HERRING TAGGING EXPERIMENTS IN SOUTHEASTERN ALASKA

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ABSTRACT

Results of herring tagging experiments in southeastern Alaska during 1934–37 were studied to provide background information for more recent taggings. Recovered tags evidenced extensive movement and intermingling between Sitka and Craig stocks, which were previously considered discrete. Tagging was concentrated on a single year class during these 4 years, and the extent of the migrations apparently increased with age of the herring.

Total mortality increased with each year of recovery in each experiment, and successively later experiments indicated higher mortality rates. The fishing effort exhibited a general decline during this period. These results coupled with the concentration of tagging on a single year class support the conclusion that natural mortality increases with age.

Recommendations for future tagging in southeastern Alaska are included in the discussion.

Results of tagging experiments and racial studies on herring (*Clupea harengus pallasi*) in southeastern Alaska have influenced existing management practices in the commercial fishery. Rounsefell and Dahlgren (1933) and Dahlgren (1936), reported on tagging experiments conducted to 1935, but results of subsequent tagging in 1936 and 1937 have not been published. In recent years the need for additional tagging studies has been emphasized by three factors:

1. The recent changes in fishing areas.
2. The contention of salmon trollers that local herring populations have been seriously depleted by the commercial reduction fishery.
3. The exclusion of herring in the North Pacific Treaty rights of abstention.

Detailed information on mortality, migratory patterns, and degree of intermingling among races of herring is needed to answer questions which arise from these problems. Before undertaking additional tagging studies, it is both logical and expedient to gather as much background information as possible. The purposes of this paper are to provide a summary and analysis of results from previous experiments that may serve as a guide and basis for subsequent tagging.

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TAGGING AND RECOVERIES

As pointed out by Rounsefell and Dahlgren (1933), conventional external tagging and marking experiments on herring before 1930 had not been successful. To test the feasibility of tagging herring, they began a study at Holmes Harbor in Puget Sound, Washington, during 1932. The study was designed to provide information on the following points:

1. The relative merits of different tagging methods.
2. The mortality of tagged or marked herring.
3. The development of a field technique for tagging.
4. A method of recovery suitable for a reduction fishery.

The results of this study and the initial experiments in southeastern Alaska showed that tagging on an extensive scale was practical. Rounsefell and Dahlgren (1933) and Dahlgren (1936) presented detailed information on the methods and procedures used in tagging and recovery. Internal metal tags were found to be superior to external tags, both from the standpoint of low mortality caused by tagging and adaptability of the technique to field conditions. An electromagnet was designed to provide a mechanical means of recovering metal tags from fish meal, and later an electronic detector was developed to recover tags before the fish were processed. Detectors were not installed in all of the reduction plants, and the majority of recoveries were from electromagnets. Dahlgren (1936) emphasized the limitations of the magnet recoveries.

The allocation of tags to specific areas of catch was, at times, impractical or uncertain, and such recoveries were designated "area unknown" or "doubtful." On the other hand, when fishing was concentrated within a restricted area for an extended period, recoveries could be reliably assigned to a specific area. Further, the recapture area of tags recovered by the magnet was in many cases substantiated by tags recovered from the electronic detector. Also, though isolated recoveries were classified as "doubtful," multiple recoveries from a given area reduced the error of assigning such an area as a possible point of recovery.

From 1930 to 1940, the southeastern Alaska herring reduction fishery was concentrated on two stocks. The spawning beaches of these stocks centered about Sitka on the west coast of Baranof Island, and in the vicinity of Craig on the west coast of Prince of Wales Island. Other stocks in southeastern Alaska contributed relatively minor catches to the reduction fishery, and tagging was concentrated in the Sitka and Craig areas.

In each year, fish were tagged in the spring, and recoveries were made during the summer fishing period, June through September. For management purposes, the fishery had been divided into two general areas which were utilized for a breakdown of tag recoveries:

1. The Cape area encompassing the entire west and southeast coasts of Baranof Island. Sitka is located in this area (fig. 1).

2. The non-Cape area, including the west coasts of Kuiu and Prince of Wales Islands and the lesser islands in the vicinity. Craig is located in this area (fig. 1).

In summarizing the results of published tagging experiments, a listing of the original data is not warranted in this report, and only a gross examination of these data and unpublished data from tagging studies in 1936 and 1937 will be considered.

TABLE 1.—*Recoveries from Sitka tagging experiments*

Year of tagging	Number tagged	Year of recovery	Number and locality of recovered tags								Total
			Non-Cape area			Non-Cape or Cape		Cape area		Unknown	
			Warren Island	Kuiu Island	Other	Warren or Ommaney	Kuiu or Ommaney	Cape Ommaney	Other		
1934	11,964	1934	14	7	0	5	0	463	1	6	496
		1935	11	0	0	14	0	71	2	110	208
		1936	4	3	3	3	0	10	5	10	38
		1937	0	7	0	0	0	3	4	0	14
		1938	0	1	0	1	0	1	1	0	4
Total			29	18	3	23	0	548	13	126	760
1935	27,911	1935	86	0	0	113	0	929	68	878	2,074
		1936	87	35	21	20	120	233	34	97	647
		1937	0	130	0	4	111	97	22	21	385
		1938	0	7	0	1	5	26	2	2	43
		1939	0	0	0	0	0	1	0	1	2
Total			173	172	21	138	236	1,286	126	999	3,151
1936	10,784	1936	26	16	7	6	80	184	29	53	401
		1937	1	58	1	3	69	70	8	7	217
		1938	0	2	0	0	3	11	1	0	17
		1939	0	0	0	0	0	0	0	1	1
Total			27	76	8	9	152	265	38	61	636
1937	14,021	1937	0	50	1	3	94	122	20	12	302
		1938	0	3	0	0	1	22	2	5	33
		1939	0	0	0	0	0	1	0	0	1
Total			0	53	1	3	95	145	22	17	336
Grand total			229	319	33	173	483	2,244	199	1,203	4,883

From 1934 through 1937, 100,911 tags were inserted in herring from the Cape and non-Cape areas. The number of insertions at Sitka totaled 64,680 from which there were 4,883 recoveries (table 1). At Craig the number of insertions was 36,231, from which there were 1,114 recoveries (table 2).

