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Title: LONG-TERM VARIATION IN GROWTH OF DOVER SOLE (*MICROSTOMOUS PACIFICUS*) AND ENGLISH SOLE (*PAROPHRYS VETULUS*) AND ITS POSSIBLE RELATIONSHIP WITH UPWELLING

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Abstract approved: Dr. Albert V. Tyler

Variation in growth rate of Dover sole (*Microstomous pacificus*) off Astoria and Brookings, and English sole (*Parophrys vetulus*) growth off Astoria and Coos Bay, Oregon was studied using the distance between annuli on scales and interoperculum bones indicating growth rate for Dover sole and English sole respectively. The age at which all individuals of a given year class are recruited to the trawl fishery is nine years for Dover sole and five years for English sole.

Age-specific growth rate of Dover and English sole varies significantly between years. The maximum variation for Dover sole was 19% for the period from 1958 to 1975. English sole growth varied as much as 17% from the mean growth between 1961 and 1974. Dover and English sole captured off Astoria experienced good and poor growth during

the same years as did Dover sole captured off Brookings located 460 km south of Astoria, and English sole captured 300 km south of Astoria off Coos Bay. The growth rate was slightly greater for Dover sole captured off Astoria than it was for Dover sole captured off Brookings. There was no significant difference in the growth rate for English sole captured off Astoria and off Coos Bay. Dover sole off Astoria experienced a general long-term increase in growth rate between 1958 and 1966 followed by a gradual decrease through 1969. A similar long-term trend occurred for English sole but was less apparent due to the shorter time series. The growing season for English sole begins in March and probably extends through September. The coldest temperatures at 50 m depth also occur during this period due to summer upwelling. The most rapid growth occurs during May and June. There is no evidence that the annual fluctuations in growth experienced by Dover and English sole are affected by temperature, upwelling or stock density. This study does suggest, however, that the long-term trends in growth are associated with similar long-term trends in upwelling.

Long-term Variation in Growth of Dover Sole (*Microstomous pacificus*) and English Sole (*Parophrys vetulus*), and Its Possible Relationship with Upwelling

by

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Typed by Deanna L. Cramer for Keith Francis Kreuz

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LONG-TERM VARIATION IN GROWTH OF DOVER SOLE (MICROSTOMOUS PACIFICUS) AND ENGLISH SOLE (PAROPHRYS VETULUS), AND ITS POSSIBLE RELATIONSHIP WITH UPWELLING

INTRODUCTION

Dover sole (*Microstomous pacificus*) and English sole (*Parophrys vetulus*) are the two most important flatfishes by weight in Oregon's trawl fishery (Barss 1976). In the past decade annual landings for Dover and English sole have fluctuated around five and two million pounds, respectively. Dover sole are distributed from Southern California to the Bering Sea, and English sole from Southern California to the Gulf of Alaska (Clemens and Wilby 1961). Both are commercially important from Santa Barbara to British Columbia (Allen and Mearns 1976).

In managing a fishery it is important to understand the factors which govern the size of a fish stock. The size of the fish stock and the subsequent yield from that stock can be influenced by changes in fishing mortality, natural mortality, recruitment, and growth. It is therefore important in fisheries management to know the ages and rates of growth of the species being exploited. The factors affecting growth should also be understood so that changes in growth rate can be interpreted. An important question is what effect does varying growth rates have on fishery yield.

The major goals of this study were to develop knowledge concerning growth of Dover and English sole off Oregon that would enhance the management of these species, and also to understand better the production system along the coast of Oregon. Specific objectives were: (1) to determine if the growth rate for Dover and English sole off Oregon changes significantly between years; (2) to determine the magnitude of possible variations in growth in Dover and English sole; (3) to compare the growth rate of Dover sole off Astoria with Dover sole off Brookings; (4) to compare the growth rate of English sole off Astoria with English sole off Coos Bay; (5) to determine if good and poor years for growth occurred simultaneously for Dover and English sole found along the entire coast of Oregon; (6) to determine the growing season for English sole off Oregon; (7) to determine for Dover and English sole the ages at which all individuals of a year class are recruited to the trawl fishery; and (8) to investigate possible factors which might have influenced growth of Dover and English sole off Oregon between 1958 and 1975.

Demory (1972) developed the scale technique for aging Dover sole, and produced growth curves from measuring fish collected on research cruises from the Columbia River to Cape Blanco (Demory et al. 1976). For English sole, Palmer (1956) and El-Sayed (1959) found interopercular bones superior to otoliths. Demory et al. (1976) developed growth curves for English sole by measuring fish length and using the interoperculum for aging. Growth of Dover sole off California was investigated by Hagerman (1952) and Allen and Mearns (1976). English sole growth has been studied in several areas: Puget Sound (Holland 1969; Van Cleve and El-Sayed (1969), Georgia Strait (Smith 1936; Manzer and Taylor 1947), and Hecate Strait (Palmer 1956). None of the above studies investigated possible annual variation in growth, but geographical differences in growth rates were observed. The growth rate of Dover sole off Southern California is lower than that of Northern California populations (Allen and Mearns 1976). The growth rate for English sole inhabiting Puget Sound is lower than off Canada (Van Cleve and El-Sayed 1969).

Different growth rates between populations in the same year, or within a population over a series of years has been observed in other marine fishes such as Atlantic cod (Gadus morhua) (Kohler 1964), Pacific herring (Clupea harengus) (Isles 1968; Rounsefell 1975: p51), American plaice (Hippoglossoides platessoids) (Pitt 1967; Gulland 1977), yellowtail flounder (Limanda ferruginea) (Scott 1954), and North Sea sole (Solea solea) (de Veen 1977). The growth rates of American plaice, Atlantic cod and Pacific herring are affected by stock density. Variation in temperature influenced the growth rates of yellowtail flounder, Pacific herring and American plaice. Disturbance of bottom layers by trawling operations caused annual changes in growth of North Sea sole. Peterson (1973) correlated growth and survival of Dungeness crab (*Cancer magister*) with upwelling.

METHODS

Scales were used to test for annual variation in growth for Dover sole. The annual increment in scale radius was taken as a direct measure of absolute annual growth rate. The scales used were from Dover sole captured commercially off Astoria and Brookings, Oregon. The Oregon Department of Fish and Wildlife (O.D.F.W.) has collected scales for age determination since 1957 off Astoria, and from 1971 to 1975 off Brookings. Prior to 1966, scales taken from Dover sole were removed from various parts of the fish. Since 1966, a deliberate effort was made to remove scales from the eyed-side of the body of each fish, one or two rows dorsal or ventral to the lateral line and midway between the head and tail. For growth analysis scales must be taken from a specified area of the fish. Consequently, the scales used for analysis of growth variation off Astoria in this study were limited to Dover sole captured between 1966 and 1976. All scales from Dover sole captured off Brookings were removed from the same part of the fish as those from Astoria.

Only females were studied because males did not occur in sufficient numbers for analysis, and also male scales were generally difficult to interpret. The scales used had previously been mounted dry between two glass slides. Each scale was examined using a microprojector which projected a magnified image (38.5X) on a flat surface. Only scales which could be read with accuracy were used. The two criteria used for annulus determination were the closely spaced circuli which marked the end of a seasons growth, and a translucent ring which borders the last of the closely spaced circuli. Because of the difficulty in detecting the exact location of the first annulus, measurements between the first and second annulus were not made. Measurements between annuli began at the second annulus, which represented growth at age two. Scale growth at ages two through nine were measured for female Dover sole captured off Astoria and Brookings. For each scale, scale growth according to age and year of growth was recorded. The mean scale growth according to age and year was calculated separately for the Astoria and Brookings populations.

Demory and TenEyck (1975) state that Dover sole females are not fully recruited to the fishery until age ten, however the majority of the catch often consists of younger fish. Based on this observation, Dover sole captured younger than ten years should represent the faster growing individuals of a year class that are large enough to be retained by the gear. Using scale growth as an index of body growth, the age of full recruitment to the fishery was examined. The method will be described in the next section. Only fully recruited ages were analyzed to test for annual changes in growth.

The relationship between scale radius and body length was calculated by using scales with associated length data collected from Astoria market samples. These data were supplemented with scales collected from juvenile fish which were collected on research cruises conducted by O.D.F.W. from 1966 to 1972. Using the scale-body length relationship, the mean body growth (cm) at age was determined from age-specific growth data of scales.

Interopercular bones were used to test for growth differences in English sole off Astoria and Coos Bay. Collection of interopecular bones from commercial catches have been made by O.D.F.W. for these two areas since 1967. From each fish, the opercular assemblage was removed from the eyed-side and boiled to remove the fleshy material surrounding the bones. The interoperculum is a suitable structure for aging because unlike otoliths it varies little in thickness with advancing age. Periods of growth are seen as broad opaque zones separated by narrow translucent bands which represent annuli. Ages are determined by counting the number of complete translucent bands. Two major irregularities encountered were false annuli, and partially obscured first annuli which resulted from the ossification of the bone at the center. Because of this ossification, measurements between the focus and the first annulus were not made. As a result, measurements between annuli began at age one.

Only female English sole were studied. Males were not considered because they did not occur in sufficient numbers for analysis. A projected magnified image (18.0X) was obtained for each interoperculum bone by use of a microprojector. Only interoperculum bones which could be read with accuracy were used. For each fish, interoperculum growth according to age and year was recorded. This was done separately for English sole captured off Astoria and Coos Bay.

Female English sole are not fully recruited to the trawl fishery until age 13, although 81% are recruited by age five (Demory and TenEyck 1975). Using interoperculum growth data, the age of full recruitment to the fishery was examined as described in the next section. In testing for annual variation in growth only fully recruited ages were analyzed.

Smith and Nitsos (1969) have determined a linear relationship between interoperculum growth and body growth. The equation obtained was $y = .403\ x + 1.77$, where y = total length in cm; x = magnified interopercular length (3.4X) in mm. Using this relationship, the mean body growth (cm) at age was determined based on age specific interoperculum growth. This was done separately for English sole collected off Astoria and off Coos Bay.

The growing season for English sole was determined by measuring marginal interoperculum growth from four year old fish which were collected off Astoria during different months between 1966 and 1975. Marginal growth is the distance from the last complete annulus to the outer edge of the interopercular bone. For these years the mean marginal growth was calculated for each month.

RESULTS

Dover Sole Growth off Oregon

Scale Radius-Body Length Relationship

Based on 1383 scales, the correlation coefficient between scale radius and body length was .98. A plot of the residuals tended to fall within a horizontal band centered around zero and displayed no systematic tendencies to be positive or negative. This indicates a linear relationship exists between the two variables. The equation for the relationship between scale radius (y) and body length in cm (x) was determined as: $y = -14.227 + 3.322\ x$.

