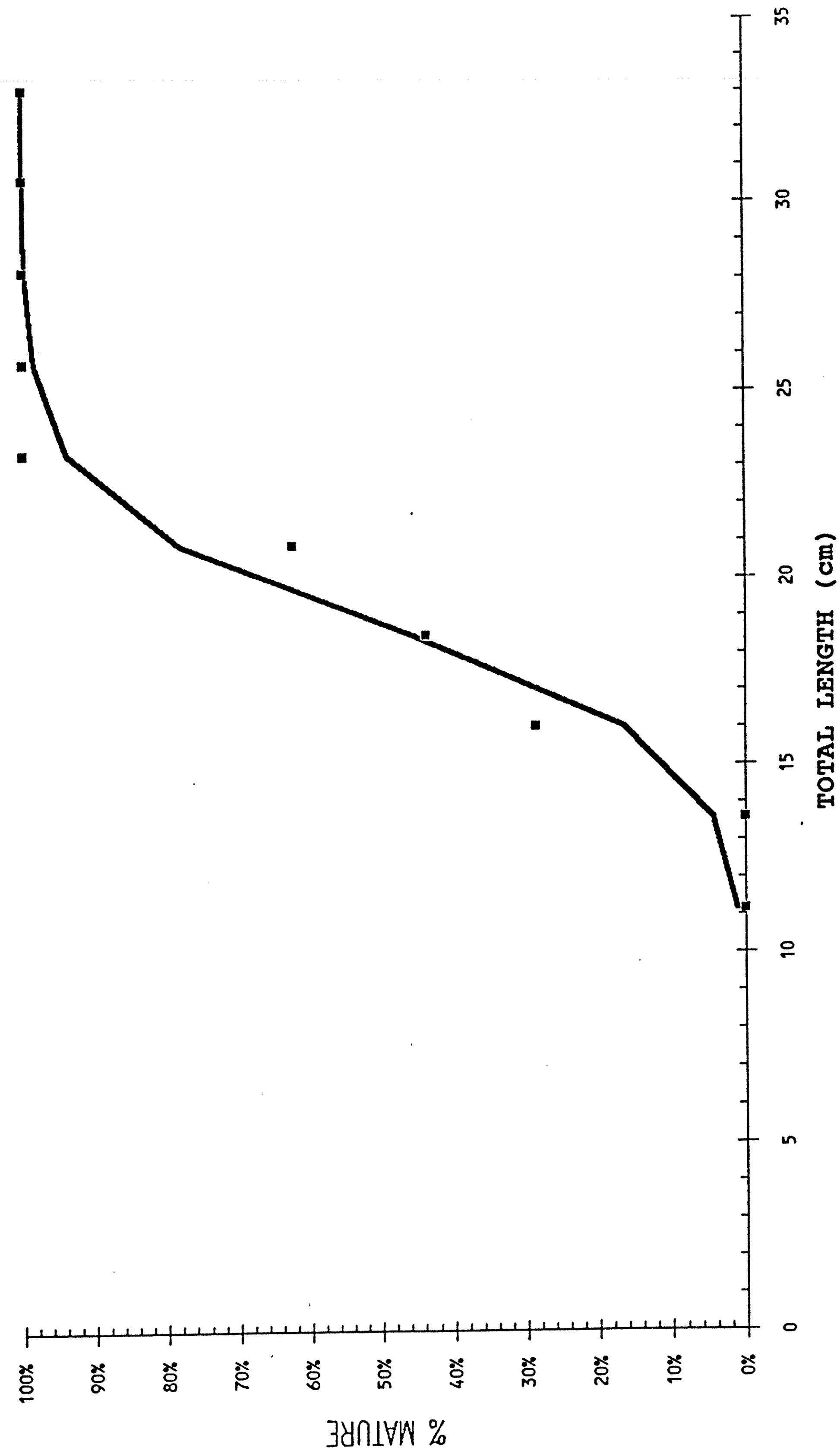


Figure 12. Length composition data for shortspine thornyheads collected by observers on board commercial fishing vessels. The data are for fish taken from the Eureka area during 1988 to 1989 by bottom trawls with 4.5 inch mesh in the codends and at depths $\geq$ 200 fathoms.

