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Implications of Increasing Otter Trawl Mesh Size to Avoid Catching Immature Cod: Effects on Spawning Biomass, Fishing Effort and Catch Rates

by

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Abstract

A simplified single species, single fishing gear (otter trawl) simulation using data from the southern Gulf of St. Lawrence cod fishery was used to examine the implications of changing the selectivity pattern of a commercial fishery to avoid catching cod below the length of 95% maturity. The length at 95% maturity of the cod stock was 47 cm. Prior to the closure of this cod fishery in 1993, the regulated codend mesh size was 130 which had and L50 (length of 50% retention) of 45 cm. It may be necessary to change to a mesh with an L50 in the order of 60 cm to avoid catching immature cod. The fishing mortality at $F_{0.1}$ for the larger mesh size was more than twice that for the 130 mm mesh, implying proportionally higher target fishing efforts in a fully operational fishery. However, there was no improvement in spawning stock biomass (SSB) over a 5-year simulation period fishing at $F_{0.1}$ with the larger mesh, and SSB declined when fishing at $F_{0.1}$ with the 130 mm mesh. There was a slight increase in SSB if the larger mesh was used with an F of about half its $F_{0.1}$ level. Catch rates of the larger mesh was initially only 40% those of the 130 mm mesh, but they doubled over the 5-year simulation period. These simulations provide general indications of the direction of changes in population status and fishing success under different mesh selection options.

Résumé

On utilise une simulation simplifiée de la pêche d'une unique espèce avec un seul engin (chalut à panneaux) faisant appel à des données sur la pêche de la morue dans le sud du golfe du Saint-Laurent pour examiner comment un changement du régime de sélectivité dans une pêche commerciale permet d'éviter la capture de morue d'une longueur inférieure à la longueur de maturité à 95 %. Chez le stock de morue du sud du golfe, cette longueur se situe à 47 cm. Avant la fermeture de cette pêcherie en 1993, le maillage réglementaire du cul-de-chalut était de 130 mm, ce qui permettait une L_{50} (longueur de rétention à 50 %) de 45 cm. Il faudra peut-être porter cette dernière à 60 cm afin d'éviter de capturer des morues immatures. Le taux de mortalité à $F_{0,1}$ associé à un plus grand maillage était plus de deux fois plus élevé que dans le cas du maillage de 130 mm, ce qui laisse supposer un effort ciblé de pêche proportionnellement plus élevé lorsque la pêche bat son plein. Par contre, la biomasse du stock de reproducteurs n'a pas augmenté au cours d'une période de simulation de cinq ans pendant laquelle la pêche s'effectuait à $F_{0,1}$ avec le grand maillage, tandis qu'elle diminuait lorsque la pêche s'effectuait à $F_{0,1}$ avec un maillage de 130 mm. Elle augmentait par contre légèrement si le grand maillage était utilisé pour pêcher à un taux de mortalité pa pêche d'environ la moitié de $F_{0,1}$. Les taux de capture avec le grand maillage ne représentaient au début que 40 % de ceux obtenus avec un maillage de 130 mm, puis ont doublé au cours de la période de simulation de cinq ans. Ces simulations donnent une idée générale des fluctuations du statut des populations et du succès de la pêche en fonction de divers maillages.

Introduction

On September 18, 1996, the Fisheries Resource Conservation Council (FRCC) requested an analysis of the implications of establishing a mesh size which would avoid catching cod below the size at 95% maturity (see letter in Annex I). The question to be answered was: What is the impact on yield, mortality, effort and catch rates of exploiting the population at $F_{0.1}$ if the fishery were conducted in such a way that the minimum fish size corresponded with the length at 95% maturity?

We have used data from the southern Gulf of St. Lawrence cod stock to address this question, however it must be stressed that the results are for illustrative purposes only. The calculations were simplified in that only a single gear fishery was simulated - one involving otter trawls. This was done because of a paucity of gear selection data for other gears and time constraints precluded a more complex approach. The fishery in the southern Gulf of St. Lawrence has traditionally involved other gears such as seines, longline and gillnets. The seine selectivity can be expected to be close to the otter trawl selectivity. However, the longline and in particular the gillnet selectivity would be expected to be different. The historical catch allocation for the fixed gears was 24% of the TAC. The available otter trawl selection data came from studies conducted outside the Gulf of St. Lawrence.

