Age, Growth, Year Class Strength, and Potential Yield For Shortbelly Rockfish

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ABSTRACT

Shortbelly rockfish (Sebastes jordani) is a highly abundant species that could support a large commercial fishery in central California. Prior studies of shortbelly rockfish growth have been based on age data obtained from scales or whole otoliths. We used broken and burnt otoliths to determine the ages of 2,578 shortbelly rockfish. That information was used to update estimates of the von Bertalanffy growth curve parameters, examine year class strength, and develop estimates of potential yield. We found that shortbelly rockfish live for up to 22 years. Males grew more slowly and reached a smaller maximum size than females. Based on the reported size at maturity, we estimated that 50% of shortbelly rockfish are sexually mature by age 2. Using the potential yield model $MSY=0.3MB_0$ and biomass estimates from hydroacoustic surveys, we estimate that maximum sustainable yield in the Ascension Canyon to Farallon Islands area is between 13,944 and 27,989 metric tons. The corresponding estimates for the fishing mortality rate $F_{0.1}$ ranged from 26,862 to 47,008 metric tons. A preliminary examination of the sample age distributions shows the 1973-1975 yearclasses were relatively strong for shortbelly rockfish. This pattern was similar to the pattern observed for chilipepper (S goodei) and different from widow rockfish (S. entomelas).

INTRODUCTION

Shortbelly rockfish (Sebastes jordani) is an abundant species in California waters. In midwater trawl surveys of juvenile rockfish conducted off central California, shortbelly rockfish are far more abundant than any other rockfish species[3]. The biomass of shortbelly rockfish in the Ascension Canyon to Farallon Islands area (Fig 1) was estimated from hydroacoustic studies[4] to be 295,000 tonnes (t) in 1977 and 152,700 t in 1980. These estimates are one to two times the estimated coastwide virgin biomass for widow rockfish (S. entomelas) (Lenarz and Hightower 1988), a species that supports a significant commercial fishery. Currently there is no commercial fishery for shortbelly rockfish, but a new processing technique involving bone softening (Okada et al. 1989), combined with their high abundance, could lead to the development of a substantial commercial fishery. If a commercial fishery does develop, it will be important to have accurate life history information for management purposes.

Previous studies of shortbelly rockfish life history characteristics have been based on age data from scales (Phillips 1964) or whole otoliths (Lenarz 1980). However, studies of other species (Six and Horton 1977, Beamish 1979a, Beamish 1979b) have shown that the ages obtained from those structures tend to be underestimates and that broken and burnt otoliths are a more reliable structure for determining fish age. Using scales, Phillips (1964) estimated the maximum age of shortbelly rockfish to be ten years. Lenarz (1980) examined the surface of whole otoliths and reported the maximum age to be twelve years.

Lenarz[5] indicated that surface aging of this species was very difficult and felt the ages could have been greater than he reported. For that reason, the objective of this study was to provide updated estimates of the age and growth of shortbelly rockfish, based on information obtained by examining broken and burnt otoliths. That information was used to obtain updated estimates of potential yield that will be useful if a commercial fishery develops for this species. We also attempted to identify strong and weak year classes and compared those results to observations for other rockfish species. By identifying groups of species within which fluctuations in year-class strength are similar, we may gain a better understanding of the factors influencing rockfish recruitment.

MATERIALS AND METHODS

Adult shortbelly rockfish were captured occasionally in 1980-1988 surveys designed to monitor the abundance of juvenile[3] and demersal adult rockfish (Gunderson and Sample 1980). We assumed that fish of all ages beyond one year were equally vulnerable to the relatively small mesh ($\leq$1.5 inch) trawl gear used in these studies. Samples were also collected during a pilot fishery development cruise (Kato 1981). In this cruise a 3-inch mesh net was used and an effort was made to catch larger fish, although the net proved capable of catching one- and two-year-old fish as well.

Otoliths were collected from 2,578 fish from 48 tows. Tows were made at various locations along the northern California - southern Oregon coast (Figure 1, Table 1). The sagittal otoliths were removed, cleaned, and either stored dry or in ethanol until they could be examined. Otoliths were examined using the break and burn technique (Chilton and Beamish, 1982). To evaluate between-reader agreement, two readers independently examined a random subsample of 200 otoliths. To evaluate within-reader agreement, a random subsample of 200 otoliths was read twice independently by one reader. To compare ages obtained by otolith surface versus broken and burnt otoliths, one reader obtained ages for a random subsample of 200 otoliths, first from the surface, and then independently from the broken and burnt sections.

The von Bertalanffy growth equation is a useful model for relating length, rate of growth, and age. The form of the model is:

$$L_t = L \quad (1-e^{-k(t-to\ )})$$

where L_t = total length (mm) at age t

L = estimate of average maximum length attained

k = growth completion rate

t_o = theoretical age when fish is length 0.

Parameter estimates for the von Bertalanffy growth equation were obtained using nonlinear regression analysis. Growth equations were fitted separately for males and females and compared using an F-test (Ratkowsky 1983).

RESULTS AND DISCUSSION

Age and Growth

The comparison between ages derived from examination of the otolith surface and from broken and burnt sections revealed that for fish older than age 4 (larger than 22 cm), ages obtained from the otolith surface tended to be less than ages obtained from broken and burnt otoliths (Figure 2). Similar results have been found for canary rockfish (S. pinniger) and black rockfish (S. melanops) (Six and Horton 1977). Between-reader agreement for shortbelly rockfish ages was good with 76% agreement to the year and 87% agreement within one year. There were no obvious trends for between-reader differences except that percent agreement decreased with increased age (Figure 3). Within-reader agreement was 77% to the year and 95% within one year (Figure 4). Six and Horton (1977) found within-reader agreements of 76% to the year for both canary and black rockfish. Between reader agreement for yellowtail rockfish (S. flavidus) was reported to be 24% to the year and 71% to within one year (Six and Horton 1977).

We believe that, in some cases, ages for fish less than three years old could be overestimated using the break-and-burn technique. This is due to a probable check close to the nucleus in some otoliths. This check was seldom visible on the otolith surface and was present in about 20% of the otoliths. The mark was assumed to be a check, given its proximity to the nucleus, the larger annuli outside it, and its absence in the majority of fish.

Based on these observations we believe that the otolith surface is the preferred age structure for small fish (< 20 cm) and broken and burnt otoliths for large fish. Our experience also leads us to conclude that otoliths from shortbelly rockfish are easier to interpret than those of chilipepper (*S. goodei*), widow rockfish or boccacio (*S. paucispinus*). However, neither conclusion can be confirmed until validation studies are done.