Age of Full Recruitment to the Trawl Fishery

A two-way analysis of variance was employed to test for differences in growth rates among ages of capture and also among years for Dover sole captured off Astoria. This was done for each age of growth. Repeated two-way analysis of variance testing showed significant differences ($P < .05$) in the age-specific growth rates on each of the following age-at-capture combinations: 6, 7, 8, 9, 10 and 7, 8, 9, 10 and 8, 9, 10. These differences are likely due to faster growing fish being caught at a younger age. There was no significant difference in the age-specific growth rate of Dover sole captured at ages 9 and 10. The lack of significance between fish captured at ages 9 and 10 suggests that for each age of growth the growth rate is the same for fish captured at nine years of age and older. Based on this finding, growth at age data according to year of growth was pooled for fish captured at ages 9 and 10. All further analysis of Dover sole were carried out on these two ages of capture. A total of 1464 Astoria female Dover sole nine years old and older were used.

Because of insufficient data off Brookings, a two-way analysis of variance could not be used to analyze for differences among ages of capture and among years of growth. Age nine was considered as the age of full recruitment based on the finding off Astoria. For Brookings a total of 274 female Dover sole age nine and older were used.

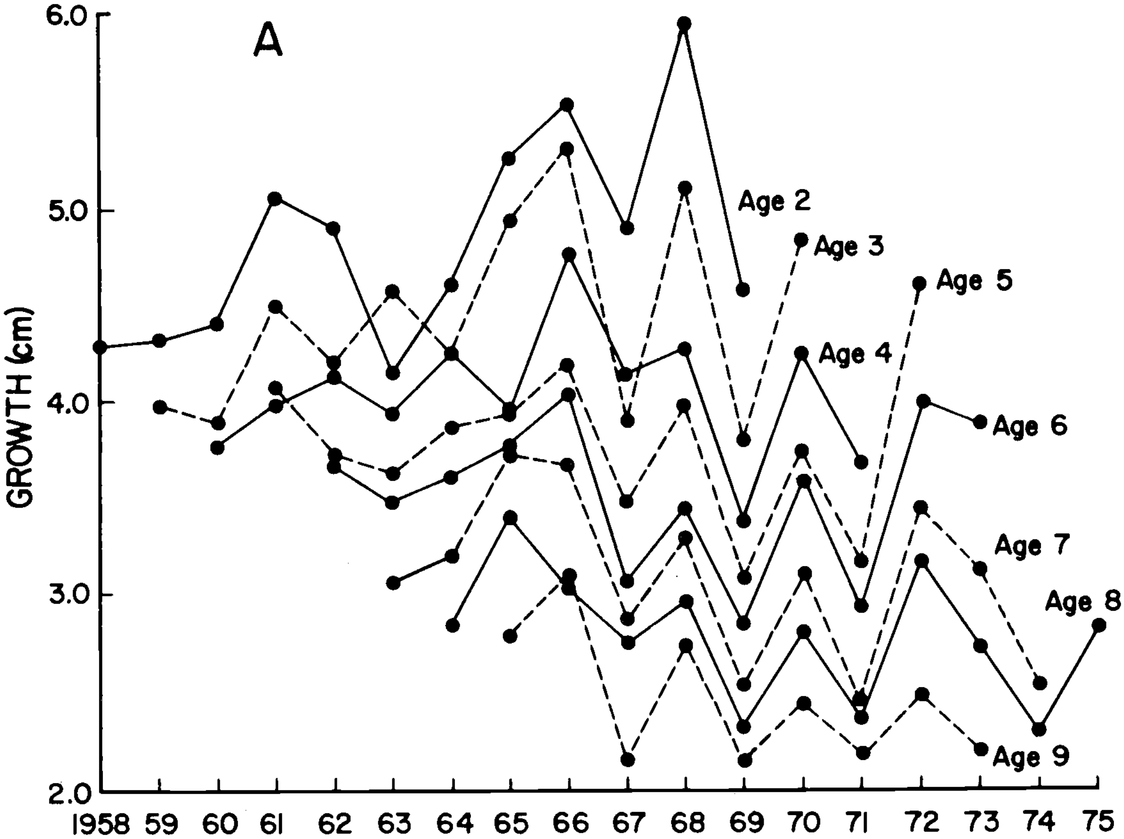
Dover Sole Growth off Astoria

The same two-way analysis of variance mentioned above also showed significant annual variation in growth off Astoria. The results show a significant difference ($P < .05$) by year for scale growth at ages 2, 3, 5, 6, 7, 8. No significant difference could be detected for growth at age four.

Dover sole of all ages responded to the same good and poor growth years (Figure 1A; Table 1). This was tested by using a non-parametric test referred to as the sign test (Wilcoxon 1945). Based on growth at ages two through nine,

Figure 1A. Average growth (cm) at age for female Dover sole by year off Astoria, Oregon.

Figure 1B. Average growth (cm) at age two by year for Astoria female Dover sole determined by adjusting growth at older ages to growth at age two (solid line) and a five year running average of growth at age two (dashed line).


A
GROWTH (cm)
6.0
5.0
4.0
3.0
2.0
1958
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61
62
63
64
65
66
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68
69
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71
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73
74
75
Age 2
Age 3
Age 5
Age 4
Age 6
Age 7
Age 8
Age 9

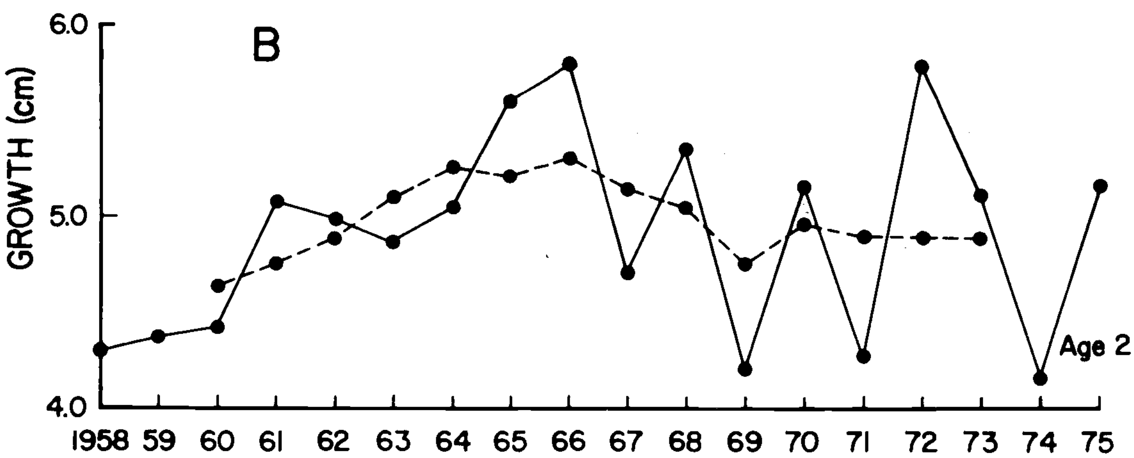

B
GROWTH (cm)
6.0
5.0
4.0
1958
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
Age 2

Figure 1

Table 1. Average annual growth (cm) at age for female Dover sole by year off Astoria, Oregon.

Age of Growth	Year of Growth																	
	1958	No.	1959	No.	1960	No.	1961	No.	1962	No.	1963	No.	1964	No.	1965	No.	1966	No.
2	4.29	60	4.32	117	4.40	75	5.07	65	4.89	89	4.14	68	4.60	100	5.26	72	5.55	69
3			3.98	60	3.89	117	4.50	75	4.21	65	4.58	89	4.23	68	4.96	100	5.32	72
4					3.76	60	3.97	117	4.12	75	3.93	65	4.24	89	3.95	68	4.77	100
5							4.07	60	3.72	117	3.63	75	3.87	65	3.93	89	4.19	68
6									3.69	60	3.49	117	3.61	75	3.77	65	4.06	89
7											3.06	60	3.19	117	3.72	75	3.68	65
8													2.84	60	3.41	117	3.02	75
9															2.78	60	3.12	38

Age of Growth	Year of Growth																	
	1967	No.	1968	No.	1969	No.	1970	No.	1971	No.	1972	No.	1973	No.	1974	No.	1975	No.
2	4.90	39	5.96	34	4.56	43												
3	3.89	69	5.09	39	3.79	34	4.84	43										
4	4.14	72	4.26	69	3.36	39	4.23	34	3.68	43								
5	3.49	100	3.99	72	3.09	69	3.76	39	3.18	34	4.65	43						
6	3.07	68	3.46	100	2.83	72	3.59	69	2.93	39	3.99	34	3.89	43				
7	2.87	89	3.29	68	2.52	100	3.17	72	2.42	69	3.46	39	3.12	34	2.53	43		
8	2.75	65	2.95	89	2.31	68	2.81	100	2.35	72	3.18	69	2.72	39	2.30	24	2.83	43
9	2.13	22	2.75	26	2.13	25	2.44	31	2.16	43	2.49	19	2.19	31	--	-	2.49	34

each year was rated better or worse than the previous year. If the growth rate for the majority of ages for a given year was greater than the previous year, then that year was considered a better year for growth. For example, 1966 was considered a better year for growth than 1965 because the growth increment at ages 2, 3, 4, 5, 6, 9 was greater in 1966 than in the previous year for those ages. There were two anomalies where growth at ages 7 and 8 were better in 1965. This procedure of determining (+) and (-) ages (agreement versus anomaly) was repeated for each year between 1960 and 1974. The total number of (+) ages (in agreement within a year) was determined, as well as the number of (-) ages (anomalies). The sign test tested the hypothesis that the number agreeing (+) was statistically different from the number of anomalies (-). A significant difference ($P < .01$) was obtained, indicating that good and poor years for growth occurred simultaneously for all ages of growth.

In order to establish one summary plot illustrating growth trends and fluctuations from 1958 to 1975, yearly growth at ages three through nine were adjusted to represent growth at age two. This could be done because it was shown above that fish consisting of these ages responded similarly to the same good and poor growth years. For growth at age three, a factor was determined for each year which, when multiplied by yearly growth at age three, would equal growth at age two for that year. Scaling factors were determined each year for which data were available. An average scaling factor over years was then determined. This average scaling factor was then used to adjust the yearly growth at age three to yearly growth at age two. This resulted in an additional (second) line representing yearly growth at age two. Yearly growth at age four was similarly scaled to fit this second line, which in turn resulted in a third line used to scale growth at age five. This iterative procedure was used to scale yearly growth at ages 6, 7, 8 and 9 to yearly growth at age two. These calculations resulted in the production of eight yearly growth lines, each representing equivalent growth at age two. By averaging these lines, a single, pooled time-growth rate line was generated (Figure 1B; Table 2). Reference to these adjusted data will be made as age two equivalent growth.

Since significant annual growth rate differences were demonstrated by analysis of variance above, evaluation of the magnitude of these differences was in order. Using yearly equivalent growth at age two, the average equivalent growth at age two for all years between 1958 and 1975, inclusive, was determined. The percent deviation from this mean was calculated for each year (Table 3). The results show 1966 to be the best year for growth with a 19% increase from the mean growth rate. The poorest year for

Table 2. Average growth at age two by year for Astoria and Brookings female Dover sole determined by adjusting growth at older ages to growth at age two, and average growth at age one by year for Astoria and Coos Bay female English sole determined by adjusting growth at older ages to growth at age one.