Most recoveries from the Sitka experiments were taken in the Cape area, whereas most recoveries from the Craig experiments were taken

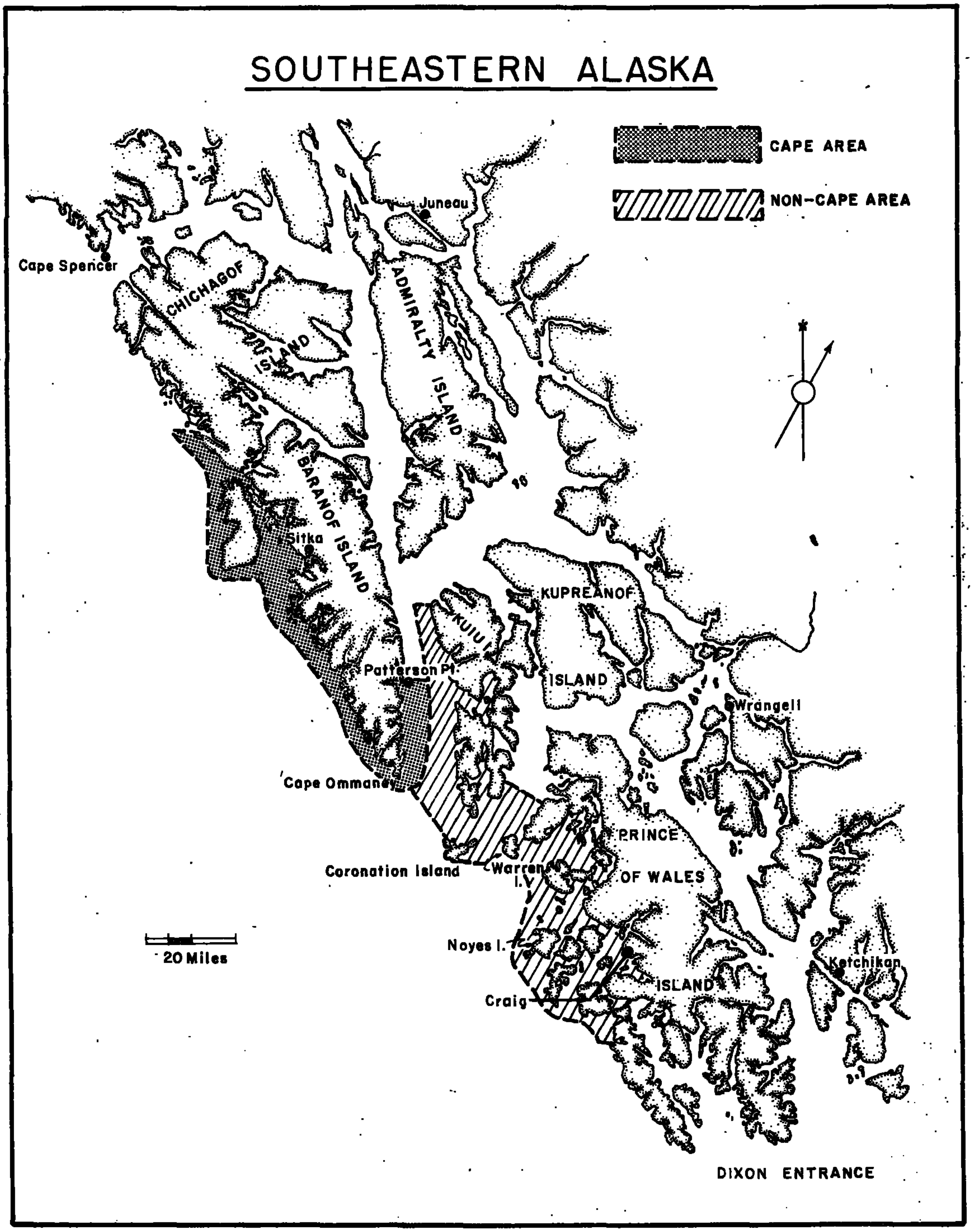

FIGURE 1.—Southeastern Alaska showing Cape and non-Cape areas of the herring fisheries.

TABLE 2.—*Recoveries from Craig tagging experiments*

Year of tagging	Number tagged	Year of recovery	Number and locality of recovered tags								Total
			Non-Cape area			Non-Cape or Cape		Cape area		Unknown	
			Warren Island	Kuiu Island	Other	Kuiu or Ommaney	Cape Ommaney	Ommaney	Other		
1934	7,439	1934	78	1	0	5	3	62	0	0	149
		1935	24	0	0	13	0	18	1	27	83
		1936	10	3	2	2	4	5	1	3	30
		1937	0	9	0	1	4	1	1	1	17
		1938	0	1	0	0	0	2	0	0	3
Total			112	14	2	21	11	88	3	31	282
1935	13,008	1935	74	0	0	61	0	31	0	117	283
		1936	34	14	26	10	13	25	4	49	175
		1937	0	42	1	3	28	12	5	6	97
		1938	0	0	0	0	2	4	1	1	8
Total			108	56	27	74	43	72	10	173	563
1936	4,880	1936	20	3	15	0	10	7	0	18	73
		1937	0	34	2	0	20	8	1	3	68
		1938	0	6	0	0	2	1	0	0	9
Total			20	43	17	0	32	16	1	21	150
1937	10,904	1937	0	49	6	1	27	7	4	4	98
		1938	0	0	7	0	5	6	0	0	18
		1939	0	0	0	0	0	0	0	3	3
Total			0	49	13	1	32	13	4	7	119
Grand total			240	162	59	96	118	189	18	232	1,114

in the non-Cape area. Although recoveries were initially designated by exact location of the catch, the low number of recoveries in certain localities discourages analyses that are based on such specific assignment. Rather, possible discrepancies are considered minimized by designating recoveries to more general areas. Unknown and uncertain recoveries have been assigned to the two areas in the same proportion as known recoveries.

MIGRATIONS

Though the distribution of recoveries in the Cape and non-Cape areas from each experiment follows a general pattern of fluctuation, the annual variations in locality distribution of recovered tags shown in tables 1 and 2 merit attention. Variations of fishing effort expended in the areas will, of course, influence the number of tag recoveries and must be considered in the analyses. The practice in the herring fishery has been to measure effort in ton-days. This unit represents the net tonnage of vessels utilized and the number of vessel-days fished and provides an index comparable with the early years of the fishery when vessels were smaller than in recent years. Large vessels were found to be more efficient than small ones. Rounsefell (1930) discussed the significance of change in vessel size to 1929 and the accompanying graph (fig. 2) extends Rounsefell's data to the 1955 fishery. The average vessel size during the period of tagging experiments (1934–39) was relatively stable.

The effort expended in the Cape and non-Cape areas was obtained from records maintained by vessel and plant operators. The ratio of recoveries to effort in each recovery year from successive tagging experiments at Sitka and Craig are compared in tables 3 and 4 and figures 3 and 4.

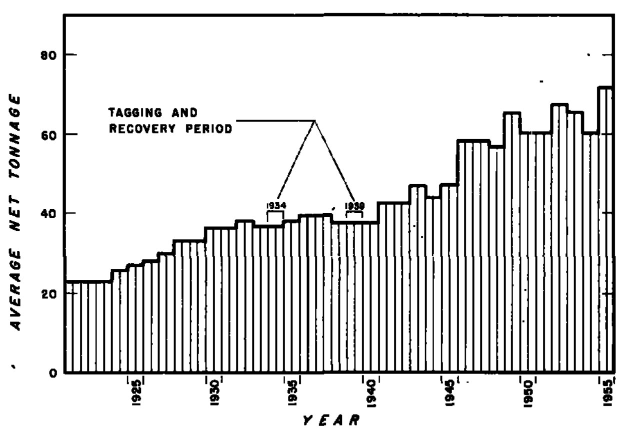

FIGURE 2.—Average net tonnage of herring vessels in southeastern Alaska, 1921–55.