We found that shortbelly rockfish live substantially longer than previously reported. The oldest fish we found was 22 years old as opposed to the previous estimate of 12 years by Lenarz (1980). Results from this and Lenarz's (1980) study indicated that 16-cm male and female fish were between 1 and 2 years old. Since Phillips (1964) determined that 16 cm was the length of 50% sexual maturity, we estimate that the age of 50% sexual maturity is between 1 and 2 years.

Our estimates of the von Bertalanffy growth curve parameters differed considerably from those reported by Lenarz (1980) and Phillips (1964) (Table 2). Our L values were 11 mm lower for males and 43 mm lower for females (Table 2) than the estimates obtained from whole otolith ages (Lenarz 1980).

Hirschhorn (1974) found that a change in the range of ages used to compute the von Bertalanffy growth curve parameters can result in changes to the parameter estimates. Lenarz (1980), using the surface of otoliths, found the maximum age to be greater than reported by Phillips (1964), and obtained lower estimates for both L and k (Table 2). In this study we found the maximum age to be nearly twice the previously reported value (22 years versus 12 years) and our estimates of L were considerably lower than the estimates obtained by either Lenarz or Phillips. The male k value in our study was about 38% less than reported by Lenarz whereas the k value for females was 20% higher. These differences may be due to the increase in maximum age as well as differences in depths and areas sampled.

We detected significant differences in parameter estimates for males and females, with males having a smaller size at age, slower growth rate and a slightly smaller maximum size ($F_{crit}(3,1000,\ 0.0001)=3.80$, $F_{calc}=99.90$) (Figure 5). The observed age-length values matched the predicted values reasonably well, although there was some tendency to overestimate mean length at ages 3-9 for males and 19-21 for females (Figure 6). Although sample sizes were small for the older ages, the results seemed to indicate that the oldest females were smaller than somewhat younger females. Similar patterns were evident in results for female yellowtail rockfish (Leaman and Beamish 1984) and female Pacific ocean perch (Leaman, In Press). Leaman (In Press) suggested that there may be a selective advantage to slower growth such that faster growing fish experience a higher mortality rate. Alternative explanations for the smaller size of the oldest fish are shrinking of older fish through senescence (Liu and Walford 1969), or a time trend in growth rates (Leaman, In Press).

Potential Yield

The historical estimate of maximum sustainable yield (MSY), 44,250 t, was based on the relationship $MSY=0.5MB_0$ (Gulland 1971), where M was the instantaneous rate of natural mortality and B_0 was an estimate of virgin biomass (PFMC 1982). M was assumed to be 0.275 and B_0 was assumed to be equal to the 1977 survey estimate of Ascension Canyon to Farallon Islands area (Figure 1) biomass (295,000 t)[3].

A second hydroacoustic biomass estimate for shortbelly rockfish in the Ascension Canyon to Farallon Islands area was made in 1980 (152,700 t). Both the 1977 and 1980 estimates had confidence intervals in excess of 50% and were not significantly different. Consequently, we use an estimated biomass of 223,850 t (the mean of the two estimates) to calculate MSY in this paper.

We obtained revised estimates of M using several approaches. Using Hoenig's (1983) regression equation relating longevity and total mortality (Z, which equals M in this case), we obtained estimates of 0.212 and 0.203 for males and females respectively (Table 3). We obtained higher estimates for both males (0.373) and females (0.358) by using Hoenig's (1983) exponential model, in which the estimate of Z was based on both maximum observed age and sample size. Pauley (1980) suggested an alternative method for estimating M based on temperature, average maximum length, and growth completion rate. We used mean yearly temperature at a depth of 200 meters from three different parts of the geographical range for shortbelly rockfish (Bodega Bay, Ascension Canyon, and Pt. Sur) (Lynn et al. 1982). The estimates for males (0.337-0.374) and females (0.414-0.459) from Pauley's model were similar to those obtained from Hoenig's (1983) exponential model (Table 3). In all cases, we used an average of the male and female M estimates to calculate MSY.

Our revised estimates of MSY were obtained from Gulland's

(1971) original method ($0.5MB_0$) and a more conservative model ($0.3MB_0$) that Gulland proposed because the former equation was thought to overestimate MSY (Gulland 1983). Results for other rockfish species indicate that biomass at MSY is less than 50% of virgin biomass (widow rockfish - 42%, Lenarz and Hightower 1988; yellowtail rockfish - 25% (INPFC Vancouver area), 27% (INPFC Columbia area) Tagart 1988). For that reason, we recommend using the yield estimates from Gulland's more conservative model. Using that approach, our estimates of MSY ranged from 13,944 to 27,989 t (Table 3). Two of the three predictive models that we used produced estimates of M exceeding 0.35; thus, based on the available data, 25,000 t appears to be a reasonable estimate of MSY for the Ascension Canyon to Farallon Islands area.

The above estimates of MSY were based on the assumption that the fishing mortality rate (F) that produces MSY would be about equal to M. An alternative approach for obtaining a recommended F would be to use a yield-per-recruit model to calculate $F_{0.1}$, the F at which the slope of the yield curve was one-tenth the slope of the curve at the origin (Gulland and Boerema 1973). Compared to managing for MSY, the $F_{0.1}$ policy usually results in greater economic efficiency when constant recruitment is assumed (Gulland and Boerema 1973, Sissenwine 1981). We used Ricker's (1975) approach to calculate yield-per-recruit at a range of levels for M, F, and age at recruitment (Figure 7). Except for the case where M=0.15, yield-per-recruit generally increased as age at recruitment decreased or as F increased. Consequently, our estimates of $F_{0.1}$ were higher than M in all cases, and increased moderately with increases in age at recruitment (Table

4). Using the potential yield model $0.3B_0F_{0.1}$ and assuming M was about 0.35, recommended yield was 26,862 to 47,008 t, or moderately higher than estimated from Gulland's model.

These estimates of MSY for the Ascension Canyon to Farallon Islands area are greater than the current (coastwide) acceptable biological catch (10,000 t) established to permit development of a fishery (PFMC 1987); therefore, a change in acceptable biological catch does not appear to be necessary to protect the stock. Estimates of shortbelly rockfish abundance (and potential yield) to the north and south of the surveyed area may not be feasible prior to the development of a fishery. However, the limited data available suggest that other aggregations may exist, particularly in the channel islands area off southern California. In a study of larval rockfish distributions from Baja, California to Bodega Bay, California, 49% of all shortbelly rockfish larvae were found in the Ascension Canyon to Farallon Islands area, but about 35% were caught near the channel islands (MacGregor 1986). In demersal trawl surveys of adult rockfish from southern California to Vancouver, British Columbia, Gunderson and Sample (1980) found the highest concentration of shortbelly rockfish in the Ascension Canyon to Farallon Islands area but also detected concentrations in the channel islands, in the Pt. Sur area of California, and off Bodega Bay, California. A smaller concentration was found off the Columbia River in Oregon. Additional survey or commercial catch data is needed in order to determine whether these concentrations are large enough to support commercial fishing operations.