Although the analysis should be considered as an illustration, the direction of the changes seen in catch rates, yield and effort would remain the same with a more detailed analysis. It should also be noted that the analysis was conducted using yield per recruit in relation to a specific size at maturity. Other considerations, such as the impact on spawning stock biomass, recruitment and discarding of fish below commercial size should also be considered in a more detailed analysis.

Methods

The calculations involved yield per recruit analyses and catch projections using information on gear selectivity and the size and age structure of the population following an approach described in Halliday and White (1989). The main difference was that they used exclusively the commercial fishery catch composition while we used a combination of research vessel survey and commercial fishery results. The following steps were used.

1) Determine size at 95% maturity
2) Determine mesh selectivity for the gear used prior to closure
3) Describe the selectivity of a mesh which would avoid catching fish smaller than the size at 95% maturity (test mesh size)
4) Determine the current size structure of the population
5) Calculate the partial recruitment and average weight at age for 130 mm and test mesh sizes
6) Use yield per recruit analysis to determine $F_{0.1}$ for 130 mm and test mesh sizes.

7) Conduct short-term projections at $F_{0.1}$ and constant F.
8) Compare changes in catch rate, population biomass and fishing effort

<u>Size at Maturity</u>

Information on the size at maturity of cod in the southern Gulf of St. Lawrence was obtained from research vessel surveys. Maturity stage was determined by macroscopic observation of male and female gonads following procedures described by Hurlbut and Clay (1990). Procedures for calculating maturity at length and age were recently reviewed by a DFO working group (Trippel, et al. 1996). The working group noted the difficulty of distinguishing immature cod from those that have spawned at least once but are in a resting state. Similar observations are described by Morrison (1990). Consequently, the preferred method would base maturity estimates on data collected as close to the spawning period as possible. Research vessel surveys provide the bulk of maturity data, and in the southern Gulf, two main surveys have been conducted. One in September from 1971 to the present, which covers the entire area. The second was conducted in July from 1990-1995 in the Shediac Valley area. The latter survey was chosen for maturity estimation given its closer proximity to the spawning period.

Maturity at length and age was calculated using probit analysis as described by Trippel, et al. (1996). There was little difference in the maturity at length between surveys and between sexes, thus all years and sexes were combined. The resulting maturity ogive indicated that the length of 95% maturity (5% immature) was 47 cm (Fig. 1).

<u>Mesh Size Information</u>

The basic principle in adjusting the mesh size of an otter trawl is that larger meshes allow smaller fish to pass through the net, and thus not be caught. Mesh selection studies are conducted using a control mesh size that will retain most of the fish encountered by the gear, and the test mesh size. A "selection ogive" is calculated which gives the proportion of fish of a given length that are retained by the test mesh. This is estimated by calculating the ratio of test mesh catch divided by the control mesh catch for each length interval. Mesh selection ogives are typically "S" shaped curves because the mesh selection occurs over several length intervals. The length where X% of the available fish are retained by the test mesh is called the LX, e.g. the L50 of a mesh is the length where 50% of the population is retained. The "selection range" is the length interval between the L25 and the L75. A formula for calculating a selection ogive from L50 and selection range parameters is given in Halliday and White (1989).

Prior to 1993, the regulated minimum mesh size for mobile gear in the southern Gulf groundfish fishery was 130 mm diamond mesh. Since the closure of the cod fishery, other groundfish fisheries have remained open and the mesh sizes have varied between 130 mm (square mesh) for winter flounder to 155 mm (square mesh) for American plaice. Because of cod by-catch rules, fishermen are reporting using even larger mesh sizes (up to 170 mm square mesh) to avoid closures. Although cod is a by-catch in many of these fisheries, for the purpose of this analysis, 130 mm (diamond mesh) was used as the reference mesh size since it was the mesh size used in the period leading to the closure of the fishery.

A number of selectivity experiments on mobile gear have been conducted in recent years in Atlantic Canada. Studies of mesh selectivity for various species conducted in the Maritimes Region were summarized recently by R.G. Halliday (pers. com., Department of Fisheries and Oceans, Bedford Institute of Oceanography). The average selectivity of two 130 mm diamond mesh experiments were used for the reference gear. The resulting selection ogive had an L50 of 45 cm and a selection range of 10 cm. The retention of 47 cm fish was 60%.

