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PACIFIC MARINE FISHERIES COMMISSION

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IDAHO-ALASKA

Bulletin 7

RESULTS OF ENGLISH SOLE TAGGING IN BRITISH COLUMBIA WATERS

DISPERSAL OF ENGLISH SOLE, *Parophrys vetulus*, TAGGED OFF THE WASHINGTON COAST IN 1956

RESULTS OF ENGLISH SOLE TAGGING OFF CALIFORNIA

AGE, GROWTH, AND MORTALITY OF RACES OF ENGLISH SOLE (*Parophrys vetulus*) IN PUGET SOUND, WASHINGTON

AGE, GROWTH, AND PRODUCTIVITY OF AN ENGLISH SOLE (*Parophrys vetulus*) POPULATION IN PUGET SOUND, WASHINGTON

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A REVIEW OF SABLEFISH TAGGING EXPERIMENTS IN CALIFORNIA

THE OREGON TRAWL FISHERY FOR MINK FOOD, 1958-65

Portland, Oregon
1969

PACIFIC MARINE FISHERIES COMMISSION

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FOREWORD

Bulletin 7 is published in partial fulfillment of the purpose of the Compact which created the Pacific Marine Fisheries Commission in 1947. Since then, the Commission has issued at irregular intervals six Bulletins which present historical, statistical and biological information on fisheries of common interest on the Pacific Coast of North America. The year of publication, the titles of the papers, and the names of the authors are listed for each of the previous Bulletins on the inside of the back cover of this Bulletin.

At the suggestion of the Technical Sub-Committee of the International Trawl Fishery Committee appointed by the Second Conference on Coordination of Fisheries Regulations between Canada and the United States, it was initially intended to restrict Bulletin 7 to papers concerning English sole, *Parophrys vetulus* Girard, but when sufficient papers on this species were not received, the content of the Bulletin was broadened to include papers on other bottomfish.

The Pacific Marine Fisheries Commission thanks the Fisheries Research Board of Canada for the contribution of a paper on English sole, frequently referred to as lemon sole in British Columbia.

Leon A. Verhoeven

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Results of English Sole Tagging in British Columbia Waters

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RESULTS OF ENGLISH SOLE TAGGING IN BRITISH COLUMBIA WATERS

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INTRODUCTION

Between 1943 and 1961, over 25,000 English sole or lemon sole *(Parophrys vetulus)* were tagged in Canadian waters as part of the Fisheries Research Board's program to obtain knowledge of the biology of several important species which contribute to the otter-trawl fishery. This report summarizes information on movements as indicated by tag recaptures and endeavours to answer questions on the identity of stocks and directive factors in migration.

The English sole occurs from southern California to the Gulf of Alaska (Clemens and Wilby, 1961), and in British Columbia waters is at or near the northern limit of its commercial range. It has varied in its importance to the Canadian fishery, but over the long term has tended to be the second or third ranking species among flatfishes landed for human consumption. Since 1945, over 90% of the production (Table 1) has tended to originate from two widely separated regions of the British Columbia coast: northern Hecate Strait (PMFC Area 5D) and the Strait of Georgia (PMFC Area 4B).[1] It is in these two regions that most of the tagging has been conducted.

METHODS

In early years of the groundfish investigation some tagging was conducted from commercial trawling vessels during regular fishing operations and some from chartered vessels, but after 1947 the bulk of the tagging was done from research vessels of the Board. In all English sole taggings, plastic disc tags of the Petersen type were used. Discs were attached by nickel tagging pins until the end of 1951. In a transition period of the next 2 or 3 years various other metals were tested for affixing tags (Forrester and Ketchen, 1955). These tests and earlier studies by California workers (Calhoun et al., 1951) showed that nickel pins had a high susceptibility to corrosion and their use was subsequently abandoned. Stainless steel wire (Type 316) was used in 1954 and in subsequent years it gave way to manufactured stainless steel pins. The latter are now used for all flatfish tagging conducted by the Nanaimo Station. Attachment of the tag was through the musculature at the base of the dorsal fin close to the greatest dorso-ventral width, a location considered least damaging to the fish (Manzer, 1952).

At time of tagging, each English sole was measured to the nearest centimetre for total length, i.e., from the tip of the snout to the tips of the central rays in the caudal fin.

As an incentive to reporting and returning of tagged fish a reward of 50 cents was established for recovery data specifying place and date of capture, size and sex. Beginning in 1947, a reward of 75 cents was paid to persons submitting tagged fish directly to the Board's observers stationed at Vancouver, Victoria and Prince Rupert. This added incentive enabled collection of more and better information on growth and location of capture.

[1]In 1956, informal agreement was reached among various research agencies along the Pacific coast to establish a uniform description of fishing areas as a means of coordinating the collection and compilation of ottertrawl catch statistics. This work was undertaken by the Pacific Marine Fisheries Commission (representing the States of Washington, Oregon, and California) with the informal cooperation of the Fisheries Research Board of Canada. Areas 1A, 1B, and 1C encompass waters off the California coast, while Areas 2A-2D involve waters adjacent to Oregon and a small part of southern Washington. The remainder of the Washington coast and the waters off the west coast of Vancouver Island comprise Areas 3A-3D, while United States and Canadian inshore waters (Juan de Fuca Strait, Strait of Georgia, and Puget Sound) are represented by Areas 4A and 4B, respectively. Fishing grounds between the northern end of Vancouver Island and the British Columbia-Alaska boundary are represented by Areas 5A-5E. The entire Alaskan coast is designated as Area 6, but except for a small amount of fishing in inshore channels, this area has not been trawled intensively by North American nationals.

TABLE 1

Mean Annual Catch of English Sole Taken by Canadian Fishermen in British Columbia Waters (catch in 1000's of lb.).

Year	PMFC Area								Total
	4B	3B	3C	3D	5A	5B	5C	5D	
1945-49	649	..	58	3	12	7	11	1073	1813
1950-54	609	..	48	2	33	45	19	1980	2736
1955-59	416	1	31	3	13	20	27	1028	1539
1960-64	434	43	45	3	23	17	41	1105	1711
Mean	527	11	45	3	20	22	25	1297	1950
%	27.0	.6	2.3	.2	1.0	1.1	1.3	66.5	100.0

RESULTS

General

At various intervals 25,183 English sole were tagged and released on British Columbia fishing grounds between 1943 and 1961 (Table 2). Approximately 58% (14,100) were released in several projects conducted in the Strait of Georgia (PMFC Area 4B) and 41% (10,230) in waters north of Vancouver Island (PMFC Areas 5A to 5D, Fig. 1). Most of the releases in the latter region were in northern Hecate Strait (PMFC Area 5D), the site of the main Canadian fishery for English sole. In addition, 155 fish were released on grounds off the west coast of Vancouver Island (PMFC Areas 3C and 3D), 282 fish in the Strait of Juan de Fuca off Victoria (PMFC Area 4B) and 416 fish in inlets adjoining Queen Charlotte Strait (PMFC Area 4B). To June, 1966, a total of 6,653 (26.4%) recaptures had been reported.

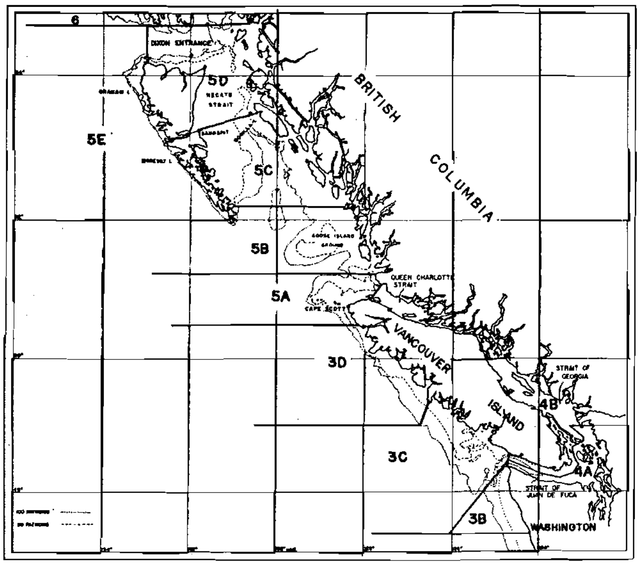

FIGURE 1. International (Pacific Marine Fisheries Commission) Statistical areas along the British Columbia coast.

Details by Area

Strait of Georgia (PMFC Area 4B)

Over 14,100 tagged English sole have been released in the Strait of Georgia since October 1944, principally in three areas of long-standing importance to the winter trawl fishery. They are: (1) the Cape Lazo-French Creek area off the middle east coast of Vancouver Island, (2) the Boat Harbour-Satellite Channel area of the Gulf Islands and (3) the area off the mouth of the Fraser River between Point Atkinson and Point Roberts (Fig. 2). Detailed accounts of the taggings in the Strait of Georgia have not been published, but general summaries have been presented by Ketchen and Forrester (1955) and Forrester and Ketchen (1963).

In the Cape Lazo-French Creek area 8,456 English sole were tagged and the majority of these (over 7,000) were released during the winter months on spawning grounds in Baynes Sound (Union Bay to Yellow Rock—Fig. 2) and off Cape Lazo (Table 3). The balance were released during the summer and early fall months on grounds between Yellow Rock and French Creek.

Approximately 25% (2,097) of the tags released in the Cape Lazo-French Creek area were recovered in subsequent years and all but 27 of these were made in the general tagging area. There were more than twice as many emigrants (17) reported from the summer tag-

TABLE 2

English Sole Tag Releases by Canada and Recoveries from Waters Adjacent to the British Columbia Coast (by Canadian and United States trawlers) and Adjacent to the United States Coast (by United States trawlers).

Location of tagging	Number tagged	Total recovered		Recoveries off					Period covered
				Canadian coast		U.S. coast*		Location unknown	
		No.	%	No.	%	No.	%		
Hecate Strait	8,353	2,659	31.8	2,599	99.9	3	0.1	57	1945-64
Queen Charlotte Sound	1,877	222	11.8	194	96.0	8	4.0	20	1952-64
Queen Charlotte Strait	416	45	10.8	45	100.0	0	0	0	1952-64
West coast of Vancouver Island	155	36	23.2	15	49.4	16	51.6	5	1945-64
Strait of Georgia	14,100	3,619	25.7	3,530	99.7	12	0.3	77	1944-64
Strait of Juan de Fuca	282	72	25.5	34	53.1	30	46.9	8	1960-64
Total	25,183	6,653	26.4%	6,417	98.9%	69	1.1%	167	

*Other than in PMFC Area 4A (Puget Sound and United States waters in southern Strait of Georgia).

ging as there were from the winter tagging (8), despite the fact that numbers released during the summer were only one-fifth as numerous. Seven of the emigrants reported from the summer tagging were caught by United States vessels. Two of these were recaptured off the open coast: one near Umatilla Lightship and the other off northern California, approximately 625 miles from the tagging site. The remaining 5 also were taken in United States waters of the Strait of Georgia near Point Roberts.

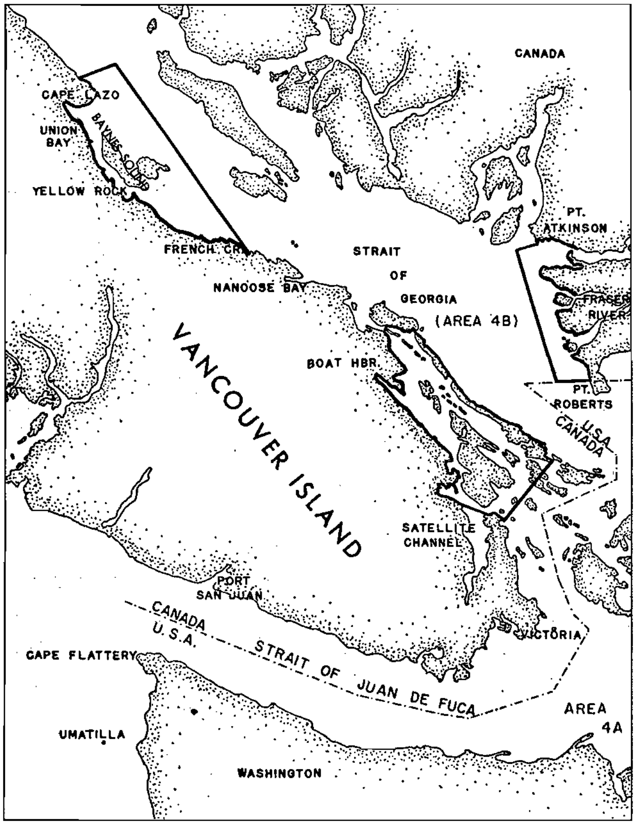

FIGURE 2. English sole tagging areas in the Strait of Georgia.

In the Boat Harbour-Satellite Channel area 3,876 tagged fish were released and subsequent recaptures amounted to 1,011 or 26%. The majority of releases were made during winter months on or near a spawning ground at the northern end of this area. Only 21 of the fish recaptured had emigrated beyond the area of which 17 were recaptured on the eastern side of the Strait of Georgia either in the vicinity of the Fraser River estuary or immediately to the south in United States waters (PMFC Area 4A). One was recovered in the Cape Lazo-French Creek area. The remaining 3 were recaptured on grounds outside the Strait (1 each on grounds near Port San Juan and Ucluelet off the west coast of Vancouver Island and 1 in the Destruction Island area about 30 miles southerly of the Umatilla Lightship off the Washington coast).

In the Fraser River area largest taggings were conducted during winter months on the Point Atkinson spawning ground (1,019 fish) and during the summer and fall months off the mouth of the Fraser River (499 fish). Recaptures from these 2 taggings totalled 376 fish of which 252 were made in the general tagging area. Eighty-eight of the total 95 so-called emigrants were caught on contiguous grounds in United States waters to the south of the tagging site, which grounds are considered to be indistinguishable biologically from those of the general tagging area (Ketchen and Forrester,

TABLE 3

Summary of English Sole Tagging and Recoveries in the Strait of Georgia.

Location of tagging	Number tagged	Total recovered		Number recovered						
		No.	%	Cape L. French Cr.	Boat Hbr. Gulf Is.	Fraser River	U. S. St. of Georgia	Offshore waters	Other St. of Georgia	Unknown
Cape Lazo-French Creek										
Summer	1381	189	13.7	169	..	6	5	2	4	3
Winter	7075	1908	27.0	1858	6	1	1	..	2	40
Total	8456	2097	24.8							
Boat Harbour-Satellite Channel	3876	1011	26.1	1	990	8	9	3	..	..
Fraser River										
Summer	499	177	35.5	..	..	123	34	6	..	14
Winter	1019	199	19.5	..	1	129	54	..	..	15
Total	1518	376	24.8							

1955). One of the other emigrants was taken in the Boat Harbour-Satellite Channel area and 6 were taken on grounds off the open coast of the United States. The latter were from the summer and fall tagging experiments.

The existence of 3 fairly distinct "populations" of English sole within the Strait of Georgia is suggested by the general lack of exchange among the 3 tagging or principal fishing areas (Table 3). Fish inhabiting the Fraser River area are probably part of a population which extends into United States waters of the Strait.

In the Cape Lazo-French Creek area there appear to be at least 2 sub-populations with little intermingling between them (Forrester and Ketchen, 1963). The spawning site of one is off Cape Lazo while that of the other is in the central part of Baynes Sound (Taylor, 1947).

There is apparently little movement of English sole to grounds outside the Strait. However, the tendency for summer taggings to result in more recaptures off the open coast than winter taggings, suggests the existence of a small, highly migratory element which enters the Strait during summer and returns to open water in the autumn.

Seasonal movements. Within populations, seasonal movements of English sole in the Strait of Georgia are difficult to describe because of the seasonal nature of the fishery and the existence of several areas which have been closed to trawling at various times since 1947 (Forrester and Ketchen, 1963). Still, there is some evidence to support the conclusion that there are seasonal north-south movements associated with spawning.

In August 1950, 944 English sole were tagged in the (closed) southern part of the Cape Lazo-French Creek area. During the following winter 27 recaptures were made on the (open) Cape Lazo spawning ground (approximately 30 miles north of the general tagging area).

In the Boat Harbour-Satellite Channel area, Taylor (1947) demonstrated a southward post-spawning movement from the Boat Harbour ground in the northern part of that area.

On the eastern side of the Strait (Fraser River area), tagging conducted on a small spawning ground near Point Atkinson in March 1954, revealed a southward dispersion. In the 12 months following tagging, 70 recaptures were made off the Fraser estuary and 19 were made still farther to the south in United States waters of the Strait. In the tagging area itself, which is closed to groundfish trawling, one recapture was made by a shrimp trawler. No recaptures were made to the north of the tagging site, but this may reflect the small amount of fishing effort on the eastern side of the Strait.

Northern Hecate Strait (PMFC Area 5D)

Three large-scale taggings of English sole (6,727 tags) were conducted in northern Hecate Strait in the region of the "edge" between a locality SW of Warrior Rocks and the Two Peaks ground during the years 1945, 1950 and 1952 (Table 4 and Fig. 3). In the years of tagging and in later years, approximately 99% of the 2,458 recoveries (for which location of recapture was known) were made within PMFC Area 5D which encompasses the tagging sites. Twenty recaptures were made to the south of that area, with 3 off the Washington coast (Area 3B, Fig. 4). None was to be expected from areas to the north of Hecate Strait as no trawl fishery existed there during the years (up to 1959) when recoveries were likely to be made. Still, 1 recapture was reportedly made by a line fisherman off Cape Spencer, Alaska, 350 miles to the north of the tagging site.

The pattern of intra-seasonal migration of English sole in northern Hecate Strait has been summarized for these and other Hecate Strait taggings by Ketchen (1950, 1956). He concluded: (1) that there was a northward migration in the spring months which began at

TABLE 4

Summary of English Sole Tagging and Recoveries in Northern Hecate Strait.

Date and location of tagging	No. tagged	Number (and %) recovered in and outside of tagging area			Recovery location unknown	Total recovered
		Total	In tagging area	Outside tagging area		
March - 1945 SW Butterworth Rks to Two Peaks Gd.	1490	316	312 (98.7)	4 (0.3)	15	331
April - 1950 SW Warrior Rocks to SW Archibald Is.	3018	1405	1395 (99.3)	10 (0.7)	21	1426
June - 1952 SW Warrior Rocks to Two Peaks Gd.	2219	737	730 (99.1)	7 (0.9)	16	753

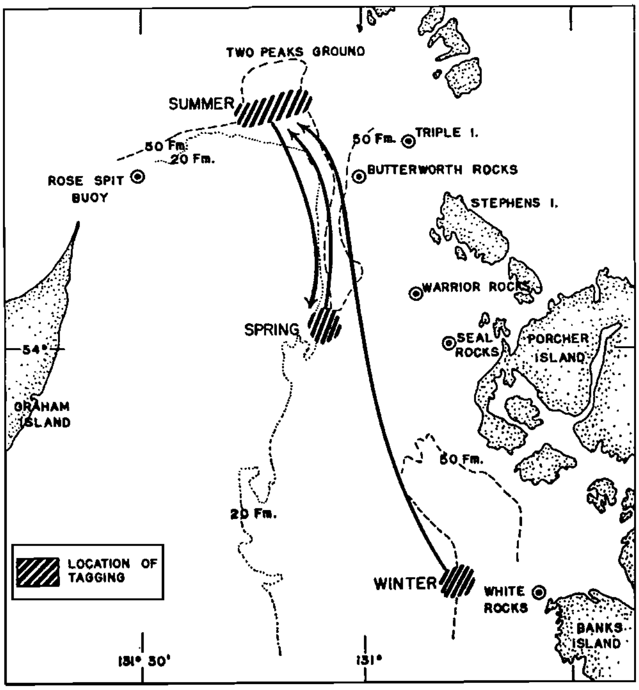

FIGURE 3. Location of taggings and general migration route of English sole tagged at various seasons in northern Hecate Strait.

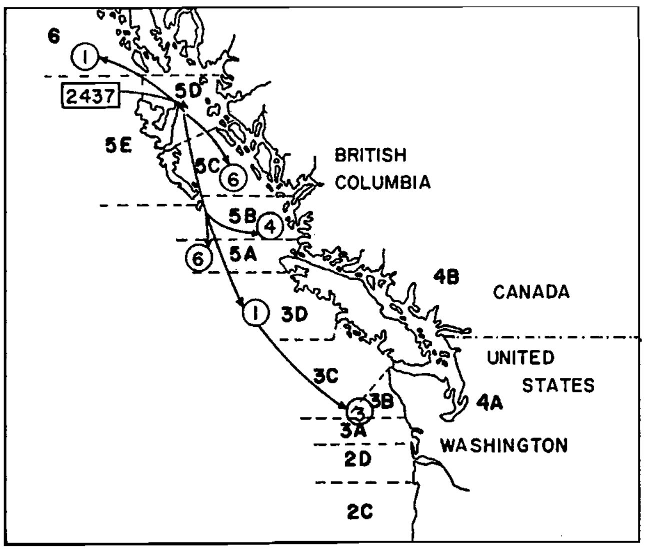

FIGURE 4. Pattern of recovery of English sole tagged in northern Hecate Strait during the years 1945 to 1952 (number tagged = 6,727). Recoveries are shown by area, with those in the rectangle taken in the area of tagging.

least as far south as the White Rocks ground (Fig. 3); (2) the movement appeared to terminate on the Two Peaks ground during the summer months at which time the fish seemed to be widely dispersed on the grounds; and (3) there was evidence of a southerly or return movement in the early fall.

Results of tagging in April 1950 on a small concentration of spawning English sole found in a portion of Prince Rupert harbour (inshore and 25 miles northeast of the Hecate Strait bank) suggested that contribution to the main fishery in Hecate Strait was small (Ketchen, 1956). There were only 35 recoveries from the total tagging of 962 fish, 24 of which were returned from the inshore grounds and 11 from the offshore grounds (Area 5D). These recoveries might suggest that about 30% (11/35) of the tagged fish had migrated to the region of the fishery in Hecate Strait. However, fishing effort in the inshore region is mainly by shrimp trawlers and amounts to only about 1/50 of that in the open waters of the Strait. A weighting of recoveries according to effort would reduce the outside recoveries to negligible significance.

Queen Charlotte Sound (PMFC Area 5B)

During May and June in the years 1952 to 1954, inclusive, a total of 1,877 English sole was tagged and released on the Goose Island ground in Queen Charlotte Sound. Up to 1962 there were 222 recoveries (11.8%). The majority of these (75%) were in the area of tagging, but there was widespread dispersion of some tagged fish, mainly to the south (Fig. 5). Five recoveries came from grounds in northern Hecate Strait, 18 on the adjoining Cape Scott bank or grounds, with the remainder (for which recovery location was known) from grounds farther to the south. Four recoveries were made off the west coast of Vancouver Island (PMFC Areas 3C and 3D) and five were made in the months of January and February during the regular winter fishery for English sole on grounds off the upper Washington coast (Area 3B). One recovery was made in the Columbia River area, one off the Umpqua River, Ore-

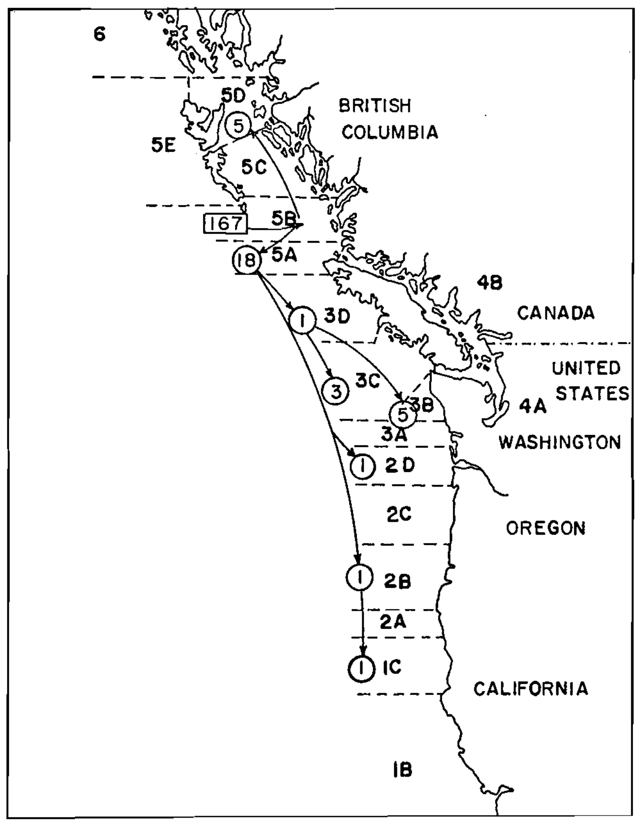

FIGURE 5. Pattern of recovery of English sole tagged on the Goose Island grounds during the years 1952 to 1954 (number tagged = 1,877). Recoveries are shown by area, with those in the rectangle taken in the area of tagging.

gon, and another off Crescent City, California, some 650 miles south of the tagging area. The last-mentioned (a 42-cm female) had travelled this distance in 327 days, a net southward movement of about 2 miles per day.

West Coast of Vancouver Island (PMFC Areas 3C and 3D)

Approximately 85% of the 155 English sole tagged off the west coast of Vancouver Island were released in June 1945 off Wickaninish Bay (PMFC Area 3C). Sixteen of the 29 recoveries, for which recovery location was known, were made in waters off the United States (Fig. 6), with the majority being reported from the area between Cape Flattery and Destruction Island off the Washington coast (PMFC Area 3B), in the winter months immediately following tagging. This is the site of a major English sole fishery by United States vessels (Alverson, 1960). Manzer (1946) suggested that off the west coast of Vancouver Island there is a southward movement of English sole in autumn and a return to the tagging area in the summer.

The remaining 15% tagged off the upper west coast of Vancouver Island (23 fish in June 1945) yielded only 2 recoveries: 1 of unknown locality and 1 from the Cape Flattery-Destruction Island area off Washington, in February, 1947.

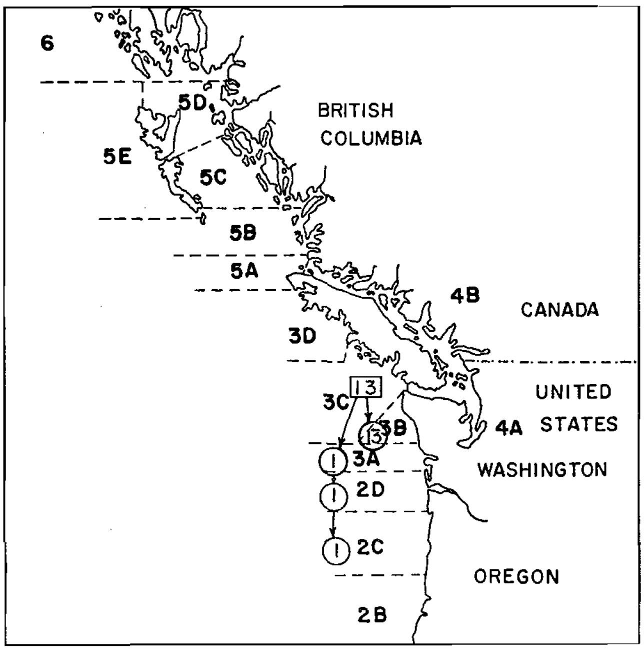

FIGURE 6. Pattern of recovery of English sole tagged off the lower west coast of Vancouver Island in 1945 (number tagged = 132). Recoveries are shown by area, with those in the rectangle taken in the area of tagging.

Queen Charlotte Strait (upper portion of PMFC Area 4B)

None of the tagged fish released in this area in 1952 and 1953 (mainly in inlets) were ever recaptured in the fishery off the open coast. All recoveries (10.8% of those tagged) were made in the immediate area of tagging.

Strait of Juan de Fuca (southwest portion of PMFC Area 4B)

In April 1960, 282 English sole were tagged in the vicinity of William Head near Victoria in the Strait of Juan de Fuca. Within 3 weeks of tagging 2 recoveries were made at the entrance to the Strait, approximately 55 miles west of the tagging site. In the first 7 months after tagging (to December 1960) 22 recoveries were made in the vicinity of tagging, 6 near the entrance to the Strait (1 slightly south, off Umatilla) and 4 to the

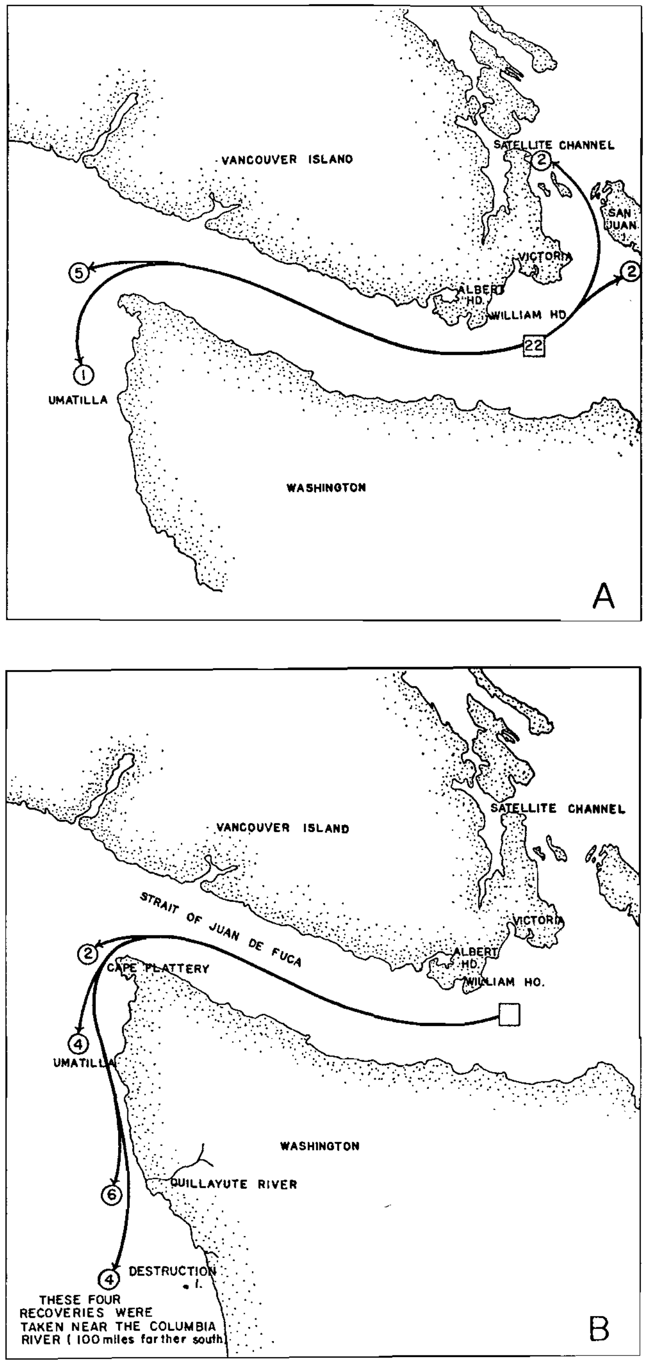

FIGURE 7. Pattern of recovery of English sole tagged in the Strait of Juan de Fuca in April 1960 (number tagged = 282). (A) Recoveries during April to November 1960 (inclusive); (B) Recoveries during December 1960 to April 1961 (inclusive). Recoveries shown in the rectangle were taken in the area of tagging.

northeast of the tagging area (off Orcas Island in United States waters and in Satellite Channel in Canadian waters — Fig. 7A). In the period of December 1960 to April 1961 inclusive, the pattern of recovery was markedly different (Fig. 7B). Fishing effort was low in the Victoria area and no recoveries were made there. Sixteen recoveries were made off the Washington coast, with 12 coming from the region between Cape Flattery and Destruction Island (PMFC Area 3B) and 4 from waters near the estuary of the Columbia River (Areas 2D and 3A). There were also 6 recoveries from unknown localities by United States vessels.

In the period from May 1961 to May 1963 inclusive, 17 more recoveries were made: 1 from the tagging area, 2 from the Point Roberts region in United States waters inside the Strait of Georgia and 13 from United States waters between Cape Flattery, Washington and Newport, Oregon. Eleven of the latter came from grounds between Cape Flattery and Destruction Island. It is apparent that some of the English sole inhabiting waters off Victoria congregate offshore as part of the Cape Flattery-Destruction Island spawning aggregation.

DISCUSSION

Problems of Interpretation

It is inevitable that information on the recapture of tagged fish will be subject to certain errors in reporting. Fishing areas may be inadvertently mis-identified by fishermen — for example, some United States fishermen in the past have made no distinction between fishing grounds of Queen Charlotte Sound and Hecate Strait, and have used the latter name to distinguish the much broader area (Alverson, 1956). Tagged fish, not discovered until a vessel unloads, may be mixed catches originating from several areas. Thus, in the words of Cleaver (1949) ". . . it is certain that if none of the tagged fish had left the place of tagging, the recovery reports would nevertheless tend to indicate some migration." Although care has been exercised in the selection of data used in the present report, it is probable that some errors escaped detection, hence perhaps maximizing the extent of dispersion.

For most of the years under consideration, there was insufficient information on the distribution of fishing effort to permit its use in the interpretation of tag returns. Yet it is obvious that without such information there are inherent dangers of bias. The likelihood of recapturing a tagged English sole will be biased in favour of areas where fishing effort for that particular species is highest. Conceivably there could be situations where the direction of migration, as indicated by gross tag returns is the reverse of the true main direction. While such extreme distortions are unlikely in the present case, lack of uniformity in the distribution of fishing effort affects to some extent the patterns of dispersion which have been described.

Jones (1959) notes that movement may be the resultant of two components: (a) a group component showing movement of a group of fish in a particular direction, and (b) an undirected or random component that measures the way movement of any individual departs from the overall directional average. In interpreting the geographical domain of a fish stock, the extremes of the dispersion are frequently represented by solitary tag recoveries. Occasionally these occur, in years subsequent to tagging, during the same month or season as when tags were released. If any of these cases of "extreme" migration are the result of random movement, their presence in gross analysis of dispersion tends to exaggerate the geographic limits of a stock.[2]

[2]Two example of possible random movement that are extreme are: (1) an English sole tagged off French Creek, Strait of Georgia, in September 1951 was recovered in October 1952 off Eureka, California, (2) an English sole tagged on the Goose Island grounds in May 1952 was recovered off Crescent City, California, in March 1953.

Stock Units in Canadian Waters

Catch statistics on the English sole fishery along the Canadian coast alone point to the existence of two major stocks — one in northern Hecate Strait (Area 5D) the other in the Strait of Georgia (Area 4B) (Table 1). This is supported by evidence from tagging as no exchange was noted between the two areas.

Taylor (1957) concluded from a study of meristic characters that there were at least two major groups of English sole off the British Columbia coast — a Strait of Georgia group and an offshore group extending from northern Hecate Strait to the Washington coast. However, he acknowledged the probable existence of relatively discrete units within the major groups. On the basis of tag returns, relatively discrete units appear to exist in northern Hecate Strait, Queen Charlotte Sound, Queen Charlotte Strait area and in at least three localities in the Strait of Georgia. Some of these units appear to have a highly mobile (random?) component which mingles with stocks off the United States coast.

Taylor also considered that English sole which inhabited the eastern end of Juan de Fuca Strait were part of a second offshore group extending southward to the Oregon-California border. Tagging results suggest that at least some of the English sole in the Victoria area are associated with this southern group. More recently it has been suggested that the latter may be composed of two groups, one centred in the Cape Flattery-Columbia River area and the other in the Cape Blanco-Cape Mendocino area off the United States (Anon., 1961).

Evidence of Intermingling with Stocks off the United States Coast

From all taggings conducted along the Canadian coast, only 69 recaptures (1.1%) were made in waters adjacent to the open coast of the United States (Table 2). Relatively high percentages, however, were recorded from taggings conducted close to the international boundary — west coast of Vancouver Island, 51.6%; Strait of Juan de Fuca, 46.9%. Similarly, in inshore waters (Strait of Georgia) highest returns from the United States (20.7%) were recorded from the tagging conducted near the Fraser estuary (Table 3). Most of the recaptures in waters off the open coast of the United States were made during the winter months and in the Cape Flattery-Destruction Island area, where spawning is known to occur. Some individuals from taggings conducted in Hecate Strait, Queen Charlotte Sound and the Strait of Georgia were also recaptured there.

Migration and the Sex of Migrants

Recovery information suggests that extensive migrations are more characteristic of female English sole than of males. Of 20 tagged English sole which had shown extensive migrations (i.e., from Hecate Strait, Queen Charlotte Sound or the Strait of Georgia to offshore United States waters) 16 were females. There was no such imbalance in the sex ratio of total recoveries from taggings in which these fish were released. Overall recoveries ranged from approximately 1:1 to no more than 1.3:1 in favour of females.

This same phenomenon has been noted by Best (1963) for petrale sole *(Eopsetta jordani)* tagged off California and by Westrheim and Morgan (1963) for Dover sole *(Microstomus pacificus)* tagged off southern Washington.

Directive Factors in Migration

There is some evidence that distribution and movement of English sole off the British Columbia coast may be influenced by water circulation. Ketchen (1956) suggested that distribution of juvenile English sole (age group 0) in northern Hecate Strait is governed by drift of pelagic eggs from some region to the south of the rearing area. He also showed, through tagging, a northward post-spawning migration of adult English sole in early spring months and a southward return of adults in the early fall. In Hecate Strait, there is a net northerly flow of water which is best developed during the winter months (Crean, 1967). This fact, together with the tagging information, suggests a contranatant (upstream) southerly pre-spawning migration of English sole in northern Hecate Strait and hence a post-spawning downstream northerly movement to summer feeding grounds.

In the Strait of Juan de Fuca the English sole tagging of April 1960 showed movement of adult fish to the area just outside and south of the entrance to the Strait. Herlinveaux and Tully (1961) have demonstrated that there is a tidal "pump effect" which forces ocean waters eastward along the bottom of Juan de Fuca Strait to the Strait of Georgia. If the spawning migration is contranatant, this inward flow would direct winter migration of English sole out of the Strait of Juan de Fuca. There remains, of course, the question of how English sole are replenished in the Strait, presuming that such is the case. They may swim downstream or drift passively with the bottom current and be carried back into the Strait.

Within the Strait of Georgia, the two populations of English sole found along the western shore of the Strait (Cape Lazo-French Creek; Boat Harbour-Satellite Channel) tend to disperse southward from their main spawning grounds. Although the mechanics of circulation are known to be complex and variable, Waldichuk (1957, p. 480) suggests that there is a net counterclockwise circulation in the Strait of Georgia, which supports the hypothesis of a downstream, post-spawning migration.

On the eastern side of the Strait (off the Fraser River estuary) results of tagging suggest a southward, post-spawning movement from Point Atkinson to the Fraser estuary and further south into United States waters. The mechanics of water circulation in this region are complex and highly variable. For this reason and also for lack of information on the biology of English sole in waters south of the international boundary, it is impossible to say whether fish movements are in accord with the above-mentioned hypothesis.

In addition to the observed latitudinal migrations, the English sole is known to engage in seasonal bathymetric movements of moderate extent. In summer, adults occur at depths approximately 20 fathoms (37 metres) shallower than they do in winter (Ketchen, 1956; Alverson, 1960). This is further supported by observations from tagging. For example, in the Cape Lazo-French Creek area of the Strait of Georgia, most of the summer taggings were conducted in shallow water (less than 20 fathoms in depth) and succeeding winter recaptures were made on the Cape Lazo spawning ground where the mean depth was 42 fathoms or 77 metres (Ketchen, 1950).

SUMMARY

1. Between 1944 and 1961, approximately 25,000 English sole were tagged and released in British Columbia waters. Most of the tagging took place in the Strait of Georgia and northern Hecate Strait, the principal trawling areas for English sole.
2. Approximately 6,500 recaptures (with usable information on locality) have been reported. Of these only 1.1% indicated movement to waters off the United States coast (exclusive of recoveries in the Strait of Georgia). Taggings conducted near the

international boundary yielded the highest returns from United States waters, but none of these taggings was in localities supporting significant Canadian fisheries.

3. Most of the recaptures off the open coast of the United States were in the region between Cape Flattery and Destruction Island, Washington, where spawning is known to occur in winter months.
4. Tagging results, supported by results of meristic studies and the geographical distribution of catch, suggest there are two major stocks of English sole in British Columbia waters: one in Hecate Strait and the other in the Strait of Georgia. Within the latter area there appear to be three sub-stocks or populations. Minor populations occur in other regions of the coast, such as Queen Charlotte Sound and various coastal inlets.
5. In light of available information on water circulation, there is support in the tagging results for the hypothesis that the English sole engages in contranatant (upstream) migrations to various spawning areas.

ACKNOWLEDGMENTS

The cooperation of British Columbia and United States trawl fishermen in conscientiously recording their tag recoveries is greatly appreciated. A large number of these tags were processed through the office of the Board's liaison officer in Vancouver, Mr. R. M. Wilson.

Thanks are due to Dr. K. S. Ketchen for his efforts in tagging a high proportion of these English sole and for his critical review of the manuscript.

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Dispersal of English Sole, *Parophrys vetulus* Tagged off the Washington Coast in 1956

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BULLETIN 7

PACIFIC MARINE FISHERIES COMMISSION
Portland, Oregon

1969

DISPERSAL OF ENGLISH SOLE, *Parophrys vetulus*, TAGGED OFF WASHINGTON COAST IN 1956

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ABSTRACT

In an attempt to define the migration and distribution patterns of a commercially important concentration of English sole along the northern Washington coast, a total of 862 fish were tagged between LaPush and Destruction Island. The tagging was done during a 10-day period, between July 23 and August 1, 1956. A total of 85 English sole or 9.9% of the fish tagged was recovered over a 6-year period following tagging. Recoveries exhibited a southerly movement during the winter months. No migrations were noted north of the general tagging area.

INTRODUCTION

The English sole, *Parophrys vetulus* Girard, is a major contributor to the Washington trawl fishery. Intensive fishing for this species occurs throughout the year off the northern Washington coast between Cape Flattery and Destruction Island. During the summer of 1956, a limited tagging experiment was conducted in an effort to determine the migratory and distribution patterns of these fish. This report is an expansion of a summary presented in the Thirteenth Annual Report of the Pacific Marine Fisheries Commission for the Year 1960.

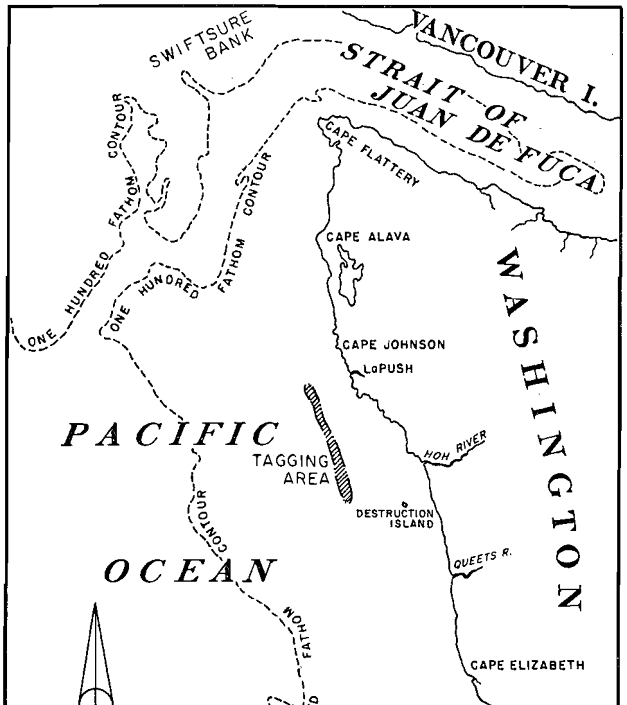

FIGURE 1. English sole tagging area — July 23 to August 1, 1956.

