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Method of Estimating the Effect on Trawl Catches of Changes in Trawl Selectivity

by

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Introduction of fishery zones calles for more exact controlling of commercial stocks abundance and more rational fishery as a whole. The latter depends in the first hand on optimal intensity of catches and optimal selectivity of fishery. Since changes in gear selectivity result in stock changes in years to follow, while estimating gains and losses one should use a method which enables to calculate the dynamics of gains and losses in subsequent years too.

Gulland's method (1961) of the estimation of the effect on catches of changes in gear selectivity is widely used for the calculation of the influence that modification in selectivity of trawl's cod-ends has over the results of fishery. However this method gives no chance to trace the dynamics of the catches with introduction of a new cod-end's mesh. Besides that, Gulland's method is not precise and has little theory behind it. To end, the method is wrong itself to consider dynamics of age groups and not of size groups in catches and sifted fish, because in view of uneven growth several linear groups of fish happen to be united in one age group.

The present work suggests a method of direct count of subsequent catches of the fish earlier sifted by the cod-end with a new mesh. The present method in some aspects is similar to cohort analysis, i.e. several age groups of fish released by a selective cod-end resemble generation cohorts analysed during estimation of stock. This method has nothing to do with any selected differential equation of the catch but catches of every age group in any subsequent year of fishery are co-ordinated with a selectivity coefficient of fishing gear with a new mesh. The method provides for direct and strict count of weight growth of every age group of fish in any year of fishery, while the dynamics of catches in subsequent years of fishery is determined by a precise transitional period. The end of the latter is characterized by a new fishery level and is determined by absence of the last age-group (the first age group of fish released in the first year of fishery from a gear with a new mesh) which is due to its old age and more rarely to its being completely taken by fishery.

Material and method

For the calculation there was used information of cod and deepwater redfish in some areas of north-west Atlantic collected by PINRO. This comprises size-age keys and the curves of cod-end's selectivity of trawls, both with old and new mesh for the cod in Central Labrador area (CL) (Table 1) and for males and females of deepwater redfish in Flemish Cap (FC) (Tables 2, 3) and Great Newfoundland Bank (GNB) (Tables 4, 5). In calculations there were also used the values of instantaneous commercial mortality rate F and of natural mortality rate M for cod and deepwater redfish of the said areas.

As a calculation method there was used the one given below which we call the Method of Analysis of Selectivity Cohorts (ASC). With instantaneous change for a new mesh everysubsequent year of fishery will sift the fish of younger age.groups, though the fish earlier released which has grown by the time of subsequent year of fishery will be taken. This category of fish will be taken on the basis of selectivity of trawl's cod-end with a new mesh size. Therefore for calculation it is sufficient to consider the dynamics of catches of the fish once sifted by the trawl with a new mesh (the fish of the first cohort) during the whole transitional period the end of which is determined by disappearance of the last age group (the youngest age group of the released fish). The catches in every subsequent year of fishery will be accumulated catches of the chosen calculation scheme. Beverton-Holt equation being regected, there has to be reconsidered the expression used for the calculation of number of taken fish from an age-group. In particular, we do not use for exploitation rate the formula

$E = \frac{F}{F+M} (1 - \exp (-F + M))$, as a result of integrated catch equation of the Beverton-Holt type.

Instantaneous commercial mortality rate F is usually found with the help of the data concerning abundance of older age groups in catches. Selectivity is to diminish F values for medium and younger age-groups of fish. Therefore F value should also be considered within the range of trawl's selectivity, the more so that the range of some fish species comprises their whole life cycle. Thus according to PINRO materials (Sahno, Sadohin) for deepwater redfish of the GNB area selectivity rate μ even at the age of 21 is different from 1 : $\mu = 0.9$ The result of the study of cod-end's selectivity and further use of the size-age key is the Selectivity Curve $\mu(t)$ (Fig.1a). Asymptotic level of $\mu = 1$ is likely to correspond to the traditionally determined F value in the theory of fishery. Therefore by multiplying ordinate of the graph taken from Fig. 1a by the value of F we are going to obtain the curve of commercial mortality of fish F_s (t) with regard to actual trawl's selectivity (Fig.1b). Therefore