We then calculated a selection ogive for a hypothetical test mesh which had an L05 of 47 cm. We assumed this mesh had the same selection range as the 130mm diamond, but a higher L50. Given the shape of the selection ogive, this required an L50 of 60 cm. We also calculated a family of selection curves with L50s increasing at 3 cm intervals between the 130 mm and test gears in order to investigate the sensitivity of the $F_{0.1}$ estimates to mesh selection characteristics.

Population Length Frequency

Estimates of the population size structure were obtained from two sources: 1) the abundance at age of the population (N_a)was taken from the sequential population analysis (SPA) of the most recent stock assessment (Sinclair, et al. 1996); and 2) the length frequencies at age of the population were obtained from research vessel surveys. Data from 1980 and 1995 were used to investigate the sensitivity of the $F_{0.1}$ estimates to changes in size at age in the population. Southern Gulf cod were considerably larger at age in 1980 than now.

Not all ages are fully recruited to the survey and thus the survey was first adjusted to the SPA numbers at age. The population abundance at length l was calculated in two steps as

$$N_{al} = \frac{A_{al} N_a}{A_a}$$

$$N_l = \sum_{a=3}^{15} N_{al}$$

where A_{al} = the survey population estimate at age a and length l

Partial Recruitment and Average Weight

The next step was to apply the mesh selection characteristics of the fishing gear to the fish population. Not all of the population will be large enough to be caught. To determine what fraction of the population is "fishable", it was assumed that the fishable population at age a for gear g (N'_{ag}) is the sum of the products of the population length frequency and the selectivity of the mesh.

$$N'_{ag} = \sum_{l=1}^{\infty} N_{al} S_{lg}$$

where S_{lg} = the proportion retained at length l by gear g

The "partial recruitment" at age a (S_a) is then the ratio of the fishable population at age divided by the total population at age.

Since the mesh will retain the larger individuals of a partially recruited age group, the mean length and weight of the age group in the catch will be larger than that in the population. The mean weight of fish in the catch was thus calculated by applying a length-weight relationship (Sinclair, Chouinard and Currie 1996) to the fishable population length frequencies at age.

$$\overline{W}'_{ag} = \frac{\sum_{l=1}^{\infty} N_{al} S_{lg} W_l}{\sum_{l=1}^{\infty} N_{al} S_{lg}}$$

where W_l = the estimated weight of a fish of length l

Yield per Recruit

Target fishing mortalities corresponding to $F_{0.1}$ were estimated for the family of mesh selection ogives and for the simulated 1980 and 1995 populations. The objective was to investigate the direction and magnitude of changes in fishing effort and yield per unit of recruit that would be implied by a change in mesh size. The amount of fishing effort needed to achieve the target fishing mortalities was assumed to be proportional to the estimated $F_{0.1}$. In order for this to be valid, it was important to use a standard reference partial recruitment value. Age 15 was chosen because all gears had the same PR at this age (see Table 1). It was also assumed that all fish that pass through the meshes of the net survived and were available to the fishery again in the future. Yield per recruit statistics were calculated using the method of Thompson and Bell as described by Rivard (1982). The input data are given in Tables 1 and 2. Spawning stock biomass was calculated using the maturity at age estimated from July surveys and weights at age for the population. Fishery yields were calculated using the estimated commercial weights at age.

Short Term Projections

The short term impacts of changing mesh size on fishing effort, yields, and spawning biomass were investigated using 5-year catch projections. These were done to illustrate the potential range and direction of effects of changing mesh size. The beginning of year 1996 population estimates were obtained from the most recent assessment, and recruitment at age 3 was fixed at 20 million, similar to the recently observed low level. Projections were calculated using the method described by Rivard (1982). The input partial recruitment and weights at age were estimated from the 1995 research vessel survey results (Table 3).

Results

Changes in Partial Recruitment and Weights at Age

The fishable populations available to the 130 mm and test gears were very different (Fig. 2). The 130 mm mesh had a substantial biomass of age 3-9 fish in its fishable population while the larger mesh had very few. The estimated partial recruitment's emphasize these differences (Table 1). Where over 50% of the ages 6 and above are partially recruited to the 130 mm mesh, it is not until age 10 that partial recruitment reached 50% for the larger mesh. Ages 12+ were essentially fully recruited to the 130 mm mesh, but only age 15 was fully recruited to the largest mesh.

As expected, the estimated weights at age in the catches were higher than in the population (Table 1).

It should be noted that the estimated PR on ages 12+ were based on very low catches in the research vessel survey, 21 fish in all. Thus there is considerable uncertainty in these estimates.