METHODS AND MATERIALS

The University of Washington College of Fisheries research vessel *COMMANDO* was chartered for a 10-day period extending from July 23 to August 1, 1956. A standard 400-mesh eastern trawl, with a mesh size of 4.5 inches throughout, was used to obtain specimens for tagging. A total of 45 drags, lasting from 1 to 1.5 hours each, was made in the area between LaPush and Destruction Island at a depth of 18 to 34 fathoms (Figure 1). English sole were sorted from the catches and placed in a holding tank on deck. Fresh sea water was pumped periodically into the tank to keep the fish as healthy as possible during the tagging operation.

A total of 862 English sole was tagged and released. Of these, 647 were tagged with yellow vinyl plastic tubing, and the remaining 215 were tagged with nylon leader which held a white plastic sleeve. Both tag types were serially numbered for identification.

The tags were applied to the fish on the anteroventral edge of the caudal peduncle. The plastic tubing was slipped over the butt end of an aluminum knitting needle, strung through the fish, cut to the desired length, and tied off with a figure-8 knot. Groups of 25 tags, each tag attached to a needle, were kept ready for application by using corks as pincushions. Both tags were applied to the fish in the same manner, but due to the smaller diameter of the nylon leader a hypo-

TABLE 1
Recoveries from 862 Tagged English Sole Listed by PMFC Trawl Statistical Areas and Years of Capture.

PMFC Area	YEAR 1956	1957	1958	1959	1960	1961	Total
3B	6	26	16	6		1	55
3A		3					3
2D	1	5	1	1			8
2C		1	3	2			6
2B			2				2
2A							
1C		1	1				2
1B							
1A							
Unknown		4	1	4			9
Total	7	40	24	13		1	85

dermic needle was used to string the tag in place. Both types were relatively slow to apply and required considerable care to keep them in order.

The majority of tag returns were received from trawl fishermen and fish-house filleters. A reward of $0.75 was sent to the finder of each tag returned, along with a letter of appreciation containing area and time of release information.

RESULTS

The 862 English sole tagged averaged 335 mm in length, with a range from 180 to 620 mm (Figure 2). A total of 85 English sole or 9.9% of the fish tagged was recovered over a period of 6 years following tagging. Recoveries ranged from Cape Flattery south to off the Klamath River on the northern coast of California (Figure 3). Recoveries are listed by Pacific Marine Fisheries Commission trawl statistical areas and years of capture (Table 1).

The longest migration was 370 nautical miles south of the tagging site to the area off the Klamath River, California (PMFC Area 1C). The majority of the tag recoveries (64.7%) occurred within the immediate area of tagging or at least within PMFC Statistical Area 3B. Twenty-one fish, or 24.7% of the recoveries, occurred south of the tagging area. There were no authenticated recoveries north of Cape Flattery.[1]

Table 2 summarizes the recoveries of English sole by PMFC trawl statistical areas and months of capture.

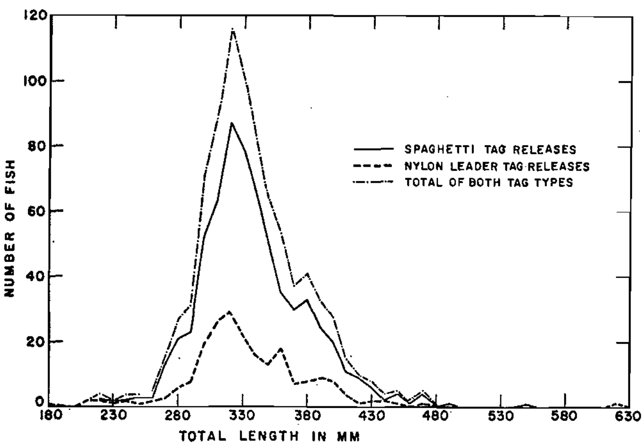

FIGURE 2. Length frequency of tagged English sole released between LaPush and Destruction Island (1956).

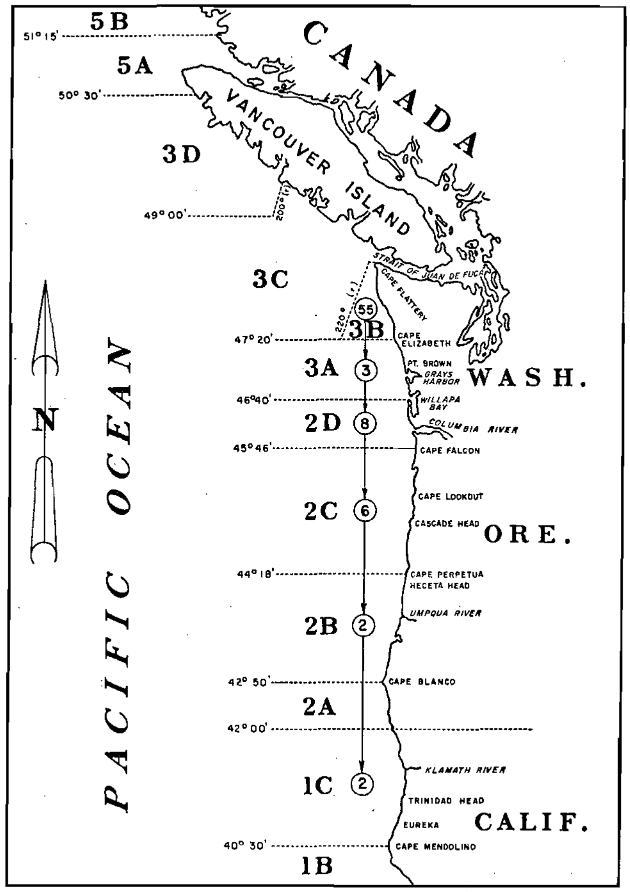

FIGURE 3. Dispersal of English sole tagged off the Washington coast in July, 1956, and diagram of Pacific Marine Fisheries Commission trawl statistical areas. Numerals in circles indicate number of recoveries in each area.

TABLE 2

Recoveries from 862 Tagged English Sole Listed by PMFC Trawl Statistical Areas and Months of Capture, 1956 through 1961 combined.

PMFC Area	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
3B	1	8	2	6	2	3	14	8	3	4	2	2	55
3A		2		1									3
2D		2		1	1				1	3			8
2C				1	1	1				2		1	6
2B	1									1			2
2A													
1C	2												2
1B													
1A													
Total	4	12	2	9	4	4	14	8	4	10	2	3	76

[1]It was reported in the Thirteenth Annual Report of the Pacific Marine Fisheries Commission, that a tagged English sole from among those released between La Push and Destruction Island, was recovered ". . . from the Cape Scott area off northern Vancouver Island." This recovery has since been disproved. The actual recovery of this fish occurred within the original tagging area.

All the years in which recoveries were made were combined to permit an analysis of monthly recoveries by area. A seasonal pattern of recoveries is demonstrated and appears to be similar from year to year (Figure 4). The longest migrations, those south of PMFC Area 2C, occurred during winter months (December through February). Recoveries made between Cape Elizabeth, Washington and Cape Perpetua, Oregon (PMFC Areas 3A, 2D and 2C), occurred during the spring and fall. No tag recoveries were made during the summer months of July and August south of the tagging area. Tag recoveries were made during all months within the tagging area. Coastwide fishing activities during recovery years were considered to be intensive enough to reflect any major migratory movements of the tagged fish.

DISCUSSION

The English sole tag recoveries exhibited a southerly movement. It also appears that certain numbers of English sole in the LaPush-Destruction Island area remain on these grounds during the entire year. Those that moved to more southerly grounds did so during the fall months. Recoveries of these tagged fish indicate

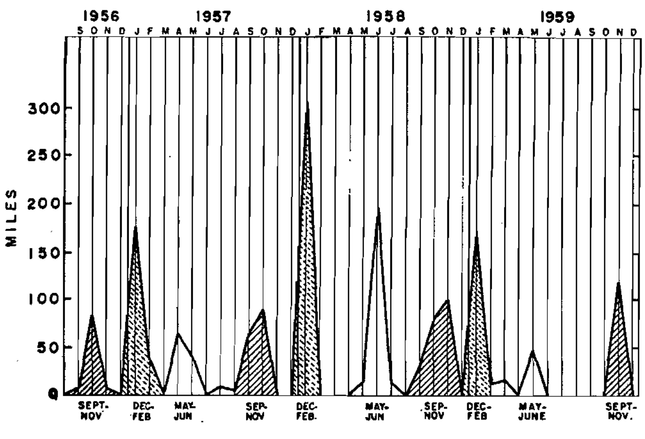

FIGURE 4. Average distance from tagging area by month and year for English sole tagged between LaPush and Destruction Island, July, 1956 (modes are shaded differently to show seasonal pattern by year and time of year).

that their return migration northward occurred in the spring.

Tagging by the Oregon Fish Commission in April, 1959, showed that English sole off the central Oregon coast moved both southerly and northerly, with the movements to the north most frequent (Anon. 1960). Numbers of these English sole were recovered along the Washington coast during all seasons of the year. The principal area of mixing for the Oregon and Washington tagged groups of fish was between Cape Lookout, Oregon, and Destruction Island, Washington. Mixing as indicated from the tag recoveries occurred throughout the year.

Results from tagging done by the California Department of Fish and Game in November and December of 1958 off Eureka, California showed only minor mixing of English sole from California coastal waters with those from Washington and Oregon waters *(ibid.)*.

It can be concluded that a portion of the English sole which were available between Cape Flattery and Destruction Island during the time of tagging (1956) migrated southward. This southerly movement occurred during the fall and winter months. Tag recoveries indicate that these fish returned to northern waters during the spring and summer. The principal direction of migration was south along the northern Oregon coast although a portion of this migratory group continued as far south as northern California.

Recoveries of tagged fish north of the tagging area indicated that the northward movement of these fish occurred only as far as Cape Flattery (within PMFC Area 3B). All recoveries of tagged fish were made on the continental shelf in waters less than 100 fathoms deep.

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Results of English Sole Tagging off California

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BULLETIN 7

PACIFIC MARINE FISHERIES COMMISSION
Portland, Oregon

1969

RESULTS OF ENGLISH SOLE TAGGING OFF CALIFORNIA

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INTRODUCTION

English sole (*Parophrys vetulus* Girard) are distributed from bays and estuaries to depths of about 200 fathoms between Baja California, Mexico, and Alaska. They support commercial fisheries between Santa Barbara, California, and Hecate Strait, British Columbia.

A knowledge of migrations and population structure of English sole off California and the rest of the Pacific Coast is required for management recommendations. To provide this information, a tagging program was initiated by the California Department of Fish and Game in 1936. The final experiment was completed in 1963. This report presents the results of this tagging program.

HISTORY OF THE ENGLISH SOLE FISHERY

English sole has been one of the major species supporting the trawl fishery since 1876, when a pair of lateen sailboats began paranzella trawling in San Francisco Bay. Trawling was confined to the bay for several years until fishermen ventured outside the Golden Gate. Power vessels gradually replaced sailboats and paranzella trawling was extended to most coastal areas off California. By 1909, trawling was conducted off Bodega Bay, San Francisco, in Monterey Bay, off Santa Barbara, San Pedro, and San Diego. The San Pedro and San Diego trawl fisheries were eliminated by legislative acts of 1913 and 1915. Trawling in the Santa Barbara area has been conducted on an irregular basis. No regular fishery occurred there between 1924 and 1945.

Beginning in 1929, paranzella trawlers began to fish during summers off Fort Bragg and Eureka, and by the mid-thirties, waters between Monterey and the Oregon border to 100 fathoms were well fished (Clark, 1935).

Otter trawling largely supplanted paranzella trawling by 1940 and the center of trawling activity was shifted from San Francisco to Eureka. In 1945, trawling operations were extended to the Morro Bay area and the Santa Barbara fishery was re-activated. Trawling was extended to depths of 200 fathoms in 1948 (Holmberg, 1948). Shortly thereafter, English sole were harvested by the trawl fleet in a major portion of their bathymetric and coastwise range off California except within 3 miles of shore and in the southern part of the State where trawling was prohibited.

Trawl catch records from 1924 to 1965 show fluctuations between 2 and nearly 9 million pounds in the annual English sole catch. The peak year was 1929 when 8,764,970 pounds were landed from old grounds as well as new areas off Fort Bragg and Eureka. In 1942, during World War II, landings dipped to 2 million pounds, but thereafter, annual landings increased until over 8 million pounds were recorded for 1948 and 1950. Concurrent with the rise in prominence of the Dover sole fishery, annual English sole landings declined and since 1950 have averaged about 4.3 million pounds per year (Table 1). For further historical details of the California trawl fishery, see Clark (1935), Scofield (1948), and Hagerman (1952).

Geographical boundaries of fishing areas considered in this report are located as follows: (1) southern Oregon, Cape Blanco to California-Oregon border; (2) Eureka, Oregon border to Cape Mendocino; (3) Fort Bragg, Cape Mendocino to Point Arena; (4) San Francisco, Point Arena to Pigeon Point; (5) Monterey, Pigeon Point to Point Piedras Blancas; (6) Morro Bay, Point Piedras Blancas to Point Conception; and (7) Santa Barbara, Point Conception to Point Dume. These

TABLE 1
Annual California English Sole Landings
1924-1965

Year	Pounds Landed	Year	Pounds Landed
1924	7,696,431	1945	2,360,271
1925	7,481,009	1946	5,431,439
1926	7,157,337	1947	4,336,787
1927	8,649,164	1948	8,165,818
1928	7,588,298	1949	5,664,294
1929	8,764,970	1950	8,045,269
1930	6,757,589	1951	5,624,269
1931	3,482,961	1952	4,909,549
1932	6,435,883	1953	4,098,997
1933	6,089,986	1954	3,748,941
1934	5,181,067	1955	4,134,779
1935	5,880,039	1956	3,824,952
1936	6,180,549	1957	4,819,872
1937	5,616,133	1958	5,150,234
1938	4,724,651	1959	4,617,491
1939	5,102,647	1960	2,375,383
1940	5,012,739	1961	3,645,918
1941	3,233,351	1962	4,206,048
1942	2,005,430	1963	4,259,545
1943	2,968,057	1964	4,592,752
1944	2,841,902	1965	4,892,040

fishing areas are situated in PMFC statistical areas 2A, 1C, 1B, and 1A (Figure 1).

English sole grounds off San Francisco have been productive throughout the history of the fishery. Since 1929, grounds off Fort Bragg and Eureka have produced substantial poundages, and in the past decade Santa Barbara landings have become an important part of the total California catch. Between 1961 and 1965, catches from areas off San Francisco and Eureka have comprised, respectively, about 43 and 28% of the total annual catch. During this period, catches in the Santa Barbara, Monterey, Fort Bragg, and Morro Bay areas contributed 11, 8, 7, and 3% of the annual catch, respectively.

The importance of the various grounds off California and southern Oregon becomes evident when we analyze the origin of the catches from the different California Fish and Game block areas (10-minute rectangles). The catch originates from virtually the entire coastal area between Santa Barbara and southern Oregon with areas of high productivity located off Eureka, San Francisco, and Santa Barbara (Figure 1).

TAGGING EXPERIMENTS

A total of 9,065 English sole was tagged and released between 1936 and 1963 in major fishing areas off California. The various experiments ranged in scope from single incidental releases to the release of a group of 3,940 tagged fish. During this period, minor releases of 113, 2, and 123 tagged English sole were made off

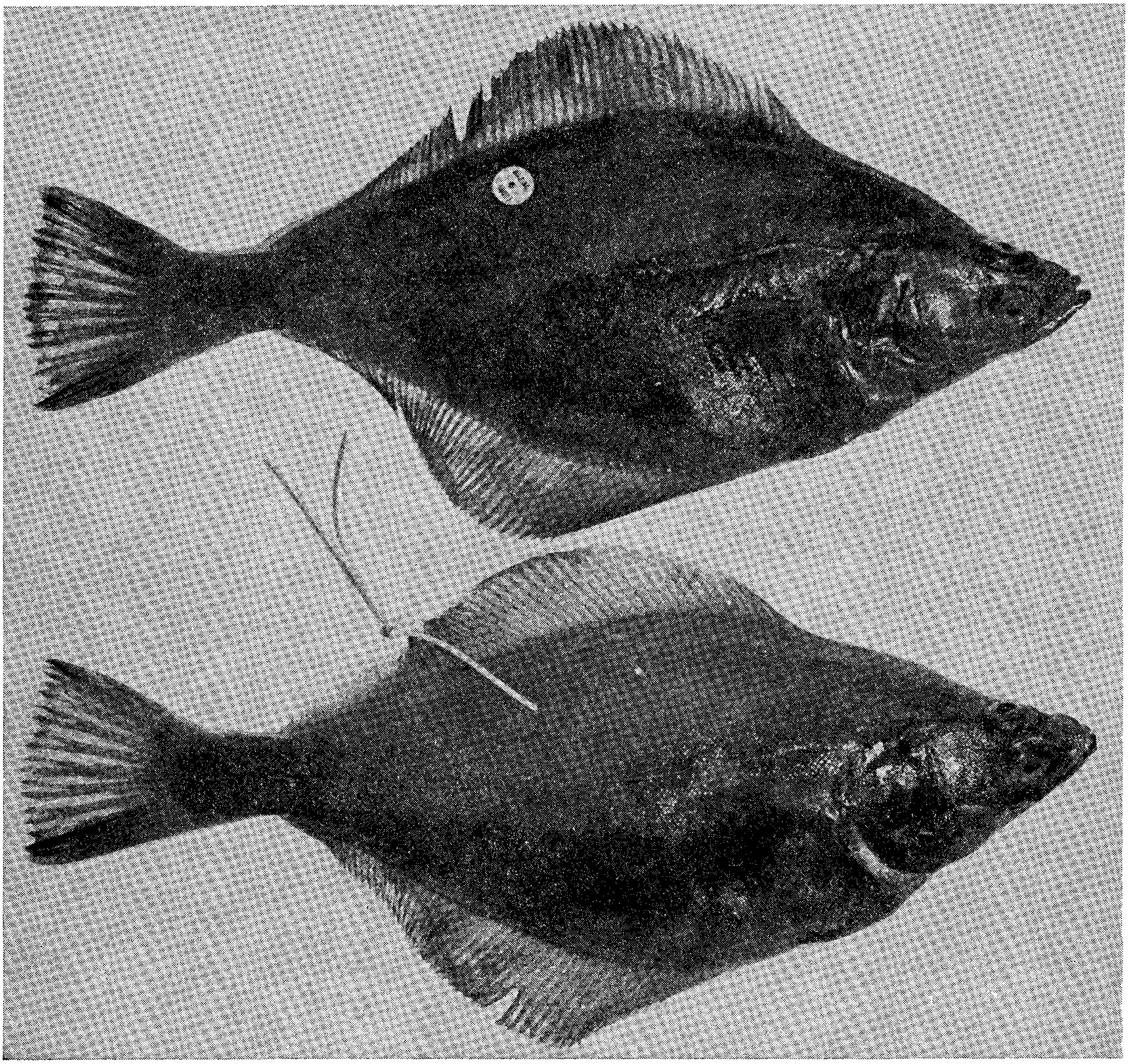

FIGURE 2. English sole tagged with disc and spaghetti tags. Photograph by Paul A. Gregory.

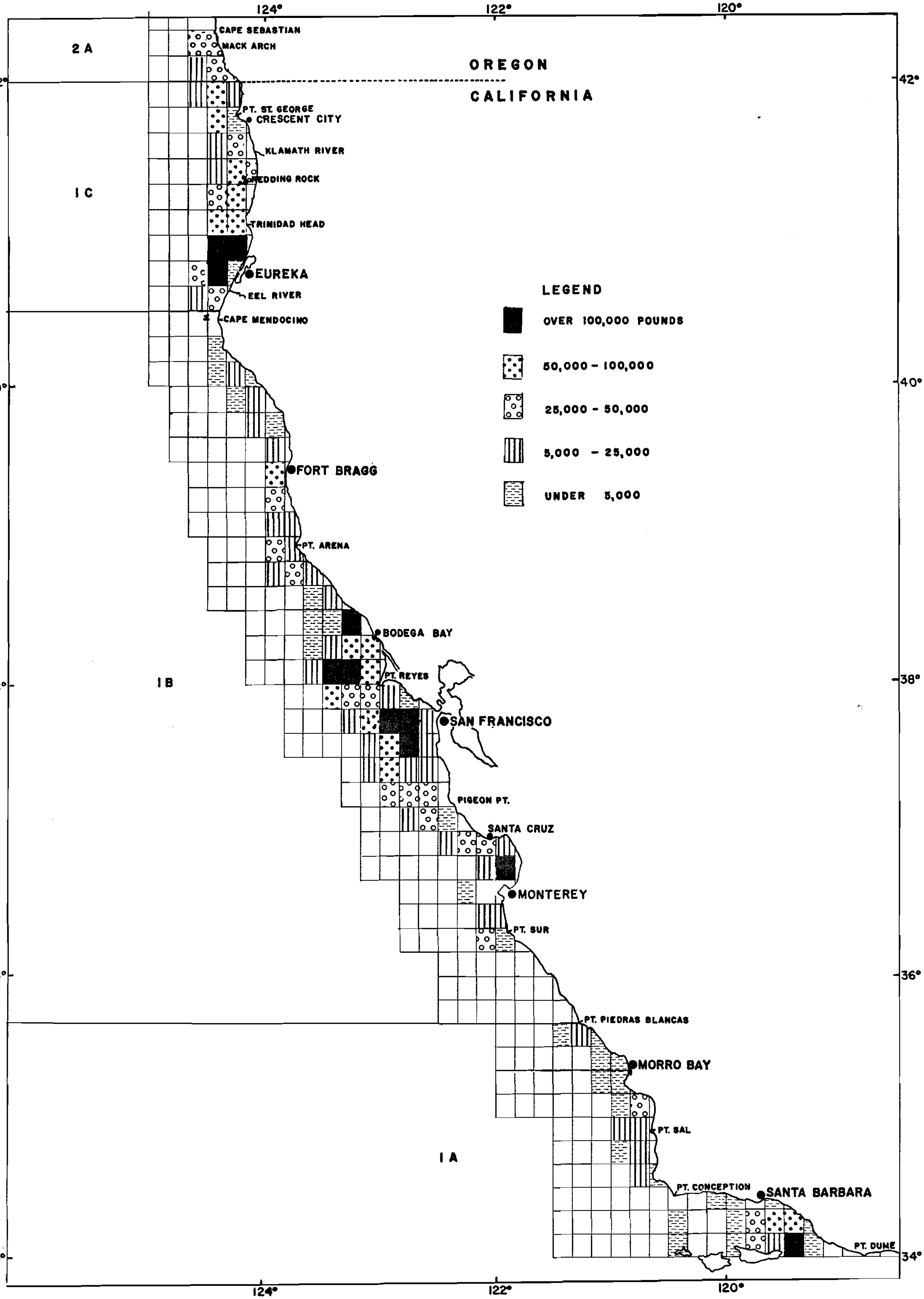

FIGURE 1. PMFC statistical areas and average annual catch for 1961-1965 of English sole in California Fish and Game blocks (10' rectangles) off California and southern Oregon.

Santa Barbara, Morro Bay, and Monterey, respectively. Respective numbers of tagged English sole released in the San Francisco, Fort Bragg, and Eureka areas were 2,097, 1,135, and 5,595 (Table 2).

MATERIALS AND METHODS

All tagging was done aboard Department research vessels. Tagging prior to 1938 was accomplished aboard the *Albacore*. The *N. B. Scofield* was used for tagging between 1939 and 1959, while in 1963 tagging was done aboard the *Alaska*.

English sole captured during short tows with otter or beam trawls were placed in portable tubs containing circulating sea water. Viable fish were dipped from the holding tubs, measured, tagged, and immediately released.

Petersen disc tags fastened with nickel or silver pins were used prior to 1958; thereafter, a modified type G, vinylite spaghetti tag of the design described by Blunt and Messersmith (1960) was used. Tags were applied through the dorsal musculature in the posterior part of the fish (Figure 2).

Tags were returned by fishermen and fish processors. Since no rewards were paid for tag recoveries prior to 1963, Department biologists personally informed trawler captains and processors of the tagging programs to stimulate interest and enlist cooperation. Letters of information and commendation cards bearing the tagging history of each recovery were sent to persons who returned tags. In 1958, when numerous tag returns made the notification of each tag finder impossible, tagging summaries describing preliminary results were issued periodically to all interested persons. In 1963 a reward of $1 was offered for each tag recovery.

MOVEMENTS OF TAGGED ENGLISH SOLE

PMFC Area 1A

Santa Barbara area

A total of 113 tagged English sole was released in the Santa Barbara Channel in December 1963. Eight (7%) from this release were recaptured within 10 miles of the release areas between June 1964 and December 1965 (Figure 3). However, it is possible some fish moved southward to areas closed to trawling or to areas immediately north of Point Conception where the chances for recovery were fewer because of less fishing effort. Considerably more fishing effort occurs in the Santa Barbara area than in the area between Point Conception and Point Piedras Blancas, the northern boundary of PMFC Area 1A.

Morro Bay area

Concurrent with Santa Barbara tagging in December 1963, two English sole were tagged and released off Point Sal. One of these was caught in February 1964 near Bodega Bay in PMFC Area 1B, 210 miles north of the release area and 69 days after tagging (Figure 3).

This recovery, showing distant movement at the rate of over 3 miles a day, is of considerable interest. One return is obviously inadequate for any definitive conclusions on fish movements.

PMFC Area 1B

Monterey area

In the Monterey area, 123 tagged English sole were released between 1936 and 1950.

December 1936. Sixteen English sole were tagged and released in shallow water near Santa Cruz. There was 1 recovery near the area of release in April 1937.

April 1937. Forty-five tagged English sole were released in 20 fathoms near Monterey. There were 9 recoveries. Six were caught in the release area between

TABLE 2
Numbers of Tagged English Sole Released off California by Area and Date, 1936-1963

	PMFC Area						
	1A		1B			1C	
Month and Year	Santa Barbara	Morro Bay	Monterey	San Francisco	Fort Bragg	Eureka	Total
Nov-Dec 1936			16				16
April 1937			45				45
August 1938					1	398	399
Mar-Apr 1939			38	30			68
Jul-Aug 1940				744	1,103	846	2,693
Oct-Nov 1949				923	28	402	1,353
July 1950			5	200	2	9	216
October 1950			19		1		20
Nov-Dec 1958				97		3,940	4,037
March 1959				103			103
December 1963	113	2					115
Total	113	2	123	2,097	1,135	5,595	9,065

April 1937 and May 1938. Two were caught during March and April 1938 near Santa Cruz. The remaining recovery was made in April 1938, 50 miles north of the release area near Point San Pedro.

March 1939. Thirty-eight English sole were tagged in 12 to 18 fathoms of water near Santa Cruz. A recapture in the tagging area in June 1939 was the only recovery.

July 1950. None of 5 tagged English sole released near Davenport was recovered.

October 1950. Nineteen English sole were tagged and released in 30 to 35 fathom depths north of Monterey. One was caught over a year-and-a-half after release in April 1952 near the tagging site.

TABLE 3

Recaptures of English Sole Tagged in Monterey Bay, 1936-1950, by Month and Distance from Release Areas

Month	Area of Recovery		Total
	Monterey Bay 0-25 miles	San Francisco 50 miles	
January	1		1
March	2		2
April	5	1	6
May	3		3
TOTAL	11	1	12

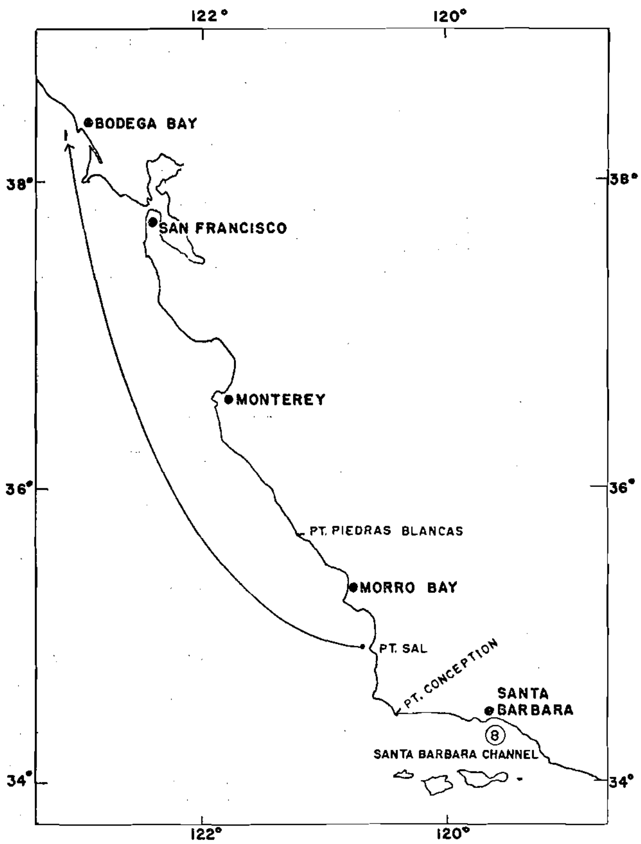

FIGURE 3. Localities of capture for English sole tagged off Point Sal and Santa Barbara in December 1963. Enclosed numeral represents recaptures in the tagging area.

Summary of movements of English sole tagged in Monterey area

Eleven of the 12 recoveries from the combined release of 123 English sole were from the areas of tagging, while 1 moved 50 miles to the open coast near Point San Pedro (Table 3, Figure 4). No opportunities, prior to 1945, existed for recaptures south of the tagging area for fished tagged between 1936 and 1939 if southward movements occurred, as no trawling was conducted south of Monterey until 1945.

San Francisco area

A total of 2,097 English sole was tagged and released between Fort Ross and Pigeon Point between 1939 and 1959.

April 1939. Thirty English sole were tagged in shallow water in Drakes Bay. Only 4 (13%) of the 30 were recovered. During October 1939, one was recaptured near Bodega Bay and another in Monterey Bay. A third was caught at Cordell Bank in January 1940, while the final return was captured off Bodega Bay in May 1941.

Only the Monterey recovery indicated a significant movement of 90 miles. The other returns were caught within 35 miles of the release site.

July-August 1940. A group of 744 tagged English sole was released in shallow depths of Drakes Bay. There were 23 recoveries (3%) from this group. Between September 1940 and December 1941, 13 were

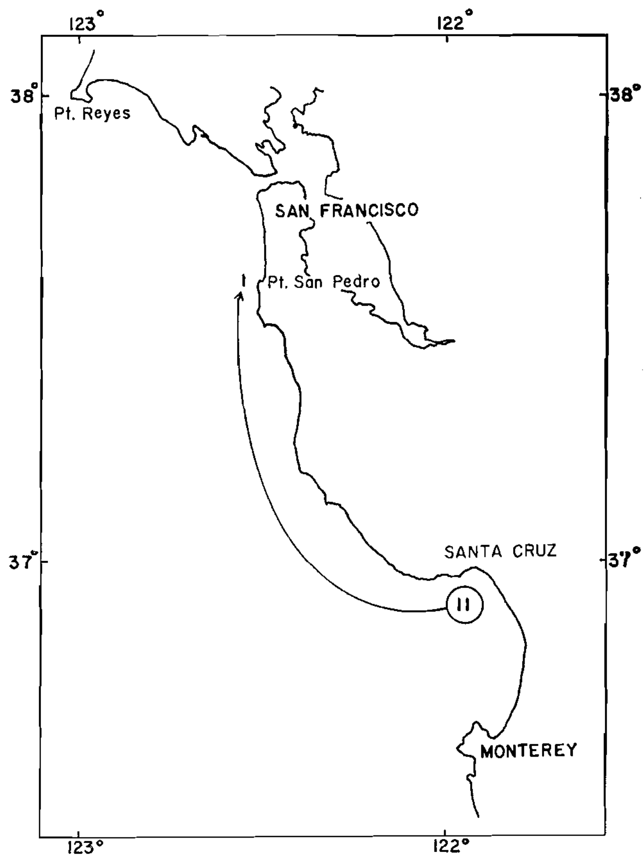

FIGURE 4. Localities of capture of English sole tagged in Monterey Bay, 1936 to 1950. Enclosed numeral represents recaptures in the tagging area.

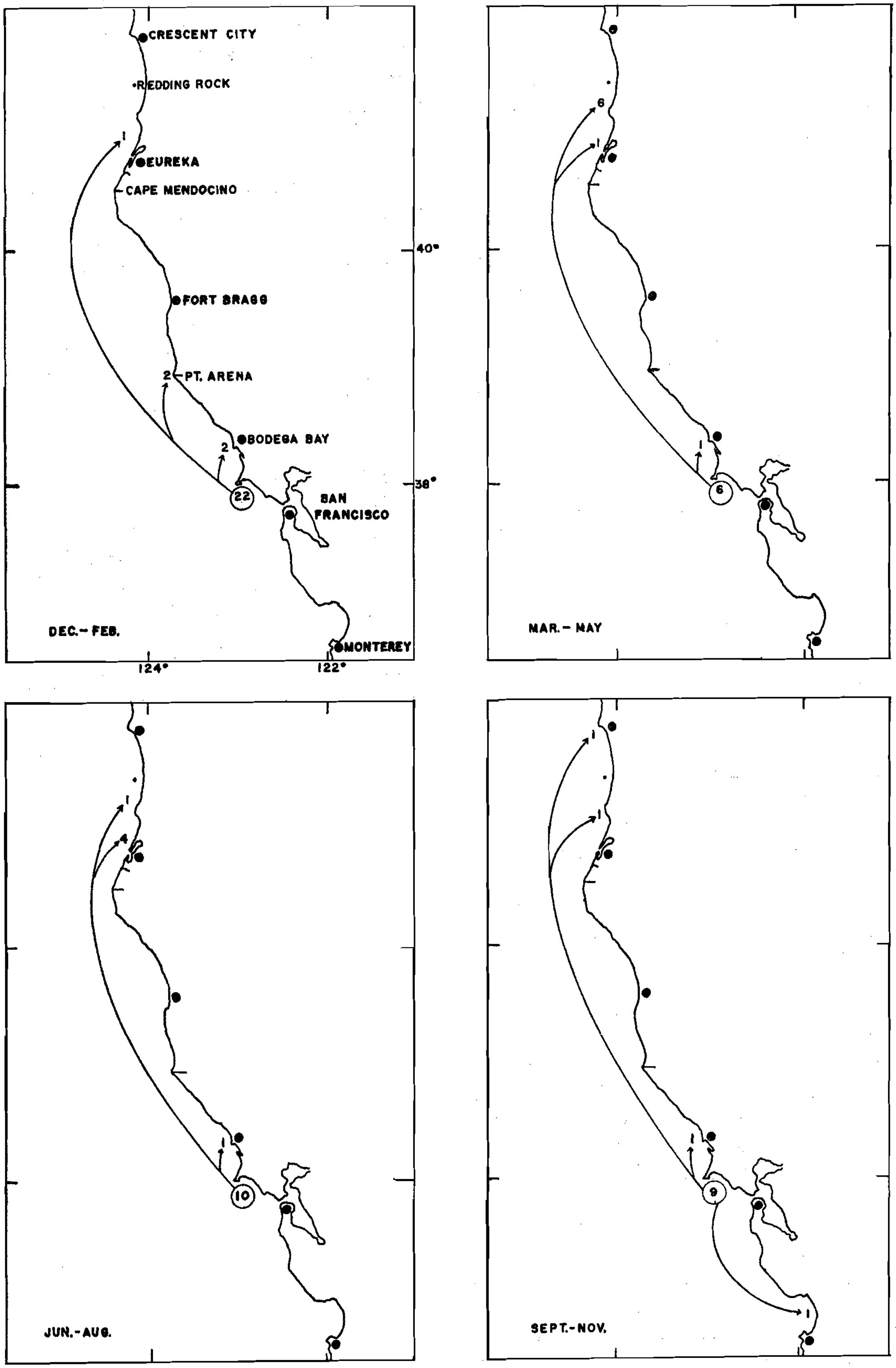

FIGURE 5. Localities of capture by season regardless of year for English sole tagged off San Francisco, 1939 to 1959. Enclosed numeral represents recaptures in the tagging area.

recaptured within 25 miles of the release area. One tagged fish was taken in February 1941 off Point Arena, 70 miles north of the release site. Seven were caught 200 miles north in PMFC Area 1C off Eureka between December 1940 and June 1942. Two recoveries were returned without catch information.

November 1949. At several locations between Drakes Bay and Point San Pedro, 923 tagged English sole were released in depths of 10 to 60 fathoms. There were 34 tag returns from this group. Thirty-two (3.4%) were recaptured between January 1950 and October 1951 near their release sites. The majority of these returns showed no movements, while 8 moved distances between 15 and 40 miles. Unfortunately, the date for 1 return, caught 100 miles north of Fort Bragg, is unknown. Another tagged fish was taken in Area 1C off Eureka, 200 miles north, during July 1950.

July 1950. In the Drakes Bay area, 200 tagged English sole were released in depths between 10 and 40 fathoms. Five (2.5%) were recaptured. Four were recaptured near release sites between January 1951 and February 1953. The fifth was recovered 85 miles north of the release area off Point Arena in December 1951.

December 1958. Ninety-seven tagged English sole were released in 47 fathoms off Point Reyes. A total of 6 tagged fish (6.1%) were recaptured in Area 1C between Eureka and the Oregon border, 200 to 270 miles north of Point Reyes between April 1959 and October 1961. Three were caught during April and one each was caught in September and October of 1959. The other return was taken in October 1961.

March 1959. A release of 103 tagged English sole was made off Bodega Bay in 29 to 56 fathom depths. Two tags (1.9%) were recovered in 1959. One fish was recaptured at its release site in April, while the other was caught in Area 1C off Eureka, 200 miles north, in August.

Summary of movements of English sole tagged in the San Francisco area

Seventy-seven tagged English sole were recaptured from the 2,097 released during the 5 San Francisco area experiments. Most of the tagged fish were taken near release areas. Recoveries caught 26 or more miles from release areas exhibited a trend toward northerly movement.

Distances from tagging areas to known recovery locations of 72 tag returns were as follows: 1 was caught 90 miles south near Monterey; 48 were recaptured within 25 miles of release areas; 5 were taken 26 to 50 miles north; 2 were caught off Point Arena, 51 to 75 miles north; another was taken 100 miles north near Fort Bragg; and 15 were captured near Eureka, showing northern movements of 151 to 275 miles (Table 4).

Northward movement into the Eureka area varied among experiments. None of the April 1939 nor July 1950 releases was recaptured off Eureka. Seven (33%) of 21 recoveries with recapture data from the August 1940 release were taken off Eureka. One (3%) of 34 recaptures released in November and December 1949 moved to Eureka. All of 6 English sole recoveries released in December 1958 and 1 of 2 tagged in March 1959 were caught off Eureka. Recaptures in the Eureka area were largely made during the spring and summer months. Twelve of the 15 Eureka recaptures were caught between March and August, while 3 were taken between September and February (Figure 5).

Distant southward movement was indicated by the single recovery off Monterey from the 1939 tagging lot. There is the possibility of greater southward movement that would not be shown by tag recoveries because of the smaller amount or lack of fishing effort in southern areas.

Fort Bragg area

Tagged English sole were released during 5 cruises of Department research vessels during 1938, 1940, 1949, and 1950 in the Fort Bragg area. No tags were recovered from 4 experiments which consisted of release lots ranging from 1 to 28 tagged fish (Table 2).

In August 1940, Department biologists tagged and released 1,103 English sole in 21 to 45 fathoms off Ten-mile River, about 5 miles north of Fort Bragg.

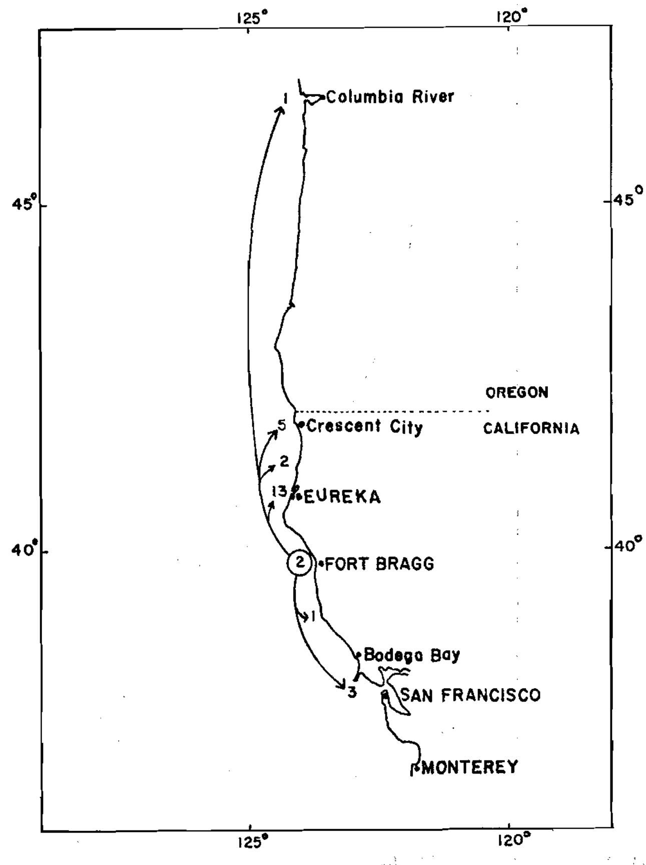

FIGURE 6. Localities of capture for English sole tagged off Fort Bragg in August 1940. Enclosed number represents recaptures in the tagging area.

TABLE 4

Recoveries of English Sole Tagged in the San Francisco Area, 1939-1959, by Month, Area, and Distance from Release Areas

Month and Year of Recovery	Area of Recovery									Total
	1B					1C				
	Monterey	San Francisco			Fort Bragg	Eureka			Unknown	
	Distance in Miles									
	76-100	0-25	26-50	51-75	76-100	151-200	201-250	251-275		
April 1939										
Tagging—30 fish										
Oct. 1939	1		1							2
Jan. 1940		1								1
May 1941			1							1
Total	1	1	2							4
July-August 1940										
Tagging—744 fish										
Sept. 1940		4								4
Dec.		2				1				3
Jan. 1941		2								2
Feb.		1		1						2
Mar.						1				1
Apr.		1					1			2
May							2			2
June		2				1				3
Aug.									1	1
Dec.		1								1
Mar. 1942									1	1
June						1				1
Total		13		1		4	3		2	23
November 1949										
Tagging—923 fish										
Jan. 1950		5							1	6
Feb.		1	1							2
Mar.		2								2
May		1								1
July		5				1				6
Aug.		1	1							2
Sept.		1							1	2
Oct.		1								1
Dec.		3								3
Month unknown		1								1
Jan. 1951		1							1	2
Feb.		2								2
Apr.		1								1
June		1								1
Aug.		1								1
Sept.		1								1
Oct.		2								2
Month unknown					1					1
Total		30	2		1	1			3	37
July 1950										
Tagging—200 fish										
Jan. 1951		1								1
Apr.			1							1
Dec.				1						1
Feb. 1952		1								1
Feb. 1953		1								1
Total		3	1	1						5
December 1958										
Tagging—97 fish										
Apr. 1959							3			3
Aug.							1			1
Sept.							1			1
Oct. 1961								1		1
Total							5	1		6
March 1959										
Tagging—103 fish										
Apr. 1959		1								1
Aug.						1				1
Total		1				1				2
GRAND TOTAL	1	48	5	2	1	6	8	1	5	77

Twenty-seven (2.4%) tagged English sole were recovered. Two were recaptured near the release area: 1 in December 1940 and the other in August 1941. Four were recovered off San Francisco: 1 each was caught in February and December 1941, March 1942, and January 1943. A single recovery was made off the Columbia River in May 1946. This tagged sole was at liberty 2,113 days and had moved 440 miles northward. This was a record for both time at liberty and distance traveled for English sole tagged off California.