Table 3.—*Fishing effort and recoveries of Sitka tagging experiments*

Year of tagging	Year of recovery	Cape area: Effort in ton-days f	Cape area: Recoveries R	Cape area: $\frac{R}{f}$	Non-Cape area: Effort in ton-days f	Non-Cape area: Recoveries R	Non-Cape area: $\frac{R}{f}$
	1934	3,278	474	0.1446	693	22	0.0317
	1935	3,065	181	.0591	1,200	27	.0225
1934	1936	1,604	23	.0143	1,005	15	.0149
	1937	2,147	7	.0033	1,743	7	.0040
	1938	1,294	3	.0023	1,136	1	.0009
	1935	3,065	1,909	.6228	1,200	165	.1375
	1936	1,604	421	.2625	1,005	226	.2249
1935	1937	2,147	184	.0857	1,743	201	.1153
	1938	1,294	34	.0268	1,136	9	.0079
	1939	898	2	.0022	1,806	0	0
	1936	1,604	326	.2032	1,005	75	.0746
1936	1937	2,147	123	.0573	1,743	94	.0539
	1938	1,294	14	.0108	1,136	3	.0026
	1939	898	0	--------	1,806	0	0
	1937	2,147	215	.1001	1,743	77	.0442
1937	1938	1,294	29	.0224	1,136	4	.0035
	1939	898	1	.0011	1,806	0	0

The results show that the vulnerability of tagged fish from each Sitka experiment is greater in the Cape area than the non-Cape area during the first years of recovery; but that vulnerability in subsequent years is about equal in the two areas.

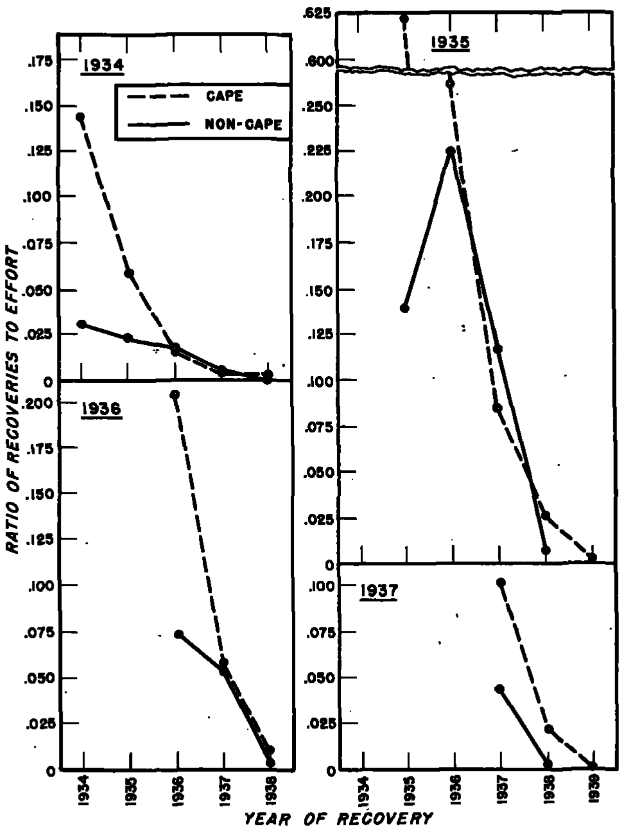

Figure 3.—Sitka tagging experiments: the ratio of tag recoveries to effort in the Cape and non-Cape areas.

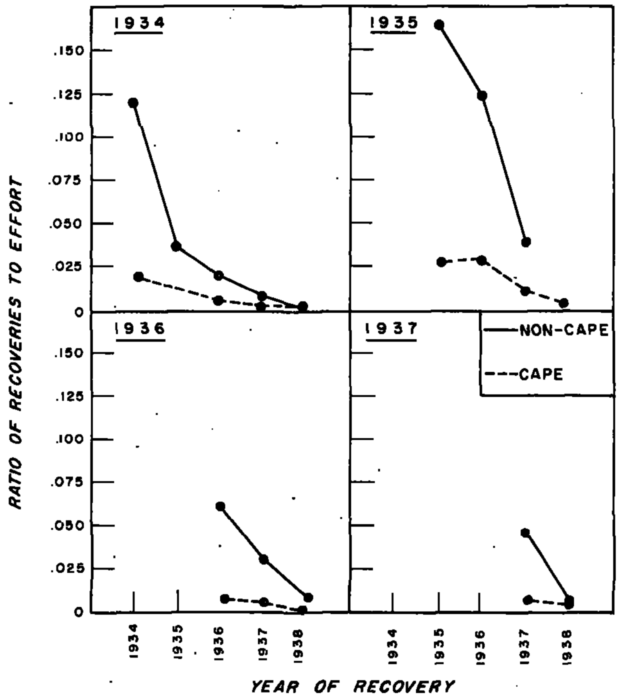

Figure 4.—Craig tagging experiments: the ratio of tag recoveries to effort in the Cape and non-Cape areas.

Similarly, results of each Craig experiment show a higher vulnerability in the non-Cape area than the Cape area during the earlier years of recovery, but the difference decreases in the later recovery years of each tagging. The ratio of recoveries to the catch in each area exhibits the same phenomenon.

Individual examination of either Sitka or Craig experiments would perhaps suggest that the change of vulnerability was due to a differential mortality rate in the two recovery areas. The change, how-

Table 4.—*Fishing effort and recoveries of Craig tagging experiments*

Year of tagging	Year of recovery	Cape area: Effort in ton-days f	Cape area: Recoveries R	Cape area: $\frac{R}{f}$	Non-Cape area: Effort in ton-days f	Non-Cape area: Recoveries R	Non-Cape area: $\frac{R}{f}$
	1934	3,278	66	0.0201	693	83	0.1198
	1935	3,065	37	.0121	1,200	46	.0383
1934	1936	1,604	9	.0056	1,005	21	.0209
	1937	2,147	3	.0014	1,743	14	.0080
	1938	1,294	2	.0015	1,136	1	.0009
	1935	3,065	84	.0274	1,200	199	.1658
1935	1936	1,604	49	.0305	1,005	126	.1254
	1937	2,147	27	.0126	1,743	70	.0402
	1938	1,294	8	.0062	1,136	0	0
	1936	1,604	12	.0075	1,005	61	.0607
1936	1937	2,147	14	.0065	1,743	54	.0310
	1938	1,294	2	.0015	1,136	8	.0070
1937	1937	2,147	16	.0075	1,743	82	.0470
	1938	1,294	8	.0062	1,136	10	.0088

ever, follows the same pattern in each series of experiments from both areas and rather indicates a movement and progressive mixing of fish between the Cape and non-Cape areas. This conclusion is based on the apparent rapid decrease of the vulnerability ratio in the area where tags were inserted as compared to the relatively slow change in the other recovery area.

After the 1934 and 1935 tagging, Dahlgren (1936) concluded that only "occasional migrants" from Sitka experiments mingled with fish in the non-Cape area and that there was "no counter migration" of the Craig stock to the Cape area. The vulnerability of tagged individuals during these 2 years indicates partial agreement with Dahlgren's findings. Subsequent recovery years (1936–39), however, indicate a more extensive and progressive mixing of the two stocks. This mixing may be the result of random dispersion or may be associated with definite migration patterns. To further examine the mixing phenomenon, the expected recoveries from equal effort in the two areas are compared.

