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Analysis of Populations of the Pacific Sardine on the Basis of Vertebral Counts

By
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CONTENTS

1. INTRODUCTION

1.1. History of Sardine Vertebral Studies

When any species of fish is exploited over a large portion of its range, it is important to know whether that species consists of several populations each keeping to a limited area or whether there is intermingling between different areas. The sardine, Sardinops caerulea (Girard), is fished with varying intensity along a North American coast line of approximately 2,000 miles, from British Columbia south to Cape San Lucas on the southern tip of Lower California. To determine the amount of intermingling of sardines on these far-flung fishing grounds, several types of investigations have been conducted. The results from each study confirm or support the findings from the other approaches. One of these investigations deals with the variations in the number of vertebrae of sardines taken in different localities. It has been held that, as a general rule, fish from warm waters have a smaller average number of vertebrae than do fish of the same species from colder waters (Hubbs, 1934). Thus, if there were little or no intermingling, it might be expected that sardines taken off southern Lower California would have on the average fewer vertebrae than those taken in British Columbia waters and fish from California would occupy an intermediate position. If the populations do interchange, many complexities in the average number of vertebrae might occur, especially if the interchange is a partial one only.

Five previous papers have been published giving summaries of counts on vertebrae from sardines taken along the Pacific coast of North America. Hubbs (1925) presented the results of counts made on 1,910 fish taken in Central and Southern California and concluded that racial distinction between the populations in the two localities had been neither demonstrated nor disproved. Thompson (1926) made comparisons between California and European sardines and found statistically significant differences in the averages. Because of variations within each population, however, he felt that doubt was cast on the biological significance of these differences. Hart (1933) published two papers comparing counts from British Columbia and from California. Again variations between collections from the same locality prevented interpreting differences between localities as biologically significant. Clark (1936b) tabulated additional data for collections from Alaska to Mexico and summarized all counts made to that date. These results indicated a complex adult population, perhaps resulting from the intermingling of sardines from many localities; but significant differences between the counts on young fish taken in California and on those taken in southern Lower California suggested a lack of admixture between the latter and the former.

Since 1936 many counts have been added for both adult and young sardines taken from British Columbia to the Gulf of California. The present paper tabulates all data and attempts to interpret the results.

1.2. Summary of Results

These vertebral counts indicate that sardines from British Columbia to Pt. San Eugenio in central Lower California comprise a mixture of populations, the young of which may have been reared on nursery

grounds in any of these localities. For most seasons, presumably, the nursery grounds off California and northern Lower California make the greatest contributions to the population.

Sardines living off southern Lower California and in the Gulf of California probably comprise a distinct group which does not mix with the northern fish; or if a mixture occurs, the proportion of southern fish to the total northern population is small.

The interchange between nursery grounds begins early, perhaps before the sardines are a year old.

The number of vertebrae varies between year-classes, and certain year-classes are characterized by high or low averages in all localities.

The average number of vertebrae is approximately 51.7 for all sardines north of southern Lower California and about 51.2 for sardines from southern Lower California.

1.3. Source of Material

The fish from Alaska were collected and the vertebral counts made by Dr. George A. Rounsefell of the U. S. Fish and Wildlife Service.

The records for British Columbia sardines include tabulations by Hart (1933) plus additional counts published here through the courtesy of the Fisheries Research Board of Canada. These additions are 61 counts made by Dr. H. C. Williamson in 1927, 6,900 made by Dr. J. L. Hart and his associates between 1934 and 1940, and 400 made by the writer on material forwarded to California by Dr. Hart.

From Oregon, counts on 25 sardines were furnished by Dr. Hart. Eighteen specimens of young fish were taken in albacore stomachs by Captain Svenson, 30–35 miles off the Columbia River, and forwarded to the California Division of Fish and Game by the Pacific Marine Products Company of Oregon. The remainder of the material from Washington and Oregon was collected by the U. S. Fish and Wildlife Service and counts were made by the writer.

The California data consist of records made by Hubbs (1925) and Hart (1933), and much additional material collected by the staff of the Bureau of Marine Fisheries of the California Division of Fish and Game. Also counts were made by the writer on 240 young sardines from the collections of the Museum of Zoology, University of Michigan, furnished through the courtesy of Dr. Carl L. Hubbs.

With the exception of 588 fish collected by Dr. L. A. Walford, U. S. Fish and Wildlife Service, material from Mexico was collected by the California Bureau of Marine Fisheries.

From the California and Mexican collections about 60 percent of the counts were made by the writer and the remainder by the staff of the California State Fisheries Laboratory. Special mention should be made of the assistance furnished by C. R. Clothier who handled about 20 percent of the counting and of J. B. Phillips who made about 5 percent. This help from the staff of the Bureau of Marine Fisheries is gratefully acknowledged as well as that from the Fisheries Research Board of Canada and the U. S. Fish and Wildlife Service.

