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Taylor's paper "Effects of Intensity and Kind of Exploitation on the Resources"

Transmitted herewith is a revision of Taylor's paper "Effects of Intensity and Kind of Exploitation on the Resources"

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Enclosure

Fishery Management: Effects of Intensity and Kind of Exploitation on the Resource

by

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Introduction:

The purpose of regulation of the haddock fishery in Subarea V of the convention area of the International Commission for the Northwest Atlantic Fisheries is to obtain the maximum sustained yield of this resource. Regulation is based on control of the minimum mesh size used by otter trawlers engaged in fishing haddock, thus affecting directly the age at which fish escape from or are retained by the fishing gear.

The maximum sustained yield of a fishery depends on a number of factors, among which are the growth rate, the natural mortality rate, the rate of fishing, and the age at which the fish are first captured. Any of these factors may vary from year to year and from one year class to another in the fishery. Since it is the long-term maximum sustained yield that is sought, the expected results of regulation to achieve this yield must be predicated on the long-term averages in variations in the above factors. The part these factors play in formulating a suitable mesh regulation for the Subarea V haddock fishery is reviewed here.

Growth Rates:

Study of the growth rate of haddock from Georges Bank, the principal fishing ground in Subarea V, shows that the variations in growth which occurred in the various year classes over the period 1930 to 1950 have been of minor importance, at least as far as their effect on yields are concerned. It is, therefore, possible to construct a growth curve for haddock which will be closely representative of any haddock year class of the future, barring some major change in the general ecology of the area. The chief feature in the growth of these fish is that they grow much more rapidly than haddock of the neighboring banks in Subareas III and IV, especially during the first four years of life. (Figure 1).

Mortality Rates:

Over a period of 17 years, the average total annual mortality rate has been about 45 percent (Figure 2). This represents both natural and fishing mortality. In assessing the probable effects of an increase in mesh size, various combinations of fishing and natural mortality were used over a range of natural mortalities from 0 to 30 percent. It was the considered opinion of the Scientific Advisors to Panel V that the natural mortality probably did not exceed 15 percent. Recent studies of the average age of capture of each year class and the contribution in numbers during the lifetime of the year class in the fishery support this conclusion.

Age of First Capture:

Prior to the enactment of a mesh regulation in Subarea V, the average mesh size used in the haddock fishery was 2-7/8 inches (stretched, inside knots measurement when wet and in use). This mesh has a fifty percent selection point for haddock about 1-1/2 years old. The mesh required after mesh regulation is 4-1/2 inches (measured wet and in use) and has a 50 percent selection point at 2-1/2 years. The 4-1/2 inch mesh was selected as an initial step toward attaining the optimum age of first capture of about 3-1/2 years. This initial increase is designed to allow the escapement of unmarketable fish which were formerly caught and discarded at sea. The escapement of these fish to be recaptured at a later date is a substantial contribution to the overall benefits to be expected from the present regulation.

The Effect of Variations in Fishing Intensity:

While growth and natural mortality rates may fluctuate about stable norms and so may be assumed as constant values over long periods, and while the age of first capture may be established by mesh size, control of the amount of fishing in Subarea V has not been sought.

The relation of the present mesh size with an age of first capture at 2-1/2 years to variations in the amount of fishing within Subarea V and to the catches of individual boats must be considered.

Over the 18-year study period annual landings of Georges Bank haddock have averaged 94.2 million pounds with an average effort of 7,278 fishing days. The various comparisons which follow may be related to these figures as the "average", or the 100 percent base, level of catch and effort.

Beverton has shown that the instantaneous fishing mortality rate varies as $-\log(1-p)\,n$, or

$$F = k\left[-\log(1-p)\,n\right] \qquad (1)$$

where F is the instantaneous fishing mortality rate, p is the gear efficiency, n is the number of units of effort, and k is a constant.

If it is assumed that the units of gear are not competitve, equation (1) reduces to a simple linear relationship between fishing mortality and effort:

$$F = kn \qquad (2)$$

The effect of gear competition is to change the efficiency, p, in equation (1). The assumption of no gear competition is equivalent to stating that the fish redistribute themselves over a fished area so that subsequent hauls continue to remove the same proportion, p, of the remaining population.

Under intensive, localized fishing, this condition may not be realized, especially for short periods. From equation (2) we see that doubling or halving the effort will double or halve the instantaneous fishing mortality rate (but not the total annual rate or the annual fishing mortality rate).