Yield per Recruit

Shifting the partial recruitment toward older ages had a major effect on both the estimated fishing mortalities at $F_{0.1}$ and the associated yield per recruit. The estimated $F_{0.1}$ increased with the L50 of the selectivity curves (Fig. 3). The relationship between the two was upward sloping with the highest rate in increase at the highest L50. If the 1995 population size structure was used, the estimated $F_{0.1}$ was higher for all selectivities than if the 1980 data were used, and the $F_{0.1}$ for the mesh size with an L05 of 47cm (L50 = 60 cm) was twice as high as that for the 130 mm mesh size. If the 1980 size structure was used, the $F_{0.1}$ for the largest mesh was 1.6 times as high as for the 130 mm mesh. The yields per recruit at $F_{0.1}$ also increased with the L50s (Fig. 4). Yield per recruit was higher for the 1980 population size structure, but its sensitivity to L50 was less than that for the 1995 population size structure.

Short Term Projections

Three fishing mortality scenarios were investigated: 1) Fishing mortalities were set at the respective $F_{0.1}$ level for the reference (130 mm) and test (L05 = 47 cm) mesh sizes. This was used to indicate possible trends if the fisheries reopened immediately at the respective operational target fishing mortality: 2) A constant fishing mortality of 0.2 was used for the larger mesh. This would correspond to fishing mortality of about half the estimated $F_{0.1}$ for this gear and could represent a rebuilding strategy for the stock: 3) A constant fishing mortality of 0.5 was used for the 130 mm mesh. This would indicate what might happen if the fishery reopened at the larger mesh fishing effort target but the fishery was conducted with the traditional mesh size. This could occur if a change in regulated mesh size was not effectively implemented.

Spawning biomass: The initial spawning stock biomass was the same under each scenario since this was a characteristic of the population at the beginning of the projection period, before fishing. If there was no fishing, the spawning biomass was projected to increase by 40% (Fig. 5). Under the $F_{0.1}$ scenario, the spawning biomass was projected to decline throughout the projection period for the 130 mm mesh, while it rose slightly then declined for the larger mesh. If F was 0.2 and the larger mesh size was used, the spawning biomass increased by about 10% by year 5. Spawning biomass declined by approximately 50% in the case where F was 0.5 for the 130 mm mesh.

Catch rates: Under the assumptions of these projections, catch rates are proportional to "fishable biomass", i.e. the stock biomass selected by the fishing gear. Since the two mesh sizes have different PR patterns (they catch different age groups), their catch rates will also vary. Trends in catch rates for the projection period are shown in Fig. 6. All values are scaled to the 1996 130 mm catch rate at $F_{0.1}$.

For each fishing mortality scenario, the 1996 catch rate of the 130 mm mesh was more than 2.5 times that of the larger mesh. Catch rates declined for the 130 mm mesh in each scenario, but the most severe decline (more than 50%) was if the fishing mortality was 0.5. Catch rates increased for the larger mesh. However, the increase was less and covered only the first 3 years under the $F_{0.1}$ scenario. If the fishing mortality was set at 0.2, the catch rates for the larger mesh doubled during the 5-year projection period.

Yield: When F is held constant and for a given mesh size, yield will vary in proportion to fishable biomass. When the PR pattern varies between gears, as is the case between the 130 mm and larger mesh sizes, the gear that has the highest fishable biomass will also have the highest yield for any level of F. This is reflected in the trends in yield shown in Fig. 7. All values are scaled to the 1996 130 mm yield at $F_{0.1}$.

Under the $F_{0.1}$ scenario, yield declined for the 130 mm mesh but increased for the larger mesh. Where the 130 mm yield was greater than the yield to the larger mesh in the first year, this was reversed in year 5. If F was 0.2 for the larger mesh, the 1996 yield was about 40% that of the 130 mm mesh fishing at $F_{0.1}$. However, by the final year, the yield to the larger mesh more than doubled. If F was 0.5, the 1996 yield to the 130 mm mesh was twice as high compared to the yield at $F_{0.1}$. This declined rapidly, however, as the fishable biomass declined.