Year of Growth	Dover sole-Astoria Growth (cm)	Dover sole-Astoria No.	Dover sole-Brookings Growth (cm)	Dover sole-Brookings No.	English sole-Astoria Growth (cm)	English sole-Astoria No.	English sole-Coos Bay Growth (cm)	English sole-Coos Bay No.
1958	4.29	60						
1959	4.36	177						
1960	4.42	252						
1961	5.05	317			6.94	60		
1962	4.98	406			7.29	363	7.34	100
1963	4.86	474			7.01	738	7.50	211
1964	5.03	574			6.87	890	6.95	251
1965	5.59	646	5.39	56	7.45	1070	7.29	326
1966	5.81	576	5.76	103	7.81	1255	8.18	422
1967	4.70	524	5.32	160	6.58	1156	7.12	535
1968	5.35	497	5.34	213	7.00	1025	7.44	537
1969	4.19	450	5.24	213	6.25	922	6.58	601
1970	5.14	388	5.42	213	7.16	717	7.58	523
1971	4.25	300	5.56	213	6.85	594	7.20	555
1972	5.78	204	5.77	177	7.92	439	7.87	407
1973	5.09	147	6.41	123	7.58	236	7.36	230
1974	4.14	77	5.51	66	6.11	116	6.03	146
1975	5.15	77						

Table 3. Annual percent deviation from average age two equivalent growth for female Dover sole collected off Astoria and Brookings, Oregon, and annual percent deviation from average age one equivalent growth for female English sole collected off Astoria and Coos Bay, Oregon.

Year	Dover Sole Astoria	Dover Sole Brookings	English Sole Astoria	English Sole Coos Bay
1958	-.12			
1959	-.11			
1960	-.09			
1961	.03		-.02	
1962	.02		.03	.01
1963	-.01		-.01	.03
1964	.03		-.03	-.04
1965	.14	.03	.05	.00
1966	.19	.04	.11	.13
1967	-.04	-.05	-.07	-.02
1968	.09	.03	-.01	.02
1969	-.14	-.19	-.11	-.09
1970	.05	-.01	.01	.04
1971	-.13	-.05	-.03	-.01
1972	.18	.11	.12	.08
1973	.04	.16	.07	.01
1974	-.16	.00	-.13	-.17
1975	.05			

growth was 1974 which showed a 16% decrease from the average growth rate. These data indicate poor growth occurred in 1958, 1959, 1960, 1967, 1969, 1971 and 1974.

A five year running average (based on five successive years of age two equivalent growth) indicates a general long-term increase in Dover sole growth rate between 1958 and 1966, followed by an average decrease through 1969. The average growth rate tended to increase slightly from 1969 to 1975 (Figure 1B). This long-term trend was substantiated by a t-test. A significant difference ($P < .01$) was found when the mean equivalent growth at age two from 1964 to 1966 was compared to the mean equivalent growth at age two from 1958 to 1960, and also between 1969 and 1971. The maximum percent deviation of the running average points from the overall mean, annual, equivalent growth rate of the period (calculated from the running averages between 1958 and 1975) was 7%. This deviation occurred between 1958 and 1962. The maximum annual variation around the long-term trend occurred in 1972 with a 18% deviation from the trend. The average annual variation around the trend was 7%.

Dover Sole Growth Off Brookings

Mean scale growth according to age and year for Dover sole captured off Brookings was determined by combining scale growth data from fish captured at ages nine and ten.

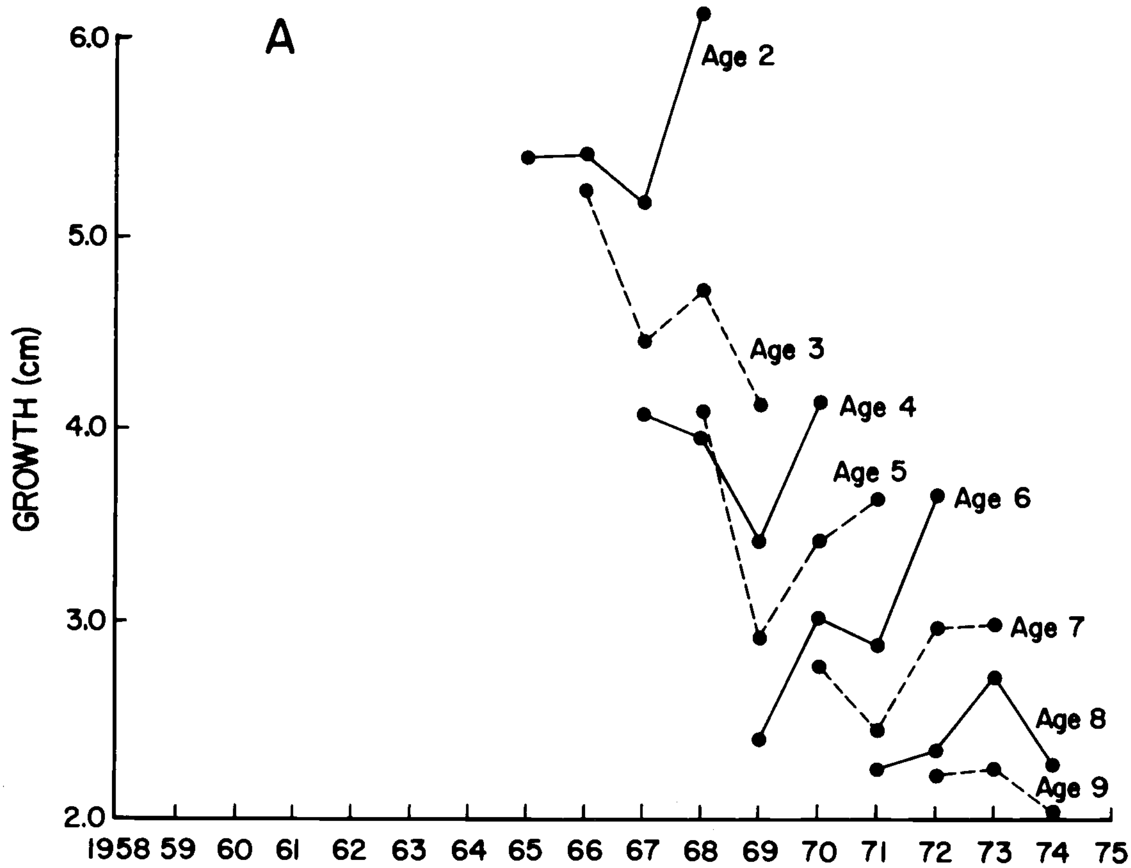
The sign test as described above, showed that all ages responded similarly to the same good and poor years for growth (Figure 2A; Table 4). One summary plot illustrating equivalent growth at age two from 1965 to 1974 was determined in the same manner as calculated for Dover sole off Astoria (Figure 2B; Table 2). These data reveal that 1969 was an exceptionally poor year for growth with a 19% decrease from the average equivalent growth rate for this period. Good growth occurred in 1966, 1968, 1972 and 1973. Growth in 1973 showed a 16% increase over the average growth rate (Table 3).

Comparison of Dover Sole Growth Off Brookings and Off Astoria

The annual growth changes for Dover sole off Brookings were similar to changes observed off Astoria between 1965 and 1974. The sign test was used to test the hypothesis that good years for growth off Astoria were also good years for growth off Brookings. Growth at ages two through nine from both the Astoria and Brookings populations were used in this test. Based on growth at age from both populations, each year was rated better or worse than the previous year. For a given year of growth, if a simple majority of ages showed better growth than the previous year, then that year was considered a better year for growth. The number of ages which made up the majority were counted. The number of ages not in agreement were also

Figure 2A. Average growth (cm) at age for female Dover sole by year off Brookings, Oregon.

Figure 2B. Average growth (cm) at age two by year for Brookings female Dover sole determined by adjusting growth at older ages to growth at age two.


A
GROWTH (cm)
6.0
5.0
4.0
3.0
2.0
Age 2
Age 3
Age 4
Age 5
Age 6
Age 7
Age 8
Age 9
1958 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

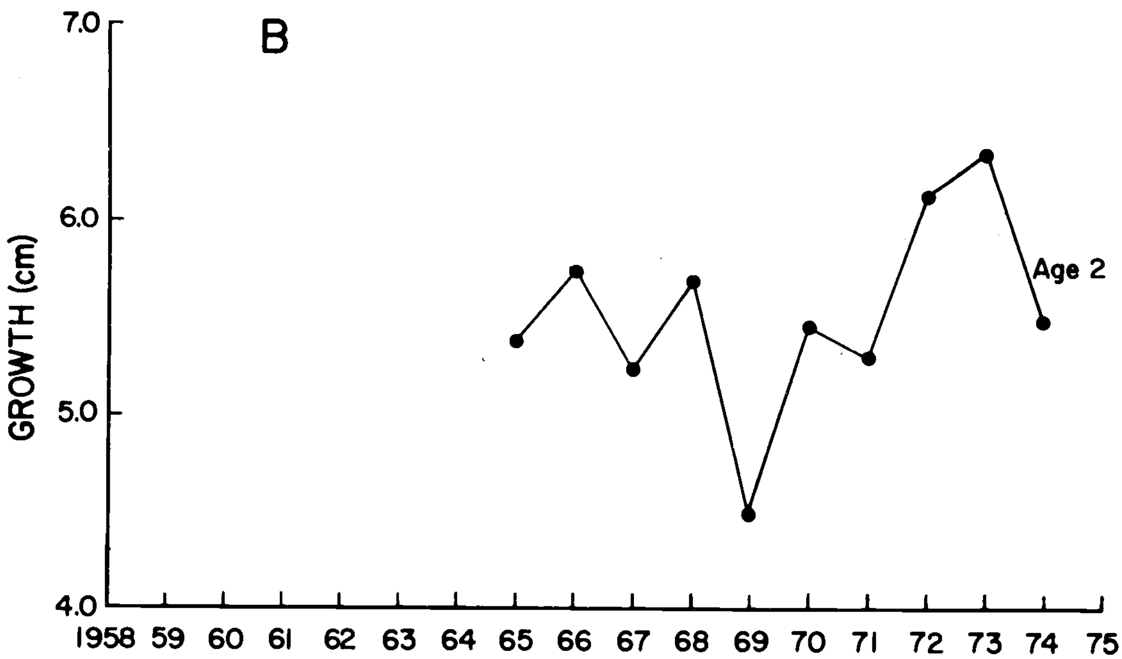

B
GROWTH (cm)
7.0
6.0
5.0
4.0
Age 2
1958 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

Figure 2

Table 4. Average annual growth (cm) at age for female Dover sole by year off Brookings, Oregon.