Table 1 presents levels of fishing effort referred to the average effort of 7,278 days as 100 percent, and the various mortality rates corresponding to these levels of effort.

Maximum sustained yields:

Applying the mortality rates of Table I, the equilibrium yield per 10,000 recruits entering the fishing area at age 1 is calculated for each level of fishing effort, both before and after a change in mesh size. With the present mesh, it is assumed that 50 percent of 1-1/2 year old fish escape through the net. Data on present culling practices indicates 37 percent of fish of age 1-1/2 are retained as marketable and 81 percent of the 2-1/2 year old fish. From mesh selectivity experiments and knowledge of culling practices, it is estimated that 50 percent of 2-1/2 year old fish will escape through the 4-1/2 inch mesh net and that 90 percent of the 2-1/2 fish brought on deck will be retained as marketable.

Under average conditions, prior to any mesh change, the natural mortality rate (15 percent) is assumed to operate from ages 1 to 1-1/2 before the recruits become available to fishing. After the proposed mesh change, this rate operates 1-1/2 years (age 1-2-1/2) before the recruits become available.

It is pointed out that natural mortality and growth rate are assumed to remain constant at all levels of population density. This assumption is probably incorrect. Natural mortality may increase and growth rate decrease with the high populations accompanying decreased effort, while the reverse may occur at the lower population levels accompanying increased effort. These effects would tend to offset to some degree some of the apparent advantages of decreased effort.

Table 1.—Annual effort in days, as percent of average effort, and the corresponding instantaneous and annual mortality rates.

Annual Effort (Days)	Annual Effort (%)	Instantaneous Rates Fishing	Instantaneous Rates Natural	Instantaneous Rates Total
1,820	25	0.1	0.2	0.3
3,639	50	.2	.2	.4
5,459	75	.3	.2	.5
7,278	100	.4	.2	.6
9,098	125	.5	.2	.7
10,917	150	.6	.2	.8
12,737	175	.7	.2	.9
14,556	200	.8	.2	1.0

Table 2 presents the equilibrium yields to be expected at effort levels varying from 25 percent to 200 percent of "average" effort by 25 percent intervals prior and subsequent to a mesh change effecting an age of first capture at 2-1/2 years.

The maximum sustained yield using present mesh would occur with a decrease of 25 percent in effort. This decrease in effort would increase the catch about three percent or a little less than three million pounds.

With the proposed increase in mesh size, the maximum sustained yield would be obtained with about 25 percent increase over average effort. The increase, however, would be relatively small, about one percent.

It is interesting to note that over the effort range 100-200 percent, the sustained yield is almost constant after the proposed mesh change. Doubling average effort decreases the catch less than two percent of its maximum value. With the proposed mesh change, it becomes impossible to capture fish prior to their period of maximum growth rate. In contrast, doubling the effort with the small mesh would decrease the maximum yield by about 22 percent, the result of an intensive fishery concentrated on small, rapidly growing fish.

Table 2 presents the equilibrium yields to be expected at effort levels varying from 25 percent to 200 percent of "average" effort by 25 percent intervals prior and subsequent to a mesh change effective an age of first capture at 2-1/2 years.

The maximum sustained yield using small mesh would occur with a decrease of 25 percent in effort. This decrease in effort would increase the catch about three percent or a little less than three million pounds.

With the large mesh size, the maximum sustained yield would be obtained with about 25 percent increase over average effort. The increase, however, would be relatively small, about one percent.

It is interesting to note that over the effort range 100-200 percent, the sustained yield is almost constant after the proposed mesh change. Doubling average effort decreases the catch less than two percent of its maximum value. With the larger mesh, it becomes impossible to capture fish prior to their period of maximum growth rate. In contrast, doubling the effort with the small mesh would decrease the maximum yield by about 22 percent, the result of an intensive fishery concentrated on small, rapidly growing fish.

Table 2.—Equilibrium yields in pounds per 10,000 recruits and as annual total catches in millions of pounds, various effort levels prior to and following mesh change.