$$F_s = \mu F \qquad (1)$$

Thus in the chosen calculation scheme instead of the constant commercial mortality F for all age groups there is introduced the variable selective commercial mortality. F_s which is determined by trawl's selectivity and is specific for every age group of a particular year of fishery. The natural loss of released fish is handled according to exponential principle. It is assumed that fishery does not last long so that the losses from natural mortality and from commercial one are calculated separately. Therefore the balance of fish before the new fishery period is determined by e^{-M} factor. The catch of age group i released by a new trawl will be as follows:

$$C_i = N_{i\ nat\ bal}\ (1 - e^{-\mu_i F}) \tag{2}$$

$N_{i\ nat\ bal}$ - the balance of fish belonging to i age group after natural loss which followed the previous fishery season;

μ_i - selectivity of the new trawl regarding age group;

F - instantaneous commercial mortality rate of older age groups determined by traditional methods.

Here are the formulae for the first two years of fishery. The net loss of catches in weight during the first year of fishery with a new trawl is

$$W_{los} = \sum_{i=i_o}^{i=i_f} w_i\ N_{iR} \tag{3}$$

i_o, i_f - original and final age of fish released by the trawl with a new mesh in the first year of fishery;

N_{iR} - number of fish of i age group released by a new cod-end mesh.

Evidently $C_1 = 0$. Before the second year of fishery as a result of natural mortality the abundance of every age group will be smaller:

$$N_{(i+1)nat\ bal} = e^{-M}\ N_{iR} \tag{4}$$

The catch of the i + 1 age group of released fish at the end of the second year with regard to expression (2) will be as follows:

$$C_{2,i+1} = e^{-M}\ N_{iR}(1-\exp(-\mu_{i+1}\ F)) \tag{5}$$

or the same expressed in weight:

$$W_{2,\ i+1} = e^{-M}\ N_{iR}\ w_{i+1}(1-\exp(-\mu_{i+1}F)) \tag{6}$$

w_{i+1} - weight of fish of i + 1 age group.

The total catch W_2 at the end of the second year of fishery will be

$$W_2 = \sum_{i=i_o}^{i=i_f} W_{2,\ i+1} \tag{7}$$

The balance of fish belonging to i + 1 age group after the second year of fishery is equal to

$$N_{2,\ i+1(bal)} = N_{1R}\ e^{-(M - \mu_i\ F)} \qquad (8)$$

As soon as during the second year of fishery with a new trawl fish is released for the second time (the release of the second cohort) which determines the same loss W_{los} (3), the total loss of the fishery due to the catches of W_{los} (7) will be lower and the result of the fishery for the second year will be

$$\Delta W_2 = W_{los} - W_2 \qquad (9)$$

The same way the following years of fishery are calculated There is used for these calculations the curve of weight growth of fish of this particular commercial stock which is obtained from biologic data and is graphically smoothed. Judging by experience the precision of graphical smoothing of weights of age groups is quite acceptable. Calculation is made till the last year of fishery in transitional period. The catches of all the cohorts of released fish are determined as an accumulated catch by the year j of fishery:

$$W_{j-1} = \sum_{i=1}^{i=j-1} W_i \qquad (10)$$

with $C_1 = W_1 = 0$. Then by year j of fishery gains-and-losses in catches resulting from introduction of new mesh in cod-end will be

$$\Delta W_{j-1} = W_{j-1} - W_{los} \qquad (11)$$

The same as in the used experimental method, the suggested method needs correlation of gains-losses in catches with the catches by an old trawl. If these are W_{old}, comparative gains-losses in catches will be as follows:

$$\Delta \bar{W}_1 = \frac{W_{los}}{\bar{W}_{old}} \cdot 100\%;\ \Delta \bar{W}_2 = \frac{\Delta W_2}{\bar{W}_{old}} \cdot 100\% \ ..\ \Delta W_n = \frac{\Delta W_n}{\bar{W}_{old}} \cdot 100\% \qquad (12)$$