Age of Growth	Year of Growth 1965	No.	1966	No.	1967	No.	1968	No.	1969	No.	1970	No.	1971	No.
2	5.39	56	5.41	47	5.18	57	6.01	53						
3			5.23	56	4.44	47	4.72	57	4.11	53				
4					4.07	56	3.96	47	3.42	57	4.13	53		
5							4.08	56	2.92	47	3.43	57	3.64	53
6									2.40	56	3.04	47	2.89	57
7											2.78	56	2.44	47
8													2.24	56
9														

Age of Growth	Year of Growth 1972	No.	1973	No.	1974	No.
2						
3						
4						
5						
6	3.69	53				
7	2.98	57	2.99	53		
8	2.33	47	2.72	57	2.28	53
9			2.25	13	2.62	10

summed. This procedure was repeated for each year from 1967 to 1973. The number of ages agreeing were totaled as were the number not agreeing over this period. The sign test tested the hypothesis that the number of ages agreeing was statistically different from the number of ages not agreeing. If there was no significant difference, it would be caused by a large number of ages not agreeing. This in turn would be attributed to a different annual growth response for each of the two areas. The results of this test showed a significant difference ($P < .01$), indicating few anomalies, and that years conducive for Dover sole growth off Astoria were also favorable years for growth off Brookings.

There is a slight difference in the growth rate for Dover sole captured off Astoria and off Brookings. This was tested by comparing the growth rates determined from the 1964, 1965, and 1966 year classes from both populations. For each area the regression relationship between annual length increment at age and length at age (Gulland 1975; p 37) was determined. Since no scale measurements were made for the first two years of life, the initial length was equated to the mean growth at age two. Lengths at subsequent ages were determined by adding the mean growth which was calculated for each age. Each regression was weighted according to the sample size at each age. An

F-test was used to determine if there was a significant difference between the error obtained by a single pooled regression, and the error obtained by adding the errors from each regression line separately (Neter and Wasserman 1974; p 160). The result of this test produced and F value of 4.13 which was significant ($F_{.95}(2,10) = 4.10$) indicating that the two lines were different. Further testing showed that the difference between the two lines was due to differences in the Y-intercept and not the slope. The Y-intercept was larger for the Astoria population which indicated that fish from this area grow faster than those from Brookings.

Age-Length Relationship Determined from Scale Growth

The scale-body length relationship was used to convert scale growth to body growth. The mean length (cm) at age for females was determined using 11.43 cm as the length attained by two year old Dover sole (Demory 1975), and utilizing the converted scale growth data. Scale growth at each age was determined separately for the Astoria and Brookings populations by combining the growth data from the 1964, 1965, and 1966 year classes. Length at age data was fitted to the von Bertalanffy growth curve using the method described by Ricker (1975; p 225). The resulting equations for the Astoria and Brookings populations were: lt =

65.00 $(1-e^{-.094(t+.109)})$ and lt = 57.00 $(1-e^{-.118(t-.063)})$ respectively. Statistics for female Dover sole from both areas followed the calculated von Bertalanffy growth curve closely (Table 5). The calculated length at infinity of 57.00 cm for the Brookings population is substantially less than 71 cm which is the maximum length on record for this species (Hart 1973). Comparison of the two curves reveals little difference in the growth rate between the two areas (Figure 3). Demory _et al_. (1976) has fitted the von Bertalanffy growth curve from female Dover sole collected from the Columbia River to Cape Blanco. The resulting equation obtained: lt = 60.7 $(1-e^{-.111(t+.18)})$, varies only slightly from the equation parameters calculated here.

Comparison of Dover Sole Growth Off Oregon and Other Areas

Lengths at different ages from several locations are given in Table 6. These data do not point to any large scale geographical difference in growth rate for Dover sole. It would be difficult to test for minor variation in growth from these data because it was collected during different years, and is largely from commercial catches. Geographical differences in growth apparently do exist however. A previous study has demonstrated that the growth rate for Dover sole taken south of Santa Barbara is slower than those taken further north (Allen and Mearns 1976). The slower growth rate south of Santa Barbara was

Table 5. Computed mean length at age calculated from scale growth data, and mean length at age estimated by von Bertalanffy's growth equation for female Dover sole collected off Astoria and Brookings, Oregon.

	Astoria		Brookings	
Age (year)	Computed mean length (cm)	Estimated mean length (cm)	Computed mean length (cm)	Estimated mean length (cm)
1		6.44		5.97
2	11.43*	11.69	11.43*	11.65
3	16.84	16.47	16.77	16.69
4	21.08	20.83	21.33	21.18
5	24.93	24.79	25.12	25.17
6	28.31	28.39	28.50	28.71
7	31.78	31.69	31.77	31.86
8	34.78	34.67	34.64	34.66
9	37.53	37.39	37.09	37.14
10	40.02	39.87	39.30	39.35

*11.43 cm is the average length of two year old female Dover sole collected off Oregon (Demory 1975). Computed lengths at other ages was obtained by adding converted age-specific scale growth.

Figure 3. Age-length relationship for female Dover sole collected off Astoria and off Brookings, Oregon.

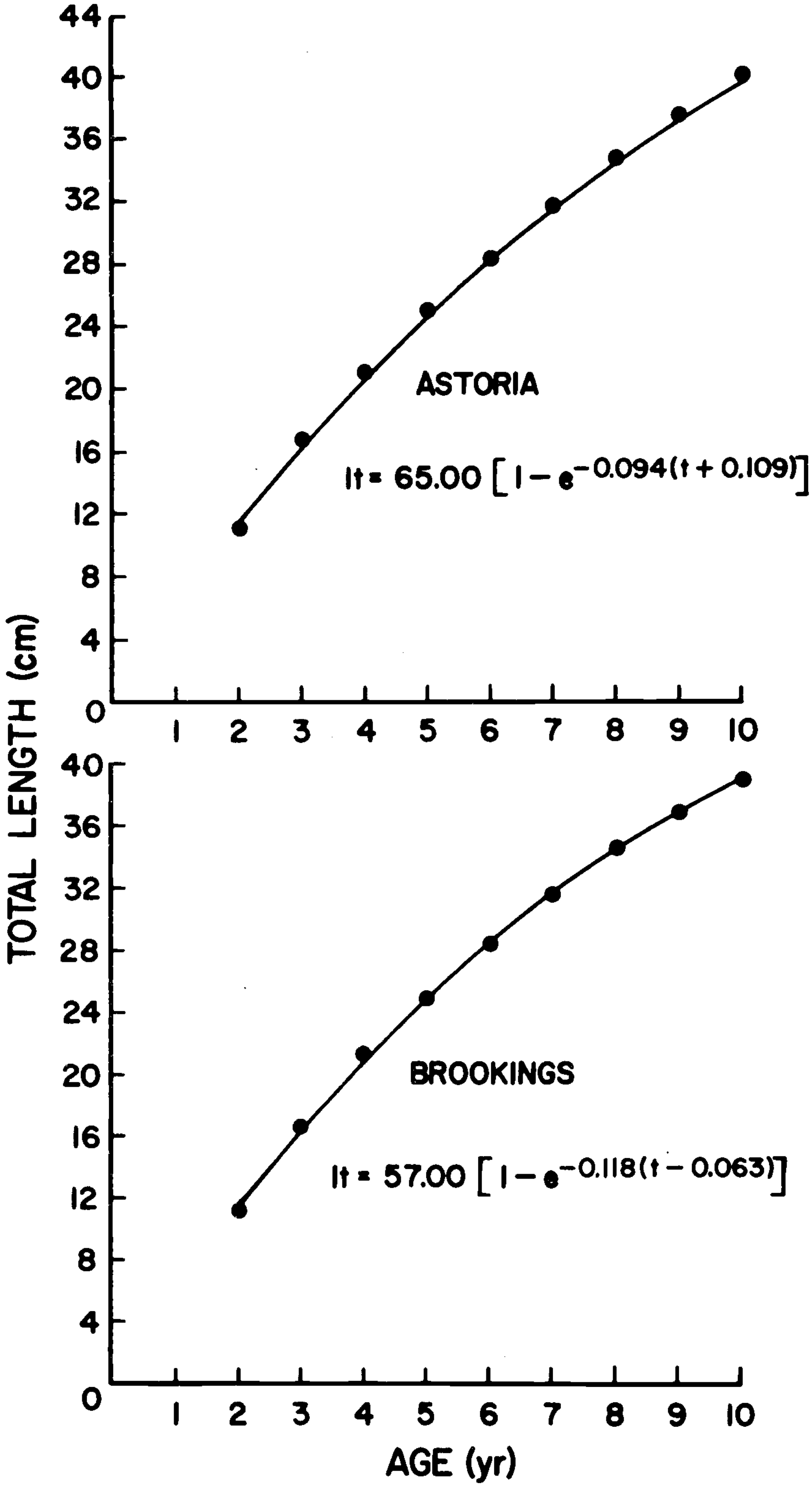

ASTORIA
lt = 65.00 [1 − e^−0.094(t + 0.109)]
BROOKINGS
lt = 57.00 [1 − e^−0.118(t − 0.063)]
TOTAL LENGTH (cm)
AGE (yr)
0
4
8
12
16
20
24
28
32
36
40
44
1
2
3
4
5
6
7
8
9
10

Figure 3

Table 6. Comparison between observed lengths in centimeters at age for female Dover sole collected from different localities.

	San Francisco market sample sampled 1977		Eureka market sample sampled 1970		Eureka research cruise sampled 1969-1970		Brookings market sample sampled 1973-1974		Brookings scale growth sampled 1973-1975	
Age	L	No.	L	No.	L	No.	L	No.	L	No.
1										
2					17.36	24			11.43*	
3					24.81	18			16.77	102
4					29.86	18			21.33	102
5					31.74	18	30.57	7	25.12	102
6	34.76	11	35.13	23	34.12	33	34.91	35	28.50	102
7	34.68	47	36.59	41	36.02	39	36.49	89	31.77	102
8	35.89	114	38.18	33	38.54	34	37.68	80	34.64	102
9	36.79	170	39.93	41	39.89	25	39.64	66	37.09	102
10	38.43	160	40.97	37	41.17	12	41.12	67	39.30	20
11	40.96	97	42.18	28	43.45	15	42.85	33		
12	43.42	36	45.09	23	43.96	10	43.86	28		
13	44.59	21	44.33	9			47.05	19		
14	48.76	18					48.30	10		
15							50.43	7		

Table 6 (continued)

Age	Astoria market sample sampled 1973-1974		Astoria scale growth sampled 1973-1975		N.E. Gulf of Alaska research cruise sampled 1975	
	L	No.	L	No.	L	No.
1						
2			11.43*			
3			16.84	102	26.00	5
4			21.08	102	26.80	5
5	33.22	9	24.93	102	30.12	43
6	35.07	69	28.31	102	33.32	31
7	36.10	175	31.78	102	35.39	49
8	37.48	214	34.78	102	36.57	35
9	38.53	175	37.53	102	39.72	29
10	40.27	117	40.12	34	41.12	25
11	41.76	107			41.67	9
12	42.39	88			43.30	10
13	44.44	54			44.40	5
14	46.40	42				
15	46.91	21				

*11.43 cm is the average length of two year old female Dover sole collected off Oregon (Demory 1975). Computed lengths at other ages were obtained by adding converted age-specific scale growth.

attributed to the fact that this is near the southern end of the geographical range for Dover sole and apparently does not provide optimal conditions for growth in this species.