1.4. Methods

Many workers have attempted to make population studies of the sardine based on variations in fin rays and gill rakers and in body proportions. Accurate fin ray counts are difficult to make and studies of this

character were abandoned due to the labor involved in making compilations for large numbers of fish. Gill raker counts can be made with fair accuracy but these vary with the size of the specimen and this precludes direct comparisons between young and adult sardines. The proportional measurements vary not only with size of fish but also between fresh and preserved material; in addition it is difficult to compare measurements made by different individuals. Because of these complexities this study has been confined to tabulations of the total number of vertebrae.

Counts made by the California workers and those published by Hubbs and by Thompson include the hypural. In Hart's publications the hypural was omitted but his data have been adjusted to make them directly comparable with the remainder of the material.

When specimens were handled fresh, the whole fish was boiled and the flesh removed from the backbone so that the number of vertebrae could be readily counted. For preserved material the flesh was cut away from one half of the body and the back bone exposed on one side. For small fish sufficient magnification was used to make the individual vertebrae readily distinguishable. All counts were checked by a second count. No attempt was made to distinguish between abdominal and caudal vertebrae.

As with other fishes abnormal vertebrae occur in sardines. These consist of fused and partly fused vertebrae and excess spines. In only a few instances was the back bone so deformed that no accurate count could be made. All partial fusions were counted as separate vertebrae. Vertebrae bearing extra spines were considered as single vertebrae. Fortunately the number of sardines with vertebral abnormalities is small. Fish with back bones so badly deformed that they had to be discarded comprised 0.03 percent of the California fish and those with fused vertebrae and additional spines 0.33 percent. Dr. Hart through correspondence with the writer indicated that sardines with abnormalities involved 0.32 percent of the British Columbia specimens.

The collections were divided into three age groups, adults, I group and O group. These age classifications were determined on the basis of size of fish and time of collection. Fish were considered adult if they were 150 mm. in standard length or greater. Most of the adult fish were obtained from the commercial fishery and were larger than 170 mm. Sardines were classed in the O group if they were fish of the year, taken between July and the succeeding January. These consisted of sizes ranging from about 30 mm. to about 120 mm. and represented fish up to about eight months old. The I group comprised fish taken from February through July when they were about 8 to 14 months old. These fish had a size range approximating 100 to 150 mm. In the I group were also included two collections made in northern Lower California in September. These were placed in the I group on the basis of size but their true age is subject to question.

1.5. Location of Collections

The adult sardines used in this study were taken on the fishing grounds off British Columbia, Washington and Oregon; off San Francisco and Monterey; and in southern California between Point Conception and the Mexican boundary. One gill net collection of 46 fish was

made off Shelter Cove in northern California, and 31 adult sardines were taken in the Gulf of California in a dip net under a light at night.

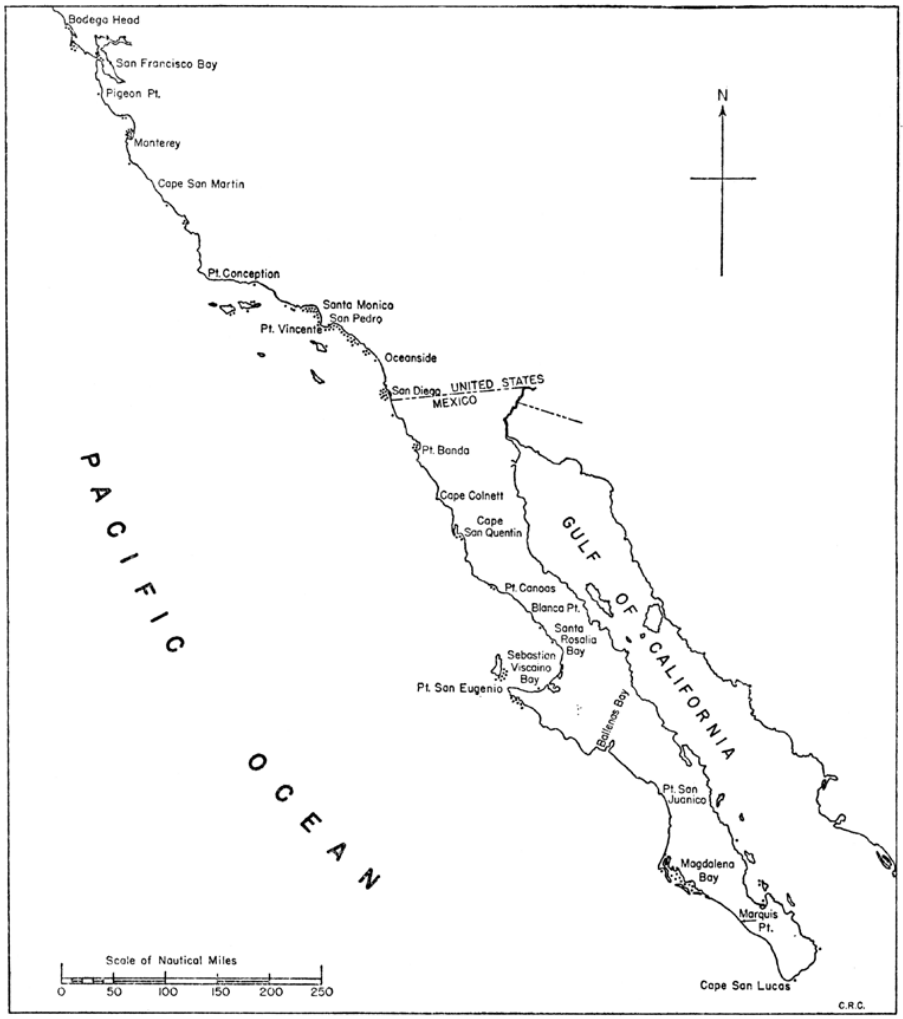

FIG. 1. Localities, indicated by dots, where O group sardines were collected.