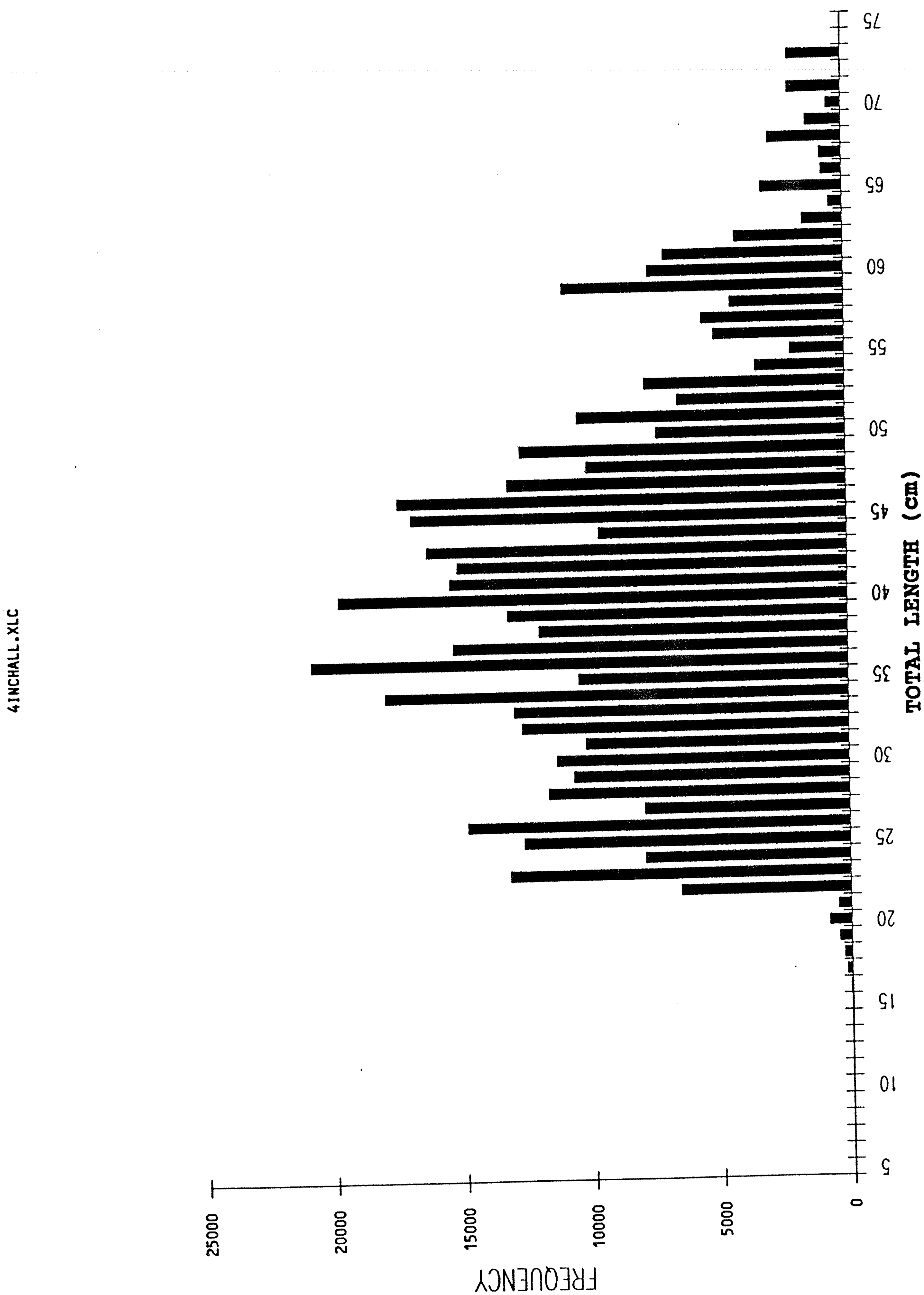

4INCHALL.XLC
FREQUENCY
0
5000
10000
15000
20000
25000
TOTAL LENGTH (cm)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75

Figure 13. Length composition data for longspine thornyheads collected by observers on board commercial fishing vessels. The data are for fish taken from the Eureka area during 1988 to 1989 by bottom trawls with 4.5 inch mesh in the codends and at depths ≥ 200 fathoms.

