REPORT OF THE
INTERNATIONAL PACIFIC HALIBUT COMMISSION

APPOINTED UNDER THE CONVENTION BETWEEN THE UNITED STATES
AND CANADA FOR THE PRESERVATION OF THE
NORTHERN PACIFIC HALIBUT FISHERY

NUMBER 42

MORTALITY ESTIMATES FROM TAGGING EXPERIMENTS ON PACIFIC HALIBUT

BY

RICHARD J. MYHRE

COMMISSIONERS:

WILLIAM M. SPRULES	HAAKON M. SELVAR
HAROLD E. CROWTHER	FRANCIS W. MILLERD
MARTIN K. ERIKSEN	L. ADOLPH MATHISEN

SEATTLE, WASHINGTON
1967

FOREWORD

The Convention of 1953 between Canada and the United States for the preservation of the Halibut Fishery of the Northern Pacific Ocean and Bering Sea continued the conservation objectives of the three previous conventions, and requires that the stocks of halibut be developed to levels which will permit maximum sustained yield and that the stocks be maintained at those levels. These objectives require accurate knowledge of the effects of fishing upon the stocks.

This report presents estimates from tagging data of the fishing and total mortality rates experienced by halibut. Such estimates provide a basis for comparing and predicting the effects of fishing on different grounds and at different seasons and are necessary for the scientific management of the fishery.

MORTALITY ESTIMATES FROM TAGGING EXPERIMENTS ON PACIFIC HALIBUT

By

RICHARD J. MYHRE

CONTENTS

ACKNOWLEDGMENTS

Most members of the Commission's staff, past and present, have assisted in the accumulation and compilation of the data used in this report. Also, without the cooperation of fishermen employed in the tagging of fish at sea on chartered vessels and without the return of recaptured tags by the commercial fishery this work would not have been possible. Fish dealers and many officers of the governments of Canada and the United States gave valuable assistance by forwarding recovered tags and information to the Commission. The long series of experiments analyzed herein were conducted under the successive supervision of W. C. Herrington, J. L. Kask and the author. The helpful suggestions of F. Heward Bell, present Director of Investigations and D. G. Chapman, University of Washington are gratefully acknowledged.

INTRODUCTION

Management of a fishery requires knowledge of the effect of fishing upon the stocks of fish. The International Pacific Halibut Commission has used catch statistics, age composition data and tagging experiments to measure such effects. Conclusions supported by these three independent data sources warrant a degree of confidence that could not have been achieved from the analysis of tagging data alone.

The estimation of mortality rates of halibut from tagging data has been a continuing effort beginning with the work of Thompson and Herrington (1930). A number of methods of estimation have been attempted in the ensuing years. However, the one described herein appears to be the most satisfactory of those tested.

This report covers the estimation of the mortality rates from 60 tagging experiments conducted from 1925 to 1955 between Cape Scott, at the north end of Vancouver Island in British Columbia, and the Shumagin Islands in western Alaska, or between 60-mile statistical areas 9 and 32 as shown in Figure 1. During this 30-year period approximately 64,000 halibut were tagged and released in the region, over 14,700 of which were recovered by the end of 1963.

Total mortality and fishing mortality are estimated for each experiment. The relationship between the standard deviation of total mortality estimates and the number of fish tagged is examined and the optimum number of releases for a single tagging experiment is determined.

TAGGING AND RECOVERY METHOD

The procedure for tagging and recovering tagged halibut was described in detail by Thompson and Herrington (1930) and is only briefly reviewed herein. To assure comparability the procedure has not been materially changed in the intervening years.

Halibut were caught by chartered fishing vessels using regular halibut setline gear except in the experiments conducted in 1947 when bottom trawl nets were used. The time and area of operations was specified by the Commission based upon the need for tagging data. The distribution of locations fished within the specified area tended to be more restricted when large catches were obtained and vice versa.

Usually 30 to 50 percent of the halibut were suitable for tagging based on a subjective appraisal of their viability. A monel metal strap tag was promptly attached on the dark or right side near the insertion of the operculum and the fish was forthwith returned to the sea. The date, location, length and apparent tagging injury were recorded with the tag number.

Tagged halibut were recovered for the most part by the setline halibut and blackcod fisheries, the bottomfish trawl fishery or the salmon troll fishery. Posters providing instructions for the reporting and return of tagged halibut were prominently displayed in all fish plants where halibut were landed. To encourage the reporting of recovered tags a reward of from fifty cents to two dollars was paid for the return of recovered tags, the amount of the reward depending upon the completeness of the recovery information. In addition, the finder was provided with information on the time and place of release of the recovered fish.

At the major halibut landing ports, Commission employees contacted halibut vessels at the completion of each trip to copy the fishing records and to redeem recaptured tagged halibut. Fish buyers and representatives of other governmental agencies cooperated by forwarding the recovered tags and information from ports where the Commission was not represented.

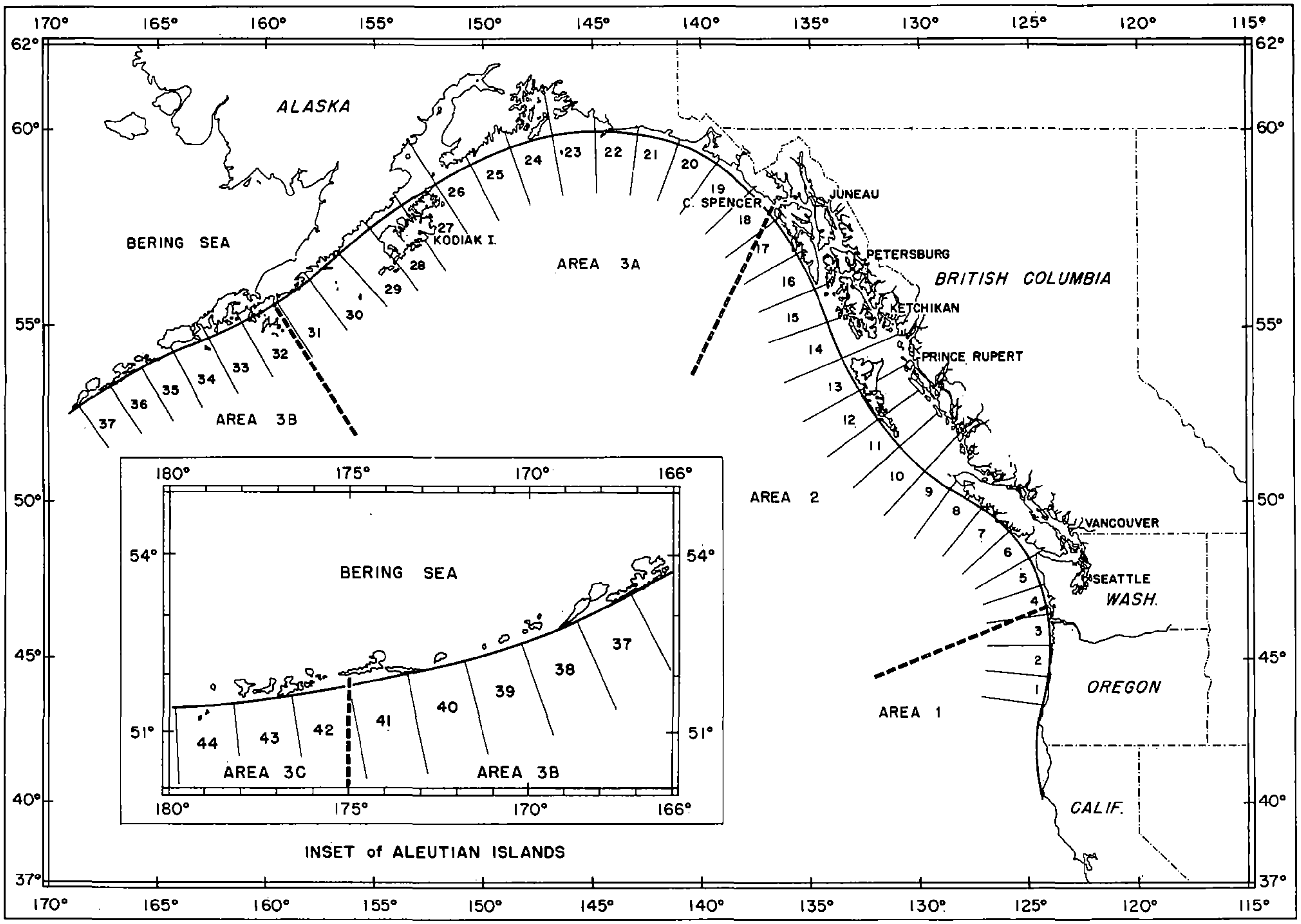

Figure 1. Pacific Coast of North America showing International Pacific Halibut Commission statistical areas and 1966 regulatory areas exclusive of those of Bering Sea.

METHOD OF ESTIMATION

The estimation of the mortality rates of halibut from tagging data is a two-stage process. The first stage involves the estimation of the mortality rates affecting the tagged individuals. The second stage involves the projection of these estimates to the total population from which the tagged individuals were taken. The distinction between the two stages is important because the assumptions employed in each are not the same.

Three basic methods are available for determining the mortality rates of marked fish. Ricker (1958) described a method in which the total mortality rate is estimated from the decline in recoveries with time. The total mortality rate is then partitioned into mortalities of two types, those attributable to fishing and those due to all other causes. The latter type of mortality is called the disappearance rate herein, a term which is synonymous with the 'other loss' of Beverton and Holt (1957). This separation of the two components of total mortality is based on the weighted average proportion of marked members recovered each year from the initial number of survivors of the previous year.

A second method in which the logarithm of the number of recoveries *per unit of fishing effort* is regressed against time was described by Gulland (1963). The use of linear regression analysis for estimating mortality rates from the decline in recoveries had been previously reported (Graham, 1938; Beverton and Holt, 1957; Chapman, 1961) but the method of Gulland is particularly well suited for halibut data. The slope of the regression line is the average total mortality rate and the intercept at the time of tagging is the logarithm of the expected number of initial recoveries per unit of fishing effort. The average catchability, which is defined as the average proportion of the stock that is caught by a standard unit of fishing effort, is estimated by dividing the value of the intercept by the number of marked individuals released. Fishing mortality is then obtained as the product of the catchability coefficient and the total fishing effort used.

A third method uses multiple regression analysis to compute the catchability coefficient and the disappearance rate separately (Chapman 1961). This method does not require that the number of marked individuals released be used in the calculation. However, pronounced changes in fishing effort between successive fishing periods and a constant catchability coefficient are required.

The multiple regression method is preferable from a theoretical standpoint but unrealistic estimates such as positive fishing and disappearance rates are frequently obtained with halibut data, even from large experiments. These anomalous results probably arise because of short term variations in the catchability coefficient. The same problems were encountered when the linear method of Beverton and Holt (1957) was used with halibut data and apparently for the same reasons.

The proportional and the linear regression methods of Ricker and Gulland respectively both yield satisfactory results with halibut data because short term variations in catchability tend to be compensatory over the long term. Of these two methods, the linear regression method was selected for use in this report because it provides variance estimates for the values of total mortality and catchability.

The linear regression model is derived from the basic equation

$$\frac{n_i}{f_i} = \frac{N_0 q}{Z_i} \left(e^{-Z_i (i-1)} \right) \left(1 - e^{-Z_i} \right) \qquad (1)$$

where n is the number of tags recovered, f is the number of units of effort fished, N_o is the number of tags released, q is the catchability and Z is the total mortality. The subscripts refer to the i^{th} interval which is one calendar year throughout this report. The definition of catchability used herein is more general than that used by some other authors in that unequal vulnerability of different stock components is recognized.

