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ESTIMATION OF THE STOCK STRENGTH OF THE NORWEGIAN WINTER HERRING

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1. Theory.

The idea of employing the recaptures from taggings in estimation of the stock-strength, is founded on the assumption that tagged and untagged fish are caught in the same proportion. In mathematical terms we may express our assumption in the following way:

$$\frac{y}{S} = \frac{R}{t} \quad (1) \quad \text{where}$$

y denotes the fishery yield,
S the stock present,
R the number of recaught tagged fish, and
t the tagged fish present.

In principle the calculation of the stock-strength is very simple. For various reasons, however, the practical task is more complicated. A necessary condition for the validity of our basic assumption is that the tagged fish are evenly distributed in the stock. Also it is required that they are sufficiently numerous to appear in representative numbers in the catch. From this follows firstly, that we must allow for a certain time after tagging before the spreading can be effected, and secondly that the number of liberated[x] fish must be in relation to the suspected fishing mortality. It must be left to a consideration of the actual recoveries to decide whether these basic requirements are satisfied reasonably well for practical purposes. But even if we knew this to be the case, the calculation of the stock would still not be a straight-forward task. The figures y, R, and t are not known and have to be derived from the catch-statistic, recovered tags, and tagged amounts respectively. We migt express this for short:

[x] tagged

$$y = f\,(c) \qquad (2)$$
$$R = \varphi\,(r) \qquad (3)$$
$$t = \psi\,(T) \qquad (4)$$

where
c is the landing figure
r the recovered tags, and
T the tagged amount.

Before the stock calculation can be carried out, we must establish these relationships. We will consider the functions in turn.

y = f (c). The form of this equation is dependent on the unit in which we choose to express our stock-figure. In Norway, the landing figure, c, is usually given in hl, which is the original measuring unit when the fishermen bring in their catches for delivery. Owing to the rather unique fishermens sales organization, in which all catches are recorded, the statistic, c, is brought to a very high standard of accuracy. We may therefore place confidence in this figure, the error of which is probably only a fraction of one per mille and ought not to influence the result unduly. If we want to have our stock figure expressed in hl, equation (2) takes the simple form y = c and this will be sufficient in most cases.

For some purposes, however, it is desirable to have the catch expressed in number of individuals. The figure, c, must then be converted by means of sampling data. This can be done in various ways. In any case it will be a formidable task if accuracy is required. With a proper knowledge of the average number of herring per hl equation (2) would take the form: $y = \bar{a} \, . \, c$, where $\bar{a}$ denotes the average number of infividuals per hl. The first approximation to $\bar{a}$ is obtained by averaging all the samples. A better estimate is effected by br aking down the catch statistic into "area-time" cells and weighing the samples. How far this breaking can be carried, will depend on the number and distribution of the samples and on the structure of the statistical system. In Norway, we will have to be content with pooling the samples within each week and weighing them by weekly landings. If the average number of herring per hl within each week is denoted by $a', a'', \ldots\ldots, a^{(n)}$ and the weekly landings by $c', c'', \ldots\ldots, c^{(n)}$, we get:
$y = a' \, . \, c' + a'' \, . \, c'' + \ldots\ldots + a^{(n)} \, . \, c^{(n)}$. Naturally we cannot be fully confident in the figure y in this case. A rough calculation shows that there will be about half a million times more herring in the catch than those covered by the sampling in the later years. Moreover, the samples are almost exclusively based on seine-caught herring because the gill nets act selectively. This will in turn bias the result since the gill nets are responsible for a substantial portion of the catch.

$\underline{R = \varphi(r).}$ In our tagging experiments we have mainly been using internal **steel** tags as will be evident from this and earlier reports from the taggings (Fridriksson & Aasen 1950, 1952). In theestimation of the stock the results from the internal taggings only will be considered.

To the actual number of tags returned to the proper authorities, we may allow for a certain number of tags lost after recovery. This problem, however, is greatly simplified by the fact that the overwhelming majority of the returns come from the magnet-separators which have been installed in the reduction plants. In the factories there are only **a few** workers who attend to that part of the machinery where the magnets are placed, and thus we have only to deal with a fairly limited number of people. In all the plants there are placed/with detailed instructions/poste of what to do with the recovered tags. The object and importance of the tagging experiments are explained, and in order to further stimulate the interest a worthwhile reward is offered for each recovery. This last is not the least important in carrying the tagging scheme with due respect to the genuine interest on the part of the managements and employees of the reduction plants. The premium paid is evidently so tempting that it is reasonable to suppose that the finder will try to get his money. In some few cases there have been reports on losses of tags after recovery. In such cases no reward is paid unless the numbers are noted and the actual finding is certified by reliable witnesses. Such reports run about one per mille of the total returns and may be regarded as insignificant. In a couple of instances false tags have been forwarded. They are **easily** spotted and no reward is paid. Their number is quite negligible. Tags may also be rendered unreadable in the machinery. For such tags the premium is paid to encourage reports of this kind. The number of unreadable tags is about three per mille of the total, and may be disregarded. That tags should be kept for souvenirs is not very likely since herring tags are now a quite familiar object in the factories, and it is likewise not probable that a significant number of recoveries should fail to be forwarded through neglect. As a whole we may be justified in disregarding losses of tags after recovery in the reduction plants. Without doubt the small error thus introduced will be completely overshadowed by the error arising from another source presently to be dealt with. As wel known, only a part of the catch is reduced to oil and meal. We may well assume that there will be proprotionately the same amount of tags in **the other** part used in fresh frozen, or cured condition. It is easy to correct for the number of overlooked recaptures in this part since the factories keep very accurate records of the reduced quantity. The discrepancy emerging from this operation would not amount to much. In the same way we may cut out and correct for the amount going through factories without magnet-separators or with faulty installations. But the question still remains how many tags, going through a plant with satisfactory magnets, will get stuck in the machinery or fail to show up on the separator for other reasons. No doubt there will be a substantial amount of recaught tags disappearing this way. To overcome this difficulty the efficiency of the magnets has been tested by tagging a known number of herring and placing them on the conveyor-belt from the storage bins. The fractior between the recovered tags and the tagged number provides an estimate of the efficiency of the magnet. Such efficiency tests have been carried out in most of the plants, but unfortunately it has not been possible to cover every factory in all years. These tests may sometimes show varying figures from year to year and even within the same season for the same factory in which case we may choose one or the other or taking the average value if the results are fairly close. Obviously, here may be introduced errors which seriously will affect our calculations. It is/comforting thought that since we operate with many plants the errors will supposedly be on either side of the correct figure and thus in the end be evened out. As a result of the preceding discussion the following expression for equation (3) emerges:

