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LOSS OF TAGS FROM PACIFIC HALIBUT AS DETERMINED BY DOUBLE-TAG EXPERIMENTS

BY

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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 conventions which preceded it and specifically required that the stocks of halibut be developed to those levels which will permit the maximum sustainable yield and that they be maintained at those levels. These objectives require accurate knowledge of the effects of fishing upon the Pacific halibut.

This report presents estimates of tag loss from marked halibut and describes a method of estimation. With such estimates, fishing mortality rates obtained from tagging experiments can be made more accurate.

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Many 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 the fishing fleet and their crews in the tagging of fish at sea on chartered vessels and in the return of recaptured tags in the commercial fishery this work would not have been possible. The contributions of Douglas G. Chapman, University of Washington and Charles O. Junge, who aided in the development of the analytical methods, of K. W. Exelby who drew the line figures, of H. A. Dunlop who was Director of Investigations when the project was initiated and of F. Heward Bell the present Director are gratefully acknowledged.

INTRODUCTION

The International Pacific Halibut Commission, hereinafter called the Commission, employs tagging experiments to provide estimates of fishing and natural mortality rates. The value of the estimates is enhanced if allowance can be made for any loss of tags that may occur.

The measurement of tag loss is largely a mathematical problem involving a system of equations depicting how tags are believed to be lost. Usually such models are oversimplifications of the true relationships, yet they may still provide satisfactory estimates. Furthermore, as more is learned about the process of tag loss, the model can be improved so that in time tag loss can be estimated with an increasing degree of precision.

The experimental data, though limited, provide a basis for correction of mortality rate estimates for the loss of tags and serve as a preliminary test of the model itself.

EVIDENCE OF STRAP TAG LOSS

After examining and testing several alternative tags the Commission adopted the monel metal strap tag as its standard tag in 1925. These tags are attached to the gill cover or operculum on the eyed- or dark-side of the fish as shown in Figure 1. A more detailed description of the attachment of the tag is given in the section on method of tagging (p. 13).

When properly attached, the large and small strap tags embrace about 27 and 21 millimeters of opercular bone respectively. Some tags are found at recovery to have worked their way very close to the margin of the opercle with loss apparently imminent. Some fish are found with healed opercular wounds that could have been made by strap tags. Occasionally fishermen report that they recovered a tagged fish while on the fishing grounds, only to find that the tag is missing when the fish is unloaded and with only a fresh opercular wound as remaining evidence of the tag.

Corrosion does not appear to be an important cause of strap tag loss. Although about 6 percent of recovered tags show evidence of corrosion, only about one percent are so seriously corroded as to suggest impending loss or to render some of the digits in the tag number illegible.

Approximately 87 percent of recovered halibut tags are discovered by the fishermen while they are on the fishing grounds. The remainder are found while the fish are being unloaded or on the dock shortly thereafter. Strap tags have been placed on halibut in the holds of vessels that were unloading their catch. Approximately half of these marked fish were discovered during or after the unloading operation by fishermen and dockworkers who were unaware of the experiment, indicating that some strap tags are overlooked.

The above are some of the more noteworthy indications that strap tags are lost from marked halibut. These losses are classified as either shedding or nonreporting losses depending upon their functional relationship with time. Shedding losses are those that occur at some average rate so that their effect increases with the duration of the experiment. Nonreporting losses are those that occur only once regardless of the duration of the experiment.

METHODS USED TO MEASURE TAG LOSS

Direct observation of tag loss can be made in live-boxes or aquaria. This method has been applied with varying success to small pelagic species (Calhoun, Fry and Hughes, 1951; Calhoun, 1953; Nesbit, 1933; Janssen, 1939; Janssen and Aplin, 1945; Hart and Tester, 1937; Dahlgren, 1936, and others). This direct method will be most effective in measuring losses that occur soon after tagging because of the difficulties encountered in holding most fish for any protracted period of time. The method also has been criticized (Graham, 1929; Rounsefell, 1942) on the grounds that results may not be applicable to conditions in nature.

Experiments comparing alternative types of tags have been widely used (Rounsefell and Kask, 1945) to determine the one producing the highest recovery rate. They will not provide a measure of tag loss. Also, conclusions may be misleading if a higher recovery rate results because of a gear selectivity for one tag. As mentioned earlier, Thompson and Herrington (1930) tested alternative tags and

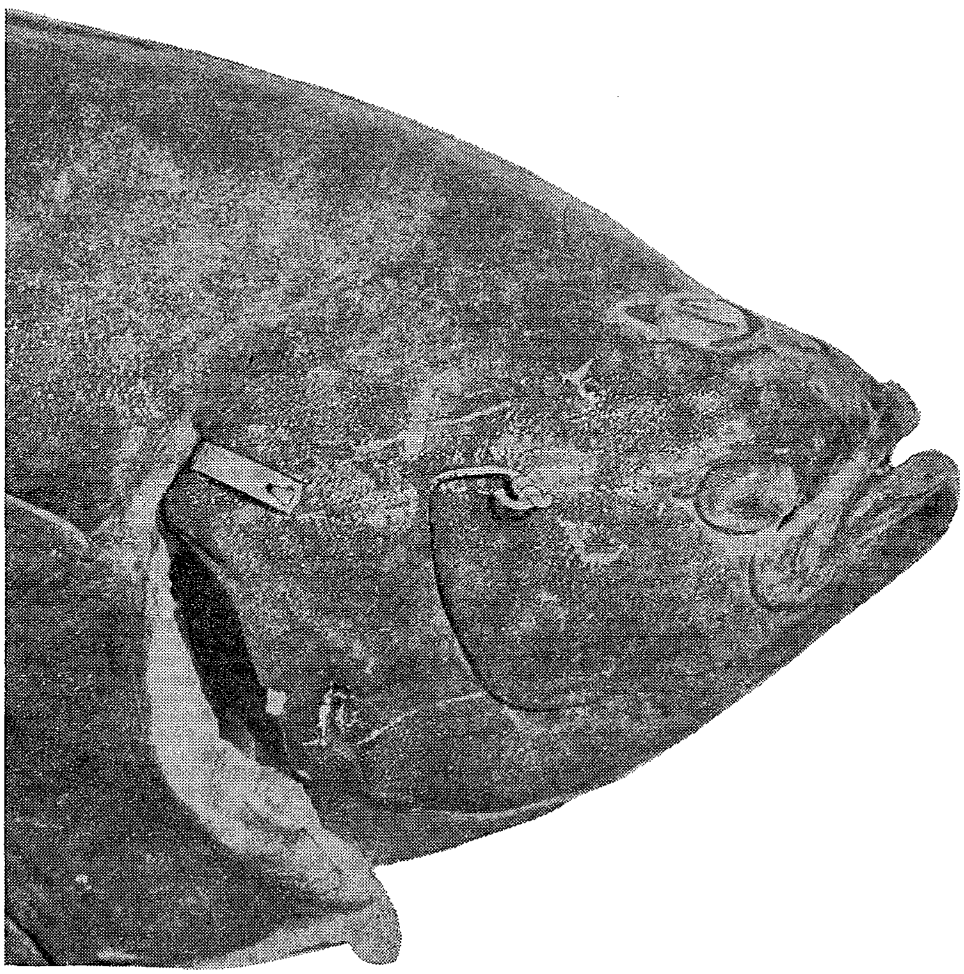

Figure 1. Double-tagged halibut showing the large strap tag attached to the opercular bone and a wire-spaghetti tag attached to the preopercular bone.

concluded that the monel metal strap tag was the more suitable one for marking halibut. The validity of their conclusion is supported by the analyses reported herein.

The overlooking of tags during the unloading process has been studied by planting tags in fish about to be unloaded (Hart, 1938; Shuman, 1939; Clark and Janssen, 1945). This method can provide valuable information about the loss of tags after the fish are recaptured but it cannot be used to measure losses that occur between the time of tagging and recapture.