The discribed calculation scheme is not difficult to be presented in form of index formula for the catch in year j of fishery in transitional period:

$$W_j = \sum_{n=1}^{j} e^{-nM} \sum_{f=i_o}^{i_f} w_{f+n} \left(1-\exp(-\mu_{f+n})\right) \prod_{l=o}^{j-1} e^{-F\mu_{f+1,l}} \quad (13)$$

P - product, with l = o there should be $\mu_{f,o} = o$, that is $\exp(-F\mu_{f,o}) = 1$, the other values $\mu_{f+1,l} = \mu_{f+1}$. In this construction of the general formula there is overcome the difficulty of absence of the factor $\exp(-F\mu_{f+1,l})$ for the first year of fishery. Formula (13) determines the value of W_j in the expression (11). Relative values of gains and losses in every year of fishery in transitional period are calculated according to formula (12). On the basis of such calculation data there can be built the graph of fishery dynamics with the use of a new mesh in trawl's cod-end in transitional period.

As an example the present calculation scheme was used to determine gains and losses of cod and deepwater redfish fishery in some areas of north-west Atlantic with eventual change of the mesh size from 120 mm to 130 mm. For calculations there were also used estimated values of the rates F and M recommended by PINRO: for cod in CL area F = 0.45, M = 0.22, for deepwater redfish in FC area F = 0.10 M = 0.10 and in GNB F = 0.09, M = 0.10.

As the calculations according to the present method of ASC are made by age groups, the initial data based on size groups has to be transformed. For this purpose selectivity curve is built as function of linear size of fish l and with the help of size-age key l(t) is recalculated as the function of age of fish. Recalculation of the abundance of size groups released by a new mesh for the abundance of age groups is made somewhat differently. At first there is built the dependenc of the accumulated abundance of size groups of the released fish as function of their size. Then according to size-age key there is found the accumulated abundance of age groups belonging to those released by a new mesh. This transformation of groups in a test is effected, the latter being represented by catch while surveying selectivity curve. Following that, by method of backwards calculation the abundance of every age group is found which is needed for the present ASC method.

Results

The results of calculations according to the suggested ASC method in form of relative percentage of gains and losses in catch with a change for a bigger mesh are presented for cod in CL area in Fig.2, for deepwater redfish of FC and GNB areas in Fig. 3. As it can be seen in Fig. 2, the initial losses in cod catches are 5.2% and in deepwater redfish from 35% to 47%. The growth rate of catches in transitional period also turned out to be different. The transitional period of Labrador cod is 13 years. That of deepwater redfish was 23 years for the FC area and 20 years for the GNB area. At the end of the transitional period a new constant level of fishery is established. For cod it turned out to be positive - 0.5%. Yet for deepwater redfish of both regions fishery will not reach the same level, so that the new level will become negative effected by negative value of relative losses, which are stable and long-term ones. For the FC area losses will be 14% and for the GNB - 21%.

With new positive level of fishery the stepped graph of gains-and-losses dynamics in Fig.2 crosses the zero line of deviations, i.e. the line of former fishery. In this case besides the transitional period there should be introduced two more notions: the period when fishery reaches its former level and the period of full compensation of losses in catch. The former level of cod fishery will be reached in the CL area during the seventh year. As it has been mentioned, the deepwater redfish catches do not reach the former level of fishery within the transitional period. For the cod of the CL area the period of full compensation of losses makes 34 years, which is rather long time.

The results of the calculations cannot be considered optimistic. It could be attributed to lower growth rate of the Labrador cod. In process of calculations there was discovered high sensibility of the present ASC method to the growth rate of fish. It looks like actual yearly growth of fish of different age groups should be used for calculations.