Year Class Strength

Detailed analysis of the age structure of the shortbelly rockfish population was difficult due to apparent age segregation (separate schooling of young and old fish) and the limited spatial and temporal coverage of our samples. Mean age in our samples ranged from one to thirteen with modes at ages one and five (Figure 8a). Median age also showed a bimodal distribution, with modes at ages one and seven (Figure 8b). If there were no age segregation, both distributions should be unimodal and shifted toward young fish. In addition, the mode of the mean ages would have been at an older age than the mode of the medians because the less abundant older fish would affect the mean age more than the median. Since gear types were similar between samples and all ages were assumed to be vulnerable to the gear (based on the small mesh size and the catches of both young and old fish in different tows with the same gear), it is unlikely that differences in gear selectivity can account for these results. Both distributions indicate a large number of samples with predominantly one-year-old fish. The second mode, occurring after age 4, indicates a considerable number of samples composed mainly of older fish. The distribution of median ages shows that a few old fish in some samples were not responsible for the bimodal distribution observed for the mean age distribution. We believe the segregation is probably a localized, spatial phenomenon.

Lenarz (1980) also noted age segregation in his study, with age tending to increase with increases in depth or latitude.

Because of the difficulty of interpreting the sample age distributions, our only conclusion was that the 1973-1975 year classes appeared to be strong (Figure 9). This was particularly evident in samples from the Ascenscion Canyon study area. No other cohorts appeared to be consistently strong or weak in our samples. Norton (1986) suggested that some rockfish species show a pattern of recruitment related to environmental variation within the ocean. He hypothesized that groups of species with similar life history characteristics should show similar patterns of recruitment and that these should correlate with oceanic conditions. His results indicated that chilipepper had strong year classes in 1973-1975, whereas widow rockfish had weak year classes in 1972-1976. If, in fact, the 1973-1975 year classes were strong for shortbelly rockfish, then perhaps chilipepper and shortbelly rockfish respond similarly to oceanographic conditions. The oceanographic conditions thought to improve chilipepper recruitment are cool water with increased southerly flow of the California current (Norton 1986).

The evidence for a chilipepper-shortbelly rockfish recruitment linkage is strengthened by studies of juvenile rockfish conducted in central California from 1983-1988[6]. Data from standardized annual surveys of abundance show that bathymetric distributions appear to be similar for the two species, in that the highest catches were made near the surface (10-30m). In contrast, juvenile widow rockfish catches tended to be larger for tows made deeper in the water column (100m). Peak catches of juvenile shortbelly rockfish and chilipepper were significantly correlated (r=0.895, 4 D.F.). Positive but nonsignificant correlations were detected for catches of widow rockfish and chilipepper (r=0.454, 4 D.F.) and for widow rockfish and shortbelly (r=0.619, 4 D.F.) The primary difference in relative abundance was that the 1985 year class was much stronger than the 1984 year class for juvenile widow rockfish whereas the two year classes were similar for juvenile shortbelly rockfish and chilipepper. Further work is needed to establish the degree of difference among rockfish species in year class strength as juveniles and adults, the life history stage at which differences arise, and the physical or biological factors that produce those differences.

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Table 1. Number of trawl tows containing adult shortbelly rockfish by region (see Figure 1) and year. Numbers in () indicate total number of fish in the samples.

REGION	1980	1981	1982	1983	1986	1988
CAPE SEBASTIAN, OREGON	2 (175)	2 (100)		3 (130)		
PT. ARENA	1 (54)	1 (18)				
FARALLON IS.		1 (49)			1 (107)	
PESCADERO	1 (108)	2 (10)				2 (60)
ASCENSION CYN	6 (423)	3 (147)	3 (152)	1 (126)	2 (91)	2 (101)
MONTEREY						2 (97)
PT. SUR		13 (630)				
TOTAL	10 (760)	21 (954)	3 (152)	4 (256)	3 (198)	6 (258)

Table 2. Estimates of the Von Bertalanffy growth parameters from scales (Phillips 1964), whole otoliths (Lenarz 1980), and broken and burnt otoliths (this study). Note: Phillips did not report separate values for males and females; Lenarz did not report t_0 values.

	SCALES	WHOLE OTOLITHS		BREAK AND BURN
L_∞	315mm	Males	290mm	279mm
		Females	324mm	281mm
t_o	-0.2703	Males		-3.649
		Females		-2.514
k	0.2752	Males	0.2980	0.184
		Females	0.2112	0.253

Table 3. Estimates of the instantaneous rate of natural mortality (M) and maximum sustainable yield (MSY) for shortbelly rockfish. Estimates of M from Hoenig's (1983) regression equation were based on maximum observed ages of 21 and 22 years for males and females respectively. In Hoenig's (1983) exponential model, M was estimated using maximum observed age and sample size (1,252 for males, 1,326 for females). Estimates of M from Pauley's (1980) method were calculated for three different geographical areas of the shortbelly rockfish range (Bodega Bay, Ascenscion Canyon, and Pt. Sur) (Lynn et al. 1982). Estimates of MSY were calculated using a mean M for males and females and a mean estimate of virgin biomass (B_0) of 223,850 t.

Method	M			$0.3MB_0$	$0.5MB_0$
	Male	Female	Average		
Hoenig regression model	0.212	0.203	0.208	13,944	23,240
Hoenig exponential model	0.373	0.358	0.366	24,562	40,936
Pauley estimate Bodega Bay (7.8°)	0.337	0.414	0.376	25,234	42,056
Pauley estimate Ascenscion Cyn (8.0°)	0.356	0.437	0.397	26,645	44,408
Pauley estimate Pt.Sur (8.2°)	0.374	0.459	0.417	27,989	46,648

Table 4. Estimates of yield for the Ascension Canyon/Farallon Islands area at fishing mortality rate $F_{0.1}$ for four different natural mortality rates (M) and five ages at recruitment. Virgin biomass (B_0) was estimated to be 223,850 t.

M	AGE	$F_{0.1}$	$0.3F_{0.1}B_0$	$0.5F_{0.1}B_0$
0.15	1	0.18	12,088	20,147
	2	0.21	14,102	23,504
	3	0.24	16,117	26,862
	4	0.26	17,460	29,101
	5	0.28	18,803	31,339
0.25	1	0.30	20,146	33,577
	2	0.41	27,534	45,889
	3	0.42	28,205	47,008
	4	0.44	29,548	49,247
	5	0.45	30,219	50,366
0.35	1	0.40	26,862	44,770
	2	0.50	33,577	55,962
	3	0.54	36,264	60,439
	4	0.66	44,322	73,870
	5	0.70	47,008	78,347
0.45	1	0.60	40,293	67,155
	2	0.69	46,336	77,228
	3	0.76	51,038	85,063
	4	0.85	57,081	95,136
	5	>2.0	N/A	N/A

Legends for Figures

Figure 1. Sample locations along the Oregon-California coast at which adult shortbelly rockfish were collected. Boundary of the Eureka and Monterey International North Pacific Fisheries Commission areas are shown for reference.