A direct census method of detecting overlooked or non-reported tags was described by Paulik (1963). As with planted tags, the direct census method does not provide evidence of shedding loss. Such evidence could be obtained if the lost tags leave detectable scars as was suggested by Ricker (1948). Bevan (1959) found two red salmon with tag scars from a total recovery effort that produced 910 tags. Because the scars were too difficult to detect it was concluded that they were not a practical indicator of tag loss.

Double-tag experiments can provide estimates of both shedding and non-reporting loss of tags under actual conditions. This involves marking with two tags instead of the usual one. If tags are lost from these fish, recoveries will consist of a group of two-tag fish and two groups of one-tag fish (depending upon which tag is lost). A fourth group which will have lost both tags will not be recovered because of the lack of identifiable marks.

The first double-tag experiment by the Commission was conducted in 1929 by William C. Herrington. A strap tag was placed on the opercula of both the dark and white-sides of the fish. The results of this marking are described in this report.

Further double-marking experiments were conducted by the Commission in 1935 (Kask, 1935; British Columbia Fisheries Department, 1936). One group was released with a strap tag and a tattoo mark and another group was released with a strap tag and a body-cavity tag. Final results of the tattoo and body-cavity tag experiments are also presented in this report.

Myhre (1960) described a method for estimating losses of two kinds: shedding loss which occurs as a function of time and post-recapture loss which occurs only once, at recapture. The model used is described in detail in this report.

Double-tag experiments have also been used with other species to estimate tag loss. Beverton and Holt (1957) and Gulland (1963) used the same tag type for both marks on double-tagged plaice to estimate shedding loss which was assumed to be equal for both tags. A similar procedure was followed by Chapman, Fink and Bennett (1965) in experiments with yellowfin tuna except that single-tagged fish were released along with double-tagged ones. Scheffer (1950) and Roppel, Johnson and Chapman (1965) double-tagged fur seals using strap tags attached to a flipper and either a body brand or a hole punched in the web of a flipper. Robson and Regier (1966) used two different marks for double-tagging whitefish, a plastic streamer and a fin clip. The latter mark was assumed to be permanent.

Although the methods of analysis employed by the above authors are similar in principle, there are important differences because the assumptions used are not the same.

MODELS FOR MEASURING LOSS OF TAGS FROM HALIBUT

In the usual tagging experiment a group of fish are marked with an A tag and released. Some tags will be shed and some will be retained during a period of time, say one year. Each tagged fish may be regarded as a trial and shedding of the tag may be regarded as an event that is equally likely in each trial. If shedding is assumed to occur at some average rate ${}_{A}s$ during the first year, the proportion that will have shed tags and retained tags at the end of the year will be ${}_{A}s$ and $(1\text{-}{}_{A}s)$ respectively. The relative frequency at which A tags have been shed will be given by the proportion of the recaptured fish that have lost their tags, as given in the equation.

$$\frac{{}_{-A}n_1}{{}_{A}n_1 + {}_{-A}n_1} = {}_{A}s \qquad (1)$$

where ${}_{A}n_1$ and ${}_{-A}n_1$ are the number of A-tagged fish recaptured at the end of the first year with and without the A tags respectively. If the number of ${}_{-A}n_1$ fish recaptured can be determined, perhaps from tag scars, equation (1) will provide an estimate of the rate of shedding of A tags. Similarly, if recovery takes place over several years, an equation similar to (1) is available.

$$\frac{{}_{A}n_i}{{}_{A}n_i + {}_{-A}n_i} = (1 - {}_{A}s)^i \qquad (2)$$

where the subscript i denotes the recovery year.

Although shedding of tags at some uniform rate throughout the period of the experiment may be expected, the possibility that shedding may change with time cannot be ignored. If the change in rate is not considerable, the computed rate may be considered as an average rate without appreciable error. If the rate of loss changes appreciably it may be necessary to consider losses in each year separately. This problem will be considered further under the section dealing with regression estimates of tag loss.

In addition to shedding losses, a proportion ${}_{A}k$, of the A-tagged fish may be expected to lose their tags due to non-reporting losses. Since fish can lose a tag only once, the proportion of the recaptured sample that will have retained the A tags at the end of the ith year from the combined effects of shedding and non-reporting losses is given by the equation

$$\frac{{}_{A}n_i}{{}_{A}n_i + {}_{-A}n_i} = (1 - {}_{A}s)^i\,(1 - {}_{A}k) \qquad (3)$$

In a double-tag experiment a group of fish are marked with two tags, an A and a B tag, where the two tags may be the same or different types. If the two tags are of the same type and ${}_{A}s$ is assumed to be equal to ${}_{B}s$ the model can be simplified (Gulland, 1963). The more general case where the two tags are different is developed here.

Recaptures from a double-tag experiment will be divided into four groups, one group with both A and B tags, a group with A tags only, a group with B tags only, and a group with no tags. The first three groups will be recovered while the last group will not. The advantage of the double-tag experiment is that it is possible to estimate tag loss even when the number of tagged fish recaptured but not recovered because of tag loss is unknown.

The relative number of recaptures in each group will depend jointly upon the magnitude of the shedding loss and the non-reporting loss associated with each tag, provided no cause of loss simultaneously removes both tags from a two-tag fish. Such a loss might occur if negligent finders will not turn in tagged fish regardless of the number or kind of tags borne by the fish. This type of loss cannot be estimated by the double-tag technique but its presence does not interfere with the estimation of other losses.

From equation (3) it will be seen that the relationship between the number of recoveries observed in each group one year after tagging and the tag losses of each kind suffered by fish in the double-tagged sample during the first year is given by the equations

$$ {}_{A+B}n_1 = (1-{}_As)(1-{}_Bs)(1-{}_Ak)(1-{}_Bk)\,u_1\,{}_{A+B}N_0 \qquad (4) $$

$$ {}_{A-B}n_1 = (1-{}_As)(1-{}_Ak)[{}_Bs + (1-{}_Bs){}_Bk]\,u_1\,{}_{A+B}N_0 \qquad (5) $$

$$ {}_{B-A}n_1 = (1-{}_Bs)(1-{}_Bk)[{}_As + (1-{}_As){}_Ak]\,u_1\,{}_{A+B}N_0 \qquad (6) $$

$$ {}_{-A-B}n_1 = [{}_As\,{}_Bs + (1-{}_As){}_Bs\,{}_Ak + (1-{}_Bs){}_As\,{}_Bk + (1-{}_As)(1-{}_Bs){}_Ak\,{}_Bk]\,u_1\,{}_{A+B}N_0 \qquad (7) $$

where ${}_{A+B}N_0$ is the number of fish originally tagged and u_1 is the proportion of the original tagged members that are recaptured and discovered one year after being tagged.

The following is a list of the assumptions used in developing the theoretical model to this point.

1. Shedding loss occurs at some average or uniform rate.
2. Non-reporting loss results in the failure to recover some average proportion of each group of recaptured tagged fish.
3. Likelihood of recapture is independent of the number or kind of tags borne by the fish.
4. No cause of loss jointly removes both tags from a two-tag fish.
5. Likelihood that a tag will be lost as a result of shedding or non-reporting is independent of the presence or absence of the other tag.

The first three assumptions should be largely assured if care is exercised in selecting the marks to be used and if reasonable consistency in marking technique and in recovery effort is maintained. If the fourth assumption fails there will be an additional non-reporting loss of tagged fish which is not measured by the double-tag experiments. The fifth assumption describes a condition which may be difficult to satisfy. Therefore two models will be considered; an independent model which is appropriate when the tag losses of each kind are independent and a dependent model which will hold when the tag losses of each kind are dependent. The independent model is described first although it will be seen subsequently that the independent model is a special case of the dependent model.

Independent Model

The loss of A tags can be computed by dividing equation (4) by the sum of equations (4) and (6) which, when simplified, becomes

$$1 - \frac{{}_{A+B}n_1}{{}_{A+B}n_1 + {}_{B-A}n_1} = {}_As + {}_Ak - {}_As\,{}_Ak \qquad (8)$$

Similarly the loss of B tags is computed from equations (4) and (5).

To minimize the number of equations in the text, only equations required for the estimation of loss of A tags will be given. Comparable equations for loss of B tags can be obtained by substituting A for B and B for A in the subscripts of each term in the various equations.