Literature

Gulland J.A. The estimation of the Effect on Catches of Changes in Gear selectivity, J.Conseil, v.26, No.2, p.p.204-214, 1961.

Table 1. The table of initial data obtained by PINRO for calculation by ASC method of gains-and-losses dynamics with the change of cod-end's mesh from 120 mm to 130 mm in cod fishery in the Central Labrador area.

Length of cod cm	Number of fish (x 10^3 pcs)		
	taken with old mesh	taken with new mesh	released
34	0.007	-	0.007
37	0.016	0.003	0.013
40	0.047	0.014	0.033
43	0.097	0.038	0.059
46	0.242	0.121	0.121
49	0.431	0.297	0.234
52	0.816	0.694	0.122
55	1.031	1.000	0.031
58	1.288	1.288	-
61	1.099	1.099	-
64	0.668	0.668	-
67	0.295	0.295	-
70	0.115	0.115	-
73	0.023	0.023	-
76	0.017	0.017	-
79	0.008	0.008	-
82	0.004	0.004	-
85	0.006	0.006	-
88	0.004	0.004	-
91	0.003	0.003	-
94	0.003	0.003	-

The mass of fish taken with old mesh 12,094 t
The mass of fish taken with new mesh 11,518 t
Instantaneous commercial mortality rate 0.45
Instantaneous natural mortality rate 0.22

Table 2. **The table of initial data obtained by PINRO for calculation by ASC method of gains-and-losses dynamics with the change of cod-end's mesh from 120mm to 130 mm in deepwater redfish fishery in the Flemish Cap area**

Age, years	Number of fish x 10^6 pcs		
	taken with old mesh	taken with new mesh	released
4	0.056	-	0.056
5	-	-	-
6	0.203	-	0.203
7	1.209	0.302	0.907
8	1.466	0.528	0.938
9	1.959	0.882	1.077
10	1.454	0.727	0.727
11	1.264	0.746	0.518
12	2.132	1.364	0.768
13	1.989	1.353	0.636
14	2.094	1.445	0.649
15	1.957	1.429	0.528
16	1.498	1.094	0.404
17	0.733	0.557	0.176
18	0.625	0.500	0.125
19	0.648	0.531	0.117
20	0.388	0.334	0.054
21	0.284	0.247	0.037
22	0.187	0.170	0.017
23	0.029	0.027	0.002
24	0.009	0.009	-
25	0.006	0.006	-

The mass of fish taken with old mesh 11,733 th.t
The Mass of fish taken with new mesh 7,976 th.t
Instantaneous commercial mortality rate 0.10
Instantaneous natural mortality rate 0.10

Table 3. The table of initial data obtained by PINRO for calculation by ASC method of gains-and-losses dynamics with the change of cod-end's mesh from 120 mm to 130 mm in deepwater redfish fishery in the Flemish Cap area (males only)

Age, years	Number of fish x 10^6 pcs		
	taken with old mesh	taken with new mesh	released
4	0.018	-	0.018
5	0.014	-	0.014
6	0.286	-	0.286
7	0.654	0.164	0.490
8	1.574	0.566	1.008
9	1.729	0.778	0.951
10	1.881	0.941	0.940
11	1.743	1.028	0.715
12	3.163	2.024	1.139
13	2.182	1.484	0.698
14	1.775	1.225	0.550
15	1.305	0.953	0.352
16	0.961	0.702	0.259
17	0.388	0.295	0.093
18	0.175	0.140	0.035
19	0.131	0.108	0.023
20	0.047	0.040	0.007
21	0.023	0.020	0.003
22	0.009	0.008	0.001

The mass of fish taken with old mesh 8.332 th.t

The mass of fish taken with new mesh 5.216 th.t

Instantaneous commercial mortality rate 0.13

Instantaneous natural mortality rate 0.10

Table 2. **The table of initial data obtained by PINRO for calculation by ASC method of gains-and-losses dynamics with the change of cod-end's mesh from 120mm to 130 mm in deepwater redfish fishery in the Flemish Cap area**