The approximation,

$$\left(1-e^{-Z_i}\right)=Z_i\left(e^{-\frac{Z_i}{2}}\right) \quad (2)$$

is reasonable when Z_i is small (Chapman, 1961). Even with Z_i as large as 1.0, the right-hand side of equation (2) is within four percent of the left-hand side. Substituting the above approximation into equation (1) yields the equation

$$\frac{n_i}{f_i}=N_oqe^{-Z_i\,(i-0.5)} \quad (3)$$

Converting to logarithms and substituting Z for Z_i yields

$$\text{Ln}\,\frac{n_i}{f_i}=\text{Ln}\,(N_oq)-Z\,(i-0.5)+\varepsilon \quad (4)$$

where Z is the arithmetic average of all Z_i and ε is the error term which is assumed to be normally distributed and to have an expected value of zero.

The substitution of Z for Z_i is necessary to satisfy the requirements for linear regression. Since f_i is known to vary and q and the disappearance rate are assumed to be constant then Z_i will vary with f_i. Most of the effect of annual variation in f_i is eliminated when the number of recoveries in each year is divided by the corresponding f_i. Residual effects of varying f_i will appear in the error term provided no trend in f_i exists. If f_i increases or decreases during the course of the experiment, small errors in q and Z may result.

The probable magnitude of the errors of this type was examined by calculating estimates of q and Z from trial data involving varying levels of effort. The greatest error in q of 16 percent was obtained when effort in recovery years two through five was double that in recovery year one. In the same trial the error in Z was only five percent. Changes in effort observed in the experiments described herein were smaller than that used in the above trial. Therefore, errors in estimates of q and Z due to changing effort are expected to be small in most cases and to be less than 16 and 5 percent respectively for any experiment.

Equation (4) contains two constant unknowns, Ln (N_oq) and Z which are estimated from the intercept and slope respectively from linear regression analysis. The value of q is obtained algebraically from Ln (N_oq) since N_o is known from the number of tagged fish originally released. Of course, q would be underestimated if some of the tagged fish die or lose their tags shortly after tagging but the estimate of Z would be unaffected. Live-box experiments were conducted in 1958 to test for tagging mortality. Mortalities during the first two weeks after tagging were estimated to be five percent or less and most deaths due to tagging appeared to have occurred by that time (Peltonen, Ms.).

Non-reporting of tags which causes the loss of a proportion of each group of recaptures will also result in the underestimation of q. Non-reporting loss of tags can occur for a variety of reasons and does not necessarily imply indifference on the part of persons who recapture tagged halibut. Myhre (1966) used double-tag experiments to measure non-reporting loss as well as shedding loss. Non-reporting losses were estimated to be 0.04 of recaptured tags but losses that operated on both tags jointly could not be measured by this technique. Thus losses due to non-reporting of tags could be greater than 0.04.

The value of Z in equation (4) is the average total mortality rate for the experiment and includes all factors which cause tagged fish to decrease in numbers with time. Two important components of total mortality are fishing and natural mortality. Also included will be any shedding of tags which occurs continuously during the course of the experiment.

The estimation of total mortality requires constant catchability of the tagged fish. If this condition is not satisfied, total mortality will be overestimated or underestimated depending upon whether the tagged fish become more or less catchable with time.

The estimates of fishing and total mortality are affected by the manner of dealing with migrant tagged fish. If migration did not alter the chances of recovering tagged fish, such migrants could be included as usable recoveries as if they had remained in the tagging area and the decline in numbers would be a valid indicator of total mortality. In practice, fishing mortality varies from area to area so this solution would be approximate at best. A second alternative would be to exclude migrant recoveries in which case migration out of the area could become an important part of the disappearance rate and the fishing mortality estimates obtained would reflect the utilization of non-migrant tagged fish only.

A third alternative, and the one used in this report, is to calculate the n_i/f_i for each statistical area. These values are then summed over all statistical areas to obtain the desired statistic for the dependent variable in equation (4). The estimates of fishing and total mortality thus obtained closely approximate the rates to which the tagged fish would have been exposed if emigration did not occur.

Since the amount of fishing area differs between recovery areas, gear density is used as the index of fishing intensity. Gear density is proportional to the effective overall fishing intensity of Beverton and Holt (1957) and is defined as the weighted mean number of standard units fished per square nautical mile per year.

The gear density for the jth area in the ith year is given by the equation $g_{ij} = \frac{f_{ij}}{A_j}$ where A_j is the bottom area in the jth statistical area. The mean gear density for an experiment in the ith year depends upon the number of recoveries taken from each of the k areas in that year as shown by the equation

$$\bar{g}_i = \frac{\sum\limits_{j=1}^{k} n_{ij}}{\sum\limits_{j=1}^{k} \left(\frac{n_i}{g_i}\right)_j} \qquad (5)$$

Bottom area is defined as the amount of bottom in square nautical miles over which halibut and halibut gear are distributed. Preferably allowance should also be made for non-uniform distribution of fishing gear but detailed data on distribution of effort were not available for all years and areas employed in this report. Myhre (1963) measured the bottom area for statistical areas 9 to 32 using a planimeter and charts published by the United States Coast and Geodetic Survey or by the United States Hydrographic Office. These calculations which have been repeated and extended to statistical area 36 are given in the following table.

Statistical Area	Bottom Area* in Square Miles	Statistical Area	Bottom Area* in Square Miles
9	2960	23	2990
10	3980	24	3350
11	3200	25	4900
12	2360	26	7940
13	2810	27	5200
14	3710	28	4410
15	2950	29	6030
16	2120	30	5710
17	1390	31	4770
18	2320	32	3560
19	2580	33	2630
20	2560	34	2400
21	1550	35	2230
22	1370	36	1130

*The bottom areas differ from those given in Myhre (1963) but should be considered as more precise.

Incorporating both the utilization of migrants and the gear density concept in equation (4) yields the relationship

$$\mathrm{Ln} \sum_{j=1}^{k} \left(\frac{n_i}{\bar{g}_i}\right)_j = \mathrm{Ln}\ (N_o q) - Z\ (i-0.5) + \varepsilon \qquad (6)$$

which is the one used for the estimation of Z and q. Since the total number of annual recoveries, $\sum_{j=1}^{k} n_{ij}$ is expected to decrease with increase in i, the dependent variable (left-hand side of equation 6) was weighted by n_i. Further justification for this weighting procedure is given in a later section of this report.

DATA USED

Most of the fish tagged from 1925 to 1955 could be grouped into experiments according to time and place of tagging. Some experiments were unsatisfactory for the estimation of mortality rates because they produced too few recoveries or because recoveries were not obtained over at least three full recovery years. A total of 60 experiments that could be used for the estimation of mortality rates are listed in Table 1 which shows the year and the statistical area or areas of tagging.

The month of tagging varies considerably from experiment to experiment and some experiments include tagged fish that were released over a period of two or three months. Since the method to be used for estimating catchability requires definition of the specific time of tagging, a weighted mean time of tagging (M_t) was determined for each experiment using the equation

$$M_t = \frac{\sum_{i=1}^{k} T_i d_i}{365T.} \qquad (7)$$

where d_i is the i^{th} day of the year, T_i is the number of fish tagged on that day and T. is the total number of fish tagged in the experiment.

January 1 of the year of tagging is defined as zero time and the year of tagging is defined as the zero year. The midpoint of fishing and, hence, of recovery was usually at about mid-May or at about 0.45 of the way through the year. Although the length of the fishing season was considerably reduced from the early to the more recent years, the midpoint of fishing changed little because the opening date was set later in the year as the length of the season declined. The midpoint of recovery in the first and subsequent recovery years of each experiment is therefore defined as 1.45, 2.45 and so on. Variations from these midpoints are considered small enough to satisfy the requirements of the fixed regression model.

Most of the experiments included some tagged fish that were too small to be fully available to halibut gear at the time of tagging. Both the modal size of the fish tagged and the percentage recovery during the first full recovery year by size at tagging were used to determine the size of full recruitment for fish released in each experiment.

Differences in modal size between experiments that were similar with respect to area and year were smoothed visually to overcome statistical variations. When the division occurred within a size-class, the entire class was considered to be fully recruited in anticipation of some additional growth during the remainder of the zero year. The number of fish tagged in each experiment by length class and the separation of pre-recruits and full recruits (vertical line) is given in Table 2.

Area 2 fish are seen to be fully recruited at a smaller size than Area 3 fish and fish tagged in the 1920's in both areas were found to be fully recruited at a smaller size than those tagged in more recent years. Recruitment is usually thought to be a

Table 1. Year, month and statistical area of tagging for 60 experiments conducted from 1925 to 1955.

Experiment Number	Year	Month	Statistical Areas
1	1925	June-August	12, 13
2	1925	July	11
3	1925	June	13
4	1925	August	15
5	1926	June	10
6	1926	July	13
7	1926	July-August	15
8	1926	November-December	20
9	1927	November	25
10	1927	December	22
11	1929	April-May	32
12	1933	February-March	11
13	1933	January-February	20, 22
14	1933	December	24, 25
15	1933	December	21, 22
16	1935	May-June	10
17	1935	May	9
18	1936	May	10
19	1939-1940	December-January	11
20	1940	November-December	16, 17
21	1947	May-June	10
22	1947	June	13
23	1947	June	13
24	1947	June	9
25	1949	July-August	26, 27
26	1949	July-September	13
27	1950	August-September	28, 29
28	1950	September	10
29	1951	February-April	17, 18
30	1951	July	27-29
31	1951	August	20, 21
32	1951	August-September	13
33	1951	September	11
34	1951	September-October	10
35	1952	March-April	9
36	1952	April	13
37	1952	May	25, 26
38	1952	May	27
39	1952	June-July	11
40	1952	June-July	13
41	1953	April	13
42	1953	May	13
43	1953	April-May	12
44	1953	May-July	11
45	1953	June	10
46	1953	July	9
47	1953	June	15
48	1953	July	13
49	1954	May	25
50	1954	May-June	28
51	1954	June	20, 21
52	1954	June-July	25, 26
53	1954	August	20, 21
54	1955	July	10
55	1955	August	13
56	1955	August	15
57	1955	August-September	13
58	1955	September	11, 12
59	1955	September-October	10
60	1955	November-December	20-22

Table 2. Length frequency of all fish tagged and size of full recruitment (vertical line) of fish in each experiment.

	Length in Centimeters																
Experiment Number	< 50	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100-104	105-109	110-114	115-119	120-124	125-129	≥130
1	9	18	74	107	68	44	26	11	6	3	5	4	3	3	0	0	1	4
2	15	21	46	46	64	37	28	19	9	7	0	5	2	1	0	1	0	2
3	9	27	59	107	147	99	76	21	20	13	14	4	4	4	1	1	0	2
4	2	1	6	23	36	20	8	6	0	0	0	0	0	1	0	0	0	0
5	7	77	232	384	372	245	81	45	28	25	10	5	2	1	0	1	0	1
6	8	28	37	91	70	17	2	0	0	0	0	0	0	0	0	0	0	0
7	36	89	259	370	296	120	48	13	9	0	0	0	0	0	0	0	0	0
8*	0	0	4	28	151	271	264	216	237	240	172	91	39	24	9	1	0	0
9*	3	4	37	111	170	190	143	137	121	102	69	38	21	12	7	0	0	0
10*	0	2	2	35	96	173	161	168	166	161	143	105	72	32	13	7	1	1
11*	2	13	39	100	177	139	135	79	59	50	26	28	22	10	7	4	2	7
12	0	0	3	20	53	86	71	59	36	31	19	13	11	5	5	4	1	13
13*	0	1	3	10	21	47	42	40	25	32	22	18	15	21	10	11	10	12
14*	0	1	8	16	30	26	22	22	13	10	9	14	10	9	9	10	10	24
15*	0	0	0	3	16	29	31	27	20	21	26	11	8	6	10	7	3	21
16	0	0	5	16	38	73	82	70	31	30	14	14	8	7	3	1	0	0
17	0	0	2	7	25	47	37	36	9	12	6	5	3	2	3	4	2	2
18	0	2	29	40	66	84	74	56	25	20	16	6	8	7	1	0	5	3
19	0	0	3	8	32	56	88	62	76	83	70	58	51	65	43	45	22	94
20	0	3	11	11	29	34	33	23	17	16	6	11	15	14	14	29	19	88
21	7	100	230	334	477	472	300	182	100	53	28	7	13	8	5	2	4	9
22	7	14	25	66	54	51	26	14	8	9	0	1	1	0	0	3	0	2
23	16	34	48	88	154	154	79	30	11	1	1	1	0	0	0	0	0	2
24	0	0	0	12	79	109	57	28	7	5	3	4	1	2	0	0	0	1
25*	10	13	31	66	91	148	142	143	93	54	39	37	19	35	37	46	41	203
26	0	0	4	38	105	228	219	199	99	60	38	29	21	35	9	12	9	39
27*	3	7	40	65	70	82	84	93	74	104	93	84	95	59	59	59	33	57
28	0	0	1	4	10	27	51	51	40	36	31	17	14	4	1	2	1	3
29	3	12	43	84	115	141	119	163	115	96	70	104	92	71	69	68	65	258
30*	8	17	20	51	68	91	96	116	92	65	61	72	70	70	54	63	57	107

* Area 3 experiment.