Figure 2. Shortbelly rockfish ages derived from broken and burnt otoliths and from surface readings of whole otoliths. Numbers at each point refer to the number of otoliths examined.

Figure 3. Shortbelly rockfish ages derived independently by two readers using broken and burnt otoliths. Numbers at each point refer to number of otoliths examined.

Figure 4. Shortbelly rockfish ages derived by the same reader on two independent readings. Numbers at each point refer to the number of otoliths examined.

Figure 5. Estimated von Bertalanffy growth curves for male and female shortbelly rockfish.

Figure 6. Mean length-at-age and fitted von Bertalanffy growth curves for male and female shortbelly rockfish. (Range of values -thin line; and one standard error range -thick line.)

Figure 7. Yield per recruit (grams/individual) at a range of levels for fishing mortality (F) and age at recruitment for four values of natural mortality (M).

Figure 8. Frequency distributions of A) mean and B) median ages in 48 samples of shortbelly rockfish collected at several stations (see Figure 1) from 1980-1988.

Figure 9. Age composition of shortbelly rockfish from several sample areas from 1980-1988. N=Number of samples, ()=number of fish in all samples.

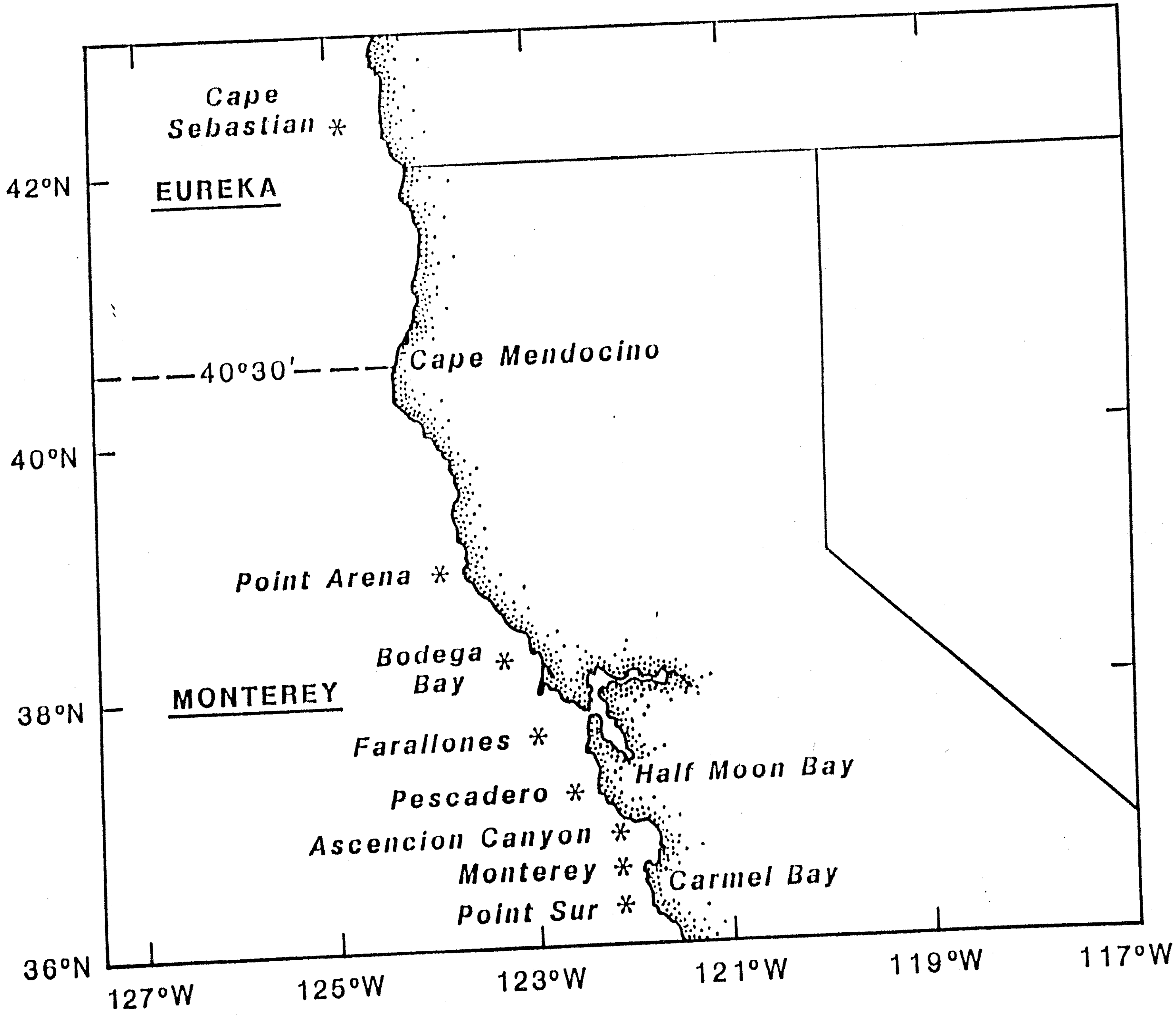

Cape Sebastian
EUREKA
42°N
40°30′
Cape Mendocino
40°N
Point Arena
Bodega Bay
MONTEREY
38°N
Farallones
Half Moon Bay
Pescadero
Ascencion Canyon
Monterey
Carmel Bay
Point Sur
36°N
127°W
125°W
123°W
121°W
119°W
117°W