SITKA EXPERIMENTS

Assuming that the proportion of recoveries to effort in the non-Cape area would not be significantly altered by a change in effort, the expected number of non-Cape recoveries can be calculated from effort equal to that of the Cape area. With this adjustment, a comparison of the vulnerability of tagged fish in the two areas can be made—that is, the ratio of the non-Cape recoveries to the total recoveries, Cape and non-Cape (fig. 5). The ratio increases with each year of tagging until 1938 when a decrease is recorded. The increase indicates a greater proportion of tags available in the non-Cape area from one year to the next. The phenomenon points again to migration from the Cape area. The successively higher ratio of non-Cape recoveries to total recoveries is also noted in the initial recovery year of the four experiments. The 1938 decrease suggests a reversal of the 1934–37 trend.

CRAIG EXPERIMENTS

Again adjusting to equal effort, the ratios of Cape recoveries to the total recoveries from Craig experiments do not show as concise a trend as the Sitka experiments (fig. 6). The ratios from 1934 through 1937 fall within the same general range

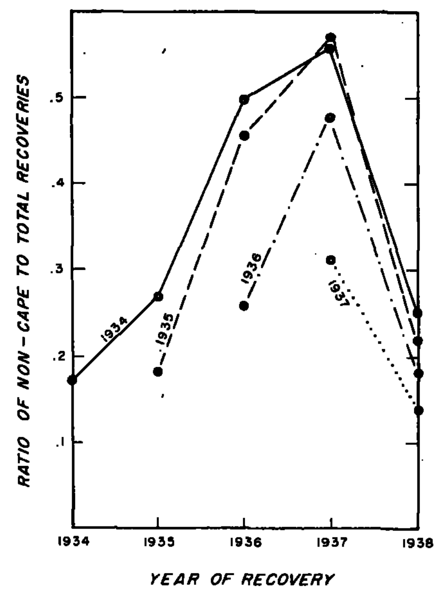

FIGURE 5.—Sitka tagging experiments: ratio of non-Cape to total recoveries.

of 0.10 to 0.25. Apparently, the migration of Craig stocks to the Cape area during this period is considerably less and more consistent than the migration of Sitka stocks to the non-Cape areas. The 1938 data indicate that individuals tagged in the Cape and which had migrated to the non-Cape area, apparently returned en masse to the Cape area. An explanation is not apparent, but the phenomenon may indicate that migration patterns are indeed flexible.

In view of the intermingling between the two stocks, there is some question as to the validity of the Cape and non-Cape divisions for purposes of managing the fishery. Verification of the extent of intermingling is essential to the proper management of the fishery. Management practices have been based on the existence of independent populations and regulatory measures were instituted accordingly. If the mixing of the two stocks, Sitka and Craig, is extensive and consistent, the management concepts should be altered accordingly. For example, the recovery data

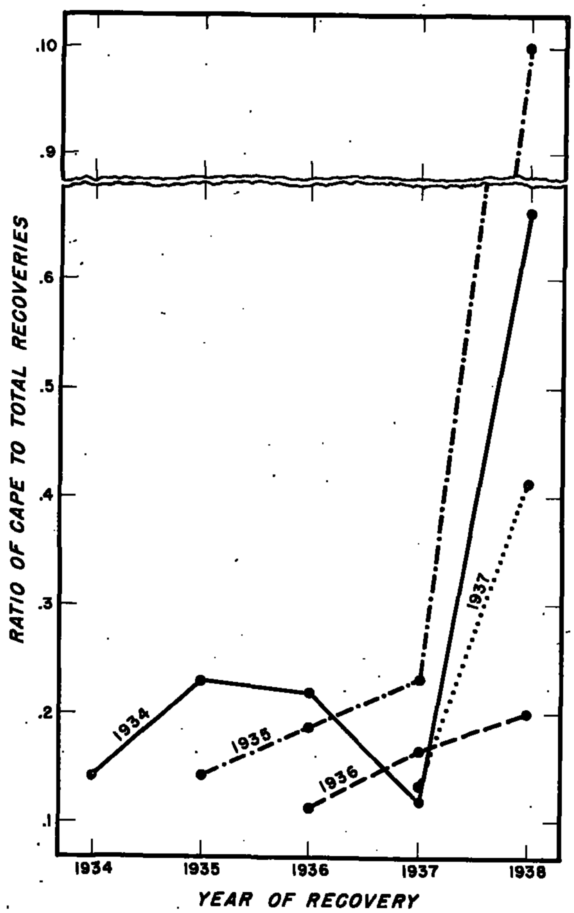

FIGURE 6.—Craig tagging experiments: ratio of Cape to total recoveries.

(tables 1 and 2) show considerable mixing of the two stocks in the vicinity of Kuiu and Warren Islands, and the allocation of these islands to the non-Cape area is not justified.

The conclusions of racial studies by Rounsefell and Dahlgren (1935) do not support the hypothesis of mixing derived from the tagging data. The authors, however, make this statement in their summary (page 140)—

> . . . It must be borne in mind that where morphological differences have not been shown we can only assume that the populations are the same, until such time as we obtain evidence to the contrary. Such evidence may come from tagging experiments.

Ideally, comparisons of the two hypotheses should utilize data from the same year classes but meristic counts and morphological measurements were not recorded during the years of tagging. Re-examination of racial data for other year classes (Rounsefell and Dahlgren, 1935) does provide some evidence in support of intermingling between the Cape and non-Cape areas. The information presented cannot be conclusively credited to mixing, as there is a geographic progression of meristic characters and length of fish which may occur in response to environmental differences. This progression, however, does agree with expected results from mixing and should be noted. Mean vertebral counts from Cape Ommaney samples were higher than those from Craig, and mean counts from Warren and Noyes Islands (located between the Cape and Craig) were intermediate in value (see figure 1 for locations). The mean vertebral counts for the 1926 year class were: Cape, 52.423; Warren, 52.357; Noyes, 52.342; and Craig, 52.254. That the status of Warren Island samples was questioned is apparent in the statement of Rounsefell and Dahlgren (1935):

> Therefore the Warren Island samples must be regarded with some suspicion, especially as the proportion of the observed *z* forms of the calculated *z* is larger in the Warren Island samples than in those from other localities.

Length-frequency data listed by these authors for the 1926 and 1927 year classes show a comparable progression, the size of fish from Warren Island being intermediate to those from Noyes Island and Cape Ommaney (fig. 7). Rounsefell and Dahlgren (1935) made the following statement (page 133) about fish size which also can be explained on the basis of mixing.

> To gain an insight into the growth increments during the summer months the data have been grouped by 10-day periods. (See table 8). For Larch Bay 5-year-olds (herring in their fifth summer) taken during 1930, a consecutive series of eight periods shows no consistent changes in length during the first five periods (from June 21 up to and including August 10). There is an abrupt increase in length, however, between the fifth and sixth periods, the fish of the last three periods averaging about a half centimeter greater in body length. Such a sudden increase in length can scarcely be ascribed to growth but is probably due to an influx of new schools of herring onto the fishing grounds.
>
> That such a sudden change in body length is not due to growth is supported by the Noyes Island data, in which both the 4- and 5-year-olds taken during the last of June, the largest difference, that between the 5-year-olds, being 6 millimeters.