$$R = \frac{r}{e} \cdot \frac{c}{p} \quad \text{where}$$

r is the actual number of returns,

e the efficiency of the magnets,

c the landing figure, and

p quantity reduced in plants

since r, c and p are precisely known this expression demonstrates clearly the prime importance of e.

$\underline{t = \psi(T).}$ As soon as a batch of tagged herring is liberated on the fishing ground, things start happening which will reduce the number. When analysing these reductive agents, we might as well start thinking in terms of seasons because both the Icelandic and the Norwegian fisheries for mature herring are typically seasonal.

It is important to know what is left of the tagged fish when the season closes. Any tagging mortality and shedding of tags will presumably take place relatively soon after tagging. It is then possible to investigate empirically whether excessive mortality is induced by the tagging or if any shedding occurs. In Report No. 1 on the taggings is referred to some experiments with respect to the vitality of the herring after tagging. The conclusion drawn from these experiments was that the tagging did not affect the herring seriously when properly executed on fish in good condition (Fridriksson & Aasen, 1950). The fact that tags are still returned in number after six years in the sea, supports this view. So do also the results from the double taggings, in which both internal and external tags are fitted to the fish. Doubly tagged herring have been brought in to the Marine Research Institute in Bergen after different lengths of time in liberty. Although the material is scanty for a thorough judgment, it seems that the wound show signs of healing after a fortnight. It may be visible for a couple of months, but after one year in the sea, the wound is completely healed and not even a scar can be seen. In no case the internal tag could be seen to have done damage to vital organs, but they are frequently found inside the gonads which is quite naturel since it is mostly full herring which have been doubly tagged. Wounds in the gonads are evidently not fatal. The tags show never any signs of corrosion and as a whole we may conclude that internal tags cause no harm which is not healed after comparatively short time. With the evidence from the vitality experiments, supported by the observations on the internal tags in recaught doubly tagged herring, and further corroboration from the returns six years after tagging, it is reasonable to assume that no significant excessive mortality is induced by the tagging.

Parallel with the "live" experiments in 1948 and 1950, there were also carried out shedding tests. The first of these experiments yielded a shedding percentage of 1% after 14 days. The second experiment showed no shedding of tags after 19 days (Fridriksson & Aasen, 1950). According to this, shedding may be regarded as insignificant. There is, however, evidence which contradicts this conclusion. In two cases in 1952, the internal tags were reported missing in recaught doubly tagged herring. One of these reports came in from Sweden, the other one from Scotland, and these observations leave doubt as to the validity of the earlier conclusion regarding the shedding. These herrings were tagged in the first larger scale doubly tagging and the technique has since then been completely revised by introduction of the "tagging sluice". From the later experiments there are no records of missing internal tags. The question will receive close attention in the future. In the meantime, however, we maintain the first conclusion that no significant shedding takes place with internal taggings when properly executed.

When tagging mortality and shedding thus may be ruled out as insignificant, the only other sources for depletion of the tagged number of fish within the tagging season are natural and fishing mortality. The first of these cannot be evaluated at present, and the other will also offer difficulties. Because of the time lapse necessary for the tagged herring to spread in the stock, we cannot be sure that the tagged fish will be caught in the same proportion as the untagged. The calculation of the probable number of recaught tags within the tagging season is thus rendered difficult. Fortunately, the returns are few. The actual number of returns must be reckoned in per mille, and the error introduced when disregarding them will not seriously affect the result. This is particularly true for the Spring herring taggings executed at the very end of the season. (For one tagging in 1951, 8B, executed in inshore waters, the returns were very numerous. This experiment will have to be discarded for the stock calculations).

After the herring has left the fishing grounds, there are two possible ways of accounting for the number not returning the following season. One part will meet death for some reason. The quotient between the remaining and the original number of tagged herring we will call the coefficient of survival, ρ . We cannot be sure, however, that all the surviving herring will be present on the fishing grounds in the next season. It has been customary to regard the Norwegian winter herring as a fairly well defined tribe which only to a moderate **extent** intermixes with the herring tribes in adjacent waters. The taggings have revealed, however, that, in some years at least, substantial numbers migrate into the North Sea and the Skagerak and mix with the herring there (Fridriksson & Aasen, 1952, Aasen, 1953). This observation is not new, for Einar Lea found the same general feature many years ago through his scale studies (Lea,   ). This "dispersal" has an important bearing on our problem. It may and may not be that the herring spread out in this manner, will be lost in the future for the spawning shoals on the Norwegian Coast. The taggings have yielded evidence that herring may visit entirely different spawning grounds in different years (Fridriksson & Aasen, 1952). We should keep in mind that it is not only the North Sea and Skagerak areas that may draw on the Norwegian winter herring and diminish their number on the usual grounds. Extensive spawnings undoubtedly take place, in some years at least, on the Helgeland banks and outside the Lofoten Island and Vesteraalen (Runnström,   Wiborg,   ). These grounds are not fished for herring, and the taggings have accordingly given no evidence whether tagged herring may be lost through "dispersal" this way.