Age, years	Number of fish x 10^6 pcs		
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4	0.056	-	0.056
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7	1.209	0.302	0.907
8	1.466	0.528	0.938
9	1.959	0.882	1.077
10	1.454	0.727	0.727
11	1.264	0.746	0.518
12	2.132	1.364	0.768
13	1.989	1.353	0.636
14	2.094	1.445	0.649
15	1.957	1.429	0.528
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18	0.625	0.500	0.125
19	0.648	0.531	0.117
20	0.388	0.334	0.054
21	0.284	0.247	0.037
22	0.187	0.170	0.017
23	0.029	0.027	0.002
24	0.009	0.009	-
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The mass of fish taken with old mesh 11,733 th.t
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Age, years	Number of fish x 10^6 pcs		
	taken with old mesh	taken with new mesh	released
4	0.018	-	0.018
5	0.014	-	0.014
6	0.286	-	0.286
7	0.654	0.164	0.490
8	1.574	0.566	1.008
9	1.729	0.778	0.951
10	1.881	0.941	0.940
11	1.743	1.028	0.715
12	3.163	2.024	1.139
13	2.182	1.484	0.698
14	1.775	1.225	0.550
15	1.305	0.953	0.352
16	0.961	0.702	0.259
17	0.388	0.295	0.093
18	0.175	0.140	0.035
19	0.131	0.108	0.023
20	0.047	0.040	0.007
21	0.023	0.020	0.003
22	0.009	0.008	0.001

The mass of fish taken with old mesh 8.332 th.t
The mass of fish taken with new mesh 5.216 th.t
Instantaneous commercial mortality rate 0.13
Instantaneous natural mortality rate 0.10

Table 4. The table of initial data obtained by PINRO for calculation by ASC method of gains-and-losses dynamics with the change of cod-end's mesh from 120 mm to 130 mm in deepwater redfish fishery in the Great Newfoundland Bank (females only)

Age, years	Number of fish x 10^6 pcs		
	taken with old mesh	taken with new mesh	released
5	0.958	0.019	0.939
6	1.431	0.057	1.374
7	1.284	0.103	1.181
8	2.101	0.210	1.891
9	1.304	0.170	1.134
10	1.422	0.256	1.166
11	0.879	0.211	0.665
12	1.188	0.368	0.820
13	0.855	0.342	0.513
14	0.751	0.376	0.375
15	0.896	0.538	0.538
16	0.418	0.293	0.125
17	0.163	0.127	0.036
18	0.254	0.213	0.041
19	0.291	0.256	0.035
20	1.188	1.093	0.095
21	0.285	0.268	0.017
22	0.375	0.360	0.015
23	0.181	0.177	0.004

The mass of fish taken with old mesh 8.195 th.t
The mass of fish taken with new mesh 4.330 th.t
Instantaneous commercial mortality rate 0.09
Instantaneous natural mortality rate 0.10

Table 5. The table of initial data obtained by PINRO for calculation by ASC method of gains-and-losses dynamics with the change of cod-end's mesh from 120 mm to 130 mm in deepwater redfish fishery in the Great Newfoundland area (males only)

Age, years	Number of fish x 10^6 pcs		
	taken with old mesh	taken with new mesh	released
5	1.266	0.038	1.228
6	1.481	0.089	1.392
7	1.133	0.102	1.031
8	1.026	0.133	0.893
9	1.279	0.217	1.062
10	1.231	0.283	0.948
11	0.720	0.216	0.504
12	0.660	0.264	0.396
13	0.649	0.326	0.323
14	0.429	0.275	0.154
15	0.212	0.155	0.057
16	0.187	0.144	0.043
17	0.097	0.082	0.015
18	0.084	0.076	0.008
19	0.030	0.029	0.001
20	0.054	0.053	0.001
21	0.012	0.012	-
22	0.006	0.006	-