Figure 1

Figure 2

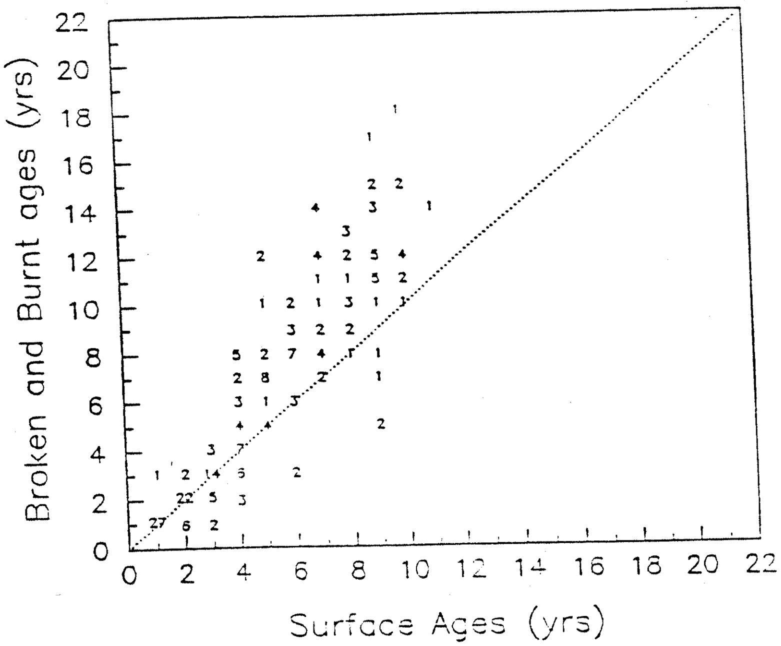

Broken and Burnt ages (yrs)
Surface Ages (yrs)
0
2
4
6
8
10
12
14
16
18
20
22

Figure 3

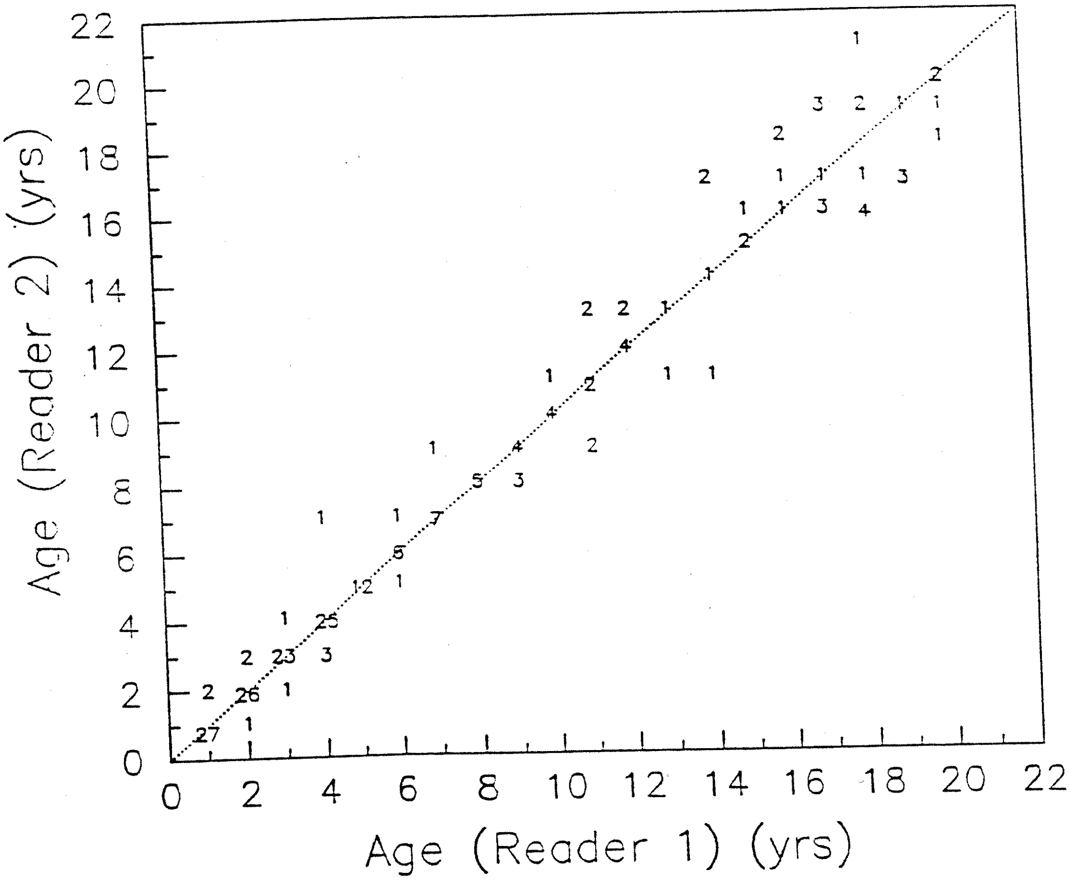
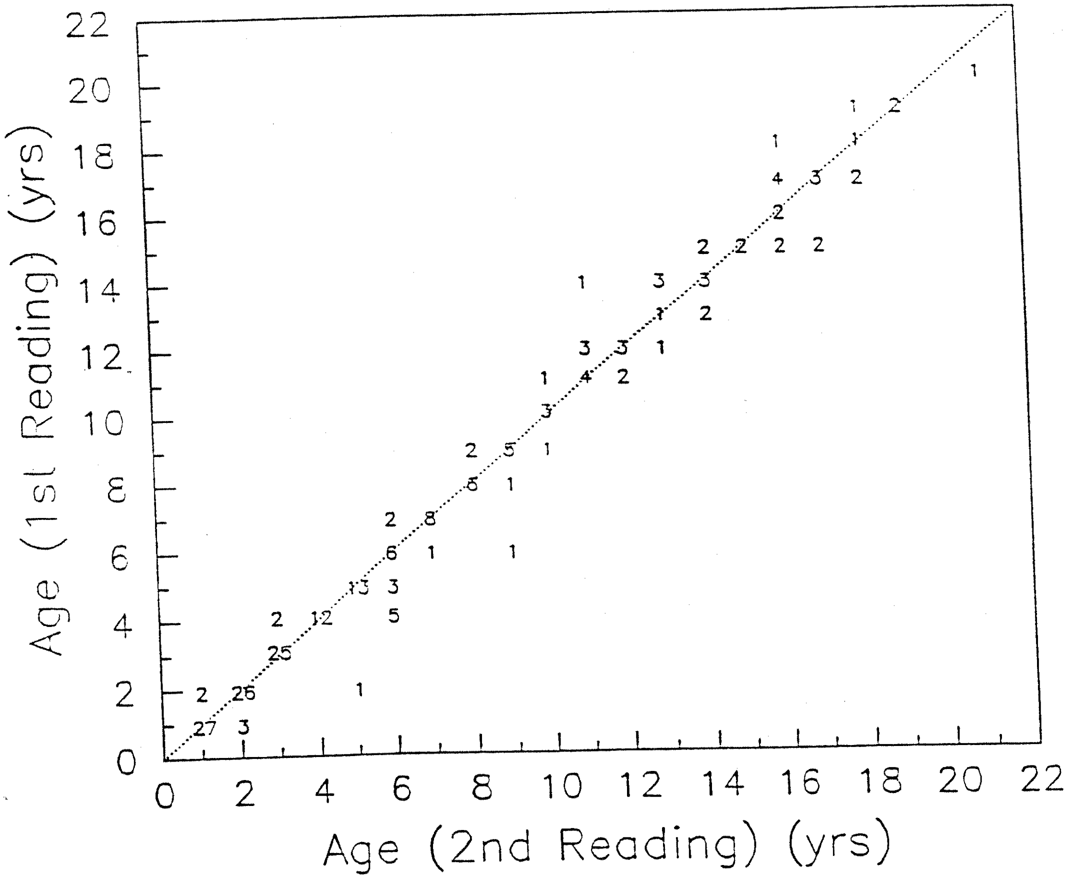
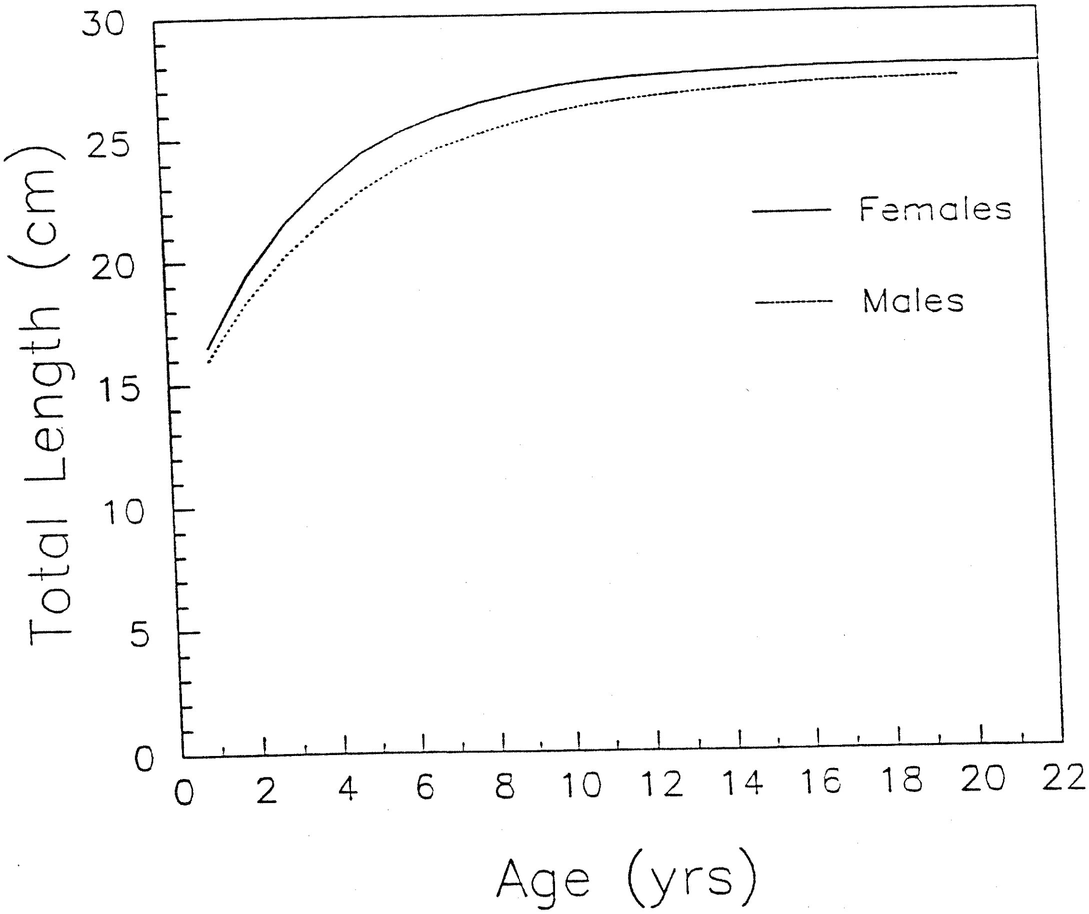