To account for the tagged herring disappearing in this manner, we introduce a dispersal coefficient expressing the quotient between the herring moving to other grounds and the original number. It is more convenient, however, to calculate with the complement to this quotient, an expression we will term the "gathering coefficient" and denote it by γ . We may assume that the dispersal will be determined from the route the herring takes when leaving the fishing grounds. The natural mortality has by then taken an insignificant toll only and we may regard the gathering coefficient γ and the survival coefficient ρ as independent of each other. Introducing the parameters γ and ρ in (4) this expression takes the form:

$$t = T\gamma\rho \quad \text{where}$$

the product $\gamma\rho$ denotes the quotient between the returning herring and the original numbers. As will be seen, within season recaptures, tagging mortality and shedding effects, are disregarded in accordance with the preceding discussion. The first of these will probably not be quite insignificant except for the Spring herring tagging.

Substituting the expressions for (2), (3), and (4) in (1) and re-arranging, we get our stock figure:

$$S = T\gamma\rho \cdot \frac{e.p}{r} \qquad (5)$$

If we want the stock expressed in number of individuals, we have to multiply p with the average number of herring per measuring unit:

$$S = T\gamma\rho \cdot \frac{e \cdot p}{r} \cdot \bar{a}$$

and this expression simply states that the stock is equal to the tagged herring present, multiplied by the ratio of untagged to tagged fish. This statement is rather self-evident, and if no dispersal existed, the stock-calculation would be a rather straight-forward task. Let us examine such a case. If we in an experiment tag a number T1 , there will after one year be $T_1\rho_1$ left when ρ_1 is the coefficient of survival in the first year. We will assume that one year is amply sufficient for the tagged herring to get thoroughly mixed in the stock. In the second year this tagging yields $r_1^{(2)}$ returns of an amount of $e_2 p_2$ cleared for tags. The stock is then in year 2:

$$S_2 = T_1\rho_1 \frac{e_2 \; p_2}{r_1^{(2)}} \qquad (6)$$

For the next year we get with analogous symbols:

$$S_3 = T_1\rho_1\rho_2 \frac{e_3 p_3}{r_1(3)} \qquad (7)$$

If we now in year 2 had tagged an amount of T_2, we could construct another expression for S_3, likewise with analogous symbols:

$$S_3 = T_2\rho_2 \frac{e_3 p_3}{r_2(3)} \qquad (8)$$

(7) and (8) yield:

$$\rho_1 = \frac{T_2 \cdot r_1^{(3)}}{T_1 \cdot r_2^{(3)}} \qquad (9)$$

which together with (6) gives:

$$S_2 = T_2 \cdot \frac{r_1^{(3)}}{r_2^{(3)}} \cdot \frac{e_2 \; p_2}{r_1^{(2)}} \qquad (10)$$

This equation, (10), is important, because, if we could assume that the herring tagged in a season would disperse in the same manner as the untagged, the same expression (10) would be obtained:

$$S_3 = (T_1\gamma_1\rho_1)\gamma_2\rho_2 \frac{e_2 \; p_2}{r_1^{(3)}} \qquad (11)$$

$$S_3 = T_2\gamma_2\rho_2 \frac{e_2 \; p_2}{r_2 \; (3)} \qquad (12)$$

From (11) and (12) we derive:

$$\gamma_1\rho_1 = \frac{T_2 \; r_1^{(3)}}{T_1 \; r_2^{(3)}} \qquad (13)$$

which together with (5) yields (10). However, we cannot be sure that the dispersal will be the same since the within-season tags are not evenly distributed in the stock. Instead of (13) we get in this case:

$$\frac{\gamma'_2}{\gamma_2}\gamma_1\rho_1 = \frac{T_2 \; r_1^{(3)}}{T_1 \; r_2^{(3)}} \qquad (14)$$

where γ_2 and γ'_2 refer to the within-season tags and the stock respectively. The issue is still more complicated because γ_1 may be influenced by reentering of dispersed herring tagged in the first year. This, however, is a point of minor interes

What is important is that: $\frac{T_2\, r_1^{(n)}}{T_1\, r_2^{(n)}}$ from year 3 and onwards will be constant if there are no later immigrations of dispersed herring or, in case such immigrations do take place, the herring from the two taggings re-enter in the same proportion. That would be a rather odd coincidence to happen if different proportions of dispersed herring were going into different areas in the two years. By studying a series of $\frac{T_2\, r_1^{(n)}}{T_1\, r_2^{(n)}}$ we may therefore decide whether dispersals and re-entering have taken place. Fig. 1 represents, in diagrammatic form, the idea behind this structure and demonstrates how an irregular series (obtained by the 1948 and 1949 Spring herring taggings) may be explained in a rational way. The yearly coefficient of survival is chosen at 0.80 and applies both to dispersed and undispersed herring. Any dispersal after year 3 (1950) is not considered because it would not influence the proportion of the returns in this series and thus un-necessarily complicate the diagram which is shown for the purpose of illustration only.

It is obvious that such dispersal effects, if traced, will seriously affect any calculation of mortality rates and stock. It must be left to a consideration of the results to decide whether such calculations are possible or not.