Equation (8) describes the relationship for the particular case when $i=1$. For the more general form, i can be any positive whole number. The resulting equation is

$$\frac{{}_{A+B}n_i}{{}_{A+B}n_i + {}_{B-A}n_i} = (1 - {}_As)^i\,(1 - {}_Ak) \qquad (9)$$

The right-hand side of equations (9) and (3) are identical, since the same parameters are being estimated. The left-hand members differ in that in equation (9) all recoveries bear the B tag, while in equation (3) the fish were tagged and recovered with the A tag only.

Equation (9) is of the general form $y=ab^x$ which can be converted to the linear form by using logarithms. The resulting equation is

$$\log\left(\frac{{}_{A+B}n_i}{{}_{A+B}n_i + {}_{B-A}n_i}\right) = \log(1 - {}_Ak) + i\log(1 - {}_As) \qquad (10)$$

where the left hand side of equation (10) corresponds to the dependent variable and the recapture period i represents the independent variable. The resulting line will have a value at the time of tagging of $\log(1\text{-}{}_Ak)$ and a slope of $\log(1\text{-}{}_As)$ from which ${}_Ak$ and ${}_As$ can be computed.

The estimate of ${}_As$ obtained from equation (10) will be an annual rate if the recapture samples are taken at one year intervals. In practice recoveries will be summed by recapture periods of, say, one year. If recoveries are taken during a short fishing season each year, the mean recovery time will be approximated by the midpoint of the fishing season.

For a continuous fishery it may be desirable to use recapture periods of less than one year. Equation (10) will then yield a line with a slope $\log(1\text{-}{}_AsT)$ where T is the duration of the recapture period in years. The resulting estimate of ${}_As$ is readily changed to an annual rate in the usual manner. In the text that follows a recapture period of one year will be used so $T=1$ and can be omitted from the equations.

In using the regression method of measuring tag loss it is assumed that ${}_As$ is a constant rate so that the data can be adequately fitted by a straight line. A visual examination of the plotted data may be a sufficient test of this assumption. Data that cannot be described by a single straight line may indicate that the rate of shedding changed with time.

The regression method also requires that the mean and variance of the dependent variable are independent. It is unlikely that this assumption will be satisfied since tag recoveries are binomially distributed, the variance and mean are related, and since the mean value of the dependent variable will change with time if shedding occurs. Fortunately when the data are converted to logarithms to obtain a linear relationship they are also transformed, which will tend to correct for the relationship between the variance and mean of the dependent variable. An advantage of the regression method for estimating ${}_{A}s$ and ${}_{A}k$ is the availability of confidence limits with little additional computation.

As will be seen later, the logarithmic transformation does not satisfy the requirement of common variance. For this reason the data for each observation are also weighted in proportion to the number of recoveries involved.

Equation (9) will be useful for estimating "gross tag loss" from small experiments where recoveries are too few to analyze by the regression method. Gross tag loss is defined as the average proportion of the tagged fish present at the start of a period that will have lost tags during that period from the combined effect of shedding and non-reporting loss. In this case recoveries of each type are summed over the total recapture period. When the total mortality rate is not small, the average gross loss will apply at the geometric rather than the arithmetic midpoint of the recapture period. The mean recovery time, $\bar{t}$, can be approximated from the equation

$$\bar{t} = \frac{1}{(F+X)} \tag{11}$$

if $(F+X)$, the instantaneous total disappearance of tagged fish having the mark in question is constant and continuous.

Estimates of gross tag loss must be compared cautiously because the geometric mean recapture times will usually differ betwen experiments. However, such estimates will be indicative of the overall effect of tag loss.

Dependent Model

In the independent model it was assumed that both shedding and non-reporting loss of A and B tags was independent. Thus the occurrence of each kind of loss was not affected by the presence or absence of the other tag. This assumption probably holds with regard to shedding losses but it may fail for non-reporting losses when a particular tag on a two-tag fish is more readily detected than it is on a one-tag fish. For example, if A tags were dependent upon B tags, there would be two rates at which A tags would be lost after recapture, ${}_{A}k$ in the case of two-tag fish and ${}_{\underline{A}\text{-}B}k$ for fish with an A tag only. We may similarly designate ${}_{B}k$ and ${}_{\underline{B}\text{-}A}k$ as the rates at which B tags are lost after recapture for the two- and one-tag condition respectively. This relationship is given by the equations

$$(1 - {}_{A}p) = \frac{(1 - {}_{\underline{A}\text{-}B}k)}{(1 - {}_{A}k)} \tag{12}$$

and

$$(1 - {}_{B}p) = \frac{(1 - {}_{\underline{B}\text{-}A}k)}{(1 - {}_{B}k)} \tag{13}$$

The term ${}_{A}p$ is defined as an additional A-tag loss that occurs as a result of the loss of the B tag while ${}_{B}p$ is the additional B-tag loss that occurs as a result of the loss of the A tag. Also, ${}_{A}p$ and ${}_{B}p$ will be referred to as the dependency loss of A tags and B tags respectively. Both ${}_{A}p$ and ${}_{B}p$ are assumed to be constants.

When equations (4) through (7) are altered to include ${}_{A}p$ and ${}_{B}p$ the resulting equations are

$${}_{A+B}n_1 = (1 - {}_{A}s)(1 - {}_{B}s)(1 - {}_{A}k)(1 - {}_{B}k)\,u_1\;{}_{A+B}N_O \qquad (14)$$

$${}_{A-B}n_1 = (1 - {}_{A}s)(1 - {}_{A}k)[{}_{B}s(1 - {}_{A}p) + (1 - {}_{B}s)\,{}_{B}k]\,u_1\,{}_{A+B}N_O \qquad (15)$$

$${}_{B-A}n_1 = (1 - {}_{B}s)(1 - {}_{B}k)[{}_{A}s(1 - {}_{B}p) + (1 - {}_{A}s)\,{}_{A}k]\,u_1\,{}_{A+B}N_O \qquad (16)$$

$${}_{-A\,-B}n_1 = [{}_{A}s\,{}_{B}s + (1 - {}_{A}s)\,{}_{B}s\,{}_{A}k + (1 - {}_{B}s)\,{}_{A}s\,{}_{B}k + (1 - {}_{A}s)(1 - {}_{A}k)\,{}_{B}s\,{}_{A}p + (1 - {}_{B}s)(1 - {}_{B}k)\,{}_{A}s\,{}_{B}p + (1 - {}_{A}s)(1 - {}_{B}s)\,{}_{A}k\,{}_{B}k]\,u_1\,{}_{A+B}N_O \qquad (17)$$

These equations may be used as before to solve for A-tag loss, using the same steps as in the case of the independent model. The resulting equation is

$$\frac{{}_{A+B}n_1}{{}_{A+B}n_1 + {}_{B-A}n_1} = \frac{(1 - {}_{A}s)(1 - {}_{A}k)}{(1 - {}_{A}s\,{}_{B}p)} \qquad (18)$$

It is worth noting that ${}_{B}p$ occurs after recapture and results in an additional loss of B tags, yet it will lead to an underestimation of A-tag loss if the independent model is assumed to hold when the dependent model is more appropriate. This seeming anomaly arises because ${}_{B-A}n_1$ which is used to indicate loss of A tags is also the term which is affected by ${}_{B}p$. More generally when tags are recovered in the ith recapture period, this equation becomes

$$\frac{{}_{A+B}n_i}{{}_{A+B}n_i + {}_{B-A}n_i} = \frac{(1 - {}_{A}s)^i(1 - {}_{A}k)}{1 - {}_{B}p\,[1 - (1 - {}_{A}s)^i]} \qquad (19)$$

When ${}_{B}p=0$, the right-hand side of equation (19) becomes $(1\text{-}{}_{A}s)^i\,(1\text{-}{}_{A}k)$ as in the independent model. However, when ${}_{B}p$ is not zero, the number of ${}_{B\text{-}A}n_i$ recoveries will be reduced by an amount almost inversely proportional to $i_{B}p$. If the regression method is used to estimate ${}_{A}s$ and ${}_{A}k$ and the independent model is erroneously assumed to hold, the slope and intercept will be too low and ${}_{A}s$ and ${}_{A}k$ will be underestimated. The errors involved will be small if the product ${}_{B}p_{A}s$ is small as will usually be the case.