The tagging results coupled with the morphometric inconsistencies, which can be explained by mixing, favor the acceptance of stock intermingling

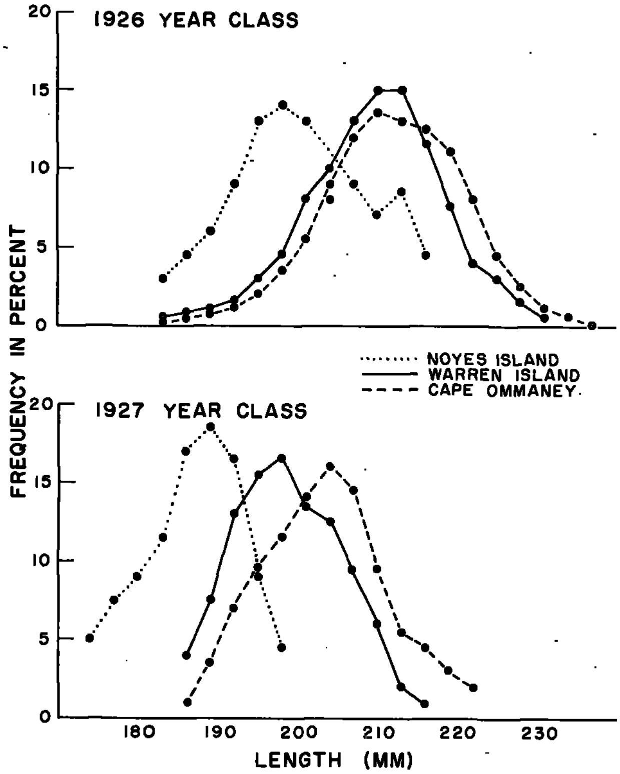

FIGURE 7.—Length-frequency distribution of two year classes taken in 1930. (Data from Rounsefell and Dahlgren, 1935.)

rather than a theory of discrete populations within the Cape and non-Cape areas.

MORTALITY ESTIMATES

Delineation of the migration patterns and mixing areas can be determined generally by examining recovery data. Estimates of population parameters, however, necessitate the assurance that the data fulfill certain requirements and that the limitations be known. Other than the previously mentioned limitations regarding tag recovery, the following items are not accounted for in the data:

1. Proportion of each year's catch which was searched by the magnets.
2. Efficiency of the various magnet installations.
3. Efficiency of tag collection by reduction plant personnel.

The assumption is that the proportion of catch examined and efficiency of recovery varied slightly among the years of study.

To determine whether tagged individuals were distributed as untagged members of the population, the recoveries from each experiment can be compared to the catch of the year classes which were in the postrecruit stage at the time of tagging. Dahlgren and Kolloen (1944) estimated the numbers of herring taken from each year class from 1929 through 1938. These estimates were obtained on an annual basis from the total catch, percentage age contribution, and average weight at each age. To utilize these data, the first consideration is to determine the age at which the majority of fish are recruited to the fishery. After the method described by Tester (1955), the estimates of Dahlgren and Kolloen have been weighted to 10,000 fish per year and averaged to establish the age of recruitment (table 5). It is evident that recruitment continues during the 5th year of life in some years, but the major portion of recruitment is completed by the 4th year of life.

TABLE 5.—*Estimated numbers of herring by year of life, weighted to 10,000 fish per year*

Year of capture	Year of life								
	2	3	4	5	6	7	8	9	10+
1929	------	151	8,913	461	220	119	99	9	29
1930	------	39	1,797	7,689	209	140	72	30	24
1931	------	1,250	1,020	2,247	5,125	258	20	60	20
1932	------	410	3,817	1,179	1,217	2,967	410	------	------
1933	------	319	960	2,768	1,279	1,488	3,185	------	------
1934	------	9	7,684	439	859	399	479	131	------
1935	------	121	379	9,070	309	70	51	------	------
1936	40	871	1,403	839	6,492	218	113	16	8
1937	210	4,600	1,832	679	462	2,139	70	8	------
1938	------	2,090	6,125	466	289	257	740	16	16
Total	250	9,860	33,930	25,837	16,461	8,055	5,239	270	97
Average	25	986	3,393	2,584	1,646	805	524	27	10

The catch estimates by Dahlgren and Kolloen (1944) for the tagging and recovery period are based on Cape catches, but from the evidence in the previous section on intermingling, their data are considered representative of both Cape and non-Cape for this analysis (table 6). Further, the age composition of the catch is considered representative of the population at time of tagging. In each year of capture, the number of fish taken during the 4th year of life is underscored in table 6 with a solid line and the year classes below this line are not considered members of the population at time of tagging. (Unpublished data of several workers indicate that although some southeastern Alaska herring enter the summer fishery during their 3d year of life, relatively few of them are

TABLE 6.—*Estimated catch of herring from each year class in millions of fish* [1]

Year class	Year of capture					Total by year class
	1934	1935	1936	1937	1938	
1926	5.5	------	------	------	------	6
1927	20.2	------	0.1	------	------	20
1928	16.8	1.3	0.2	------	------	18
1929	36.2	1.8	1.4	0.2	0.1	40
1930	18.5	7.9	2.7	1.8	0.1	31
1931	323.8	232.2	80.5	55.1	4.6	696
1932	.04	9.7	10.4	11.9	1.6	34
1933	------	3.1	17.4	17.5	1.8	40
1934	------	------	10.8	47.2	2.9	61
1935	------	------	0.5	118.5	38.1	157
1936	------	------	------	5.4	13.0	18

[1] The number of fish taken from the original population during the tagging year is determined by adding the number of individuals in the 4th year of life and older.

mature the previous spring.) The total number of fish taken from the original population during the tagging year is determined by adding the number of individuals in the 4th year of life and older. The number of fish taken from the same population the following year is obtained by adding the number of individuals in the 5th year and older. Thus, the figures above the dotted lines in table 6 are added to determine the numbers captured from the initial population of each tagging experiment in a given year of fishing.

The number of fish removed each year from each tagging population is compared with recoveries of tagged individuals from the same population (table 7). The recoveries are the total for each year of tagging and recovery as shown in table 1. The recoveries from each tagging experiment can now be compared with the catch in the several recovery years from each experiment. To analyze the results of each tagging year and of subsequent recoveries, the ratio of each year's recovery to the previous year's recovery and the ratio of each year's catch to the previous year's catch are determined (fig. 8). As shown in the scatter diagram, an increase in the catch ratio, C_i/C_{i-1}, is generally reflected by an increase in the recovery ratio, R_i/R_{i-1}. A *t*-test,

TABLE 7.—*Comparison of tagged individuals recovered and catch (in millions of fish) from initial tagging population*

Year of capture	Tagging year							
	1934		1935		1936		1937	
	Recoveries	Catch	Recoveries	Catch	Recoveries	Catch	Recoveries	Catch
1934	645	421	------	------	------	------	------	------
1935	291	243	2,357	253	------	------	------	------
1936	68	85	822	95	474	113	------	------
1937	31	57	482	69	285	87	400	134
1938	7	5	51	6	26	8	51	11