Figure 4



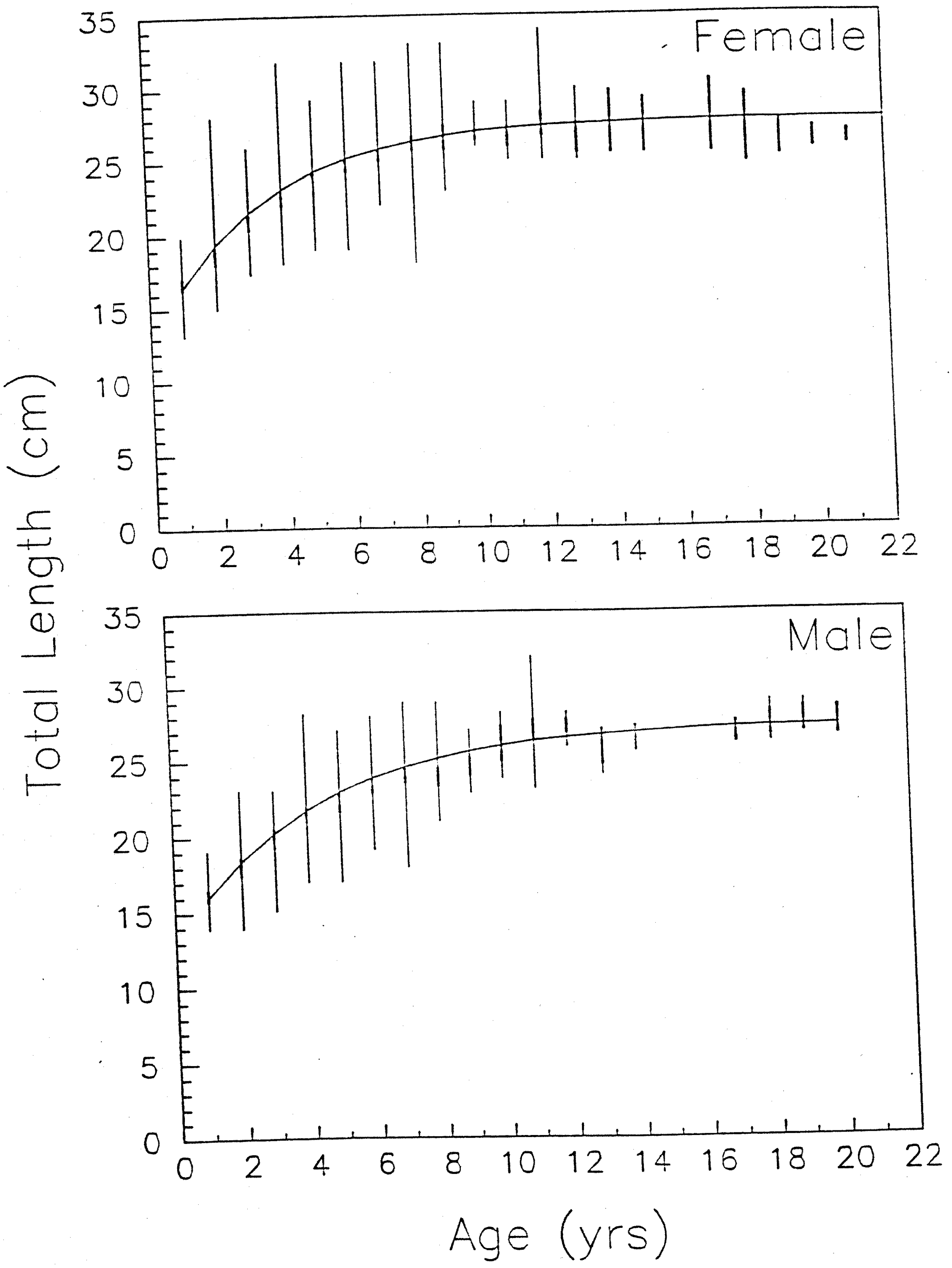
Age (1st Reading) (yrs)
Age (2nd Reading) (yrs)
0
2
4
6
8
10
12
14
16
18
20
22