FIG. 1. Localities, indicated by dots, where O group sardines were collected

The locations of collections of O group fish are shown by dots in Figure 1. Most of these fish were taken in small round haul nets either by bait fishermen or in experimental catches made by the staff of the California Bureau of Marine Fisheries. Fish of the I group from south of San Francisco were collected in the same general localities and by similar methods.

The collecting localities have been grouped into six major regions: Pacific Northwest, from Alaska to the Oregon-California line; Northern California from the Oregon line to Point Conception; Southern California, from Point Conception to the Mexican boundary; northern Lower California, from the boundary to Pt. San Eugenio; southern Lower California, from Point San Eugenio to Marquis Point; and Cape San Lucas and the Gulf of California.

2. ADULT SARDINES

Details of the counts on adult sardines are given in Table 1. The averages from different regions indicate no definite trend from north to south. One of the lowest averages occurs in the Alaska collections, and variations between collections made in one region in different years are as great as those between regions. The only group which shows outstanding differences is that from the Gulf of California. These 31 fish averaged 50.97 vertebrae which is over one-half vertebra less than the average of any other collection of adult sardines.

The P values obtained from analyses of variance of vertebral counts within localities and between localities are given in Table 4. For adults these values indicate that differences between year-lots taken in the same locality are statistically significant for the Pacific Northwest and for Northern California and probably so for Southern California. Also the counts for the Pacific Northwest specimens differ significantly from those of Northern California but the differences between Northern and Southern California data are not significant. On the other hand, Southern California material shows a high probability of being significantly different from fish taken in the Gulf of California.

Since the differences between collections made in different years within one locality are as great as those for collections from different localities, these additional data substantiate conclusions drawn from former studies of vertebrae. These are that adult sardines along the California, Oregon, Washington and British Columbia coasts intermingle and the populations on these fishing grounds are complex, receiving in one year or another contributions of young fish from many sources. No adults from Mexican waters are available with the exception of the 31 sardines taken in the Gulf of California. These fish have a sufficiently low vertebral average to suggest that an independent population may occur in the Gulf. Studies on young fish help to verify this conclusion.

It is difficult to assign a value for the average number of vertebrae for all adults. The weighted average for all adults, excluding the Gulf, is 51.688 (Table 1). Three times as many fish, however, were counted from the Pacific Northwest as from either of the California localities, and an average giving equal representation to each of the three major areas might define more accurately the whole population. This average is 51.698, and for general purposes the average number of vertebrae for adult sardines may be considered 51.70.

TABLE 1

Vertebral Counts on Adult Sardines

Locality	Latitude	Date	Number of vertebrae						Number of fish	Average vertebrae
			49	50	51	52	53	54		
Alaska	56°	1931			13	10	1		24	51.500
British Columbia	49°	1926-27		3	53	111	16		183	51.765
		1930	1	23	651	1,470	102	1	2,248	51.735
		1931		49	1,178	1,779	189		3,195	51.660
		1932	1	34	1,007	1,522	151	2	2,717	51.660
		1933		7	159	231	20		417	51.633
		1934		5	207	272	25		509	51.623
		1935		6	210	285	31		532	51.641
		1936		19	448	673	53		1,193	51.657
		1937		23	438	700	57	1	1,219	51.651
		1938		16	532	828	89	1	1,466	51.677
		1939		10	355	548	59	1	973	51.677
		1940	1	10	306	608	85		1,010	51.758
British Columbia total			3	205	5,544	9,027	877	6	15,662	51.676
Pacific Northwest total			3	205	5,557	9,037	878	6	15,686	51.676
Shelter Cove, California	40°	1938			14	30	1	1	46	51.761
San Francisco, California	37° 40′	1928		5	121	175	33	2	336	51.720
		1938	2	5	111	278	39		435	51.798
San Francisco total			2	10	232	453	72	2	771	51.764
Monterey	36° 49′	1921-22		4	114	244	28		390	51.759
		1923		1	66	139	15		221	51.760
		1926		12	199	265	18		494	51.605
		1927			81	118	8		207	51.647
		1930	2	21	377	431	36		867	51.551
		1938		9	68	154	11		242	51.690
		1939	1	12	314	650	71	2	1,050	51.747
		1940		11	296	614	79		1,000	51.761
Monterey total			3	70	1,515	2,615	266	2	4,471	51.688
Northern California total			5	80	1,761	3,098	339	5	5,288	51.700