While the recaptures do not show a pattern of movement in time and space, they were predominately caught north of the tagging area (Figure 6). Recaptures were made off Eureka during all months between April and December (Table 5). The lack of fishing effort during early months of the year off Eureka precluded recaptures at that time.

From the distribution of tag recoveries, the English sole tagged in the Fort Bragg area appear to be closely allied with those of the Eureka area (Figure 6).

PMFC Area 1C

Eureka area

A total of 5,595 English sole was tagged and released in the area between Cape Mendocino and the Oregon border during the years 1938, 1940, 1949, 1950, and 1958.

August 1938. A group of 398 tagged English sole was released in shallow water near Crescent City.

TABLE 5

Recoveries from 1,103 English Sole Tagged in the Fort Bragg Area in August 1940 by Month, Area, and Distance from the Release Area

Month and Year of Recovery	Area of Recovery 1B			1C			2D	Total
	San Francisco		Fort Bragg	Eureka			Columbia River	
	Distance in Miles 76-100	26-50	0-25	51-75	76-100	101-125	440	
Sept 1940				1				1
Nov				1				1
Dec			1	1				2
Feb 1941		1						1
Apr						1		1
May				1	1			2
June				1				1
July						1		1
Aug			1					1
Sept						1		1
Dec	1							1
May 1942	1							1
June				2		1		3
Sept				2	1			3
Oct				1				1
Jan 1943	1							1
May						1		1
July				2				2
Aug				1				1
May 1946							1	1
Total	3	1	2	13	2	5	1	27

Thirty (7.5%) of these fish were recovered between August 1938 and April 1940. Catch location data were obtained for 28 returns. Three were caught 160 to 260 miles south of the tagging site in the San Francisco fishery between March and June of 1939. Twenty-five were taken in the Eureka area between August 1938 and April 1940 (Table 6).

The tag recoveries from this experiment show a limited movement (3 of 28) to the San Francisco area (Figure 7). Most (25 of 28) were caught in the tagging area. Little trawling occurred off southern Oregon (Area 2A) during the tag recovery period, so there may have been undetected movement to that area.

August 1940. A release of 846 tagged English sole was made in depths of 20 to 30 fathoms at localities near Trinidad Head and Redding Rock.

Sixty-seven (8%) tagged fish were recovered between August 1940 and September 1943. Recaptures were made only during the months between April and December, except for one caught in February from an unknown area. The lack of trawling off Eureka during January through March inhibited recaptures.

While 6 tags were returned without catch information, the majority of recoveries (35 of 61) with recapture information were caught in the release area. Two fish moved southward to Area 1B: 1 was caught 60 miles south of the tagging area off Point Arena; and the other was taken 170 miles south, near Bodega Bay.

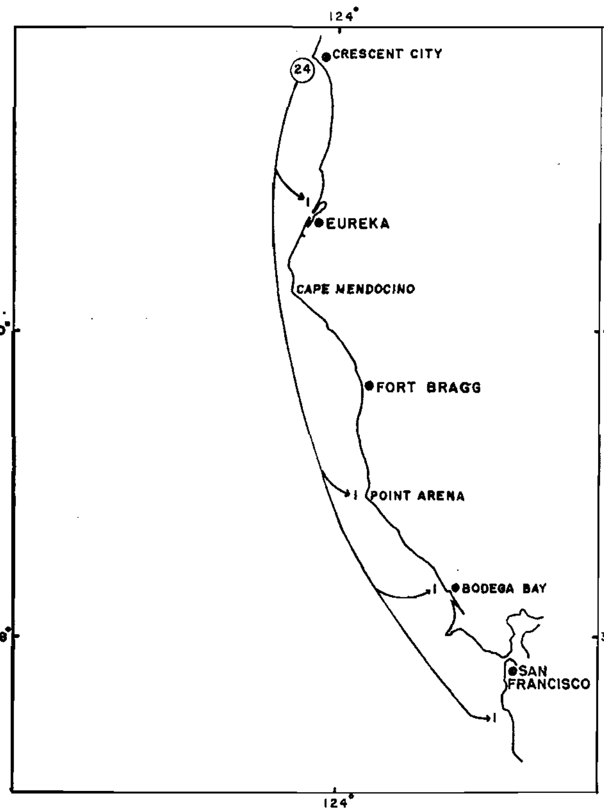

FIGURE 7. Localities of capture for English sole tagged near Crescent City (Eureka Area) in August 1938. Enclosed numeral represents recaptures in the tagging area.

Twenty-three of the tagged English sole were caught 21 to 50 miles north of the areas of release. One fish was recaptured 185 miles north, off Heceta Head, Oregon in Area 2D.

The 61 recaptures with catch information exhibited a northward trend in movement which was most evident during the fall months, September to November (Table 7, Figure 8). The absence of a fishery in southern Oregon (Area 2A) precluded recaptures in that area.

October 1949. A total of 402 tagged English sole was released in depths between 25 and 40 fathoms in the area between the Eel River and Trinidad Head.

There were 83 recoveries, 21% of the 402 released. These were caught between November 1949 and October 1951. Of 70 returns with catch information, there were 11 recaptures in the San Francisco area and 3 in the Fort Bragg area. Fifty-six were caught in the Eureka area (Table 8).

Recaptures showing distant southward movement were taken predominately during fall and winter months (Figure 9) with most recaptures occurring in January. Recoveries in the tagging area occurred during all months, with peak numbers occurring in July and September.

There was no indication of a seasonal trend in the recaptures north of Eureka, as only 9 tagged fish were recaptured 21 to 50 miles north of the release areas (Table 8).

Although by 1950 a substantial amount of fishing effort was being expended during the summer in southern Oregon, Area 2A, there were no recaptures from that area.

July 1950. Nine tagged English sole were released in 24 fathoms northwest of Eureka. One of these was recaptured near Redding Rock in October 1951.

November - December 1958. Releases of 3,940 tagged English sole were made at 2 localities between Eureka and Crescent City. Six fish were tagged and released in depths of 70 to 195 fathoms, 15 miles southwest of Crescent City. The remaining 3,934 tagged English sole were released 10 miles northwest of Eureka in depths between 36 and 65 fathoms. Most of the tagged fish (3,900) were released in 36 to 49 fathoms.

Three of the 6 fish released near Crescent City were recaptured between June and August 1959. One of these was recaptured near Eureka, 50 miles south of the tagging area. The other 2 were recaptured near Redding Rock. All 3 tagged fish had moved inshore to shallow water depths of 36 to 46 fathoms (Figure 10).

A total of 819 (20.8%) tag recoveries was made from the release of 3,934 tagged English sole near Eureka. There were 196 returns without catch information. Tags were returned between December 1958 and September 1963.

The majority, 437 of 623, of tag recoveries with catch locality information, were recaptured within 20 miles of the release area. Recaptures were made in the tagging area each month of the year, with the largest numbers of recoveries occurring between March and June. There were 170 recoveries at localities 21 or more miles north of the release area: 115 were caught in the vicinity of Redding Rock; 40 were caught between the Klamath River and the Oregon border; 13 were caught in PMFC Area 2A in southern Oregon; and 2 were taken between Coos Bay and the Umpqua River in PMFC Area 2B, 150 to 180 miles north of the release area (Table 9).

There were 16 recaptures of tagged fish in localities

TABLE 6

Recoveries from 398 English Sole Tagged in the Eureka Area, August 1938, by Month, Area and Distance from Release Area

Month and Year of Recovery	Recovery Area 1B		1C			Total
	San Francisco		Eureka		Unknown	
	Distance in Miles 225-300	160	50	0-25		
Aug. 1938				3		3
Sept.				12		12
Oct.				2		2
Mar. 1939	1	1	1			3
April				5	1	6
May					1	1
June	1					1
Aug.				1		1
April 1940				1		1
Total	2	1	1	24	2	30

TABLE 7

Recoveries from 846 English Sole Tagged in the Eureka Area, August 1940, by Month Regardless of Year, Area, and Distance from Release Area

Month	Recovery Area 1B	1C					2B		Total
	San Francisco	Fort Bragg	Eureka				Heceta Head	Unknown	
	Distance in Miles 170	60	0-20	21-30	31-40	41-50	185		
Jan.									
Feb.								1	1
Mar.									
Apr.			2					1	3
May			11	1					12
Jun.	1		4	2	2				9
Jul.			2						2
Aug.			1					1	2
Sep.			7	1			1	1	10
Oct.			1	5		3			9
Nov.		1	4	9					14
Dec.			3					2	5
Total	1	1	35	18	2	3	1	6	67

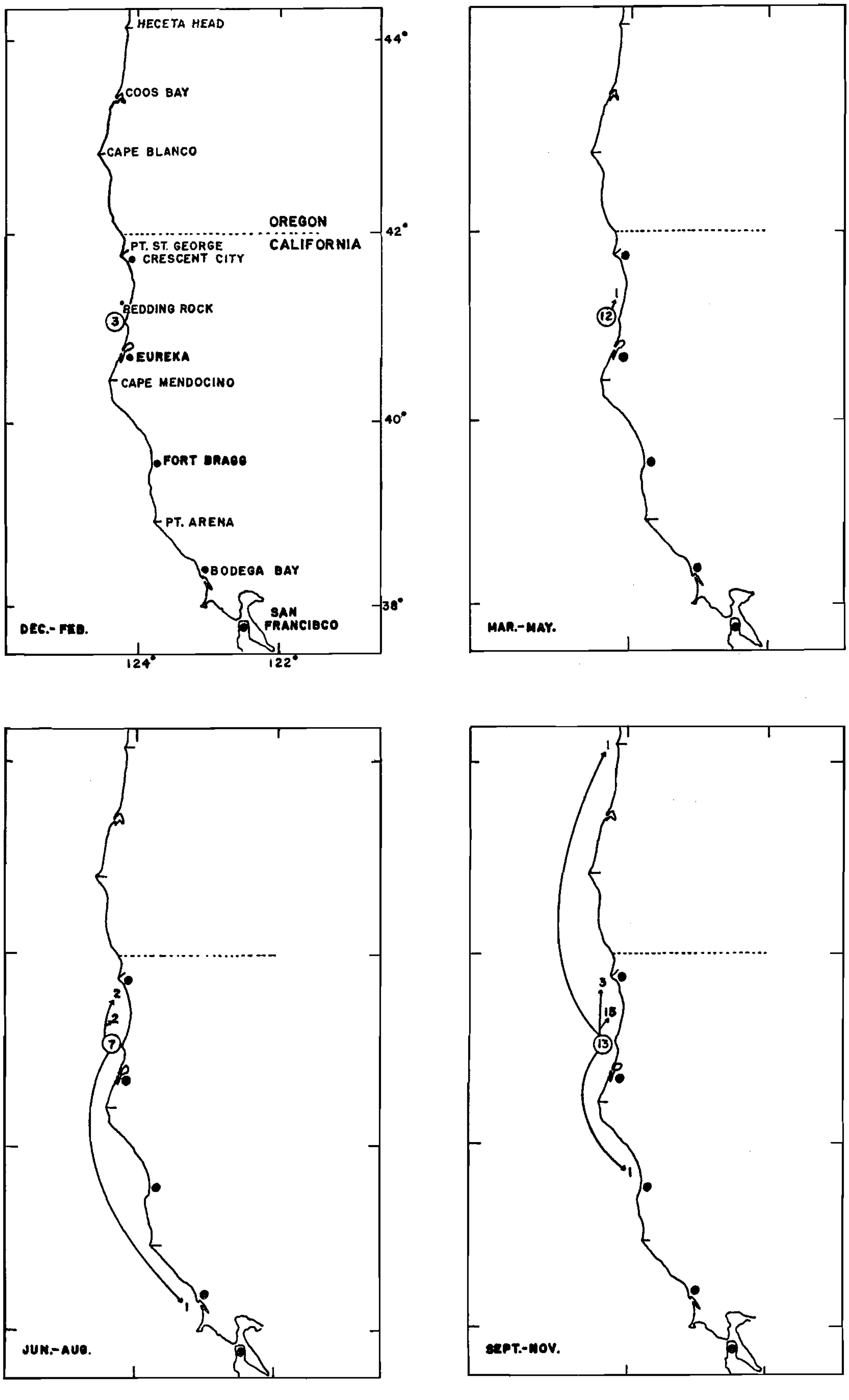

FIGURE 8. Localities of capture by season regardless of year for English sole tagged off Eureka in August 1940. Enclosed numerals represent recaptures in the tagging area.

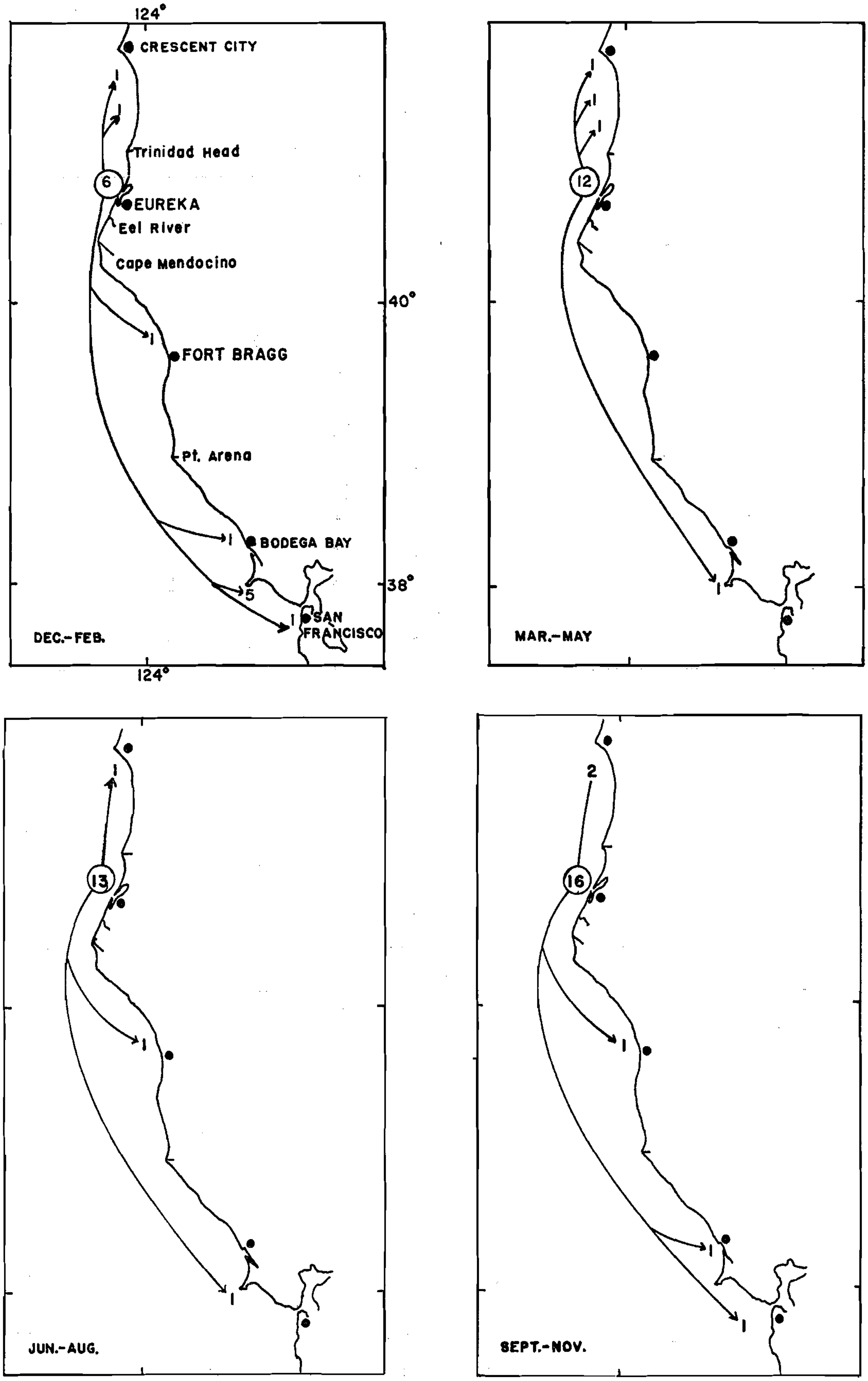

FIGURE 9. Localities of capture by season regardless of year for English sole tagged off Eureka in October 1949. Enclosed numeral represents recaptures in the tagging area.

TABLE 8

Recoveries from 402 English Sole Tagged in the Eureka Area, October 1949, by Month Regardless of Year, Area, and Distance from Release Area

Month	Recovery Area											Total
	1B						1C					
	San Francisco				Fort Bragg		Eureka				Unknown	
	Distance in Miles											
	255	201-250	151-200	101-150	76-100	51-75	0-20	21-30	31-40	41-50		
Jan.	1		4	1	1		4					11
Feb.							1					1
Mar.			1				4					5
Apr.							4	1		1	4	10
May							4		1		1	6
Jun.							2				1	3
Jul.							10					10
Aug.			1			1	1			1	3	7
Sep.			1				10		1		2	14
Oct.		1					5				2	8
Nov.						1	1	1				3
Dec.			1				1	1	1			4
Unknown								1				1
Total	1	1	8	1	1	2	47	4	3	2	13	83

TABLE 9

Recoveries of 3,934 English Sole Tagged in the Eureka Area, November and December, 1958, by Month Regardless of Year, Area, and Distance from Release Area

Month	Recovery Area									Total
	1B		1C				2A	2B		
	San Francisco	Fort Bragg	Eureka				Southern Oregon	Central Oregon	Unknown	
	Distance in Miles									
	151-200	76-100	21-40	0-20	21-40	41-60	61-100	150-200		
Jan.	2			5	33			1	16	57
Feb.	4			18	8				1	31
Mar.				59	2	4	1		12	78
Apr.				130					33	163
May		5		49	3				8	65
Jun.				51	4				6	61
Jul.				18					11	29
Aug.		1		31	5				48	85
Sep.			2	19		14	2		23	60
Oct.		1		13	27	5			15	61
Nov.				6	12	17	10		5	50
Dec.	1			38	21			1	18	79
Total	7	7	2	437	115	40	13	2	196	819

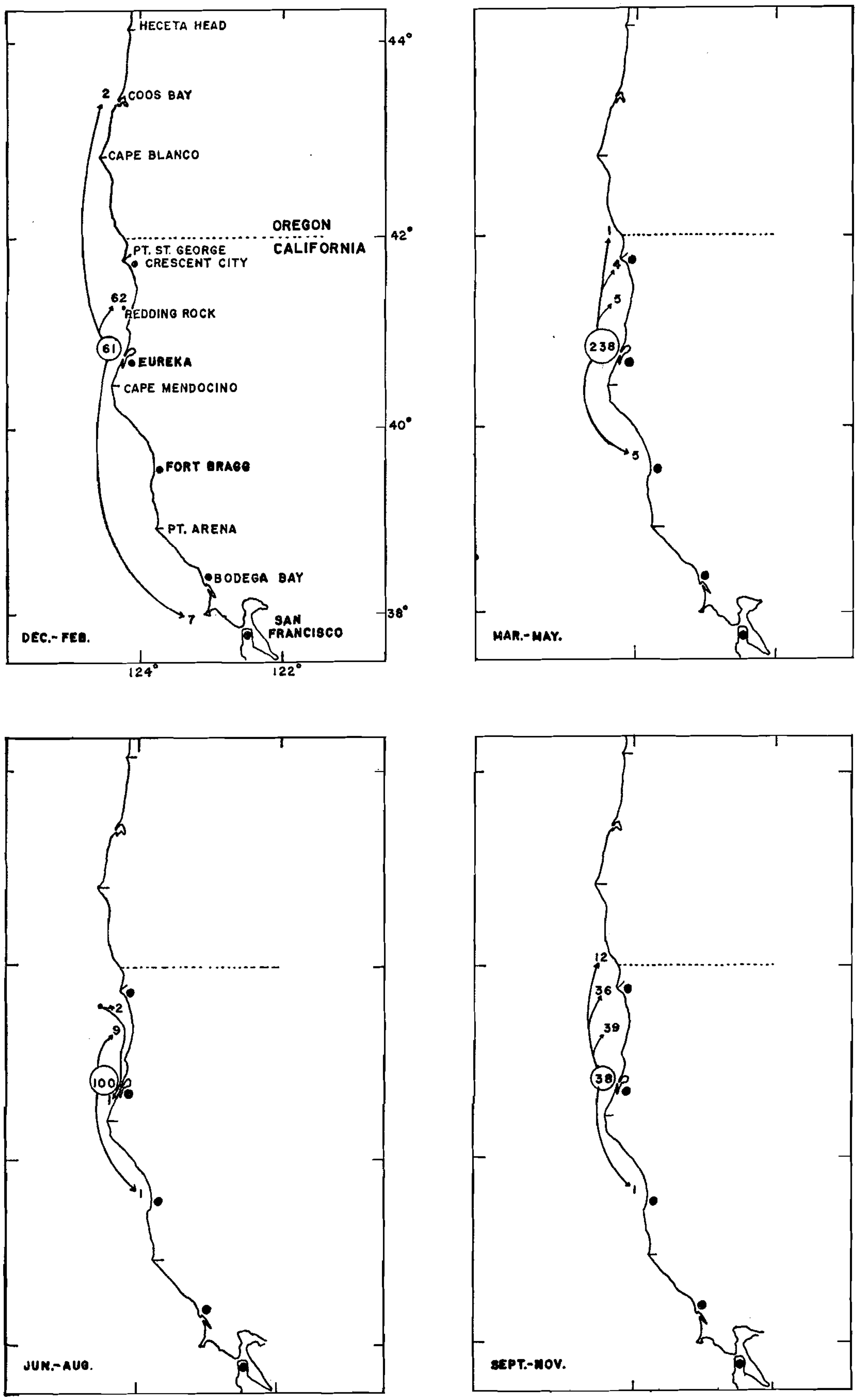

FIGURE 10. Localities of capture by season regardless of year for English sole tagged off Eureka in November-December 1958. Enclosed numerals represents recaptures in the tagging area.

south of the tagging area: 2 were caught near Cape Mendocino, and 14 were caught in PMFC Area 1B. Seven of the latter were recaptured about 100 miles south of the release area near Fort Bragg and the other 7 were recovered in the San Francisco area.

Recoveries taken 21 or more miles from the tagging area showed a northward movement trend which was intense during the fall and winter months. A return to the tagging area was suggested by the numerous recoveries in that area during spring and summer months (Figure 10).

Besides the coastwise movement, a seasonal offshore-inshore movement was evident from examination of depth data for 539 tag recoveries. Recapture depths ranged from 21 to 200 fathoms. Compared to release depths of 36 to 49 fathoms for the majority of tagged fish (3,900 of 3,940), recaptures from February through May were from deeper water. In July and August, most recoveries were from shallower water, while during November and December they were mainly from depths similar to release depths (Table 10).

Summary of movements of English sole tagged in the Eureka area

There were 786 tag recoveries with adequate catch data from the 1938 to 1959 English sole tagging in the Eureka area. Most of the tag returns (736 or 93.6%) were recaptured within PMFC Area 1C. Tag recoveries caught 21 or more miles from release sites showed a northerly movement trend during the fall and winter months.

Only 50 (6.4%) of the 786 recoveries were taken in PMFC Areas 1B, 2A and 2B. There were 13 recaptures from Area 2A, southern Oregon, with 12 recaptured during the fall months. Three were recaptured off central Oregon, Area 2B, and the northernmost recapture location was Heceta Head, Oregon near the northern border of Area 2B.

English sole fisheries at Fort Bragg and San Francisco returned 12 and 22 recaptures, respectively. Recaptures off Fort Bragg were highest in spring and fall months, while those at San Francisco were most numerous in winter (Table 11).

TABLE 10

Recoveries of 3,940 English Sole Tagged in the Eureka Area in November and December, 1958, by Depth and Month

Recapture Depth in Fathoms	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
21-30	2	—	3	2	—	4	14	19	3	—	—	—	47
31-40	23	5	2	9	4	15	13	6	3	28	26	10	144
41-50	11	2	10	18	11	20	1	5	19	9	10	22	138
51-60	1	1	36	43	11	—	1	—	—	—	—	6	99
61-70	—	7	9	19	7	3	3	1	2	—	—	—	51
71-80	—	1	—	17	9	—	1	3	2	—	—	—	33
81-90	1	—	3	1	1	1	1	1	—	—	—	—	9
91-100	—	—	—	—	3	1	—	—	—	—	—	—	4
151-200	—	2	1	3	5	—	—	—	1	2	—	—	14
Total	38	18	64	112	51	44	34	35	30	39	36	38	539

PROPOSED ENGLISH SOLE STOCKS OFF CALIFORNIA

The simultaneous separation in space of spawning aggregations, the results of tagging studies, and studies of variations in meristic characters by Taylor (1957) provide the bases for the designation of several stocks of English sole off California. The term stock is defined as aggregations of fish in an area which may intermingle with fish of other areas during the year, but are unique in distribution at spawning time. Each stock may consist of one or more subpopulations which Marr (1957) defined as fractions of a population that are genetically self-sustaining.

English sole spawn simultaneously at several widely separated areas off the California coast. Villadolid (1927) found English sole in spawning condition off San Francisco in the area between Bodega Bay and Point Montara during the months December to April, with the highest incidence in January and February. Budd (1940) stated that the spawning season in Monterey Bay extends from January to May, with the peak in spawning activity occurring in late March or April. He acknowledges that, according to G. H. Clark of the California Division of Fish and Game, the spawning is usually a month or two earlier. In recent Department studies, fish in spawning condition have been observed between December and April in Santa Monica Bay and in the Santa Barbara Channel, and off San Francisco between November and April, and in the area between Eureka and the Oregon border during the months October to May. The peak in spawning activity for all areas seem to occur in January and February.

There are, then, several geographically separated spawning areas and doubtlessly other areas of varying importance exist which are not delineated. Three major areas are recognized on the basis of available data. The Santa Barbara and Santa Monica Bay areas are combined as are areas in Monterey Bay and off San Fran-

TABLE 11

Summary of Tag Recaptures from Tagging in the Eureka Area, 1938-1958, by Area and Season

Season	Recovery Area					Total
	1B		1C	2A	2B	
	San Francisco	Fort Bragg	Eureka	Southern Oregon	Central Oregon	
Spring Mar-May	3	5	283	1		292
Summer Jun-Aug	3	2	141			146
Fall Sep-Nov	2	4	178	12	1	197
Winter Dec-Feb	14	1	134		2	151
Total	22	12	736	13	3	786

cisco. The third major spawning area is located between Eureka and southern Oregon.

Results of tagging in major California fishing areas show little intermingling by sole from different areas; however, tagging data for areas south of San Francisco are limited.

The Santa Barbara data suggests a stationary population. In contrast, an English sole released off Morro Bay was recaptured north of San Francisco. The population status of fish off Morro Bay is uncertain due to inadequate information. The few recaptures from Monterey tagging show little movement. One of 12 recaptures moved 50 miles north to the open coast.

Recaptures from tagging in the San Francisco and Eureka areas were largely taken near release areas although limited intermingling occurred between these fishing areas. Recaptures of fish tagged off Eureka by San Francisco fishermen, mainly in the winter, and recaptures of fish tagged in the San Francisco area by fishermen off Eureka in summer suggest a seasonal movement to and from San Francisco spawning grounds.

Tagging English sole at Fort Bragg resulted in recaptures mainly off Eureka and San Francisco with a small proportion recaptured near the tagging area.

Taylor (1957) studied the variation in numbers of vertebra and dorsal, anal, and pectoral fin rays, and on the bases of 3 of the 4 characters, distinguished 2 regional groups in central California. One group occurred in the Estero Bay-San Luis Obispo Bay (Morro Bay) region, while the other was from the Monterey Bay region. Furthermore, his material from Trinidad Head differed sufficiently to identify a third California group.

Tagging data suggest there are 4 California stocks. It is recognized that the designations of some stocks are based on data of questionable adequacy and modifications may be in order as new information is obtained.

The 4 stocks are as follows:

1. *Southern California stock.* This stock inhabits the Santa Barbara Channel. Point Conception marks the northern limit of its range, while the southernmost limit is unknown.

2. *South-central California stock.* The range of this stock is tentatively given as from Point Conception north to the San Francisco area. The winter distribution is at the southern portion of the range, while spring migration to northern areas is suggested by a single tag return.

The designation of this stock is based on scant information. Additional tagging and delineation of spawning areas are required.

3. *Central California stock.* Units of this stock are found between Monterey and Eureka. It is comprised of subpopulations which spawn in Monterey Bay and in areas between Point Montara and Bodega Bay. For the most part these units are nonmigratory, but there are highly migratory units which migrate as far north as Eureka during the spring and summer. Recaptures off San Francisco, mainly during the winter, of tagged English sole released off Eureka and Fort Bragg, suggest a return movement following the spring and summer northward migration.

4. *Northern California stock.* This stock spawns in the area between Eureka and southern Oregon, with the major spawning area being located between Redding Rock and the Oregon border. Most units of this stock are relatively stationary, but some exhibit localized movements northward in fall, returning in spring. There is also a shift to deep water in spring with a return to shallow water in summer.

A few members of this stock undertake distant movement. Summer movement occurs southward to Fort Bragg as well as northward to British Columbia. A return movement from the Fort Bragg area is suggested by summer tagging in that area resulting in recaptures off Eureka. A return southward movement in winter to northern California spawning areas following northward spring and summer movement is indicated by tagging conducted off Oregon, Washington and British Columbia. Nine English sole tagged by Oregon biologists in April 1959 off Cape Lookout, Area 2C, and 2 others tagged by Washington biologists during the summer of 1956 off Destruction Island, Area 3B, were recaptured off Eureka (Pacific Marine Fisheries Commission, 1961). An English sole, tagged by the Oregon Fish Commission in August 1948 off the Columbia River (Area 2D), was recaptured in January 1949 off St. George Reef near Crescent City (Hagerman, 1949), and another tagged in summer by the Fisheries Research Board of Canada in Georgia Strait, Area 4B, was recaptured off Eureka (Ketchen and Forrester, 1955).

GROWTH

Growth estimates of English sole were sought from measurements and ages determined from interopercles of recaptured tagged sole. Data were available only for recaptures of fish tagged off Eureka in November and December 1958.

A von Bertalanffy growth equation (Beverton and Holt, 1957 was fitted to ages and lengths of 291 female sole recaptured between February 1959 and January 1962. The use of a computer program designed by Abramson (1965) facilitated computations. For comparative purposes, another equation was fitted to data from 695 female sole sampled between 1960 and 1965 in Eureka markets. The respective equations from tag and market data are as follows:

$$1_t = 483 \left\{ 1\text{-exp} \quad [-0.18964 (t + 2.2661)] \right\}$$

and

$$1_t = 502 \left\{ 1\text{-exp} \quad [-0.155671 (t + 3.3772)] \right\}$$

The lower asymptotic size ($L\infty$) of 483 mm and shorter observed and fitted lengths for each age (Table 12) for recaptured tagged sole compared to the $L\infty$ of 502 mm and length and age values of sole in market samples suggest that tagging or the presence of tags adversely affect growth.

These equations differ considerably from that determined by Smith and Nitsos (1969) of

$$1_t = 42.84 \left\{ 1\text{-exp} \quad [-0.2584 (t + 0.3125)] \right\}$$

for female English sole trawled with 1½-inch mesh nets from Monterey Bay. The large difference is suspected to be due to the biases created in the equations of this study by the selectivity of 4½-inch mesh nets used in the capture of tagged and market fish. The mean lengths of the younger ages are greater than actual mean lengths of the population due to the selectivity of 4½-inch mesh nets for the larger young fish.

SUMMARY

A total of 9,065 English sole was tagged and released between 1936 and 1963 in major fishing areas off California. Minor releases of 113, 2, and 123 tagged English sole were made off Santa Barbara, Morro Bay, and Monterey, respectively. Respective numbers of tagged fish released off San Francisco, Fort Bragg, and Eureka were 2,102, 1,135, and 5,595.

Recaptures of tagged fish were largely from tagging areas; nevertheless, a limited amount of intermingling occurs for areas north of Morro Bay. The distant recoveries for English sole tagged off Morro Bay and Monterey were too few to show patterns of movement. The small amount of intermingling among English sole from the San Francisco, Fort Bragg, and Eureka areas appears to be seasonal. San Francisco migrants seem to move to Eureka in spring and summer and return in winter. There is some movement from Eureka south to Fort Bragg in summer with a return in winter. A movement of fish from the Eureka area to northern areas in summer with a return in winter is suggested by our tag data and those of other agencies. Localized movement which is northward in fall and winter, along with offshore and inshore movement, also occurs for fish tagged in the Eureka area.

Four stocks of English sole are proposed on the basis of tagging data, spawning distribution data, and studies of meristic variations. These are as follows:

1. Southern California stock which is found in the Santa Barbara Channel. Point Conception may be the northern limit of distribution for this group, while the southern limit is unknown.
2. South-central California stock. The delineation of this stock is based on scant information. Its range is tentatively given as Point Conception to Bodega Bay.
3. Central California stock. This stock is distributed from Monterey to Eureka, and some of its units migrate to Eureka in summer and return to the central California spawning grounds in winter.
4. Northern California stock. Most units of this stock are relatively stationary and are distributed between Eureka and southern Oregon. Migratory units of this stock undertake movements south to Fort Bragg and northward to British Columbia.

Growth equations were calculated for recaptured tagged female English sole and for those sampled at Eureka, respectively. Differences in asympotic sizes and lengths for each age between tagged sole and sampled sole suggest that tagging adversely affected growth.

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TABLE 12
Fitted and Sample Total Lengths (in MM) by Age of Female English Sole Among Recaptured Tagged and Market Sampled Sole from Eureka Area, 1C

	Recaptured Tagged			Market Sampled		
Age	Number	Fitted Length	Sample Mean Length	Number	Fitted Length	Sample Mean Length
II	..	268	No Data	3	285	301
III	32	305	307	39	316	315
IV	151	336	335	112	343	344
V	73	361	361	151	366	365
VI	27	382	382	135	385	384
VII	6	399	427	93	402	404
VIII	2	414	359	74	417	414
IX				57	429	437
X				24	439	433
XI				7	448	431
Total	291			695		

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Age, Growth and Mortality of Races of English Sole (*Parophrys vetulus*) in Puget Sound, Washington

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AGE, GROWTH, AND MORTALITY OF RACES OF ENGLISH SOLE *(Parophrys vetulus)* IN PUGET SOUND, WASHINGTON[1]

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INTRODUCTION

The English sole *(Parophrys vetulus* Girard) is the most abundant of the commercially important flatfish in Puget Sound, where it is a mainstay of the otter trawl fishery. A major part of southern Puget Sound south and west of Point Defiance (near Tacoma) has been closed to otter trawling since March 3, 1942. Although the two remaining fishing grounds of importance, Carr Inlet and Case Inlet, were open to commercial fishing until April 20, 1948,[2] little or no fishing took place largely because of the predominance of sole with red-colored nematode worms *(Philametra americana)* in the flesh of the fish.

This study was largely confined to two areas, Carr Inlet in southern Puget Sound and off Golden Gardens beach in Shilshole Bay, within the Seattle city limits. The inner portion of Carr Inlet (north of Green Point) has a surface area of about 25 square miles, a depth of less than 50 fathoms, and lies well within the area of approximately 160 square miles of lower Puget Sound south and west of Point Defiance. A limited study was made of English sole obtained from Case Inlet, which is separated from Carr Inlet by a long peninsula and is also well within lower Puget Sound. English sole in Carr Inlet were apparently more numerous than in the other areas, even nearby Case Inlet, which also had not been exploited commercially. On the other hand, the waters of Shilshole Bay in middle Puget Sound are contiguous with an area which has always been open to a commercial fishery and is separated from Port Madison, another study area, only by a deep basin whose maximum depth of 156 fathoms is east of Point Jefferson. Relatively few specimens were taken from either of these two areas at depths greater than 50 fathoms. Approximate latitude and longitude of each study area are as follows:

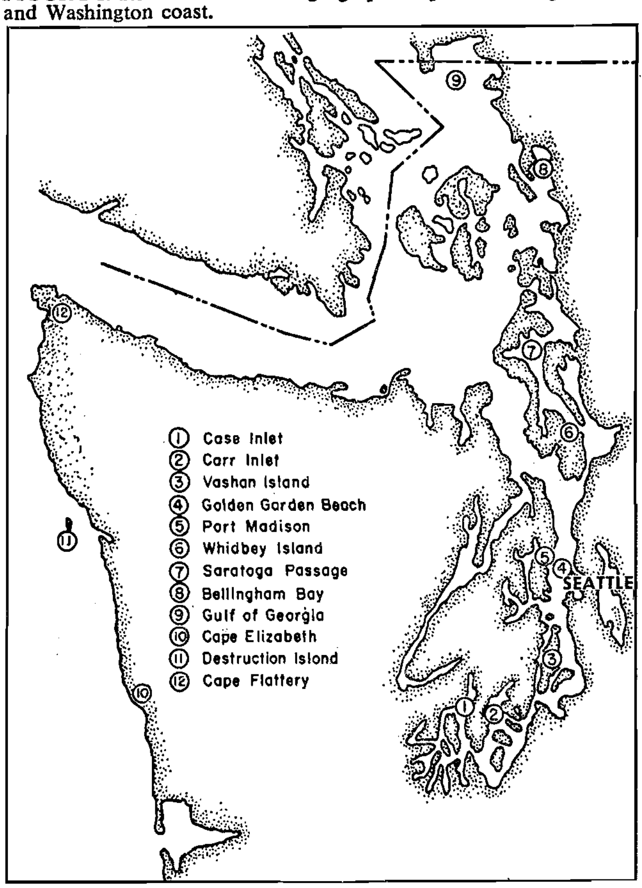
Area	N. Latitude	W. Longitude
Carr Inlet	47° 20′	122° 42′
Case Inlet	47° 18′	122° 50′
Shilshole Bay (Golden Gardens)	47° 41′	122° 25′
Port Madison	47° 44′	122° 32′

The relative location of each of these geographical points is illustrated in Figure 1.

One of the objectives of this investigation was to determine if a differential growth rate existed in Carr Inlet because of population density. Another objective was to determine if the Carr Inlet population were a distinct race and could be distinguished from the others on the basis of meristic counts, morphological measurements, and tagging experiments. Possible differential rates of natural mortality were determined on the basis of random samples of age groups from each area.

Population samples were taken for this study from

FIGURE 1. Relative location of geographical points on Puget Sound and Washington coast.



[1]Based on a thesis submitted in 1954 in conformity with the requirements for the degree of Master of Science at the University of Washington, Seattle.

[2]All waters were then closed to commercial fishing until January 16, 1956 when most of the waters of lower Puget Sound south and west of Point Defiance (47°19′ lat. N, 122°33′ long. W) were opened annually to commercial fishing of bottomfish for any purpose, including mink food, from December 1 through March 31.

September 1950 to April 1952 by means of otter trawl gear operated from the M. V. *ONCORHYNCHUS* and by beach seines manned by faculty and students from the College of Fisheries. The beach seines had 1-inch mesh (stretched measure) in the wings and ¾-inch mesh in the bag. Dimensions of the three types of otter trawls were as follows:

Type No.	Foot Rope	Head Rope	Mesh Size Wings	Mesh Size Cod-End
1	44 ft.	36 ft.	2.5 in.	1.5 in.
2	57 "	47 "	2.5 "	1.25 "
3	56 "	46 "	4.25 "	3.5 "

Virtually all the specimens for this study were taken by beach seines and otter trawl No. 2.

RACIAL STUDIES

Meristic Characters

Morphological characters, such as vertebrae and fin rays, which can be counted at an early stage in the life of fish and are not altered by subsequent environmental conditions, are commonly used to distinguish between various populations or "races." Rollefsen (1939) observed that the number of vertebrae and fin rays in fry of flounders *(Pleuronectes flesus)* seemed to depend upon the temperature to which the fry had been exposed during the first 8 to 14 days after hatching. Devold (1942) found only a slight variation in vertebral counts in the plaice *(Pleuronectes platessa)* with increasing latitude along the outer Norwegian coast, and although there seemed to be an inverse correlation between the number of vertebrae and water temperature, he did not believe that this justified a separation of the plaice populations.

Smith (1936) made counts of the dorsal and anal rays and the vertebrae for a racial analysis of the English sole *(Parophrys vetulus)* from five localities in northern Puget Sound and one in southern Puget Sound. He selected only fish in their second year of life for his study, and only dorsal and anal fin ray counts were used. Smith found statistically significant differences between the means of the fin ray frequencies in some cases, and the data indicated a gradual decrease in the mean of these frequencies with increasing distance from the Strait of Juan de Fuca of the areas sampled in Puget Sound. However, there were usually no significant racial differences between fish in adjacent areas such as the Gulf of Georgia and Bellingham Bay.

To demonstrate the dependence or independence of the stocks of English sole in adjacent areas, tagging experiments were begun in Puget Sound in 1939. In an unpublished manuscript Cleaver (1945) observed that English sole released in lower Puget Sound south of Point Defiance were never recovered elsewhere, nor were tags from areas north of Point Defiance ever recovered in the southern portion of Puget Sound. English sole tagged on the west side of Whidbey Island, in Bellingham Bay, and in the Strait of Georgia showed a greater tendency to travel, and the relatively few tagged fish released in the coastal waters of Washington made the longest migratory movement. A slight interchange of fish between the coastal waters and waters of northern Puget Sound was noted. Cleaver's data indicate a tendency for large fish to travel farthest, although they seldom migrated more than 20 miles in Puget Sound even after several years at liberty. However, in the coastal waters, fewer than one-half of the recoveries were made within 20 miles of the point of release.

Subsequent tagging experiments were carried on in lower Puget Sound from 1949 to 1951 by the Washington Department of Fisheries and the University of Washington College of Fisheries (unpublished data). As mentioned previously, southern Puget Sound was then closed to a commercial fishery. Therefore, the opportunities for recovery of tagged fish in this area were limited to periods when the M. V. *ONCORHYNCHUS* and chartered commercial trawlers were sampling the fish populations with otter trawl gear. Of the 6,672 English sole tagged and released in Carr Inlet during this period only 3 fish, all females, were recovered outside of southern Puget Sound, approximately 47 miles from the point of release. All of the other 158 recoveries were made inside Carr Inlet except for 2 fish which were recaptured within 10 miles of the entrance. Although the recoveries of tagged fish from these experiments did not demonstrate the existence of a discrete stock, it has not been demonstrated whether English sole from other populations migrate into Carr Inlet or emigrants from Carr Inlet remain permanently in other areas. However, Blegvad (1935) showed that such straying of plaice from racially distinguishable stocks occurred naturally in the North Sea and Belt Sea.

Since the theory of sampling assumes that the samples being compared adequately represent their respective populations, any difference that is statistically significant does not necessarily denote a racial difference unless the sampling requirement is met. On the other hand, an absence of significant differences between samples of the same year class does not necessarily mean that the populations of any two areas are identical, since a similarity of environmental conditions during critical periods of development may lead to a similarity of fish from two separate localities. This, of course, assumes that the meristic characters are not hereditarily fixed.

Although Smith (1936) presented data indicating the independence of some stocks of English sole in northern Puget Sound, he confined his study to fish in their second year, when the males become mature and spawn for the first time, while the females are all immature.