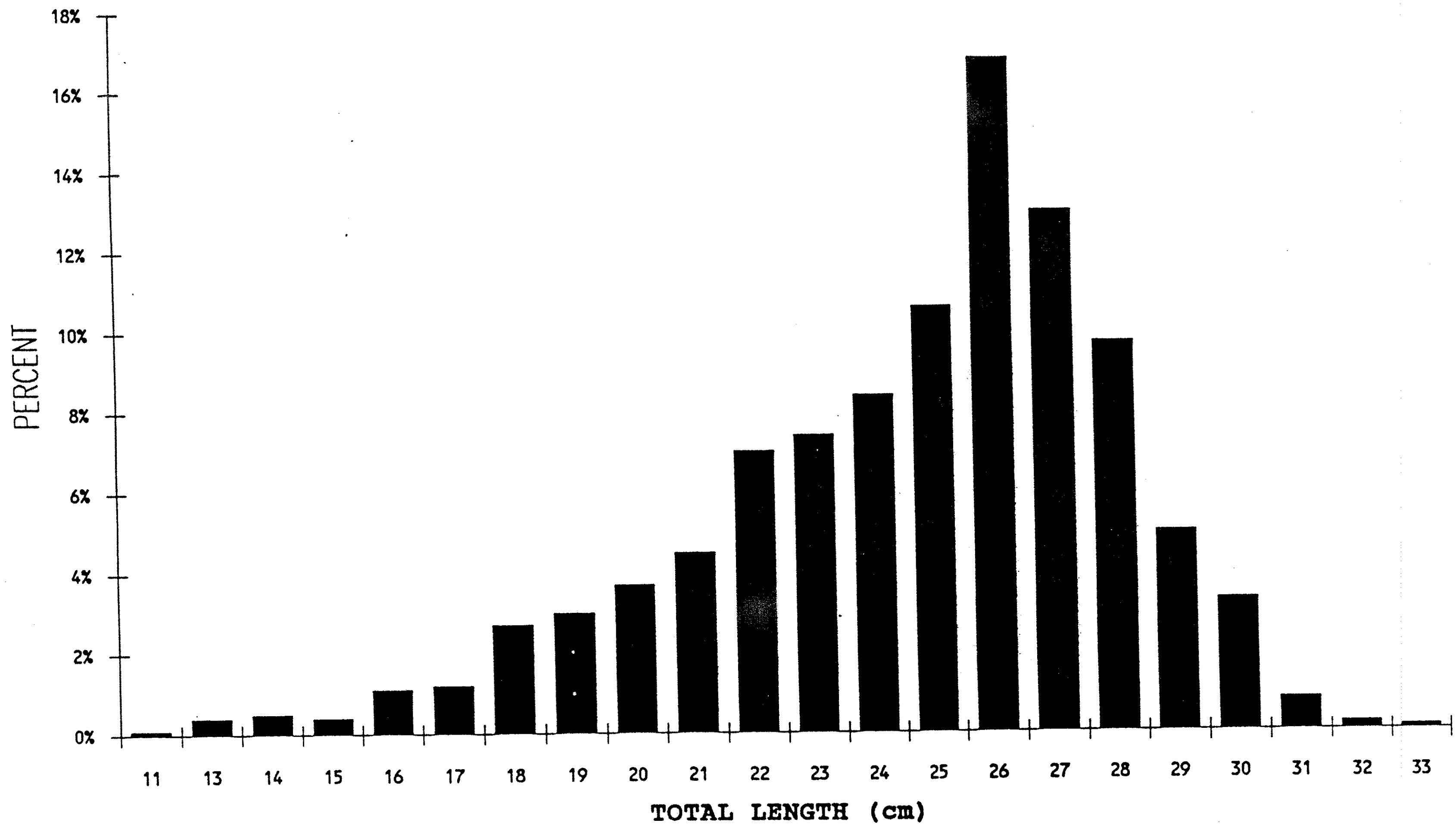

18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
PERCENT
11
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
TOTAL LENGTH (cm)

Figure 14. Yield, revenue and spawning biomass per recruit for shortspine thornyheads for bottom trawls with 4.5 inch mesh in the codends and $M = 0.03\ yr^{-1}$. Revenue per recruit was calculated assuming that the exvessel price for small fish (≤ 10 inches TL) was either zero (corresponding to a minimum size limit) or 64% (corresponding to a two-tiered price structure) of the price for large fish. Yield and revenue are plotted on the same relative scale for ease of comparison. Maximum yield per recruit was 0.30 kg, maximum spawning biomass per recruit was 40 kg.