TABLE 1

Vertebral Counts on Adult Sardines

San Pedro, California	33° 45′	1922	----------	10	141	234	24	----------	409	51.665
		1928	----------	6	220	330	31	1	578	51.656
		1938-39	----------	13	309	609	77	2	1,010	51.749
		1939-40	----------	11	288	546	54	----------	899	51.715
		1941	1	9	235	465	62	----------	772	51.749
San Pedro total			1	49	1,193	2,174	248	3	3,668	51.716
San Diego, California	32° 40′	1922	----------	----------	84	177	15	----------	276	51.750
		1928	----------	----------	23	35	5	----------	63	51.714
San Diego total			----------	----------	107	212	20	----------	339	51.743
Southern California total			1	49	1,300	2,386	268	3	4,007	51.719
Gulf of California	24°	1940	1	5	19	6	----------	----------	31	50.968
All adults excluding Gulf of California			9	334	8,618	14,521	1,485	14	24,981	51.688

TABLE 1—Cont'd.

TABLE 2

Vertebral Counts on I Group Sardines

Locality	Latitude	Date	Number of vertebrae					Number of fish	Average vertebrae
			50	51	52	53	54		
British Columbia	49°	V-VII: 1940	2	145	332	52	2	533	51.826
Washington	47°	IV:1938		3	5	1		9	51.778
Oregon	46°	V: 1939		88	179	33		300	51.817
		VI-VII:1940	3	93	201	28		325	51.782
Oregon total			3	181	380	61		625	51.798
Pacific Northwest total			5	329	717	114	2	1,167	51.811
Humboldt Bay	40° 50′	VI: 1926		21	44	11		76	51.868
		VI-VII: 1935	5	168	336	29		538	51.723
Humboldt Bay total			5	189	380	40		614	51.741
San Francisco	37° 40′	IV: 1923		49	123	17		189	51.831
		V-VI: 1935	6	260	406	28		700	51.651
		V: 1938	1	86	172	39	2	300	51.850
San Francisco total			7	395	701	84	2	1,189	51.730
Monterey	36° 40′	II-VI: 1935	4	112	208	19		343	51.706
		II-V: 1936	5	185	419	62		671	51.802
		II-IV: 1937	7	190	345	48		590	51.736
		II-IV: 1938	2	148	296	53	1	500	51.806
Monterey total			18	635	1,268	182	1	2,104	51.769
Northern California total			30	1,219	2,349	306	3	3,907	51.752

TABLE 2

Vertebral Counts on I Group Sardines

Pt. Conception to Pt. Vincente 34°	II: 1936	----------	32	59	9	----------	100	51.770
Pt. Vincente to Oceanside 33° 30′	IV-VII: 1935	9	118	133	11	----------	271	51.539
	III-VII: 1936	9	138	266	36	1	450	51.738
	II-V: 1937	5	180	287	29	----------	501	51.679
	I-V: 1938	7	187	392	57	1	644	51.750
San Pedro total		30	623	1,078	133	2	1,866	51.707
Oceanside to Mexican Boundary 32° 50′	III: 1922	6	107	177	15	----------	305	51.659
	IV-VI: 1928	1	29	45	6	1	82	51.720
	IV: 1931	3	64	119	14	----------	200	51.720
	IV-V: 1937	3	148	229	27	----------	407	51.688
	III-VI: 1938	4	160	451	59	----------	674	51.838
San Diego total		17	508	1,021	121	1	1,668	51.749
Southern California total		47	1,163	2,158	263	3	3,634	51.728
Boundary to Pt. San Eugenio 30°	III: 1938	1	10	10	2	----------	23	51.565
	X: 1938	----------	37	56	7	----------	100	51.700
	X: 1940	----------	6	4	2	----------	12	51.667
Northern Lower California total		1	53	70	11	----------	135	51.674
Magdalena Bay 24° 30′	VI: 1934	2	44	75	6	----------	127	51.669
	IV: 1938	6	32	12	----------	----------	50	51.120
	II: 1941	11	88	21	----------	----------	120	51.083
Southern Lower California total		19	164	108	6	----------	297	51.340

TABLE 2—Cont'd.