Table 2.— (continued)

Experiment Number	Length in Centimeters																
	< 50	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100-104	105-109	110-114	115-119	120-124	125-129	≥ 130
31*	0	1	6	16	38	82	121	170	210	184	171	147	117	89	71	40	23	16
32	1	1	9	50	139	268	301	306	216	173	88	79	45	41	30	23	13	37
33	0	0	0	5	14	23	14	16	30	13	17	5	11	10	7	7	10	22
34	0	0	3	38	167	317	467	512	416	271	185	115	74	47	45	13	17	22
35	0	0	4	14	45	111	118	99	80	67	48	40	31	32	32	16	13	22
36	0	0	0	11	38	74	119	93	51	30	18	10	7	8	2	2	7	8
37*	0	5	22	33	65	64	66	56	56	68	63	75	59	42	47	36	46	94
38*	6	9	27	40	58	57	34	22	20	25	19	12	26	24	27	16	20	51
39	0	0	0	3	8	16	24	39	34	42	39	54	52	50	50	56	45	146
40	0	2	1	2	13	27	44	68	55	49	50	44	37	44	28	21	21	200
41	0	10	13	14	18	34	56	75	57	51	50	50	38	43	36	31	26	48
42	0	2	0	6	23	94	130	142	117	66	44	30	17	8	6	1	4	2
43	0	1	8	23	41	120	181	188	130	105	61	34	18	11	9	6	2	6
44	10	10	38	68	80	159	225	254	224	224	244	194	173	135	96	71	50	87
45	0	0	0	3	10	26	36	43	36	23	9	2	1	1	1	0	0	0
46	0	0	0	1	4	10	33	29	19	18	8	9	4	3	0	1	0	0
47	3	25	49	78	123	115	114	83	62	38	34	26	34	22	25	34	26	75
48	0	0	1	1	5	12	12	17	29	22	18	17	8	10	3	3	5	10
49*	0	0	0	1	20	28	26	25	32	39	36	65	48	66	69	86	56	138
50*	0	0	0	0	17	22	31	25	33	18	16	32	35	37	43	45	36	95
51*	0	0	0	0	36	54	68	59	49	57	67	76	63	52	47	35	27	51
52*	0	0	0	0	38	37	36	33	31	21	15	24	22	35	34	34	28	121
53*	0	0	0	0	24	43	44	55	51	66	75	109	85	94	88	55	51	119
54	0	0	0	0	95	233	254	310	278	201	117	98	89	79	48	41	39	80
55	0	0	0	0	32	48	82	113	120	113	141	110	100	85	81	68	67	177
56	0	0	0	0	125	188	219	167	132	91	88	56	40	46	41	38	25	144
57	0	0	0	0	153	324	476	547	347	204	77	61	45	44	42	33	30	152
58	0	0	0	0	18	59	60	51	33	23	20	26	12	22	17	15	15	21
59	0	0	0	0	69	174	167	125	78	48	37	29	29	22	22	19	22	60
60*	0	0	0	3	27	57	48	57	49	53	49	67	68	81	84	104	84	411

* Area 3 experiment.

characteristic of the gear rather than the fish but the above differences could not be attributed to gear diversities.

To determine the amount of bias that might result from the inclusion of incompletely recruited individuals in the data used to estimate q and Z, four experiments were analyzed with and without pre-recruits. The following table summarizes the result of this comparison:

	Without Pre-recruits		With Pre-recruits	
Experiment	q	Z	q	Z
30	0.012	0.48	0.011	0.50
31	0.019	0.39	0.018	0.40
44	0.045	0.61	0.044	0.61
54	0.030	0.57	0.030	0.58

The changes in q and Z resulting from inclusion of all pre-recruits are small and may even result from changes in sample size. Thus it is concluded that for halibut the determination of the point of full recruitment is not a critical matter in the estimation of q and Z.

The mean time of tagging, the minimum size of full recruitment and the number of fully recruited fish tagged are given for each experiment in Table 3.

Zero-year recoveries must be omitted from mortality calculations because the availability of tagged halibut in that year is frequently atypical of subsequent years. Occasionally this condition carries over to the first full recovery year. At least two

Table 3. Mean time of tagging, size at full recruitment and number of fully recruited fish tagged in each experiment.

Experiment number	Mean tagging time	Size at full recruitment (cm)	Number of fully recruited fish tagged	Experiment number	Mean tagging time	Size at full recruitment (cm)	Number of fully recruited fish tagged
1	.55	60	285	31*	.60	80	1238
2	.53	60	221	32	.69	75	1352
3	.46	60	513	33	.67	75	162
4	.61	60	94	34	.75	75	2184
5	.46	60	1200	35	.26	75	598
6	.54	60	180	36	.32	75	355
7	.58	60	856	37*	.38	80	642
8*	.92	65	1715	38*	.40	80	262
9*	.87	65	1010	39	.48	75	631
10*	.94	65	1299	40	.51	75	661
11*	.34	65	745	41	.30	75	561
12	.18	65	407	42	.36	75	567
13*	.04	70	305	43	.37	75	751
14*	.95	70	188	44	.48	75	1977
15*	.96	70	220	45	.44	75	152
16	.42	70	333	46	.54	75	124
17	.41	70	168	47	.48	75	568
18	.38	70	305	48	.50	75	154
19	.01	70	813	49*	.37	80	660
20	.91	70	319	50*	.40	80	415
21	.41	70	1183	51*	.46	80	583
22	.45	70	115	52*	.51	80	398
23	.45	70	279	53*	.64	80	848
24	.47	70	217	54	.56	75	1634
25*	.60	70	1037	55	.60	75	1257
26	.67	70	997	56	.63	75	1087
27*	.67	70	976	57	.67	75	2058
28	.72	70	278	58	.71	75	315
29	.20	75	1290	59	.74	75	658
30*	.56	75	923	60*	.89	80	1107

* Area 3 experiment.

reasons for this difference are known at present. First, some or all of the zero-year fishing effort may have been expended before the tagged fish were released. Second, tagged halibut appear to be relatively unavailable to the fishery for up to 3 months after tagging. This phenomenon is illustrated by experiments 17 and 18 which were conducted on the Goose Islands grounds in May of 1935 and 1936 respectively. The increasing availability of these tagged fish, as shown by the number of recoveries taken per thousand skates of gear fished, is shown in the following table.

	Experiment 17			Experiment 18		
Months after tagging	Number recovered	Gear fished (1000 skates)	Recoveries per 1000 skates	Number recovered	Gear fished (1000 skates)	Recoveries per 1000 skates
0	0	12.5	0.0	0	11.4	0.0
1	6	11.0	0.5	2	9.1	0.2
2	7	8.2	0.8	11	14.0	0.8
3	12	8.2	1.5	9	4.9	1.8
4	5	2.9	1.7	—	—	—

Elimination of zero-year recoveries poses no particular problem in the estimation of catchability by the linear regression method. However, if the expected number of recoveries based on the survival slope were not taken by fishing in the zero-year, as was usually the case, the number of tagged fish surviving to the start of the first recovery year would be greater than expected and a positive bias in the catchability estimate would result. An iterative process is used to calculate the effective number of fish tagged in the experiment which is the number that would have had to have been released to obtain the number of recoveries per unit effort in years one and following if zero-year recoveries had been a uniform part of that series. Three steps in the iterative process were usually sufficient to obtain successive estimates within one fish of each other.

Recoveries by trawl net gear are excluded because fishing for halibut by trawl net is prohibited by the Commission's regulations. Hence, in this analysis the tagged and untagged populations are presumed to suffer no trawl net fishing mortality. Trawl fishermen are encouraged to turn in tagged fish but since these are excluded from the analysis, recovery of tagged fish by trawlers will appear as a component of the disappearance rate and not as fishing mortality.

The distribution of recoveries by statistical area and year of recovery is given in Table 4. Recoveries from statistical areas below area 9 are shown in the table but excluded from the totals and from the analyses. In each experiment recoveries such as those in the zero year which were not used in calculating the regression line are separated from all others by a horizontal line but are included in the totals. Also for each experiment bold type is used to indicate recoveries in the statistical area or areas of tagging.

The calculated number of standard skates* of setline gear fished in statistcial areas 9 to 36 for the years 1926-1963 is given in Table 5. These data were calculated by dividing the total catch by the average catch per skate for each area in each year. The average catch per skate was obtained from fishing records made available to the Commission by operators of the individual fishing vessels.

---

*The unit of fishing effort in the Pacific halibut fishery is called a skate. The standard skate as defined by the Commission consists of 300 fathoms (1800) feet of groundline with 120 hooks spaced at equal intervals.

Table 4. Distribution of recoveries by statistical area and year of recovery.

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total 9-36
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
1	0				1	**1**	**4**	1																							7
	1	2	1	1	6		**38**	4	3																						53
	2	1		1	2	**4**	**17**	1	1		1																				27
	3		1			**2**	**3**																								6
	4					**2**	**3**	2	1																						8
	5						**1**																								1
	6						**1**																								1
	7						**1**																								1
Total		3	2	2	9	**9**	**68**	8	5		1																				104
2	0			1	**8**																										9
	1		1	2	**36**	3	1																								43
	2	1		2	**12**	5																									19
	3				**6**	1																									7
	4					1																									1
	5				**1**	1																									2
	6				**1**																										1
Total		1	1	5	**64**	11	1																								82
3	0						**42**	6	1																						49
	1	2				2	**90**	8	4	1	1																				106
	2	3				1	**29**	1	2																						33
	3	1			1		**11**																								12
	4						**4**																								4
	5						**1**																								1
	6						**1**																								1
Total		6			1	3	**178**	15	7	1	1																				206
4	0						1																								1
	1				1				**26**																						27
	2						1		**9**																						10
	3								**3**																						3
	4								**2**																						2
Total					1		2		**40**																						43
5	0		2	**156**	3		1																								162
	1		6	**267**	5	1		1	2																						282
	2	1	6	**128**	3																										137
	3	1	3	**64**	2		1			1																					71
	4	1	1	**8**																											9
	5			**8**					1																						9
	6			**5**																											5
Total		3	18	**636**	13	1	2	1	3	1																					675
6	0						**11**																								11
	1		2		1	1	**28**																								32
	2	1	1				**8**	1		1																					11
	3		1	1			**3**																								5
	4						**1**																								1
Total		1	4	1	1	1	**51**	1		1																					60