Figure 5



Total Length (cm)
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
22
Age (yrs)
Females
Males

Figure 6



Female
Male
Total Length (cm)
Age (yrs)
0
5
10
15
20
25
30
35
0
2
4
6
8
10
12
14
16
18
20
22

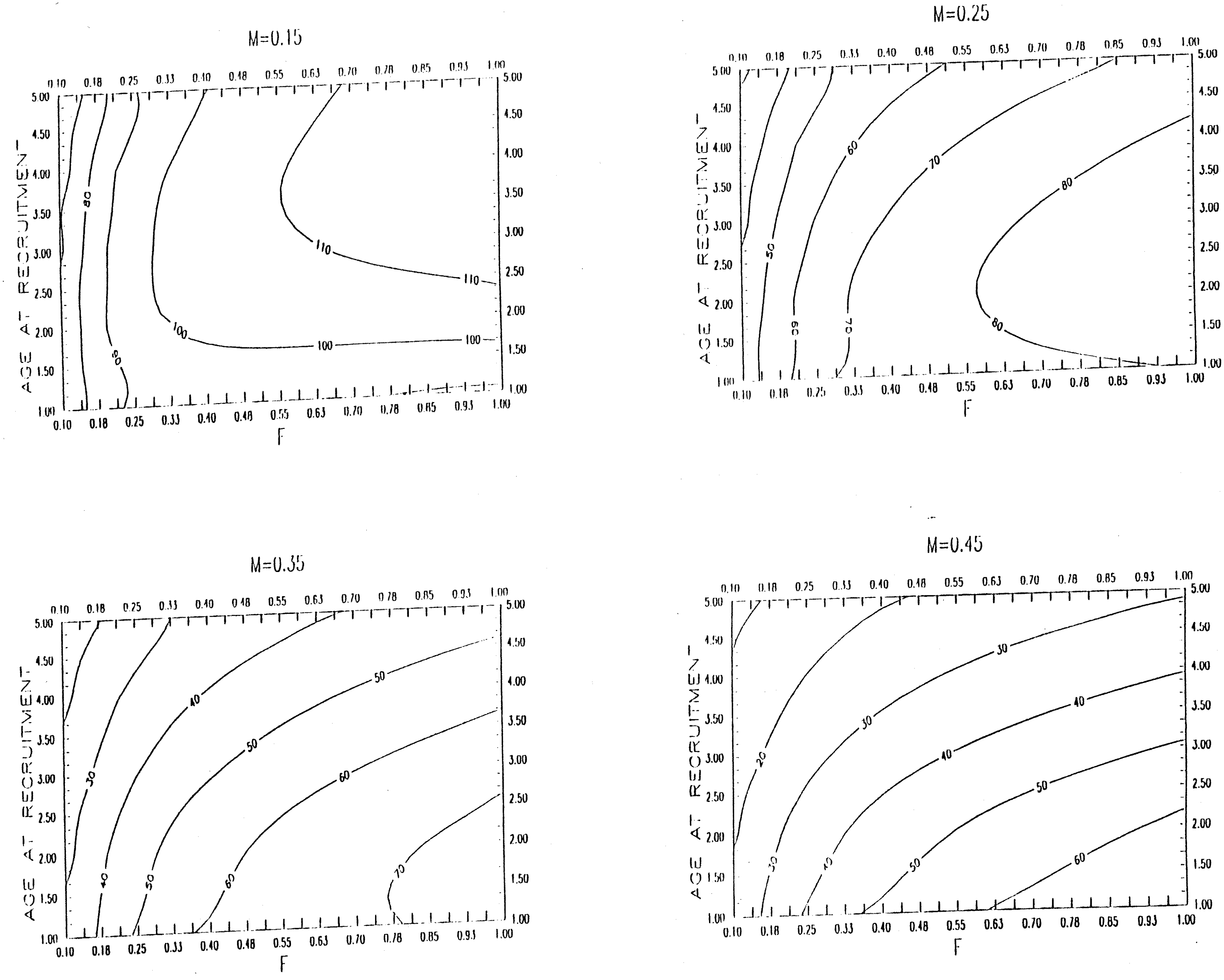

M=0.15
M=0.25
M=0.35
M=0.45
AGE AT RECRUITMENT
F
0.10
0.18
0.25
0.33
0.40
0.48
0.55
0.63
0.70
0.78
0.85
0.93
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
20
30
40
50
60
70
80
90
100
110