TABLE 3

Vertebral Counts on O Group Sardines

Locality	Latitude	Date	Number of vertebrae							Number of fish	Average vertebrae
			48	49	50	51	52	53	54		
Oregon	46°	IX: 1937				4	13	1		18	51.833
Bodega Head to Pigeon Point	37° 40′	XI: 1939			1	34	81	16		132	51.848
		XI: 1940			3	63	121	14	1	202	51.738
San Francisco total					4	97	202	30	1	334	51.781
Pigeon Pt. to Cape San Martin	36° 35′	XII: 1934		1	5	16	25	3		50	51.480
		XI: 1935-I: 1936			12	271	529	87	1	900	51.771
		IX: 1936-I: 1937	1		7	272	540	75	1	896	51.762
		VIII-IX: 1937			6	223	526	80	3	838	51.822
		VIII: 1938-I: 1939			5	326	716	94		1,141	51.788
		IX-XI: 1939			5	182	296	35	1	519	51.701
		XI: 1940			2	45	48	6		101	51.574
Monterey total			1	1	42	1,335	2,680	380	6	4,445	51.767
Cape San Martin to Pt. Conception	35°	XI: 1940			2	52	111	14		179	51.765
Northern California total			1	1	48	1,484	2,993	424	7	4,958	51.769
Pt. Conception to Pt. Vincente	34°	X: 1932				35	80	5		120	51.750
		VII-XII: 1935			1	53	132	14		200	51.795
		VIII-XI: 1936			6	94	181	21		302	51.719
		VIII: 1937			1	20	37	5		63	51.730
		VI-X: 1938			9	296	687	100		1,092	51.804
		VII-IX: 1940			4	158	224	19		405	51.637
Santa Monica total					21	656	1,341	164		2,182	51.755
Pt. Vincente to Oceanside	33° 30′	XII: 1924			1	16	19	3	1	40	51.675
		IX: 1926			2	64	129	5		200	51.685
		VIII: 1931				24	30	4		58	51.655
		VII-XII: 1935		1	2	219	425	52	1	700	51.754
		VII-X: 1936		1	12	231	416	60	1	721	51.728
		VII-XI: 1937		1	9	144	388	55	2	599	51.823
		VII-IX: 1938			8	366	914	104		1,392	51.800
		X-XI: 1939				28	74	9		111	51.829
		VII-IX: 1940			6	131	155	4	1	297	51.539
San Pedro total				3	40	1,223	2,550	296	6	4,118	51.756

TABLE 3

Vertebral Counts on O Group Sardines

Oceanside to Mexican Boundary----32° 50′	X-XI: 1935		1	12	157	281	34		485	51.691
	XII: 1936			2	113	187	17	1	320	51.694
	IX: 1937			1	20	71	9		101	51.871
	IX: 1938			5	94	189	23		311	51.740
San Diego total			1	20	384	728	83	1	1,217	51.719
Southern California total			4	81	2,263	4,619	543	7	7,517	51.750
Boundary to Pt. Canoas----31°	X-XI: 1938				114	151	14		279	51.642
	X: 1940			5	180	230	13		428	51.586
Boundary to Pt. Canoas total				5	294	381	27		707	51.608
Sebastian Viscaino Bay----28°	VII: 1936			5	32	53	3		93	51.581
	IV: 1937			1	17	32	5		55	51.745
	X-XI: 1938			5	187	238	15		445	51.591
	X: 1939			3	91	182	24		300	51.757
	X: 1940			8	93	91	8		200	51.495
Sebastian Viscaino Bay total				22	420	596	55		1,093	51.626
Northern Lower California total				27	714	977	82		1,800	51.619
Pt. San Eugenio to Pt. San Juanico----27°	XI: 1926			1	35	17			53	51.302
	VII: 1935			5	29	30	2		66	51.439
	XI: 1938			13	189	95	3		300	51.293
	X: 1939				22	50	6		78	51.795
	X: 1940			12	132	55	2		201	51.234
	X: 1941			1	10	1			12	51.000
Pt. San Eugenio to Pt. San Juanico total				32	417	248	13		710	51.341
Magdalena Bay----24° 30′	III-VII: 1936		1	23	157	53	1		235	51.128
	VII-XI: 1938			21	343	190	6		560	51.323
Magdalena Bay total			1	44	500	243	7		795	51.265
Southern Lower California total			1	76	917	491	20		1,505	51.301
Cape San Lucas----23°	V: 1939			12	82	21			115	51.078
Gulf of California----24°	VI: 1934		1	11	55	18	1		86	51.081
	III: 1935			15	88	21	1		125	51.064
	V: 1939			18	148	42			208	51.115
	II: 1941			42	211	31	1		285	50.968
Gulf of California total			1	86	502	112	3		704	51.043
Cape San Lucas and Gulf total			1	98	584	133	3		819	51.048

TABLE 3—Cont'd.

TABLE 4

Average Number of Vertebrae for Sardines Taken in Various Localities and Values of P Obtained from Analyses of Variance

Locality	Average vertebrae	Percentage values of *P*					
		Pacific Northwest	Northern California	Southern California	Northern Lower California	Southern Lower California	Cape San Lucas and Gulf
				Adults			
Pacific Northwest	51.676	1—					
Northern California	51.700	1	1—				
Southern California	51.719		12	2			
Cape San Lucas and Gulf	50.968			2			
				I Group			
Pacific Northwest	51.811	20+					
Northern California	51.752	1—	16				
Southern California	51.728		9	15			
Northern Lower California	51.674			20+	20+		
Southern Lower California	51.340				1—	1—	
				O Group			
Pacific Northwest	51.833						
Northern California	51.769		20+				
Southern California	51.750		10	20+			
Northern Lower California	51.619			1—	1—		
Southern Lower California	51.301				1—	1—	
Cape San Lucas and Gulf	51.048					2	4

TABLE 4

Average Number of Vertebrae for Sardines Taken in Various Localities and Values of P Obtained from Analyses of Variance

3. YOUNG SARDINES

3.1. I Group

For fish here classified as the I group, collections are available from British Columbia to Magdalena Bay, Lower California.