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	9-36
7	0								**29**	1																					30
	1	1		2				1	**153**	1																					157
	2	2	1	1	1	1	4		**23**	4																					35
	3					1		1	**38**	3		1																			44
	4			1			1		**12**																						14
	5								**1**			1																			2
	6		1																												1
	7								**1**																						1
Total		3	2	4	1	2	5	2	**257**	9		2																			284
8	0																														0
	1	2		1	2		5	1	3	1	1		13	**29**	1	17	3	10	11	7	6	7	4	3	4	6					135
	2		2				1			2		2	10	**17**	6	1	3	1	12	5	4	8	4	3		1	1	1			84
	3								1				4	**6**	4	2	3	5	9	10	4	1	8	3		2					62
	4			1									8	**4**	2	2		3	6	1	1	3	2		2	2					37
	5						1			1			4	**4**		1		2	2			1	2	5	1	1		1	2	1	29
	6													**1**	1			1			1	1	2								7
	7												1	**2**	1			1		1					1	1					8
	8													**1**						1		1	1								4
	9																		1				1								2
	10													**1**								1	2								4
	11																							1							1
Total		2	2	2	2		7	1	4	4	1	2	40	**65**	15	23	9	23	41	25	16	23	26	15	8	13	1	2	2	1	373
9	0																														0
	1						1				1				1	1			**44**	20	6	8	1	3		3		1			90
	2		1								1				1	2	1	5	**18**	12	7	4	8	4	1	3					68
	3			2										1			1		**10**	4	2	1	2	5	1				1	2	32
	4																		**4**	2	1	2	2	1					2		14
	5																		**3**		1		3								7
	6							1											**4**	2	2	1	2								12
	7																		**2**	2											4
	8																	1		1		1			1						4
	9																		**1**			1									2
	10																						1								1
Total			1	2			1	1			2			1	2	3	2	6	**86**	43	19	18	19	13	3	6		1	3	2	234
10	0																														0
	1	1					1			2			1	2	3	**10**	2	8	19	20	12	9	1	3	1	2	1				97
	2											1		4	1	**10**	1	7	18	11	4	6	6	12	3	2					86
	3		1								1				1	**5**	1	6	7	6	3	4	8	9	2	2			1		57
	4											1			1	**1**	1	1	1		1	1	1	4	1						14
	5																1	1	2				2	1							7
	6															**2**		1	4	1	1	1									10
	7																					1		2							3
	8																1		1		1		1								4
	9																						2								2
Total		1	1				1			2	1	2	1	6	6	**28**	7	24	52	38	22	22	21	31	7	6	1		1		280

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	9-36
11	0													1				1			1		1	2	1	**30**	1	1			39
	1													2			1					1	1	7	5	**12**			1		30
	2											1				1			1			1	3	3	6	**4**		1		1	22
	3			1				1		2		1	1							1	2	1	1	3		**3**					17
	4			1								1	1									1	2	1							7
	5						1		1			1		1						1			1			**2**					8
	6																	1	1	1						**3**					6
	7																						1		2						3
	8																				1										1
	9																							1	1						2
Total				2			1	1	1	2		4	2	4		1	1	2	2	3	4	4	10	17	15	**54**	1	2	1	1	135
12	0	1	4	18	**35**	6		1																							64
	1	3		8	**38**	2	1																								49
	2				**36**	2																									38
	3			1	**12**																										13
	4		1	1	**5**	2																									9
	5		1		**1**																										2
	6			1	**1**																										2
	7				**1**																										1
Total		4	6	29	**129**	12	1	1																							178
13	0											1		**2**	**1**	**3**	1		4	2	1	1	1	1							18
	1							1						**2**		**1**			4					1							9
	2	1										1	1	**1**				1	1			1									6
	3															**1**			1												2
	4																		2												2
	5															**1**			1												2
Total		1						1				2	1	**5**	**1**	**6**	1	1	13	2	1	2	1	2							39
14	0																														0
	1						1											**1**	**3**	2	2		1								10
	2																		**2**												2
	3																			2			1								3
	4																	**1**	**1**						1						3
Total							1											**2**	**6**	4	2		2		1						18
15	0																														0
	1																1		2			1	1								5
	2																1	1			1	2									5
	3															**1**		1	2		1										5
	4																				1		1								2
	5													1					1												2
	6																		1												1
	7																			1											1
Total														1		**1**	2	2	6	1	3	3	2								21

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	9-36
16	0		2	**30**									1																		33
	1	2	9	**34**	1	1																									45
	2		2	**26**	2																										30
	3	1	2	**24**																											26
	4	1	1	**18**			1																								20
	5		1	**7**	1	1																									10
	6			**8**		1																									9
	7			**4**			1																								5
	8				1																										1
	9			**1**																											1
Total		4	17	**152**	5	3	2						1																		180
17	0	1	**4**	1																											5
	1		**21**	3																											24
	2		**11**	2	1																										14
	3		**10**	1																											11
	4		**1**	2											1																4
	5	1	**3**		1																										4
	6		**4**																												4
Total		2	**54**	9	2										1																66
18	0		2	**15**																											17
	1	1	9	**34**	2		1																								46
	2		8	**13**		1																									22
	3		4	**13**		1				1																					19
	4		1	**7**			1			1																					10
	5			**3**																											3
	6			**1**																											1
	7				1																										1
	8			**1**																											1
Total		1	24	**87**	3	2	2			2																					120
19	0	6	14	16	**23**	5	2																								60
	1	1	10	19	**17**	5						1																			52
	2	1	8	11	**8**	4																									31
	3	2	1	4	**3**	4	1	1																							14
	4	1		1	**2**																										3
	5		1			1	1																								3
	6			1	**2**																										3
	7			1								1																			2
Total		11	34	53	**55**	19	4	1				2																			168
20	0																														0
	1		1	1		2	3	2	3	**8**	**1**																				21
	2				1				4	**2**																					7
	3		1		1		2		2	**1**																					7
	4						1			**1**																					2
	5			1						**2**																					3
	6									**1**																					1
	7								1	**1**																					2
Total			2	2	2	2	6	2	10	**16**	**1**																				43

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	9-36
21	0			**14**																											14
	1	1	3	**154**						1																					158
	2	1	2	**64**		1																									67
	3		1	**27**																											28
	4			**13**																											13
	5		1	**3**			1																								5
	6			**5**										1																	6
	7			**9**																											9
	8			**3**	1																										4
Total		2	7	**292**	1	1	1			1				1																	304
22	0																														0
	1						**13**																								13
	2					2	**5**																								7
	3						**1**																								1
	4						**2**																								2
Total						2	**21**																								23
23	0																														0
	1	2	1		1	1	**10**																								13
	2	1					**11**			1																					12
	3						**5**																								5
	4						**10**																								10
	5						**6**																								6
	6						**1**																								1
Total		3	1		1	1	**43**			1																					47
24	0																														0
	1		**27**	4																											31
	2		**7**	3																											10
	3		**3**																												3
	4		**2**																												2
Total			**39**	7																											46
25	0																														0
	1																		5	**19**	2		1								27
	2														1		1			**5**	3										10
	3																		2	**12**	1										15
	4																		2	**4**											6
	5																1	2	1	**2**											6
	6																		2	**3**											5
	7																				1										1
	8																		1	**2**											3
	9																			**2**		1									3
Total															1		2	2	13	**49**	7	1	1								76

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total 9-36
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
26	0																														0
	1					9	**84**	1		1																					95
	2	1				6	**76**	1																							83
	3				2	4	**38**																								44
	4					1	**17**			1																					19
	5					1	**6**																								7
	6						**3**																								3
Total		1			2	21	**224**	2		2																					251
27	0																														0
	1										1								1	1		**10**	**7**	1							21
	2						1	1						1	1							**9**	**4**								17
	3															1			1			**2**							1		5
	4																			1		**1**	**2**								4
	5																					**4**	**1**								5
	6														1					1			**2**	1							5
	7														1							**1**	**1**								3
	8																					**1**									1
Total							1	1			1			1	3	1			2	3		**28**	**17**	2					1		61
28	0																														0
	1	1	2	**7**																											9
	2	1		**22**																											22
	3			**13**		1																									14
	4			**11**			1																								12
	5			**6**																1											7
	6		1																												1
Total		2	3	**59**		1	1													1											65
29	0										**27**	**47**																			74
	1									1	**10**	**63**						1													75
	2										**6**	**31**																			37
	3									2	**12**	**19**																			33
	4										**8**	**14**																			22
	5										**3**	**10**																			13
	6										**4**	**3**																			7
	7										**1**	**2**																			3
	8										**2**																				2
Total										3	**73**	**189**						1													266
30	0																														0
	1	1													1			2	3	4	**2**	**12**	**6**	1							31
	2	1			1		1											2		1		**3**	**2**								10
	3	1									1						1			1	**2**	**4**	**1**								10
	4																			1	**1**	**2**	**1**								5
	5																					**1**									1
	6																			1	**1**		**1**								3
	7																				**1**	**1**	**1**								3
Total		3			1		1				1				1		1	4	3	8	**7**	**23**	**12**	1							63

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total 9-36
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
31	0																														0
	1	2				1	2		1			2	4	**29**	**56**	5	4	1	3												108
	2	1	1				1			1	1	2	1	**41**	**30**		3		1												82
	3	1	1	2	2					1	1	1	6	**27**	**30**	1	1			1											74
	4											1	2	**10**	**6**					3											22
	5									1		1		**11**	**2**																15
	6											1	1	**1**	**8**	1															12
	7												1	**4**																	5
	8													**1**																	1
	9													**1**																	1
	10													**2**																	2
Total		4	2	2	2	1	3		1	3	2	8	15	**127**	**132**	7	8	1	4	4											322
32	0																														0
	1				2	8	**252**	2		2																					266
	2				1	11	**173**		1	1																					187
	3			2	1	4	**66**	1																							74
	4					2	**23**	1																							26
	5					2	**12**																								14
	6						**6**																								6
	7						**1**	1																							2
Total				2	4	27	**533**	5	1	3																					575
33	0																														0
	1				**7**				1																						8
	2			1	**9**																										10
	3		1		**7**																										8
	4				**2**	2																									4
	5				**1**	1																									2
	6				**2**																										2
	7				**1**																										1
Total			1	1	**29**	3			1																						35
34	0																														0
	1	1	2	**54**		1	2																								59
	2	2	1	**221**	4	1								1																	228
	3	1	2	**226**		1						1																			230
	4		1	**81**			3																								85
	5	2		**40**	1		1											1													43
	6	1	1	**10**										1																	12
	7		1	**4**	2							1																			8
	8			**3**	1																										4
	9			**1**																											1
	10			**1**																											1
	11			**1**																											1
Total		7	8	**642**	8	3	6					2		2				1													672

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total 9-36
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
35	0	1	**1**	2		1																									4
	1	1	**14**	3	2																										19
	2		**18**	6	1																										25
	3		**10**	1																											11
	4		**6**	2	1																										9
	5		**2**																												2
	6		**4**	1																											5
	7		**1**																												1
Total		2	**56**	15	4	1																									76
36	0						**36**	1																							37
	1		1	1		2	**58**																								62
	2					2	**14**																								16
	3					2	**4**																								6
	4						**1**																								1
	5						**1**																								1
	6									1																					1
Total			1	1		6	**114**	1		1																					124
37	0																		**3**	**1**											4
	1																	5	**13**	**5**		1									24
	2			1														1	**7**	**6**		1									16
	3																		**10**	**4**											14
	4													1					**4**	**2**											7
	5															1			**4**												5
	6																		**3**	**1**											4
	7																		**5**												5
Total				1										1		1		6	**49**	**19**		2									79
38	0																				**1**										1
	1																			2	**5**										7
	2																			1	**2**	1									4
	3																				**4**	2									6
Total																				3	**12**	3									18
39	0				**23**	1																									24
	1				**40**	3	3																								46
	2		1	1	**24**	1	1																								28
	3				**18**																										18
	4				**7**		1																								8
	5			1	**6**																										7
	6				**2**																										2
	7				**3**		1																								4
	8				**5**																										5
	9				**3**																										3
	10				**4**																										4
Total			1	2	**135**	5	6																								149