Effort		Yield in Pounds			
		Prior to Mesh Change		After Mesh Change	
Days	%	Per 10,000 Recruits	Annual Total (Millions of lbs)	Per 10,000 Recruits	Annual Total (Millions of lbs)
1,820	25	7,905	70.7	8,235	73.6
3,639	50	10,341	92.5	11,607	103.8
5,459	75	10,803	96.6	12,916	115.5
7,278	100	10,532	94.2	13,491	120.7
9,098	125	10,025	89.7	13,643	122.0
10,917	150	9,481	84.8	13,611	121.7
12,737	175	8,912	79.7	13,507	120.8
14,556	200	8,396	75.0	13,354	119.4

Table 3 shows the catch per standard boat day both prior to and following mesh change. These tables and figures do not reveal, however, a secondary effect of considerable biological as well as economic importance. As effort decreases, natural mortality is assumed to remain constant (and may even increase). Consequently, natural mortality in terms of pounds of fish becomes a larger and larger proportion of total mortality as effort decreases, natural mortality exceeding fishing mortality when the latter is about 15 percent (culling and escapement account for the fact that the amounts of fish dying from each cause are not exactly equal when the rates are equal). Table 5 compares the pounds of fish dying from natural causes with the pounds of fish actually landed. At low levels of effort, many fish survive to die of natural causes after attaining considerable size. At higher levels of effort the chances of a fish dying of natural causes after reaching such sizes is reduced.

Natural mortality represents, in a very real sense, a loss both in food and in income to the fishermen. It is quite clear that reduction in effort, though it might under small-mesh conditions increase the yield slightly, would, after the mesh change, result not only in a decreased yield, but also in an increased loss through natural mortality. (Table 4). From the standpoint of total haddock production from Georges Bank, then, it is not desirable to reduce the total fishing effort.

The catch per standard boat day at various effort levels does not indicate the relative change in income per boat per year, for there are other factors of importance affecting the income per boat.

Table 3.--Annual effort in days, expected annual catch, and catch per boat day prior to and following mesh change.

	Before Mesh Change		After Mesh Change	
Effort Days	Annual Catch (Millions of lbs.)	Catch/boat day (Thousands of lbs.)	Annual Catch (Millions of lbs.)	Catch/boat day (Thousands of lbs.)
1,820	70.7	38.8	73.6	40.4
3,639	92.5	25.4	103.8	28.5
5,459	96.6	17.7	115.5	21.2
7,278	94.2	12.9	120.7	16.6
9,098	89.7	9.9	122.0	13.4
10,917	84.8	7.8	121.7	11.1
12,737	79.7	6.3	120.8	9.5
14,556	75.0	5.2	119.4	8.2

Table 4.—Relative magnitudes of catch and natural mortality prior to and following mesh change.

Effort Days	Before Mesh Change: Annual Catch (Millions of lbs.)	Before Mesh Change: Annual Natural Mortality (Millions of lbs.)	After Mesh Change: Annual Catch (Millions of lbs.)	After Mesh Change: Annual Natural Mortality (Millions of lbs.)
1,820	70.7	152.0	73.6	157.8
3,639	92.5	96.6	103.8	113.7
5,459	96.6	73.6	115.5	87.0
7,278	94.2	56.1	120.7	69.8
9,098	89.7	44.4	122.0	58.0
10,917	84.8	36.3	121.7	49.6
12,737	79.7	30.5	120.8	43.3
14,556	75.0	26.3	119.4	38.5

The average effort over the past 18 years on Georges Bank 1/ has been 7,278 fishing days per year. The average length of trip has been almost exactly eight days, approximately five of which were spent actually fishing. At higher levels of haddock abundance, the fishing time required to obtain an average trip becomes less, while the running time remains more or less fixed.

The maximum number of trips a boat can make in a year is about 30. The 7,278 fishing days divided by 5, the number of days fishing per trip, represents, then, 1456 boat-trips per year, or 30 trips by each of about 49 boats. Since the total trip time averages 8 days, the average boat spends, in a year, about 240 days out of port. The remainder of the year represents lay-overs between trips (seldom less than 2 days), over-haul time, and time lost by bad weather. It is fairly safe to assume, therefore, that regardless of haddock abundance, a trawler fishing Georges Bank will not spend more than 240 days at sea per year and that three days of each trip, regardless of the trip's total length, will represent running time. 2/

A further complication, limiting the possible productivity of trawlers, is a union rule limiting the length of trip to Georges Bank to 8 days during the summer months. This rule is relaxed somewhat during the winter months. In the present calculations, trips up to but not exceeding 10 days are considered.

1/ This figure represents the average annual fishing time by all categories of boats fishing Georges Banks.