Details are given in Table 2. In contrast to the adult sardines, the averages for the I group show a definite trend from the north to the south. The highest average is in the Pacific Northwest, and for the four major areas the averages show a consistent decrease from 51.81 in the north to 51.34 at Magdalena Bay.

Analyses of variance (Table 4) indicate that collections within one locality show no significant differences except for the three lots from Magdalena Bay in southern Lower California. Pacific Northwest counts differ significantly from Northern California but Northern and Southern California differences are not significant nor are those for Southern California and northern Lower California. On the other hand, northern Lower California material does differ significantly from southern Lower California.

3.2. O Group

Collections of O group sardines extended from Oregon to the Gulf of California. Figure 1 shows the locality of these collections and Table 3 gives the average number of vertebrae for each locality. As with I group fish, these youngest sardines show a general decrease in the number of vertebrae from the north to the south, the highest average occurring in Oregon and the lowest in the Gulf of California.

Tests of significance (Table 4) indicate that vertebral counts of O group sardines from various California nursery grounds do not differ significantly either between year-classes or between localities. For the Lower California material, however, the differences within one locality between year-classes are significant. These differences between year-classes in Lower California may explain the significant differences between Southern California and northern Lower California as well as those between the two Lower California regions.

4. COMPARISON OF ADULTS WITH YOUNG

The comparison of adults with young sardines is shown graphically in Figure 2. This figure gives the average number of vertebrae for the three groups of sardines according to the approximate degrees of latitude where collections were made. From 32° to 42° there is no great difference in the averages. These latitudes correspond closely with the

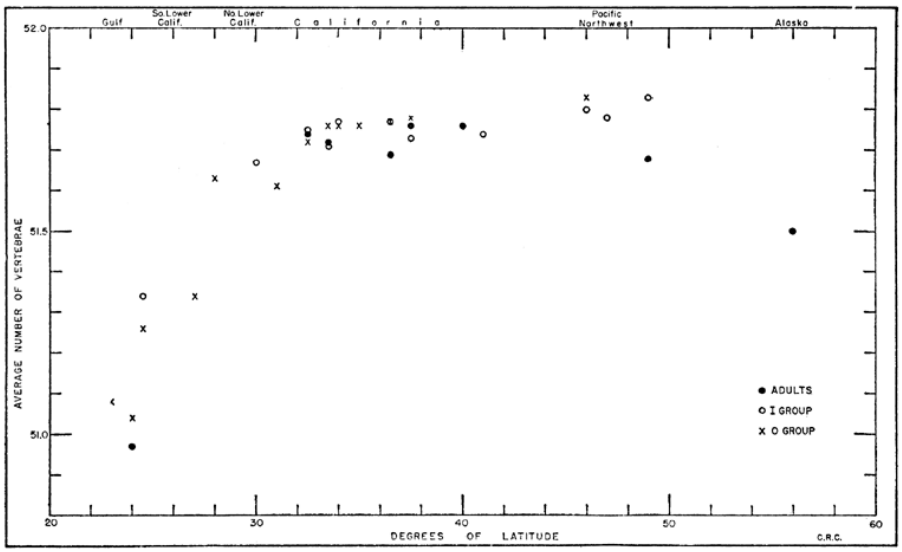

FIG. 2. Average number of vertebrae by latitude for adult, I and O group sardines.

FIG. 2. Average number of vertebrae by latitude for adult, I and O group sardines

California boundary lines. For more northerly latitudes the average for young sardines increases slightly, whereas that for adults does not. In the southerly latitudes (Mexican waters) the average for young fish decreases rapidly with each degree. Table 4 indicates that there is no significance in the differences between localities in California for any of the groups of fish. Both Pacific Northwest and Mexican fish, however, tend to differ significantly from California collections; and collections from different Mexican localities differ significantly from each other.

In Table 5 comparisons are made among adults, I group and O group fish in each locality, and the values of *P* are given for such comparisons. For the Pacific Northwest, differences are significant when the three groups are compared, and the adults differ significantly from the I group. The O group does not so differ from the other two, but since there are only 18 fish in the O group, the data are not indicative. In Northern California the three groups differ significantly and in each pair of comparisons the adults are significantly different from the I and O group but comparisons between the I and O groups show no significance. For Southern California the adult and I group differences are not significant but the O group differences are. For Mexican waters none of the available comparisons is significant.