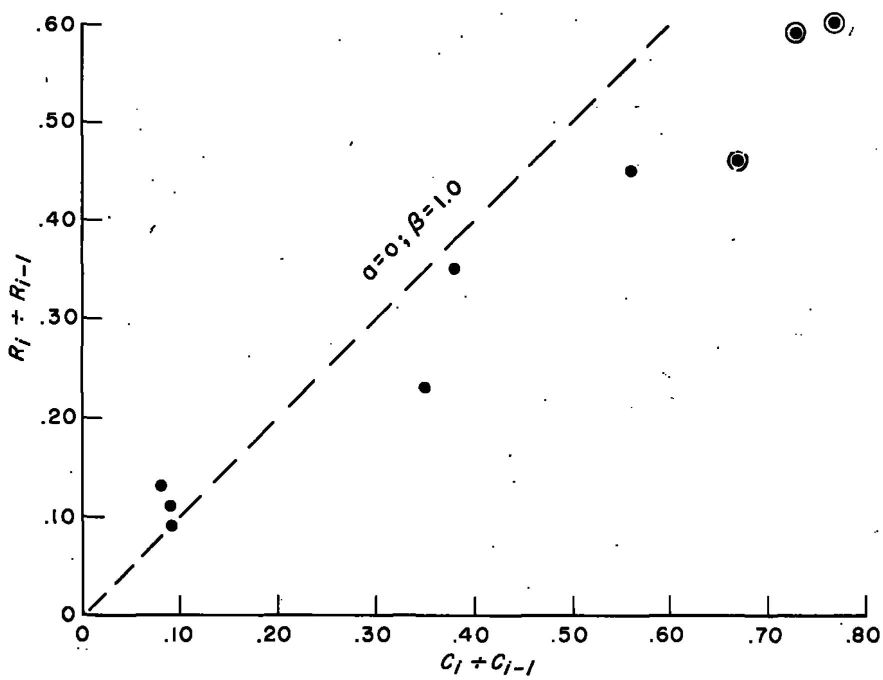

FIGURE 8.—Comparison of tag recoveries ratios (R_i/R_{i-1}) and commercial catch ratios (C_i/C_{i-1}), 1934–38. Circled dots represent data from the years 1936 and 1937.

however, indicates rejection of the hypothesis that the regression of the recovery ratios on catch ratios is 1.0. These results lead to the conclusion that the population of tagged fish is not distributed as the population(s) of untagged fish in the catch; however, further examination of the data reveals features which suggest that this conclusion should be qualified.

The catch ratios generally exceed the recovery ratio, and, presumably, this difference might account for losses caused by tagging mortality, lost tags, inadequacies of the recovery method, or immigration of fishes from other than the original tagging population. That immigration is an important consideration is evidenced by the following exercise. By subtracting the recoveries of non-Cape experiments from the total recoveries (table 7), the regression of catch ratio and recovery ratio deviates further from the hypothetical 1: 1. This indicates that fish of non-Cape origin emigrate and contribute to catches in the Cape area and that non-Cape tagging experiments must be included to validate the comparison. Immigration from populations of unknown origin is also considered plausible, and the 1936–37 catch data may reflect such a phenomenon. This ratio, C_{37}/C_{36}, is suspiciously higher than any of the other catch ratios in the three tagging experiments in which it is represented. When these three ratios (circled in figure 8) are omitted from the calculation of the regression, the "*t*-test" indicates that a regression of 0.95 is not rejected. Considering the limitations of the recovery data, coupled with the limitations of the catch estimates, it is perhaps surprising that the regression is as close to 1.0 as shown. With this evidence, the assumption is made that differences in the distribution of tagged and untagged fish are not sufficiently great to negate a comparison of recovery and catch data.

Estimates of mortality rates from the tagging data are influenced by the limitations listed in the previous section. Because of these limitations, specific values of population parameters are open to question. Nevertheless, the estimates are considered useful in determining the comparative success of the several experiments and the differences in mortality of the Sitka and Craig stocks.

The following equation was selected as most suitable for the data, and calculations of mortality for each year of the Sitka and Craig experiments are derived by this method.[1] The symbols utilized are essentially those of Ricker (1948 and 1958).

The reader will note that fishing effort is assumed proportional to the rate of exploitation. Justification of this assumption is discussed in the appendix which includes excerpts from a letter (dated March 18, 1958) from R. A. Fredin.

The equation:

$$\frac{R_t}{R_{t-1}}=\frac{Nk[1-(u_{t-1}+v_{t-1})]\frac{f_t}{f_{t-1}}u_{t-1}}{Nk\,u_{t-1}}$$

$$\frac{R_t}{R_{t-1}}=[1-(u_{t-1}+v_{t-1})]\frac{f_t}{f_{t-1}}$$

where:

$(u_{t-1}+v_{t-1}) = a =$ Annual rate of mortality [2]
$N =$ Number of fish tagged
$k =$ Tagging mortality
$R =$ Recoveries
$u =$ Exploitation rate
$v =$ Natural death rate [2]
$f =$ Effort

The results of these analyses provide the calculated "*a*" for successive tagging experiments at both Sitka and Craig (fig. 9). A point located on a given year expresses the rate of mortality from the previous year to the given year. The two rates circled on the graphs are presumed aberrant but do not materially influence the trend established by the remaining points. The comparison is concerned with the trend of a given experiment as well as the results between successive experiments. The results show:

1. In a given experiment, the mortality increases with each year of recovery. The two exceptions are circled on the graphs.
2. Between experiments, the later tagging exhibits a progressively higher rate of mortality in the initial and subsequent recovery years. An exception to this progression occurs in the Sitka

[1] The selection of an equation suitable for providing estimates of mortality rates created a number of problems, and in seeking advice, the author seldom found agreement among the critics as to the appropriate choice. Most individuals agreed, however, that mortality estimates should be presented and were necessary as comparative indexes for studying the tagging results. Of the different approaches tested, each either had characteristics which were not applicable or necessitated assumptions which the data could not meet. Comments from the reader regarding the treatment of the data will be welcomed.

[2] See Discussion section for comments on the definition of terms *a* and *v*.

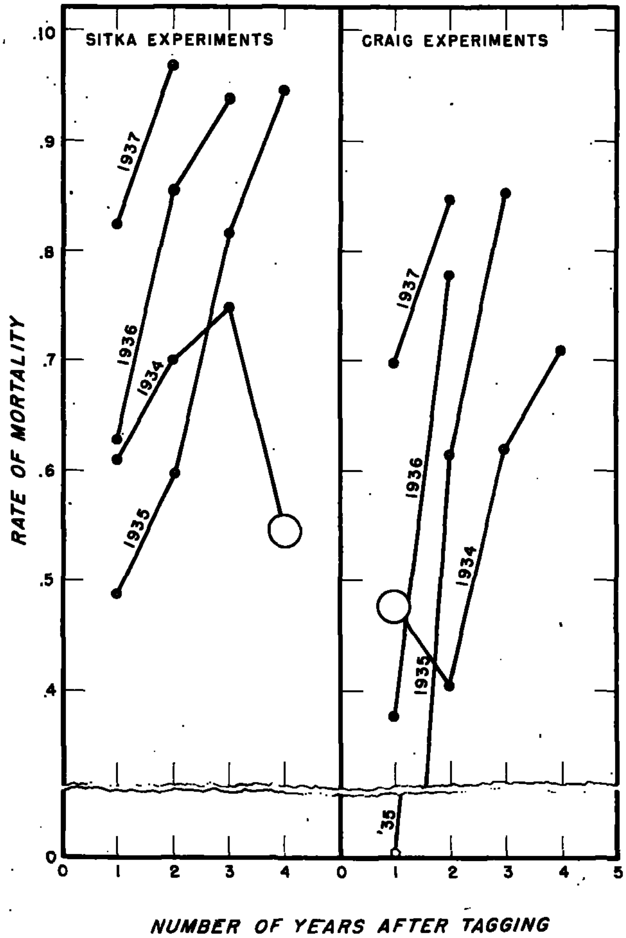

FIGURE 9.—Annual total mortality rates by year of recovery as determined from Sitka and Craig tagging experiments.

and Craig experiments of 1934. In some instances the mortality rates in the first and second recovery years of this experiment exceed the mortalities indicated in later experiments.