The tagging experiments by Cleaver (unpublished manuscript) and the College of Fisheries indicated a tendency for the smaller and immature fish to migrate less than the larger and mature fish. Therefore, Smith's data cannot be deemed a complete test of racial differentiation. In other words, Smith confined his study to the first possible spawning season of English sole without investigating the possibility that more active migration of the older fish would tend to obliterate population differences.

Since this species has pelagic eggs which drift with the tidal currents, an exchange of eggs and young between various localities in Puget Sound is possible. No attempt was made to demonstrate whether or not such a diffusion by the currents occurs. If such dispersion does not occur, and if the populations remain within a particular locality throughout their lives, then it might be possible to demonstrate racial differences at all seasons of the year between the various areas for all year classes combined, provided one or more factors exist which might reflect such differences. Even with such diffusion, it might be possible to have racial differences, provided the stocks remain separate in the later stages.

Although none of the material for racial analysis was gathered during the spawning season (January-March), spawning fish were observed in the localities studied. Meristic characters were counted in random samples of fish of all year classes taken at Golden Gardens in 1951 during April, August, September, October, November, and December, and of a single sample taken at Port Madison in September. Samples taken in Carr Inlet in July and November, and in Case Inlet in July of 1951, were also used in this study.

The total number of vertebrae, not including the hypural plate, ranged from 41 to 45, but the number of abdominal vertebrae was almost invariably 11. The mean number of vertebrae found in English sole from Golden Gardens, Port Madison, Carr Inlet and Case Inlet was 43.43, 43.38, 43.53 and 43.30 respectively. When analyzed statistically, the vertebral counts of the 531 fish sampled from these 4 areas were not significantly different.

The 797 anal fin ray counts listed in Table 1 ranged from 53 to 68 and dorsal ray counts from 71 to 90 in fish from the 4 areas. To test the hypothesis of equal variances in these populations, a method outlined by Dixon and Massey (1951, p. 90) was applied. This method tests the assumption of a common variance among independent samples of different populations, a more critical assumption than that of normality in data to which "analysis of variance" is subsequently applied. Since the "F" values of 0.33 and 1.25 for the dorsal and anal fin ray counts respectively were less than the critical value of "F" (2.62) at the 5 per cent level of significance, the hypothesis that the 4 populations have equal variance was accepted. When "analysis of variance" was applied to the data, the computed values of "F" for both the dorsal fin ray counts (27.79) and anal fin ray counts (33.59) were well outside the 1 per cent point of the distribution of "F" (Snedecor, 1956, p. 249), indicating that the number of rays in the dorsal and anal fins of the 4 populations differed significantly.

Comparisons between the fin ray counts of different localities can be validly made for showing population differences only when comparisons are made between fish of the same year class, because of possible variations between different year classes. To determine which populations had a significant difference in mean fin ray counts, the differences between each two sets of means were divided by the standard deviation of the difference between those means for each year class sampled in the various localities.

By this method it was demonstrated that there was no statistically significant difference between the means of dorsal and anal fin ray counts of the Golden Gardens and Port Madison populations, or between the Carr Inlet and Case Inlet populations (Holland, 1954). On the other hand, significant differences were indicated between fish of Carr and Case Inlets and those of Golden Gardens and Port Madison until their fourth year of life. Carr and Case Inlets (southern Puget Sound) are about 40 to 50 miles distant from the other 2 areas. These differences in fin-ray counts may be due to different hydrographical conditions to which the eggs and larvae had been exposed and are not necessarily genotypical. The lack of significant differences in older age classes could be due to small sample size, migration or intermingling of these fish after 4 years of age, or error in determination of age groups.

Morphological Measurements

A very dense population of English sole was found during this study in Carr Inlet, similar to that described by Jensen (1938) for the plaice in the Horns reef area of the North Sea. In order to ascertain whether morphometrical differences existed between English sole in Carr Inlet and elsewhere, measurements were made of the length of the head, maximum depth of the body, and total length of the fish sampled in July and November, 1951. For comparison, similar measurements were made of English sole taken off the beach at Golden Gardens in August, September, and October, 1951.

Head and total lengths were measured on 647 fish in these 2 areas, and 113 measurements were made of the maximum body depth. The data were grouped by sex and area in the form of a double frequency distribution, or correlation table, of one centimeter intervals of length. Since the data showed no departure from linearity over the size ranges involved, the lines of regression, their correlation coefficients, and standard error of estimate were calculated by methods presented by Snedecor (1956). His methods of regression analysis

TABLE 1

Statistics Describing (A) Anal Fin Ray Counts and (B) Dorsal Fin Ray Counts of Various Year Classes of English Sole in Different Areas

($s_{\bar{X}}$ = Standard deviation of the mean, $\bar{X}$)

(A)	Golden Gardens			Port Madison			Carr Inlet			Case Inlet		
Year Class	N	$\bar{X}$	$s_{\bar{X}}$	N	$\bar{X}$	$s_{\bar{X}}$	N	$\bar{X}$	$s_{\bar{X}}$	N	$\bar{X}$	$s_{\bar{X}}$
1951	73	60.78	0.253	7	61.43	0.939	174	60.18	0.174	—	—	—
1950	40	62.48	0.353	15	62.33	0.724	9	59.44	0.603	—	—	—
1949	69	62.13	0.294	11	61.91	1.044	6	60.50	1.172	4	60.50	1.376
1948	27	60.74	0.387	5	61.40	1.150	28	59.43	0.399	24	59.08	0.453
1947	16	60.13	0.713	2	63.00	4.240	26	59.42	0.465	21	59.90	0.472
1946	34	59.62	0.439	—	—	—	28	59.18	0.299	15	59.13	0.540
1945	10	60.20	0.813	—	—	—	31	58.81	0.375	11	59.09	0.769
1944	7	60.85	0.735	—	—	—	23	60.09	0.452	—	—	—
1943	1	59.00	—	—	—	—	27	59.59	0.469	10	59.60	0.843
1942	—	—	—	—	—	—	17	58.82	0.590	6	59.17	0.866
1941	—	—	—	—	—	—	10	58.40	1.080	3	60.33	1.787
1940	—	—	—	—	—	—	5	57.80	1.815	1	55.00	—
1939	—	—	—	—	—	—	1	58.00	—	—	—	—
Total	277	61.15		40	61.98		385	59.69		95	59.39	
(B)												
1951	71	81.08	0.349	7	79.86	1.363	176	79.74	0.229	—	—	—
1950	40	81.98	0.506	15	83.20	0.576	9	78.33	0.830	—	—	—
1949	69	82.17	0.361	11	81.73	1.133	6	78.50	0.698	4	79.75	0.728
1948	27	80.59	0.512	5	79.80	1.815	28	79.79	0.507	24	78.50	0.537
1947	16	80.56	1.023	2	85.00	4.240	26	79.31	0.537	21	78.90	0.718
1946	34	79.24	0.563	—	—	—	29	78.90	0.473	15	79.33	0.798
1945	10	79.50	0.947	—	—	—	31	78.87	0.514	11	78.73	0.940
1944	7	81.29	0.935	—	—	—	23	79.30	0.679	—	—	—
1943	1	81.00	—	—	—	—	27	79.63	0.619	10	78.90	1.025
1942	—	—	—	—	—	—	17	79.24	0.704	5	79.20	1.680
1941	—	—	—	—	—	—	10	78.10	0.760	3	79.33	1.787
1940	—	—	—	—	—	—	5	79.40	1.440	1	75.00	—
1939	—	—	—	—	—	—	1	79.00	—	—	—	—
Total	275	81.13		40	81.88		388	79.43		94	78.87	

(Chapters 6 and 7) and analysis of covariance (Chapter 13) were followed to test whether differences between sexes and areas were significant.

These analyses indicated that when adjustments were made for differences in total lengths of males and females sampled in Carr Inlet, the mean head lengths differed significantly. Sexual dimorphism was also apparent at the one per cent level of significance in the Golden Gardens area. When similar tests were made of differences between fish of the same sex from the 2 areas, the differences in regression slopes and adjusted means were found to be significant in both sexes, although the difference between regression coefficients of the males in the two areas was between the 1 and 5 per cent levels of significance.

Sexual dimorphism was indicated by differences in maximum body depth when adjustments were made for differences in total lengths of the males and females. Tests of differences in body depth of the same sex from the 2 areas indicated significance at the 5 per cent level of probability (Holland, 1954).

Although the differences in the relationship between head length and total length could distinguish the English sole populations in Carr Inlet from those of Golden Gardens on a statistical basis, the data on maximum body depth were not as conclusive. The phenotypes of English sole were not as readily distinguished as those of the Horns Reef and Belt Sea plaice which differed 5.3 per cent in relationship of body depth to total length and 14.5 per cent in relationship of head length to body depth (Jensen, 1938). Comparable differences for the Carr Inlet and Golden Gardens populations were only 0.9 and 4.8 per cent respectively.

Parasites

The stocks of English sole in southern Puget Sound, especially in Carr Inlet, have long been characterized as "wormy." Smith (1936) recorded that English sole from this region were not commonly marketed due to the presence of red-colored nematode worms *(Philametra americana)* in the flesh and inner margins of the fin rays, giving the fish an unappetizing appearance. In one sample taken in Hale's Passage with otter trawl gear, he noted that 22 per cent of the otherwise marketable fish were discarded because of their wormy condition. Williams (1950) observed that of samples taken in 1949 by a commercial trawler, 72 per cent of the Carr Inlet English sole were wormy, as compared with an infestation of 41 per cent of this species in Nisqually Reach and 36 per cent in the vicinity of Fox Island. Of the 4,109 English sole tagged in 1950 and 1951 in Carr Inlet by students from the College of Fisheries, 71 per cent were recorded as infested with one or more worms.

During this study the percentages of wormy English sole observed were 72 per cent in Carr Inlet, 95 per cent in Case Inlet, 35 per cent in Port Madison, and less than 1 per cent at Golden Gardens. Incidence of these worms was insignificant until the fish were about 210 mm long and were at least 1 year old. Thereafter the incidence of infestation seemed to be the same for both sexes and all sizes. The degree of infestation apparently is not a function of population density, since sampling in these areas indicated that English sole were less numerous in Port Madison than at Golden Gardens and less numerous in Case Inlet than in Carr Inlet. If infestation of these fish by *Philametra americana* is endemic, the populations in Port Madison and Golden Gardens are apparently distinct. However, further knowledge is needed of the life history of this nematode worm to determine its significance as a means of distinguishing separate populations.

Sex Ratios

Except for the specimens of the 0-year group (1951 year class), collected by means of beach seines (¾-inch mesh), the only specimens used in this study were taken with otter trawl Type No. 2 (1.25″ mesh in cod-end). It is assumed that these two types of gear sampled the respective year classes and sexes in proportion to their true distribution in the various areas. Of 4,990 English sole collected from different areas during this study, 67.2 per cent were males. The highest relative number (77.6 per cent) of males occurred among the 2,318 fish sampled in Carr Inlet. In the Golden Gardens area 60 per cent of the 1,579 specimens collected were males. Samples from other areas of southern and middle Puget Sound contained fewer fish and perhaps did not reflect the true sex ratio.

These data indicate that a preponderance of males is a function of population density, provided the population had been randomly sampled, i.e., the gear had not selectively taken a higher proportion of males than was actually present in the population. Even the samples of fish less than 1 year old in Carr Inlet showed the same preponderance of males. The sex ratio of fish less than about 5 months old was not determined. If the common 1:1 sex ratio occurs at the time of birth, then there must be a differential ability on the part of the Carr Inlet females to withstand conditions existing during the first few months of life.

In most recorded sex ratios of various fish populations, females are more numerous than males, presumably because of the higher mortality of males as the fish become older. This phenomenon has been observed even in unexploited populations, such as the plaice of the Barents Sea (Atkinson, 1907-10). However, the predominance of male English sole in all age classes of the Carr Inlet population sampled during this study cannot be explained on this basis. Either there was an actual predominance of males in the initial sex ratio or the sampling gear was selective in capturing males.

Subsequent studies by Van Cleve and Pruter (1956), Jurkovich (1954) and El-Sayed (1959) have demonstrated the selective action of trawls on English sole. Jurkovich (1954) demonstrated that the smaller the meshes in the cod-end the higher the percentage of smaller fish caught in samples of the same population. He attributed this effect to the restricted flow of water through the net by the smaller meshes and to the more rapid collection of fish and debris which decreased the current speed at the trawl mouth and allowed the escape of the larger, more rapidly swimming fish, most of which were females.

Length-Weight Relationship

Since the weight of most species of fish accrues at a greater or lesser rate than the cube of the length, this relationship is generally expressed by the following equation:

$$Y = aX^{b}, \text{ where } Y = \text{weight}$$
$$X = \text{length}$$
$$a = \text{a constant}$$
$$b = \text{relative growth constant}$$

Discrepancies in weight of English sole due to the development of the gonads before the spawning period, and subsequent loss of weight after spawning, were avoided by sampling during the summer and autumn months. The data for the Carr Inlet population included 795 males, ranging in total length from 97 to 346 mm, and 264 females ranging from 106 to 432 mm. The regression line for the males was fitted by the equation:

$\text{Log } Y = \bar{2}.0132 + 2.970 (\log X)$, or in its exponential form,

$$Y = 0.1031 X^{2.970}$$

For the females the regression line was fitted by the equation:

$$Y = 0.1407 X^{3.077}$$

The length-weight data for the Golden Gardens population included 258 males which were 83 to 321 mm in total length and 176 females ranging from 82 to 367 mm. For the males the equation expressing the length-weight relationship was calculated to be $Y = 0.00001321 X^{3.033}$ and for the females $Y = 0.00001168 X^{3.012}$.

The samples from the two areas are not strictly comparable, inasmuch as they do not include the same ranges of lengths and weights, nor was the same type of sampling gear used in both areas. Otter trawl gear equipped with a cod end of 1¼-inch mesh was used for the Carr Inlet samples, but 53 per cent of the Golden Gardens specimens used for calculation of the length-weight relationship were collected by beach seines. Although the samples were taken over a 2-year period, differences in the length-weight relationship of English sole from the two areas probably were mainly due to gear selectivity rather than actual regional differences. As shown in Figure 2, the greatest differences between the empirical and calculated weights at the various lengths of the Carr Inlet fish are apparent at the upper ranges of length for which there were only a few observations.

AGE AND RATE OF GROWTH

Material and Methods Used

The sagitta was used for age determination. Both otoliths were removed from each fish. In most cases, the otoliths were simply cleaned and kept dry in coin envelopes, serially numbered to correspond with the recorded data taken from each fish: sex, length, weight, fin ray counts, morphological measurements, etc. In a few samples, the otoliths were transferred immediately to vials containing a solution of 50 per cent glycerin in water with a few crystals of thymol. The markings of otoliths stored or cleared in the glycerin solution were not as clearly defined as those on otoliths which had been kept dry. All otoliths were examined and measured in reflected light while resting in xylene on black matting paper. With this dark background the translucent "winter" rings appeared under low-power magnification as dark concentric bands alternating with the opaque "summer" rings.

In a sample taken on August 16, 1951 at Golden

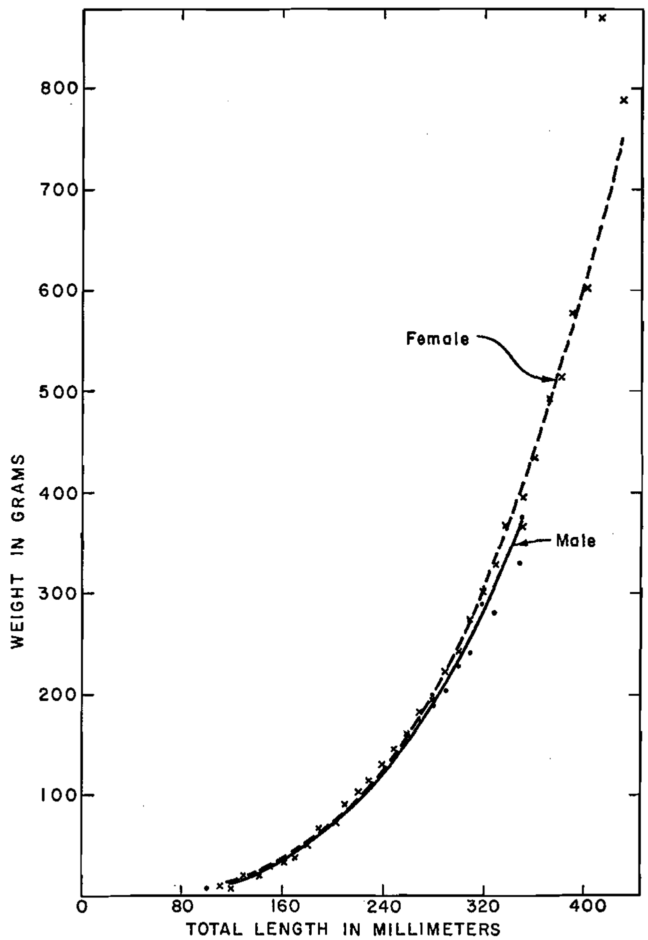


FIGURE 2. Length-weight relationship of *Parophrys vetulus* in Carr Inlet, Puget Sound.

Gardens 2.3 per cent of the otoliths had begun formation of the winter ring. Subsequent samples from this area indicated that formation of the winter ring had started on over 50 per cent of the otoliths by the latter part of September, and on all otoliths by November 1. Growth of the summer ring had begun on 50 per cent of otoliths by the end of March. No samples were taken in August and September in Carr Inlet, but inception of the winter growth on all otoliths had occurred by November, and winter growth was virtually complete by the end of April. Therefore, the main period of winter ring formation apparently occurred from about October 1 to April 1 of the following year.

The winter ring, representing retarded growth, is called the annulus. Its outside edge was considered the limit of the annulus and was used in the measurements of the otoliths. The comparatively few rings found on the margins of otoliths sampled at other times of the year were not considered to be a true annulus but an accessory mark formed by retardation of growth caused by some unusual circumstance. The accessory marks were not considered to be "spawning zones," such as those observed in cod otoliths by Rollefsen (1935), since Smith (1936) observed the spawing season to be almost simultaneous throughout the Puget Sound region, lasting from about January 10 to April 1, with the height of spawning occurring between February 1 and March 20. However, spawning occurs as early as October in some areas.

The ages of *Parophrys vetulus* refer to the number of completed "winter" rings. For example, fish which have not completed their first year of growth are placed in the 0-group, and those in their second and third years in the I-group and II-group, respectively. Agreements between two independent readings of each otolith were accepted as the age of the fish. In event of disagreement a third reading was made, and if this agreed with either of the other two, this reading was accepted as the age. If not, the otolith was discarded.

Otolith Measurements

Growth of the English sole was calculated from the relationship between total length of the fish and measurements of the otolith. Similar studies have been made by means of the scales of various species of fish, but only to a very limited extent with otoliths, because of the technical difficulties in obtaining proportional measurements.

The length of the otolith was measured along the antero-posterior axis of the concave exterior side. Occasionally the nucleus in otoliths from fish less than 87 mm in length was located on this axis. However, it was never observed in a position ventral to this line, even in the otoliths from a 28 mm fish. Maximum length of the otolith and of each annulus was measured with a filar micrometer from the anterior to the posterior edge of the otolith. The nucleus was not equally distinct in all otoliths, but was focused as clearly as possible in the center of the field and was used as a reference point dividing the anterior and posterior axes of the otolith.

Because the annuli of the right otoliths of the English sole are more eccentric than those of the left otoliths, the outer margins of the annuli on the posterior axis are not as readily discerned. In some cases, only the last annulus was measured, and occasionally another annulus was not measured because its outside margin was not clearly defined on the posterior axis. The average length of each annulus on both the right and left otoliths was greater in the females than in the males. Measurements of the annuli on left otoliths of 302 males and 172 females from Carr Inlet showed that the females have a higher rate of growth and a greater range in length of the annuli of the various year classes (Tables 2 and 3). Less than 10 per cent of the left otoliths from fish of the zero-age group were greater in length than the right otoliths, but in fish ranging from 2 to 11 years of age over 80 per cent of the left otoliths were greater in length.

In plotting the relationship of total lengths, head lengths, or maximum body depths of 711 Carr Inlet fish and total length of their left otoliths, a curvilinear relationship was apparent for fish ranging from 28 to 431 mm in length. The mean lengths of both the fish and otoliths were determined within each centimeter interval of total lengths of the fish, and the following parabola was fitted to the unweighted means:

$$Y = -0.3217 + 0.032424X - 0.00002625X^2$$

In general, the curve fitted the data very closely except at the upper part of the range of total fish length, probably due to an insufficient number of samples to represent the true average.

When the formula $Y = bX^k$ was used to express the relationship between otolith length (Y) and fish length (X), the following equation was obtained: $Y = 0.03206X^{0.9417}$. The "coefficient of heterogony" (k), or constant differential growth ratio of the left otolith, decreased from 0.8886 in males from 10 to 25 cm in length to 0.7281 in males larger than 25 cm. In the females "k" decreased from 0.9208 to 0.5829 in fish over 26 cm in length. Huxley (1932) observed that such abrupt changes in the ratio of growth occur frequently in nature, and in many cases they coincide with a well-defined physiological event such as the onset of puberty. In Carr Inlet the male English sole mature at about 20 cm in length, some of the females mature at about 25 cm, and all are mature at approximately 29 cm. Therefore, the decrease in observed ratio of left otolith length to fish length was possibly due to the onset of sexual maturity.

TABLE 2

Number of Measurements, Mean Lengths, and Standard Deviations of Mean Lengths of Annuli in Left Otoliths of Male *Parophrys vetulus* in Various Year Classes from Carr Inlet

Annulus and		Year Class											
Statistic		1950	1949	1948	1947	1946	1945	1944	1943	1942	1941	1940	Total
I	N	12	55	71	48	26	8	9	11	2	1		243
	$\bar{X}$	3.12	3.06	3.28	3.49	3.33	3.36	3.37	3.47	3.18	3.25		3.28
	$s_{\bar{X}}$	.0983	.0458	.0451	.0592	.0863	.1272	.0767	.1265	.3759	—		
II	N		5	70	48	26	9	9	11	2	1		181
	$\bar{X}$		4.99	4.86	4.93	4.94	4.84	4.75	4.91	4.50	4.70		4.89
	$s_{\bar{X}}$		.1071	.0454	.0606	.0725	.1200	.1167	.1627	.2482	—		
III	N			44	48	26	9	10	10	2	1		150
	$\bar{X}$			5.73	5.62	5.56	5.52	5.38	5.46	5.35	5.55		5.61
	$s_{\bar{X}}$			.0468	.0519	.0706	.1367	.1108	.1456	.4298	—		
IV	N				24	26	9	10	11	2	1		83
	$\bar{X}$				6.21	5.98	5.96	5.79	6.02	5.80	5.95		6.02
	$s_{\bar{X}}$				.0755	.0745	.1567	.1139	.1386	.2456	—		
V	N					24	8	9	9	1	1		52
	$\bar{X}$					6.26	6.29	6.09	6.43	6.15	6.15		6.26
	$s_{\bar{X}}$					.0959	.1979	.1267	.1667	—	—		
VI	N						17	11	11	2	1		42
	$\bar{X}$						6.33	6.32	6.64	6.30	6.35		6.41
	$s_{\bar{X}}$						.1117	.1235	.1386	.0993	—		
VII	N							6	13	2	1		22
	$\bar{X}$							6.45	6.79	6.48	6.55		6.66
	$s_{\bar{X}}$							.1959	.1274	.1773	—		
VIII	N								17	3	1		21
	$\bar{X}$								6.85	6.72	6.70		6.82
	$s_{\bar{X}}$								.1092	.1618	—		
IX	N									10	2		12
	$\bar{X}$									6.74	6.85		6.76
	$s_{\bar{X}}$									.3300	—		
X	N										8		8
	$\bar{X}$										6.86		6.86
	$s_{\bar{X}}$										.2040		
XI	N											1	1
	$\bar{X}$											7.40	7.40
	$s_{\bar{X}}$											—	

TABLE 3

Number of Measurements, Mean Lengths, and Standard Deviations of Mean Lengths of Annuli in Left Otoliths of Female *Parophrys vetulus* in Various Year Classes from Carr Inlet

Annulus and	Statistic	Year Class											
		1950	1949	1948	1947	1946	1945	1944	1943	1942	1941	1940	Total
I	N	16	23	28	24	9	9	4	8	5	—	1	127
	$\bar{X}$	3.09	3.19	3.44	3.45	3.35	3.15	3.91	3.81	3.60	—	3.55	3.37
	$s_{\bar{X}}$	.0600	.0917	.0832	.0796	.1867	.1333	.4550	.2085	.1380	—	—	
II	N		11	28	24	9	8	4	8	5	—	1	98
	$\bar{X}$		5.30	5.23	5.17	4.98	4.88	5.28	5.24	5.02	—	4.85	5.16
	$s_{\bar{X}}$		.1747	.0813	.1000	.0967	.1590	.3750	.1979	.3661	—	—	
III	N			19	24	9	8	4	8	5	—	1	78
	$\bar{X}$			6.42	6.09	5.78	5.69	6.20	6.24	5.76	—	5.60	6.09
	$s_{\bar{X}}$			.1009	.1143	.1433	.1484	.3350	.1590	.1830	—	—	
IV	N				24	9	9	4	8	5	—	1	60
	$\bar{X}$				6.56	6.37	6.21	6.50	6.91	6.34	—	6.35	6.50
	$s_{\bar{X}}$				.0857	.1933	.2300	.2300	.1095	.1830	—	—	
V	N					12	9	4	8	5	—	1	39
	$\bar{X}$					7.43	6.63	7.28	7.34	6.87	—	6.90	7.13
	$s_{\bar{X}}$					.1474	.2900	.3800	.3110	.1920	—	—	
VI	N						14	4	8	5	—	1	32
	$\bar{X}$						7.54	7.64	7.71	7.25	—	7.20	7.54
	$s_{\bar{X}}$						.2139	.3900	.1025	.1875	—	—	
VII	N							13	8	5	—	1	27
	$\bar{X}$							7.90	7.99	7.50	—	7.70	7.85
	$s_{\bar{X}}$							.1607	.0954	.2232	—	—	
VIII	N								21	5	—	1	27
	$\bar{X}$								7.81	7.73	—	7.90	7.80
	$s_{\bar{X}}$								.1092	.2143	—	—	
IX	N									14	—	1	15
	$\bar{X}$									8.04	—	8.05	8.04
	$s_{\bar{X}}$									.1658	—	—	
X	N										6	1	7
	$\bar{X}$										7.66	8.25	7.74
	$s_{\bar{X}}$										.1384	—	
XI	N											3	3
	$\bar{X}$											8.48	8.48
	$s_{\bar{X}}$											.2486	.2486

Length-Weight Relationship of Otoliths

According to the Archimedean principle, the volume of similar figures increases as the cube of the linear dimensions. Mathematically this relationship is expressed by the formula: $W = kL^3$, where W = weight, L = length, and k = a constant. Since a survey of the literature* revealed that such a relationship in fish otoliths apparently had not been investigated, a study was made of otoliths from 119 male and 83 female English sole, obtained in Carr Inlet on July 18, 1951. The males ranged in total length from 97 to 318 mm and the females from 107 to 430 mm. Right and left otoliths were also weighed from 7 fish of undetermined sex ranging from 32 to 87 mm in length. The otoliths were carefully cleaned and thoroughly dried before weighing on analytical balances and recording weights to the nearest tenth of a milligram. The weights of the left otoliths of the 7 fish under 87 mm in length were the same as those of the right otoliths, or slightly greater. Only 20 of the 202 left otoliths in the larger fish were lighter than the right otoliths. While these differences averaged only 0.0007 gram, the remaining 182 left otoliths ranged up to 0.0092 gram heavier than the right otoliths. This difference generally became greater with increasing length of the fish. The comparative length-weight relationship of otoliths in bilaterally symmetrical fish or of sinistral flatfish is unknown, and the cause of such differences in the length and weight of the otoliths from the same fish also is a subject for further study.

For calculation of the length-weight relationship of the otoliths, only the left otolith was used, but the regression lines for the two sexes were calculated separately by the method of least squares. The differences were so slight as to be of no apparent significance. For males the equation was: $Y = 5.097\ X^{2.704}$, where Y = weight in mg and X = length in mm of the left otolith, ranging from 2.67 to 8.12 mm in length. For the female otoliths the regression line was fitted from the equation: $Y = 5.723\ X^{2.761}$, where the left otoliths ranged from 3.00 to 9.13 mm in length.

Observed and Calculated Rates of Growth

After separating the fish in each sample into age groups, the arithmetic mean of their total lengths at each age was computed separately for the two sexes, taking into consideration the date on which the samples were taken. Growth is comparatively rapid until the second year and then declines steadily, especially in the males. Growth curves for the two sexes were fitted by inspection of the plotted data for comparison with the calculated rate of growth, as determined by the fish-otolith length relationship (Table 4).

The scales on many fish are not formed until the fish has attained a certain amount of growth, necessitating the application of a correction factor. In the English sole, however, the otoliths are present at the time of hatching (Budd, 1940).

One method of establishing the rate of growth at each age assumes a direct relationship between otolith and fish length, viz.

$1 = \frac{sL}{S}$, where

1 = calculated length of fish at that annulus.
s = measured length of left otolith at that annulus.
L = total length of fish at time of capture.
S = total length of left otolith.

These lengths were calculated separately for the sexes in individual samples of the various year classes (1940-1950). Mean lengths computed for each age of that year class of English sole in Carr Inlet are listed in column (1) of Table 4 for comparison with the mean observed lengths, tabulated in column (5). The calculated lengths of the females closely fitted the observed lengths, but the calculated body lengths in the males tended to be lower than the average obtained by empirical means.

In the foregoing calculations the fish length-otolith length relationship was assumed to be linear, although it was previously demonstrated that this relationship is curvilinear. The second degree equation expressing this relationship was: $Y = -0.3217 + 0.032424X - 0.00002625X^2$, where Y = otolith length and X = fish length. The estimation of the length of the fish at each age by means of this formula is shown in column (2) of Table 4. For fish which were older than seven years and not adequately represented in the samples, the curvilinear relationship between otolith length and fish length for both sexes does not adequately express the age-length relationship for each sex. The lengths of each sex were estimated from the average length of the annuli of all year classes (tabulated in Tables 2 and 3), whereas the lengths calculated in column (1) of Table 4 were calculated from weighted mean lengths at various ages of the fish in the individual year classes.

Because the curvilinear regression was calculated for the combined sexes, without consideration of a possible differential or disproportionate increase in length of the fish and the otolith with increasing age, the parabolic equation logically could not be used for calculating the lengths. Hence, the equation $Y = bX^k$ was used to express this relationship, where Y = length and X = age. The lengths in columns (3) and (4) were calculated by means of a single logarithmic equation for each sex to express the body-otolith length relationship for all fish lengths greater than 10 cm.

*A report on this subject has been published recently:
Southward, G. M. and D. G. Chapman
1965 Utilization of Pacific halibut stocks: study of Bertalanffy's growth equation Internat. Pac. Halibut Comm. Report No. 39: 1-33

TABLE 4

Observed and Calculated Lengths in Millimeters at Each Age of *Parophrys vetulus* in Carr Inlet

Sex and Annulus	A. Calculations Based on Otolith Measurements			B. Observed Lengths	
Males	(1)	(2)	(3)	(5)	(6)
I	132	123	122	145	150
II	196	192	195	205	188
III	226	223	229	235	214
IV	244	243	249	250	236
V	253	256	260	263	253
VI	264	264	268	275	269
VII	273	278	280	285	283
VIII	285	288	288	292	295
IX	277	284	285	298	307
X	299	290	290	303	318
XI	289	324	317	307	328
Females	(1)	(2)	(4)	(5)	(7)
I	144	126	123	150	145
II	218	202	207	220	197
III	259	247	254	260	235
IV	284	269	275	293	267
V	313	305	308	317	295
VI	340	333	330	335	319
VII	357	356	347	350	341
VIII	362	352	344	364	362
IX	368	370	358	376	381
X	392	347	341	389	399
XI	381	402	382	400	416

(1) $1 = \frac{sL}{S}$
(2) $Y = -0.3217 + 0.032424X - 0.00002625X^2$
(3) $Y = 0.05567\,X^{0.8491}$
(4) $Y = 0.06805X^{0.8117}$
(5) Fitted by eye
(6) $Y = 14.98\,X^{0.3263}$
(7) $Y = 14.53\,X^{0.4388}$

Since approximately 50 per cent of the otoliths had completed formation of the "winter" ring by April 1, this date was used in the calculation of the "empirical" lengths at each age (recorded in column (5) of Table 4). A rough estimate was obtained by averaging the lengths of fish of that age in samples taken during a 6-month period prior to and after April 1. When curves were "eye-fitted" to the plotted data (Figure 3), the values shown in column (5) of Table 4 were estimated.

Finally, an attempt was made to estimate the lengths at each age by means of the equation: $\log Y = \log a + b \log X$, where Y = length in millimeters and X = age in years. All ages were tabulated in a frequency correlation table to the nearest year (April 1) and lengths to the nearest centimeter. For the males the regression line was fitted by the equation: $Y = 14.98X^{0.3263}$ and for the females: $Y = 14.53X^{0.4388}$. The calculated lengths at each age are recorded in column (6) of Table 4 for the males and in column (7) for the females. As in the other methods of estimation, these calculated lengths tended to be lower than the observed lengths.

To determine the validity of both the technique of growth determination in the otolith and age determination in the fish by the method suggested by Parkhurst (1939), it is necessary that the tagged English sole be at liberty for at least one year before recapture. Left otoliths from only 14 such fish were available. These tagged fish had been released in October 1950 or in January 1951 in Carr Inlet and had grown 2 to 30 mm in length during the time they were at liberty. The length of the otolith at the time of tagging was estimated by reference to the annulus formed in the interval between time of release and time of recapture. Length of the fish at the time of tagging (l_t) was computed from the equation:

$$l_t = \frac{s_t\,L}{S}, \text{ where}$$

s_t = estimated length of otolith at time of tagging
S = total length of otolith at time of recapture
L = total length of fish at time of recapture.

With one exception, the calculated lengths of the fish at the time of tagging were found to be within 3 mm of the actual lengths.

Corroboration of the growth of tagged fish through measurements of the otoliths must take into account an apparent cessation of growth, or even shrinkage, of the fish after tagging. For example, of the 15 English sole tagged in Carr Inlet in October 1951 and recaptured in January of the following year, 10 fish showed a shrinkage of from 1 to 5 mm, 2 showed no growth, and the 3 remaining fish showed growths of 2, 3, and 4 mm.

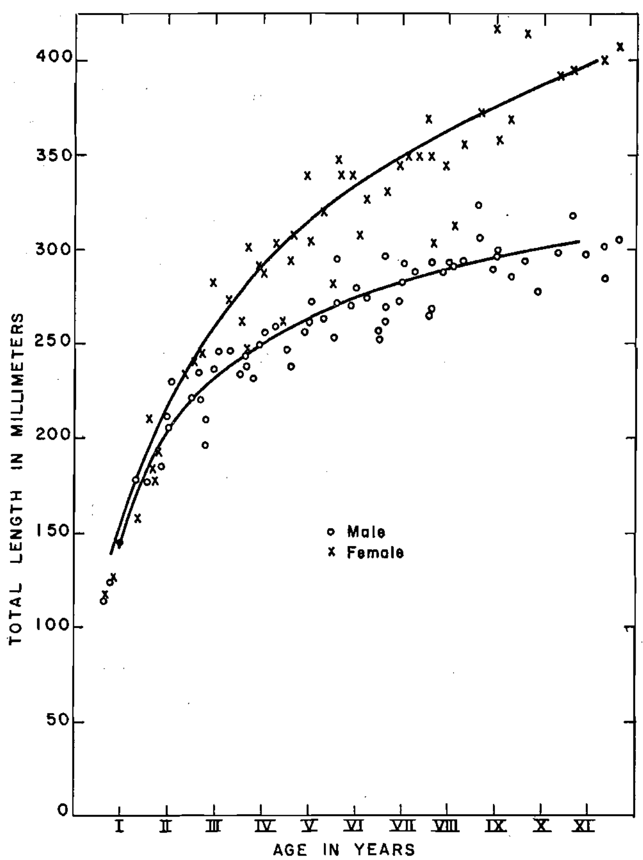


FIGURE 3. Rate of growth of *Parophrys vetulus* as indicated by average lengths of year classes in samples taken from Carr Inlet in 1950-1951.

Sinistral specimens of *Parophrys vetulus* rarely occur. One such specimen, a female 221 mm in length and in its third year, was taken near Golden Gardens beach on June 25, 1952. Not only was the right otolith larger than the left, but its nucleus was more centrally located than in any of the right otoliths examined from dextral specimens.

MORTALITY RATES

Natural mortality rates of the English sole were determined from their age distribution under the following assumptions: (1) that the populations in the four different areas had been adequately and uniformly sampled; (2) that these were unexploited virgin populations which had not previously been subjected to fishing mortality; and (3) that the rate of natural mortality had been stabilized for each age. Three samples, totaling 620 fish, were taken in Carr Inlet in March, April and July of 1951. A total of 607 fish was also obtained from the Golden Gardens area during the same year in March, April, August, September and October. A single sample of 100 fish was taken in Case Inlet in July 1951, and two samples totaling 316 fish were taken in Port Madison on September 25, 1950. All samples were taken by means of an otter trawl (Type No. 2) with a 1¼-inch mesh cod end, and the ages of all the English sole in the catches were determined. The depths sampled in Carr Inlet ranged from 14 to 42 fathoms, at Golden Gardens from 5 to 40 fathoms, in Port Madison from 12 to 24 fathoms, and in Case Inlet from 25 to 27 fathoms. The age distributions of the fish from these four areas are shown in Table 5.

To obtain a representative picture of natural mortality by age groups, the frequencies in Table 5 were smoothed by a moving average of three to construct the catch curves (Figure 4). The ascending left limbs in these curves represented an incomplete sampling of age groups in relation to their actual abundance. This was especially evident in the Carr Inlet catch curve for fish less than 6 years of age, indicating incomplete sampling, an actual dominance of the older classes, or a temporary absence of the younger age groups from the area sampled.

Usually the modal age is close to the first year in which availability to the sampling gear, or recruitment, is considered complete. Recruitment apparently was complete at 3 years of age for fish in the Golden Gardens population, as compared with 7 or 8 years for fish in the Carr Inlet samples. The entirely convex Carr Inlet catch curve may have been due to an increase in rate of natural mortality with age, variation in strength of year classes, or inability to discern more than 12 annuli on the otoliths. However, there was some indication of a decreased rate in the 5th and 6th years in the Golden Gardens catch curve. To demonstrate whether this irregularity was due to random errors of sampling or the presence of a dominant year class, it would have been necessary to sample these year classes for several successive years. In the catch curves for both the Port Madison and Case Inlet fish, a portion of the right limb was considerably more convex upward. The percentages of annual survival rates found by taking tangents at each successive age on the smoothed curves of Figure 3 are given in Table 6.

In the Carr Inlet population the rate of natural mortality between 8 and 9 years was 38.2 per cent for the males and 26.6 per cent for the females. Between 9 and 10 years the rate was 51.0 per cent and 47.7 per cent respectively. For these 2 age groups the average mortality rate of the males was 44.6 per cent, of the females 37.2 per cent, and of both sexes 42.6 per cent.

Comparison of natural mortality rates with the other three areas was hardly possible due to evidence of incomplete recruitment and inadequate sampling of the age groups.[3] Natural mortality rates between 3 and 5 years of age averaged 32.9 per cent for the males and 35.7 per cent for the females in the Golden Gardens

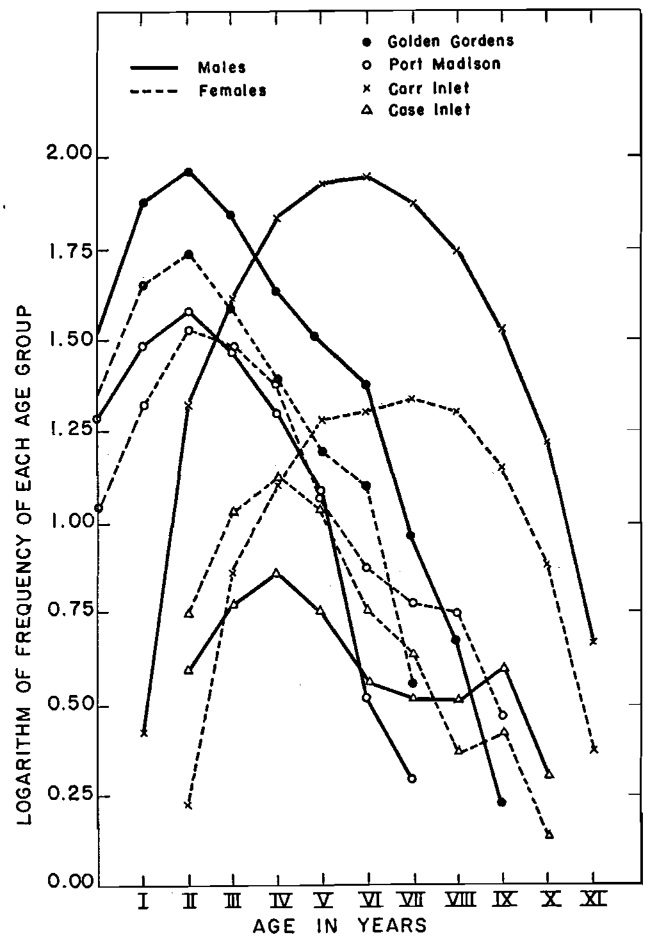


FIGURE 4. Catch curves for populations of *Parophrys vetulus* in four areas of Puget Sound.

[3]Van Cleve and Pruter (1956) pointed out that because of differences in net selectivity it is necessary to combine samples from different mesh sizes for more accurate data on growth and on age frequency. El-Sayed (1959) demonstrated that despite the different levels of mesh selection, the regression lines of the catch curves had a common slope.

TABLE 5

Percentage Age Composition of *Parophrys vetulus* in Carr Inlet, Case Inlet, and at Golden Gardens in 1951, and in Port Madison in September 1950

Age Group	Golden Gardens			Port Madison			Carr Inlet			Case Inlet		
	Number			Number			Number			Number		
	Males	Females	Per Cent	Males	Females	Per Cent	Males	Females	Per Cent	Males	Females	Per Cent
0	1	5	1.0	5	2	2.2	—	—	—	—	—	—
I	101	62	26.9	53	31	26.6	1	—	0.2	—	—	—
II	126	69	32.1	35	30	20.6	7	2	1.5	3	1	4.0
III	51	33	13.8	26	40	20.9	54	3	9.2	9	16	25.0
IV	30	14	7.2	29	21	15.8	62	17	12.7	6	16	22.0
V	49	27	12.5	5	11	5.1	92	19	17.9	7	9	16.0
VI	14	7	3.5	3	4	2.2	96	21	18.9	4	8	12.0
VII	9	4	2.1	2	8	3.2	73	20	15.0	—	—	—
VIII	4	—	0.7	1	6	2.2	56	24	12.9	6	5	11.0
IX	1	—	0.2	—	3	0.9	36	16	8.4	4	2	6.0
X	—	—	—	—	—	—	10	4	2.3	2	1	3.0
XI	—	—	—	—	—	—	4	3	1.0	—	1	1.0
XII	—	—	—	—	1	0.3	—	—	—	—	—	—
Total	386	221	100.0	159	157	100.0	491	129	100.0	41	59	100.0

TABLE 6

Annual Survival Rates of English Sole in Four Areas of Puget Sound (in per cent)

Age	Golden Gardens		Port Madison		Carr Inlet		Case Inlet	
	Males	Females	Males	Females	Males	Females	Males	Females
III	74.5	70.7	79.0	90.1	—	—	—	—
IV	62.8	63.8	66.7	79.1	—	—	—	—
V	71.5	64.9	61.7	50.0	—	—	77.4	80.5
VI	77.4	79.3	27.0	63.9	—	—	64.7	51.6
VII	37.5	28.9	60.1	78.2	86.2	—	90.7	76.4
VIII	51.9	—	50.0	94.5	73.3	92.3	100.0	53.8
IX	35.8	—	—	52.9	61.8	73.4	100.0	100.0
X	—	—	—	—	49.0	52.3	50.0	49.8
XI	—	—	—	—	28.0	30.4	—	—

population, as compared with 35.8 per cent and 35.5 per cent, respectively, in the Port Madison population. Because of the inevitable differences in abundance of different year classes, natural mortality rates calculated on the basis of age frequencies in samples taken during a single year may not be indicative of the actual rates. In any event, the data for the populations of southern Puget Sound indicate a greater survival rate to an older age. As previously mentioned, there was no evidence that the Golden Gardens and Port Madison stocks had been subjected to a significant fishing mortality.