TABLE 5

Comparison of Average Vertebrae by Age Groups

Locality	Average vertebrae			Percentage values of *P*			
	Adults	I Group	O Group	All Groups	Adults with I Group	Adults with O Group	I Group with O Group
Pacific Northwest	51.676	51.811	51.833	1—	1—	20+	20+
Northern California	51.700	51.752	51.769	1—	1—	1—	20+
Southern California	51.719	51.728	51.750	1—	20+	1—	1—
Northern Lower California	----------	51.674	51.619	----------	----------	----------	20+
Southern Lower California	----------	51.340	51.301	----------	----------	----------	20+
Cape San Lucas and Gulf	50.903	----------	51.048	----------	----------	20+	----------

TABLE 5

Comparison of Average Vertebrae by Age Groups

These various comparisons of the vertebral averages by localities and age groups indicate a complex admixture in the sardine population. Except for the Gulf of California, adult sardines taken in any locality show no indication that they are composed exclusively of fish reared in the same locality. Also the significant difference between the I and O groups in Southern California and the fact that in each locality averages for the I group occupy an intermediate position between the O group and the adults suggest that the admixture begins at an early age, perhaps before the fish are a year old. This admixture evidently involves sardines from all localities between Alaska and Pt. San Eugenio in the central part of Lower California. On the other hand, the rapid decrease in average vertebral number for sardines taken south of Pt. San Eugenio and the significant differences in the averages suggest that the southern Lower California fish and those from Cape San Lucas and the Gulf may comprise an independent population or populations which seldom, if ever, mingle with the fish to the north. All fish, adults and young, collected south of Pt. San Eugenio had an average vertebrae number of 51.223.

5. ADMIXTURE OF POPULATION

It would be useful to know how much each of the nursery grounds contributes to the adult sardine population. No definite answer can be derived from the sardine vertebral counts but some interesting approximations can be made. Since collections of O group fish do not differ significantly throughout California, Northern and Southern California collections may be combined. This gives five major localities for which data are available and the vertebral averages for the O group are as follows:

Pacific Northwest	51.83
California	51.76
Northern Lower California	51.62
Southern Lower California	51.30
Gulf of California	51.05

If these values are combined giving each locality equal weight, an average of 51.51 results. This is far below the approximate average of 51.70 for adult sardines and it is evident that all localities do not contribute equally to the adult population. If the Gulf of California is omitted and the four remaining localities combined on an equal basis, the average becomes 51.63, again below that for all adults. Omitting the two localities south of Pt. San Eugenio, the three remaining localities average 51.74. This is somewhat above the 51.70 average for adults. A combination of California and northern Lower California gives an average of 51.69 which is practically identical with that for all adults. This may indicate that the major portion of adult sardines are reared on the nursery grounds off California and northern Lower California. Obviously, however, many other combinations could be made which would give an average approaching that of the adults. At times young sardines reared in the Pacific Northwest have contributed to the adult population and similar contributions may come from southern Lower California. A determination of the composition of the stock from vertebral counts would require adequate data on the variations between year-classes in each locality as well as between localities.

6. VARIATIONS BETWEEN YEAR-CLASSES

Table 3 indicates that members of the O group collected in one locality vary in vertebral count from year to year and certain year-classes have a consistently higher or lower average in many of the localities where collected. The averages for six year-classes are compared in Table 6. All available material for O group fish has been included in this table plus I group fish from the Pacific Northwest. This latter addition is necessary to give comparisons with the northern region and seems justified because there are reasons to think that these yearlings were derived from northern spawnings. The largest sample is of the 1939 year-class and in that year extensive spawning is known to have occurred in the northwest. Furthermore, the remoteness of the northern spawning grounds renders it unlikely that the northern spawned fish could have moved entirely out of that area as yearlings or that young sardines would have moved in from the south. Averages based on less than 100 specimens should be interpreted with caution. The 1937 year-class has consistently high averages in all localities for which data are available. The 1939 year-class also has high averages for all regions except Northern California and the Cape San Lucas-Gulf area. In contrast, averages for the 1940 year-class are low.

Differences between year-classes from the Pacific Northwest were not significant, nor were those from Cape San Lucas and the Gulf. For the other localities the year-classes varied significantly with P values of less than 1 percent for all localities except Northern California where the value of P was 2 percent. Attempts were made to correlate the changes in average vertebrae for the different year-classes with differences in water temperatures. The results were not conclusive due probably to inadequate temperature records from the waters where sardines spawn and the larvae develop. The major spawning grounds in Southern California are well off shore where complete water temperature records have not been collected.

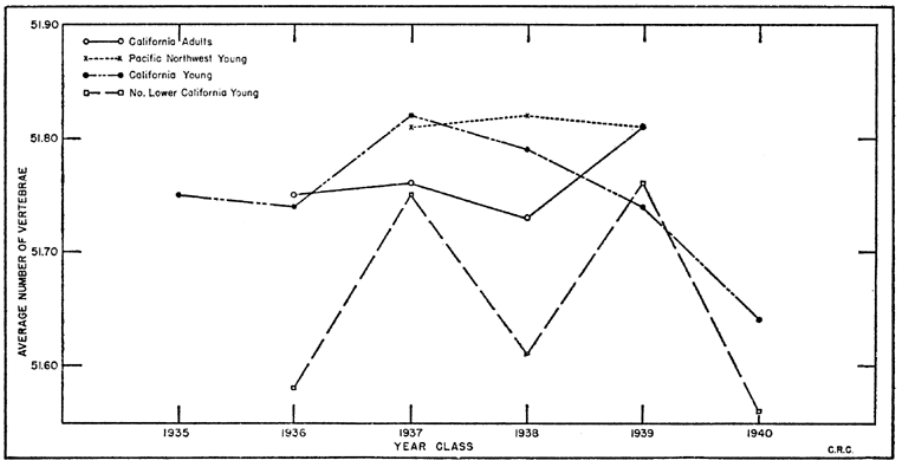

FIG. 3. Average number of vertebrae by year-class for three localities.