Test for Dependency

To test for dependency, two single-tag experiments may be carried out in conjunction with the double-tag experiment, one in which the fish are marked with an A tag only and the other with a B tag only. To assure a comparability between experiments, individual fish should be assigned to one of the three groups on a rotation basis.

The relationship between the numbers tagged and recovered with an A tag from the single-tagged and double-tagged fish will be

$$\frac{{}_{A}n}{{}_{A+B}n + {}_{A-B}n} = \frac{{}_{A}N_O(1 - {}_{A}p)}{{}_{A+B}N_O} \qquad (20)$$

If ${}_{A}p \neq o$ then the left-hand side of equation (20) will be less than the right-hand side. A simple chi-square test will show whether the difference is significant or not. Note that a one-sided test is appropriate since the probability that the left side of (20) exceeds the right side is excluded.

MARKING AND RECOVERY OF HALIBUT

Five double-tag experiments are available for analysis in this study. The earliest experiment was conducted on grounds near the Shumagin Islands in western Alaska, while the remaining experiments were conducted on the Goose Islands ground which is located off the northern end of Vancouver Island, British Columbia.

The tagging and recovery process described by Thompson and Herrington (1930) has been changed very little in the interest of maintaining comparability between experiments. Fish for tagging were captured on setline halibut gear. Each fish that was brought aboard was carefully examined and only those fish deemed to have a good likelihood for survival were selected for tagging. These fish were measured and tagged with the monel metal strap tag which was attached to the dark-side operculum near its insertion (Figure 1). The B mark was then applied and the fish was returned to the water. Since a different B mark was used in each of the five double-tag experiments, descriptions of these marks and the manner of attachment will be described under the respective experiments. The entire tagging operation usually required no more than about 40 seconds per fish.

The size range of halibut taken on setline gear is so great that two sizes of strap tags are employed. The larger strap tag measures 69 millimeters long, 8 millimeters wide and .65 millimeters thick, while the small strap tag measures 58 millimeters long, 6.5 millimeters wide and .6 millimeters thick. In the wire and dart spaghetti-tag experiments small strap tags were used on fish less than 80 centimeters at tagging, while in the remaining experiments fish less than 70 centimeters were marked with small strap tags.

At the major landing ports, Commission employees contact halibut vessels to copy the fishing logs and redeem recovered tags. Fish buyers and representatives of governmental agencies cooperate by forwarding recovered tags from ports where the Commission is not represented.

Tag posters are displayed in all fish plants where halibut are landed so that the employees, as well as fishermen, will recognize halibut tags and will know how and why they should be returned to the Commission with all available recovery information. To encourage the reporting of recovered tags a reward of from fifty cents to two dollars is offered, the size of the reward depending upon the amount of recovery information provided. Subsequently, a letter is sent to the finder providing information regarding the release location and size at tagging of the recovered tagged fish.

All tagged fish recoveries were included in the following analyses regardless of the gear used in their recapture. Myhre (1960) omitted trawl caught recoveries because a different level of loss of tags was suspected with this kind of gear. Subsequent examination has failed to show measurable difference, either because the number of trawl recoveries was too small to have had a significant effect on the results or because no difference exists.

A tagged-fish recovery will be assumed to signify the recapture and death of the fish and the return of the tag to the Commission. A tag that was accidentally lost by the finder was counted as a recovery if the correct number was turned in with a statement explaining the absence of the tag. The tattoo or cut-mark was tabulated as being recovered when seen by the person who redeemed the fish or when described to him by the finder. If a double-marked fish was recaptured and only the A or B mark was returned, the recovery was recorded as an ${}_{A\text{-}B}n_i$ or a ${}_{B\text{-}A}n_i$ recovery respectively. If both marks were returned, either separately or together, it was recorded as an ${}_{A+B}n_i$ recovery.

ANALYSIS

Double-strap Tag Experiment

In May 1929, 221 halibut were double-tagged in the vicinity of the Shumagin Islands, in western Alaska. The secondary or B mark used in this experiment consisted of a large strap tag placed on the white side of the fish in a position analogous to that occupied on the dark side by the primary or A mark, also a large strap tag. All individuals tagged were 70 centimeters or longer when released. It was expected that this experiment might indicate the more efficient place of attachment.

A total of 55 fish had been recovered by the end of 1940 and of these, two had the white-side and six the dark-side tag only. Table 1 shows the number of recoveries in each group by years.

Table 1. Number of recoveries by years from the double-strap tag experiment.

Year	Both Tags	Dark-side Tag Only	White-side Tag Only	Total
1929	10	—	1	11
1930	8	2	—	10
1931	13	1	1	15
1932	8	—	—	8
1933	2	—	—	2
1934	3	—	—	3
1935	1	—	—	1
1936	1	1	—	2
1937	—	1	—	1
1938	—	1	—	1
1939	—	—	—	—
1940	1	—	—	1
Total	47	6	2	55

Eleven of the 55 recoveries were made in 1929, the 0-year of the experiment. The year-to-year recoveries were too few and inconsistent to permit use of the regression method. The only remaining choice was to compute estimates of gross tag loss using equation (9).

For dark-side tags an estimate of gross tag loss of 0.04 was obtained. For white-side tags a gross tag loss of 0.119 was estimated. These estimates would apply at a mean time of about mid-1932 based upon an estimated survival rate of 0.768. The apparent difference between dark- and white-side tag loss cannot be regarded as statistically significant because of the small number of returns.

The above estimates are based upon the assumption that the independent model is applicable. Although no direct proof of this assumption is available, the strap tag was used for both primary and secondary marks and the 1960 dart-spaghetti-tag experiment provided evidence that at least the large strap tag is free of dependency loss.

Tattoo Experiments

In June 1935 and in May 1936, the Commission released halibut that had been marked with a tattoo in addition to the strap tag. These experiments were carried out on Goose Islands ground. Fish less than 70 centimeters in length were tagged with a small strap tag while those above 70 centimeters were marked with a large strap tag. All fish released in the 1935 sample were double-marked, while in 1936, 214 single-marked fish were randomly interspersed with double-marked fish.

Two methods of tattooing were used in the 1935 sample. One method consisted of injecting India ink subcutaneously into the cheek or nape on the white side of the fish. The second method consisted of rubbing India ink into a cut made in the skin also on the cheek or nape of the white side of the fish. Each mark consisted of the letters I.F.C. and a number, the latter identifying the day of tagging but not the individual fish. Only the cut-mark was used as a secondary mark on fish released in the 1936 sample. The number of fish tagged and recovered in each group is shown in Table 2.

Table 2. Number of fish tagged and number and percentage recovered from 1935 and 1936 tattoo experiments.

Mark Used	1935 Number Tagged	1935 Number Recovered	1935 Percent Recovered	1936 Number Tagged	1936 Number Recovered	1936 Percent Recovered
Strap Tag Only	—	—	—	214	79	37
Strap Tag Plus Tattoo	259	106	41	—	—	—
Strap Tag Plus Cut	83	41	49	249	98	39
Total	342	147	43	463	177	38

Recoveries were obtained through 1942. At the time of redemption of any marked individuals the finder was questioned as to which mark was seen first and whether the second mark was also seen.

Ordinarily, the dissimilar 1935 and 1936 samples would be analyzed separately. However, the small number of usable recoveries makes separate treatments impractical. On the other hand, the two types of secondary mark were similar in nature and the results did not appear to differ so that a joint treatment seems justified. Data for large and small strap-tagged fish are combined to increase sample size. Table 3 shows the usable information tabulated by years after tagging.

Several additional assumptions are required if these data are to be used to estimate tag loss. First, it must be assumed that the information provided with the 82 recoveries shown in the above table is a representative sample of the total recoveries. Next, it must be assumed that if one mark was indicated as having been

Table 3. Number of double-marked halibut recovered by years after tagging from the 1935 and 1936 tattoo experiments.