English Sole Growth Off Oregon

Age of Full Recruitment to the Trawl Fishery

A two-way analysis of variance was used, as described for Dover sole above, to test for significant differences in growth rate among ages of capture and among years. For English sole captured off Astoria a significant difference ($P < .05$) in age-specific growth rate was found for fish captured at ages 4, 5, 6, 7, 8 but not for fish captured at ages 5, 6, 7, 8. These results suggest that the age of full recruitment to the fishery is five years for English sole off Astoria. Based on this finding, growth at age data according to year of growth were pooled for fish captured at ages 5, 6, 7, 8. A total of 1913 English sole five years old and older were used.

For English sole captured off Coos Bay a two-way analysis of variance showed a significant difference ($P < .05$) in age-specific growth rate for fish captured at ages 4, 5, 6, 7. When the two-way classification model tested for differences in growth for fish captured at ages 5, 6, 7 a significant difference ($P < .05$) was found for growth rate at age 3, but not for ages 1, 2, 4. Because growth at age three was barely significant, and no significant difference was observed for the other ages of growth, age five was considered as the age of full recruitment. From this, growth at age according to year of growth was taken from fish which were captured at age five and older. A total of 973 female English sole interperoculum were used.

English Sole Growth Off Astoria

The same two-way analysis of variance which tested for differences in growth rate among ages of capture also showed a significant difference ($P < .05$) in annual growth for all ages of growth. Female English sole ages one through six responded similarly to good and poor growth years (Figure 4A; Table 7). This was tested by using the applied sign test as described above for Dover sole.

Based on interopercle bone growth, growth conditions for English sole off Astoria could be evaluated between 1961 and 1974 by scaling yearly growth at older ages to yearly growth at age one in the same manner as described above for Dover sole (Figure 4B; Table 2). Poor years for growth occurred in 1967, 1969, 1971 and 1974. Pronounced good years for growth occurred in 1965, 1966, 1972 and 1973. When compared to the mean equivalent growth at age one from 1961 to 1974, the best year for growth occurred in 1972 with a 12% increase above the average (Table 3).

Figure 4A. Average growth (cm) at age for female English sole by year off Astoria, Oregon.

Figure 4B. Average growth (cm) at age one by year for Astoria female English sole determined by adjusting growth at older ages to growth at age one (solid line) and a five year running average of growth at age one (dashed line).

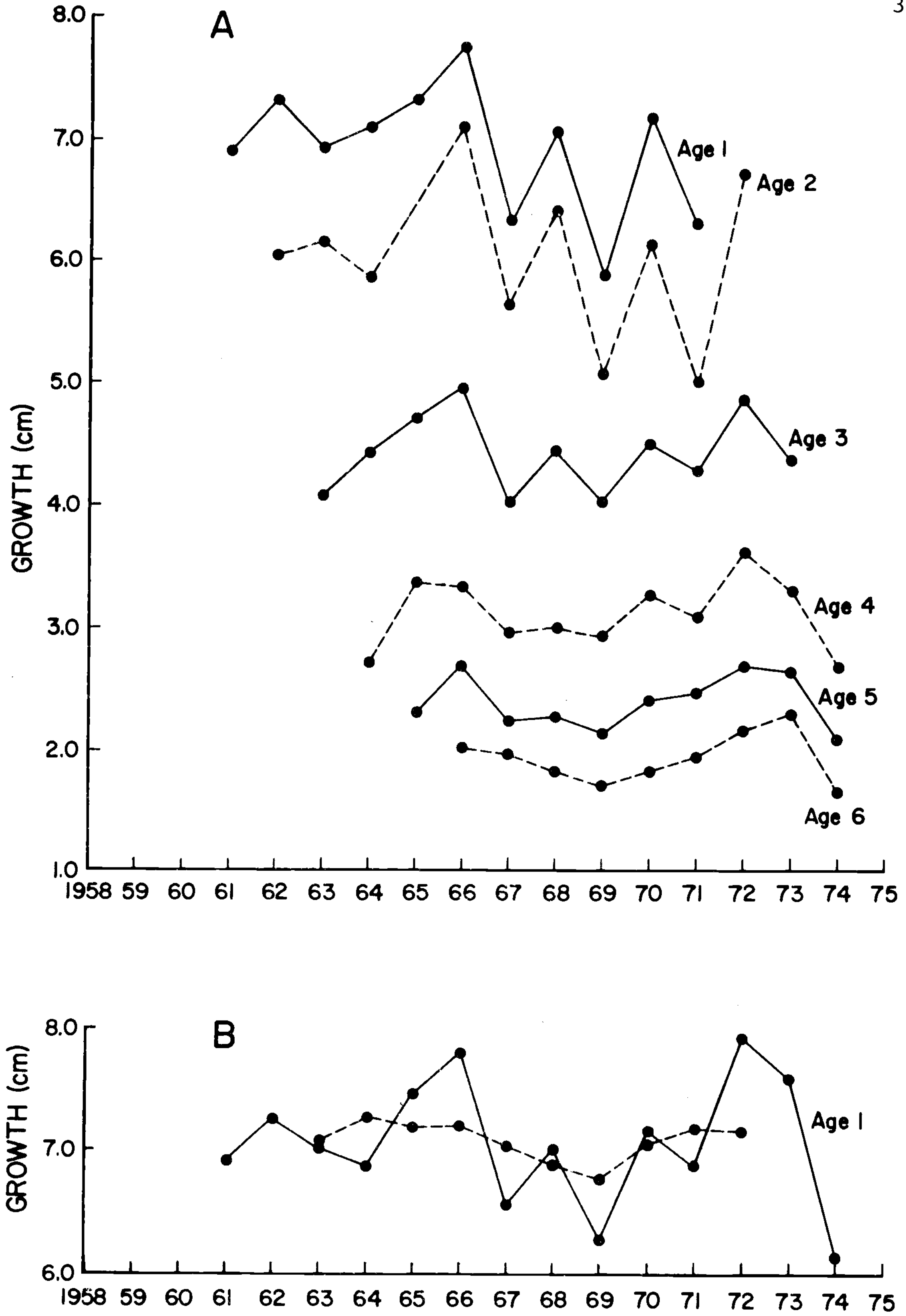

A
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
GROWTH (cm)
Age 1
Age 2
Age 3
Age 4
Age 5
Age 6
1958 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75
B
8.0
7.0
6.0
GROWTH (cm)
Age 1
1958 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

Figure 4

Table 7. Average annual growth (cm) at age for female English sole by year off Astoria, Oregon.

Age of Growth	Year of Growth													
	1961	No.	1962	No.	1963	No.	1964	No.	1965	No.	1966	No.	1967	No.
1	6.94	60	7.34	303	6.99	375	7.12	152	7.35	180	7.77	228	6.35	228
2			6.06	60	6.18	303	5.86	375	6.49	152	7.09	180	5.66	228
3					4.08	60	4.41	303	4.72	375	4.96	152	4.07	180
4							2.77	60	3.38	303	3.34	375	2.93	152
5									2.31	60	2.73	269	2.22	215
6											2.04	51	1.99	125
7													1.57	50

Age of Growth	Year of Growth													
	1968	No.	1969	No.	1970	No.	1971	No.	1972	No.	1973	No.	1974	No.
1	7.08	138	5.87	133	7.16	60	6.30	56						
2	6.52	228	5.09	138	6.16	133	5.08	60	6.70	56				
3	4.42	228	4.05	228	4.49	138	4.31	133	4.86	60	4.38	56		
4	3.01	180	2.91	228	3.27	228	3.12	138	3.63	133	3.31	60	2.70	56
5	2.27	92	2.13	102	2.43	93	2.46	137	2.67	91	2.65	56	2.09	33
6	1.82	109	1.71	46	1.80	49	1.96	48	2.15	81	2.30	37	1.67	27
7	1.59	50	1.47	47	1.57	16	1.52	22	1.80	18	1.83	27	1.64	17

The poorest year for growth occurred in 1974 with a 13% decrease from the average growth rate. A five year running average points to a gradual increase in growth rate from 1961 through 1966. The growth rate declined slightly from 1966 to 1969 followed by a small increase through 1973 (Figure 4B). A significant difference ($P < .01$) was determined when the average equivalent growth at age one for the period from 1964 to 1966 was compared to the average equivalent growth at age one for the period from 1961 to 1963, and also from 1969 to 1971. These results support the conclusion that a long-term trend in growth did occur. The maximum percent deviation of the running average points from the overall mean, annual equivalent growth rate of the period (calculated from the running averages between 1961 and 1974) was 4%. This deviation occurred between 1967 and 1971. The maximum variation around the long-term trend occurred in 1972 with a 11% deviation from the trend. The average annual variation around the trend was 5%.

<u>English Sole Growth Off Coos Bay</u>

The same two-way which tested for differences in age-specific growth rate among ages of capture off Coos Bay, also showed a significant annual difference ($P < .05$) in growth rate among years at all ages of growth except at age four. After their first year of life, English sole of all ages responded similarly to the same good and poor years for growth (Figure 5A; Table 8). This was tested using the sign test. Yearly growth at ages two through six was adjusted to represent yearly growth at age one (Figure 5B; Table 2). Analysis of mean interoperculum growth according to year showed poor growth in 1964, 1967, 1969, 1971 and 1974. Exceptionally good growth occurred in 1966 and 1972. When compared to the mean equivalent growth at age one from 1962 to 1974, the best year for growth occurred in 1966 with a 13% increase over the average. The poorest year for growth occurred in 1974 showing a 17% decrease. A five year running average on growth reveals a gradual long-term decrease in growth from 1964 to 1969. The average equivalent growth at age one from 1964 to 1966 is significantly different ($P < .01$) from the average equivalent growth at age one from 1969 to 1971. This result demonstrates that a long-term trend in growth for English sole did occur off Coos Bay. The maximum percent deviation of the running average points from the overall mean, annual, equivalent growth rate of the period (calculated from the running averages between 1962 and 1974) was 2%. This deviation occurred between 1967 and 1971. The maximum variation around the trend occurred in 1972 with a 11% deviation from the trend. The average annual variation around the long-term growth trend was 6%.

Figure 5A. Average growth (cm) at age for female English sole by year off Coos Bay, Oregon.

Figure 5B. Average growth (cm) at age one by year for Coos Bay female English sole determined by adjusting growth at older ages to growth at age one (solid line) and a five year running average of growth at age one (dashed line).