2. Discussion of Results.

Since only the recaptures in Norway are numerous enough to attempt any quantitative treatment, this section will only deal with these data. In the Tables 1 - 5 are shown the distribution on the factories of the recaptures from the different experiments in the years 1950 to 1954. Before 1950 there were too few factories with magnets in Norway and the returns were accordingly too few for statistical treatment. These tables will also serve as an illustration of the development in the building up of the recovery-installations. The first row in the tables gives the year of recapture. In the second row are listed the different experiments. LH, SH and OH refer to Large herring, Spring herring and North Coast herring respectively. In this last is also included herring tagged in the Norwegian Sea. The symbols e and p has the same meaning as explained in the theoretical part. The tables include only tags from factories in which efficiency tests have been made, and will therefore not correspond with the figures given in the text tables and in this earlier reports.

Generally speaking we may say that the tags are reasonably well randomly distributed in the catches. In this first treatment, however, we shall not attempt to demonstrate this by any tests.

Table 1 - 1950

Factory No.	p.(hl)	e	e.p.(hl)	1948 S.H.	1948 O.H.	1949 S.H.	1950 L.H.	1950 S.H.	Total
1	147.532	0.97	143.106	4	1	4	0	2	11
2	201.052	0.96	193.010	1	1	2	0	0	4
5	104.929	0.94	98.633	1	1	2	0	0	4
7	123.169	0.87	107.157	1	0	1	0	0	2
12	73.157	1.00	73.157	0	0	2	0	0	2
17	40.349	0.94	37,928	0	0	1	0	0	1
18	230.181	1.00	230.181	0	1	4	0	0	5
23	340.507	0.39	132.798	2	2	4	0	2	10
29	261.024	0.67	174.886	1	0	0	0	0	1
31	415.402	0.89	369.708	1	1	3	0	0	5
42	158.991	0.78	124.013	0	1	1	0	0	2
43	116.040	0.97	112.559	3	1	2	0	0	6
Total	**2.212.333**	**0.81**	**1.797.136**	14	**9**	**26**	**0**	**4**	**53**

Table 2. - 1951

Factory No.	p.(hl)	e	e.p.(hl)	1948 S.H.	1948 O.H.	1949 S.H.	1950 L.H.	1950 S.H.	1950 O.H.	1951 L.H.	1951 S.H.	Total
1	160.526	0.97	155.710	1	0	2	0	1	0	3	0	7
2	206.626	0.96	198.361	2	0	3	1	1	1	2	0	10
5	109.226	0.94	102.672	0	0	0	0	0	0	2	0	2
7	125.028	0.87	108.783	0	0	1	2	0	0	1	0	4
11	198.969	0.53	105.454	0	0	0	0	0	1	0	0	1
17	47.465	0.94	44.617	1	0	0	0	0	0	1	0	2
18	249.253	1.00	249.253	2	0	4	0	0	1	6	0	13
23	315.131	0.39	122.901	2	1	4	0	2	0	3	0	12
29	220.189	0.67	147.526	1	0	0	1	0	0	1	0	3
31	418.790	0.89	399.423	1	1	1	5	1	1	7	0	17
35	438.625	0.18	78.953	1	0	1	0	0	0	0	0	2
37	242.557	0.95	230.429	0	1	3	0	0	0	0	0	4
38	258.200	0.59	152.338	0	1	1	1	2	2	2	0	9
40	125.075	0.67	83.800	0	0	0	1	0	0	0	0	1
42	447.319	0.78	348.909	0	3	0	3	2	4	1	0	13
43	181.889	0.97	176.442	1	0	2	0	0	0	1	0	4
Total	3.774.868	0.72	2.705.571	12	7	22	14	9	10	30	0	104

Table 3. - 1952.

Fact. No.	p.(hl)	e	e.p.(hl)	1948 S.H.	1948 O.H.	1949 S.H.	1950 L.H.	1950 S.H.	1950 O.H.	1951 L.H.	1951 S.H.	1951 O.H.	1952 L.H.	1952 S.H.	Tot.
1	186.531	0.97	180.935	3	1	1	1	1	2	1	4	1	2	0	17
2	253.455	0.96	243.317	1	1	1	0	1	1	0	4	3	1	0	13
5	125.365	0.94	117.843	0	0	5	0	0	2	0	5	3	0	2	17
7	164.492	0.87	143.108	0	1	0	0	0	1	1	0	5	1	0	9
8	112.826	0.78	88.004	0	0	1	0	1	0	0	1	1	2	0	6
11	153.997	0.78	120.118	1	0	1	0	0	0	0	6	1	0	1	10
15	213.626	0.91	194.400	2	0	3	0	0	2	0	6	2	0	0	15
17	42.226	0.94	39.692	0	0	0	0	0	0	0	0	0	0	0	0
18	243.759	1.00	243.759	3	1	1	1	2	0	4	11	4	1	0	28
20	280.171	0.97	271.766	5	0	2	1	1	2	2	9	5	0	0	27
22	37.244	0.88	32.775	0	0	0	0	0	0	0	1	0	0	0	1
23	456.830	0.87	397.442	1	0	1	1	2	2	2	4	2	0	1	16
29	146.563	0.93	136.304	0	0	1	0	0	0	1	0	1	0	0	3
31	562.801	0.89	500.893	1	1	2	1	1	1	2	1	6	3	9	28
35	472.537	0.35	165.388	1	0	0	0	0	0	1	0	0	0	0	2
37	320.845	0.75	240.634	0	0	0	2	0	1	2	2	4	16	0	27
38	327.947	0.71	232.842	0	0	1	0	0	0	0	2	1	0	0	4
40	121.100	0.74	89.614	0	0	1	0	0	0	0	1	3	2	0	7
42	538.400	0.89	479.176	4	0	1	5	0	1	4	0	9	8	0	32
43	185.133	0.97	179.579	1	2	3	2	0	1	1	6	4	1	0	21
52	328.564	0.88	289.136	0	2	0	0	0	0	2	0	0	11	0	15
Total	5.274.412	0.83	4.386.725	23	9	25	14	9	16	23	63	55	48	13	298