Years After Tagging	Strap Tag		Tattoo or Cut	
	Noticed First	Not Noticed	Noticed First	Not Noticed
0	6	—	19	1
1	20	—	7	14
2	3	—	2	7
3	—	—	—	2
4	—	—	—	—
5	—	—	—	1
Total	29	—	28	25

seen first, it can be inferred that the other mark was also seen. Finally, if one mark was not noticed, it must be assumed that the other mark was noticed. On the basis of these assumptions, the number of recoveries in each group for each year were obtained as shown in Table 4.

Assuming that the experimental results satisfy the independent model, the absence of tattoo recoveries would indicate that no strap tags were lost. On the other hand, when the recoveries obtained in years one through five are used in equation (9), a point estimate for ${}_{B}s$ of 0.31 is obtained and this would apply at about one year after tagging. Shedding loss, or fading in the case of a tattoo, was substantiated by observations of those redeeming the returned marked fish. In many cases in the second year after tagging and thereafter, the tattoo and cut-marks were difficult or impossible to distinguish, even when the fish being examined was known to have been so marked.

Because of the small number of usable recoveries and the additional assumptions required, the only safe conclusions are that the loss of strap tags is not excessive and that tattoo and cut-marks using India ink fade rapidly. These conclusions are also suggested by a non-significant statistical difference in the percentage recovery of 1936 single and double-marked fish shown in Table 2.

Table 4. Assumed number of recoveries of each kind obtained from the 1935 and 1936 tattoo experiments by years after tagging.

Years After Tagging	Both Marks Seen	Strap Tag Only	Tattoo or Cut Only	Total Recovered
0	25	1	—	26
1	27	14	—	41
2	5	7	—	12
3	—	2	—	2
4	—	—	—	—
5	—	1	—	1
Total	57	25	—	82

Body-cavity Tag Experiment

This experiment was conducted on Goose Islands ground in June, 1935 in conjunction with the tattoo experiment. On each day when body-cavity tags were used as the secondary or B mark, all fish so marked received a strap tag in addition as the primary or A tag. Usually, but not invariably, body-cavity tags were used on alternate days. All fish less than 70 centimeters were marked with a small strap tag and those 70 centimeters or longer were marked with a large strap tag. A total of 252 fish were tagged, 221 with the large strap tag and 31 with the small strap tag.

The secondary mark consisted of an orange-red celluloid marker that was inserted into the body-cavity through an incision barely large enough to admit the tag. The mark itself was made of Number 60 celluloid, $\frac{1}{8}$ inch thick, $2\frac{1}{2}$ inches long, $\frac{7}{8}$ inch wide at one end and tapered to $\frac{3}{4}$ inch at the other end. Each was stamped with a serial number and instructions for its return.

Recoveries of double-tagged fish were made through 1950. Those marked with the large strap tag produced 123 recoveries, of which 12 were returned without the strap tag and 14 were returned without the body-cavity tag. The group marked with the small strap tag produced 17 recoveries of which 5 were returned without the strap tag. The body-cavity tag was returned with all 17. Table 5 shows the number of recoveries in each group obtained in each year.

Table 5. Number of recoveries by years from the 1935 body-cavity tag experiment.

	Large Strap Tags				Small Strap Tags			
Year	Both	Strap Only	Body-cavity Only	Total	Both	Strap Only	Body-cavity Only	Total
1935	10	2	—	12	1	—	—	1
1936	26	5	2	33	5	—	1	6
1937	16	3	3	22	4	—	—	4
1938	20	—	2	22	2	—	1	3
1939	11	1	—	12	—	—	1	1
1940	9	1	1	11	—	—	—	—
1941	3	2	2	7	—	—	1	1
1942	—	—	2	2	—	—	1	1
1943	—	—	—	—	—	—	—	—
1944	1	—	—	1	—	—	—	—
—								
1950	1	—	—	1	—	—	—	—
Total	97	14	12	123	12	—	5	17

The regression method was used to estimate large strap tag loss from the 1936 to 1940 recoveries. Zero year recoveries and those returned after 1941 were omitted. The resulting values are shown in Figure 2 with the least squares line of best fit. Weighting was introduced according to the number of recoveries used for each recovery period. The plotted data are scattered and can be fitted by a straight line as well as by any other simple line.

The regression line shown in Figure 2 has a slope of $\log(1-{}_{A}s)=0.026$ and an intercept at $\log(1-{}_{A}k)=0.044$ which are solved for the two kinds of loss. The resulting estimates of shedding and non-reporting loss for large strap tags with the 80 percent confidence limits were $-0.023<0.026<0.072$ and $-0.215<0.043<0.247$ respectively. Combining recoveries from the large and small strap tagged groups, estimates for shedding and non-reporting loss for body-cavity tags with the 80 percent confidence limits were $-0.041<0.012<0.061$ and $-0.166<0.088<0.287$. The regression method was not used to estimate loss of small strap tags because of the small number of returns.

The body-cavity tag used in this experiment had several advantages as a secondary mark. First, it was not likely to be shed because the opening through which it was inserted was so small that the tag could not pass through without considerable force. Secondly, during the period when body-cavity tagged fish were being recovered, a substantial price was paid for the liver and part of the stomach and intestines of halibut because they contained high potency vitamin A oils. Body-

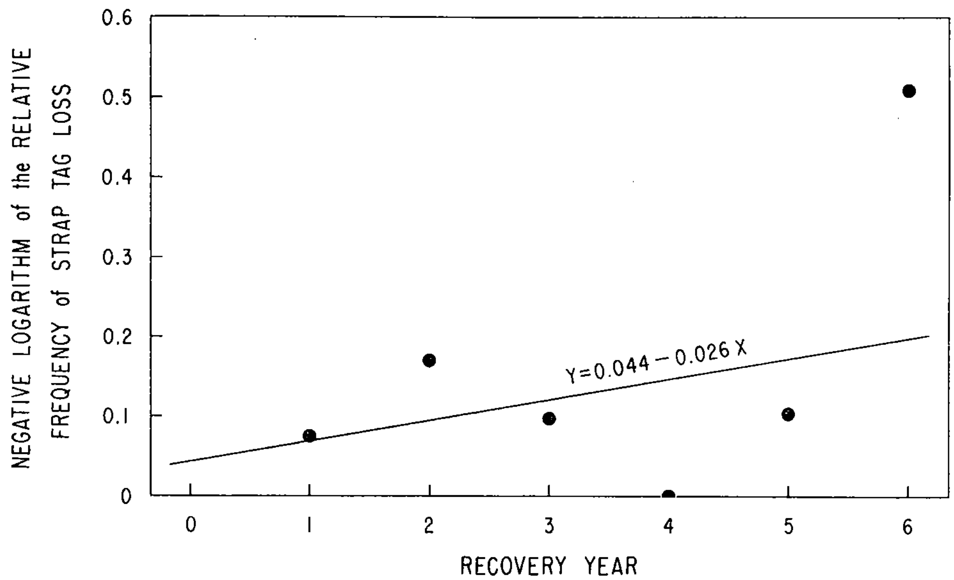

Figure 2. Negative logarithm of the relative frequency of large strap tag loss by years from the body-cavity tag experiment with the regression line of best fit.

cavity tags were frequently found while the fishermen were selecting the parts of the viscera that were to be saved. Unfortunately the market for natural vitamin-bearing oils largely disappeared in the United States with the advent of synthetic vitamin A and most of the halibut viscera are now discarded at sea immediately upon removal from the fish. Consequently, the efficiency of the body-cavity tag may not be as great now as it was in earlier years.

It appears from Table 5 that small strap tags may be lost more frequently than large strap tags. A test of the hypothesis that there is no difference in the loss of large and small strap tags yields an adjusted chi-square 3.57 ($p=0.06$).