As effort did not increase, evidence of the mortality increase in the tagging experiments coupled with the fact that the trend parallels the decline of the fishery suggests that the mortality increase was not spurious and represents an actual biological change in the population.[3] Examination of both fishing and natural mortality is necessary to determine the causal factors of this trend.

[3] Catches in 1934 and 1935 averaged 120 million pounds per year, whereas catches in 1936 and 1937 averaged 85 million pounds, and in 1938 and 1939, less than 50 million pounds per year (Skud, Sakuda, and Reid, 1960).

Tester (1955) discusses a mortality increase with age in herring of British Columbia and the possibility of such an increase in the Alaska data should be considered. Ages of southeastern Alaska tagged herring were not determined, and the only means of checking the age composition of the tagged fish recovered would have been from the catches of the commercial fishery. However, this assumes that age groups in the commercial fishery are comparable to age groups on the spawning grounds where the fish were tagged. Field work undertaken by the author in 1956 provides a comparison of age groups from the summer fishery and the bait fishery—the latter being conducted on the Sitka spawning grounds (fig. 10). The age composition of the two groups, as determined from scales, does compare favorably and suggests the assumption is not unreasonable.

The data of Dahlgren and Kolloen (1944) in table 6 are utilized to calculate the percentage age composition during the years of tagging (fig. 11). As mentioned earlier in this section, fish in their 3d year of life in the summer fishery are not considered members of the previous spring's spawning population, and the percentage age composition presented includes only fish in their 4th year and older. The age composition during

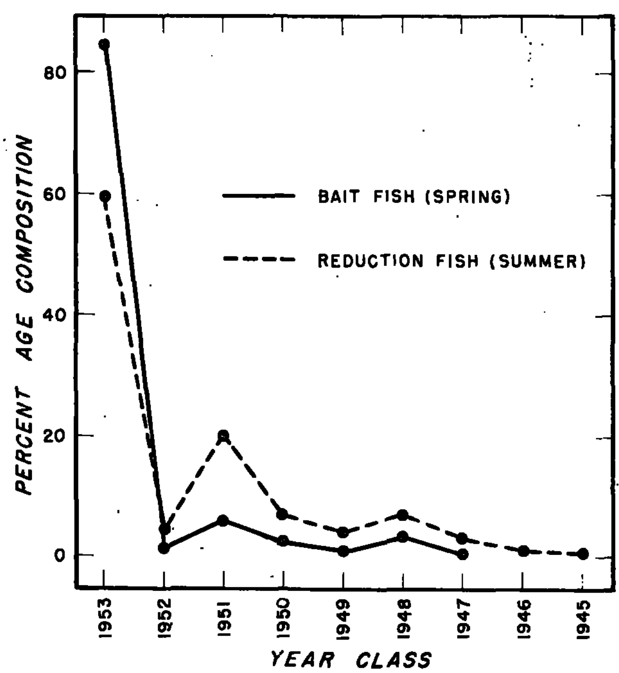

FIGURE 10.—Age composition of herring in the spring and summer fishery in southeastern Alaska.

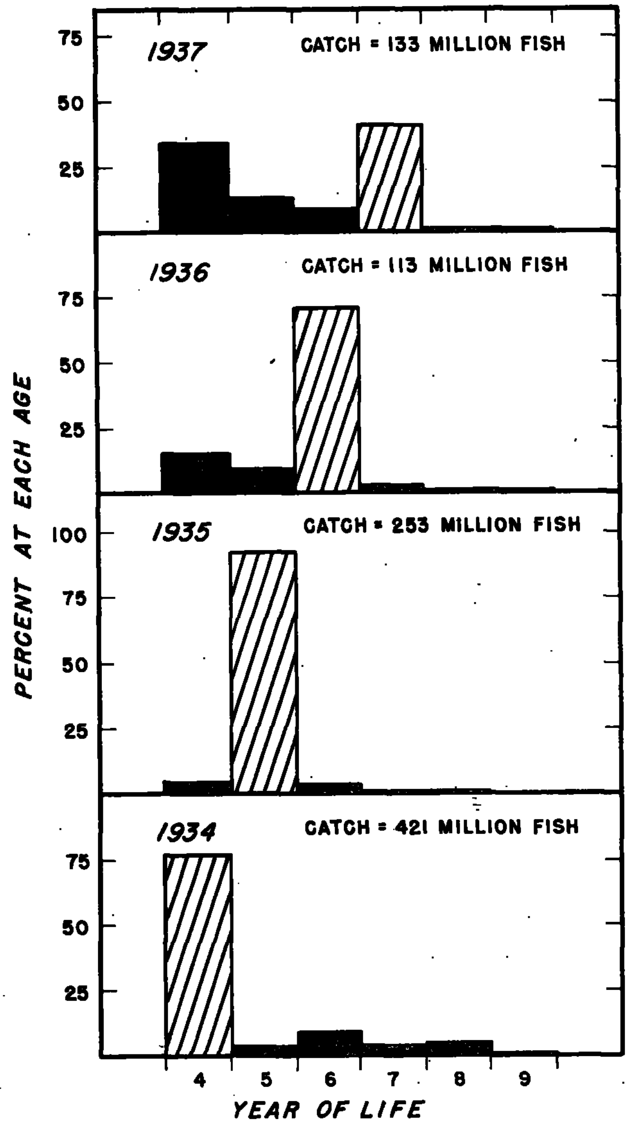

FIGURE 11.—Age composition of the catch in the summer fishery, 1934–37.

this period is dominated by the 1931 year class. In 1934, 1935, and 1936, this year class, represented by fish in their 4th, 5th, and 6th year of life, respectively, annually accounted for more than 70 percent of the total age composition. As fish in their 7th year, the contribution of the 1931 year class approximated 40 percent and was still dominant. In essence, the tagging experiments must have been concentrated on a single year class, 1931, and analyses of recovery data should reflect this phenomenon.

If we consider that the major portion of the tagging was carried out on a single year class and that the catch generally declined during this period, reexamination of figure 9 indicates an apparent mortality increase with age. That is, the earlier experiments carried out with younger fish exhibited a lower mortality than later experiments with older fish. From Sitka recoveries, calculations of mortality rates assigned to year of capture represent mortality between successive ages of the year class (fig. 12). Again, as in figure 9, the trend depicted by the 1935, 1936, and 1937 experiments is disrupted by the 1934 tagging experiment. Other than the 1934 experiment, an increased mortality with age is indicated. One difference in the 1934 experiment which may have influenced returns of tags is the heavy recruitment of the 1931 year class that occurred after the 1934 tagging.

Figure 5, which shows that the availability of Sitka tags in the non-Cape area generally increases with time, suggests that the movement of herring also may be associated with age.