Table 4. - 1953

Factory no.	p.(hl)	e	e.p.(hl)	1948 S.H.	1948 O.H.	1949 S.H.	1950 L.H.	1950 S.H.	1950 O.H.	1951 L.H.	1951 S.H.	1951 O.H.	1952 L.H.	1952 S.H.	1952 O.H.	1953 L.H.	1953 S.H.	Total
1	69.351	0.97	67.270	1	0	0	0	0	0	1	0	1	0	0	9	1	0	13
2	112.352	0.96	107.858	0	0	0	0	0	0	1	2	3	0	0	9	0	0	15
5	78.919	0.94	74.184	0	0	0	0	2	1	1	2	1	0	3	5	0	0	15
7	112.380	0.98	110.132	1	1	0	1	0	1	0	0	3	1	1	6	0	0	15
8	94.229	0.78	73.499	0	0	1	0	0	0	0	1	1	0	2	8	0	0	13
11	111.535	0.78	86.997	0	0	3	0	0	0	0	0	3	0	5	14	4	0	29
12	59.332	1.00	59.332	0	1	1	1	0	0	0	2	0	0	2	2	0	0	9
15	146.130	0.91	132.978	2	0	1	0	1	1	1	3	2	0	9	9	0	0	29
16	150.543	0.99	149.038	1	1	0	1	0	1	2	7	1	1	8	9	2	0	34
17	28.318	0.94	26,619	0	0	0	0	0	0	0	0	0	0	1	2	0	0	3
18	171.492	1.00	171.492	2	1	0	0	1	0	0	7	1	0	12	8	0	0	32
20	308.359	0.97	299.108	1	1	3	0	0	1	3	10	0	3	9	7	0	0	38
21	216.065	1.00	216.065	1	1	2	0	0	0	1	7	2	2	8	16	0	0	40
22	39.336	0.88	34.616	0	0	0	0	0	0	1	1	0	0	0	3	0	0	5
23	194.320	0.87	169.058	0	0	0	0	0	1	2	0	2	0	3	14	2	0	24
24	158.064	0.83	131.193	0	1	0	0	0	0	2	1	0	1	0	3	2	0	10
29	163.349	0.93	151.915	0	0	0	0	1	0	0	0	3	0	0	14	0	0	18
31	270.362	0.83	224.400	2	2	0	0	0	2	1	6	6	0	7	27	2	20	75
35	303.340	0.35	106.169	1	0	0	0	1	1	1	1	2	1	0	18	0	0	26
37	222.199	0.75	166.493	0	0	2	3	0	1	1	4	7	1	1	18	0	0	38
38	224.253	0.71	159.220	0	0	1	0	0	0	1	1	0	0	0	4	0	0	7
40	81.903	0.74	60.608	0	0	0	1	0	1	0	0	1	0	0	3	0	0	6
42	312.802	0.89	278.394	2	0	1	2	2	0	1	4	9	5	0	22	0	0	48
43	190.662	0.97	184.942	0	0	0	1	0	2	1	0	6	2	1	11	0	0	24
45	59.066	0.66	38.984	0	0	1	0	0	0	0	0	0	0	0	1	0	0	2
52	88.413	0.88	77.803	1	0	1	0	0	0	0	1	0	1	0	2	0	0	6
55	33.740	0.96	32.390	0	0	0	0	0	0	1	0	0	0	1	2	0	0	4
Total	4.000.814	0.85	3390.757	15	9	17	10	8	13	22	60	54	18	73	246	13	20	578