SHORTSPINE THORNYHEAD, M=0.03

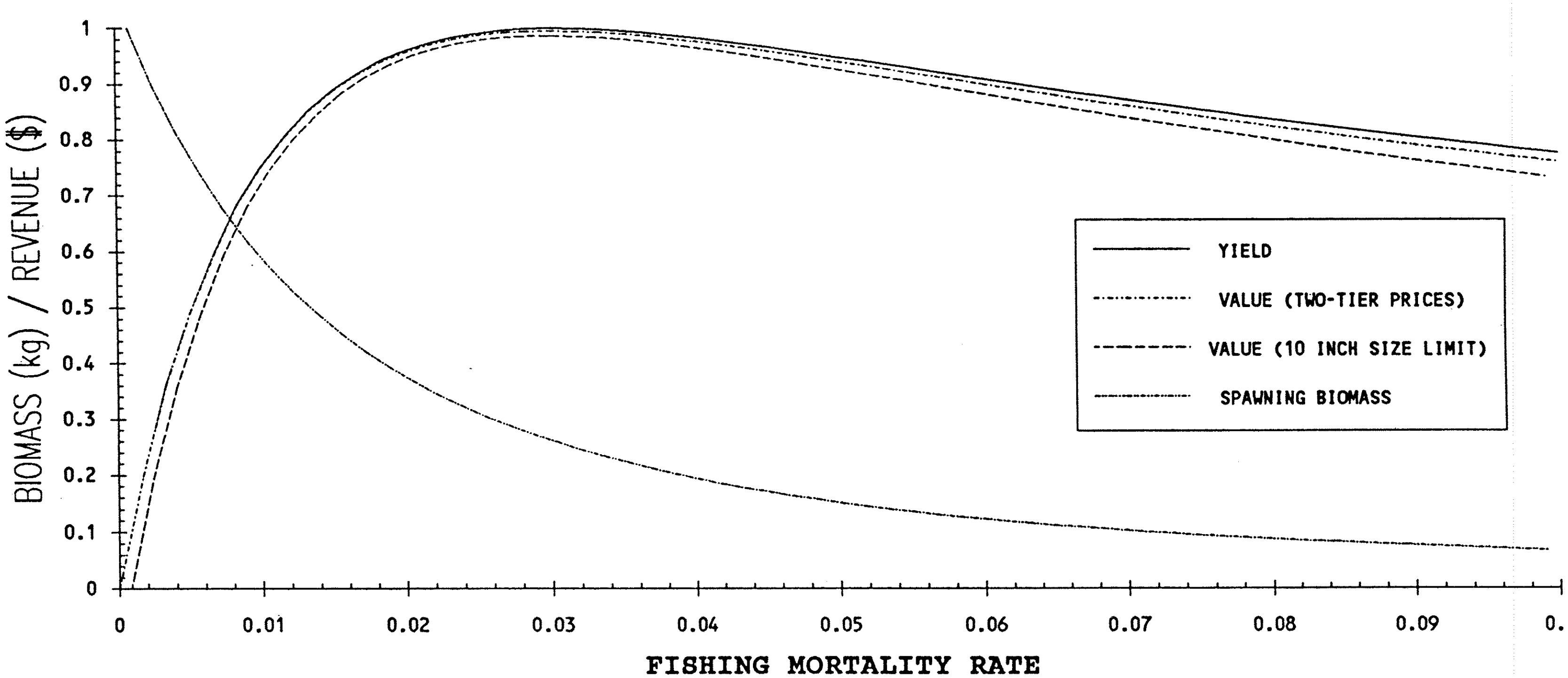
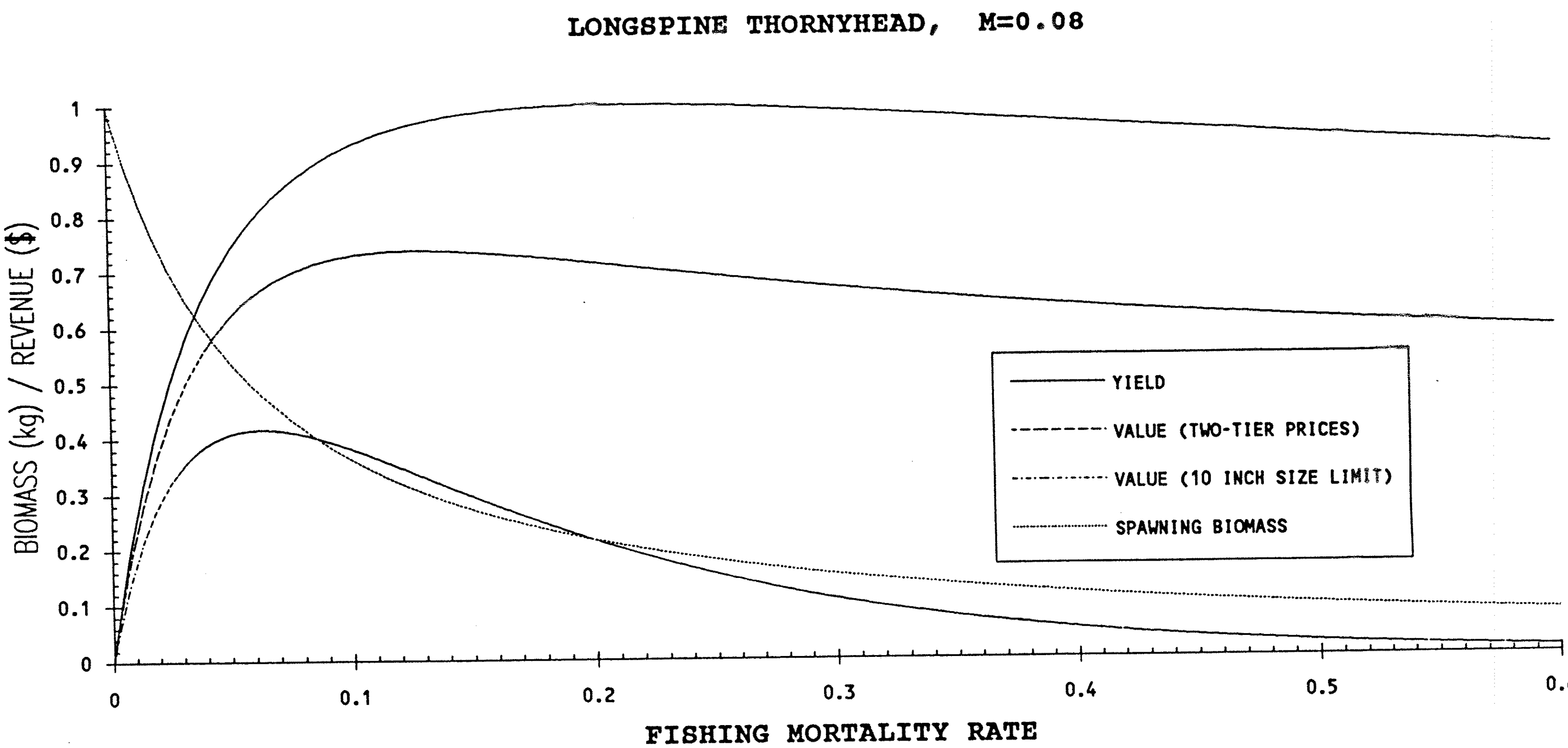


Figure 15. Yield, revenue and spawning biomass per recruit for longspine thornyheads with 4.5 inch mesh in the codends and M = 0.08 yr^{-1}. Revenue per recruit was calculated assuming that the exvessel price for small fish (≤ 10 inches TL) was either zero (corresponding to a minimum size limit) or 64% (corresponding to a two-tiered price structure) of the price for large fish. Yield and revenue are plotted on the same relative scale for ease of comparison. Maximum yield per recruit was 0.044 kg, maximum spawning biomass per recruit was 1.4 kg.


LONGSPINE THORNYHEAD, M=0.08
BIOMASS (kg) / REVENUE ($)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
FISHING MORTALITY RATE
YIELD
VALUE (TWO-TIER PRICES)
VALUE (10 INCH SIZE LIMIT)
SPAWNING BIOMASS

STATUS OF THE PACIFIC COAST GROUNDFISH FISHERY THROUGH 1991 AND RECOMMENDED ACCEPTABLE BIOLOGICAL CATCHES FOR 1992

Stock Assessment and Fishery Evaluation

Pacific Fishery Management Council
Metro Center, Suite 420
2000 SW First Avenue
Portland, Oregon

September 1991