FIG. 3. Average number of vertebrae by year-class for three localities

TABLE 6

Average Number of Vertebrae by Year-Class

Locality	1935		1936		1937		1938		1939		1940	
	Number of specimens	Average vertebrae	Number of specimens	Average vertebrae	Number of specimens	Average vertebrae	Number of specimens	Average vertebrae	Number of specimens	Average vertebrae	Number of specimens	Average vertebrae
Young Fish												
Pacific Northwest					27	51.81	300	51.82	858	51.81		
Northern California	999	51.77	896	51.76	838	51.82	1,141	51.79	651	51.72	482	51.71
Southern California	1,385	51.74	1,343	51.72	763	51.82	2,795	51.79	111	51.83	702	51.59
Northern Lower California			93	51.58	55	51.75	724	51.61	300	51.76	628	51.56
Southern Lower California	66	51.44	235	51.13			860	51.31	78	51.89	201	51.23
Cape San Lucas and Gulf	125	51.06							323	51.10		
Adults												
California			422	51.75	1,306	51.76	1,033	51.73	156	51.81		

TABLE 6

Average Number of Vertebrae by Year-Class

Through a cooperative study with the U. S. Fish and Wildlife Service, counts and age readings were made on adult fish taken at Monterey and San Pedro in the 1939–1940 and 1940–1941 seasons. From this material the average number of vertebrae were calculated for each year-class. This gave counts for four classes from 1936 to 1939. The averages for the adults are included in Table 6 and the trends of the vertebral averages for adults and young are shown in Figure 3. To simplify the comparisons, in this figure, the data from Northern and Southern California were combined.[1] The average for the 1936 adults corresponds closely with the California O group averages, whereas those for 1937 and 1938 are below the California averages for these respective year-classes. This suggests an admixture of Mexican fish in these two groups. On the other hand, the 1939 year-class shows anomalies. In this year-class the averages for Lower California are higher than those for California and the average for adults is the same as for the I group taken in the Pacific Northwest. Because smaller numbers of specimens were involved in the adult collections, the results may have small significance, but if the differences are valid they indicate that the adult collections contained a high proportion of fish reared in northern latitudes. An unusual amount of spawning is known to have occurred in the Pacific Northwest in 1939 and the resultant sardines presumably made a goodly contribution to the adult population along the coast.

[1] The O group averages as given in Table 3 did not differ significantly between the two localities and tests of individual year-classes from the two regions gave values for P above 10 percent except for the 1940 group. For this year-slass P was below the 1 percent level. Since only the one year-class showed significant differences, the combining of all material for California as used in Figure 3 seemed justified.

7. COMPARISON OF VERTEBRAE COUNTS WITH OTHER SARDINE STUDIES

Exploratory work (Scofield, 1934) indicates that spawning may occur throughout the range of the sardine population but that the heaviest concentration is off Southern California. This implies a movement of adult fish into this region. Investigations of the ocean currents off Southern California (Tibby, 1939) show that larvae from these spawning grounds would be carried to the nursery grounds off Southern California or northern Lower California.

Studies on length frequencies of sardines taken in the fishery at various California ports (Clark, 1936a) show that the same dominant year-classes are present on all the California fishing grounds. Also similar size progression from smaller to larger fish occurs each season at all California ports. Such consistent size changes would not be expected if there were not an interchange of sardines between the fishing grounds.

An extensive tagging program (Clark and Janssen, 1945; Hart, 1943) has demonstrated that such intermingling does occur. Fish released in California waters have been recovered in the Pacific North west and fish tagged off British Columbia and Oregon have been retaken in California. Sardines marked and released along the Lower California coast from the boundary south to Point San Eugenio have been recovered in Southern and Northern California.

Young sardines (in all probability members of the 1939 year-class spawned in the Pacific Northwest) were tagged off Oregon in the spring of 1940. Tags from these fish were recovered in the California fishery in succeeding seasons thus indicating that the nursery grounds in the Pacific Northwest do at times supply sardines to the adult population in the more southern regions.

No recoveries have been made from 963 sardines released during April, 1938, in Magdalena Bay, Lower California. Negative results on returns from one tagging lot comprising less than 1,000 fish cannot be considered proof that sardines from southern Lower California do not intermingle with the northern population. The low average vertebrae count for these southern sardines tends, none the less, to confirm the results of the tagging investigations.

The tentative conclusion seems justified, therefore, that sardines found in southern Lower California and the Gulf of California constitute a separate population which rarely intermingles with the northern population, but that a considerable, and perhaps variable, amount of interchange takes place throughout the range of the northern population from Alaska to Pt. San Eugenio in central Lower California.

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