Table 5. - 1954

Factory no.	p.(hl)	e	e.p.(hl)	1948 S.H.	1948 O.H.	1949 S.H.	1950 L.H.	1950 S.H.	1950 O.H.	1951 L.H.	1951 S.H.	1951 O.H.	1952 L.H.	1952 S.H.	1952 O.H.	1953 L.H.	1953 S.H.	1953 O.H.	1954 L.H.	1954 S.H.	Total
1	101.349	0.97	98.309	1	1	0	2	0	0	0	0	3	0	0	2	0	0	8	0	0	17
2	177.207	0.96	170.119	0	0	5	0	0	0	0	4	4	1	0	11	0	2	11	1	0	39
5	94.814	0.80	75.851	0	0	0	0	0	0	1	1	0	0	3	4	0	0	7	1	0	17
7	178.288	0.98	174.722	0	1	3	0	0	2	1	1	4	1	2	10	1	0	7	4	0	37
8	121.087	0.78	94.445	2	1	3	0	0	1	0	2	2	0	3	5	0	0	6	7	0	32
9	133.938	0.83	111.169	0	0	0	1	0	0	0	1	0	0	1	3	0	0	5	1	0	12
11	138.650	0.83	115.080	1	0	1	0	1	0	0	1	2	0	2	6	0	1	8	4	0	27
15	193.384	0.91	175.979	0	0	1	0	0	0	0	2	1	1	6	8	1	5	7	5	0	37
16	192.399	0.99	190.475	0	0	4	0	0	1	0	3	2	0	5	16	2	3	10	8	0	54
17	41.546	0.93	38.638	0	0	0	0	0	0	0	2	1	1	0	1	0	0	0	0	0	5
18	243.921	0.95	231.725	1	2	3	3	1	0	0	5	7	0	8	14	2	2	12	5	0	65
20	312.367	0.89	278.007	0	1	1	1	0	0	0	5	3	0	7	16	1	2	11	3	0	51
21	278.424	1.00	278.424	1	0	1	0	0	1	0	3	5	1	4	7	3	1	14	7	0	48
22	53.210	0.94	50.017	0	0	1	0	0	0	0	1	0	0	1	3	0	0	5	4	0	15
23	301.233	0.80	240.986	1	0	1	0	0	1	0	3	3	1	3	16	0	3	9	7	0	48
24	495.000	0.83	410.850	1	1	1	5	1	1	6	4	6	1	2	33	0	1	25	10	2	98
29	270.402	0.80	216.322	1	1	1	2	2	1	1	2	3	0	13	12	2	2	13	2	1	59
31	406.963	0.70	284.874	2	1	7	0	3	1	5	3	4	4	5	28	2	3	22	11	3	104
33	270.789	0.88	238.294	0	1	1	1	1	1	1	1	3	0	7	18	3	0	14	3	0	55
35	417.695	0.68	284.033	0	1	2	1	0	1	1	1	6	2	1	23	0	0	13	0	0	52
37	416.154	0.75	312.116	1	1	4	0	0	0	2	4	4	2	3	13	1	2	11	1	6	55
38	513.120	0.71	364.315	2	0	0	0	0	0	2	2	2	1	6	8	0	4	6	6	8	45
40	177.410	0.82	145.476	0	0	0	0	0	0	1	1	1	2	0	5	0	0	5	0	1	16
42	629.338	0.82	516.057	0	0	1	2	2	2	4	7	13	3	15	36	1	2	24	2	19	133
43	402.404	0.97	390.332	0	0	2	0	0	0	0	8	1	3	4	11	0	3	11	6	10	59
45	171.310	0.66	113.065	0	0	0	0	0	0	0	0	2	1	2	7	0	1	3	0	0	16
52	164.156	0.88	144.457	1	0	1	0	0	0	2	1	2	1	3	10	0	0	5	0	0	26
55	38.071	0.96	36.548	0	0	0	0	1	0	0	0	0	0	1	2	0	0	2	0	0	6
Total	6.934.629	0.83	5.780.685	15	12	44	16	12	13	27	68	84	26	107	328	19	37	274	96	50	1228

In Table 6a is presented a summary of the total number of recoveries. In the top part of the table is given the year of tagging, the number tagged, and the category of herring. The within season recoveries are left out. In Table 6b the recaptures are expressed as % returns per million hl. There are two striking features of this table. Firstly, we should normally expect the percentage of recoveries to decrease with time because of the mortality. We notice, however, that most of the experiments do not conform to this rule. In 1953, for instance, we have an almost allover rise in the figures giving the % returns per million hl (Table 6b). Secondly, we see that the herrings tagged off the Icelandic North Coast and in the open ocean yield relatively more returns than the herrings tagged on the Norwegian Coast except for 1948. Generally, the Large herring gives the lowest percentage of recoveries. The Spring herring tagged in 1950, however, is an exception.

Table 6a.-Number of returns for the different experiments.

Year	1948	1948	1949	1950	1950	1950	1951	1951	1951	1952	1952	1952	1953	1953	1953
of Re-	6018	7475	8261	9085	11215	1827	5998	9986	5076	10295	10763	17308	10080	10046	10181
capture	SH	OH	SH	LH	SH	OH	LH	SH	OH	LH	SH	OH	LH	SH	OH
1950	14	9	26												
1951	12	7	22	14	9	10									
1952	23	9	25	14	9	16	23	63	55						
1953	15	9	17	10	8	13	22	60	54	18	73	246			
1954	15	12	44	16	12	13	27	68	84	26	107	328	19	37	274

Table 6b. - % Returns per million hl.

1950	1.30	0.67	1.75												
1951	0.74	0.35	0.98	0.57	0.30	2.03									
1952	0.87	0.28	0.68	0.35	0.18	2.00	0.87	1.41	2.48						
1953	0.74	0.36	0.61	0.33	0.21	2.10	1.08	1.77	3.14	0.52	2.00	4.18			
1954	0.43	0.28	0.92	0.31	0.19	1.23	0.78	1.18	2.86	0.44	1.72	3.27	0.33	0.64	4.66

The first of these phenomenons may be explained in part by failure of recruitment to the stock in 1953. It is also a fact that the herring in that year was exceptionally large. But that would not account for the rise in the per mille returns per unit of catch. There must also have taken place a re-immigration of dispersed tagged herring which has been on some other grounds in the previous season or seasons. In 1954 the situation seems more normal in corroboration with the fact that the sampling of the herring shows that the recruitment to the stock was good. The returns for the 1949 Spring herring, however, shows a marked increase in their relative abundance, showing that a re-immigration must have taken place. It may be of interest to study this more detailed. In Table 7 are presented the expression equivalent to (14), separately for the Spring herring (7a), the Large herring(7b), and the North Coast herring (7c). Each of the experiments within the different categories is compared with all the others. To the left in this table are given the years of recapture. The top part and the right hand side give the different experiments. The table is then to be read like a co-ordinate system, for instance, the Spring herring taggings for 1948 and 1949 give 0.74 in 1950 and 0.47 in 1954. If there were no disturbing effects of dispersal and re-entering, this table should have the following properties: 1. all the figures should be lower than one, 2. there should be a regular decrease from left to right within each partition, 3. read vertically each column should give the same figure for all years. An inspection of this table reveals such a spreading of the figures, that all the experiments seem to have been effected by dispersal (and re-entering), some very seriously.