Wire-Spaghetti Tag Experiment

This experiment was conducted on Goose Islands ground in July, 1955. Fish less than 80 centimeters long were tagged with the small strap tag and those above with the large strap tag. Half of the fish in each group were also marked with a second tag which was made of Number 20 white polyethylene tubing reinforced by inserting a piece of 20 gauge spring nickel-silver wire. The wire-spaghetti tag, also referred to as the wire tag, was passed around the preopercular bone and the two free ends were then twisted together to form a closed loop (Figure 1). In this experiment single and double-tagged fish were released alternately. Table 6 shows the numbers of tags released in each group and the number of recoveries of each kind obtained through 1965.

Recoveries obtained from the group marked with large strap tags in the four-year period between 1956 and 1959 were used to estimate tag loss by the regression method. Recoveries after 1959 were too few to provide additional information. Figure 3 shows the plotted data for the estimate of large strap tag loss and the line of best fit. The slope and intercept for the regression line were $\log(1-{}_{A}s)=0.013$ and $\log(1-{}_{A}k)=0.031$, which were then solved for both kinds of large strap tag loss. The resulting estimates of shedding and non-reporting loss with the 80 percent confidence limits were $-0.027<0.013<0.052$ and $-0.073<0.031<0.125$ respectively. Returns during 1956-1958 from the group marked with small strap tags provided estimates and confidence limits of shedding and non-reporting loss for small strap tags of $-0.422<0.089<0.416$ and $-1.754<0.031<0.660$ respectively. Finally, returns during 1956-1959 provided estimates and confidence limits for shedding and non-reporting losses of wire tags from the combined large and small strap-tagged groups of $0.010<0.017<0.024$ and $0.139<0.155<0.170$ respectively.

The above estimates indicate that few large strap tags are lost. This observation is further substantiated by the nearly equal number of returns from the equal number of single- and double-tag releases. The fact that the single-tagged fish produced more recoveries with strap tags than did the double-tagged fish, suggests the possibility of an additional loss due to the wire tag. Such a loss could result from the additional time the fish must be out of water to permit attachment of the wire tag. The observed difference, most of which occurred in 1958, is not statistically significant but it raises a point worthy of consideration in such experiments. Furthermore, if such a tagging mortality was associated with the wire tag, it would not affect the estimates of tag loss computed above.

The estimates of tag loss computed above were based upon the assumption that the independent model applied. Dependency of wire tags upon strap tags cannot be tested because single-tagged fish marked with wire tags only were not released. Single-tagged fish marked with strap tags only were included in the experiment so dependency of strap tags on wire tags can be tested. The appropriate test is a comparison of the probability of recovery for strap tagged fish released with and without the wire tag as shown in equation (13). Since single-tagged fish produced more recoveries with strap tags than did the double-tagged fish it is apparent that evidence against the use of the independent model for estimation of wire-tag loss is lacking.

The relative frequency at which small strap tags were lost was greater than that for large strap tags. Chi-square was used to test the difference between the

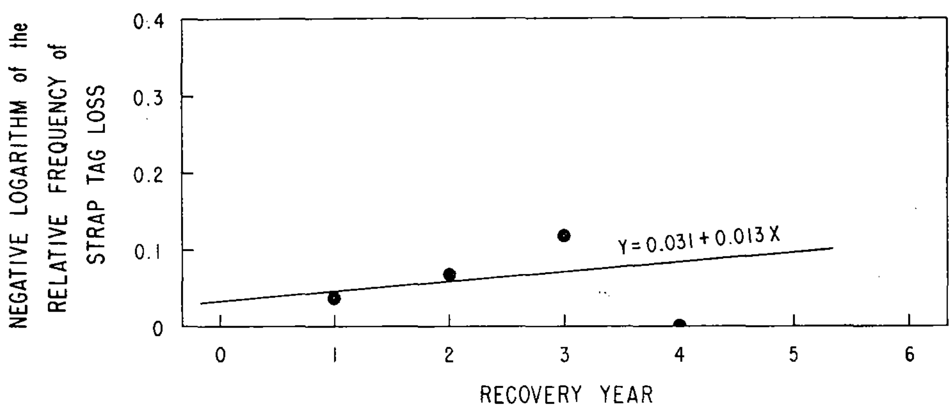

Figure 3. Negaive logarithm of the relative frequency of large strap tag loss by years from the wire-spaghetti tag experiment, with the regression line of best fit.

loss of large and small strap tags. An adjusted chi-square of 3.09 with one degree of freedom is obtained ($p=0.08$).

Dart-Spaghetti Tag Experiments

Double-tagged fish were released on Goose Islands grounds in April and again in August, 1960 using a dart-spaghettti tag as the secondary mark. The dart-spaghetti tag, also referred to herein as the dart tag, was made of No. 13 orange plastic tubing to which was cemented a nylon single-barbed dart. A hollow needle with a beveled point was used to insert the dart between the preopercular and interopercular bone on the white side of the fish. This application site was selected because it was deemed desirable to have the two tags on different sides of the fish to reduce observational interaction. Other sites might have yielded a higher retention of dart tags. The dart tags used in April were 12 inches long while those released in August were 8 inches long.

At recovery a number of the dart tags were found with illegible serial numbers. Such fish, if bearing a dart tag only, could not be related to the tag combination applied at release and had to be omitted from the analysis. These omitted tags were the same as lost tags and are included in estimates of shedding and non-reporting. This problem was studied further to determine how loss of legends affect estimates of shedding and non-reporting loss of each kind of tag. The number and percentage of dart tags with lost legends on fish double tagged in April and retaining both tags at recovery is shown by recovery year in the following table.

Table 6. Number of recoveries by years from single and double-tagged halibut released in the 1955 wire-spaghetti tag experiment.

	Number Released			Number Recovered				
					Double-tagged			
Group	Single-tagged	Double-tagged	Recovery Year	Single-tagged	Both Tags	Strap Tag Only	Spaghetti Tag Only	Total
			1955	6	5	1	0	6
			1956	98	78	14	3	95
Large Strap	392	392	1957	35	29	4	2	35
			1958	30	16	2	2	20
			1959	5	8	0	0	8
			1960	4	3	0	3	6
			1961	2	0	1	1	2
			1962	1	1	0	0	1
			1963	2	1	1	0	2
			1964	0	0	8	0	0
			1965	0	0	1	0	1
Total				183	141	24	11	176
			1955	0	1	0	0	1
			1956	29	31	4	2	37
Small Strap	177	177	1957	18	15	2	7	24
			1958	2	14	2	3	19
			1959	5	2	1	0	3
			1960	1	0	0	2	2
			1961	0	1	0	0	1
			1962	1	0	0	0	0
			1963	0	0	0	0	0
			1964	0	1	0	0	1
			1965	0	0	0	0	0
Total				56	65	9	14	88

	Recoveries of Both Tags				
	Legend On		Legend Lost		
Year	No.	%	No.	%	Total
1960	184	100	0	0	184
1961	51	72	20	28	71
1962	12	67	6	33	18
1963	8	73	3	27	11
1964	3	75	1	25	4
1965	3	100	0	0	3
Grand Total	261	90	30	10	291
1961-65 Total	77	72	30	28	107

None of the 1960 recoveries had missing legends but from 1961 to 1964 the proportion with missing legends varied between 25 and 33 percent* and from 1961 to 1965 it averaged 28 percent. It is probable that the location of some legends brought them in contact with the bottom when the fish was resting and that these would be rubbed off within one year. Legends not in contact with the bottom would be protected from this loss which explains the absence of change after the first year. Thus, after 1960 only 72 percent of recovered dart tags would still have legible legends. Correction must be made for loss of legends from dart tags in estimating strap tag loss. Loss of legends appear in the estimates of non-reporting loss of dart tags.

In both the April and August experiments many of the fish 80 centimeters or longer at tagging were released in groups of four to provide information on dependency losses of the large strap and dart tags. The first two fish in each group of four were tagged with a large strap tag and a dart tag. The third and fourth individuals in each group of four were marked with a single large strap and a single dart tag respectively. The number of tagged fish of each type released and recovered from the April and August grouped releases are shown in the following table.