In his calculations of mortality rates of *Parophrys vetulus* on British Columbia fishing grounds, Ketchen (1947) used only samples of age groups presumably free from gear selectivity and incomplete recruitment. Total annual mortality rates (including fishing mortality) ranged from 50 to 67 per cent on the more heavily exploited grounds. However, in the virtually virgin populations of northern Hecate Strait the natural mortality rate of the male and female English sole was estimated to be 38 per cent and 30 per cent respectively.

SUMMARY

1. Material for this study of age, growth, and natural mortality of the English sole *(Parophrys vetulus)* was obtained from September 1950 to April 1952 from two areas in southern Puget Sound (Carr Inlet and Case Inlet) and two areas in middle Puget Sound (Golden Gardens and Port Madison).

2. Statistically significant differences in dorsal and anal fin ray counts were found between these areas of southern Puget Sound and the areas of middle Puget Sound, 40 to 50 miles away.

3. At a given age the females are larger and have a significantly greater head length and body depth than the males.

4. Infestation of *Parophrys vetulus* by a nematode worm, *Philametra americana,* is more prevalent in southern than in middle Puget Sound.

5. A preponderance of male English sole was found in the samples taken throughout the year from Carr Inlet probably due to the selectivity of the 1¼-inch mesh cod-end.

6. The equations for the curves of the length-weight relationship of English sole in Carr Inlet were calculated to be:

   Males: $Y = 0.01031\ X^{2.970}$

   Females: $Y = 0.01407\ X^{3.077}$

   For the English sole at Golden Gardens the length-weight curves were fitted by the method of least squares:

   Males: $Y = 0.00001321\ X^{3.033}$

   Females: $Y = 0.00001168\ X^{3.012}$

   In these equations $Y =$ weight in grams and $X =$ length in millimeters.

   Although the length-weight relationships of the sexes in each area and of the same sex in these two areas were significantly different, they are not strictly comparable, since they do not include the same range of lengths and weights, different types of gear were used for sampling, and samples were taken over a 2-year period.

7. A curvilinear relationship exists between growth of the left otolith and growth of the fish when the length of the otolith is measured along its antero-posterior axis, ventral to its nucleus.

8. Measurements of the length of annual rings in the left otoliths of females were greater than those of corresponding rings in left otoliths of males, illustrating the faster growth rate of the females.

9. The length-weight relationship of left otoliths in English sole in Carr Inlet was calculated by the method of least squares, and the following formulae derived:

   Males: $Y = 5.097\ X^{2.704}$

   Females: $Y = 5.723\ X^{2.761}$

   In these equations $Y =$ weight in milligrams and $X =$ length in millimeters.

10. The observed rate of growth of the English sole was approximately the same in the four areas sampled in southern and middle Puget Sound.

11. The rate of growth calculated from the left otoliths generally corresponds with the observed rate of growth of male and female English sole in Carr Inlet.

12. At the time of this study English sole survived to an older age in Carr Inlet than in the areas sampled in middle Puget Sound. In Carr Inlet, natural mortality rates for males increased from 38.2 to 51.0 per cent between the 8th and 10th year and for females from 26.6 to 47.7 per cent. At Golden Gardens the natural mortality rates between 3 and 5 years of age averaged 32.9 per cent for the males and 35.7 per cent for the females.

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Age, Growth, and Productivity of an English Sole (*Parophrys vetulus*) Population in Puget Sound, Washington

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AGE, GROWTH, AND PRODUCTIVITY OF AN ENGLISH SOLE (*Parophrys vetulus*) POPULATION IN PUGET SOUND, WASHINGTON*

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On January 1, 1953 Holmes Harbor (Figure 1) was re-opened to commercial trawling after being closed since 1937. This presented an opportunity to observe the effects of fishing on an accumulated stock of English sole (*P. vetulus*) though unfortunately the closed area was not sampled before it was opened to fishing. A cooperative program was developed between the College of Fisheries and Washington State Department of Fisheries to study the population of *P. vetulus* in the Holmes Harbor, Saratoga Passage area. This program included a series of tagging experiments and measurements of lengths of fish from samples of the commercial catches on board the vessels and as landed, as well as a series of measurements of length, age and weight by sex of fish taken with three different mesh nets using the University of Washington research vessel *Oncorhynchus*. This report covers data taken during the years of 1953 to 1956.

The life history and growth of *Parophrys vetulus* in California, Oregon, Washington, and British Columbia were studied first by Villadolid (1927) who used scales to determine age. Otoliths were used by Smith (1936), Ketchen (1947), Holland (1954), and Harry (1956). Manzer and Taylor (1947) calculated growth increments of *P. vetulus* from the Strait of Georgia from recovered tagged fish. Palmen (1956) at the suggestion of the present authors used the interoperculum to determine ages of fish from Hecate Strait, British Columbia.

In this investigation a total of 58,890 fish of both sexes were measured for length and identified by sex. Ages were determined for 13,480 of these. The greatest number was taken from the Holmes Harbor-Saratoga Passage area (Figures 1 and 2), from a population which tagging had indicated is virtually isolated (Van Cleve and Pruter, 1956). Fish were taken in Carr Inlet to compare the growth rate of *P. vetulus* in southern Puget Sound with those in northern Puget Sound. Growth of the "zero" age-group of *P. vetulus* was studied from monthly samples taken between August 1953 and August 1954, with a beach seine at Golden Gardens (Seattle, Washington) and from a series of samples of young fish collected by the staff of the Oregon Fish Commission in Yaquina Bay, Oregon, between February 1952 and June 1953. The latter were taken with a small otter trawl called a "try net."

Sampling

All trawls used were of a standard western commercial design with a foot rope 50 feet long with cod-ends of 1½-, 3½-, and 4½-inch mesh. Hauls with the different mesh nets were usually taken consecutively at each station but the order in which the different meshes were used differed at each station. The nets were hauled over about the same ground at each station in an attempt to sample the full range of sizes of *P. vetulus* present. The length of each haul varied with location, depth, and expected numbers of fish, and averaged 15.8 minutes in Holmes Harbor and Saratoga Passage, 46.5 minutes in Port Gardner and 18.9 minutes in Carr Inlet. Depths sampled ranged from 9 to 80 fathoms.

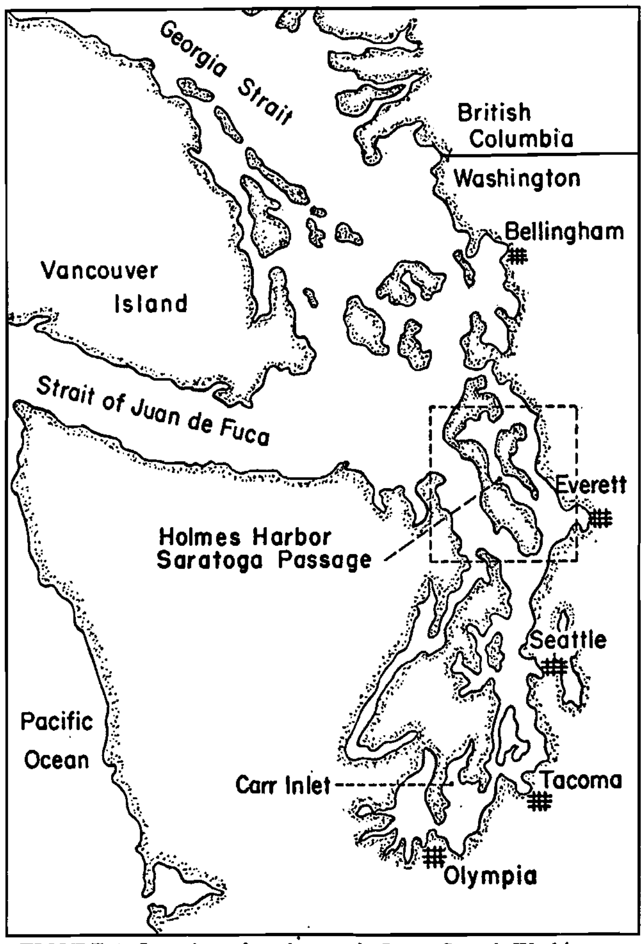

FIGURE 1. Location of study area in Puget Sound, Washington.

All specimens were measured for total length from the tip of the lower jaw (with the mouth closed) to the tip of the middle rays of the caudal fin. Interopercula were removed from the right or eyed side of all fish when the numbers taken were not too great to be handled conveniently. Total weights to the nearest 0.1 gram were obtained at different times of the year in 1953 to establish the length-weight relationship.

*Contribution No. 72, College of Fisheries, University of Washington

Comparison of the age distributions of all fish in a trip with samples of five and of ten specimens randomly selected from each centimeter-length class indicated that a sample of five was insufficient to give an accurate picture of the age distribution even when the samples from eight or ten hauls during one trip were combined. The use of ten fish from each centimeter-length class from each haul yielded distributions that did not differ significantly from those obtained by aging all fish in a trip, when the significance of the difference between the two distributions was tested by Chi-Square. Accordingly, the right opercle was removed from ten fish in each centimeter-length class in which ten or more specimens fell, in all catches which were large enough to be handled in this way. All fish were aged in length classes with less than ten fish. The interopercula were cleaned by soaking in water just warm enough to coagulate the flesh and loosen the skin.

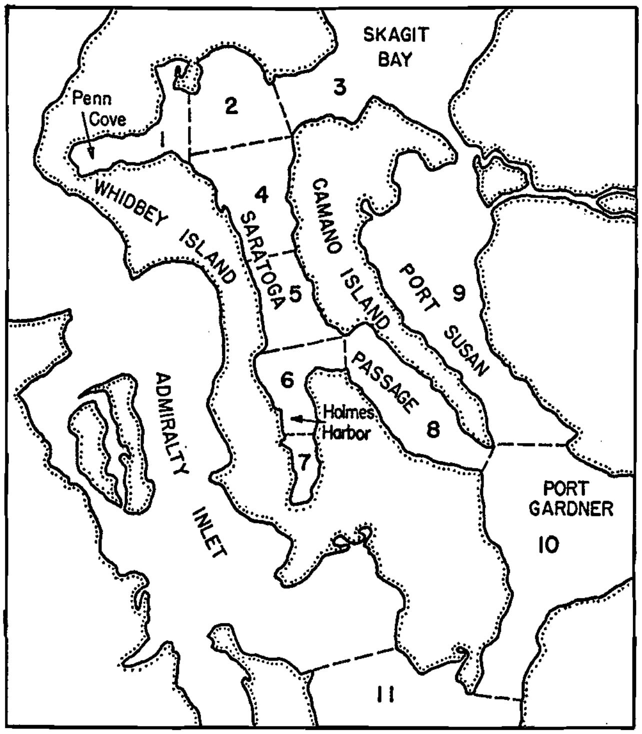

FIGURE 2. Detailed map of study area showing Saratoga Passage and adjacent waters.

Determination of Age

It was found that the age of *P. vetulus* more than six years old was difficult to determine from otoliths due to crowding and overlapping of the outer rings. Examination of the skeleton of *P. vetulus* led to the use of the interoperculum which provided the clearest pattern of alternate opaque and clear growth zones in this species.

The variability of ages determined from otoliths taken in 1953 is shown in Table 1 in which the year classes

TABLE 1

Comparison of Otolith Readings by Two Readers.

(Numbers included between the diagonal lines indicate area of agreement.)

Reader 1

Reader 2: Year Class	1953	1952	1951	1950	1949	1948	1947	1946	1945	1944	1943	1942	1941
1953	1												
1952		10											
1951			44										
1950				17	1	1							
1949			1	2	34								
1948				1	2	29	1						
1947						1	13	7	1	1			
1946						1	2	15	7	1	2		
1945							1	3	12	1		1	
1944						1		1	1	5	6	1	1
1943							1	1	1	1	12	4	
1942											2	1	1
1941										1			
1940												1	

assigned to 255 otoliths by two readers are compared. The differences in assigned ages increased with the age of the fish although there was 74.6 per cent agreement between the two readers, with a total of 42 of the 63 disagreements accounted for by a difference of one annulus. A correlation coefficient of 0.959 was found between the 255 pairs of readings. A correlation of 0.922 was also found between ages as determined from the otoliths and percentage disagreements at each age between readers, i.e., the number of disagreements increased with the age of fish. The ages assigned from the otoliths are compared in Table 2 with those assigned from interopercula taken from the same fish in which the year classes assigned to individual specimens from the otoliths are listed vertically and the year classes of the same specimens assigned from the interopercula are listed horizontally. These readings were made independently by the two readers without reference to the length or sex of the fish involved. Agreement between the ages as determined from the 2 structures was obtained in 205 out of 295 or approximately 70 per cent of the readings. Only 4 otolith readings exceeded those from the interopercula by more than one ring, while 31, or 10.5 per cent, of the otoliths were assigned to year classes that were 2 or more years younger than the year class assigned from the interopercula. Seventeen, or 5.8 per cent, of the otoliths were read with one year more than the interopercula.

A correlation coefficient of 0.934 was calculated between the 295 pairs of otolith and interoperculum readings. This correlation was compared with that between paired readings of otoliths (Table 1). Using Fisher's z, $z = 2.937$ which is significant at the 1 per cent level. Thus the correlation between pairs of readings of the otoliths was significantly greater than the correlation between pairs of readings from otoliths and interopercula from the same fish. Examination of Table 2 indicates that the difference between otolith and interoperculum readings increases with age and that the otolith readings tend to be progressively smaller.

A still higher correlation coefficient ($r = 0.991$) was calculated between 905 pairs of interopercula read by 2 readers shown in Table 3. When this correlation was compared with that between otolith readings in Table 1, $z = 11.163$ for which $P < 0.01$.

After the size of the first annulus of the interoperculum had been established (see below), re-examination of the bones with disagreements in first readings made it possible to reach agreement on 93.74 per cent of a

TABLE 2

Comparison of "Final" Ages Determined by 2 Readers from 295 Otoliths and Interopercula from the Same Fish.

(Numbers included between the diagonal lines indicate area of agreement.)

Interopercula

Otoliths: Year Class	1953	1952	1951	1950	1949	1948	1947	1946	1945	1944	1943	1942	1941	1940	1939	1938
1953	1															
1952		10														
1951			44	2	1	1										
1950				16	3											
1949					37	4										
1948				1	4	31	7	2	1							
1947					1	4	18	4	1				1			
1946							4	17	2		1		1			1
1945								2	13	2	4		4			
1944										4	5					1
1943							1		1	1	11	4	2	4	1	
1942											2	2	1	2		2
1941													1	3		1
1940															1	

total of 3,970 bones taken in 1953 and 1954. This high percentage of agreement between two readers, together with the clarity of the zones even in older fish led to the use of the interoperculum in preference to the otolith in studying the age of *P. vetulus*. The clean dried bones are most easily read at a magnification of 3X while immersed in 95 per cent alcohol.

Determination of the Size of the First Annulus

Duplicate readings (from a different trip from that used for Table 3 readings) of 928 interopercula made by 2 individuals disagreed in 15.4 per cent of the bones. It was found that the major cause of disagreements of one year was in identifying the first annulus. It appears that a permanent clear zone may be formed in the center of the interoperculum of young fish hatching from eggs spawned in the late fall. These fish are ready to settle to the bottom and may begin to grow rapidly by late February or early March depositing a sharply marked opaque zone around the small clear center of the bone. On the contrary, young fish produced later in the spawning season during February, March or later may not settle to the bottom until May, June or as late as July and while they grow rapidly after settling to the bottom, their interopercula remain clear and do not form an opaque zone until the beginning of growth at the start of their second year of life. While relatively few fish exhibit the small clear zone which represents only a few months of growth the number was sufficient to require determination of the size of the interoperculum at the end of the first year of growth.

In Figure 3 are shown the size frequencies of the

TABLE 3

Comparison of Interoperculum Readings by Two Readers.
(Numbers included between the diagonal lines indicate area of agreement.)

Reader 1; Reader 2

Year Class	1953	1952	1951	1950	1949	1948	1947	1946	1945	1944	1943	1942	1941	1940	1939	1938	1937	1936
1953	51	5																
1952		156	9	1														
1951			36	6	2													
1950			2	76	12	2												
1949				8	109	10	1											
1948					11	82	9	2										
1947						11	62	2										
1946						2	6	49										
1945								4	25	1								
1944								1	3	42	2							
1943									2	4	22	3						
1942									1	1	3	19						
1941											1	2	20	1				
1940													6	7	1			
1939															7			
1938															1	1	1	
1937																1	0	
1936																		1

interopercular radii of juvenile *P. vetulus* (sexes not separated) taken off Golden Gardens between August 1953 and August 1954. The minimum radius reached 5.2 mm (29.4 units in Figure 3) on December 21, 1953. These specimens were all assigned to the 1953 year class. Approximately the same minimum was found for the same year class in the February 1954 sample.

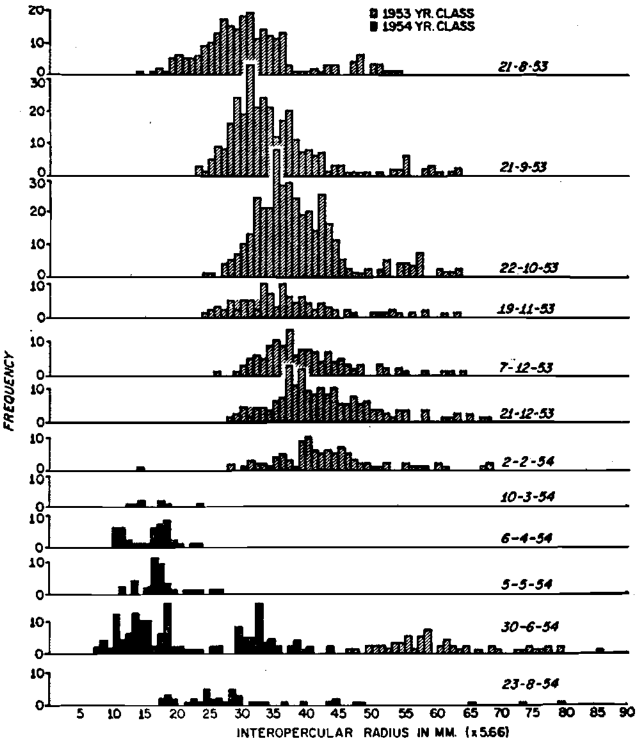

FIGURE 3. Frequency distributions of interopercular radii of *P. vetulus* (sexes not separated) taken off Golden Gardens between August 1953 and August 1954.

Comparison of the size of Golden Gardens fish with specimens taken between February 1952 and June 1953 in Yaquina Bay in Figure 4 shows the minimum interopercular radius of age zero fish belonging to the 1952 year class was 1.41 mm (8.00 units) in March 1952. The minimum interoperculum radius for zero fish in February 1953 was 1.76 mm (9.96 units) while the minimum radius for 1-year fish in February was 5.8 mm (32.8 units).

Examination of the radii of interopercula from age I fish taken in Holmes Harbor in March 1954 showed that less than 5 per cent had a radius of less than 6.2 mm (35.1 units). It was decided that 6.2 mm could be accepted as the minimum radius that would be counted as a first annulus. This overlaps the largest interopercula of the zero group fish and may have caused some confusion between the zeros and the next older age group. However, it has not resulted in any major error in the growth curves since all but a few of the first annuli lie well above the minimum size established.

Validity of Age Determination

The interopercular ages were checked against the annual growth pattern of young fish and throughout the year with the occurrence of clear or opaque growth around the margin of the interopercula observed at different times of year.

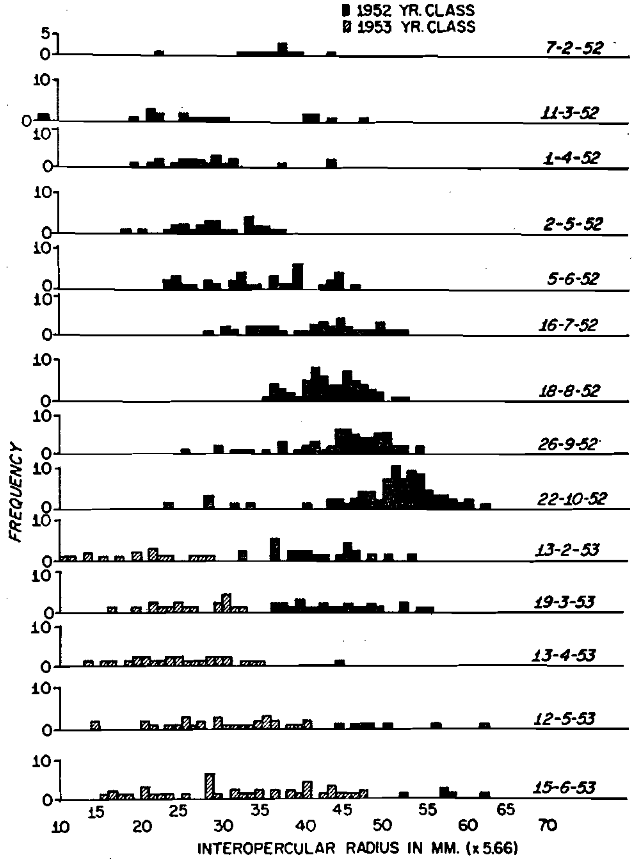

FIGURE 4. Frequency distributions of interopercular radii of *P. vetulus* (sexes not separated) taken in Yaquina Bay between February 1952 and June 1953.

Length-Frequency Curves of Young Fish

The growth during the first year was followed in length-frequencies on successive dates of sampling. The length frequencies of fish from Yaquina Bay taken between February 1952 and June 1953 are shown in Figure 5. While a few fish of the 5-cm size group were present in May 1952, no smaller fish were taken at that time. A more extended spawning season than that indicated by Smith (1936) is indicated by a few fish less than 5 cm long in the June 1953 sample. The progression of modes for a dominant size group is plain in the Yaquina Bay samples indicating growth from about 7 cm in May 1952 to 14 cm in October. Use of a finer mesh net in 1953 gave a modal length of 4 cm in February and 7 cm in May of 1953. Confusion is introduced by the 4 cm mode below the larger group of fish with a mode at 10 cm in the sample taken in June 1953.

The Golden Garden samples (Figure 6) were taken with a ½-inch (stretch mesh) beach seine. The mode of 7 to 8 cm in the August 1953 sample increased to 10 cm by October of that year, but thereafter showed no change until February of 1954 when it had increased 1 cm. In the same sample in February 1954, one 4-cm fish was taken. The number of small fish ranging from

2 to 7 cm reached maximum numbers in the May sample in 1954 with a modal length at 5 to 6 cm. The zero group ranged from 2 cm to 10 cm in length. In the June samples, a second group of small fish had moved into the intertidal area and the modal group, so numerous the month before, had either moved out or was not sampled. The bimodal distribution is evident in the distribution of radial measurements as well as in the fish lengths but was lost in the small August sample.

Small *P. vetulus* were taken with a 6-foot hand seine at Richmond Beach at low tide on June 23 and August 5, 1956, by Dr. Allan C. DeLacy. The lengths of these

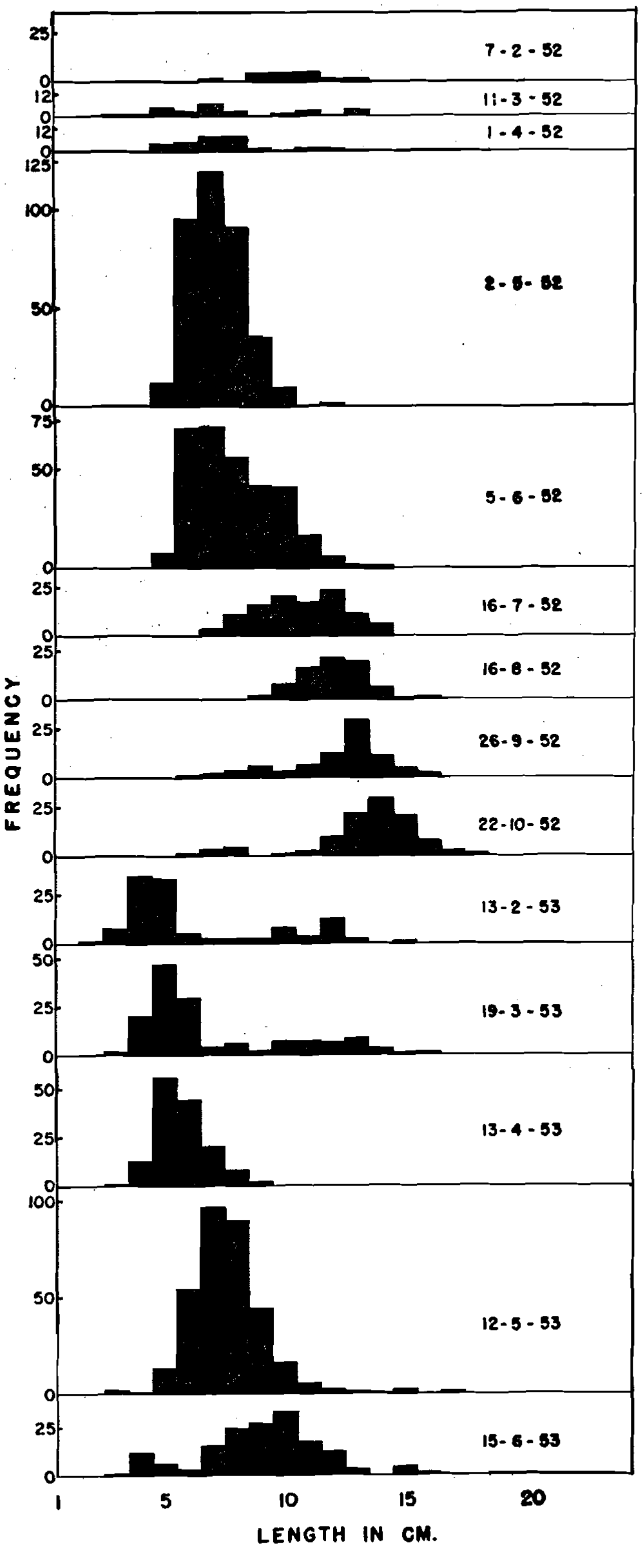

FIGURE 5. Frequency distributions of length of *P. vetulus* (sexes not separated) taken in Yaquina Bay, Oregon, between February 1952 and June 1953.

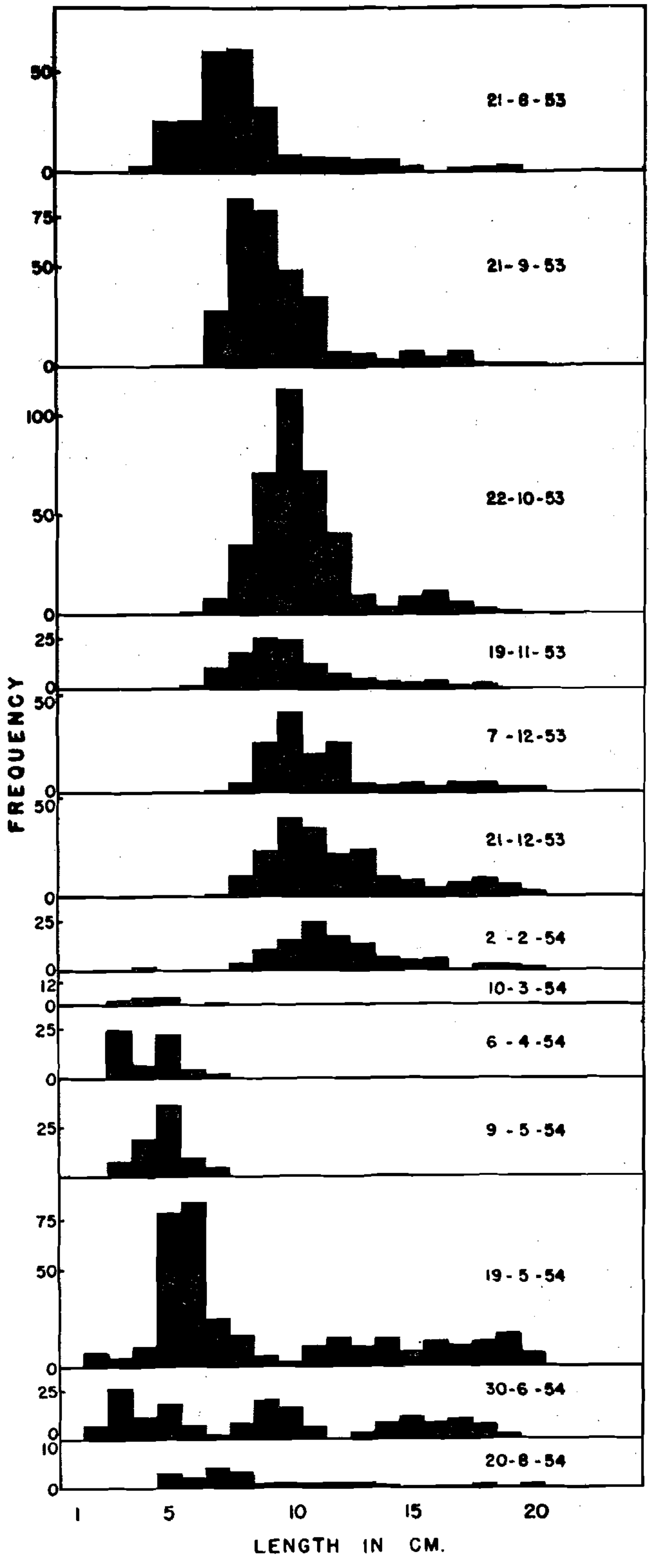

FIGURE 6. Length frequency of *P. vetulus* taken off Golden Gardens, Wash., between August 1953 and August 1954.

specimens were not included in Figure 6; they varied from 19 to 30 mm in the June sample and from 21 to 47 mm in the August sample. They extend the period of occurrence of the first bottom stages of *P. vetulus* from June into August. While the exact ages of these small specimens are not known, it is unlikely that they would be more than 2 months old which indicates that *P. vetulus* may spawn as late as May in Puget Sound. They also extend the August 1953 length frequencies shown in Figure 6, two cm toward the smaller sizes and would require a minimum growth of 5 cm between August 1 and late December when the minimum length taken was 7 cm. The length distributions in 1953 indicate that such growth would not be impossible. However, the smallest fish were probably not sampled in the fall of 1953. The Yaquina Bay length distributions shown in Figure 5 indicate a growth of 6 to 7 cm between June and October but no samples were taken there between October 1952 and February 1953. The appearance of these young fish in the spring at the two localities corresponds with the incidence of growth on the interopercular bones.

Formation of the clear and opaque zones on the edges of the interopercula was studied in the specimens taken at Golden Gardens between August 1953 and August 1954. The bones were classified into the following three categories: (1) the edge totally or partially clear; (2) the clear margin so narrow it could barely be discerned; (3) opaque growth on edge. The numbers and percentages found in each category are shown in Table 4. The highest percentages of opaque edges were found between May and November which may thus be considered the season of growth. This same period included the lowest percentages of definitely clear margins. The two December samples show the greatest percentages of Category 2 edges which included those which could not be placed definitely in either Categories 1 or 3. The results agree with the hypothesis that one clear and one opaque zone is formed each year although false marks — with incomplete clear zones also occur. The small numbers of clear margins observed between May and August 1954 as well as in August to October 1953 is significant.

The formation of opaque and clear zones on 3,322 adult fish taken in the study area between February 18, 1953 and July 12, 1954 was also studied and gave essentially the same picture although difficulties in distinguishing clear edges due to lack of growth, from clear edges due to especially rapid growth, somewhat obscured the results. Nevertheless it seems apparent that a clear zone is normally deposited between December and April with opaque (growth) zones being deposited the rest of the year.

Relation of Interopercular Radius to Total Fish Length

The relationship between interopercular radius and total fish length was studied from photographs taken at a magnification of 5.66 of interopercula from 569 females and 541 males. Measurements were made in millimeters from the center of growth to the exterior edge of the bone (Figure 7). The origin (c) was taken to be the point which lies at the intersection of the two straight lines (a) and (b) drawn tangent to the obtuse angle of the dorsal edge of the interoperculum as shown by the intersection of lines in Figure 7. The position of this point can be judged with accuracy.

TABLE 4

Numbers and Percentages of Interopercula Showing Various Types of Growth on the Margin in Samples Taken from Golden Gardens.

Date	Category I (Clear Margin)		Category II (Barely Visible Clear)		Category III (Opaque Margin)		Total
	No.	%	No.	%	No.	%	No.
Aug. 21, 1953	0	0	0	0	259	100	259
Sep. 21, 1953	16	5	27	8	299	87	342
Oct. 22, 1953	44	12	39	11	271	77	354
Nov. 19, 1953	33	29	1	1	80	70	114
Dec. 7, 1953	69	42	24	14	72	44	165
Dec. 21, 1953	150	57	46	18	66	25	262
Feb. 2, 1954	87	83	7	7	11	10	105
Mar. 10, 1954	7	78	2	22	0	0	9
Apr. 6, 1954	21	38	4	7	30	55	55
May 5, 1954	0	0	1	2	39	98	40
June 30, 1954	5	2	6	3	194	95	205
Aug. 23, 1954	1	2	1	2	42	96	44

The relation between body length and interopercular radius shown in Figure 8 is described by straight lines which fit the following equations:

Females: $L = 3.945 + .2069$ Op.
Males: $L = 3.428 + .2122$ Op.
where L = total fish length in cm
Op = magnified interopercular radius in mm

From the equations it appears that the fish would have an average length of some 3.4 to 3.9 cm when the interoperculum is just formed. In the development of pleuronectids the relationship between interopercular radius and body length changes markedly at metamorphosis (Thompson and Van Cleve 1936).

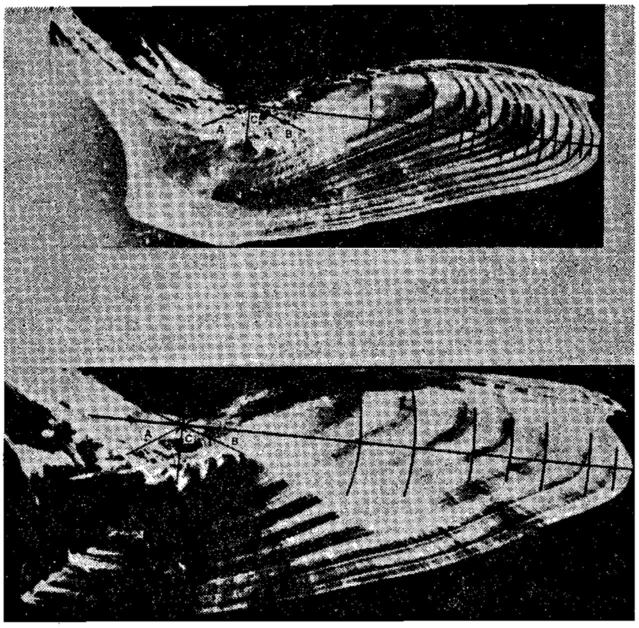

FIGURE 7. Photographs of typical male (upper) and female (lower) interopercula. The maximum anterior radius of each winter zone is marked on the photograph by a compass and is then measured by a ruler along a line drawn from the center "c" to the farthest anterior point. "a" and "b" are straight lines intersecting "c."

Lengths were calculated at each age from measurements of 1,110 interopercula photographed at a magnification of 5.66X using the outside radius of each clear zone measured from the "focus" anteriorly as indicated in Figure 7. The calculated lengths which are compared with observed lengths of fish taken in trip 5305* (Figure 8) show fair agreement. Since the interopercula used for the calculations were taken from fish captured in March, April and July of 1953 and were compared with those taken in February 1953, it is not surprising that differences increase at both smaller and greater lengths. Further study and possible refinement of the relationship would be desirable if the interopercular radius were to be used to calculate fish lengths but an attempt to fit a second degree equation to the relationship resulted in a non-significant coefficient for the higher power of the independent variable.

*Each trip is referred to here by four figures, the first two of which refer to the year in which the trip was made and the last two figures refer to the number assigned to that particular trip, e.g., trip 5305 refers to the fifth trip made in 1953.

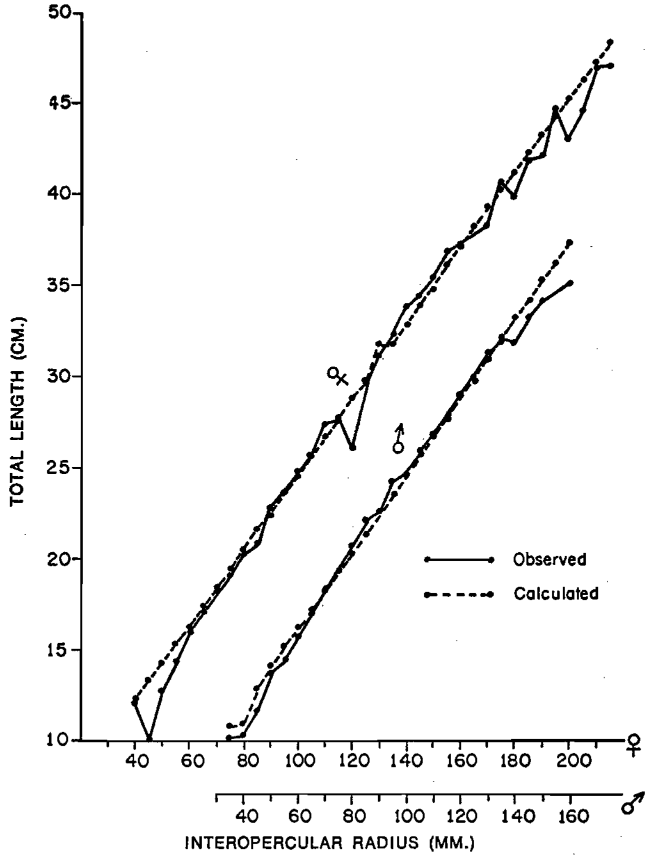

FIGURE 8. Mean observed and calculated lengths of male and female *P. vetulus* corresponding to radii of interopercula.

The validity of the first age mark was determined by comparison with changes in length frequencies during the year. The occurrence of clear and opaque edges on the interopercula indicates one of each is formed each year. Further indication of the validity of the interoperculum as a source of age measurements is the linear relationship found between interopercular radius and length. This combined with high consistency of repeated readings makes the interoperculum clearly a superior source of age data in *P. vetulus.*

Growth of *P. vetulus* in Puget Sound

The different growth rates of the males and females made it necessary to deal with them separately. For computing a general growth curve the measurements of each sex from each trip were combined from all meshes. The observed mean lengths at capture of each age are shown in Table 5 (females) and Table 6 (males) for samples taken during January, February, or early March of each year. The lengths vary between years but show no trend for the females as may be seen in Figure 9. The apparent increase in lengths of older males shown for ages 4 to 10 in Figure 10 is not shown in the lengths of ages 12 through 16, if 1956 is compared with 1954 (Table 6). The change shown is un-

TABLE 5

Mean Lengths in Centimeters of Female *P. vetulus* at Each Age Group in Trips Made in 1953, 1954, 1955 and 1956.

Trip / Age Group	5305 (1)	5307 (2)	5405 (3)	5501 (5)	5604 (6)	Aver. of: (1), (2), (3) (5) and (6)
I	14.89	17.00	14.42	15.20	14.84	15.27
II	21.21	19.44	21.61	20.79	21.00	20.81
III	25.78	25.05	28.38	22.06	26.82	25.62
IV	29.35	30.61	30.38	28.05	31.88	30.05
V	33.31	33.27	33.76	33.27	34.49	33.62
VI	33.37	34.40	35.78	35.03	36.38	35.99
VII	35.89	35.78	37.71	36.25	37.58	36.64
VIII	37.00	37.91	39.53	39.40	39.58	38.68
IX	37.25	40.00	39.76	38.56	40.28	39.17
X	39.92	38.40	41.00	39.00	41.47	39.87
XI	38.40	39.00	42.64	41.00	40.67	40.34
XII	42.00	43.00	43.50	39.00	42.28	41.96
XIII	41.37	44.00	43.00	39.00	40.25	41.52
XIV	39.00	44.00	42.75	40.00	43.50	41.85
XV	43.33	....	....	45.00	41.33	43.22

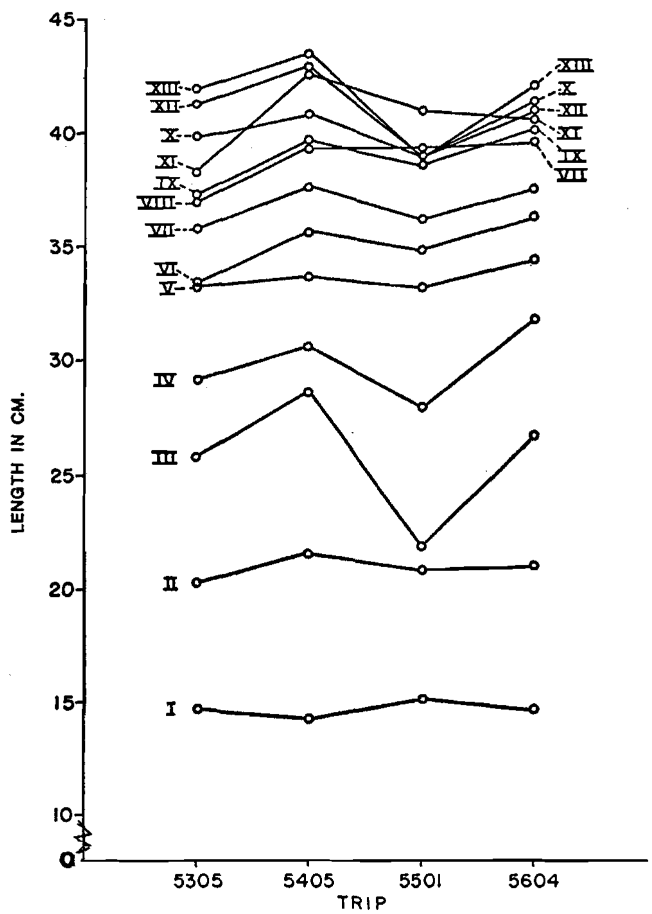

FIGURE 9. Average sizes of age groups I-XIII of female *P. vetulus* caught in the study area in samples taken in trips 5305, 5405, 5501 and 5604.

TABLE 6

Mean Lengths in Centimeters of Male *P. vetulus* at Each Age Group in Trips Made in 1953, 1954, 1955 and 1956.