Figure 7

Figure 8

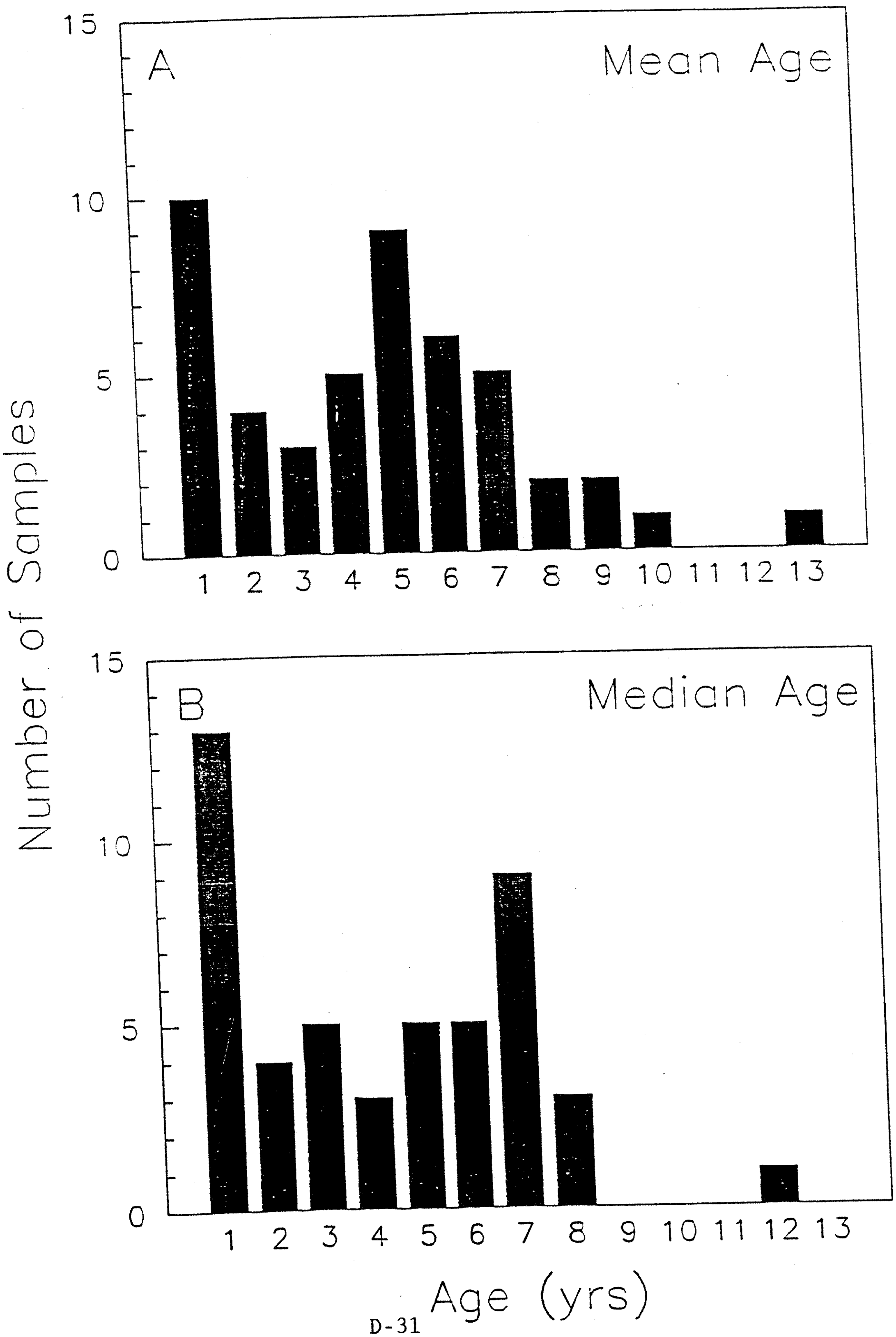
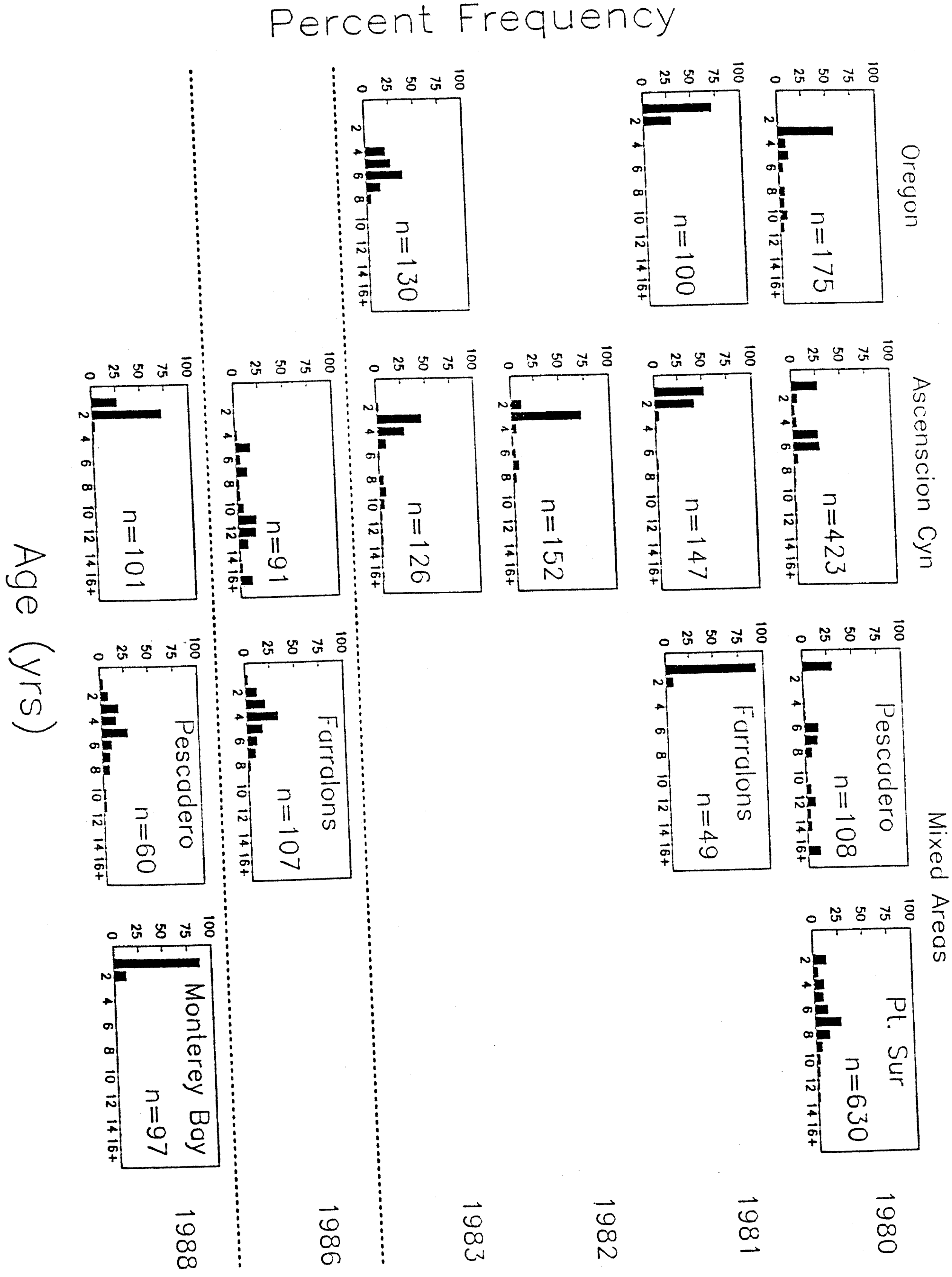

A
Mean Age
B
Median Age
Number of Samples
Age (yrs)
0
5
10
15
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 9



Percent Frequency
Age (yrs)
Oregon
Ascension Cyn
Mixed Areas
1980
1981
1982
1983
1986
1988
n=175
n=100
n=130
n=423
n=147
n=152
n=126
n=91
n=101
Pescadero
n=108
Pt. Sur
n=630
Farralons
n=49
Farralons
n=107
Pescadero
n=60
Monterey Bay
n=97
0
25
50
75
100
2
4
6
8
10
12
14
16+