Release Type	No. Released	Recovery Condition	Year Recovered 1960	1961	1962	1963	1964	1965	Total
April		Both	65	27	3	3	0	1	99
Double Tagged	416	Strap Only	15	11	10	14	3	3	56
		Long Dart Only	1	0	0	0	0	0	1
		Total	81	38	13	17	3	4	156
Single Tagged	208	Strap Only	28	22	17	7	2	2	78
	208	Dart Only	26	12	2	3	1	0	44
August		Both	0	22	6	8	2	1	39
Double Tagged	140	Strap Only	0	4	1	6	0	0	11
		Short Dart Only	0	0	1	0	0	1	2
		Total	0	26	8	14	2	2	52
Single Tagged	70	Strap Only	1	8	6	5	2	3	25
	70	Dart Only	1	9	4	5	1	0	20

*1965 recoveries too few to be considered.

These data are used in equation (20) to estimate dependency loss. The following table shows the data used and the resulting estimates of dependency loss of large strap tags and dart tags.

Tag Type	April			August			April and August		
	Single	Double	Dependency	Single	Double	Dependency	Single	Double	Dependency
Large Strap	78	155	-0.06	25	50	0.0	103	205	0.005
Dart	44	100	0.12	20	41	0.03	64	141	0.092

Estimates of dependency loss for large strap tags and dart tags were 0.005 and 0.092 respectively. It was concluded that large strap tags were free of dependency loss. An adjusted chi-square of 0.50 was obtained in the test for dependency loss of dart tags ($p=0.24$). However, the power of this test is relatively weak because of the small sample size and the above evidence of dependency loss of dart tags was accepted.

In adjusting for dependency loss and for loss of legends to obtain corrected estimates of strap tag loss it is noted that these two losses are not mutually exclusive. That is, dependency loss will occur with equal likelihood on dart tags with and without legends. Accordingly, the two losses are added together to obtain a joint loss of 0.37 percent. The corrected estimate of shedding loss for strap tags is found by dividing the observed rate by 0.63.

The total tagged sample also included some fish 80 centimeters and larger marked with double tags, single straps or single darts that were released out of sequence, and all fish less than 80 centimeters at release. Most of the fish between 65 and 79 centimeters were double-tagged with a small strap and a dart tag, but a few were marked with either a single small strap tag or single dart tag. Fish less than 65 centimeters at tagging were usually marked with a single dart tag.

A summary of all double-tagged releases connected with the long dart tag experiment in April is given in Table 7 which shows the number of recoveries of each type by year of recovery from the 438 fish 80 centimeters or longer tagged

Table 7. Summary of recoveries through 1965 from all double-tagged fish released on Goose Islands grounds in April, 1960.

Mark Type	Number Released	Recovery Years	Number of Recoveries			Total
			Both	Strap Only	Long Dart Only	
Large Strap and Long Dart	438	1960	65	15	2	82
		1961	31	11	0	42
		1962	3	10	1	14
		1963	3	15	0	18
		1964	0	3	0	3
		1965	1	3	0	4
Total			103	57	3	163
Small Strap and Long Dart	828	1960	119	19	15	153
		1961	40	46	7	93
		1962	15	26	3	44
		1963	8	25	0	33
		1964	4	3	3	10
		1965	2	6	1	9
Total	1266		188	125	29	342

with a large strap and a long dart tag and the 828 fish less than 80 centimeters marked with the small strap and a dart-spaghetti tag.

From the group tagged with the large strap and long dart tag, only three were recovered with darts only, showing that few large strap tags are lost. Equation (9) was used with all recoveries summed from 1960 through 1965 to estimate a gross loss of large strap tags over a six-year period of 0.03. Correction for dependency and for loss of legends from dart tags would raise the combined loss to 0.048. The geometric mean recovery time would be about mid-1961 based on a survival rate of about 0.50 and the month of tagging. Shedding would have started at the time of tagging in April, 1960. Thus the estimate of gross loss will include about one year's shedding loss plus non-reporting loss.

The regression method was used to estimate the two types of loss of small strap tags from the same experiment. The plotted data and the fitted regression line are shown in Figure 4. Estimates of shedding and non-reporting loss with 80 percent confidence intervals were $0.001<0.049<0.095$ and $-0.053<0.097<0.226$ respectively. A correction for dependency and loss of legends of dart tags would raise the non-reporting loss to $-0.084<0.154<0.359$. Estimates of shedding loss should not be affected by these other losses. A slight but unimportant error is incurred in both estimates by making a blanket correction for loss of legends since this loss did not appear until 1961.

The regression method was also used to estimate the two kinds of loss of long dart tags. Data for the groups released with large and small strap tags were combined to obtain a larger sample size. The resulting estimates of shedding and non-reporting loss with 80 percent confidence limits were $0.208<0.294<0.370$ and $-0.291<0.143<0.431$ respectively. These estimates should not be affected by dependency loss if the small strap tags, like the large strap tags, are not so affected. The effect of loss of legends is included in the estimate of non-reporting loss.

A summary of all double-tag releases in the short-dart tag experiment in August is given in Table 8 which shows the number of recoveries of each type by recovery year for large and small strap tagged fish.

Table 8. Summary of recoveries through 1965 from double-tag releases on Goose Islands grounds in August, 1960.

Mark Type	Number Released	Recovery Years	Number of Recoveries			Total
			Both	Strap Only	Short Dart Only	
		1960	0	0	0	0
Large		1961	22	5	0	27
Strap and	148	1962	6	1	1	8
Short Dart		1963	8	7	0	15
		1964	2	0	0	2
		1965	1	0	1	2
Total			39	13	2	54
Small		1960	0	0	0	0
Strap and		1961	54	25	5	84
Short Dart	329	1962	18	9	5	32
		1963	10	3	3	16
		1964	4	7	5	16
		1965	2	2	1	5
Total	477		88	46	19	153

Again a small amount of large strap tag loss is indicated by the recovery of only two fish with the short dart tag only. The best estimate of large strap tag loss is obtained by summing recoveries over the entire period of the experiment to obtain a combined shedding and non-reporting loss of 0.05 over a period of five years 1960-1965. Again there is little likelihood of appreciable error in this estimate due to dependency of the dart tags but correction for loss of legends from dart tags would raise the combined loss to 0.079. The geometric mean recovery time is estimated to be early 1962 but shedding must be assumed to have started at the time of tagging in August, 1960. Thus the gross loss estimate would include about one and one-half years shedding loss plus non-reporting loss.

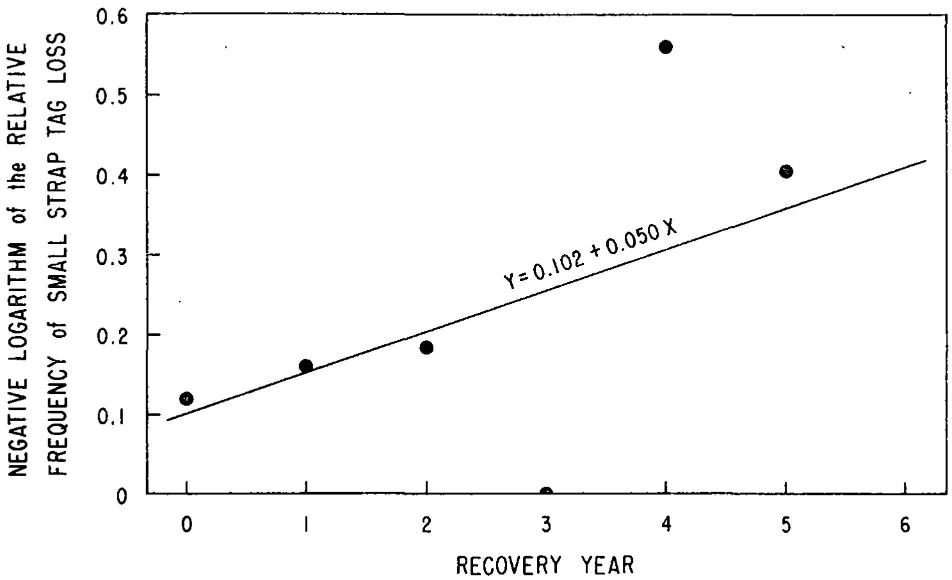

Figure 4. Negative logarithm of the relative frequency of small strap tag loss by years from the long dart tag experiment with the regression line of best fit.