Trip / Age Group	5305 (1)	5307 (2)	5405 (3)	5501 (5)	5604 (6)	Aver. of: (1), (2), (3) (5) and (6)
I	14.23	16.67	14.20	16.10	13.87	15.01
II	20.02	19.17	21.53	20.75	20.24	20.34
III	24.53	22.96	24.51	23.48	24.67	24.03
IV	25.01	24.61	26.35	25.59	27.93	25.89
V	26.84	25.96	28.66	27.66	28.64	27.55
VI	27.33	27.25	28.96	28.35	29.96	28.37
VII	27.88	29.00	28.96	29.37	30.67	29.18
VIII	28.31	29.69	30.61	29.55	30.38	29.71
IX	29.25	29.80	30.86	30.19	30.96	30.21
X	28.39	29.44	31.00	30.97	31.76	30.31
XI	29.27	30.28	30.46	30.31	33.22	30.71
XII	30.22	30.75	34.00	31.15	31.22	31.47
XIII	28.71	30.67	31.75	30.31	31.80	30.65
XIV	30.57	31.50	31.92	30.62	31.43	31.21
XV	32.58	31.50	32.50	31.44	32.00	32.00
XVI	....	33.00	31.67	29.00	30.00	30.92

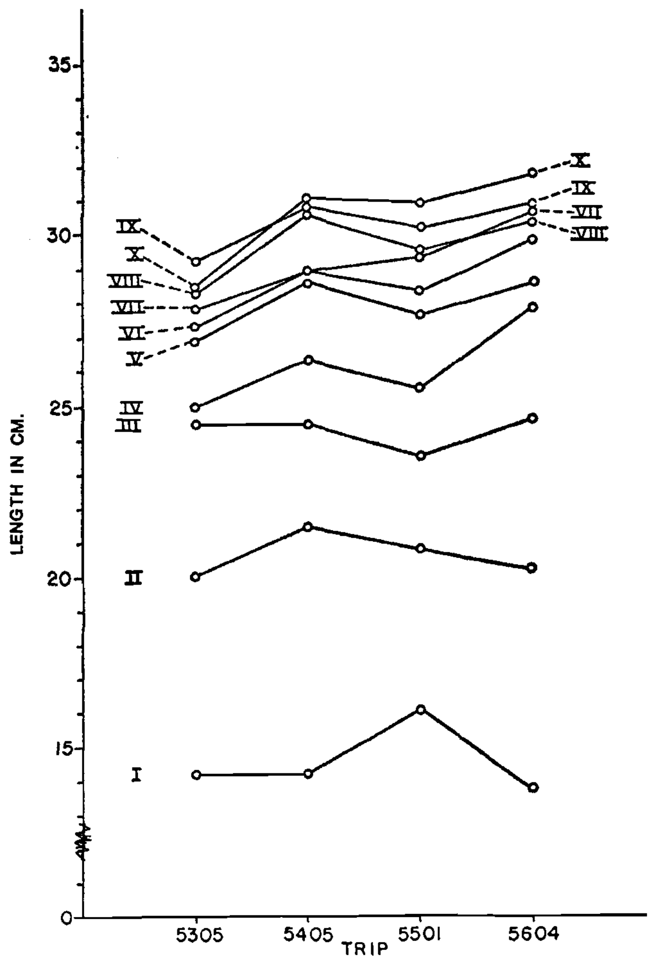

FIGURE 10. Average sizes of age groups I-X of male *P. vetulus* caught in the study area in samples taken in trips 5305, 5405, 5501 and 5604.

doubtedly due to sampling and may in part be the result of a state regulation which sets a minimum length of 29.5 cm for commercially caught *P. vetulus.* This eliminates from landings some males through age 12 and a substantial proportion of even the, oldest males taken. It thus results in a highly variable mortality on the older ages and larger males. The change in length was interpreted by Van Cleve and Pruter (1956) to indicate a change in growth rate which might have resulted from the intense fishery of January 1 to February 15, 1953. It is very doubtful, however, that even the removal of about 140,000 lb. of *P. vetulus* from Holmes Harbor alone between January 1 and February 15, 1953 could have brought about a change in growth rate by 1956 unless the thinning of the stock resulted in an immediate surplus of food. The growth curves of males and females shown in Figure 13 were fitted to average length using IBM program FRA 706.

Comparison of Present Growth Studies of *P. vetulus* with Those of Other Workers

The data on growth of *P. vetulus* collected by Villadolid (1927), Smith (1936), Holland (1954) and Palmen (1956) are not strictly comparable with the present data. Villadolid used the scales of *P. vetulus* for age-determination, while Smith and Holland used otoliths. In addition, Palmen, Villadolid and Smith obtained their samples from the commercial catch which apparently is highly selective against smaller *P. vetulus.* The sizes taken with the 1½- and 3½-inch cod-end meshes employed by Holland must have differed from those taken with the 1½-, 3½- and 4½-inch cod-end meshes used in the present study.

Despite these differences in sampling, it is interesting to see from Table 7 and Figures 11 and 12 that the growth rates of *P. vetulus* from Carr Inlet (Holland's data), Holmes Harbor (areas 1-10, present data), and Port Discovery and Strait of Georgia (Smith's data) are similar up to age four for both sexes. But, in older age groups the growth rates of fish from Port Discovery, Strait of Georgia and Hecate Strait surpass those of Carr Inlet and Holmes Harbor and thereafter maintain a marked superiority in average length at each age. The ages determined from scales by Villadolid must have been grossly in error. We have looked at the scales of *P. vetulus* but have made no attempt to use them since their structure seemed to give no evidence of age marks.

Length-Weight Relationship

Weights were obtained from fish taken in February (trip 5305), July (trip 5316) and November 1953 (trip 5327). This included 844 males and 584 females. The fish of each sex were sampled to obtain weights of at least five fish in each cm interval of total length, from

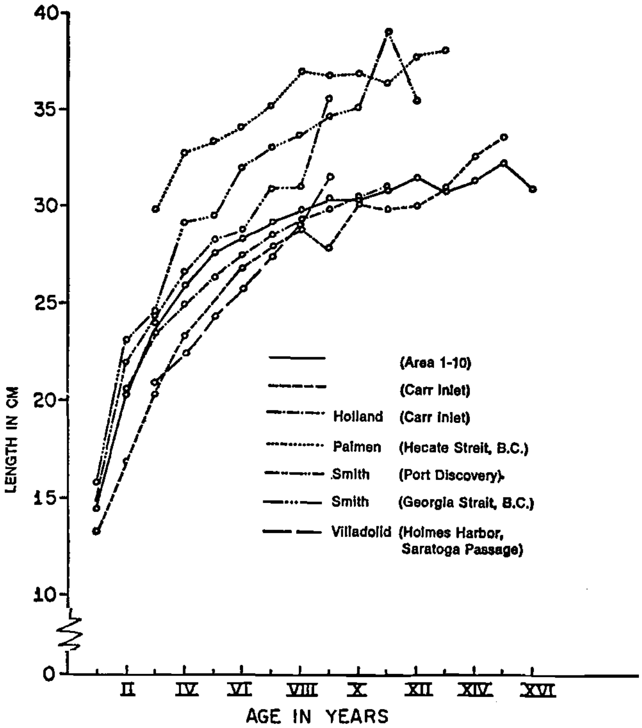

FIGURE 11. Growth curves of male *P. vetulus* in Puget Sound and British Columbia waters by various investigators compared with those of the authors in Areas 1-10 and in Carr Inlet.

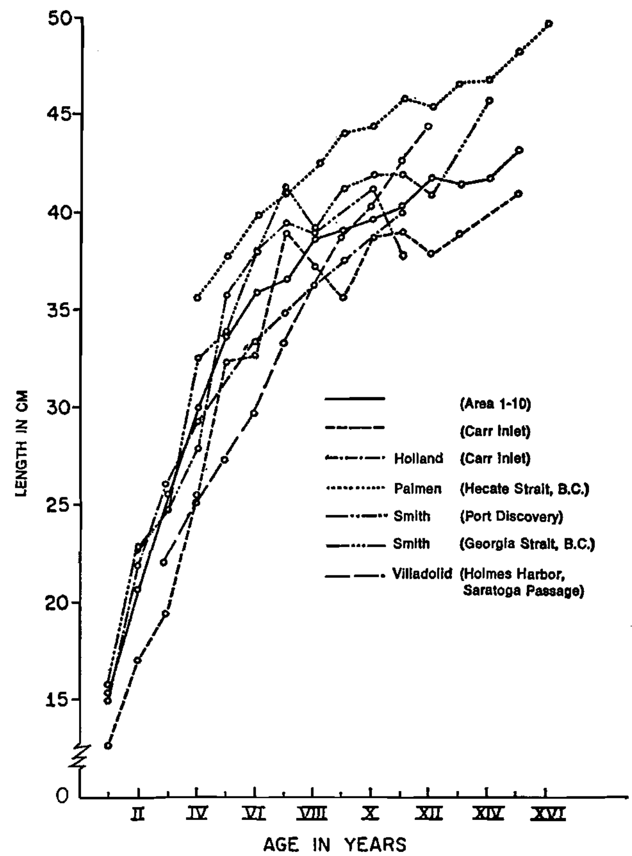

FIGURE 12. Growth curves of female *P. vetulus* in Puget Sound and British Columbia waters by various investigators compared with those of the authors in Areas 1-10 and in Carr Inlet.

TABLE 7

Comparison Between the Observed Lengths in Centimeters at Each Age of *P. vetulus* in Different Localities by Various Authors.

Locality	(1) Holmes Harbor-Saratoga Pass		(2) Georgia Strait		(3) Port Discovery		(4) Carr Inlet		(5) Hecate Strait		(6) Areas 1-10		(7) Carr Inlet	
Age	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
I	...	...	15.8	15.7	14.5	...	14.5	15.0	...	...	15.0	15.3	13.3	12.6
II	...	...	23.1	22.5	22.0	22.6	20.5	22.0	...	...	20.4	20.8	16.8	17.1
III	20.8	22.1	24.6	24.8	24.3	24.9	23.5	26.0	29.8	...	24.0	25.6	20.4	19.5
IV	22.3	25.1	29.1	32.5	26.6	28.0	25.0	29.3	32.6	35.6	25.9	30.0	23.3	25.5
V	24.3	27.4	29.5	33.9	28.2	35.7	26.3	31.7	33.2	37.8	27.6	33.6	26.3	32.3
VI	25.7	29.7	32.0	38.0	28.7	38.0	27.5	33.5	34.0	39.8	28.4	36.0	26.7	32.7
VII	27.4	33.3	33.1	41.3	30.9	39.5	28.5	35.0	35.1	41.1	29.2	36.6	28.0	39.0
VIII	29.0	36.2	33.6	39.1	31.0	39.0	29.2	36.4	36.9	42.3	29.7	38.7	28.8	37.2
IX	31.5	38.8	34.7	41.3	35.5	...	29.8	37.6	36.7	44.1	30.2	39.2	27.7	35.7
X	...	40.4	35.0	42.0	...	41.2	30.3	38.9	36.8	44.5	30.3	39.9	30.1	38.8
XI	...	42.5	39.0	42.0	...	38.0	30.7	40.0	36.2	45.8	30.7	40.3	29.9	39.0
XII	...	44.5	35.5	41.0	...	...	...	...	37.6	45.5	31.5	42.0	30.0	38.0
XIII	...	...	...	...	...	...	...	...	38.0	46.6	30.7	41.5	30.8	39.0
XIV	...	...	...	45.8	...	...	...	...	...	46.8	31.3	41.8	32.5	...
XV	...	...	...	...	...	...	...	...	...	48.4	32.1	43.2	33.0	41.0
XVI	...	...	...	...	...	...	...	...	...	49.8	30.9	...	...	...
XVII	...	...	...	...	...	...	...	...	...	...	...	...	...	...
XVIII	...	...	...	49.5	...	...	...	...	...	...	...	...	...	...

(1) Villadolid (1927)
(2) Smith (1936)
(3) Smith (1936)
(4) Holland (1954)
(5) Palmen (1956)
(6) El-Sayed (1959)
(7) El-Sayed (1959)

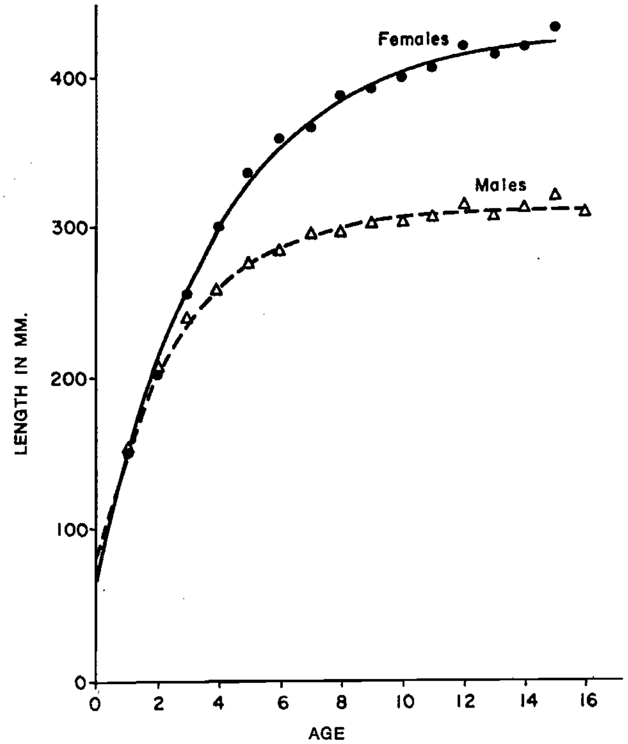

FIGURE 13. Observed average and calculated length of *P. vetulus* using the combined data from trips 5305, 5307, 5405, 5501 and 5604. The curves were fitted to average lengths using IBM program FRA-706.

each trip. The weights of all females above 40 cm in length were taken. The observed lengths and weights of *P. vetulus* for the males and females yield the following estimates of the relation between weight in gm and total length in mm:

$\log W = -2.16588 + 3.06080 \log L$ . . . (males)
and $\log W = -2.47548 + 3.28186 \log L$ . . . (females)
where: W = weight in grams, L = total length in millimeters, Sy.x = 0.07813 (males), and Sy.x = 0.07324 (females).

An analysis of covariance in Table 8 indicated that the slope of the length-weight regression line for the females differs significantly from that of the males. A test of significance of the difference between the two coefficients from the cube showed a value of "t" = 12.18 (for 583 d.f.) for the females which is significant at the 1% level. The "t" value for the males, on the other hand, was found to be 2.57 (for 843 d.f.) which is just significant at the 1% level.

The average lengths for each sex at age were fitted to the von Bertalanffy formula (Bertalanffy 1949) for the winter trip in each year and for data from the other authors cited above using IBM program FRA 706. Values for the constants are shown for each sex in Table 9. The variability of the constants between trips in the Holmes Harbor-Saratoga Passage area does not seem excessive but the values calculated by combining the data for the five trips shown, reduce the standard errors of each constant as well as the standard errors of estimate. The great differences between values calculated from other data demonstrate the error in Villadolid's age readings. They also demonstrate the higher growth

TABLE 8

Analysis of Covariance and Test of Significance Between the Slope of the Length-Weight Regression Lines of the Male and Female *P. vetulus*

Source of variation	Sum of Squares and Products: Sx^2	Sxy	Sy^2	d.f.
Males	8.28761	25.36673	81.55054	843
Females	9.93180	32.60773	110.17882	583
Total	18.21941	57.97446	191.73162	1426

	M.S.	d.f.
Mean square of the difference between male and female regression coefficients	.22338	1
Mean square of the individual deviation within each sex from the regression line in each sex.	7.03070	1424

$$F = \frac{.22338}{7.03070/1424} = 45.25^*$$

rates found by Smith in the Strait of Georgia and Palmen in Hecate Strait. The low value of K and large negative value of t_0 derived from Palmen's data resulted from the selection by commercial trawls and commercal fishermen (See Table 9).

The observed average lengths for trips 5305, 5307, 5405, 5501 and 5604 are shown with the calculated values in Figure 13. The differences in growth parameters between years in the present data must be due to sampling. Since the curves were derived from the average lengths at each age the true values for the standard errors are not available. Those given measure only the variations of the mean values about the curves. This term is often referred to as the "lack-of-fit" mean square (See Draper and Smith 1966).

Since weights were available only from 1953 the age-weight relationship was considered to be represented best by using the growth constants computed for the length data which are available from all years, with the length-weight relationship determined above for 1953. Weights calculated for each age and sex are shown in Table 10. These relationships represent an average weight for the year. Variation can be expected within the year due to variations of gonad development as well as because of variations in food consumption indicated by differences between seasons in stomach

TABLE 9

Constants Computed for von Bertalanffy Growth Equation — *P. vetulus*

Trip	L_∞	S_{L_∞}	K	S_k	t_o	S_{t_o}	SE est.
			Females				
5305	423.5	6.02	0.241162	.018206	–0.8517	0.1961	11.4173
5307	458.5	11.65	0.188756	.019866	–1.3141	0.2883	13.2719
5405	441.3	3.53	0.262533	.010813	–0.5644	0.0938	6.5961
5501	428.7	9.15	0.237034	.025509	–0.7205	0.2688	16.9439
5604	425.8	3.13	0.305759	.013643	–0.3392	0.0962	7.9152
Average	432.2	2.62	0.253180	.008250	–0.6754	0.0802	5.2919
			Males				
5305	300.3	3.28	0.386825	.039330	–0.7558	0.2424	10.3392
5307	321.9	2.65	0.236294	.014160	–2.0591	0.2199	5.5127
5405	319.5	2.57	0.386649	.028869	–0.6295	0.1733	8.7799
5501	307.5	1.75	0.374766	.021602	–0.9668	0.1515	5.8409
5604	316.2	1.80	0.476221	.026816	–0.2002	0.1021	6.9948
Average	312.2	1.11	0.366494	.012178	–0.8272	0.0837	3.6450
			Females — Other Investigators				
Villadolid	880.9	126.4	0.047080	.011021	–3.0528	0.4823	4.5262
Smith—Georgia St.	437.6	8.95	0.289119	.028968	–0.4518	0.1992	14.2339
Smith—Pt. Discovery	492.7	77.86	0.195252	.092458	–0.9126	0.9312	18.3593
Holland—Carr Inlet	415.6	4.97	0.243295	.012339	–0.9417	0.1105	5.0824
Palmen—Hecate St.	528.4	12.79	0.118987	.016944	–5.5643	1.0529	5.3996
Sayed—Carr Inlet	412.7	12.88	0.257141	.034317	–0.1782	0.2528	20.2762
			Males — Other Investigators				
Villadolid	did not converge						
Smith—Georgia St.	376.9	8.87	0.261921	.033071	–1.2296	0.3238	12.2148
Smith—Pt. Discovery	356.7	19.75	0.256819	.059536	–1.2634	0.4965	14.1149
Holland—Carr Inlet	307.2	2.84	0.347427	.021558	–0.9425	0.1416	4.9084
Palmen—Hecate St.	381.7	4.68	0.265338	.043069	–2.8357	0.8996	5.4982
Sayed—Carr Inlet	323.0	4.44	0.240787	.019011	–1.1903	0.2258	8.3912

TABLE 10

Average Weights (Grams) Observed in 1953 and Weights Calculated from Calculated Lengths at Each Age and Sex from Trips 5305, 5307, 5405, 5501 and 5604.

	Males			Females		
Age	Calc. Lengths	Calc. Weight	Average Obs. Wt.	Calc. Length	Calc. Weight	Average Obs. Wt.
0	81.6	4.2		67.9	1.8	
1	152.4	28.5	25.4	149.4	23.9	30.0
2	201.4	66.9	61.9	212.7	76.2	76.2
3	235.4	107.9	105.6	261.8	150.7	150.0
4	259.0	129.7	134.7	299.9	235.4	230.2
5	275.3	174.2	152.5	329.5	320.6	364.6
6	286.6	197.2	175.9	352.4	399.7	344.7
7	294.5	214.2	208.9	370.3	470.2	443.2
8	299.9	226.4	200.0	384.1	530.2	528.2
9	303.7	235.3	236.7	394.9	580.7	550.0
10	306.3	241.5	192.0	403.2	621.7	614.3
11	308.1	245.9	210.0	409.7	655.3	560.0
12	309.4	249.1	225.0	414.7	681.8	680.0
13	310.2	251.0	222.5	418.6	703.1	722.5
14	310.8	252.5	255.5	421.7	720.4	565.0
15	311.3	253.8	238.3	424.0	733.4	
16	311.6	254.0				
Ave. max.	312.2	256.0		432.2	780.8	

(Female) $\log W = -2.16588 + 3.06080 \log 1$

(Male) $\log W = -2.47548 + 3.28186 \log 1$

contents which are not reported here. These variations are probably not sufficient to affect the accuracy of rough computations of productivity but would form an excellent subject for further study.

The effect of cod end mesh size on the size of fish captured was observed by sampling with 1½- and 3½-inch mesh nets in 1953 to which a 4½-inch mesh net was added in subsequent years. As indicated above the nets fitted with different cod ends were operated consecutively at each station with no predetermined order of hauling. The length frequencies of each sex at each age taken with each mesh were compared by an analysis of variance of differences between hauls within trips and between trips (years). Trips 5305, 5405, 5501, and 5604 were used because they occurred roughly at the same time in each year. The "F" values calculated for each comparison were converted to probabilities. These were then converted to X^2 by the following equation:

$-2\,\Sigma \log P_i = X^2$ (Snedecor 1956, p. 217)

The probabilities were summed for all age classes in each comparison. The results (Table 11) show no significant differences between lengths of fish taken in different hauls within each year indicating that essentially the same population was being sampled each year. Lengths of fish taken with the 1½-inch mesh were also similar in different years but both males and females taken with 3½- and 4½-inch meshes showed significant differences between years. The lengths of fish taken in 1955 were smaller than in 1953 or 1954. This may have been due to the sampling time of early January, before growth had started, contrasted with the other samples which were taken in late February and March after some growth had occurred. It is also possible that the greater fishing in 1953 and 1954 shown by the total fishing effort in Table 12 might have cropped the larger fish before January 1955 (trip number 5501). This is also indicated by the low survival rates computed for males from trip 5501 taken with the 4½-inch mesh net and for females in trip 5420 taken with all meshes in October 1954 and in trip 5501 with 3½- and 4½-inch meshes (Table 13).

TABLE 11

Analysis of Differences Between Length Distributions at Each Age for Trips 5305, 5405, 5501 and 5604 Accumulated for All Ages by Calculating $X^2 = 2\Sigma \ln P_i$

Trips included	Mesh (inch)	Between hauls within years		Between years	
MALES		X^2	df	X^2	df
5305, 5405, 5501, 5604	1½	8.79784	16	22.22828	18
5305, 5405, 5501, 5604	3½	11.50512	18	52.6626**	18
5405, 5501, 5604	4½	12.78208	20	29.3100	20
FEMALES					
5305, 5405, 5501, 5604	1½	20.1526	18	25.39556	18
5305, 5405, 5501, 5604	3½	18.9014	18	53.8368**	18
5405, 5501, 5604	4½	12.23324	16	38.5862**	16

**P < 1%

TABLE 12

Total Landings of English Sole in Pounds, Average Catch per Unit of Effort, and the Estimated Fishing Effort in Areas 1-8 and Area 10 During the Period 1953-56

	Areas 1-8			Area 10		
Year	Total landing in pounds	Catch/hour trawling	Total hours trawling	Total landing in pounds	Catch/hour trawling	Total hours trawling
1953	247,045	223.3	1106	314,655	395.8	795
1954	145,299	157.0	925	257,725	355.7	724
1955	32,495	153.3	212	278,381	352.1	791
1956	77,289	194.9	396	443,922	399.8	1110

Mortality Rates

As indicated above all fish taken in each haul were measured for total length. A sample of interopercula was taken from each cm length class in which there were more than 10 fish for each sex and the ages were determined. An age-length key was constructed for each sex by combining the age-length data for all hauls in each trip then the age frequencies for each haul were developed by converting the length frequencies for that haul into ages using the age-length key for the entire trip. Survival rates were then calculated from the age frequencies of each haul using the Robson-Chapman (1961) method and program #FRA 706.* Since this program chooses objectively the youngest age group to be included, according to the method indicated in Robson and Chapman (1961) the resulting survival rates

*Information concerning computer programs FRA 706 and FRG 701B may be obtained from the Fisheries Research Institute, Univ. of Wash., Seattle.

TABLE 13

B = ln·Survival Rate Computed for Each Haul by Trip, Gear, and Sex. Chapman-Robson Method Age/Lg Matrices for Each Sex Pooled Over Gear for Each Trip.

	Males			Females		
	Mesh 1½″	3½″	4½″	1½″	3½″	4½″
5305	.377886	.301016		.317485	.319543	
	.360888	.351961		.323964	.286545	
	1.330205	.403690			.273444	
					.331404	
5307	.216138	.316279		.431146	.388611	
	.310482	.300689		.209404	.373942	
	.336723	.397134		.490380	.504607	
	.356388	.374746		.350914	.353357	
				.381518		
5312	.442581	.402407		.333558	.330315	
	.415799	.417570		.202647	.277625	
	.414765	.406105		.369072	.349633	
	.411973	.411146		.300228		
	.443720			.218654		
5316	.325213	.297091		.330834	.394487	
	.195398	.310497			.377299	
	.293811	.293430				
		.279883				
5325	.268165			.363927		
	.185129			.298092		
5405	.274325	.293063	.283289	.338675	.687823	.473664
	.414103	.246202	.345380	.277164	.316460	.461803
	.297994	.272051	.327262	.415770	.312818	.490688
		.251795	.249902			.516371
						.578592
5418	.372726	.398751	.376030	.417707		
	.387654	.408614		.494816		
	.276128					
	.397714					
	.288924					
5420	.254910	.492029	.251779	.403763	.518980	.657200
	.348027	.377162	.227127	.820791	.791518	.406050
5501	.853270	.335198	.261217	1.034459	.611445	.662774
		.247807	.350142		.579308	.477429

should be comparable and indicate differences associated with mesh size, sex and year. The natural logs of the survival rates computed for each haul are shown in Table 13.

Analysis of variance of these logs using program BMD05V (Dixon 1964) indicated significant differences between sexes (F = 9.4090 for 1 and 98 d.f.) and between years (F = 9.0396, with 2 and 98 d.f.) (Table 14). Surprisingly the differences between gear were not significant nor were differences between trips within years. A significant interaction between sex and year is indicated.

Combining trips within years the resulting analysis of variance indicates no overall differences between sexes but the differences between gear and years as well as the interaction between sex and year are all significant at the 1% level (Table 15). The interactions between sex and gear and gear and years are significant at the 5% level. When the average values for the logs are examined by gear, sex and year (Table 13) it becomes obvious that the values computed for both males and females from the single haul in 1955 with 1½-inch mesh were much larger than those in most other years. One value obtained in 1953 (5305M) for the males was also considerably larger than others. This single value in 1953 was counterbalanced by a number of lower values for males in that year so that the average values plotted in Figure 14 show only a slight decrease from 1953 to 1954 for the males. The differences in values for the males between years is not great, however, except for the single value obtained in 5501C with 1½-inch mesh. On the other hand, the mortality rates computed for females from all meshes increased each year (Figure 14).

TABLE 14

Analysis of Variance of Logs of Mortality Rates Computed from the Age-Frequency Distributions for Each Haul, 1953 to 1955 — *P. vetulus.*

Source	S.S.	df	M.S.	F
Sex	.20022	1	.20022	9.4090
Gear	.02935	2	.01468	
Year	.38471	2	.19236	9.0396
Trip (year)	.16094	6	.02682	
S X G	.03607	2	.01804	
S X Y	.15434	2	.07717	3.6265
Within	2.08541	98	.02128	

TABLE 15

Combining Trips Within Years — Analysis of Variance of Log S. *(P. vetulus)*, Holmes Harbor-Saratoga Passage, 1953-1955.

Source	S.S.	df	M.S.	F
Sex		1	.00001	
Gear	.22856	2	.11428	6.245
Year	.29279	2	.14640	8.000
S X G	.21024	4	.05256	2.872
S X Y	.38785	2	.19392	10.597
G X Y	.14603	2	.07302	3.990
S X G X Y	.00241	4	.0006	.033
Within	1.75670	96	.0183	

Except for the large values obtained in 5501C the lack of a noticeable trend in the values for males is to be expected since the size limit set by law automatically eliminates a significant proportion of males of all ages from the landed catch. The increasing mortality rates for the females might have resulted from the extension of the fishing season into the spawning season beginning in 1953 although this is not indicated by estimates of the total fishing effort expended in areas 1-8 during the years 1953 to 1955 as shown in Table 12. The age-frequency distributions of females from most hauls included at least 12 age classes older than the age of full recruitment (age 3 or 4) and it would be expected that these frequencies therefore, would take at least 12 years to become fully adjusted to a new rate of exploitation. Complex changes would be induced by the effects of the two years of heavy fishing indicated for 1953 and 1954, followed by the lighter fishing in 1955 and 1956, that would probably result in a progressive adjustment of the slope of the right hand leg of the age-frequency distribution, which in turn would yield decreasing values for the survival rates calculated from these frequencies.

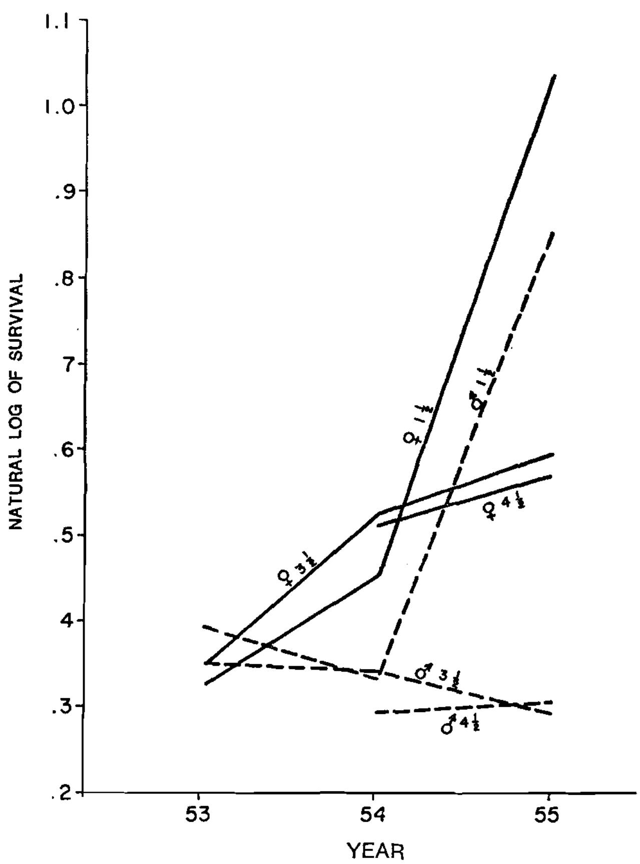

FIGURE 14. Mortality rates (-lnS) of *P. vetulus* by sex and gear averaged for each year using the individual values from Table 13.

Further sampling should be undertaken after a period of relatively stable fishing effort (if such a period could be found) to obtain valid estimates of survival rate from this method and to try to separate changes due to variations in rate of fishing from changes due to variations in year-class strength.

Menasveta (1958) estimated a value of fishing mortality of $F = 0.775$ for areas 1-8 in 1954 from tag recoveries. This can be used to scale the yield isopleths computed from the empirical model described by Beverton and Holt (1957), and modified to use the observed length-weight relationship in the growth formula rather than the cubic relationship as described by Paulik and Gales (1964). These isopleths were computed and plotted using Hirschhorn's modification of IBM program FRG 701B, the original form of which was described by Paulik and Gales (1964). The symbols used are as defined by those authors. Hirschhorn* has added to this program a UWCNPT routine that plots the isopleths. This program automatically sets $t_p = 0$. Two sets of isopleths were computed for males and two for females using the following parameters for females: maximum value of $F = 1.5$; maximum value of $t_{p'} = 8$; lg/wt exponent $= 3.28186$; $W\infty = 780.8$g; $M = 0.1$ and 0.3; $K = 0.25318$; $t_o = 0.6754$; $t_m = 20$. Parameters used for males were: maximum value of $F = 1.5$; maximum value of $t_{p'} = 12$; lg/wt exponent $= 3.0608$; $W\infty = 256.0$ g; $M = 0.1$ and 0.3; $K = 0.36649$; $t_o = -0.8272$; $t_m = 20$. Since the program as modified by Hirschhorn was written for weights measured in pounds and the *P. vetulus* measurements were in grams the recruitment was adjusted to give a calculated maximum yield of about 1,050 weight units. Thus the R_1 used for females (with $M=0$) was 4.0; R_2 for females ($M=0.3$) $= 14$; R_3 for males ($M = 0.1$) $= 10.0$; R_4 for males ($M = 0.3$) $= 24$.

The isopleths shown in Figures 15 to 18 indicate that with $t_{p'}$ at 4.5 which is about the age of full recruitment of females at the size limit now imposed, the maximum yield would be obtained at about $F = 0.37$, i.e., at about one-half the fishing effort expended in 1953 and 1954. This, of course, assumes constant recruitment and a constant $M = 0.1$. Under this hypothesis maximum yield would be obtained at $t_{p'} \sim 7.45$ and $F = 1.5$, the highest values of F included in the calculation. Both figures are plainly of only theoretical value.

Raising M to 0.3 (Figure 16) reduced the optimum recruitment age for $F = 1.5$ to 3.86. The isopleths also

*Hirschhorn, George. 1967. Personal communication. Description of CNPT routine for plotting catch isopleths.

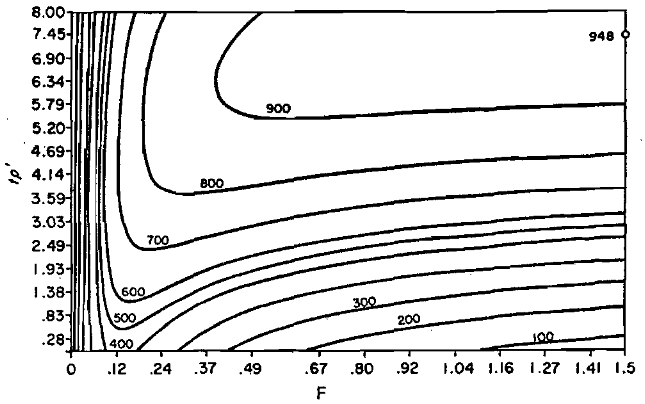

FIGURE 15. Isopleths for the Holmes Harbor-Saratoga Passage population of *P. vetulus* females (M = 0.1). See text for other parameters used.

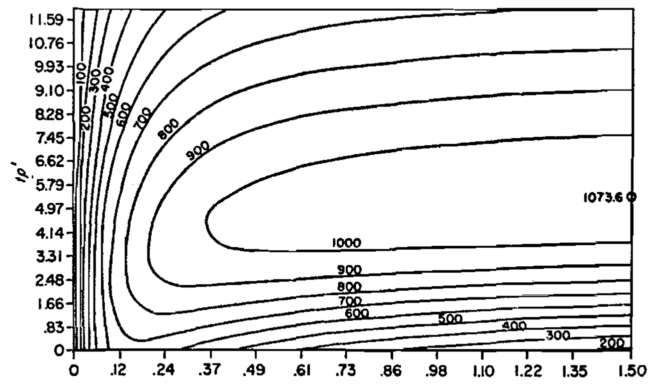

FIGURE 17. Isopleths for the Holmes Harbor-Saratoga Passage population of *P. vetulus* males (M = 0.1). See text for other parameters used.

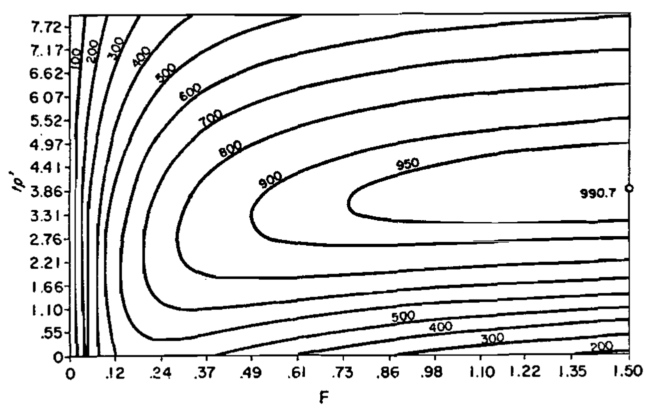

FIGURE 16. Isopleths for the Holmes Harbor-Saratoga Passage population of *P. vetulus* females (M = 0.3). See text for other parameters used.

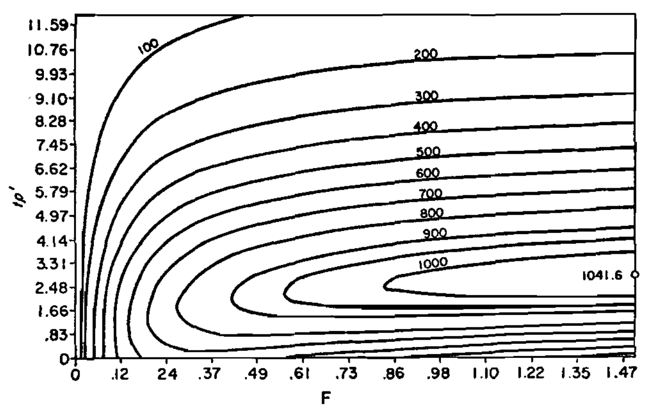

FIGURE 18. Isopleths for the Holmes Harbor-Saratoga Passage population of *P. vetulus* males (M = 0.3). See text for other parameters used.

indicate that the yield at $t_{\rho'} = 3.58$ would be only about 4% less at $F \sim 0.73$.

The two figures for males serve primarily to indicate the potential benefit in total weight of catch that might be obtained by lowering the age of recruitment into the fishery ($t_{\rho'}$). However, this benefit would have to be balanced against the much reduced stock size and hence, smaller catch of the larger, faster growing and more marketable females. Males also mature at less than 2 years of age at lengths of 200 mm and less, while most females mature at 4 years or older. If the fishery could be adjusted to take males at an average of 2 years of age the females would be recruited at age 1.5. With $M = 0.3$, $t_{\rho'} = 1.5$ the maximum catch of females would be taken at about $F = 0.41$, would be 22% less than at $t_{\rho'} = 3.31$ and $F = 0.49$, and would be composed largely of unmarketable small fish.

Such speculation is idle but indicates the nature of management problems that are associated with fisheries of this type which are similar to the problem of two species of different growth rates and marketability except that the two sexes here obviously cannot exist alone. It would appear that further study of this population of *P. vetulus* with controlled variation of rates of fishing as well as of age and size of recruitment could serve to check theoretical models used to study the changes that might take place.

SUMMARY

A study of the virtually isolated population of *P. vetulus* in the upper Puget Sound region of Holmes Harbor and Saratoga Passage indicated that interopercular bones are much easier to use and give more accurate readings of age in *P. vetulus* than otoliths. The growth rate of *P. vetulus* is about the same for both males and females during the first two years of life. After that the females grow much faster than the males. Variations in average length at the different ages in different years are apparently due to sampling. The rate of growth of *P. vetulus* in Carr Inlet, in southern Puget Sound, is slower than in the northern Sound, but comparison with data published by other authors indicates that the growth rate of this species is greater in Port Discovery, Strait of Georgia and Hecate Strait than in the Holmes Harbor-Saratoga Passage area.

Mortality rates, computed for data obtained from the latter area from the age distributions for each trip, show significant differences between sexes which is an expected result of the slower growth rate of males combined with a legal size limit that even protects some of the oldest males. However, the mortality rates for females increased from 1953 to 1956. It is pointed out that the effects of a greater fishing intensity in 1953 and 1954 would require some years to have its full effect even if the fishery had become stabilized after 1954.

The weight of females increases at a rate significantly greater than the cube of the length so the exponents calculated from length and weight data were used for a modified form of the Beverton and Holt model to compute yield isopleths separately for males and females. These demonstrate the problems involved in managing a population with such great differences between sexes in rate of growth. Further study of this population is recommended to elucidate these problems.

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Age and Growth Studies of English Sole, *Parophrys vetulus,* in Monterey Bay, California

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AGE AND GROWTH STUDIES OF ENGLISH SOLE, *Parophrys vetulus*, IN MONTEREY BAY, CALIFORNIA

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INTRODUCTION

English sole (*Parophrys vetulus* Girard) have been exploited in California coastal waters since the late 1870's when lateen sail boats using small dragnets fished in San Francisco Bay (Clark, 1935). In recent years, Pacific coast otter trawl fisheries annually have taken 11 to 12 million pounds from waters between Hecate Strait, British Columbia and Santa Barbara, California. Approximately 4.5 million pounds are landed annually in California. English sole dominated the sole catch in California through 1947, contributing about 70% of the total sole catch (Ripley, 1949). During the past decade (1955-1964), English sole landings have ranked second to Dover sole, *Microstomus pacificus*, and have comprised about 22% of the total sole or flat fish catch (Table 1).

The California Department of Fish and Game began monitoring otter trawl landings in 1924. Department of Fish and Game personnel sample English sole landings for size, age, and sex ratio. These data are used to detect long term trends in the fishery, and are used in formulating management policies. This paper reports findings of a special study on the early growth of English sole to augment other age and growth information.

The study period extended from March 1960 through June 1964. Systematic collections of juvenile and adult English sole were made by otter trawling and beach seining, and data from 4,446 individuals were used in the study. Specimens were measured to the nearest millimeter (total length) and their sex determined. Following a stratified sampling scheme, 386 opercular assemblies were selected for aging.

TABLE 1
California Trawl Landings in Thousands of Pounds, 1955-1964

Species	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1955-64 Average
English Sole	4,135	3,825	4,718	5,064	4,618	2,376	3,646	4,209	4,254	4,594	4,144
Rock Sole	1	2	1	1	—	3	1	—	1	2	1
Petrale Sole	3,617	2,824	3,391	3,097	2,632	2,475	3,391	3,038	3,317	2,699	3,048
Dover Sole	8,185	8,268	7,912	7,961	7,327	9,185	7,826	8,581	9,780	9,267	8,429
Rex Sole	1,094	1,147	1,208	1,386	1,443	1,107	1,209	1,408	1,565	1,409	1,298
Starry Flounder	640	369	482	465	1,043	248	296	298	461	370	467
Other Flatfish	1,784	2,106	1,831	1,198	1,657	1,908	934	1,160	1,312	1,384	1,527
Lingcod	724	634	1,201	1,304	1,153	1,099	1,163	819	857	673	963
Sablefish	1,272	2,016	1,251	1,393	1,703	2,133	1,340	1,690	1,660	1,618	1,608
Pacific Ocean Perch	47	8	tr+	6	tr+	20	16	—	63	85	25
Rockfish	11,128	13,076	14,109	14,364	12,240	11,712	8,896	7,757	9,744	6,702	10,973
Misc. Species	1,235	1,684	1,511	1,523	1,415	618	327	354	482	428	958
Dogfish	tr+	—	tr+	1	—	—	2	2	9	9	2
Animal Food	—	—	—	—	—	—	3,777	1,879	1,034	1,738	2,107*
Total	33,862	35,959	37,615	37,763	35,231	32,884	32,824	31,195	34,539	30,978	34,285
Effort in Hours	—	—	—	—	48,465	44,984	52,944	51,473	59,263	52,758	51,648**

* 4-year average
** 6-year average
tr+ trace is less than 500 pounds

AREA OF INVESTIGATION

The study was conducted in Monterey Bay, which is located approximately 65 miles south of San Francisco (Figure 1). The bay is nearly semicircular, about 23 miles long between the northerly and southerly extremities, and 10 to 11 miles wide at the innermost point. A submarine canyon, which bisects the bay, is a source of cool nutrient water during periods of upwelling, an oceanic phenomenon characteristic of the greater portion of the California coast (Skogsberg, 1936).