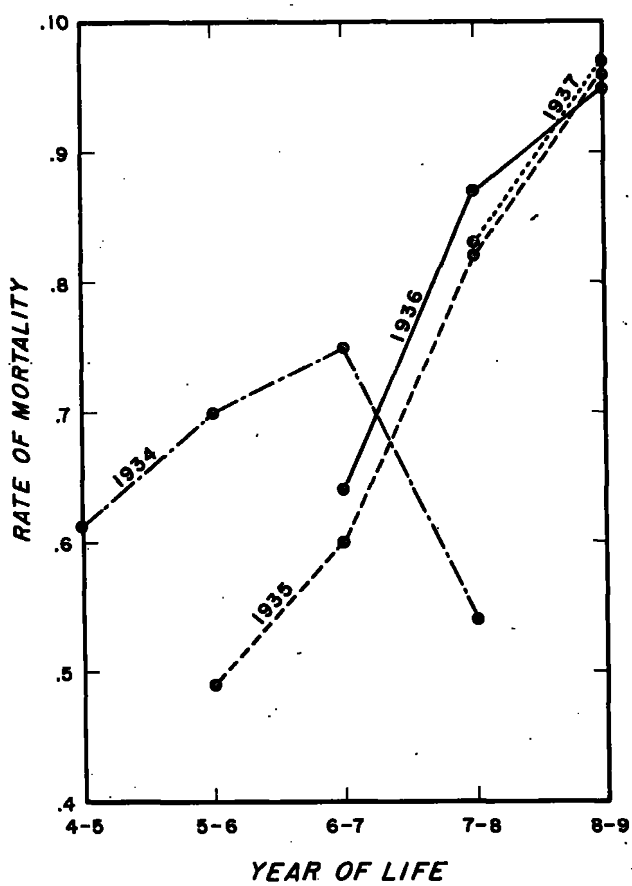

FIGURE 12.—Annual total mortality between ages as determined from Sitka experiments.

DISCUSSION AND CONCLUSIONS

Results of these tagging experiments indicate that the definition of a, total mortality, should include those losses which result from the emigration of individuals from the fishing area. The definition of v, natural mortality, lacks the connotation of losses other than natural deaths. Beverton and Holt (1957) using terms F and X present the necessary refinements for a tagging study. That is, F is the coefficient of reduction of marks due to fishing and X the sum of all other causes which reduce marks—natural deaths, tagging mortality, emigration, etc.

Estimates of population parameters based on the recovery of tagged individuals require that certain established criteria be fulfilled. The possibility of realizing such fulfillment in natural populations is slight. In this study, various assumptions regarding recoveries were necessary when precise data were lacking. Some of these assumptions have little factual support but have only a minor consequence in the analyses. The distribution of tagged fish and the efficiency of recovery, however, are factors of major consequence. A comparison of recovery data and catch data supported the assumption that tagged and untagged individuals were equally vulnerable to capture and that efficiency of recovery varied but little from year to year.

The conclusions from this report are:

1. Intermingling between Sitka and Craig stocks was more extensive than previously indicated and was centered in the vicinity of Kuiu Island and Warren Island.
2. Because of this intermingling, Cape and non-Cape divisions of the fishing grounds cannot be considered distinct in regard to management of the commercial fishery.
3. The 1931 year class dominated the age composition in the summer fishery during each tagging year, 1934–37.
4. An increase in natural mortality with age was indicated.

Whether or not these conclusions are valid in the present day fishery is not known, but they most certainly should be investigated, and the following suggestions should be considered in any future tagging experiments:

1. Design the experiment to further test the degree of intermingling between Sitka and Craig stocks.
2. Conduct summer as well as spring tagging to determine if fish return to the same spawning beaches after mixing on the fishery grounds.
3. Age tagged individuals to: (a) relate intermingling with age, (b) determine variations in recovery of age groups, (c) provide more precise estimates of mortality.
4. Assess recovery methods to: (a) determine portion of catch examined, (b) test efficiency of recovery at each plant.
5. Conduct tagging experiments in other areas to determine the degree of emigration and immigration of fish in this fishery.

ACKNOWLEDGMENTS

I did not participate in either the original field work or in compiling the original data presented in this report and I wish to acknowledge the thorough work of former investigators. The initial tagging experiments reported by Rounsefell and Dahlgren (1933 and 1935) and Dahlgren, (1936) included a comprehensive review of tagging results through 1935. Subsequent experiments were supervised by Dahlgren and the late L. N. Kolloen. The success of their early work is evidenced by the rather wide acceptance of the tagging procedures in both Canadian and European herring investigations. The author is indebted to each of these men, particularly George A. Rounsefell who suggested preparing this report and commented on the original manuscript. The author also wishes to acknowledge the comments of Reynold A. Fredin, Basil B. Parrish, William E. Ricker, and the late Clyde C. Taylor.

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APPENDIX

Excerpts from letter by R. A. Fredin (March 18, 1958):

Fishing effort is assumed to be proportional to rate of exploitation in the model (see appendix). The following indicates the amount of error introduced by this assumption when fishing effort is proportional to the instantaneous rate of fishing. The rate of exploitation is given by the equation

$$u=\frac{pa}{i}$$

when

$$a=1-e^{-(p+q)}$$

$$p+q=i$$

$$p=kf$$

k being a constant of catchability and f being the units of fishing effort.

The rate of change of u with respect to p (or f, since p is proportional to effort) is as follows:

$$\frac{\Delta u}{\Delta p}=\frac{i\frac{\Delta pa}{\Delta p}-pa\frac{\Delta i}{\Delta p}}{i^2}$$

$$\frac{\Delta pa}{\Delta p}=p\frac{\Delta a}{\Delta p}+a\frac{\Delta p}{\Delta p}$$

$$\frac{\Delta a}{\Delta p}=\frac{\Delta[1-e^{-(p+q)}]}{\Delta p}=e^{-(p+q)}$$

$$\frac{\Delta p}{\Delta p}=1$$

$$\frac{\Delta pa}{\Delta p}=pe^{-(p+q)}+a$$

$$\frac{\Delta i}{\Delta p}=\frac{\Delta(p+q)}{\Delta p}=1$$

$$\frac{\Delta u}{\Delta p}=\frac{i[pe^{-(p+q)}+a]-pa}{i^2}$$

$$=\frac{ipe^{-(p+q)}+(i-p)a}{i^2}$$

Two tables were constructed, one using p-values ranging from 0.05 to 1.90 with a q-value (natural mortality rate) of 0.1, the other using p-values ranging from 0.05 to 1.70 with a q-value of 0.3. When values for $\Delta u/\Delta p$ are plotted against p, the slope of the curve is found to be changing and not constant, which it would be if u was proportional to f. However, within a limited range of p, the error caused by a changing slope is not too great.

Using effort data from your manuscript and assigning values of k (catchability) ranging from 0.0001 to 0.0004 to the effort data and selecting q-values of 0.1 and 0.3, "true" u and estimated u-values were calculated and compared. The results show that at low fishing mortality rates (where $k=0.0001$) the difference between the "true" and estimated u-values is insignificant, less than 0.01. As the fishing rate increases (i.e., at higher k-values) the error increases up to about 0.10 in some years.