Discussion

This study investigated the impact of changing the selection pattern of a commercial fishery from a status quo situation to one in which the minimum size caught was the size at 95% maturity. We used information from the southern Gulf of St. Lawrence cod fishery as an example, however, our case study was not meant to represent the actual impact on that fishery. We included only otter trawls in a simplified single gear simulation, and recognize the importance of other gear components such as seines, longlines and gillnets. We also used 5-year catch projections to investigate these changes, and this required assumptions about recruitment and growth rates for year-classes not yet sampled or for which current information is very limited. Catch projections are normally limited to 2 years in stock assessments for this reason.

The basic principle of controlling gear selectivity is that smaller fish will escape the fishing gear and become available later in life when they are larger, give higher yield, and have contributed more to the spawning population. There is a trade-off to be made when a selectivity change is introduced between a short-term loss in yield due to the escapement of the smaller fish, and a longer-term gain once these fish have grown. This trade-off is demonstrated in the results of 5-year catch projections. It may be important, however, to consider that some of the escaping fish may not survive the selection process. Studies conducted in Europe indicate that such "post selection" mortality of cod is very low, however additional study may be warranted (Anon 1995, Halliday et al. 1996).

The analysis indicates that a substantial change in mesh selection would be required to avoid catching almost all immature cod in the southern Gulf. The mesh size used in the fishery in the early 1990s (130 mm diamond mesh) had a length of 50% retention (L50) of approximately 45 cm. The length at 95% maturity for this stock has been estimated to be 47 cm, and the 130 mm diamond mesh has a retention of approximately 60% at this length. In order to attain 5% retention of 47 cm cod, the L50 might have to increase by 15 cm.

Such an increase in mesh size would have a considerable effect on the partial recruitment of most age groups to the commercial fishery. The results of this study indicate that the partial recruitment of age 6 cod would decline from about 50% to only 3%, given the current size structure of the southern Gulf cod population. The initial fishable population biomass and commercial catch rates would be 60% lower with the larger mesh size than with the 130 mm mesh. The magnitude of these reductions would be lower if the size at age in the population increased to what it was in 1980. Under these conditions, the estimated partial recruitment of age 6 cod to the 130 mm mesh was 75%, while it was 16% for the larger mesh. The fishable biomass of the larger mesh was estimated to be 25% lower than that of the 130 mm mesh in the first year.

If this larger mesh size were used in a single gear fishery, the estimated $F_{0.1}$ (and target fishing effort), and yield per recruit would be higher than if the 130 mm mesh was used. The magnitude of the difference would depend on the growth rate of the stock. Under the current low growth rate conditions, the $F_{0.1}$ and yield per recruit estimates were 2.1 and 1.3 times higher for the larger mesh than for the 130 mm mesh respectively. If growth rates improved and approached the conditions observed in 1980, the ratios were 1.6 and 1.3 respectively. This implies considerably higher target fishing effort levels for the larger mesh sizes.

The implications of changing mesh size on the population status were investigated with 5-year catch projections. Current stock size is very low and the short term management objective is to allow it to increase. Clearly, the largest increase in spawning stock biomass (SSB) would occur if there were no fishing, the projected increase was 40% over 5 years. SSB would likely decline if fishing were conducted at the $F_{0.1}$ level (F = 0.2) with the 130 mm mesh. There would be little or no change in SSB if fishing were conducted at $F_{0.1}$ (F = 0.5) with the larger mesh size. However, if the larger mesh were used at a moderate level of fishing (F = 0.2), the projections indicate an increase in SSB of about 20% over 5 years. The worst case scenario was if the fishery was conducted at the $F_{0.1}$ level of fishing effort for the larger mesh (F = 0.5) but the 130 mm mesh size was used. In this case the SSB declined by 50%.

Commercial catch rates would be affected by a change in mesh size and the fishing strategy. The larger mesh catch rate was initially about 40% that of the 130 mm mesh due to the large difference in selectivity. The 130 mm mesh catch rates declined with fishing at its respective $F_{0.1}$ level. The larger mesh catch rates increased over the 5-year period with fishing at its $F_{0.1}$ level, but they did not reach the 130 mm mesh catch rates. Catch rates were projected to double for the larger mesh if the fishery was conducted at a moderate F (F = 0.2). As was the case with SSB, catch rates were projected to decline by 50% if the fishery was conducted at F = 0.5 with the 130 mm mesh.