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	9-36
40	0																														0
	1		1			5	**90**		1																						97
	2					5	**57**																								62
	3				2		**21**																								23
	4						**12**																								12
	5						**8**																								8
	6					1	**8**																								9
	7						**3**																								3
	8		1																												1
	9						**1**																								1
Total			2		2	11	**200**		1																						216
41	0			1	2	1	**26**	1																							31
	1	2	1	3	5	3	**43**																								55
	2			2		1	**19**																								22
	3	1					**16**		1	1																					18
	4					1	**3**	2		1																					7
	5				1		**3**	1																							5
	6						**2**																								2
	7						**2**																								2
	8				1	1	**3**																								5
	9						**1**																								1
	10						**1**																								1
Total		3	1	6	9	7	**119**	4	1	2																					149
42	0				1		**56**																								57
	1				1	2	**118**	1																							122
	2					2	**33**																								35
	3						**19**																								19
	4				1		**11**																								12
	5						**4**																								4
	6						**1**																								1
Total					3	4	**242**	1																							250
43	0				5	**12**	6																								23
	1	1			12	**50**	12																								74
	2				2	**26**	7																								35
	3				2	**25**	3																								30
	4				2	**9**	6																								17
	5				2	**2**	5																								9
	6				1	**3**	1																								5
	7			1	2																										3
	8				1	**2**	1																								4
	9				1																										1
Total		1		1	30	**129**	41																								201

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	9-36
44	0				**24**				1																						25
	1		1	4	**214**	38	17		1																						275
	2			3	**63**	15	1																								82
	3			4	**53**	18	2					1																			78
	4				**57**	8	4																								69
	5				**35**	6	2																								43
	6				**14**	1																									15
	7				**6**																										6
	8				**2**																										2
	9				**3**	1																									4
	10			1	**2**	1																									4
Total			1	12	**473**	88	26		2			1																			603
45	0																														0
	1		1	**31**			1																								33
	2			**15**																											15
	3			**4**																											4
	4			**2**																											2
	5			**2**																											2
	6			**1**																											1
Total			1	**55**			1																								57
46	0																														0
	1		**15**	2																											17
	2		**9**	2																											11
	3		**2**	2																											4
	4		**1**																												1
	5		**1**	1																											2
	6		**1**																												1
Total			**29**	7																											36
47	0								**5**																						5
	1								**14**	2	1																				17
	2								**13**		1																				14
	3								**3**		1																				4
	4								**2**	1																					3
	5								**3**	1																					4
	6					1			**1**			1																			3
	7									1																					1
	8								**2**																						2
	9						1																								1
Total						1	1		**43**	5	3	1																			54
48	0						**1**																								1
	1						**30**																								30
	2		1				**15**		1																						17
	3						**4**																								4
	4						**4**																								4
	5						**1**																								1
Total			1				**55**		1																						57

Table 4.—(continued).

Experiment Number	Recovery Year	>9	STATISTICAL AREA																												Total
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	9-36
49	0																	4	**15**	8		3									30
	1			1				1				1					1	3	**23**			2									32
	2																	5	**8**	1			1								15
	3																	1	**17**	1											19
	4																		**5**	3											8
	5													1					**12**												13
	6																		**1**	1											2
	7																		**1**												1
	8						1																								1
Total				1			1	1				1		1			1	13	**82**	14		5	1								121
50	0																				1	**3**						1			5
	1																				1	**3**		1							5
	2										1						1			1		**3**									6
	3																					**4**	2								6
	4										1								1			**4**									6
	5																					**1**									1
	6																					**1**									1
Total											2						1		1	1	2	**19**	2	1				1			30
51	0												6	**15**	**1**				1												23
	1											1	4	**36**	**3**																44
	2													**33**	**1**				1												35
	3								1				1	**6**	**3**	1															12
	4													**5**	**3**																8
	5												2	**10**	**1**	2															15
	6												2	**1**																	3
	7						1								**1**				1												3
	8													**2**																	2
Total							1		1			1	15	**108**	**13**	3			3												145
52	0																		**1**	**1**											2
	1																	1	**16**	**1**											18
	2																		**2**												2
	3																		**2**	**2**											4
	4																		**1**	**1**											2
	5																		**4**	**1**		1									6
	6																		**1**												1
	7																		**3**												3
	8																		**1**												1
	9																		**1**												1
Total																		1	**32**	**6**		1									40

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	9-36
53	0														**1**																1
	1			1			1						2	**21**	**18**	2	2			1											48
	2										3			**31**	**8**	1															43
	3	1		1					1					**5**	**14**		3		1												25
	4										1			**13**	**4**	3		1	1												23
	5													**8**	**10**		1		2												21
	6													**3**	**4**				1												8
	7								1					**8**	**5**																14
	8													**1**	**1**																2
	9															1															1
Total		1		2			1		2		4		2	**90**	**65**	7	6	1	5	1											186
54	0		1	**17**																											18
	1	2	9	**320**	2		1												1												333
	2		2	**114**	2	1			1		1																				121
	3		4	**77**	1		2																								84
	4		1	**17**		1				1																					20
	5		1	**18**	1					1		1																			22
	6			**11**	1																										12
	7			**3**																											3
	8		2	**6**		1																									9
Total		2	20	**583**	7	3	3		1	2	1	1							1												622
55	0						**8**																								8
	1				1	12	**219**	1											1												234
	2		1	1		9	**91**	2								1					1										106
	3				1	1	**51**	1																							54
	4						**23**												1												24
	5						**11**																								11
	6						**3**																								3
	7						**6**																								6
	8						**2**																								2
	9						**1**																								1
Total			1	1	2	22	**415**	4								1			2		1										449
56	0								**1**																						1
	1			1			1	1	**26**	1	1																				31
	2								**36**	4		1																			41
	3							1	**53**																						54
	4					1		1	**9**																						11
	5								**19**	1																					20
	6								**12**																						12
	7								**4**																						4
	8								**4**																						4
Total				1		1	1	3	**164**	6	1	1																			178

Table 4.—(continued).

Experiment Number	Recovery Year	<9	STATISTICAL AREA																												Total
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	9-36
57	0																														0
	1					1	**98**		1																						100
	2					3	**198**	3	1																						205
	3		1			1	**217**	3				1																			223
	4						**16**	2																							18
	5						**13**																								13
	6						**4**	1	1																						6
	7						**6**																								6
	8						**1**						1																		2
Total			1			5	**553**	9	3			1	1																		573
58	0																														0
	1			1	**18**	**5**	3																								27
	2				**15**	**9**	2																								26
	3				**14**	**2**																									16
	4				**6**	**1**																									7
	5				**4**																										4
	6					**1**																									1
	7				**1**	**2**																									3
	8					**1**																									1
Total				1	**58**	**21**	5																								85
59	0																														0
	1		5	**70**																											75
	2		3	**41**																											44
	3	1	2	**16**																											18
	4		1	**9**	1																										11
	5		1	**4**	1	1	1																								8
	6			**2**																											2
	7											1																			1
	8		1																												1
Total		1	13	**142**	2	1	1					1																			160
60	0																														0
	1		1				1				1			**3**	**13**	**23**	3	1	1			3	1	1							52
	2											1	1		**1**	**12**	2	2	1	2		3									25
	3		1											**1**	**6**	**10**	2	1	2		1	1									25
	4										1				**10**	**9**	1	1		1		3		1		2					29
	5													**1**	**3**	**3**			2	1											10
	6						1								**2**	**2**	1		2												8
	7														**2**	**1**			1												4
Total			2				2				2	1	1	**5**	**37**	**60**	9	5	9	4	1	10	1	2		2					153

Table 5. Calculated number of standard skates fished in statistical areas 9 to 36 for the years 1926-1963.*

Year	Statistical Areas 9	10	11	12	13	14	15
1926	23373	63518	61541	37297	112783	21580	27611
1927	20008	62921	51887	33866	105470	22905	29795
1928	25381	65525	69320	41581	116038	26707	34707
1929	31814	74552	66435	40485	116448	40276	53069
1930	39021	76398	60225	43856	108292	39769	53295
1931	49105	88295	53470	38258	85282	34362	32280
1932	43251	76682	37268	26314	61988	22636	24679
1933	41143	55948	35765	26092	72773	21511	20242
1934	36170	49832	33504	37383	83398	19140	22745
1935	28111	48506	28982	27937	64715	17987	26752
1936	39083	52551	29975	30513	73463	24067	34494
1937	40662	43359	31742	36731	72218	24392	23226
1938	25236	53664	31915	25318	56373	17545	22778
1939	31973	87826	35597	37153	71140	14399	20795
1940	40010	71649	35152	40333	64402	18399	23463
1941	43247	65240	28104	25577	74845	20377	19497
1942	43848	62319	27000	22226	50603	15065	26107
1943	40930	57043	22476	22523	47982	12319	18711
1944	27318	44576	25108	20159	41514	15952	17914
1945	22109	45657	13256	27999	57828	13275	10589
1946	19941	41862	14740	35661	83974	14788	18977
1947	23832	39693	13492	29237	83555	12800	17943
1948	28031	40839	10304	27995	66522	12039	19394
1949	23964	35355	9021	32975	57790	11501	21988
1950	18636	29935	13867	46685	59424	8470	19094
1951	20102	42862	30125	39312	73768	14190	15331
1952	17585	28963	25039	34151	60368	18231	14464
1953	16517	22349	28967	31488	62048	12803	12992
1954	24178	44225	13163	24243	53593	8688	8931
1955	22607	45300	10638	14723	43218	6204	9600
1956	22044	40390	15333	21330	43810	11490	16836
1957	22398	30070	19994	27231	59005	14520	22200
1958	20133	26789	23256	18239	63705	17505	25548
1959	19130	24902	23686	19331	64743	14671	24451
1960	16900	31300	21716	13707	59594	9647	24114
1961	10842	29462	25066	18228	49998	13547	28016
1962	15637	21899	31124	18516	58945	17501	38173
1963	18207	23198	26347	18913	59551	18751	28816

*In calculating effort for 1926 to 1928, the total catch for groups of statistical areas was allocated to individual areas in accord with the average distribution in the 1929 to 1931 period.

Table 5.—(continued).

	Statistical Areas						
Year	16	17	18	19	20	21	22
1926	39693	16793	28225	12006	16904	10926	11029
1927	45254	18001	36337	18479	29282	16082	15317
1928	46144	17271	34428	19129	29216	21633	22693
1929	74221	29674	49066	16732	24380	16592	14753
1930	72769	25376	48722	19040	24789	15605	17291
1931	60920	17252	44555	18625	20291	13970	6647
1932	57172	25565	33317	14170	23903	11225	11777
1933	58162	23400	44610	19654	27485	10740	13398
1934	44353	16211	35489	20987	24020	12608	10261
1935	35496	10660	48541	26078	22064	7005	9840
1936	39352	20521	59129	20883	23355	11003	11591
1937	43732	18207	59591	11386	19269	9678	7828
1938	38556	15059	54002	13565	18143	9278	7511
1939	39057	17979	60003	9781	15749	8318	5500
1940	38887	24930	50716	16110	15669	8516	6014
1941	36064	18196	38862	23044	14419	5293	2112
1942	36474	19257	32442	15614	15203	5461	4506
1943	36961	18319	28481	6688	15847	5061	6496
1944	44873	25151	33714	4896	9770	5004	6270
1945	40267	27372	38215	4662	6392	2898	2060
1946	42767	26015	38049	10325	17252	5594	4014
1947	42190	21530	49800	25425	16298	5088	6243
1948	37972	20377	30348	14229	13948	6372	5606
1949	36079	19903	31241	9150	18007	8135	8859
1950	31308	14232	27900	8331	14976	9076	10631
1951	30295	13035	20447	6279	11715	10218	12539
1952	26352	15780	18962	11663	22824	11957	10775
1953	20937	15000	17007	11059	18072	7997	7862
1954	24406	16946	23421	11587	24717	6046	9229
1955	24465	13518	21175	13976	18581	5817	9364
1956	37347	20905	20545	9637	14318	6953	9668
1957	35846	20675	19447	10826	8295	5995	6287
1958	33117	17443	20019	10191	16444	6095	6727
1959	29800	21250	18204	8715	17323	6132	8788
1960	40533	24166	23110	6610	7006	6917	8118
1961	38870	24567	19959	6983	8714	5164	7860
1962	47982	27059	19814	9827	8531	5427	6475
1963	36781	24741	19315	6268	10682	6342	8389

Table 5.—(continued).