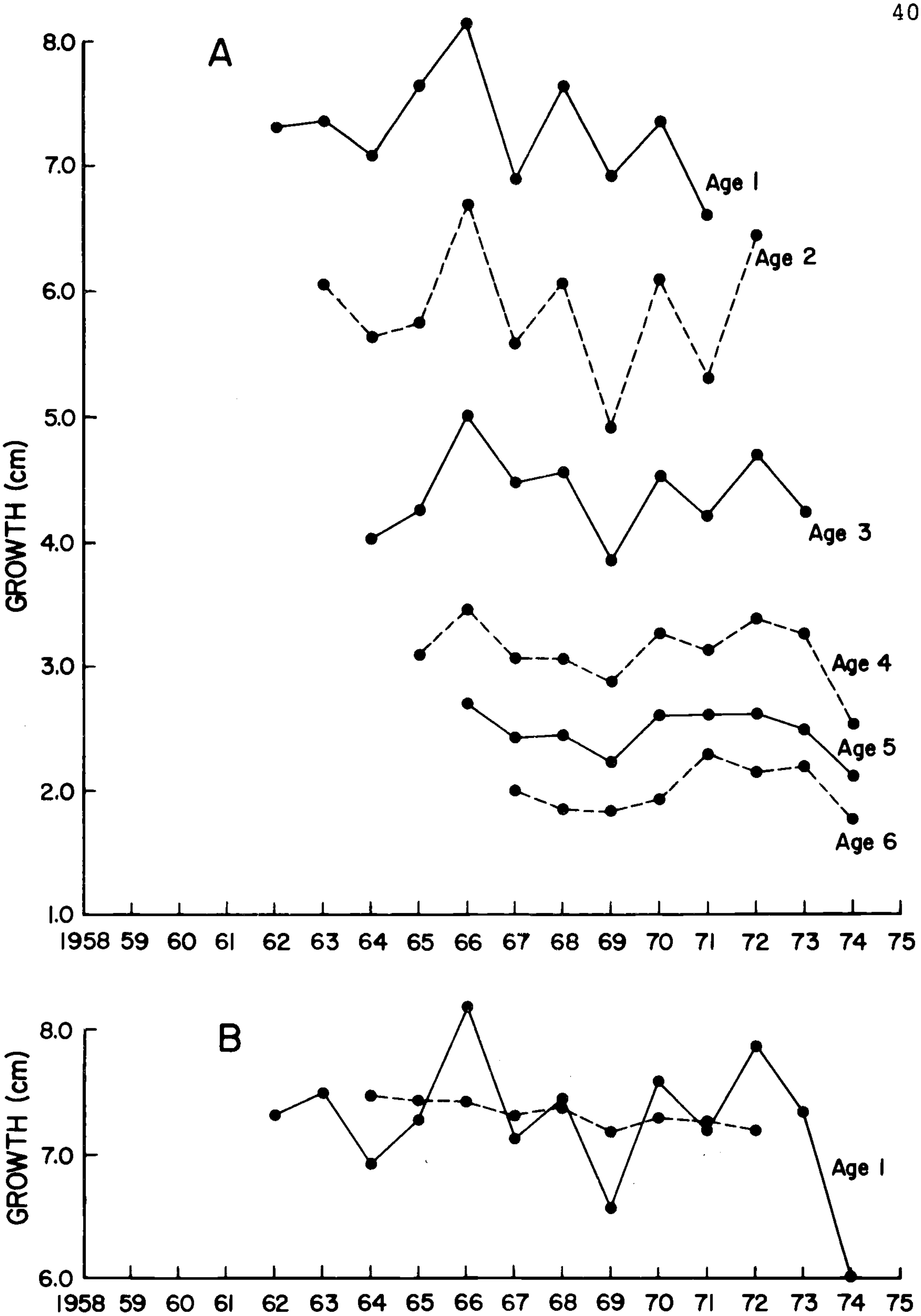

A
GROWTH (cm)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Age 1
Age 2
Age 3
Age 4
Age 5
Age 6
1958 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75
B
GROWTH (cm)
8.0
7.0
6.0
Age 1
1958 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

Figure 5

Table 8. Average annual growth (cm) at age for female English sole by year off Coos Bay, Oregon.

Age of Growth	Year of Growth													
	1962	No.	1963	No.	1964	No.	1965	No.	1966	No.	1967	No.	1968	No.
1	7.34	100	7.36	111	7.05	40	7.64	75	8.13	96	6.89	148	7.69	109
2			6.03	100	5.61	111	5.74	40	6.68	75	5.54	96	6.07	148
3					4.01	100	4.26	111	5.04	40	4.45	75	4.52	96
4							3.09	100	3.45	111	3.07	40	3.10	75
5									2.73	100	2.43	98	2.45	32
6											2.02	78	1.87	77

Age of Growth	Year of Growth											
	1969	No.	1970	No.	1971	No.	1972	No.	1973	No.	1974	No.
1	6.95	158	7.36	48	6.61	88						
2	4.86	109	6.08	158	5.31	48	6.39	88				
3	3.85	148	4.50	109	4.18	158	4.71	48	4.24	88		
4	2.88	96	3.26	148	3.16	109	3.38	158	3.23	48	2.52	88
5	2.18	61	2.59	41	2.59	120	2.59	64	2.49	65	2.09	27
6	1.85	29	1.91	19	2.35	32	2.13	49	2.18	29	1.77	31

Comparison of English Sole Growth Off Astoria and Off Coos Bay

The same years which were considered good and poor years for growth off Astoria were also observed off Coos Bay. This was tested by using the sign test as described above for Dover sole. There is no indication that the growth rate is faster in either area based on growth data collected from the 1961 through 1970 year classes from both areas. The regression relationship between annual length increment at age and length at age was determined separately for the Astoria and Coos Bay populations. Each regression was weighted according to the sample size at each age. Comparison of the two regression lines was made in the same manner as described for Dover sole above. The results showed no significant difference ($P < .05$) in the two lines.

Age-Length Relationship Determined from Interopercle Growth

Interoperculum growth was converted to body growth by the interoperculum-body length relationship developed by Smith and Nitsos (1969). The mean length (cm) at age was determined by using 11.43 cm as the mean length of one year old fish (Barss 1976), and then utilizing the interoperculum growth data. The mean interoperculum growth at each age was determined by combining the growth data from the 1961 through 1970 year classes from both Astoria and Coos

Bay. When fitted to the von Bertalanffy curve the following equation was obtained: $lt = 43.00\ (1-e^{-.266(t+.152)})$. Growth of female English sole fitted well to the von Bertalanffy growth curve (Table 9). The maximum length on record for English sole is 46 cm (Hart 1973) which is slightly greater than the L_∞ calculated above. Based on length at age data collected from O.D.F.W. groundfish surveys, Demory et al. (1976) calculated the von Bertalanffy growth equation for female English sole to be: $lt = 42.6\ (1-e^{-.265(t-.411)})$. This survey was conducted between 1971 and 1972 from Cape Bianco to the Columbia River.

Comparison of English Sole Growth Off Oregon with Other Areas

Van Cleve and El-Sayed (1969) fitted the von Bertalanffy equation to English sole captured in Holmes Harbor in northern Puget Sound, and also listed the constants for the von Bertalanffy equations computed from other areas by different authors. These areas included: Georgia St. and Pt. Discovery (Smith 1936), Carr Inlet located in southern Puget Sound (El-Sayed 1959), and Hecate St. (Palmer 1956). English sole growth in Monterey Bay, California was fitted to the von Bertalanffy growth equation by Smith and Nitsos (1969). The growth data collected by Smith (1936) and Palmer (1956) are not strictly comparable to the present study because samples were collected from the commercial catch which is selective towards

Table 9. Computed mean length at age calculated from scale growth data, and mean length at age estimated by von Bertalanffy's growth equation for female English sole collected off Astoria and off Coos Bay, Oregon.

Age (years)	Astoria and Coos Bay Computed mean length (cm)	Astoria and Coos Bay Estimated mean length (cm)
1	11.43	11.35
2	18.51	18.74
3	24.49	24.41
4	28.95	28.75
5	32.11	32.08
6	34.55	34.63
7	36.52	36.58
8	38.15	38.08

*11.43 cm is the average length of one year old female English sole collected off Oregon (Barss 1976). Computed lengths at other ages were obtained by adding converted age-specific interoperculum growth.

faster growing fish at younger ages. English sole growth data from Holmes Harbor, Carr Inlet and Monterey Bay were collected by research vessels using a smaller mesh size. Growth estimates for English sole in Monterey Bay were calculated from interoperculum growth data.

A comparison of the von Bertalanffy growth constants from all areas was made (Table 10). Despite the differences in years sampled and sampling techniques, the growth rates of English sole from all areas except Hecate St. were similar for the first four years of growth. Slowest growth at older ages is suggested for Carr Inlet. Faster growth rates at older ages is suggested for Hecate St., Strait of Georgia and Pt. Discovery.

Comparison of English Sole Growth with Dover Sole Growth

A sign test was used to test whether Dover sole from Astoria and Brookings responded to the same good and poor growth years experienced by English sole off Astoria and Coos Bay. The sign test was used in the same way as for the comparison made for growth of Dover sole off Brookings and off Astoria. The results show that Dover sole captured off Brookings and Astoria responded to the same good and poor years for growth experienced by English sole collected off Astoria and Coos Bay. These results indicate that the factors which are influencing growth are affecting both species similarly along the entire coast of Oregon.

Seasonal Growth of English Sole Off Astoria

The growing season for English sole off Astoria was determined by evaluating interopercle marginal growth. The growing season begins in March and probably continues through September. The best months for growth occur in May and June.

Table 10. Constants computed for the von Bertalanffy growth equation from various areas for female English sole.

	L_∞	K	t_o
Hecate Strait (Palmen 1956)	52.8	.119	-5.56
Georgia Strait (Smith 1946)	43.8	.289	- .452
Port Discovery (Smith 1936)	49.3	.195	- .912
Carr Inlet (El-Sayed 1959)	41.3	.257	- .178
Holmes Harbor (Van Cleve - El-Sayed 1969)	43.2	.253	- .675
Astoria-Coos Bay	42.6	.265	.411
Monterey Bay (Smith and Nitsos 1969)	42.8	.258	- .313

Correlations of the Observed Annual Changes in Growth with Environmental and Density Dependent Factors

Dover sole growth data adjusted to growth at age two, and English sole growth data adjusted to growth at age one, allowed more years of data to be incorporated into the simple regression model. Correlations were made with growth of Dover and English sole off Astoria only because more years of growth data were available there, and because stock density and upwelling estimates have been made off Astoria. The factors considered in this study which could influence the growth rate of Dover and English sole were: water temperature, upwelling and stock density.

Water Temperature

Long-term bottom temperature data off Brookings, Coos Bay and Astoria are lacking, but several years of sub-surface temperature data has been gathered off Newport by the School of Oceanography at Oregon State University aboard the research vessel *The Yaquina*. Monthly samples were collected at several positions perpendicular to the coastline at different depths. There were months each year when no sampling was conducted. It was therefore impossible to quantify the temperature data into degree-days, which is the summation over time interval of the product of temperature and the number of days which a temperature was recorded. Evaluating annual variation of temperature with respect to degree-days would have been better than average temperature based on monthly means because it would take into account temperature variation within each month.

Using the available data, the average water temperatures 15 miles offshore at a depth of 50 meters, and 25 miles offshore at a depth of 150 meters, were recorded for April, May, June, July and August each year. If no sampling was done during a given month, an estimate for that monthly temperature was calculated as the average of the preceding and following month. An average temperature for a given year at each depth was determined by taking the average of the monthly temperatures found from April through August. Because many months of data were lacking, an average annual subsurface temperature could be calculated for only five years at 50 meter depth, and for six years at 150 meter depth (Table 11).