Commercial yields would also be affected by a change in mesh size. Under the $F_{0.1}$ scenario, the initial yield to the larger mesh was projected to be less than to the 130 mm gear. However, this changed after year 2, and by year 5 the larger mesh yield was 25% higher than the 130 mm yield. It must be remembered that this was possible only because the fishing effort by the larger mesh was twice that of the 130 mm mesh. When the larger mesh was used at F = 0.2, the initial yield was about 40% that of the 130 mm mesh at $F_{0.1}$, but the yield was projected to double over the projection period. When fishing was conducted with the 130 mm mesh at F = 0.5, yields declined steadily at the expense of stock size.

The weights at age of fish in the catches were estimated to be higher for larger mesh sizes. This may be the case for a population at a given time, since the gears are selecting the larger individuals of an age group. However, these larger fish need always be available for the larger weights at age to persist into the future. It is possible that continuous selection of the larger individuals in an age group may lead to smaller fish at age in the future (Hanson and Chouinard 1992). For this not to occur, the surviving fish would need to increase their growth rates. The effect may be even more severe if size at age is genetically determined.

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Table 1: Inputs for yield per recruit analysis based on 1995 population growth characteristics. The partial recruitments and weights at age were estimated from selectivity ogives for a family of selectivity curves with different L50s and a selection range of 10 cm. The row labeled S_{45} given the probability of retention of a fish of 47 cm length.

		Partial Recruitment						Weight at Age					
	L50	45	48	51	54	57	60	45	48	51	54	57	60
	S_{45}	0.61	0.45	0.29	0.18	0.10	0.05	0.61	0.45	0.29	0.18	0.10	0.05
Age	3	0.05	0.03	0.01	0.01	0.00	0.00	0.36	0.37	0.38	0.40	0.43	0.44
	4	0.20	0.12	0.06	0.03	0.02	0.01	0.58	0.59	0.60	0.61	0.62	0.63
	5	0.35	0.23	0.14	0.08	0.04	0.02	0.76	0.78	0.80	0.82	0.84	0.85
	6	0.49	0.35	0.23	0.14	0.08	0.05	0.92	0.95	0.99	1.03	1.08	1.12
	7	0.62	0.48	0.35	0.24	0.16	0.10	1.13	1.18	1.24	1.31	1.40	1.49
	8	0.74	0.62	0.49	0.36	0.25	0.16	1.33	1.37	1.43	1.50	1.58	1.67
	9	0.81	0.71	0.59	0.47	0.36	0.27	1.71	1.78	1.89	2.03	2.22	2.44
	10	0.89	0.82	0.74	0.64	0.55	0.46	2.47	2.57	2.71	2.89	3.11	3.36
	11	0.88	0.81	0.74	0.66	0.58	0.51	2.74	2.86	3.01	3.19	3.41	3.63
	12	0.95	0.91	0.85	0.78	0.70	0.62	3.47	3.55	3.68	3.88	4.13	4.42
	13	0.98	0.96	0.92	0.88	0.82	0.75	3.62	3.66	3.72	3.82	3.95	4.12
	14	0.99	0.98	0.96	0.94	0.90	0.85	5.89	5.93	5.99	6.11	6.29	6.52
	15	1.00	1.00	1.00	1.00	1.00	1.00	8.09	8.09	8.09	8.09	8.09	8.09

Table 2: Inputs for yield per recruit analysis based on 1980 population growth characteristics. The partial recruitments and weights at age were estimated from selectivity ogives for a family of selectivity curves with different L50s and a selection range of 10 cm. The row labeled S_{45} given the probability of retention of a fish of 47 cm length.

	Partial Recruitment						Weight at Age					
L50	45	48	51	54	57	60	45	48	51	54	57	60
S_{45}	0.61	0.45	0.29	0.18	0.10	0.05	0.61	0.45	0.29	0.18	0.10	0.05
Age 3	0.08	0.04	0.02	0.01	0.01	0.00	0.39	0.39	0.40	0.40	0.42	0.46
4	0.29	0.18	0.11	0.06	0.03	0.02	0.69	0.71	0.73	0.74	0.75	0.76
5	0.58	0.43	0.30	0.19	0.11	0.06	1.00	1.02	1.05	1.08	1.10	1.12
6	0.75	0.62	0.49	0.36	0.24	0.16	1.31	1.35	1.40	1.45	1.52	1.59
7	0.86	0.77	0.66	0.54	0.42	0.31	1.73	1.78	1.84	1.93	2.04	2.18
8	0.98	0.96	0.92	0.87	0.81	0.73	3.16	3.19	3.23	3.31	3.41	3.54
9	0.99	0.98	0.97	0.95	0.91	0.86	3.87	3.89	3.91	3.95	4.00	4.08
10	1.00	0.99	0.99	0.98	0.96	0.93	4.72	4.72	4.73	4.76	4.79	4.85
11	1.00	1.00	1.00	0.99	0.99	0.98	5.31	5.31	5.32	5.32	5.32	5.33
12	1.00	1.00	1.00	1.00	1.00	1.00	6.56	6.56	6.56	6.56	6.56	6.56
13	1.00	1.00	1.00	1.00	1.00	1.00	7.94	7.94	7.94	7.94	7.94	7.94
14	1.00	1.00	1.00	1.00	1.00	1.00	7.99	7.99	7.99	7.99	7.99	7.99
15	1.00	1.00	1.00	1.00	1.00	1.00	7.82	7.82	7.82	7.82	7.82	7.82