Year	Statistical Areas 23	24	25	26	27	28	29
1926	9593	25319	32778	35812	25800	48924	23982
1927	10894	24505	38454	37379	26333	42426	36626
1928	14548	24591	42097	47433	31661	48415	28037
1929	12296	30264	47210	47907	36127	56021	46507
1930	6970	32006	41432	47403	32154	49479	37107
1931	6455	12092	29365	27346	32628	30441	31058
1932	4327	14606	36770	28191	24660	26700	21742
1933	7424	18164	44867	32144	25255	24447	23202
1934	3937	12660	39384	27308	32859	26688	31485
1935	4283	11861	33307	21281	22787	24910	27982
1936	5453	15537	30358	21761	22967	21882	29925
1937	2846	11728	33871	15451	25507	21722	23931
1938	3521	13689	28882	16665	21870	20041	21420
1939	2904	10750	36323	21551	24946	16361	18004
1940	4160	17520	34579	32450	24148	18021	17303
1941	3243	16584	30469	27068	32113	18473	28411
1942	1825	13982	31357	25518	20629	23832	25679
1943	4388	13193	23118	31814	18149	27400	26505
1944	1449	11068	21740	27410	27661	21447	17570
1945	2896	10359	31091	40202	24079	23363	23846
1946	6085	12576	28309	47691	20958	20380	19145
1947	10296	15802	14897	35331	18091	19400	23738
1948	8224	15778	31589	38089	19050	24076	19800
1949	12894	15658	26404	39005	26705	31329	24722
1950	15635	16554	36244	42588	29052	30482	23501
1951	13869	13729	53330	26332	23308	20375	21560
1952	13286	19839	34907	34287	17973	20882	11546
1953	12410	15197	35086	25148	13956	15890	10283
1954	15618	18843	41490	42565	22473	20871	10471
1955	14331	17376	38724	35616	15132	19738	13856
1956	10775	19389	30373	34703	17550	18745	23853
1957	13027	14216	38744	29016	21154	25730	21001
1958	6469	12812	37009	29019	17704	25475	12469
1959	13031	16216	34145	21182	15097	15432	11131
1960	9256	17442	30608	20269	15546	19820	24643
1961	10620	12002	37182	27304	13403	22126	26494
1962	13588	20575	40958	32294	20585	27279	20842
1963	11411	17350	47052	34217	15737	23451	28013

Table 5.—(continued).

	Statistical Areas						
Year	30	31	32	33	34	35	36
1926	15922	3499	13177	1548	876	0	0
1927	22742	5683	15695	4224	803	0	0
1928	18758	3982	12809	1689	689	288	168
1929	29956	8219	23575	3516	973	0	0
1930	46818	8598	14286	1509	1670	6365	6460
1931	23444	3071	12471	1131	5869	10187	4974
1932	19216	2952	6302	678	3098	1473	0
1933	12324	2905	3849	268	310	858	0
1934	11032	2076	2124	0	0	0	0
1935	8136	742	1374	0	0	0	0
1936	14363	1296	1356	0	0	0	0
1937	8995	2834	2156	0	0	0	0
1938	8236	3882	2157	0	0	0	0
1939	9019	2703	1769	0	0	0	0
1940	7113	2225	3551	0	0	0	0
1941	8153	2615	2584	0	0	0	0
1942	6846	1743	195	0	0	0	0
1943	13846	4321	7652	0	0	0	0
1944	9521	4767	13289	0	370	0	0
1945	18287	4094	17140	2241	1816	0	0
1946	13974	8520	16000	2893	3490	985	0
1947	10490	4866	7224	1649	1833	655	0
1948	14202	4184	15827	1055	3845	1204	527
1949	19697	1077	16443	431	1917	575	260
1950	13412	2047	15150	1284	537	453	0
1951	7993	3275	7471	733	377	0	620
1952	5511	2041	3952	1047	3808	797	1773
1953	6165	1491	3656	127	3281	783	657
1954	9287	2562	2327	234	3035	448	117
1955	9242	8249	10136	919	255	232	0
1956	19334	9888	4430	0	0	0	0
1957	16437	9576	8162	1391	542	0	0
1958	8400	12255	16027	879	169	0	29
1959	8460	8282	27374	6059	6908	761	0
1960	18999	10557	24820	4699	6781	319	936
1961	24870	18101	13239	4776	1667	161	471
1962	33479	21786	14887	6662	4462	1867	4813
1963	30462	26564	17310	11037	2189	1552	3185

MORTALITY ESTIMATES

Estimates of the catchability coefficient per skate per square mile, the average gear density in skates per square mile, the average fishing mortality, the average total mortality and its variance are given for each experiment in Table 6. The average gear density is the arithmetic mean of the gear densities for the first three years of usable recoveries for each experiment. The average fishing mortality is the product of the catchability coefficient and the average gear density.

Verification of the above estimates is at least as important as their calculation. Lacking knowledge of the true values, a useful alternative is to test the estimates for characteristics to be expected from the parameters themselves. For example, if the disappearance component of total mortality is of the same magnitude for all experiments, total mortalities should vary between experiments in direct proportion with the fishing mortality rates. Hence, the expected relationship between fishing and total mortality would be a straight line with slope of unity and an intercept on the ordinate at a point which is an estimate of the average disappearance rate.

The data appear to describe the expected linear relationship as shown in Figure 2. The intercept of the fitted (solid) line is at 0.31 (95 percent confidence interval is $0.12<0.31<0.50$). The observed slope is 1.12 which is not significantly different from unit slope (broken line) with a P of 0.11 for the two-tailed test (95 percent confidence interval is $0.97<1.12<1.27$).

Since some tagging mortality and non-reporting loss of tags is expected and these losses would result in a slope greater than unity, a one-tailed test for slopes exceeding unity is probably more appropriate than the two-tailed or symmetrical test. The one-tailed test yields a P of 0.06 which indicates that the observed slope exceeds unity by an amount unlikely to have occurred by chance. Another possible explanation in addition to the aforementioned tagging mortality and non-reporting loss is a decrease in q with age of the fish which was observed in some Area 2 experiments and will be discussed below.

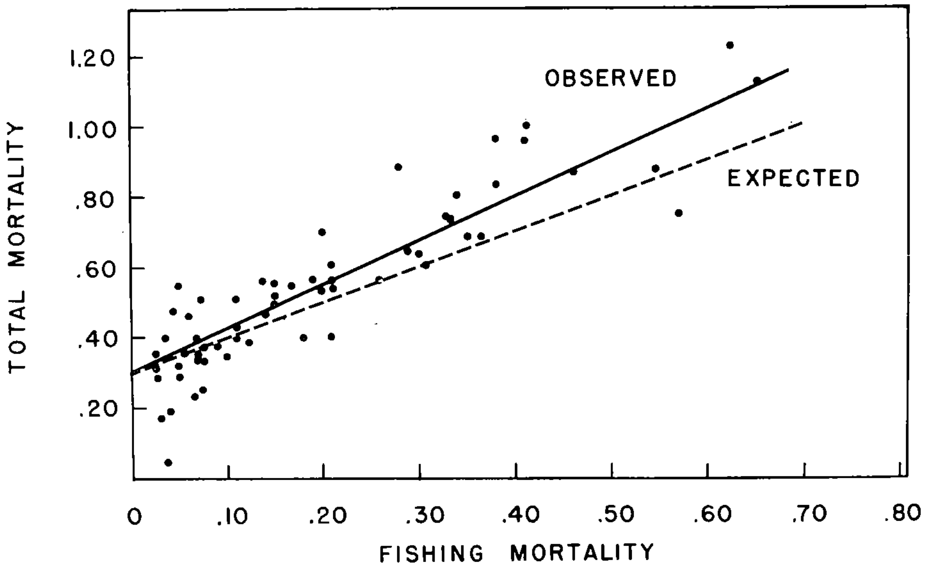

Figure 2. Expected and observed relationship between estimates of fishing and total mortality rate.

Table 6. Estimates of catchability, gear density, fishing mortality, total mortality and variance of total mortality for 60 tagging experiments.

Experiment Number	Catchability Coefficient (per skate/mi^2)	Average Gear Density (skates/mi^2)	Average Fishing Mortality	Total Mortality	
				Average	Variance
1	0.0154	21.43	0.331	0.747	0.0106
2	0.0212	17.76	0.376	0.839	0.0091
3	0.0240	25.95	0.624	1.228	0.0043
4	0.0647	9.99	0.647	1.125	0.0020
5	0.0349	15.82	0.552	0.883	0.0063
6	0.0149	25.44	0.378	0.959	0.0218
7	0.0357	11.56	0.413	1.003	0.0168
8*	0.0144	6.46	0.093	0.382	0.0016
9*	0.0175	6.23	0.109	0.403	0.0044
10*	0.0165	6.56	0.108	0.430	0,0014
11*	0.0150	2.72	0.041	0.186	0.0133
12	0.0294	10.08	0.296	0.643	0.0102
13*	0.0091	6.29	0.057	0.470	0.0142
14*	0.0076	5.02	0.038	0.044	0.1266
15*	0.0096	3.94	0.038	0.395	0.0046
16	0.0172	12.33	0.212	0.414	0.0009
17	0.0155	11.79	0.183	0.394	0.0051
18	0.0238	12.26	0.292	0.655	0.0019
19	0.0117	11.45	0.134	0.561	0.0047
20	0.0065	10.99	0.072	0.506	0.0107
21	0.0200	9.49	0.190	0.572	0.0042
22	0.0094	21.40	0.202	0.699	0.0487
23	0.0042	17.15	0.072	0.344	0.0103
24	0.0311	8.93	0.277	0.883	0.0049
25*	0.0056	4.85	0.027	0.293	0.0017
26	0.0081	20.67	0.167	0.548	0.0051
27*	0.0079	3.18	0.025	0.358	0.0016
28	0.0265	7.44	0.197	0.542	0.0100
29	0.0127	8.71	0.111	0.511	0.0009
30*	0.0122	3.55	0.044	0.482	0.0090
31*	0.0191	6.51	0.124	0.386	0.0050
32	0.0156	19.61	0.306	0.609	0.0037
33	0.0119	6.36	0.076	0.263	0.0148
34	0.0459	12.32	0.566	0.746	0.0010
35	0.0097	7.18	0.070	0.403	0.0061
36	0.0228	18.11	0.412	0.956	0.0113
37*	0.0094	5.77	0.054	0.358	0.0019
38*	0.0092	3.28	0.030	0.174	0.1941
39	0.0134	5.62	0.075	0.336	0.0033
40	0.0120	17.69	0.213	0.545	0.0017
41	0.0105	13.62	0.143	0.473	0.0041
42	0.0280	16.41	0.459	0.873	0.0030
43	0.0187	8.17	0.153	0.519	0.0012
44	0.0448	4.69	0.210	0.609	0.0014
45	0.0316	11.12	0.352	0.690	0.0085
46	0.0257	8.33	0.214	0.571	0.0089
47	0.0142	3.66	0.052	0.546	0.0075
48	0.0213	15.74	0.335	0.737	0.0374
49*	0.0114	6.45	0.074	0.376	0.0073
50*	0.0063	4.08	0.026	0.309	0.0080
51*	0.0175	5.66	0.099	0.348	0.0032
52*	0.0071	6.74	0.048	0.322	0.0076
53*	0.0131	5.04	0.066	0.231	0.0026
54	0.0300	8.74	0.262	0.572	0.0030
55	0.0218	15.69	0.342	0.813	0.0019
56	0.0094	7.57	0.071	0.351	0.0095
57	0.0183	19.94	0.365	0.691	0.0410
58	0.0221	6.86	0.152	0.498	0.0022
59	0.0180	8.53	0.153	0.548	0.0024
60*	0.0101	4.98	0.050	0.292	0.0061

* Area 3 experiments

The relationship between total mortality and fishing mortality was examined for Area 2 and Area 3 experiments separately to test the comparability of the data from the two areas. The resulting slopes were 1.03 and 0.88 respectively, neither of which were significantly different from unit slope. Thus the apparent difference from unit slope is obtained only with the combined data. It is concluded that total and fishing mortalities are linearly related as assumed in the model and that there is no statistically convincing evidence of non-reporting loss of tags in the available data.