The regression method was used to estimate the loss of small strap tags. The plotted data and the fitted regression line are shown in Figure 5. The resulting estimates of shedding and non-reporting loss with 80 percent confidence intervals were $0.067<0.144<0.215$ and $-0.251<0.054<0.285$ respectively. Adjusting the estimate of non-reporting loss for dependency and loss of legends of dart tags gives corrected estimates of $-0.399<0.086<0.452$.

The regression method was also used to estimate shedding and non-reporting loss of short dart tags. Again the small and large strap tag groups were combined to obtain a larger sample size. The plotted points and the fitted regression line are shown in Figure 5. Resulting estimates of shedding and non-reporting loss with 80 percent confidence intervals were $0.029<0.082<0.133$ and $0.059<0.215<0.344$ respectively. Again, the loss of legends is included in the estimate of non-reporting loss.

The estimate of shedding loss for the long dart tag was significantly greater than for the short dart. This additional loss is attributed to the greater length of

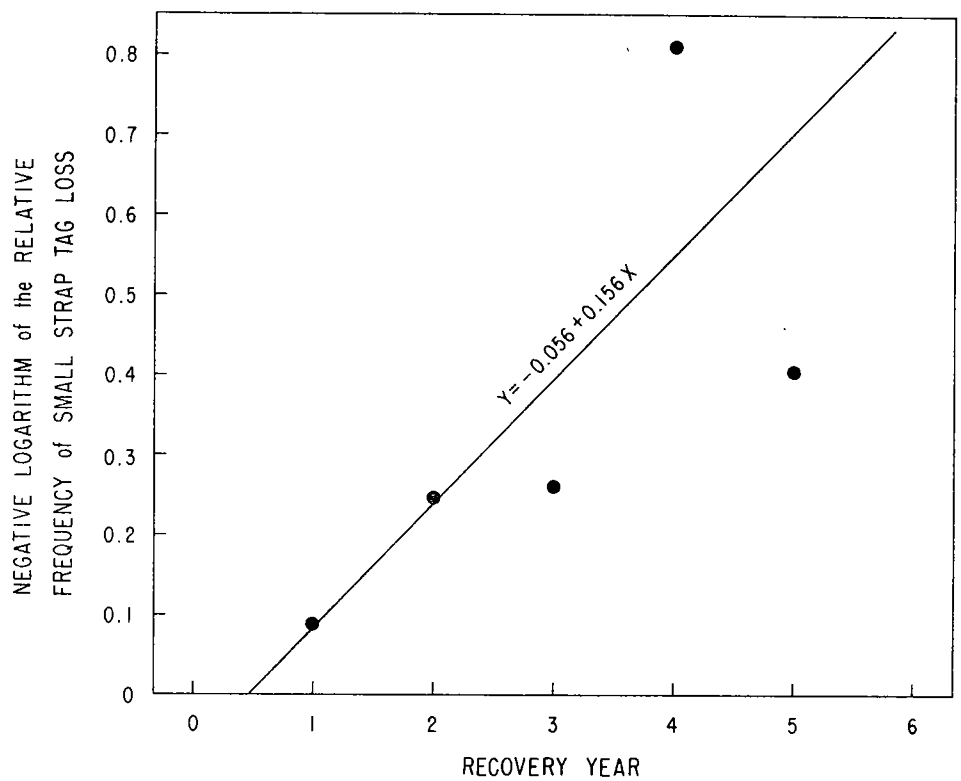

Figure 5. Negative logarithm of the relative frequency of small strap tag loss by years from the short-dart tag experiment with the regression line of best fit.

the dart tag used since the same difference was observed between fish tagged by the same individual at the two times.

The utility of the dart tag as a mark for halibut might be improved by selection of a more advantageous position of attachment and by ascertaining the optimum length of the tag. A second difficulty with the dart tags was the loss of legends as a result of abrasion on the bottom. This problem could have been reduced if not eliminated had the tags been placed on the dark side of the fish. Subsequent experiments have been conducted to test the utility of the dart tag when attached on the dark side but the results of these experiments are not yet available.

DISCUSSION

Results from the foregoing experiments are summarized in Table 9 showing estimates of shedding and non-reporting loss for each type of tag calculated by the regression method.

Values obtained from the white- and dark-side strap tag and the tattoo experiments were not included in the above table owing to the small sample size which prevented use of the regression method of analysis.

Table 9. Estimates of tag loss obtained from double-tag experiments by the regression method.

Tag Type	Experimental Group	Kind of Loss: Shedding	Non-Reporting
Large Strap	Body-cavity	0.03	0.04
	Wire-spaghetti	0.01	0.03
	Average	0.02	0.04
Small Strap	Wire-spaghetti	0.09	0.03
	Long Dart	0.05	0.15
	Short Dart	0.14	0.09
	Average	0.09	0.09
Body-cavity	Large Strap	0.01	0.09
Wire-spaghetti	Large and Small Strap	0.02	0.16
Dart-spaghetti	Large and Small Strap		
	Long Dart	0.29	0.14
	Short Dart	0.08	0.22

For large strap tags the average shedding and non-reporting losses of 0.02 and 0.04 respectively are further supported by the estimates of gross loss from the two dart tag experiments of 0.05 and 0.08.

The averages for shedding and non-reporting losses of small strap tags were 0.09 and 0.09 respectively. The individual estimates from the three experiments were of the same general magnitude but their variability suggests some reservation in accepting such mean values. Small strap tags were shed more frequently than large strap tags.

Estimates obtained for shedding and non-reporting losses of body-cavity tags were 0.01 and 0.09 respectively and for wire-spaghetti tags were 0.02 and 0.16 respectively. Though these values were based on single and comparatively small experiments the respective regression lines had relatively small variances.

Estimates of shedding and non-reporting loss of the long dart tags were 0.29 and 0.14 respectively, and for the short dart tags the respective values were 0.08 and 0.22. Estimates of non-reporting loss of secondary tags can be deemed free of dependency loss since strap tags were used as the other tag.

It is noteworthy that high values of non-reporting loss were obtained for body-cavity, dart- and wire-spaghetti tags while those of shedding loss were lower than expected. The non-reporting loss for the secondary tags could decrease in the course of an experiment as the fishermen became increasingly familiar with their existence. This would rotate the regression line of the secondary tags in a clockwise direction causing an overestimation of non-reporting loss and an underestimation of shedding loss. Also the regression line for primary tags would rotate counterclockwise causing an overestimation of shedding loss and an underestimation of non-reporting loss. The amount of the rotation depends upon both the rate of shedding loss of primary tags and the extent of the change with time in non-reporting loss of secondary tags.

Estimates of shedding and non-reporting loss of large strap tags should be little affected by this bias since shedding of these tags is negligible. Since some shedding loss of small strap tags was indicated, the possibility of bias in these estimates must be recognized.

Double-tag experiments have distinct advantages over any single tag experiments where tags may be lost. The secondary tags will then increase the recovery of tagged fish as well as provide information on the extent and nature of the tag losses involved. When corrections for tag loss can be made, the usefulness of tagging experiments in providing information on the dynamics of fish populations is enhanced.

SUMMARY

A method is described for measuring two types of tag loss from double-tagged halibut. One type, the shedding of tags, operates continuously so its effects increase with time. The second type of loss such as non-reporting operates only once regardless of the time between tagging and recovery.

Data from five double-tag experiments involving several types of tags showed that average losses from shedding and non-reporting of large monel metal strap tags were 0.02 and 0.04 respectively. For small strap tags, the respective losses were 0.09 and 0.09. Shedding loss of dart-spaghetti tags and tattoo marks was relatively high. Non-reporting loss of dart-spaghetti, wire-spaghetti and body-cavity tags was also high. Sources of error in the estimates are discussed and some corrections were applied.

It is concluded that shedding loss of large strap tags will have little effect on estimates of mortality rates from tagging experiments on Pacific halibut. However, estimates of non-reporting loss of tags from double-tag experiments does not include losses which operate on both tags jointly such as overlooking of fish bearing both tags at recovery. Further studies of this special problem are required.

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