Table 3: Inputs for 5-year catch projections.

Age	1996 Population	Proportion Mature	Weight at Age
3	20000	0.12	0.249
4	12984	0.38	0.498
5	18447	0.72	0.673
6	17630	0.92	0.838
7	16013	0.98	1.032
8	14843	1.00	1.251
9	12232	1.00	1.598
10	5541	1.00	2.332
11	1843	1.00	2.537
12	743	1.00	3.365
13	425	1.00	3.575
14	181	1.00	5.850
15	91	1.00	8.085

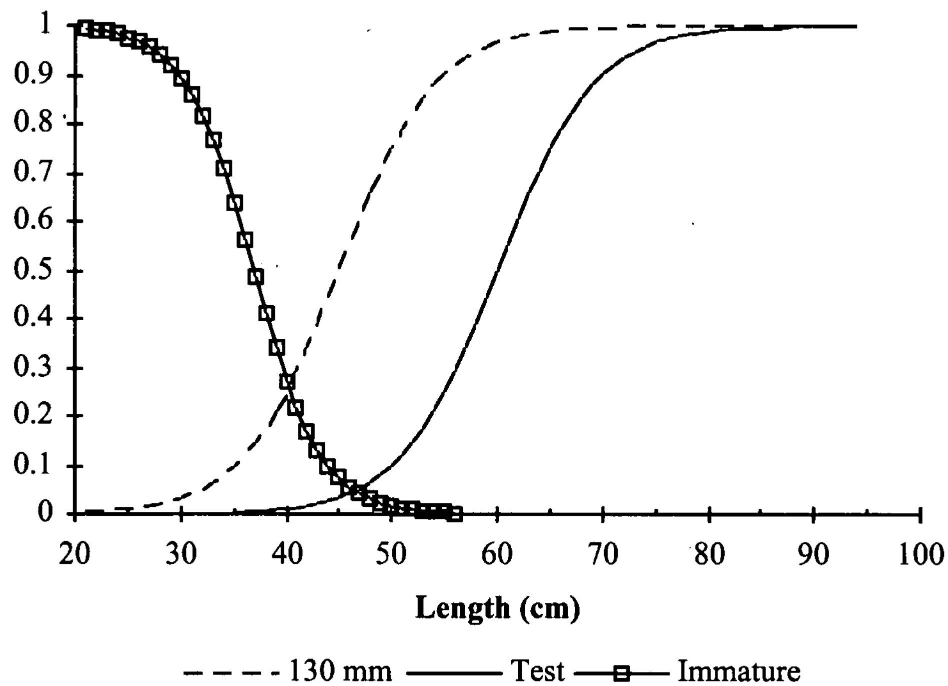

Figure 1: Comparison of the immaturity ogive (Immature) for southern Gulf of St. Lawrence cod and the selection ogives of two otter trawl codend mesh sizes, 130 mm diamond (130 mm) and one with and L05 of 47 cm (Test).