The intercepts for the regression lines for the two areas taken separately were 0.34 and 0.30 respectively and these were not statistically different from each other or from the 0.31 obtained from the combined data. Thus the average disappearance of tags which includes natural mortality and shedding loss of tags is essentially the same in the two areas. The larger estimate of disappearance for Area 2 experiments could be attributed to trawl recoveries but there is no statistical justification to support this possibility. On the other hand these values appear large for a long-lived species, and they are larger than expected from previous estimates of natural mortality of 0.20 (IPHC, 1960) and shedding loss of 0.02 (Myhre, 1966).

REPRESENTATIVENESS OF ESTIMATES

Constant catchability is a key assumption in the foregoing analysis. This assumption is deemed satisfied within an experiment if some average catchability exists for all individuals for the duration of the experiment. It is not necessary that catchability be the same for all experiments, only that it be constant within experiments.

Evidence suggesting that catchability differs by size of fish was given by Thompson and Herrington (1930) and by Kask (1935) who showed that percentage recovery of tagged fish differs by size of the fish at the time of tagging. Further evidence of this difference was obtained from four large tagging experiments, two

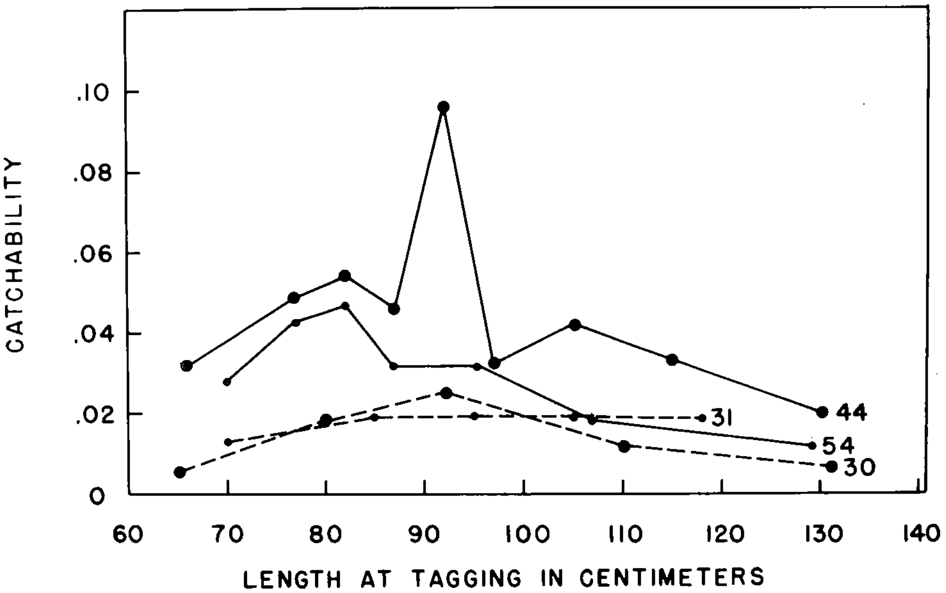

Figure 3. Relationship between estimate of catchability and length at tagging for Area 2 experiments (solid lines, experiments 44 and 54) and Area 3 experiments (broken lines, experiments 30 and 31).

from each of Areas 2 and 3. Each experiment was divided into groups of 200 to 400 individuals by length at tagging and catchability was then estimated for each group. The resulting estimates are plotted against the mean length for the group in Figure 3. The point plotted at 92 centimeters for experiment 44 is probably aberrant.

The two Area 2 experiments (44 and 54) show a declining trend in catchability with increase in size while the catchabilities for the Area 3 experiments (30 and 31) are fairly uniform with respect to size. In fact, there appears to be little difference in catchability between the 4 experiments for fish over 100 centimeters long at tagging. However, the modal size of Area 2 fish is usually about 80 centimeters long which may explain the higher catchability for Area 2 experiments. Still to be explained is the reason for the higher catchability of small fish in Area 2.

The difference in catchability between small and large fish in Area 2 suggests the possibility of a decrease in catchability for these fish as they grow to larger size. Such a change would result in an overestimation of both catchability and total mortality but the latter would be most affected. This type of error would reach important levels only in experiments in which small fish were a substantial proportion of the tagged sample and then only if small fish were substantially more catchable than larger fish in the same experiment. This type of error may have occurred in some of the experiments described above but it does not appear to be a serious problem.

Differences in catchability also occur between tagging locations as shown in Figure 4 which relates catchability to statistical area of tagging for the 60 experiments. Catchability is highest in the waters off British Columbia and declines to the north and west. This trend is consistent with the shift from smaller fish in Area 2 to larger fish in Area 3 but size does not appear to explain all of the difference. Also noteworthy is the greater range of catchabilities shown for the southern areas. This may indicate that the halibut in these areas are less uniformly distributed than are those in the western areas.

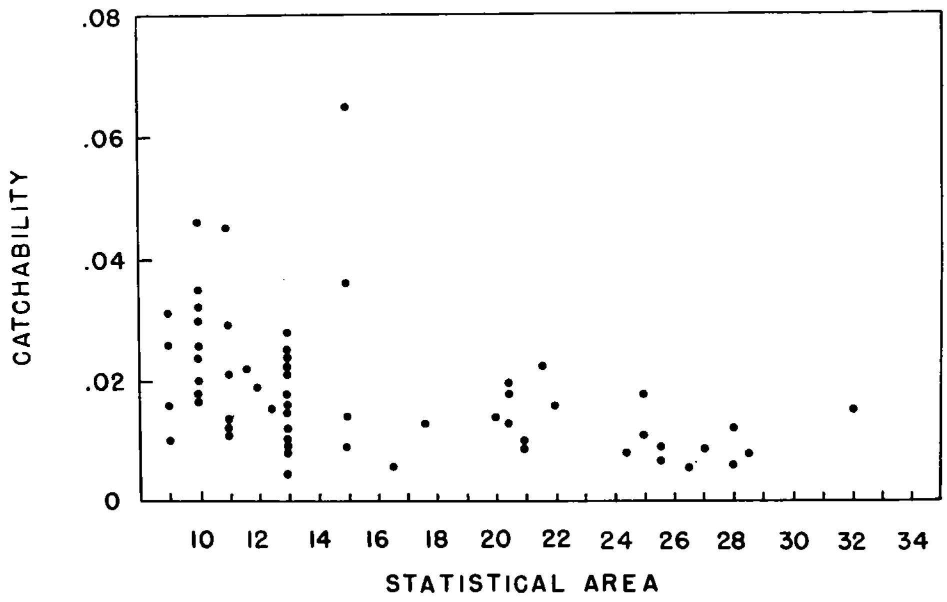

Figure 4. Relationship between estimates of catchability of halibut and statistical area of tagging.

The possibility of an historical change in catchability was tested using only experiments from statistical areas 9 to 13 (Table 1). These experiments were grouped into three 10-year periods starting with 1925. The mean catchabilities for the respective periods were 0.023, 0.017 and 0.021. The number of experiments in each group were 6, 4 and 25 respectively. Judging from the similarity of the group means and the variability of the individual estimates within each group the data provide no evidence of a change in catchability with time within the region tested.

From the above comparisons it is apparent that much of the difference in catchability between experiments is attributable to differences in the size of fish tagged and the tagging location. Such differences present no particular problem in estimating the fishing and total mortality experienced by a group of tagged fish. However, the projection of these estimates to a larger untagged population requires that the composition of the tagged and untagged population be the same. Although this requirement is probably reasonably well satisfied for most experiments described herein, it cannot be assured since the tagged individuals were not a deliberately stratified sample of the total population.

DISCUSSION

In past analyses, fishing mortality estimates from Area 3 tagging experiments were substantially lower than those from Area 2 experiments (IPHC, 1960). In the present analysis, Area 3 experiments not only exhibit lower fishing mortality estimates but there appears to be a declining trend in fishing mortalities from east to west as seen in Figure 5. This difference is difficult to reconcile with empirical evidence that the halibut stocks in both areas were producing yields at or close to their respective maximum sustained yield levels (IPHC, 1960; Chapman, Myhre and Southward, 1962). If the yield of halibut from Area 3 cannot be materially increased by increasing the fishing intensity then either the fishing mortality rates computed for the two areas

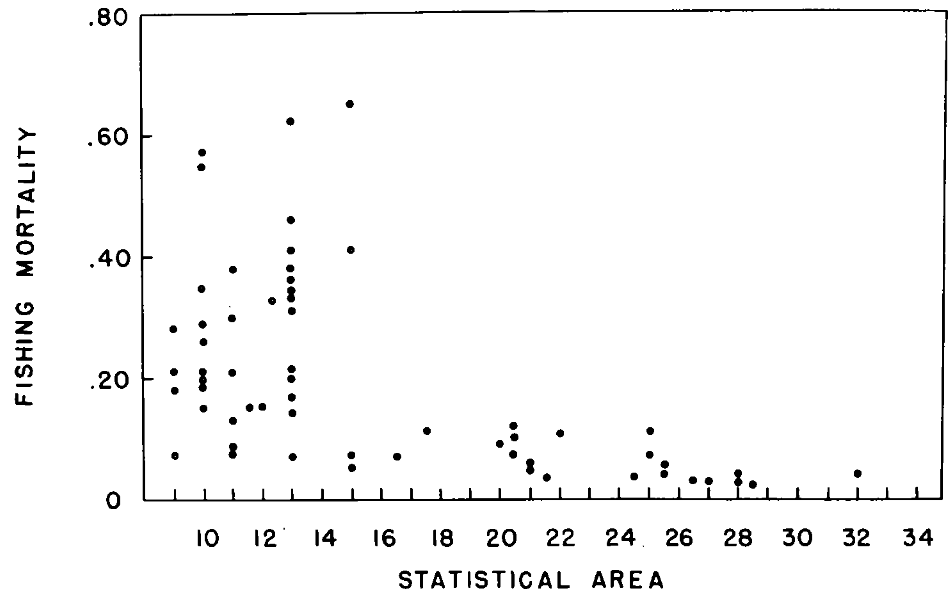

Figure 5. Relationship between estimates of fishing mortality and statistical area of tagging.

are not comparable or the productivity of halibut in Area 3 is less than in Area 2 or both.

Evidence suggesting a lack of comparability between Area 2 and Area 3 catchability estimates was noted above. First, the Area 2 catchabilities were greater than those for Area 3, particularly for the smaller fish which dominate the Area 2 catch. Secondly, the range of catchabilities for Area 2 experiments was substantially greater than those for Area 3. Such a wide range of catchabilities may indicate that the vulnerability of Area 2 halibut to fishing is markedly variable between fishing grounds. Since for most Area 2 experiments tagging and fishing tended to be concentrated on grounds where halibut are concentrated, the resulting estimates of catchability, may be too high for Area 2 halibut in general. Any such lack of comparability of catchability estimates for Areas 2 and 3 must be recognized in any comparison of the general level of utilization of the halibut of the two areas.