Table 11. Average annual temperature based on April, May, June, July and August temperatures taken at 50 meter depth 15 miles off Newport, and at 150 meter depth 25 miles off Newport, Oregon.

Year	Temperature at 50 m (°C)	Temperature at 150 m (°C)
1962	8.60	7.06
1965		7.31
1966	8.13	7.15
1967	8.83	7.52
1968	8.53	7.24
1969	8.56	7.68

The annual variation in temperature at 50 and 150 meter depths calculated from the available data is not very great, and probably would not account for the annual differences in growth shown for Dover and English sole. The relationship between sub-surface temperature and growth was tested by weighted regression analysis where weights were dependent on sample size. There is no significant correlation between growth of Dover or English sole off Astoria and water temperature at 50 meter depth ($r = -.735$ for Dover sole and $r = -.818$ for English sole). However, when temperature data at 150 meters are regressed with English sole growth off Astoria a significant negative correlation was obtained ($r = -.888$, $P < .05$). No correlation between Dover sole growth off Astoria and temperature at 150 meter depth was obtained ($r = -.759$).

It has been shown in this study that the growing season for English sole off Astoria begins in March and probably extends through September, with the fastest growth occurring during May and June. It is interesting that the fastest growth did not occur during months in which sub-surface temperatures were the warmest. The average monthly temperature at 50 meter depth collected 15 miles off Newport was determined from the average of 1962, 1966, 1967, 1968 and 1969 temperature data (Table 12). The coldest temperatures at 50 meter depth occurred during May through September which coincides with the growing Season (Figure

Table 12. Average monthly temperatures at 50 meter depth taken 15 miles off Newport, Oregon determined from the average of 1962, 1966, 1967, 1968 and 1969 temperature data.

Month	Temperature °C
January	9.75
February	9.49
March	9.19
April	9.12
May	8.93
June	8.04
July	7.91
August	7.98
September	8.35
October	9.66
November	10.41
December	10.38

6. It appears that the growing season for English sole does not begin with warmer temperatures.

Upwelling

Growth could be affected by upwelling. Quantitative upwelling indices based on monthly wind stress on the sea surface have been developed by Bakun (1973, 1975) for several areas along the Pacific Coast. These units may be thought of as the average amount (metric tons or cubic meters) of water upwelled through the bottom of the Ekman layer each second along 100 meters of coastline. For this study indices for lat. 45°N and 125°W were summed from April through September (Table 13).

No significant correlation exists between Dover or English sole growth and upwelling for the year which growth occurred ($r = .372$ for Dover sole and $r = .074$ for English sole). A second weighted regression was made using a one year time lag. Again this regression showed no significant correlation between growth and the previous years' upwelling ($r = .216$ for Dover sole and $r = .056$ for English sole). An attempt was made to see if long-term trends in upwelling were affecting growth of Dover and English sole. It was hypothesized that several consecutive years of good upwelling may be required to produce a significant increase in the food supply which would enhance the growth rate. To bring out possible trends, a five year running average was

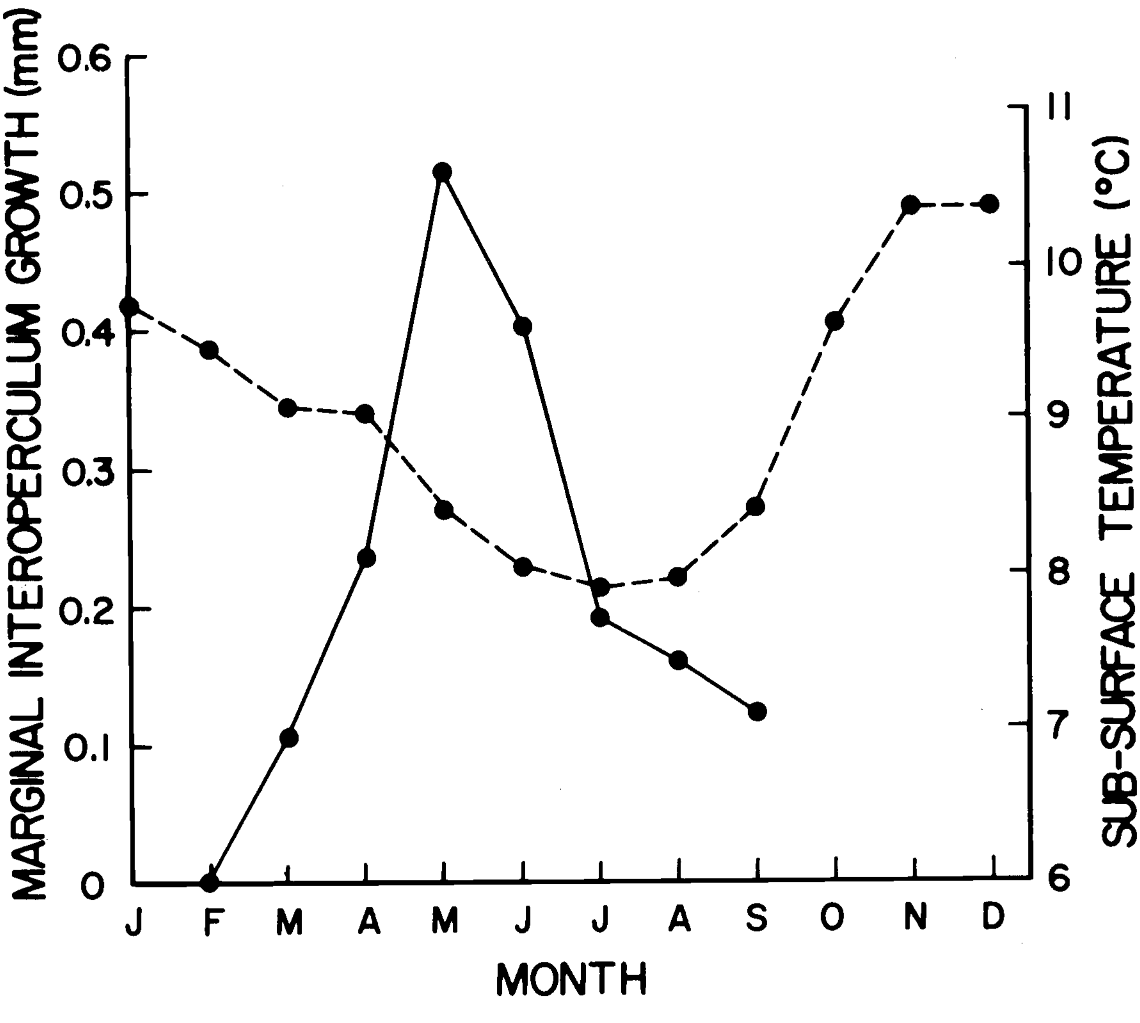


Figure 6. Plot of monthly increase of marginal interoperculum growth for four year old English sole captured off Astoria (solid line), and a plot of average monthly temperature based on 1962, 1966, 1967, 1968, 1969 temperature data taken at 50 m depth 15 miles off Newport, Oregon (dashed line)

Table 13. Annual upwelling indices for lat. 45°N and 125°W summed from April through September.

Year	Upwelling Index
1958	280
1959	279
1960	152
1961	159
1962	203
1963	139
1964	257
1965	414
1966	360
1967	476
1968	282
1969	211
1970	259
1971	174
1972	172
1973	217

calculated for the upwelling data and plotted along with a five year running average of Dover sole growth (Figure 7). The long-term trends in Dover sole growth were paralleled by long-term trends in upwelling. The five year running average of Astoria Dover sole growth points to a gradual increase from 1958 to 1966 followed by a decline through 1973. A five year running average on upwelling exhibits a similar pattern. When the five year running averages of Dover sole growth were regressed with the five year running averages of upwelling a "significant correlation" ($r = .689$, $P < .05$) was obtained. However, this is not a rigorous statistical analysis because running average points are not co-independent, and so usual probability tables cannot be applied. Though this relationship may explain the long-term trends in growth for Dover sole, it does not account for the annual fluctuations in growth.

Stock Density

A final factor considered which might affect growth is stock density. Catch per unit effort (C.P.U.E.) was used as an index of stock abundance. A major source of error with using C.P.U.E. is that it does not account for non-recruited age groups which are probably competing for the same food supply. For Dover sole there are eight age classes which are either not recruited, or not fully recruited to the fishery. With English sole there are four

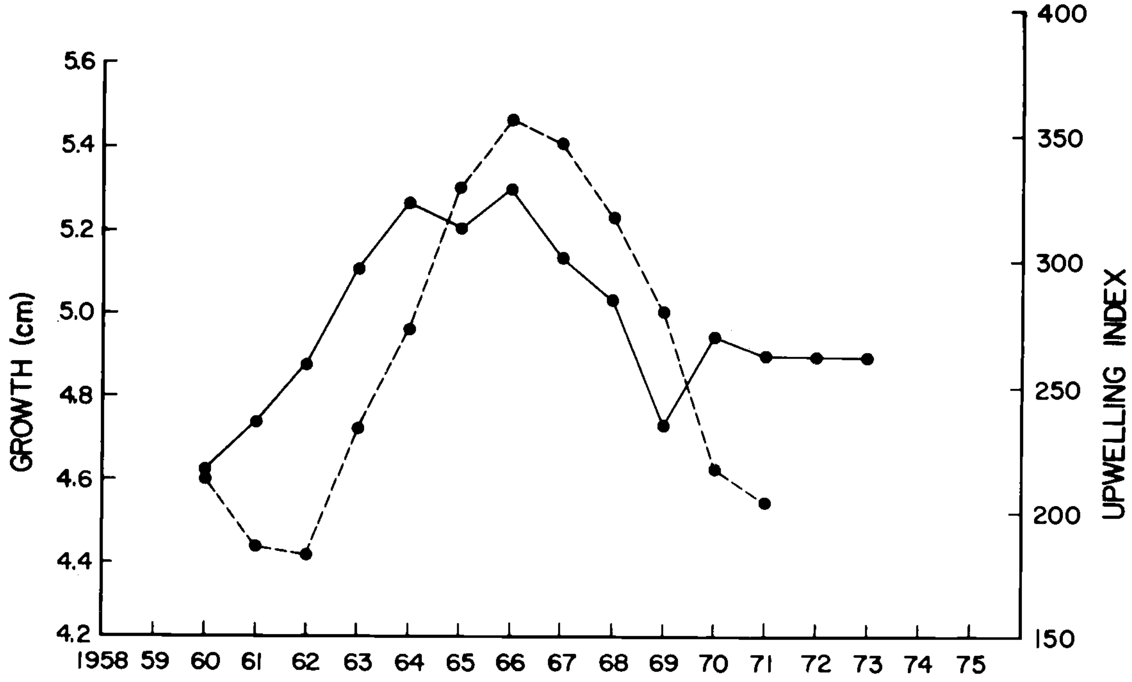


Figure 7. Five year running average of Astoria female Dover sole growth (solid line) plotted with a five year running average of upwelling indices at lat. 45°N and 125°W (dashed line).

partly or non-recruited age groups. Catch per unit effort data for Pacific Marine Fisheries Commission Area 3A (Astoria region) has been collected from logbooks of participating fishing vessels and compiled by O.D.F.W. since 1948 for Dover sole and since 1959 for English sole. The C.P.U.E. statistic for Dover sole is inaccurate, possibly due to error in measuring the effort figure, but catch per unit effort is a density index for English sole (Hayman *et al*. 1978).