Table 7.

a. Spring herring

	1949	1950	1951	1952	1953	
1950	0.74					
1951	0.75	2.49				
1952	1.26	4.77	0.61			1948
1953	1.21	3.50	0.41	0.37		
1954	0.47	2.08	0.37	0.25	0.68	
1951		3.32				
1952		3.78	0.48			1949
1953		2.89	0.34	0.30		
1954		3.71	0.68	0.54	1.45	
1952			0.15			
1953			0,15	0.11		1950
1954			0.16	0.11	0.29	
1953				0.89		
1954				0.69	1,85	1951
1954					2,70	1952

b. Large herring

	1951	1952	1953	
1952	0.40			
1953	0.30	0.63		1950
1954	0.39	0.70	0.93	
1953		2.09		
1954		1.78	2.39	1951
1954			1.34	1952

c. North Coast herring.

	1950	1951	1952	1953	
1951	0.17				
1952	0.14	0.11			1948
1953	0.17	0.11	0.08		
1954	0.23	0.10	0.09	0.06	
1952		0.81			
1953		0.67	0.50		1950
1954		0.43	0.38	0.26	
1953			0.75		
1954			0.87	0.62	1951
1954				0.70	1952

If we interprete the evidence furnished by Tables 6 and 7 from the viewpoint of the dispersal hypothesis, the mechanism producing the obtained figures would be that the mass of herring congregating on the spawning grounds on the Norwegian coast in the wintertime, split up in several bodies which may be separated for many years before rejoining. More likely than not the main part will follow the highway to the feeding grounds stretching from north of the Faroes past the North-East Icelandic Coast to the Jan Mayen area. Other parts, we know, may enter the North Sea region. Still others may take different courses which we do not know of. It seems not unreasonable to suppose that when a comparatively small number of tagged herring is injected in the huge stock, these may be carried off in numbers by one of the "stray" bodies before having time to penetrate properly into the main body. This herring may later rejoin as was the case in 1952 with the Spring herring tagged in 1948, in 1954 with the Spring herring tagged in 1949, and in 1953 with herrings from several of the experiments. Also for the Large herring may be quoted similar examples; for instance the 9th liberation, experiment 8B at Lotra in 1951 (1010 herring) gave no returns in 1952, 5 returns in 1953, and 12 in 1954. These examples show clearly that taggings, which perhaps at first seem to be a failure, well might be succesful; but it is still an unsolved riddle why the Large herring generally should be more susceptible to dispersal than the Spring herring. It is more easily conceivable that the tagged North Coast herring, being injected more directly into the major body on the main high-road should appear more numerous in the catches. We have, to be sure, similar effects here also, due probably to the fact that the tags have been injected mostly on the very fringes of the distribution. In this connection it is significant that the taggings in the Norwegian Sea proper in 1951 (the only open ocean tagging comprising a substantial number) gives higher recapture percentage in the following two years than does the North Coast tagging executed in 1951. In 1954 the results are practically the same.

The problems here discussed are highly interesting and demonstrate the intricasy of the herring migrations. The explanation offered throw new light on this complex phenomenon, and it also gives a rational explanation to certain irregularities in the age-distributions; for instance, that a regularly decreasing year-class may show a sudden rise as we have seen happen once and again in the Norwegian Winter herring. But, unfortunately, any exact calculation of the stock strength and the mortality rates is rendered impossible for the present through these complications. The parameters introduced in the theoretical part cannot be eliminated with our present series of observation; but opportunity to do so may well arise by further investigations. At present we have to be content with rough estimates.

For the evaluation of the mortality rate we will disregard the Spring herring taggings of 1950 and 1953, all the Large herring taggings, and the 1948 North Coast taggings since these experiments yield absurdly high or hopelessly low figures when compared with the other experiments (Table 7). We may now obtain an estimate of the yearly survival rate by averaging the remaining figures, - assuming that the ups and downs will balance each other at the end. We then get the following figures: $\bar{s} = 0.79$, $\bar{s}^2 = 0.50$, $\bar{s}^3 = 0.42$ and $\bar{s}^4 = 0.31$. The grand average survival rate will thus be $\bar{s} = 0.75$. This figure is not so very far from Lea's average survival rate of $\bar{s} = 0.81$, found by analysing a long series of age-determinations of the Norwegian Winter herring (Lea). Moreover, the observations do not cover the same period and the hugely expanded fishery in the post-war years may account for some of the discrepancy.

For the stock estimates we may use an indirect approach which will give some information about the stock present on fishing ground. We know that there is a continuous loss of tags due to mortality and the original tagged amount is the upper limit for the number present on the ground. From this follows that the experiment giving the highest percentage of returns per unit of catch may be used for establishing an estimate of the lower limit for the fishing mortality, From this may further be calculated the upper limit of the stock level (i.e. stock present on the fishing ground). Using the figures for OH in Table 6, we obtain the following values:

	1951	1952	1953	1954
Fishing mortality (lower limit) %	1.9	2.2	3.0	5.4
Stock level mill. (upper limit) tons	50	40	24	22