The mass of fish taken with old mesh 3,711 th.t
The Mass of fish taken with new mesh 1,329 th.t
Instantaneous commercial mortality rate 0.16
Instantaneous natural mortality rate 0.10

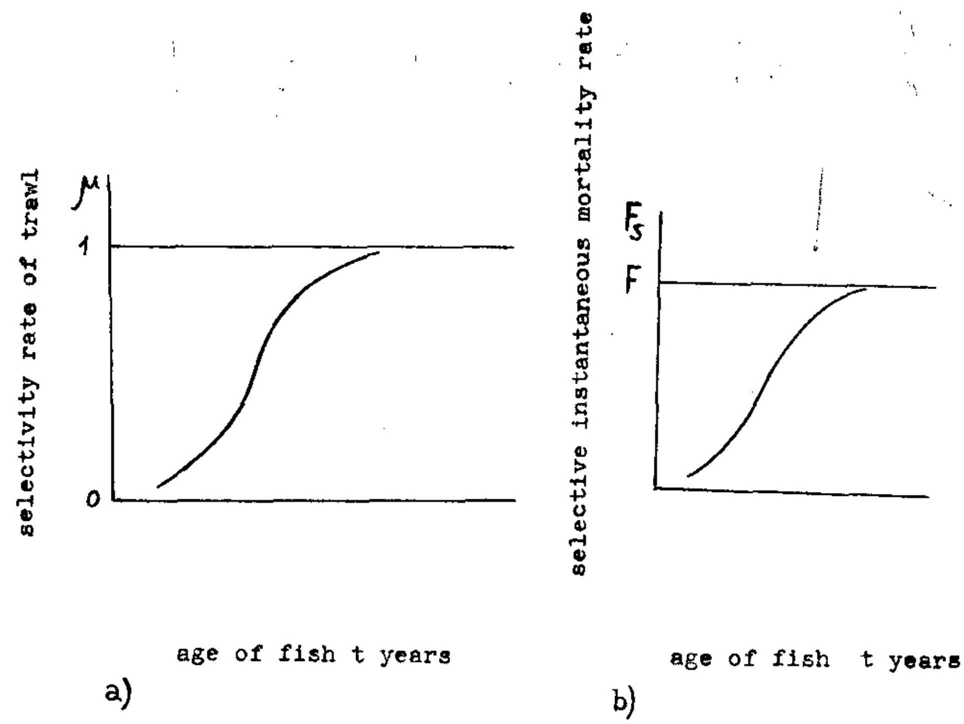


Figure 1. Qualitative dependence of selectivity rates of cod-end and selective instantaneous mortality of fish.