This is not to imply that the optimum level of fishing mortality must be equal in the two areas. Any difference in their level of productivity will result in differences in their optimum level of fishing mortality. The productivity of these areas depends upon the dynamic relationship between such population characteristics as growth, recruitment, migration, natural mortality and fishing mortality. Area 3 apparently had a growth rate lower than in Area 2 in the early years of the fishery (Thompson and Bell, 1934) but this does not appear to be the case in recent years (IPHC, 1960; Southward, 1967).

The migration of halibut from Area 3 to Area 2 exceeds that in the opposite direction as seen in Table 4 and as was reported by Thompson and Herrington (1930). As suggested by Dunlop, et al (1964), this net easterly migration would constitute a form of recruitment from western to eastern grounds. While such recruitment would contribute to the sustainable catch from the eastern grounds, it would result in a reduction in the sustainable catch from the western grounds. Further study of this problem is required to determine if the magnitude of the net contribution of halibut from western to eastern grounds is sufficient to influence the level of fishing mortality sustainable by the halibut of the two areas.

VARIANCES AND CONFIDENCE INTERVALS OF TOTAL MORTALITY ESTIMATES

The variance of a statistic provides valuable information on the amount of confidence which can be justifiably placed in that statistic. It is, therefore, a useful weighting factor when data of varying dependability are being analyzed.

Within each experiment the number of recoveries was expected to decrease from year to year in approximately the same manner as the number of tagged fish in the population. Thus it was expected that the reliability of the dependent variable in equation (6) would decrease with passage of time. The variance of the data for each year was not available so some alternative measure of reliability was required.

According to Chapman (1956) the variance of Ln (n_i/N_o) is approximately proportional to the reciprocal of n_i for $n_i > 10$. Thus, weighting the dependent variable by n_i is justified for large n_i. There remains the question of whether weighting by n_i gives too little weight to observations based on small n_i. To test the effect of more uniform weighting, total mortalities were recomputed while weighting observations by $\sqrt{n_i}$. The resulting variances of the total mortality estimates were 18 percent greater on the average than with weighting by n_i. From this it was concluded that weighting by n_i was justified.

The variances of the estimates of total mortality also provide a basis for deciding how the value of the tagging program can be maximized for the time and money invested. However, the standard deviation is more appropriate for consideration of confidence intervals than the variance.

The relationship between the number of fish tagged in each experiment and the standard deviation of the resulting estimates of total mortality is shown in Figure 6. An eye-fitted line was drawn through the data to reflect the general trend of the relationship. The broken segment on the left end of the line projects the anticipated relationship for small members of tagged fish.

The above relationship agrees in general with expectation based upon an equation for the large-sample variance of total mortality given by Chapman (1961). That equation is

$$V^2_{Z_i} = \frac{1}{n_i}[Z_i^{-2} - \triangle_i^2 e^{-Z_i\triangle_i}(1 - e^{-Z_i\triangle_i})^{-2}]^{-1} \qquad (8)$$

where $\triangle_i$ is the duration of the recovery period. Since, for a given experiment, n_i varies directly with the number tagged and $\triangle_i$ increases at a decreasing rate with increase in the number tagged, the variance is expected to decrease continuously with increase in releases. There is, therefore, no point at which additional tagging would fail to produce at least a proportionate decrease in the variance of the total mortality estimate.

The relationship between the standard deviation of the total mortality and numbers tagged will have a similar form except that the standard deviation does not decrease in inverse proportion to the numbers tagged. For example, an increase in numbers tagged from 200 to 1200 (a six-fold increase) results in approximately a 50 percent reduction in the observed standard deviation of the total mortality estimate.

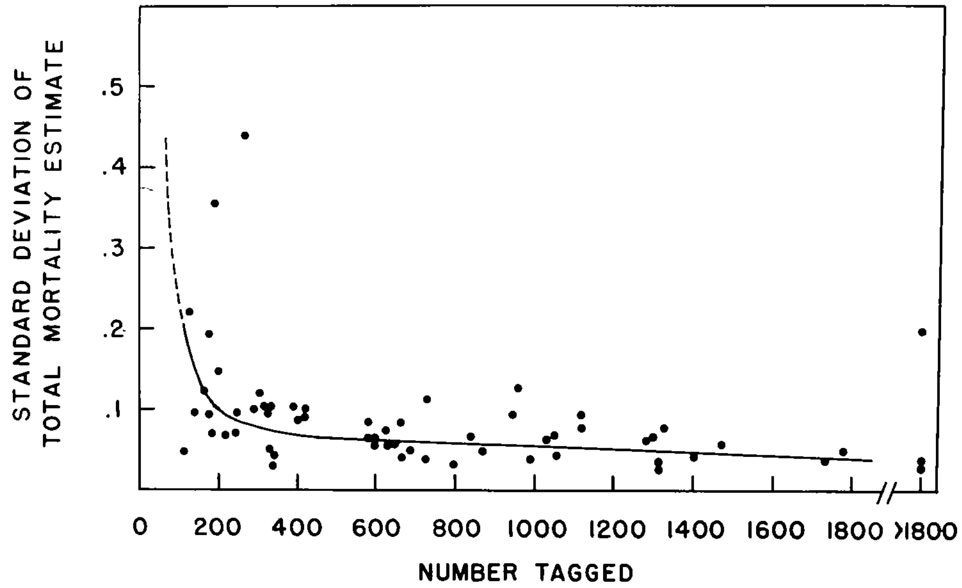

Figure 6. Observed relationship between the effective number of fish tagged and the standard deviation of the estimate of total mortality.

From the shape of the relationship in Figure 6 it is concluded that experiments involving fewer than 200 tags released are highly unreliable on the average and that the expense of releasing additional tags is well justified. On the other hand, the additional precision gained by tagging more than 400 fish in a single experiment is not justified unless either the additional tags can be released at little or no expense or a small percentage recovery is anticipated. Generally speaking, more information would be obtained if the tagging vessel would move to a new location and start a new experiment after releasing about 300 tags at one place. The average of several such estimates would provide more information than a single estimate derived from the same total number of releases.

Most of the cost of tagging halibut is fixed and, hence, independent of the number of fish tagged. Thus the cost per tagged fish will vary roughly in inverse proportion to the availability of taggable fish. From this standpoint the least expensive procedure would be to tag where halibut are concentrated.

On the other hand, "spot" or "cluster" tagging may lead to atypical mortality estimates since the commercial halibut fleet also tends to frequent locations where halibut are concentrated. This would be a serious problem except that halibut tend to disperse so the tagged members become distributed through the population. Also, the operator of the tagging vessel is not so enlightened as to invariably select fishing locations where halibut are concentrated.

Theoretically, the ideal tagging procedure is to distribute tagging effort over a predetermined grid of equally spaced stations, thus assuring the distribution of tagged members through the total population and hence the representativeness of the tagged members. Conceivably the quality of the data from grid tagging could more than warrant the added cost of the operation over that of spot tagging. At least this was the reasoning under which the Commission embarked on a program of grid tagging in 1963. Whether the value of the additional information provided by grid tagging will justify the additional cost remains to be seen.

SUMMARY

Sixty halibut tagging experiments conducted between 1925 and 1955 from Cape Scott, Vancouver Island, to Shumagin Islands, Alaska, were used to estimate fishing and total mortality for fully-recruited fish by the method of Gulland (1963). The slope of the regression line relating corresponding estimates of total and fishing mortality was found to be 1.12 which was not statistically different from the expected unit slope. The same relationship provided an estimate of 0.31 for all components of total mortality other than fishing. Similar results were obtained when the same analysis was conducted with Area 2 and Area 3 experiments separately.

Comparisons of catchabilities for halibut of different size at tagging indicated that halibut less than 100 centimeters long at tagging in Area 2 have a higher catchability than do the larger fish in that area and also higher than either large or small fish tagged in Area 3. Catchabilities for halibut tagged in British Columbia waters were higher than for those tagged to the north and west. Part of this difference may be due to the smaller average size of halibut in British Columbia waters.

Catchability estimates for that part of Area 2 lying between Vancouver Island and Dixon Entrance in British Columbia were tested for differences between 3 successive 10-year periods beginning with 1925. No evidence of a temporal change in catchability was found for this region.

Area 3 experiments yielded lower estimates of fishing mortality than did Area 2 experiments. Since other analyses have indicated that the halibut of both areas are being fished at or near their maximum sustained yield level, it is concluded that either the fishing mortality estimates lack comparability or the halibut of the two areas have different levels of productivity or both.

The variance and standard deviation of the total mortality estimates were related to the number of fish tagged. From the shape of this relationship it was concluded that a tagged sample of about 300 fish would usually produce estimates with acceptable variances. A larger sample size probably would not produce as much information as if the additional tagging effort was used in a new experiment at a different location.

LITERATURE CITED

Beverton, R. J. H. and S. J. Holt

1957 On the dynamics of exploited fish populations. Gr. Brit. Min. of Agric., Fish. and Food, Fish. Invest., Ser. II, Vol. 19: 533 pp., London.

Chapman, D. G.

1956 Estimating the parameters of a truncated gamma distribution. Ann. Math. Stat., Vol. 27 (2): 498-506.

1961 Statistical problems in dynamics of exploited fisheries populations. Proceedings of the Fourth Berkeley Symposium on Math. Stat. and Prob., Vol. 4: 153-168.

Chapman, D. G., R. J. Myhre and G. M. Southward

1962 Utilization of Pacific halibut stocks: Estimation of maximum sustainable yield, 1960. Int. Pac. Hal. Comm. Rept. (31): 35 pp., Seattle.

Dunlop, H. A., F. H. Bell, R. J. Myhre, W. H. Hardman and G. M. Southward

1964 Investigation, utilization and regulation of the halibut in southeastern Bering Sea. Int. Pac. Hal. Comm. Rept. (35): 72 pp., Seattle.

Graham, M.

1938 Rates of fishing and natural mortality from the data of marking experiments. Jour. Cons. Int. Expl. Mer., Vol. 13: 76-90.

Gulland, J. A.

1963 The estimation of fishing mortality from tagging experiments. Int. Comm. Northwest Atlant. Fish., Spec. Publ. (4): 218-227, Dartmouth.

International Pacific Halibut Commission

1960 Utilization of Pacific halibut stocks: Yield per recruitment. Int. Pac. Hal. Comm. Rept. (28): 52 pp., Seattle.

Kask, J. L.

1935 Studies in migration, fishing mortality and growth in length of the Pacific halibut *(Hippoglossus hippoglossus)* from marking experiments. Thesis, Univ. of Washington, Seattle.

Myhre, R. J.

1963 A study of errors inherent in tagging data on Pacific halibut *(Hippoglossus stenolepis)*. Int. Comm. Northwest Atlant. Fish., Spec. Publ. (4): 42-49, Dartmouth.

1966 Loss of tags from Pacific halibut as determined by double-tag experiments. Int. Pac. Hal. Comm. Rept. (41): 31 pp., Seattle.

Peltonen, G. J.

Ms. Viability of tagged halibut. To be published by International Pacific Halibut Commission, Seattle.

Ricker, W. E.

1958 Handbook of computations for biological statistics of fish populations. Fish Res. Bd. of Canada Bull. (119): 300 pp., Ottawa.

Southward, G. M.

1967 Growth of Pacific halibut. Int. Pac. Hal. Comm. Rept. (43): In press.

Thompson, W. F. and W. C. Herrington

1930 Life history of the Pacific halibut (1) Marking experiments. Int. Fish. Comm. Rept. (2): 137 pp., Seattle.

Thompson, W. F. and F. H. Bell

1934 Biological statistics of the Pacific halibut fishery. Int. Fish. Comm. Rept. (8): 49 pp., Seattle.