Judging from these figures there seems to have been a rapid decline since 1951 of the abundance of herring on the usual Winter herring grounds, somewhat checked in 1954. These figures are based on the North Coast taggings. We cannot compare these values for every year with the results from the taggings on the Norwegian coast owing to the difficulties mentioned earlier. For 1954, however, the Spring herring tagged in 1949 seems to have re-joined in force. Assuming that these have had a yearly reduction of 25% (the survival rate 0.75), we may calculate the probable minimum fishing mortality for those herrings in the same way. We will then find a value for the fishing mortality of the same order of magnitude as for the taggings on the North Icelandic Coast in 1953 (a little lower). The same applies to the 59th liberation (Large herring) previously mentioned, the order of magnitude is the same, but this time a little higher. This is corroborating evidence of some importance. These experiments are widely distributed in time and place and are yet linked up fairly well through the estimated mortality rate. Moreover it is in conformity with the dispersal hypothesis which, in fact, explains satisfactorily [+)] these rather unexpected results from the taggings and brings some order in an intricate series of numbers otherwise incomprehensible. We must stress that no undue importance should be placed on the stock figures given. They are solely to be interpreted as maxima figures i.e. that the stock cannot be any larger, provided of course, that our basic assumptions hold good. For that matter not even the apparent trend might be right. It is, however, reasonable to suppose that the estimate for 1954 - with the corroborative evidence, - might not be far from the truth, although too high. We might, therefore, conclude that the fishing mortality this year runs about 5-6% and that the stock accordingly lies about 20 million tons.

[+)] In broad outlines, the details are not followed up here.

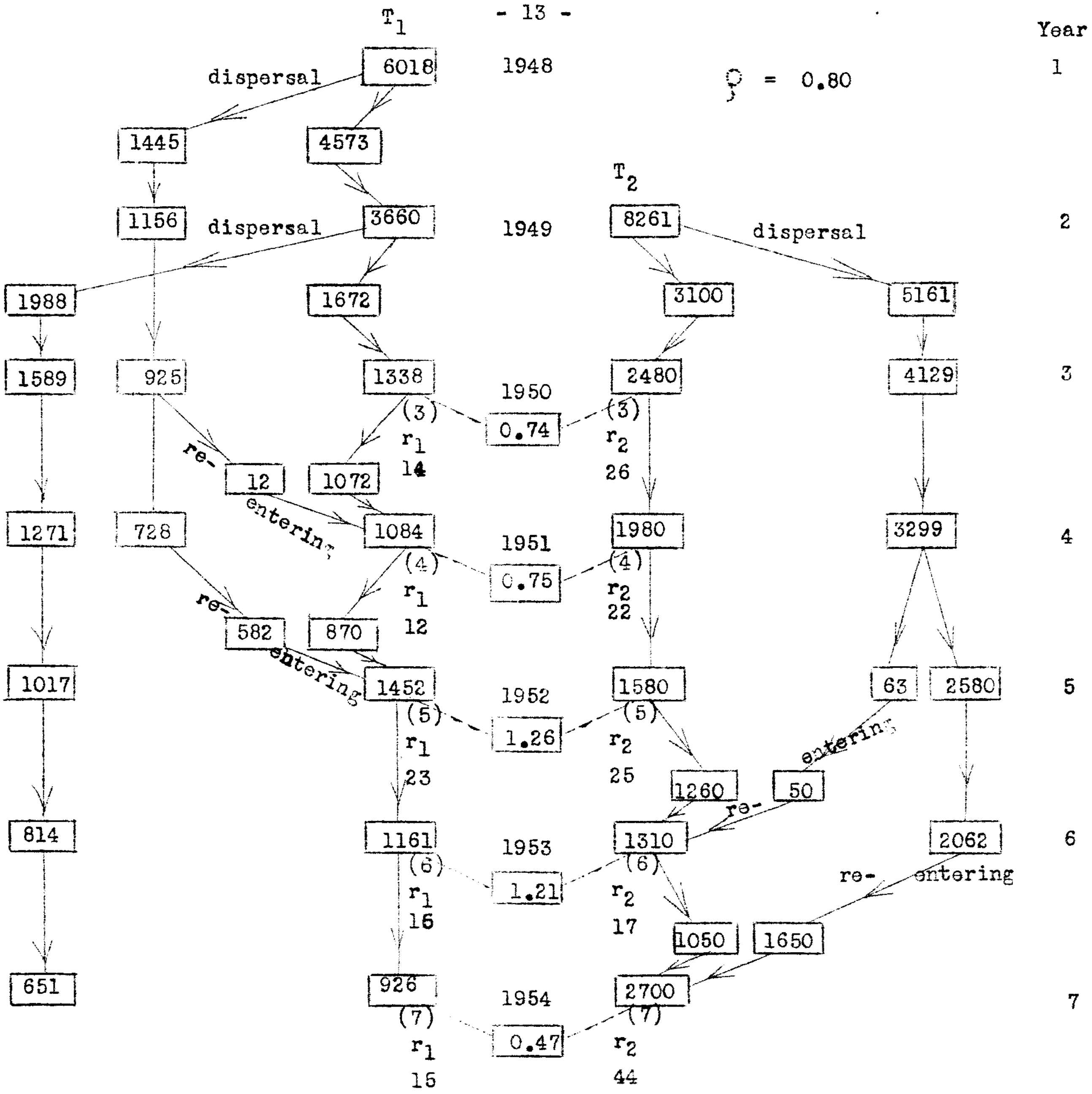
T1
1948
ρ = 0.80
Year
1
6018
dispersal
1445
4573
T2
1156
3660
dispersal
1949
8261
dispersal
2
1988
1672
3100
5161
1589
925
1338
1950
2480
4129
3
(3)
0.74
(3)
r1
r2
re-
12
1072
14
26
entering
1271
728
1084
1951
1980
3299
4
(4)
0.75
(4)
r1
r2
22
re-
582
870
12
entering
1017
1452
1952
1580
63
2580
5
(5)
1.26
(5)
r1
r2
entering
23
25
1260
50
814
re-
1161
1953
1310
2062
6
(6)
1.21
(6)
re-
entering
r1
r2
15
17
1050
1650
651
926
1954
2700
7
(7)
0.47
(7)
r1
r2
15
44

Fig. 1.