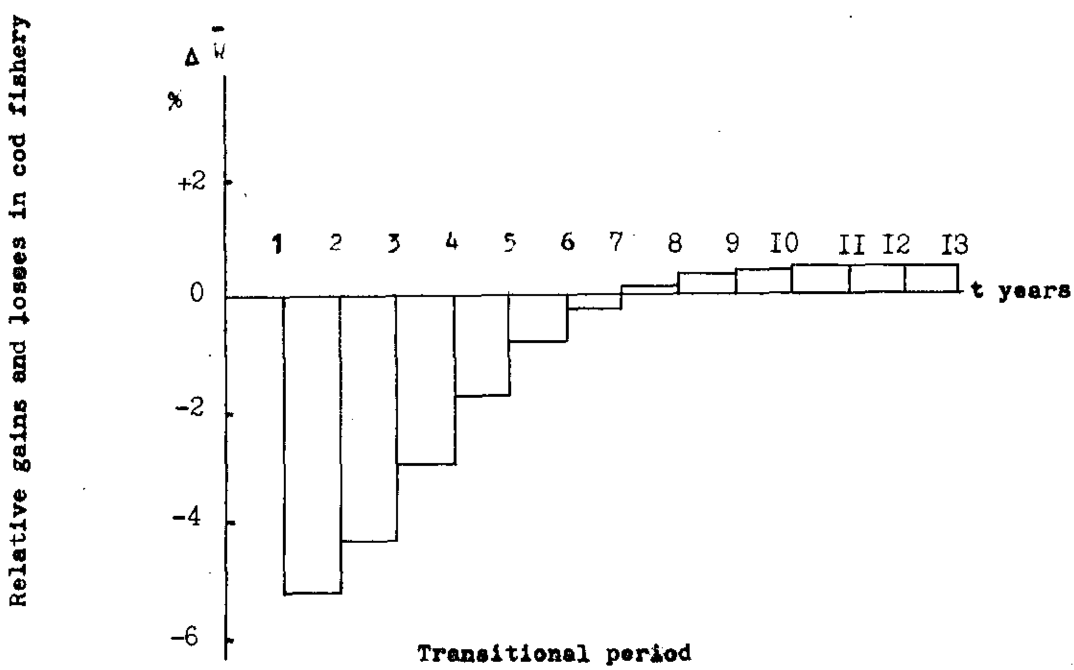
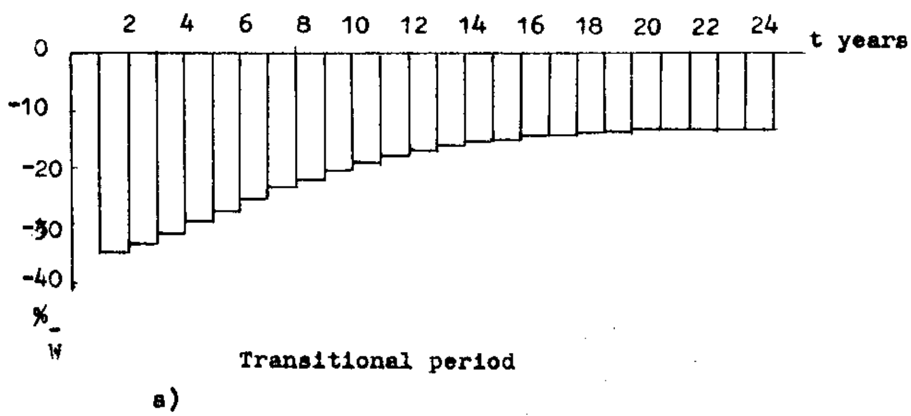


Figure 2. The graph of dynamics of relative gains-and-losses with eventual change from mesh size in cod-end from 120mm to 130 mm in cod fishery in the Central Labrador area.



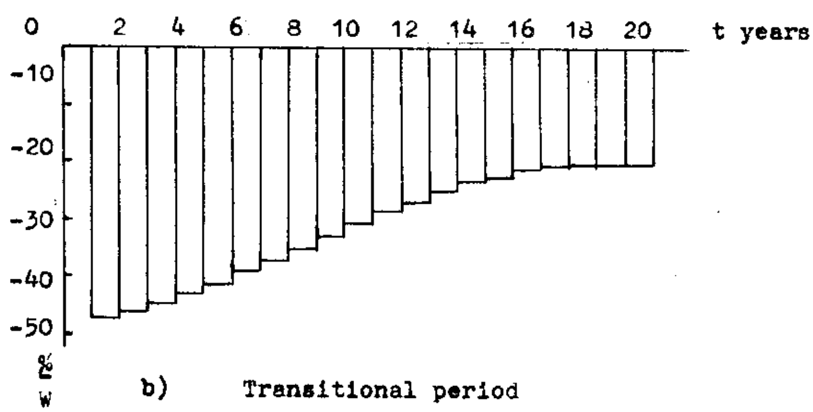


Figure 3. The graph of dynamics of relative gains and losses with eventual change of cod-end's mesh from 120 mm to 130 mm in deepwater redfish in a) Flemish Cap area, b) Great Newfoundland Bank area.