Beach Seining

Beach seining was conducted in Elkhorn Slough on a monthly basis from March through August, 1960, and June through November, 1963. A 100-foot seine of ¾-inch mesh was set from a skiff and retrieved to shore. A total of 1,718 juvenile specimens was collected in 57 sets at 3 locations during 1960 and 1963 (Figure 1). Lengths of these fish ranged from 1 to 16 cm with a mode of 4 cm (Figure 2). Seventy-one opercular assemblages were collected during 1963 for age and growth studies.

Otter Trawling

The Department's research vessel, M. V. *Nautilus,* made 5 cruises between October 1963 and June 1964 in Monterey Bay (Nitsos, 1964; Smith, 1964). A gulf shrimp trawl constructed of 1½-inch stretch nylon mesh and with a cod-end of 1-inch mesh was used. The net, with a 32-foot headrope and a 40-foot groundrope, was fished without floats, providing a height of approximately 4 feet and a working gape of approximately 128 square feet. The gape was maintained by the use of otter boards, constructed of 1-inch wood 5-feet by 30-inches with iron shoes, attached to the wings of the net. The trawling warps were attached to each otter board.

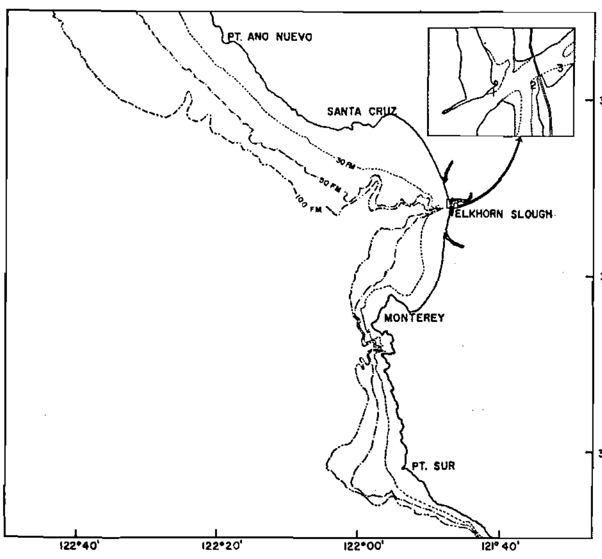

FIGURE 1. Monterey Bay English sole study area with inset of Elkhorn Slough showing seining stations 1, 2 and 3.

Seventy-eight tows, each of 20-minutes duration, were made between Santa Cruz and Monterey in depths of 10 to 50 fathoms. During the study period, 2,728 English sole, ranging in total length from 8 to 45 cm, were captured (Figure 3). Opercular assemblages from 315 fish were taken for age and growth determinations. These were selected from 2 fish of each sex for each centimeter length group encountered on each cruise.

AGE DETERMINATION

Methods of aging English sole have been investigated by several scientists. Villadolid (1927) used scales with poor success, particularly with older fish. Otoliths were used for age determination by Ketchen (1949). In comparative studies, Palmen (1956) and El-Sayed (1959) found interopercula bones superior to otoliths. California investigators have used both otoliths and interopercula, but started using interopercula exclusively in 1960.

The use of interopercular bones necessitates laboratory preparation to recover them from the opercular assemblages collected in the field. After the opercular assemblage has been boiled for approximately one minute to remove fleshy material surrounding the bones,

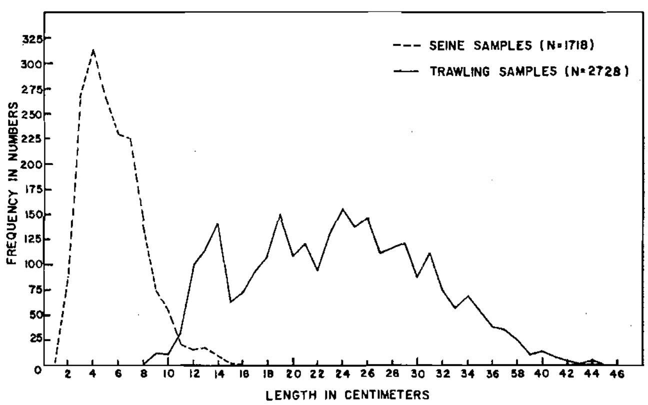

FIGURE 2. Length frequency of Monterey Bay English sole, sexes combined.

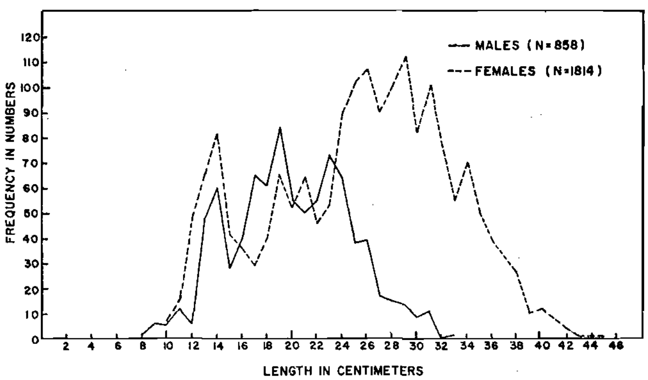

FIGURE 3. Length-frequency distribution of male and female English sole taken on research cruises.

the interoperculum can be readily separated from it, dried, and stored.

The interoperculum is a suitable structure for age determination because it varies little in thickness with advancing age. A broad opaque band of rapid summer growth and a narrow translucent band of slower winter growth occur each year, forming easily distinguishable annuli. Ages are determined by counting the number of complete translucent winter zones (Figure 4).

Ages were determined using a binocular microscope at 5.66 magnifications and later verified by projecting interopercular images through the lighthouse condenser of a photographic enlarger at 3.4 magnifications. When using a binocular microscope, the bones were submerged in 70% isopropyl alcohol to enhance clarity. When verifying ages, the focus of each interoperculum was aligned on perpendicular axes drawn on millimeter graph paper. Annuli were marked on the graph paper at points intersecting tangents of completed winter bands. Seasonal or marginal zones beyond the last completed annulus were also marked to determine the total length of the interoperculum. A graph paper recording for each bone provided a permanent record, useful for subsequent back calculation procedures.

Occasionally, interopercular irregularities occur that affect the accuracy of age determinations. Two major irregularities encountered were accessory checks (false annuli) and partially obscured first annuli resulting from ossification of bones at their foci.

The extent of seasonal or marginal growth provided a basis for placing individuals in their respective year classes. Examination of interopercular edges disclosed annulus formation occurs between December and February. Individuals showing excessive marginal increments remaining in February, were assigned to the next higher age group (next lower year class) to eliminate bias estimates of mean annual growth.

Considering the above criterion, 386 interopercula were aged. We obtained 79% agreement between two readers on the first reading and 96% after resolving differences of the first reading.

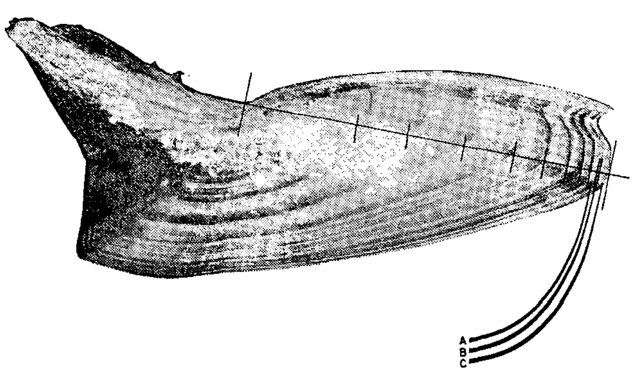

FIGURE 4. Interoperculum of a 386-mm female English sole with 9 annuli. Landed August 29, 1959. A = opaque summer growth, B = translucent winter growth, A + B = total annual growth, C = marginal growth. (Photo by R. F. G. Heimann)

VALIDITY OF AGE DETERMINATIONS

Palmen (1956) and El-Sayed (1959) established that interopercula annuli were valid age indicators for English sole taken from Hecate Strait, British Columbia; Yaquina Bay, Oregon; and Puget Sound, Washington.

Our studies of the marginal growth of interopercula, the comparison of length-frequency distribution and determined ages, and the relationship between interopercular length and total length show that interopercular annuli are valid indicators of age for English sole from Monterey Bay.

Average growth in millimeters beyond translucent winter zones of interopercula of the 1960 year-class female English sole was greatest for October and December, declined to a low point in February, and increased through June. The abrupt decrease in average growth between December and February indicates annulus formation (Figure 5).

Length-frequency data for English sole captured by seine and trawl nets show modes at 4, 14, and 19 cm. Fish in age classes I and II (determined from interopercula) averaged 14 and 20 cm, respectively (Table 2); this corresponds closely to the 14- and 19-cm length-frequency modes and the 4-cm mode obviously represents the 0-age class.

Relationship Between Interopercular Length and Total Length

Interopercular length is the measurement from the focus to the margin (Figure 4), and the relationship between it and total length of the fish was studied to obtain corroborative evidence for the validity of age determinations.

Interopercular bones were measured from 126 female and 86 male English sole captured by trawling during research cruises. The relationship of interopercular length to total length for males and females was similar

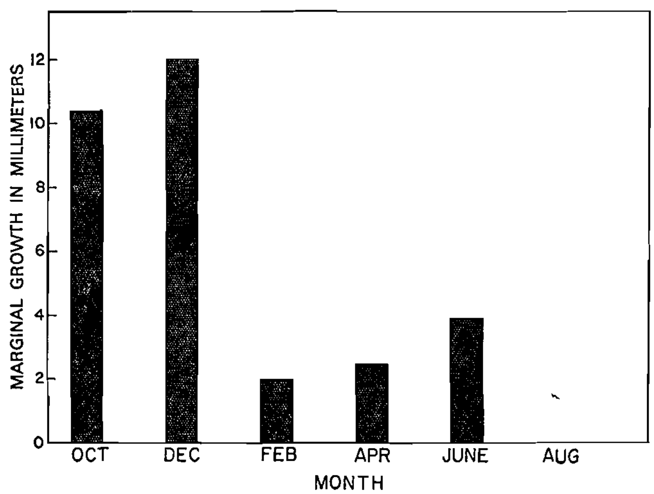

FIGURE 5. Average monthly marginal growth of the interopercular bones of female English sole from the 1960 year class.

(Figure 6). Unlike El-Sayed (1959) who fitted a regression line for each sex, we combined our data and computed a least squares line to express the relationship for all individuals examined. The combined expression for males and females is:

$$Y = 0.403X + 1.77$$
$$(r = 0.9746)$$

where Y = total length in cm; X = magnified interopercular length (3.4X) in mm.

GROWTH STUDIES

Size at First Annulus

Having established a relationship between interopercular length and total length, the size at age I was studied. One hundred and seventy-six interopercula of the 212 examined possessed at least one annulus. These English sole represented 10 year classes, 1954 through 1963, and calculated mean, maximum, and minimum lengths were compared between the year classes. These data indicate a mean length at age I of 13.5 cm with a range of 12.9 to 15.0 cm (Table 3). Assigning a 95% confidence limit about the 10-year mean of 13.5 cm, an interval of 11.2 to 15.8 cm was obtained, and the means of all the individual year classes studied fell within this interval.

Attempts to follow the growth of the 1963-year class to age I from beach seine samples proved unsuccessful because the absence of English sole in Elkhorn Slough after November precluded a complete evaluation (Table 4).

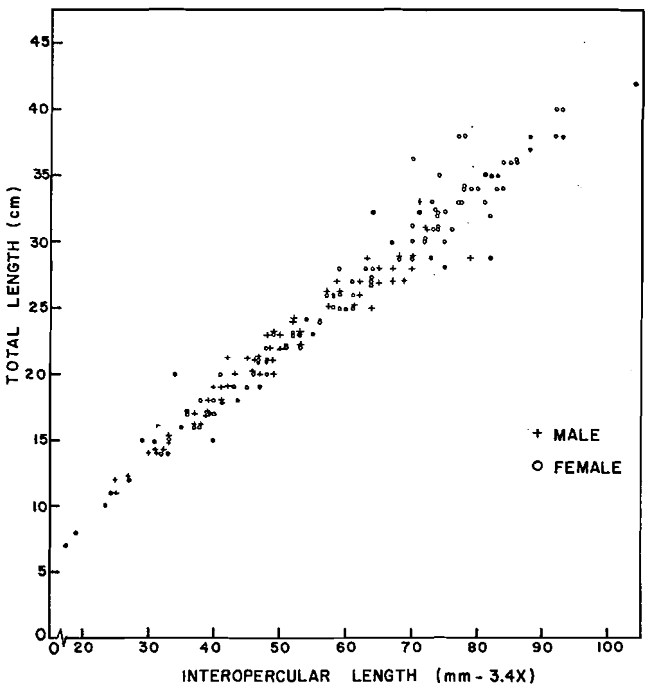

FIGURE 6. Relationship of total length to interopercular length.

TABLE 2

Calculated and Observed Total Length (mm) of English Sole by Age[1], Monterey Bay, 1960-1964

Age	Number	Female		Number	Male	
		Calculated Length	Observed Length		Calculated Length	Observed Length
I	113	137	134	68	124	128
II	89	203	204	46	184	186
III	65	254	259	31	222	225
IV	42	293	292	20	247	245
V	22	324	313	14	264	256
VI	17	347	340	10	276	268
VII	10	365	361	9	283	282
VIII	6	379	390	6	289	290
IX	5	390	409	4	292	294
X	3	399	419	3	295	312
Total	372			211		

[1]Data for English sole age beyond 10 years omitted.

TABLE 3

Mean Calculated Length at Age I of Monterey Bay English Sole Representing 10 Year Classes, Sexes Combined

Year Class	Number Examined	Calculated Mean Length (cm)	Standard Error
1963	30	13.2	0.258
1962	34	13.3	0.201
1961	42	13.4	0.234
1960	28	14.1	0.304
1959	12	12.9	0.450
1958	7	13.9	0.404
1957	9	12.9	0.463
1956	5	13.8	0.577
1955	4	15.0	0.892
1954	5	13.7	0.990
Total	176	13.5	0.115

TABLE 4

Length Frequencies of 1963-Year-Class English Sole Caught in Elkhorn Slough, Monterey Bay, California

Length (cm)	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.
0	—	—	—	—	—	—	—	—	—
1	2	—	—	—	—	—	—	—	—
2	5	19	55	5	—	—	—	—	—
3	—	42	176	48	1	—	—	—	—
4	—	71	82	151	9	—	—	—	—
5	—	44	49	103	69	3	—	—	—
6	—	4	53	92	67	13	—	—	—
7	—	—	44	123	29	28	—	—	—
8	—	—	15	74	12	34	2	—	—
9	—	—	4	24	13	29	5	1	—
10	—	—	—	12	5	22	10	5	1
11	—	—	—	2	1	2	11	4	—
12	—	—	—	—	—	4	6	5	—
13	—	—	—	—	—	3	7	6	1
14	—	—	—	—	—	—	5	4	—
15	—	—	—	—	—	—	—	2	—
Total	7	180	478	634	206	138	46	27	2
Mean Length	1.7	3.8	4.2	5.7	6.1	8.3	11.2	12.1	11.5

Rate of Growth

Growth estimates of English sole in Monterey Bay were obtained from the relationship between total length and age determined from interopercula data collected during 1963-1964. Mean total lengths for each age were calculated from interopercular measurements to the last completed annulus for males and females (Table 2).

A von Bertalanffy equation fitted[1] to these length data gave the following results:

$$l_t = L_\infty \left[1\text{-exp}\,(-kt + kt_o)\right]$$

$$\text{Males: } l_t = 30.00 \left\{1\text{-exp}\,\left[-0.3886\,(T + 0.296)\right]\right\}$$

Standard error of estimate 3.35

$$\text{Females: } l_t = 42.84 \left\{1\text{-exp}\,\left[-0.2584\,(T + 0.3125)\right]\right\}$$

Standard error of estimate 4.47.

Growth curves constructed from these data conform closely to the observed values except at the extreme ages (Figure 7).

Length-weight Relationship

A sample of 188 male and female English sole was used to compute a length-weight relationship. Measurements were made to the nearest 2 millimeters and weights were determined to the nearest ounce. Using a least squares of logarithms, a regression of weight (W in oz.) on length (L in cm) was obtained for each sex (Figure 8). The formula for female English sole was $W = 0.00024524\ L^{3.082384}$ and for males was $W = 0.00034156\ L^{2.96793}$.

[1]Programmed by Norman J. Abramson, California Department Fish and Game.

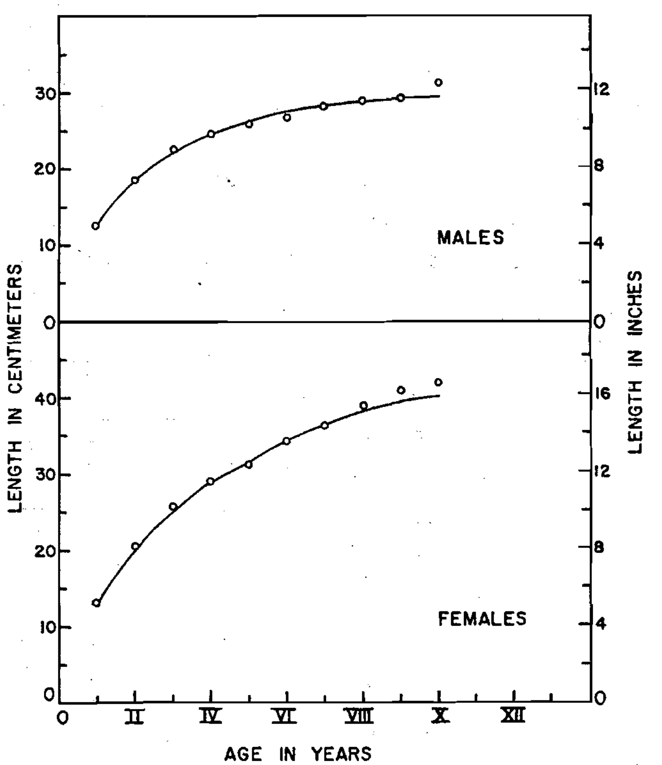

FIGURE 7. Growth curves of male and female English sole fitted by the von Bertalanffy growth equation.

SUMMARY

1. English sole are fished commercially in the eastern Pacific coastal waters from British Columbia to southern California. It is the second most important flatfish landed in California.

2. Age determinations were made using interopercular bones from sole collected by beach seine and otter trawl for biological purposes.

3. The use of a binocular microscope and a photographic enlarger to project interopercular images enhanced reading of annuli whereby 79% agreement was achieved on the first reading, and 96% when differences were resolved.

4. Interopercular annuli are considered valid age indicators since length-frequency modes correspond closely to average lengths determined for English sole in age classes I and II. Studies of marginal growth indicate annulus formation occurs between December and February.

5. A relationship was established between total fish length and interopercular length that is applicable to either sex: The combined equation is $Y = 0.403X + 1.77$, where Y = total length in cm and X = interopercular length (3.4X) in mm.

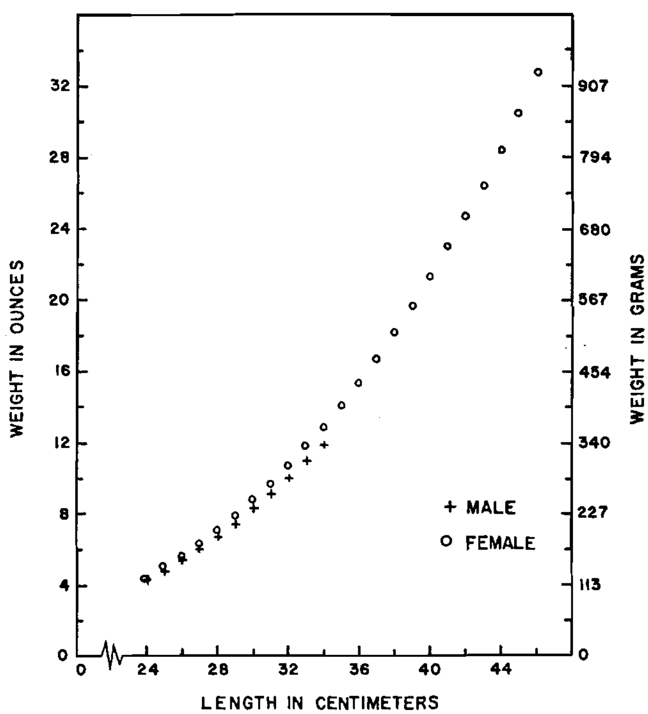

FIGURE 8. Length-weight relationship for male and female English sole from Monterey Bay.

6. Calculated mean, maximum, and minimum lengths at age I were determined from English sole representing 10 year classes. These data indicate a mean length (total length) of 13.5 cm with a range of 12.9 to 15.0 cm at age I.

7. Calculated age-length data for the study period were used in fitting a von Bertalanffy growth equation with the following results:

$$\text{Males: } l_t = 30.0 \left\{ 1\text{-exp} \left[-0.38886 \, (T + 0.296) \right] \right\}$$

$$\text{Females: } l_t = 42.84 \left\{ 1\text{-exp} \left[-0.2584 \, (T + 0.3125) \right] \right\}$$

8. The length-weight relationship of female English sole was determined to be $W = 0.00024524 \; L^{3.082384}$ and for male English sole $W = 0.00034156 \; L^{2.96793}$ where W = weight in ounces and L = total length to the nearest 2-mm size group.

ACKNOWLEDGMENTS

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A Review of Sablefish Tagging Experiments in California

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Marine Resources Operations
California Department of Fish and Game

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A REVIEW OF SABLEFISH TAGGING EXPERIMENTS IN CALIFORNIA

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California Department of Fish and Game

INTRODUCTION

In order to determine the extent of migration by sablefish, *Anoplopoma fimbria,* along the Pacific Coast of North America, the research agencies of California, Oregon, Washington, and Alaska conducted concurrent tagging experiments during the years 1950-1952, following a recommendation by the Pacific Marine Fisheries Commission. The problem was to discover if the fishery exploits a single, freely intermingling population or a series of localized stocks with limited intermixture. In the former event, any necessary regulation would need be on a coastwise basis, rather than at a local level as in the latter case.

Results of sablefish tagging experiments conducted in Alaskan waters were reported separately (Edson, 1954; Alaska Department of Fisheries, Annual Reports for 1953 and 1954).

The tagging projects conducted by California,[1] Oregon, and Washington were reported by Holmberg and Jones (1954). When the report was written, October, 1953, a total of 129 California-tagged fish had been recaptured. Since then, an additional 59 recoveries were made raising the total to 188. The last recovery was in June, 1959. The present report is a review of the tagging program on sablefish in California.

UTILIZATION

Sablefish are found from northern Alaska to northern Baja California, but are uncommon south of Pt. Conception. Annual landings of this species in California during the 20 years (1946-1965) since World War II have been between 1½ and 3 million pounds. In this period, the percent of the poundage landed in each California region was, from north to south: Eureka, 31.3; Fort Bragg, 23.0; San Francisco, 21.8; Monterey, 22.1; Santa Barbara, 1.0; Los Angeles, 0.7; and San Diego, 0.1. Nearly all fishing for sablefish is done by either setline (longline) or otter trawl (drag net). During the past decade, the latter type gear has supplanted setline gear as the greatest producer of this fish in California.

The primary market is for large fish which are processed into a smoked product for a fairly constant domestic trade. Fish destined for smoking are dressed and placed in cold storage until required. If cold storage holdings are excessive at the end of one year, it may have a depressing effect on fishing in the succeeding year because of a reduction in price to fishermen. The smaller sizes are filleted in limited amounts for the fresh fish market. Consumer acceptance of the fresh product is curtailed because of the oily nature of the flesh.

TAGGING METHOD

The California tagging was conducted in areas customarily fished by commercial setliners on 1-day trips from the ports of Monterey, Santa Cruz, Fort Bragg, and Eureka. In the Monterey region, fishing was in or near canyons off Carmel, Moss Landing, and Santa Cruz in depths of 90 to 300 fathoms; in the Fort Bragg region from southwest to northwest of the mouth of Noyo River in depths of 160 to 250 fathoms; and in the Eureka region from southwest to northwest of the entrance of Humboldt Bay in depths of 120 to 250 fathoms.

The Petersen type tag was used in this study. A tag consists of two laminated plastic disks, one on each side of a fish, connected by a wire pin inserted under the first dorsal fin. One of the disks is imprinted with a serial number, the other with a return address. Nickel pins were used on the first 85 fish and stainless steel pins on the remaining 3,993 fish tagged.

In the Monterey region, one biologist affixed tags while another recorded data. In the other regions, tags were affixed and information was recorded by one person. White celluloid sheets, impervious to moisture, were indispensible for recording data with wet or slimy hands.

Care was taken in selecting fish for tagging. Frequently, sablefish which appeared favorably hooked in the bony part of the mouth were damaged from initial hooking in the gullet. These fish were not tagged. Most of the tagged fish released were noted as being in a good or a fair condition. Unavoidably, a few had to be listed as poor. The observed condition of a tagged fish was a matter of the tagger's judgment and was based primarily on the response of a fish after release. Most fish were active and sounded immediately, but

[1]Not included in this report are 16 sablefish tagged experimentally during exploratory fishery surveys of the R/V *N. B. Scofield* in October, 1949, and October-November, 1950. The 16 sablefish were tagged with Petersen type tags and released in waters 50 to 150 fathoms deep between Monterey Bay and Trinidad Head. None of these fish was recovered.

others appeared logy and lingered at the surface. Several recaptures were made of fish which, when released, were noted variously as: light bleeder, jaw torn, body scars, eye hooked, or logy. It would appear that fish not seriously injured have a fair chance of surviving.

A total of 4,078 tagged fish were released in California as follows: 1,320 in the Monterey region during March, April, 1950, and April, May, 1951; 1,386 in the Fort Bragg region during June, July, December, 1951, and February, March, April, 1952; 1,372 in the Eureka region during May, June, August, 1952.

The fish tagged off California measured 38 to 87 cm total length (15.0-34.3 inches), with an average of 62.2 cm (24.5 inches). In the three regions, the mean length of fish tagged in each were: Monterey, 59.8; Fort Bragg, 59.5; and Eureka, 65.7 cm. The superior fish length for Eureka is due to a greater availability of fish longer than 64 centimeters in this region (Phillips, 1954).

TAG RECOVERIES

A total of 188 California-tagged sablefish, or 4.6 percent of those released, were recovered during the period April, 1950, to June, 1959. Of these, 147 were taken with setlines, 34 with otter trawls, and 1 by a salmon troller. The method of capture was unknown for 6 recoveries. Tagged fish were at liberty from 1 to 2,880 days and were taken from depths of 50 to 350 fathoms. About one-half of the total number of recaptured fish had returned to approximately the same depth as when first caught. The others were mostly from shallow water.

Not included in this summary is a recovery on August 2, 1961, of a detached tag from a fish released in the same fishing area off Eureka on June 15, 1952, 3,334 days (9.1 years) earlier. The tag was discovered on the deck of an otter trawler after a catch of mixed fish had been dumped and sorted. It might be assumed the tag had been fastened to one of the sablefish in the catch. But, it is also possible that the tag was detached from a sablefish at some previous time and had accidentally snagged in the net as it was towed on the bottom.

Although the number of fish tagged was apportioned nearly equally among three regions, the total recovery of fish tagged in the Eureka region was significantly greater (6.4 percent) than in the Fort Bragg region (3.3 percent), or in the Monterey region (3.9 percent). The larger number of recoveries of Eureka fish is associated with the excess of larger sizes released there (Table 1).

TABLE 1

Length-Frequency Distribution of Tagged Sablefish at Time of Release in California Waters, and the Number of Later Recoveries Identified with These Size-Groups.

Total Length cm	Monterey Region		Fort Bragg Region		Eureka Region		State Total*	
	Number of Fish		Number of Fish		Number of Fish		Number of Fish	
	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered	Tagged	Recovered
35-39	1	—	—	—	—	—	1	—
40-44	3	—	2	—	3	—	8	—
45-49	28	—	34	—	22	—	84	—
50-54	220	4	222	3	58	—	500	7
55-59	446	15	476	16	128	2	1,050	33
60-64	342	20	391	12	299	11	1,032	43
65-69	189	10	180	13	471	36	840	59
70-74	57	3	56	2	319	28	432	33
75-79	26	—	17	—	60	10	103	10
80-84	5	—	4	—	9	1	18	1
85-89	3	—	—	—	—	—	3	—
Total Number	1,320	52	1,382	46	1,369	88	4,071	186
Average Length	59.8	61.4	59.6	61.4	65.7	69.0	62.2	65.0
Percent Recovery	—	3.9	—	3.3	—	6.4	—	4.6

*7 fish omitted because lengths at release not noted; 2 of these were recovered in the Fort Bragg region.

There were no recoveries of fish less than 50 cm long, although 93 fish measuring 38-49 cm were released. It is possible these young fish may have been weakened by hooking and hauling from deep water. In a supplemental tagging experiment conducted in May, 1956, in Puget Sound by Washington biologists, 455 fish measuring 30-45 cm were tagged and 54 (11.9 percent) of these were recovered in the following 1½ years of freedom. However, these fish were tagged from a herring trap set in the shallow waters of Holmes Harbor and so were not subjected to hooking nor to any great change in pressure (Pruter, 1959).

Recaptures of tagged fish were divided into those taken within 30 nautical miles of release site (nonmigratory), and those caught more than 30 miles away (migratory), in conformity with the choice of Holmberg and Jones (1954). Only 13 of the 185 recoveries with recapture information were made at distances greater than 30 miles from release sites. Four of these had strayed southward and nine northward including five caught in Oregon and Washington. The longest migration was by a fish released off Fort Bragg and recovered 579 days later off Grays Harbor, Washington, 450 miles to the north (Figure 1). Although the greater proportion of the long migrations was northward, the instances were too few to demonstrate a seasonal pattern. Southward migrants were taken in the months of January, April, July, and December; northward migrants in the months of June through November. The absence of recoveries south of the Monterey region is due to a natural scarcity of this species on grounds usually fished off southern California.

An unusual recovery was that of a sablefish tagged off Eureka and discovered in a San Pedro market among a shipment of fish from Bellingham, Washington. Bellingham fishermen catch sablefish as far south as off Destruction Island (see Figure 1). The specimen in question might have been captured off Destruction Island three days prior to delivery at the San Pedro market. If so, the fish traveled a minimal distance of 412 nautical miles in 31 days, 13.3 miles per day. Although this may appear to be rapid travel for a bottomfish, it is not improbable. Two king salmon tagged off San Francisco over a decade ago moved at a faster rate. One captured off Vancouver Island 31 days after release traveled the 660 miles at an average rate of 21 miles a day. The other, which was recaptured in the Columbia River, made the 500-mile journey in 22 days, thus averaging 22.7 miles per day (Fry and Hughes, 1951).

The greatest number of sablefish recoveries (43.8 percent of total) occurred in the first 180 days after release. First season returns were heightened because the bulk of the releases were in the early portion of the fishing season, February through July. In succeeding

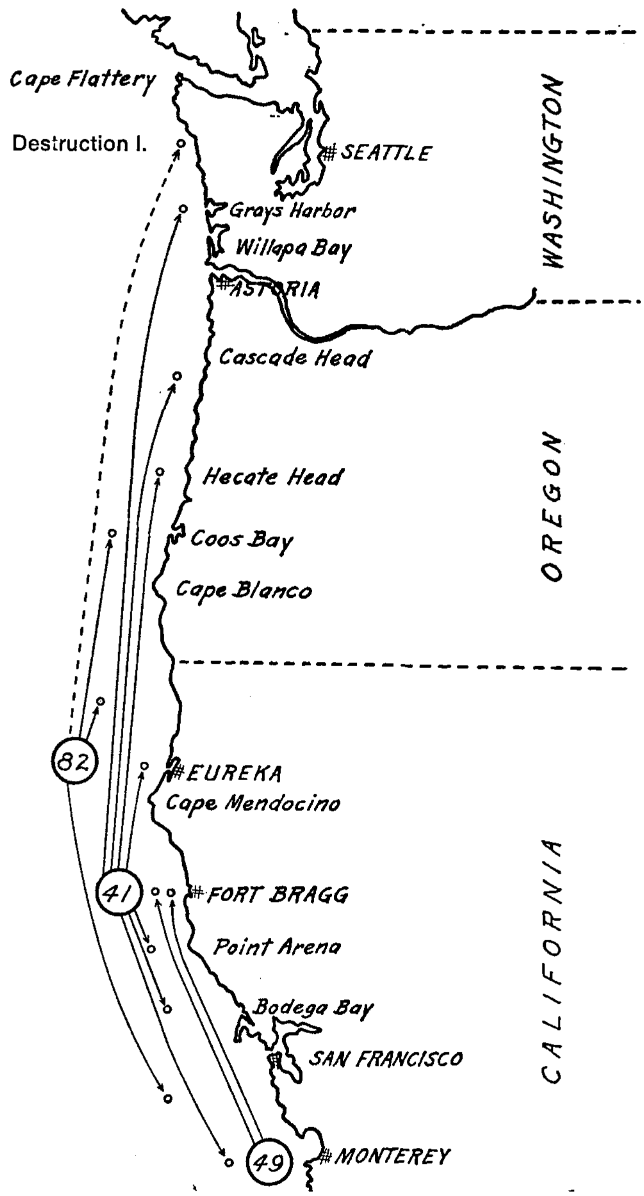

FIGURE 1. Recovery locations for 185 sablefish tagged in the Monterey, Fort Bragg, and Eureka regions of California during 1950-1952. Recovery information was lacking for 1 fish released in the Monterey region and for 2 fish released at Eureka. Number within circle represents number of fish recovered within 30 miles of tagging site. Arrow pointing to a small circle indicates an individual recovery more than 30 miles from release site (Table 3). Dashed line from off Eureka to Destruction Island, Washington, represents assumed, minimal journey of a tagged fish that had been shipped from Bellingham, Washington, to a market in San Pedro, California.

periods, the number of returns declined erratically until the end of the tenth 180-day period. During these five years, 10 of the 182 recaptures were made at distances greater than 30 miles from release sites (Table 2). In the remaining periods, representing approximately 6 through 8 years[2] after release, only 3 additional fish

[2]Following completion of this report, a tagged sablefish that had been at liberty for 16.5 years (6,037 days) was caught on a baited longline set 230 fathoms deep, southwest of Pt. Santa Cruz, Monterey Bay, California, November 6, 1967. The recovery was made about 4 miles from the site where the fish had been tagged and released on April 27, 1951. This specimen had increased only 5.1 inches, total length (from 56.0 to 69.0 cm), during the 16.5 years. In part, this may have been due to slower growth rate associated with males of this species, which do not grow as large as females.

were taken and these had migrated 155 to 327 miles to the northward (Table 3). This may indicate a greater degree of wanderlust amongst older fish. Analogously, 3 sablefish tagged in Puget Sound in 1955 and 1956 were recaptured 6 to 7 years later in the Bering Sea, about 2,100 nautical miles to the northward (Pasquale, 1964). Although it appears from fish tagged in Puget Sound that distant movements were exclusively in a northern direction, reciprocal movements were accomplished by 2 fish tagged in the Gulf of Alaska. One of these was recaptured off Puget Sound, a minimum distance of 1,230 miles from the release site (Edson, 1954).

TABLE 2

Number of California-Tagged Sablefish Recovered During Successive 180-Day Periods. (Exposed numbers represent recoveries within 30 nautical miles of release site; those in parentheses migrated beyond 30 miles.)

Year	Days at Liberty	Number of Recoveries				Percent of Total Recovered
		Tagging Region			State Total*	
		Monterey	Fort Bragg	Eureka		
1	0- 180	30 (1)	10 (0)	39 (1)	79 (2)	43.8
	181- 360	9 (0)	11 (2)	7 (0)	27 (2)	15.7
2	361- 540	1 (0)	0 (2)	7 (1)	8 (3)	6.0
	541- 720	2 (0)	5 (1)	5 (0)	12 (1)	7.0
3	721- 900	5 (0)	5 (0)	15 (1)	25 (1)	14.1
	901-1,080	——	2 (0)	5 (0)	7 (0)	3.8
4	1,081-1,260	1 (0)	1 (0)	2 (0)	4 (0)	2.2
	1,261-1,440	——	1 (1)	1 (0)	2 (1)	1.6
5	1,441-1,620	1 (0)	1 (0)	——	2 (0)	1.1
	1,621-1,800	——	5 (0)	1 (0)	6 (0)	3.2
6	1,801-1,980	——	——	——	——	——
	1,981-2,160	0 (1)	——	——	0 (1)	0.5
7	2,161-2,340	——	——	0 (1)	0 (1)	0.5
	2,341-2,520	——	——	——	——	——
8	2,521-2,700	——	——	——	——	——
	2,701-2,880	——	0 (1)	——	0 (1)	0.5
Totals		49 (2)	41 (7)	82 (4)	172 (13)	100.0

*1 Monterey and 2 Eureka region tagged fish omitted because recovery information lacking.

TABLE 3

Release and Recovery Information for Tagged Sablefish that Migrated More Than 30 Nautical Miles from California Release Sites.

Release Site	Month and Year		Miles and Direction	Days at Liberty	Locality of Recovery
	Release	Recovery			
Monterey	May, 1951	Oct., 1951	155 North	163	Fort Bragg, Calif.
Monterey	May, 1951	Nov., 1956	155 North	2,019	Fort Bragg, Calif.
Fort Bragg	June, 1951	July, 1952	32 South	390	Point Arena, Calif.
Fort Bragg	June, 1951	Jan., 1952	72 South	217	Bodega Head, Calif.
Fort Bragg	July, 1951	June, 1959	327 North	2,880	Yaquina-Cascade Hds., Ore.
Fort Bragg	Feb., 1952	Nov., 1952	118 North	273	Eureka, Calif.
Fort Bragg	Feb., 1952	Apr., 1953	156 South	419	Santa Cruz, Calif.
Fort Bragg	Feb., 1952	Sept., 1953	450 North	579	Grays Harbor, Wash.
Fort Bragg	Mar., 1952	Oct., 1955	285 North	1,292	Hecate Bank, Ore.
Eureka	June, 1952	July, 1952	412 North	31	Destruction I., Wash.
Eureka	June, 1952	Sept., 1954	33 North	808	Redding Rock, Calif.
Eureka	June, 1952	Aug., 1958	156 North	2,250	Coos Bay, Ore.
Eureka	Aug., 1952	Dec., 1953	215 South	534	Halfmoon Bay, Calif.

Since the bulk of the recaptures of fish tagged in California were made within 30 miles of initial release sites, it appears that the stocks in the three California regions are primarily non-migratory. This conclusion is in accord with that reached in an earlier analysis of tagging experiments in Washington, Oregon, and California (Holmberg and Jones, 1954), and is in harmony with findings based on returns from the experiments in Alaskan water (Edson, 1954; Alaska Department of Fisheries, Annual Reports for 1953 and 1954).

The 4.6 percent recovery of California-tagged fish is a little higher than reported for either Oregon, Washington, or Alaska tagging. But, such results are of a low order when compared to the recovery ratios for a number of other fishes that have been tagged. The method by which sablefish were caught previous to tagging had slight effect on the probability of recapture. In California and Alaska, all fish tagged were caught with setlines. But in Oregon and Washington where fish were tagged from both setline and otter trawl catches, no significant difference was noted in the recovery ratio for fish initially caught by either type of gear.

It is unlikely that all agencies concurrently experienced a considerable loss of tags by shedding, predation, or non-return of recaptured tags. A logical inference from these limited recoveries is that the population of sablefish along the Pacific Coast of North America is of greater magnitude than previously assumed. Alverson, Pruter, and Ronholt (1954) report that adult sablefish appear to inhabit the deeper waters along the continental slope throughout most of the northeastern Pacific. In numerous exploratory hauls they found this species to be one of the most abundant demersal market fishes in depths of 200 to 500 fathoms. To date, our fishermen have only casually exploited the deeper ocean waters, primarily because of the time and effort involved.

FACTORS AFFECTING TAG RETURNS

The durability of tags attached to fish has been a matter of concern in marking experiments. Plastic deterioration and metal corrosion in Petersen type fish tags are discussed by Calhoun, Fry, and Hughes (1951). Their favorable report on stainless steel wire pins for securing plastic disks to fish was confined in tagging experiments on sablefish. No corrosion in this type of wire[3] was noted during the period of 9 years of tag recoveries. Also, during this period the celluloid disks (cellulose acetate) were in good condition upon recovery. A disadvantage of this tag is that it may catch in the meshes of a net and become detached. A detached tag was discovered on the deck of a trawler after a catch made off Eureka had been dumped from the net (loc. cit.). Similarly, 4 tags that had become detached from sablefish were found entangled in the webbing of a herring trap to which released fish had returned during the course of a supplementary tagging experiment in Puget Sound (Pruter, 1959).

In some cases fishermen were too busy tending gear to notice or to set aside tagged fish. Sometimes fishermen informed marketmen of tagged fish in deliveries. In the process of dressing sablefish, marketmen found 28 tags. Nevertheless, 6 tags escaped notice initially and were returned by secondary dealers at Los Angeles and San Francisco to whom dressed, iced, or frozen sablefish had been shipped from wholesale dealers at northern ports. Also, the tag on a fish caught off Oregon was not noticed until it had been prepared for smoking.

One marketman reported that he removed a tag which was laid aside and never found again. Another, while filleting and talking to a friend, realized too late that there was a tag attached to the carcass he dropped through a hatch to a sea lion waiting below. Sea lions are extremely fond of sablefish and can demonstrate this by rarely missing a carcass tossed their way.

On one tagging trip off Eureka, fishermen on a nearby setline vessel caught a tagged sablefish but released it immediately upon observing that we were releasing tagged fish in the same area.

A monetary reward was not offered for the return of tags. But, a wallet-size, plastic commendation card bearing the two disks and information was presented for each recovery. This acknowledgment worked fairly well with souvenir-keepers except that a fisherman's interest might wane after he received several such mementos. Some successful fishermen have designated family members or friends as recipients.

GROWTH

A study of the growth during the time tagged-fish were free was restricted to 105 California releases that had been measured upon recapture and 74 of these were taken during the first 360 days (approximately one year) at liberty. The average length increments for successive intervals of 180 days at liberty exhibit an irregular but upward trend during the several years of recaptures. The average increase was from 0.6 centimeters (0.24 inches) for 57 fish at the end of 180 days, to 13.3 centimeters (5.24 inches) for one fish taken 2,880 days after release (Table 4). A few of the earliest recaptures indicated a negative growth or shrinkage of a fraction of a centimeter, but these discrepancies were considered as zero growths for the purpose of this study.

Growth information derived from apparent increases in lengths of recaptured sablefish is of a gross nature because of the small number of recoveries of fish that had been at liberty more than 360 days and other fac-

[3]Type 302, 0.032-inch diameter, "dead soft". Alloy Metal Wire Co., Prospect Park, Pennsylvania.

tors. Some disturbing factors are: shrinkage in some fishes after death (Holmberg and Jones, 1954; Holland, 1957; Best, 1963); shock caused by treatment during tagging activity; irritation caused by tags; manner in which recaptured specimens are measured; and differential growth between sexes (Pruter, 1954). Sex was not determined for recaptured sablefish that were tagged in California. This precludes comparison with the growth curves derived from scale studies of Pruter (1954).

SUMMARY

During the period 1950-1952, California participated with Oregon, Washington, and Alaska in a joint program to tag sablefish in order to determine the population structure of the species.

In California all tagging was accomplished from commercial setline vessels that operated in the usual fishing areas in the Monterey, Fort Bragg, and Eureka regions. Plastic disk tags of the Petersen type were wired to the backs of the fish released.