2/ Running time includes some time spent in moving from one part of the bank to another when the boat is not fishing.

On the basis of the catch per standard boat-day (Table 3), it is possible to calculate the fishing time required to obtain an average trip, to calculate the number of trips a boat can make in 240 days, the number of boats required for a given level of effort, and the catch per boat per year at the equilibrium populations expected for these levels of effort. These calculations are summarized for average conditions prior to mesh change in Table 5 and following the ~~proposed~~ mesh change in Table 6.

It is realized that there is some bias in these calculations because the fishing time is based on an "average" trip. At high levels of abundance, it is probable that the boats make more trips than calculated and bring in better than "average" trips and, at low levels of abundance, they would necessarily land less than average trips, because the total trip is assumed not to exceed 10 days. Since the total fishing time per year is limited, however, the effect of fewer trips with a greater catch would not change the general picture very much.

Figure ~~2~~ 3 shows the relative percentage changes in total catch and in catch per boat per year over the range of effort considered. The catch per boat per year is seen to increase very rapidly as effort decreases. It is clear, however, that increases in catch per boat are achieved at the expense of considerable declines in total catch, especially following the ~~proposed~~ mesh change.

Table 5.--Work table for calculating the size of fleet needed for the effort level and the catch per boat prior to proposed mesh change.

A Effort Days	B Fishing Time for Average Trip (Days)	C Total Trip (Days)	D Total Trips per yr.	E Time Available at sea/year (Days)	F Total Possible trips/boat	G No. Boats for Effort Level	H Yield/Boat Year (M. of lbs.)
1,820	1.7	4.7	1071	240	51	21	3.37
3,639	2.5	5.7	1456	240	44	33	2.80
5,459	3.7	6.7	1475	240	36	41	2.36
7,278	5.0	8.0	1456	240	30	49	1.92
9,098	6.6	9.6	1378	240	25	55	1.63
10,917	7.0	10.0	1560	240	24	65	1.30
12,737	7.0	10.0	1820	240	24	76	1.05
14,556	7.0	10.0	2079	240	24	87	.86

Explanation of Tables 5 and 6:

Column B is obtained by dividing the catch for a five day average trip by the catch per boat day shown in Table 4. Column C is obtained by adding three days running time to the fishing time of Column B., but the total cannot exceed a ten-day trip. Column D is obtained by dividing A by B. Column F is E divided by C. The size of fleet necessary to give the level of fishing effort of Column A is D divided by F. Column H is the equilibrium yield for the effort level (Table 3) divided by the number of boats. (Column G).

Table 6.--Work table for calculating the size of fleet needed for the effort level and the catch per boat following proposed mesh change.

A Effort (Days)	B Fishing Time for Average Trip (Days)	C Total Trip (Days)	D Total Trips per year	E Maximum Time Available at Sea per Year	F Total Possible trips/boat	G No. of Boats for Effort level	Yield per Boat per year (Millions of Pounds)
1,820	1.6	4.7	1138	240	52	22	3.35
3,639	2.2	5.2	1654	240	46	36	2.88
5,459	3.1	6.1	1761	240	39.3	45	2.57
7,278	3.9	6.9	1866	240	34.8	54	2.25
9,098	5.2	8.2	1750	240	29.3	60	2.03
10,917	5.8	8.8	1882	240	27.3	69	1.77
12,737	7.0	10.0	1820	240	24	76	1.59
14,556	7.0	10.0	2079	240	24	87	1.37

1/ For explanation, see Table 5.

Conclusions

Where it has been necessary in the foregoing analysis to assume various conditions, an effort has been made to estimate these as realistically as possible. It is believed that, on the whole, the relative magnitudes of effects are fairly accurate and that while somewhat different assumptions might change their general level, their relations to one another would remain about the same.

Several general conclusions may be drawn from these calculations:

1. The maximum sustained yield under average conditions prior to mesh change would be obtained by about 25 percent reduction in effort.

2. Under average conditions prior to mesh change, a reduction in effort was necessary to attain a maximum sustained yield. Following the proposed mesh change an increase of at least 25 percent in effort is indicated to achieve the maximum sustained yield.

3. Following mesh change, a reduction in effort would increase the catch per boat and presumably the income per fisherman, but these gains would be achieved at the expense of considerable losses in total landings and great waste of the resource through many fish dying from natural causes instead of being caught.