A regression, weighted for sample size of Dover sole growth, on C.P.U.E. for Dover sole showed no significant correlation (r = .306). No correlation was observed between English sole growth and C.P.U.E. data for that species (r = .488).

DISCUSSION

This study has produced some insight concerning growth conditions between 1958 and 1975 for Dover and English sole inhabiting the continental shelf off Oregon. Although previous studies have determined the growth rate for Dover and English sole for different areas, no attempt has been made to investigate possible annual variation in growth rates. By using scales and interoperculum bones which were collected and saved over several years, it has been possible in this study to back calculate the mean annual growth at several ages over many years. The results of this study are the first long-term time-series reflecting growth conditions in waters off Oregon.

Analysis of the growth data show that the growth rate for Dover and English sole off Oregon does vary significantly between years. Dover sole captured off Astoria tended to grow slightly faster than those captured off Brookings. No difference in growth rate was observed for English sole captured off Astoria and off Coos Bay. English sole ages one through six, and Dover sole ages two through nine responded to the same good and poor years for growth. This would be expected if these younger individuals of both species were inhabiting the same areas and utilizing the same food supply. This appears to be true. There is a tendency for older Dover sole to inhabit deeper water than English sole, although there is considerable overlap in distribution. Adult Dover sole, which are over five years of age are rarely found inside 20 fathoms but range to at least 600 fathoms. Most fish are caught beyond depths of 40 to 50 fathoms. The bulk of the younger fish are found between 30 and 50 fathoms (Demory 1975). Adult English sole, which are over four years of age can be found between 10 and 300 fathoms, but largest catches occur between 30 and 70 fathoms. During their first year of life, English sole inhabit protected inshore areas, bays and estuaries. By the end of their first year there is a general movement into deeper waters inhabited by older fish (Barss 1976).

The diets of adult Dover and English sole overlaps and consists of a large variety of infaunal and epifaunal invertebrates. The food habits of English sole off Central Oregon have been investigated by Kravitz, Pearcy and Guin (1977). The amphipod, Ampelisia macrocephala, was the most abundant single prey species and occurred in 60% of the fish sampled. Off the western coast of Canada, Forrester (1969) states that polychaetes, clams, and ophiuroids are the primary food organisms of English sole with incidental occurrences of sand lance, crab, amphipods, shrimp, squid and small fish. Gabriel (1978) found that the diet of Dover sole off Central Oregon consisted mostly of ophiuroids, pelecypods and polychaetes. Pelecypods were found to be the most important prey on a weight basis in shallow waters (74 m), and polychaetes comprised over 90% of the diet in deeper waters (148-195 m).

The growing season for English sole off Astoria was determined to be from March through September with fastest growth occurring in May and June. For other areas along the Pacific Coast and Puget Sound the growing season is very similar. The growing season for English sole off Monterey Bay was found to be from March through November (Smith and Nitsos 1961). Holland (1969) determined the growing season in southern Puget Sound to be from April through September, and Van Cleve and El-Sayed (1969) established the growing season in Puget Sound near Seattle to be from April through October.

The magnitude of the annual variation in growth rate is as much as 19% and 17% from the mean growth response for Dover and English sole respectively. Good and poor years for growth occurred simultaneously for both species from Astoria to Brookings. Forseberg and Hosie (unpublished) examined otoliths for eight species of flatfish collected between 1971 and 1972 from the Columbia River to Cape Blanco. They found 1969 and 1971 to be generally poor years for growth for all eight species. The species included: rex sole (*Glyptocephalus zachirus*), Pacific sanddab (*Citharichthys sordidus*), arrowtooth flounder (*Atheresthes stomias*), petrale sole (*Eopsetta jordani*), slender sole (Lyopsetta exilis), butter sole (Iopsetta isolepsis), sand sole (Psettichthys melanosticus), and flathead sole (Hippoglossoids elassodon). These two years were found to be unfavorable for Dover and English sole growth in this study. Poor growth in 1971 was also observed for shrimp (Pandulus jordani), coho salmon (Oncorhychus kisutch), and razor clams (Siliqua patula) (Peterson and Miller 1975). This would indicate some widespread coastal phenomenon is influencing faunal productivity in general.

The factors investigated in this study which could affect growth were water temperature, stock density and upwelling. Only a few years of sub-surface temperatures were available and these were obtained off Newport. Yearly average sub-surface temperature between March and September did not vary greatly, and it is doubtful that such a small change in temperature would produce detectable changes in growth rates. No correlation was found between temperature and growth. This study has shown that during the course of a year growth of English sole occurs during months at which sub-surface temperatures are coldest. Growth occurs during spring and summer which coincides with upwelling that brings cold water of deep shelf origin to near shore areas.

There is no indication that stock density is affecting growth. This is a difficult correlation to make with the available data because C.P.U.E. data were used as an index of abundance and includes only those ages which are recruited to the fishery. As a result several age groups were omitted from the density estimates. Available C.P.U.E. statistics may also be an inaccurate index of abundance for Dover sole (Hayman et al. 1978).

The effects of upwelling were also investigated. Upwelling is a coastwide phenomenon which varies from year to year. From April to September along the Oregon Coast winds generally blow from the north and northwest. The effect is the transport of surface water away from the coast. This surface water offshore transport is balanced by an onshore deep transport of cool, nutrient-rich water coming to the surface. This nutrient-rich water is believed responsible for an increased food supply which is utilized by pelagic and benthic organisms. The major effects of upwelling occur at the very base of the food chain and are probably separated from the benthic predators at the end of the food chain by an appreciable time lag, and by multiple interacting biological processes. Bakun (1973) states that where a complex food chain is involved any attempt to relate short term upwelling events with some characteristic of the fishery will likely be fruitless.

No significant correlation was found relating yearly growth to yearly upwelling with or without a one year lag period. Five year running averages on growth and upwelling data does point to a gradual long-term increase in growth for Dover sole from 1958 to 1966 followed by a gradual decrease through 1975 that corresponds to a similar long-term trend in upwelling during this period. This would suggest that large scale upwelling trends are influential, but not necessarily annual changes.

There is undoubtedly some lag between upwelling and the production of food utilized by benthic fishes. Upwelling usually begins in March or April off Oregon and continues through September. Studies by Anderson (1964) off the Columbia River have shown that the spring bloom in algae is caused by increased sunlight, and in 1961 the bloom occurred in May. Annual variation in zooplankton abundance off Oregon has been investigated by Miller and Peterson (1975). Their results demonstrate that low zooplankton abundance occurs in April, May and June with peak abundances occurring in late June and early July. Higher zooplankton densities appear to be associated with upwelling. A year of reduced upwelling off Oregon occurred in 1971 and resulted in lower zooplankton density than was observed in 1969 or 1970 which were better upwelling years. An additional lag is involved with the settling into the benthos of the biogenous material produced in the surface waters. Diatoms (Smayda and Boleyn, 1965; 1966a, 1966b), and organic matter (Hobson, 1967) have been reported to settle at the rate of 1 m/day. This is on the same order as the speed of upward water movements due to upwelling.

Speeds of horizontal transport are 10^3 to 10^4 times greater (Budinger, Coachman and Barnes 1964). It would appear then that several months would be required in order for this material to settle to the benthos if it were not carried off the continental shelf by currents. Eupausid fecal pellets have a significantly greater settling rate, sinking at about 40 m/day and may constitute the bulk of the biogenous particles lost in the photic zone by settling (Osterberg *et al*. (1963). This material could feasibly reach the benthos in a few days. Pearcy (1972) states that euphausids are abundant off the coast of Oregon. Under these circumstances the bulk of the biogenous material (mainly fecal pellets) would not reach the benthos to be utilized by invertebrates until July. An additional lag would be involved depending on the generation period for the prey species.

A possible effect of upwelling could be to increase fecundity of sexually mature invertebrates and to increase greater survival of the young upon settling because of the increased food reserves deposited in the benthos. A successful year class for an invertebrate species could conceivably be available as a food supply for several years depending on the longevity of that species. One polychaete, *Pectinaria californiensis* has been observed to live at least three years (Nichols 1975). This species has proven to be a substantial food source for Dover sole off Central

Oregon (Gabriel 1978). It is therefore conceivable that one or two years of good upwelling may produce increased prey densities that could be utilized by Dover and English sole for several years despite abnormally poor upwelling that may occur in subsequent years. This explanation gives some credence to the correlation made between the long-term trends in upwelling and the long-term trends in Dover sole growth off Astoria, however upwelling does not seem to account for the sharp annual fluctuations in growth exhibited, especially between 1966 and 1975.

Effects of oceanographic factors on growth of fishes would be more easily studied on a species which is fast growing and easy to age. The scales and interoperculum bones of Dover and English sole generally proved difficult to read, especially at older ages. This study was feasible only because enough fish were sampled so that fish whose ages were questionable could be discarded. For every Dover sole scale used, at least six or seven were discarded. Interoperculum bones from English sole were more easily read. A good potential indicator of growth conditions for a benthic predator off Oregon would be the butter sole (Isopsetta isolepsis) (Robert Demory, O.D.F.W., pers. comm.).

Presently the fishery for Dover and English sole is underutilized (Barss 1976; Demory 1975), however fishing pressure is increasing. When the fishery is brought under maximum sustainable yield management, knowledge of changes in growth rate could have an effect when estimating total fish biomass and subsequent yield potential. Information obtained in this study concerning annual and long-term changes in growth rate should first be incorporated into a simulation model to examine possible effects on yield.

Since geographical differences in growth rate for Dover and English sole are small or non-existent off Oregon, there is no need to continue collecting growth data from different areas. Depending on the effect that annual changes in growth rate has on yield, future data collection should concentrate on annual rather than geographical differences in growth rate. Scale and interoperculum growth data for Dover and English sole should continue to be collected to verify the relationship between long-term growth trends and long-term upwelling trends. Longer annual data series would most likely bear out the effect suggested in the running average analysis.

In testing for annual changes in growth rate for Dover and English sole, scale and interoperculum growth data are better than length at age data. For growth comparisons, length at age data should be obtained before or after the growing season. Most growth data comes from the trawl fishery which operates during periods of calmer weather, during spring and summer months off Oregon. This period coincides with the growing season for these fish. Length at age data for a given year would be biased depending upon the month which the data was collected. By using scale or interoperculum growth, measurements of fish at earlier ages can be made from fish caught at older ages by back calculation using a scale or interoperculum length-body length relationship. The time of year which the fish are captured has no influence when determining lengths at earlier ages.

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