A total of 4,078 tagged sablefish were released in California, and 188 (4.6 percent) of these were recaptured. Releases were in water depths of 90 to 300 fathoms while recaptures were from depths of 50 to 350 fathoms. Recaptures were made from 1 day to 2,880 days[4] after release. During this period, only 13 fish were taken at distances greater than 30 miles from where released. The greatest migration was 450 nautical miles northward from off Fort Bragg to off Grays Harbor, Washington.

One recovery of a detached tag discovered on the deck of a trawler following a catch of bottomfish was not included in this analysis. The tag was placed on a fish released 3,334 days earlier in the same locality and may have become detached at some previous time.

The scant number of distant recoveries of tagged fish is indicative of a limited intermixture of fish within California and between California and the adjacent Pacific Northwest region. Similar disclosures of essentially localized stocks of sablefish have resulted from the tagging experiments conducted jointly by the other Pacific coast agencies. Thus, any regulation that might be needed in the future should be applied on a local basis rather than coastwise.

A low order of recovery was a concurrent feature of all the tagging experiments. The limited recovery most likely indicates that the population of sablefish along the Pacific coast, particularly that segment in deep water, is insufficiently exploited. The commercial catch is restrained by a limited demand for large fish which are smoked. The oily nature of the flesh, which enhances the smoked product, has curtailed consumer acceptance of the flesh in a fresh form. A fuller use of this abundant, rich fish should be encouraged.

[4]See footnote 2.

TABLE 4

Average Length Increments for 105 Sablefish Tagged off California, That Were Recaptured During Successive Periods of 180 Days.

Year	Days at Liberty	Total Lengths at Release (cm)		Number of Fish	Length Increment at Recovery (cm)	
		Range	Average		Range	Average
1	0- 180	53.5-77.0	64.8	57	0- 8.3	0.6
	181- 360	51.0-79.0	62.8	17	0- 4.4	1.7
2	361- 540	59.0-71.0	67.0	7	0- 9.0	3.9
	541- 720	54.5-72.5	60.1	6	1.4- 6.7	3.3
3	721- 900	54.5-69.0	61.8	8	0- 9.8	3.7
	901-1,080	62.0-68.0	65.0	2	3.5- 6.0	4.7
4	1,081-1,260	60.5-64.0	62.3	2	4.6- 7.9	7.2
	1,261-1,440	64.0	64.0	1	8.5	8.5
5	1,441-1,620	60.5	60.5	1	7.5	7.5
	1,621-1,800	61.5-65.5	63.0	3	2.6-16.5	9.7
6	1,801-1,980	—	—	—	—	—
	1,981-2,160	—	—	—	—	—
7	2-161-2,340	—	—	—	—	—
	2,341-2,520	—	—	—	—	—
8	2,521-2,700	—	—	—	—	—
	2,701-2,880	65.5	65.5	1	13.3	13.3

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Fishermen, marketmen, and others who returned tags and information are commended for their contributions to the knowledge of our fisheries.

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The Oregon Trawl Fishery for Mink Food, 1958-65

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THE OREGON TRAWL FISHERY FOR MINK FOOD, 1958-65

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INTRODUCTION

This report supplements the one written by Jones and Harry (1961) covering the period 1948 to 1957. Its purpose is to document trends and to report changes in Oregon of the status of production of mink and of the fish used for mink food.

Mink *(Mustela vison,* Schreber) ranching in Oregon has continued to grow as an important industry, with the State ranking 5th nationally in mink production. The number of pelts produced in 1958 totaled 208,000 and in 1964 reached 376,000. Total value during this period increased from $4.4 to $6.8 million. An important source of food for these animals has been the trawl fishery. In 1956 whole fish used for mink food amounted to 14.1 million pounds or 55% of total Oregon trawl production. By 1965 this had dropped to 4.2 million pounds or 12% of the total trawl production. We are interested in the following questions concerning the otter trawl fishery for mink food: (1) What is the total annual catch by species of whole fish landed for mink food? (2) Is there a trend in the fishery? (3) Is there any change in the catch of the three principal soles — Dover, English, and petrale — used for human food? Table 1 lists the common and scientfic names of the fish mentioned in the text.

HISTORY AND DEVELOPMENT OF THE MINK-FOOD FISHERY

The early history of the mink food fishery was documented by Jones (1958) and Jones and Harry (1961). "Red Meats" obtained from horses and young dairy calves composed the staple portion of the diet fed to ranch mink up to and throughout World War II. During the War, horse meat became increasingly difficult and expensive to obtain. In contrast, abundant supplies of carcasses from filleted fish were available for mink food.

TABLE I

Fish Identified in Mink Food Samples, 1958-64.

Common Name	Scientific Name
FLATFISH	
Arrowtooth flounder, turbot	*Atheresthes stomias*
Flathead sole	*Hippoglossoides elassodon*
English sole	*Parophrys vetulus*
Rex sole	*Glyptocephalus zachirus*
Sand dab	*Citharichthys sordidus*
Rock sole	*Lepidopsetta bilineata*
Petrale sole	*Eopsetta jordani*
Sand sole	*Psettichthys melanostictus*
Bellingham sole	*Isopsetta isolepis*
Slender sole	*Lyopsetta exilis*
Dover sole	*Microstomus pacificus*
Starry flounder	*Platichthys stellatus*
Hornyhead turbot	*Pleuronichthys verticalis*
ROCKFISH	
Pacific ocean perch	*Sebastodes alutus*
Silvergray rockfish	*S. brevispinis*
Blackmouth rockfish	*S. crameri*
Splitnose rockfish	*S. diploproa*
Greenstriped rockfish	*S. elongatus*
Yellowtail rockfish	*S. flavidus*
Chilipepper	*S. goodei*
Black rockfish	*S. melanops*
Blue rockfish	*S. mystinus*
Bocaccio	*S. paucispinis*
Canary rockfish	*S. pinniger*
Flag rockfish	*S. rubrivinctus*
Stripetail rockfish	*S. saxicola*
Widow rockfish	*S. entomelas*
Shortspine channel rockfish	*Sebastolobus alascanus*
MISCELLANEOUS SPECIES	
Shad	*Alosa sapidissima*
Eel pout	Family Zoarcidae
Jack mackerel	*Trachurus symmetricus*
Lingcod	*Ophiodon elongatus*
True cod	*Gadus macrocephalus*
Hake	*Merluccius productus*
Dogfish	*Squalus acanthias*
Tom cod	*Microgadus proximus*
Sea poachers	Family Agonidae
Ratfish	*Hydrolagus colliei*
Blackcod	*Anoplopoma fimbria*
Sculpins	Family Cottidae
Skates	Family Rajidae
Anchovy	*Engraulis mordax*
Wolf-eel	*Anarrhichthys ocellatus*

Increasing number of ranchers took advantage of this inexpensive source of protein food. By 1950, bottomfish, both whole fish and fillet carcasses, made up from 50% to 70% of the diets fed to ranch mink in Oregon, west of the Cascade Mountains. Until 1953, fillet carcasses were more than adequate to supply the demand. However, curtailment of trawl-fish production due to strikes and fluctuations in the economy of the fishing industry often occurred during the summer and fall months when the need for fish by the ranchers was greatest. In order to centralize and stabilize the supply of both whole fish and fillet carcasses, a group of mink ranchers organized a cooperative known as the Oregon Fur Producers Association. This organization procured freezing and storage facilities in Astoria for receiving and holding trawl fish. Operation of the Astoria plant started in 1951 and a similar facility was opened at Newport in 1953. A slump in the fillet market in 1953 cut trawl production by 50%, from 21.3 million to 10.4 million pounds. This trend continued through 1956. As a result, the demand for fillet fish carcasses exceeded the supply, and an extensive fishery developed for whole fish for mink food. In 1955 and 1956, mink ranchers purchased trawl boats and plants for catching and processing fish. During 1955, a plant was established at Winchester Bay and in 1956 several of the Astoria and Newport fillet plants began receiving substantial quantities of whole fish for mink food.

The fillet market demand began to rise in 1957 and trawl landings were at a median level of 15 million pounds annually through 1959. Thereafter, landings have shown an increasing trend and in 1965 exceeded the previous high of 26 million pounds established in 1945. Conversely, the portion of the landings which was whole fish for mink feed dropped from a high of 14.1 million pounds in 1956 to 4.2 million pounds by 1965. However, the number of mink raised on Oregon ranches continued to rise. There were 56,000 mink raised on Oregon ranches in 1945 and by 1962 this number had increased to 513,000 on 173 ranches (Statistical Division of the National Fur Farm Organization). It remained at this level for the ensuing 3 years. Table 2 documents the landings of trawl fish by major category from 1956-65.

METHODS

Computation of the Number of Mink on Oregon Ranches

Jones (1958) calculated the number of mink on Oregon ranches for the period 1945-54. He used a constant of 3.25 as the average number of kits produced by each female. The ratio of females to males is 4 to 1. A family of mink contained 13 kits, 4 females, and 1 male. Since 1955 the ratio of kits per female has increase to 3.5. Therefore, a family unit of mink for the latter period consists of 14 kits, 4 females, and 1 male. The total number of mink reared on ranches annually is calculated from the formula: mink kit production multiplied by 19/14 or 1.357143 equals total mink. Kit production or pelts produced in Oregon for the years 1956-65 was obtained from the Statistical Division of the National Fur Farm Organization.

TABLE 2

Landings of Otter Trawl Fish in Oregon for 1956-65 by Major Categories.

	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
					Percent					
Mink food	55	40	37	30	17	22	19	19	19	12
Rockfish	9	13	17	15	21	19	22	16	14	12
Pacific ocean perch	11	12	10	10	11	18	18	26	31	41
Petrale sole	7	8	7	5	8	7	8	8	6	6
English sole	4	6	7	6	9	7	7	6	5	5
Dover sole	9	14	13	19	20	16	14	18	18	11
Rex sole	2	2	3	4	5	4	4	3	2	3
Flounder	Tr.*	1	1	1	1	2	2	1	2	1
Lingcod	1	2	1	1	3	2	2	2	2	3
Sablefish	1	1	1	Tr.	1	Tr.	1	1	Tr.	1
Misc. species	1	1	3	9	4	3	3	Tr.	1	5
					Millions of Pounds					
Food fish	10.7	15.3	15.8	15.7	21.2	19.6	25.5	24.3	25.3	27.6
Mink food	14.1	10.5	9.6	7.1	4.4	5.8	6.2	5.6	6.0	4.2
Total landings	24.8	25.8	25.4	22.9	25.6	25.4	31.7	29.9	31.3	33.2**

*Tr. indicates trace. **Includes 1.4 million pounds of industrial fish.

Computation of Fish Requirements of Mink Ranchers

Jones (1958) cited that a family unit of 18 required 2,116 pounds of feed per year or about 117 pounds per animal. The number of pounds of fish estimated to be consumed by one ranch mink west of the Cascade Mountains was calculated on the assumption that a mink was fed an average of 8 ounces of feed a day and that on a yearly average 65% of the daily ration was fish. Thus, the family which was fed 2,116 pounds of feed in a year was fed 1,375 pounds of fish. The breeder mink are fed daily as a rule throughout the year, and the mink to be pelted are fed for approximately 6 months. The average annual consumption of fish per ranch mink was 76.4 pounds. Jones states that this was probably a minimum figure.

Trends in the amount of fish used to feed mink during the period 1956 to 1965 are not well documented. Marvin Hille, Manager of Oregon Fur Producers Association, in a personal interview indicated that the amount of fish fed to ranch mink during this period has been on a definite downward trend. He estimated that the ration in 1955 contained 70% fish with slightly lower levels up to 1959. A sharp drop occurred about 1960 and by 1965 the fish portion of the ration had leveled off at 40%, of which 8% was derived from whole fish with the remaining 32% from fillet carcasses. Table 3 presents best estimates available for the calculated pounds of fish required annually for the years cited and depicts the development of the mink ranching industry and the fish required for the feeding of these animals. Total fillet fish landed was multiplied by 0.60 to obtain the weight of fillet scrap. Data covering the period 1945-54 are taken from Jones (1958).

The reason for the decrease in the amount of fish used in the diets is ascribed to research and performance, with price also a factor. Chicken and turkey by-products plus cereal grains and premix packs have been developed to produce a better grade of mink. In some cases, mutants require specialized diets. There are several methods by which the amount of feed required in a year is determined. The most popular system is based upon the feed requirements to produce a specified litter of kits. This method also takes into account the feed requirements of the breeders. Oregon Fur Producers Association and local ranchers state that 120 pounds of feed per pelt or kit is required annually. Thus a family unit of 19 animals, (14 kits, 4 females, and 1 male), requires 1,680 pounds of feed yearly. If 40% of the feed is fish the average consumption of fish per mink family on Oregon ranches is 672 pounds of 35.4 pounds per mink. This latter figure indicates a 54% decrease in the figure cited by Jones. Turbot is preferred for feeding during March to September when kits are growing. It has a high fat content and a high growth factor. The growth diet consists of approximately 20% rockfish, 10% turbot, and 10% sole. More turbot would be fed if they were available. During furring, from September until late December, the diet will typically consist of the

TABLE 3

Numbers of Mink on Oregon Ranches and Calculated Pounds of Fish Available and Required for Mink Food in Oregon, 1945-65.

Year	Thousands of Mink	Millions of Lbs. of Fillet Fish Landed	Millions of Lbs. of Fish Available for Mink Food			Millions of Lbs. of Fish Required	Percent Fish
			Fillet Scrap	Whole Fish	Total		
1945	56.3	26.0	15.6	Unk.	Unk.	4.3	65
1946	68.5	25.5	15.3	"	"	5.3	65
1947	79.0	14.1	8.5	2.8	11.3	6.0	65
1948	90.6	20.1	12.1	3.3	15.4	6.9	65
1949	91.4	16.0	9.6	4.5	14.1	7.0	65
1950	99.9	20.2	12.1	2.0	14.1	7.6	65
1951	128.2	22.2	13.3	2.0	15.3	9.8	65
1952	141.3	21.3	12.8	2.0	14.8	10.8	65
1953	171.6	10.4	6.2	5.0	11.2	13.1	65
1954	203.5	12.0	7.2	6.2	13.4	15.5	65
1955	294.5	10.6	6.3	11.0	17.3	18.2	70
1956	316.2	10.7	6.4	14.1	20.5	19.6	70
1957	321.6	15.8	9.5	10.1	19.6	18.5	65
1958	282.3	15.8	9.5	9.6	19.1	16.2	65
1959	366.4	15.7	9.4	7.1	16.5	16.2	50
1960	475.0	21.2	12.7	4.4	17.1	18.9	45
1961	458.7	19.6	11.8	5.8	17.6	18.3	45
1962	513.0	25.5	15.3	6.2	21.5	20.4	45
1963	510.2	24.3	14.6	5.6	20.2	18.0	40
1964	504.0	25.3	15.2	6.0	21.2	17.8	40
1965	528.6	31.7	19.0	4.2	23.2	18.7	40

following ingredients; sole — 15%, of which only one-half is whole fish; rockfish — 23%; liver — 1%; whole meat — 6%; beef by-products — 11%; turkey — 9%; chicken — 3%; cereal — 15%; beet pulp — 1%; and water and moisture — 16%. Fur farm cost accounting statistics suggest that turbot is the only whole fish economically feasible to feed mink.

There are two interesting side lights which should be mentioned in connection with the development of the mink food fishery. 1. The distribution of mixed trawl fish, meat by-products, and cereals daily to mink ranches by the Oregon Fur Producers Association was inaugurated in 1962. A balanced diet mix is trucked and pumped very much like a milk route delivery service. This operation had made it possible for many small ranchers to eliminate many of their own freezers and storage plants. Of course, each rancher adds to the diet as he sees fit. At times he may revert to former practices of stockpiling and mixing his own feed. 2. It was previously mentioned that ranchers puchased boats to guarantee a supply of mink feed. There are four or five vessels owned by fur farms, however, they do not operate as mink food boats at the present time, but as food fish vessels with mink feed being incidental.

ANALYSIS OF THE TRAWL FISHERY FOR MINK FOOD

Annual Production

The annual total mink food production by the Oregon trawl fleet includes both the pounds of whole fish and fillet carcasses. Poundages of whole fish for mink food for the period 1956-65 were obtained from reports filed with the Oregon Fish Commission by fish receivers. Mink food consists of many species which are reported as a single weight of mixed fish. The total weight of each species of fish used for human food received by a processing plant is required to be reported monthly. The data from these reports were compiled to determine the pounds of fish landed at each port by month.

Total annual landings of trawl-caught fish during the 6 years 1956-61 were in the magnitude of 25 million pounds. The period 1962 through 1965 saw a rise to the 30 million-pound level (Table 2). Deliveries of whole fish for mink food compared with fish landed for the fillet market illustrate an inverse relationship. During 1956 food fish constituted 10.7 million pounds or 45% of the total landings and by 1965 rose to 27.6 million pounds or 88%. Conversely, the amounts of fish sold for mink food dropped from a high 14.1 million pounds to 4.2 million pounds.

Fluctuations in the importance of the major species of bottomfish are apparent in Table 2. Pacific ocean perch illustrates a significant rise in landings for the years 1961 through 1965. Much of the success of this fishery can be attributed to gear technology, the use of "bobbins" or foot-rope rollers, which has opened previously untrawlable ground. Dover sole off Oregon also indicate increased landings until 1964. The drop in 1965 was caused primarily by increased effort on perch. Rockfish and rex sole show decreased landings. Petrale sole and English sole illustrate a slight downward trend.

Species Composition of Mink Food Landings

Over 40 species of fish are taken customarily in otter trawls, but many are not retained for human consumption and are either discarded or saved for mink food. Flatfishes and rockfishes still comprise the major species used for animal food. In the case of soles that are utilized for fillet markets, the undersized specimens are returned to the water. A legal load of mink food cannot have more than 100 fish in the aggregate of Dover, English, or petrale sole under 11-inch total length.

Sampling of deliveries is necessary to determine the species composition of mink food landings. From 1953-56, Jones and Harry (1961) sampled to determine the number and weight by species of an unsorted box of fish containing approximately 600 pounds. The fish of each species were counted and average weights were taken periodically. Length-frequency distributions of Dover, English, and petrale soles were taken.

In recent years sampling of mink food has been reduced. Presently, a visual estimate or count is made of each species in a landing, then using an approximate average weight per fish of each species the weight of each species contributing to the total weight of the landing is calculated. This is comparable to the estimates fishermen use in their hails. Sampling of the landings at each port by year was used to determine the amount of fish by weight for each species landed. In some instances, the species breakdown was based upon samples taken at sea combined with dock samples to give the best estimate for percentage weight composition. These sample perecentages by weight were applied to total production figures, and were reported by statistical area to the Pacific Marine Fisheries Commission for the years 1958-65 (Tables 4-11). Figure 1 shows the PMFC areas and Oregon ports of landings.

Turbot has been the most common species in mink food landings for the period cited. It has risen from a 32% level in 1958 to 55% in 1965. Turbot in mink food landings in 1955 and 1956 was over 4 million pounds each year. This amount has not been equalled in ensuing years. A 3-million-pound level was calculated in 1958 and in 1959. This was followed by an abrupt drop to 1.5 million pounds for 1960 and for 1961, a resurgence to 3 million pounds in 1962, and then fluctuations about the 2.5-million-pound level in 1963, 1964 and 1965. A premium price is paid for landings containing turbot only.

Bellingham or butter sole contributed heavily to the landings in 1958 and 1959 at a yearly magnitude of nearly 900,000 pounds but dropped to practically zero by 1964. Some vessels at one time sought this sole almost exclusively. It is found in shallow water.

Dover sole contributed 11% or 1.7 million pounds of the mink food landings in 1956, in 1958 it contributed only 1.0 million pounds, and by 1960 less than

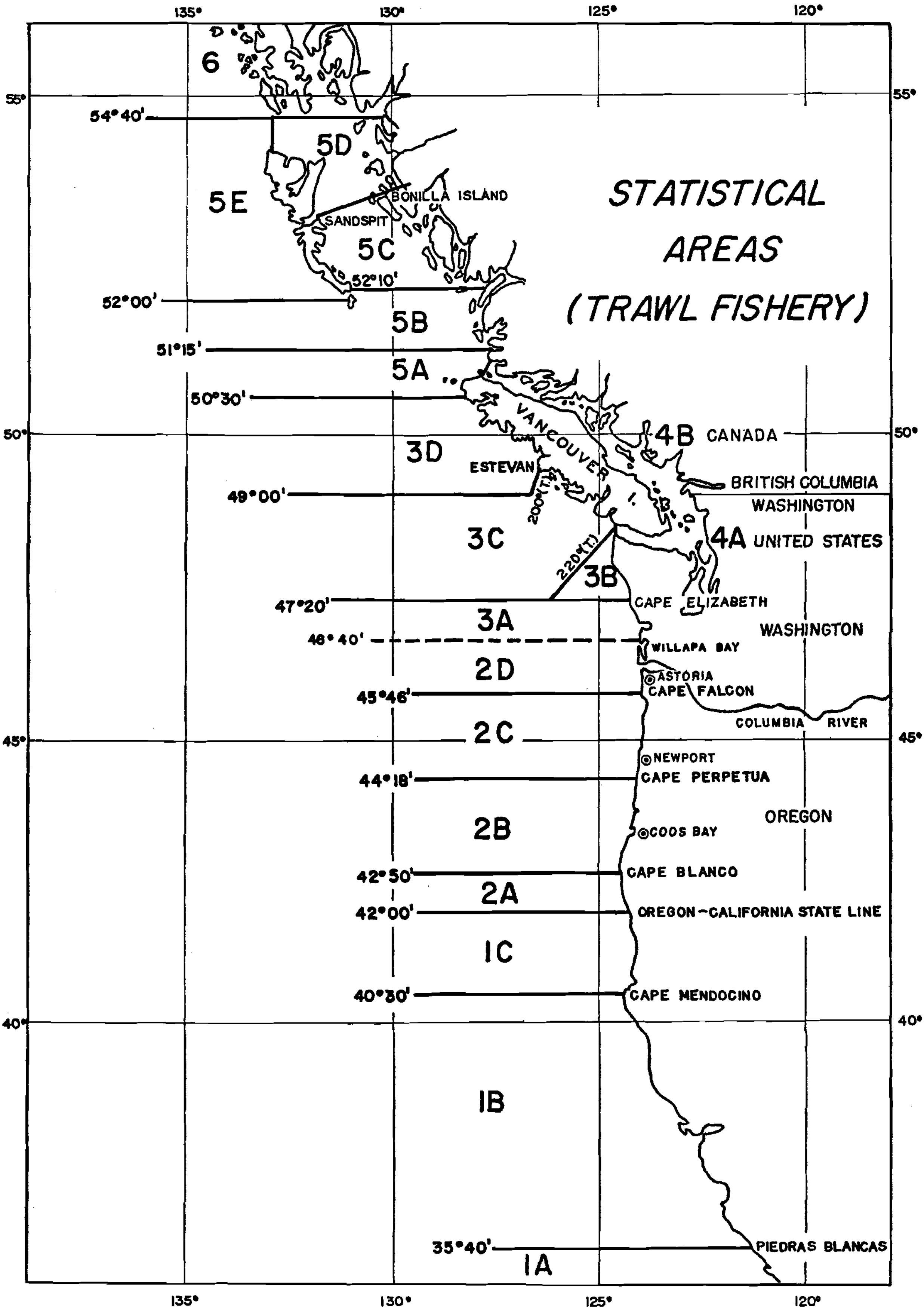

FIGURE 1. Pacific Marine Fisheries Commission trawl statistical areas.

TABLE 4

Trawl-Caught Fish Used for Animal Food in 1958 by PMFC area[1]. (in 1,000's of lb.)

Species	2B	2C	2D	3A	3B	Total	Percent
Turbot	1,076	1,026	788	153	3	3,046	31.7
Rockfish	119	113	87	17	Tr.	336	3.5
Bellingham sole	305	292	223	43	1	864	9.0
English sole	217	207	159	31	1	615	6.4
Dover sole	356	340	261	51	1	1,009	10.5
Rex sole	550	524	402	78	2	1,556	16.2
Petrale sole	88	84	65	12	1	250	2.6
Misc. sole	502	479	368	71	2	1,422	14.8
Misc. fish	180	172	132	26	Tr.	510	5.3
Total	3,393	3,237	2,485	482	11	9,608	100.0

[1]Calculated species composition as derived in 1957 from 11 port samples combined for all Oregon. No samples were taken in 1958.

TABLE 5

Trawl-Caught Fish Used for Animal Food in 1959 by PMFC area. (in 1,000's of lb.)

Species	2B	2C	2D	3A	3B	Total	Percent
Turbot	1,265	583	1,004	14	231	3,097	43.4
Rockfish	151	70	120	2	28	371	5.2
Bellingham sole	364	168	289	4	67	892	12.5
English sole	353	162	280	4	64	863	12.1
Dover sole	119	55	95	1	22	292	4.1
Rex sole	318	146	252	4	58	778	10.9
Petrale sole	12	5	9	–	2	28	0.4
Misc. sole	52	24	41	Tr.	9	127	1.8
Misc. fish	280	129	222	3	51	685	9.6
Total	2,914	1,342	2,312	33	532	7,133	100.0

TABLE 6

Trawl-Caught Fish Used for Animal Food in 1960 by PMFC Area. (in 1,000's of lb.)

Species	2B	2C	2D	3A	3B	3C	Total	Percent
Turbot	625	198	363	79	100	7	1,372	30.9
Rockfish	392	125	228	49	63	4	861	19.4
Bellingham sole	267	85	155	33	43	3	586	13.2
English sole	141	45	82	18	22	1	309	7.0
Dover sole	113	36	66	14	18	1	248	5.6
Rex sole	255	81	148	32	41	3	560	12.6
Petrale sole	79	25	46	10	12	1	173	3.9
Misc. sole	115	36	67	14	18	1	251	5.7
Misc. fish	34	11	20	4	5	Tr.	75	1.7
Total	2,021	642	1,175	253	322	21	4,435	100.0

TABLE 7

Trawl-Caught Fish Used for Animal Food in 1961 by PMFC Area. (in 1,000's of lb.)

Species	2B	2C	2D	3A	3B	Total	Percent 2B-2C	Percent 2D-3A-3B
Turbot	388	207	988	41	83	1,707	18.9	42.1
Rockfish	294	156	167	7	14	638	14.3	7.1
Bellingham sole	6	3	230	9	19	267	0.3	9.8
English sole	238	127	331	14	28	738	11.6	14.1
Dover sole	343	183	94	4	8	632	16.7	4.0
Rex sole	421	224	197	8	17	867	20.5	8.4
Petrale sole	119	63	47	2	4	235	5.8	2.0
Misc. sole	105	56	152	6	13	332	5.1	6.5
Misc. fish	141	74	141	6	12	374	6.8	6.0
Total	2,055	1,093	2,347	97	198	5,790	100.0	100.0

TABLE 8

Trawl-Caught Fish Used for Animal Food in 1962 by PMFC Area, (in 1,000's of lb.)

Species	2B	2C	2D	3A	3B	Total	Percent 2B	Percent 2C	Percent 2D-3A-3B
Turbot	322	697	1,863	74	8	2,964	23.3	51.4	56.6
Rockfish	174	310	92	4	1	581	12.6	22.9	2.8
Bellingham sole	–	–	85	4	1	90	–	–	2.6
English sole	33	77	441	18	2	571	2.4	5.7	13.4
Dover sole	257	108	168	7	1	541	18.6	8.0	5.1
Rex sole	413	68	283	11	2	777	29.8	5.0	8.6
Petrale sole	15	Tr.	43	1	Tr.	59	1.1	0.1	1.3
Misc. sole	122	27	181	7	1	338	8.8	2.0	5.5
Misc. fish	47	67	135	5	1	255	3.4	4.9	4.1
Total	1,383	1,354	3,291	131	17	6,176	100.0	100.0	100.0
No. of samples							9	9	58

TABLE 9

Trawl-Caught Fish used for Animal Food in 1963 by PMFC Area. (in 1,000's of lb.)

Species	2B	2C	2D	3A	3B	Total	Percent 2B-2C	Percent 2D-3A-3B
Turbot	193	247	1,820	37	54	2,351	19.3	58.6
Rockfish	64	82	93	2	3	244	6.4	3.0
Bellingham sole	–	–	9	Tr.	Tr.	10	–	0.3
English sole	71	91	227	5	7	401	7.1	7.3
Dover sole	156	199	99	2	3	459	15.6	3.2
Rex sole	294	376	559	11	17	1,257	29.4	18.0
Petrale sole	13	17	31	Tr.	1	62	1.3	1.0
Misc. sole	94	120	165	3	5	387	9.4	5.3
Misc. fish	115	147	102	2	3	369	11.5	3.3
Total	1,000	1,279	3,105	63	93	5,540	100.0	100.0
No. of samples							24	80

250,000 pounds. In 1961 landings rose to over 600,000 pounds and then decreased to 75,000 pounds in 1965. It was fished heavily in the Coos Bay area with the preponderance of landings being from that area.

Rex sole landings in 1956 for animal food constituted almost 2 million pounds. This species has been one of the major contributors to mink food landings although it has also gained favor as a fillet market fish in recent years.

English sole landings during the study period ranged from 800,000 to 300,000 pounds, and during the last few years has decreased to about a 400,000-pound level. It is an important fillet market fish.

Petrale sole, the most valued fillet sole, has been of minor importance in mink food landing because of sorting of the catches to satisfy the market demand.

Starry flounders is a major component of the miscellaneous sole category in mink-food landings. The abundance of this flounder in mink food reflects the low market demand for it for fillets. Starry flounder is most abundant during midsummer when trawl activity is at a peak and the overflow of less valuable fish is diverted to mink food. Other miscellaneous flatfishes such as other flounders, sand dabs, slender sole, rock sole, sandsole, and hornyhead turbot are referred in the tables as "Miscellaneous sole"; at times they have been significant in deliveries of mink food. "Miscellaneous fish" a category including 15 species, appears to contribute to animal food use in greater proportion than previously noted. This has resulted from increased utilization of low market demand species or so called scrap fish.

Rockfish include 15 species delivered for mink food. Widow rockfish is a notable addition to the list of Jones and Harry (1961). Recently because of its low demand

TABLE 10

Trawl-Caught Fish Used for Animal Food in 1964 by PMFC Area. (in 1,000's of lb.)

Species	2B	2C	2D	3A	3B	3C	Total	Percent 2B-2C	Percent 2D-3A-3B-3C
Turbot	157	241	2,123	49	73	38	2,681	19.3	58.2
Rockfish	52	80	708	16	24	13	893	6.4	19.4
Bellingham sole	–	–	7	–	Tr.	–	7	–	0.2
English sole	58	89	212	4	7	4	375	7.1	5.8
Dover sole	127	197	110	3	4	2	443	15.6	3.0
Rex sole	240	367	193	5	7	3	815	29.4	5.3
Petrale sole	11	16	22	Tr.	1	Tr.	50	1.3	0.6
Misc. sole	77	117	193	5	7	3	402	9.4	5.3
Misc. fish	94	144	80	2	3	1	324	11.5	2.2
Total	816	1,250	3,648	85	126	65	5,990	100.0	100.0
No of samples								*	95

*The 1963 species composition was used for 2B-2C because of insufficient samples.

TABLE 11

Trawl-Caught Fish Used for Animal Food in 1965 by PMFC Area. (in 1,000's of lb.)

Species	2A	2B	2C	2D	3A	3B	Total	Percent 2B	Percent 2C	Percent 2D-3A-3B
Turbot	–	517	455	1,226	52	50	2,300	64.2	40.9	60.2
Rockfish	–	47	46	204	9	8	314	5.8	4.1	10.0
Bellingham sole	–	–	90	4	Tr.	–	94	–	8.1	0.2
English sole	–	38	240	246	10	10	544	4.8	21.6	12.1
Dover sole	–	8	18	45	2	2	75	1.0	1.6	2.2
Rex sole	–	51	58	128	5	5	247	6.3	5.2	6.3
Petrale sole	–	2	69	12	Tr.	Tr.	84	0.2	6.2	0.6
Misc. sole	–	19	122	145	6	6	298	2.4	11.0	7.1
Misc. fish	–	123	15	26	1	1	166	15.3	1.3	1.3
Unknown	28	–	–	–	–	–	28	–	–	–
Total	28	805	1,113	2,036	86	83	4,151	100.0	100.0	100.0
No. of samples								6	21	94

for fillets it has been ground as animal food in 50,000-pound lots. Since 1960 it has been taken in quantity off the Oregon coast at times. Only during 1965, when other fishes were in short supply, was there any indication of this species being filleted.

Pacific ocean perch was the major rockfish species noted in mink-food landings during the period of this study, but the major portion of perch landings is used for fillets. During 1956-60 the total yearly landings averaged 2.7 million pounds. In 1961 the perch catch was 4.5 million, and by 1964 it reached 9.5 million pounds. Total perch catches for the fillet market and mink reached an all time high of 13.8 million pounds in 1965. Many plants restricted their boats regarding the amount of perch the plants woulld buy for filleting, therefore, the surplus catches were marketed as mink food.

Jones and Harry (1961) listed rockfish landings for mink food as 4.3 million pounds in 1956. By 1965 the total had dropped almost to 300,000 pounds. Table 12 indicates the change in species composition of the major rockfish species and in the quantity of rockfish landed in Oregon as mink food.

TABLE 12

Major Species of Rockfish landed in Oregon as Mink Food in 1956 and 1965

Species	1956		1965	
	Percent	Pounds	Percent	Pounds
Pacific Ocean perch	21.4	920,202	31.6	99,067
Idiot	11.6	496,419	6.1	19,248
Yellowtail	2.5	106,161	9.9	31,180
Canary	30.5	1,311,320	0.2	502
Boccacio	8.0	341,690	11.9	37,335
Flag	12.8	552,293	—	—
Widow	—	—	24.5	76,962
Other rockfish	13.3	569,915	15.8	49,706
Total rockfish	—	4,298,000	—	314,000
Total mink food	30.4	14,121,000	7.5	4,151,000

Table 13 shows the Oregon landing of various species of trawl-caught fish and the ratio of mink food to fillet-market use for the years 1958-65.

SIZE OF DOVER, ENGLISH, AND PETRALE SOLE IN MINK-FOOD LANDINGS

In 1955 a minimum mesh size of 4½ inches between knots of trawl net used for sole fishing was adopted by Oregon and Washington fishery agencies. A minimum length of 11 inches for Dover, English, and petrale soles was suggested in order to eliminate from the inshore fishery the small-mesh trawls used offshore for Pacific ocean perch and to keep the landings of small, immature soles to a minimum. Data from landings made with 4¼-inch or larger mesh nets were examined to see what numbers of small soles less than 11 inches could be expected. These data were taken from dock samples of mink feed, mesh experiments, and from sampling at sea on commercial trawlers. The data indicated that in a 10,000-pound load of mink food (only 2,000 pounds of which, by regulation, could consist of Dover, English and petrale soles), approximately 100 Dover, English, and petrale soles would be less than 11 inches. Most mink-food landings averaged about 10,000 pounds in weight. It was recognized that this would vary according to the size of fish on the grounds, species, net material, etc. However, trawl fishermen and mink ranchers maintained that a 100-fish tolerance was not practical and urged that a greater tolerance be allowed.

Morgan (1959) reported on sampling at sea during 1959. The samples included counting all fish caught and measuring all Dover, English, and petrale soles. Results indicated that there was no problem with Dover sole less than 11 inches even when the nets used on two trips did not meet requirements of the mesh regulations. This corresponded to data from past years, Table 14. Petrale sole were obtained on only one trip in any quantity and there appeared to be no problem of staying within the 100-fish tolerance. The percentage of English sole less than 11 inches ranged from 5.4% to 10.7% by number and 2.1% to 3.7% by weight.

Morgan (1959) also reported that English sole less than 11 inches in length in samples from 4 landings of mink-food ranged from 17 to 47% by number and 11 to 28% by weight. These catches were made with 4½ or larger mesh nets. Calculated numbers and pounds of English sole by size group in combined data of the 4 landings are as follows:

Size Group	Numbers	Wt. Range Ave. Fish in Lb.	Total Pounds
Less than 11 inches, 20-27 cm	9,324	0.1—0.4	2,801
11-13 inches, 28-32 cm	18,806	0.5—0.7	11,184
Greater than 13 inches, 33-50 cm	3,604	0.8—2.9	3,229
Total	31,754		17,214

TABLE 13

Landings of Various Species and Ratio of Pounds Used for Mink Food to Pounds for Fillet Market, 1958-65 (in 1,000 lb. and %)

	Rockfish[1]	English Sole	Dover Sole	Rex Sole	Petrale Sole	Misc.[2] Sole	Misc.[3] Fish
1958:							
Mink food	336	615	1,009	1,556	249	1,422	510
Fillet	6,851	1,834	3,338	666	1,754	370	127
%	4.7	25.1	23.2	70.0	12.4	79.4	80.1
1959:							
Mink food	371	863	292	778	28	127	685
Fillet	6,167	1,451	4,543	864	1,275	366	249
%	5.7	37.3	6.0	47.4	2.1	25.7	73.3
1960:							
Mink food	861	309	248	560	173	251	75
Fillet	8,126	2,454	5,208	1,280	2,143	438	413
%	9.6	11.2	4.5	30.4	7.5	36.4	15.4
1961:							
Mink food	638	738	632	867	235	332	374
Fillet	9,400	1,789	4,054	988	1,838	541	117
%	6.4	29.2	13.4	46.7	11.3	38.0	76.2
1962:							
Mink food	581	571	541	777	59	338	255
Fillet	12,914	2,295	4,454	1,333	2,607	922	65
%	4.3	19.9	12.1	36.8	2.2	36.8	79.7
1963:							
Mink food	244	401	459	1,257	62	387	369
Fillet	12,663	1,948	5,345	1,933	2,295	346	6
%	1.9	17.1	7.9	54.9	2.6	52.8	98.4
1964:							
Mink food	893	375	443	815	50	402	324
Fillet	13,695	1,562	5,529	806	1,877	680	32
%	6.5	19.4	7.4	50.3	2.6	37.2	91.0
1965:							
Mink food	314	545	75	247	83	394	194
Fillet	17,768	1,678	3,631	985	1,838	478	23
%	1.8	24.5	2.0	20.0	4.3	45.3	89.4

[1]Rockfish includes Pacific ocean perch.
[2]Miscellaneous sole includes sand dabs, flounders, slender sole, sand sole, flathead sole, and rock sole.
[3]Miscellaneous fish includes cods, skates, wolf-eel, shad, etc.

TABLE 14

Size Composition (% by numbers and weight) of Dover Sole Catches as Calculated from Samples Caught by Different Mesh Sizes in Various Years.

Year	Source of Data	Mesh Size	% by Numbers			% by Weight		
			< 11″	11″-14″	> 14″	< 11″	11″-14″	> 14″
1950	Samplings at sea from commercial boats	4½ inches or larger	0.3	9.0	91.7	0.8	4.2	95.0
1951	Sampling at sea from commercial boats	4½ inches or larger	1.0	11.0	88.0	0.3	5.2	94.5
1951	Gear experiments	3½ inches	21.0	51.0	28.0	8.0	23.0	69.0
		4½ inches	3.0	31.0	66.0	1.0	18.0	81.0
1954	Gear experiments	4½ inches	0.0	19.0	81.0	0.0	12.0	88.0
1955-56	Mink food samples	4½ inches or larger	7.0	61.0	32.0	3.0	53.0	44.0
		Various samples	7.0	49.0	44.0	3.0	37.0	60.0
1957	Mink food samples	Various samples	15.0	57.0	28.0	7.0	53.0	40.0

TABLE 15

Size Composition (% by numbers and by weight) of English Sole Catches as Calculated from Samples Caught by Different Mesh-Sizes in Various Years.

Year	Source of Data	Mesh-Size (inches)		Sample Numbers	Percent by Weight			Percent by Numbers		
		Range	Mean		< 11″	11″-13″	> 13″	< 11″	11″-13″	> 13″
1957	Mink food samples All nets and areas combined	–	–	897	53.0	38.0	9.0	31.0	50.0	19.0
1959	Mink-food samples 4 trips	4.46-4.81	4.63	2295	29.0	59.2	11.4	16.3	65.0	18.7
1959	Sampling at sea 4 trips	4.46-4.81	4.57	2059	7.1	37.5	55.4	12.8	27.6	69.6
1959	English sole tagging	4.5	4.50	4594	8.7	56.5	34.8	2.9	31.2	65.8
1960	Sampling at sea 7 trips	3.00-4.75	4.42	1404	11.3	36.8	51.9	4.6	27.1	68.3
1961	Sampling at sea 9 trips	4.02-4.69	4.42	2762	4.0	27.8	68.2	1.3	18.3	80.4
1965	Sampling at sea 4 trips	4.00-4.48	4.30	1252	16.5	44.9	38.6	7.9	36.1	56.0

English sole in the landings of these four boats were 27% of the mink-food total weight of 63,798 pounds. These data indicate that a 100-fish tolerance for English sole under 11 inches will cause sorting problems for fishermen with legal-size mesh nets. English sole are particularly vulnerable to catch because of their protruding anal spine. Fillet plants generally discard English sole less than 13 inches, but some buyers have begun to use small 12-inch sole as "skin sole"[1] because of lack of larger fish. English sole in mink food consist of males whereas fillet-destined fish are predominantly females. Most males are mature at 26 cm (10¼ inches) total length or approximately 4 years of age. Females 32 cm (12⅝ inches) total length are 3-years-old and some are mature, however, most mature at 4 years of age.

Table 15 represents the size composition of some English sole catches as calculated from samples caught by different mesh sizes during the years covered in this report.

[1]"Skin sole" are unfilleted sole marketed head-off, eviserated, fins trimmed, and dark or top-side skin and tail removed.

SUMMARY

The history of the mink-food fishery of Oregon is presented with trends and status changes documented for the years 1958 to 1965, inclusive.

Trawl-caught whole fish for mink food declined from 9.6 million pounds to 4.2 million pounds during 1958 through 1965. This has been caused by the increased feeding of mink with other ingredients such as chicken and turkey offal and other by-products, but fillet fish offal continues to be a major source of mink food. In 1956, 56% or 14.1 million pounds of the Oregon trawl-fishery production was sold as mink food. The numbers of mink husbanded on Oregon ranches rose from 282,000 animals to 504,000 having a value of $6.8 million. Approximately 20 million pounds of fish, scrap and whole, are still being fed each year.

Species composition of fish delivered as mink food is cited. Turbot is the dominant species, contributing approximately one-third of all fish sold whole for mink food each year. The catches of turbot off Oregon do not show any particular trend.

Rockfish, including Pacific ocean perch, have contributed substantially to mink food, but the sale of rockfish for mink food between 1956 and 1965 has shown a 74% decrease. Likewise, a change is noted in species composition. Perch was one-tenth of its former magnitude, yet still remained a major species in 1965 in mink food because of heavy production (13.8-million pounds for all purposes). Widow rockfish not previously monitored in mink-food landings was second in 1965. A demand for rockfish fillets has reversed the trend of using species such as orange and yellowtail rockfish for mink food.

Rex sole contributed substantially to mink food throughout the years studied. It is not protected and on the average approximately one-half of the yearly total production has been sold as mink food. It is an excellent human food fish.

Dover sole was in past years an important mink-food sole but its role has diminished considerably. English sole, a protected species like the Dover, has been very common in mink food and its high utilization in mink food is regarded as a conservation problem. Approximately one-fourth of the total English sole production is still used for mink food. Petrale sole is not common in the mink-food fishery.

Data on size composition of English, Dover, and petrale sole taken by trawl nets of various size mesh in the cod end are presented.

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