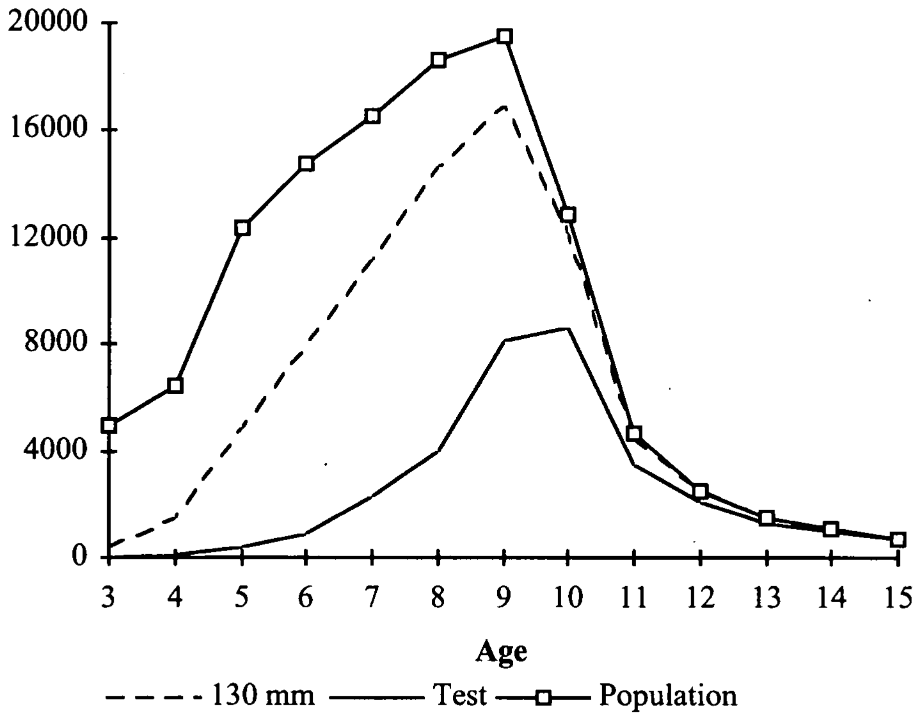

Figure 2: Comparison of the estimated biomass at age in the total population with that in the fishable populations available to two otter trawl codend mesh sizes, 130 mm diamond (130 mm) and one with and L05 of 47 cm (Test).

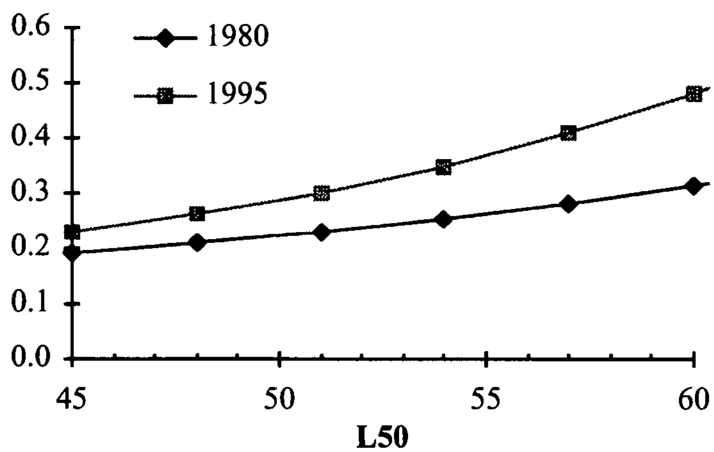

Figure 3: Fishing mortalities at $F_{0.1}$ for a family of mesh selection ogives with different L50s and a selection range of 10 cm. $F_{0.1}$ was calculated for population growth characteristics from 2 periods, 1980 and 1995.

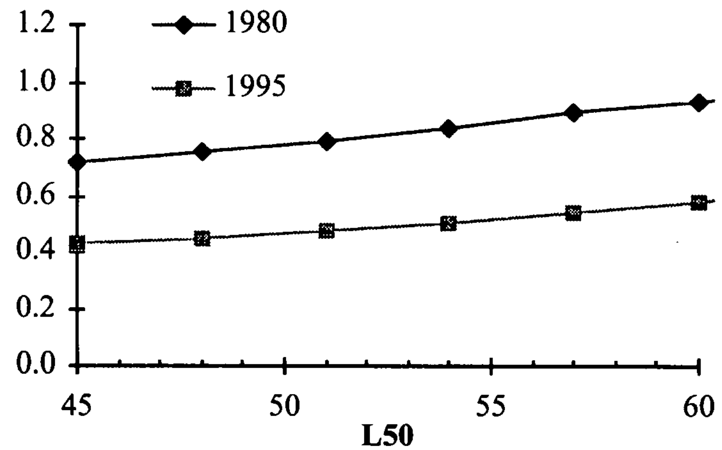

Figure 4: Yield per recruit (kg) at $F_{0.1}$ for a family of mesh selection ogives with different L50s and a selection range of 10 cm. Yield per recruit was calculated for population growth characteristics from 2 periods, 1980 and 1995.

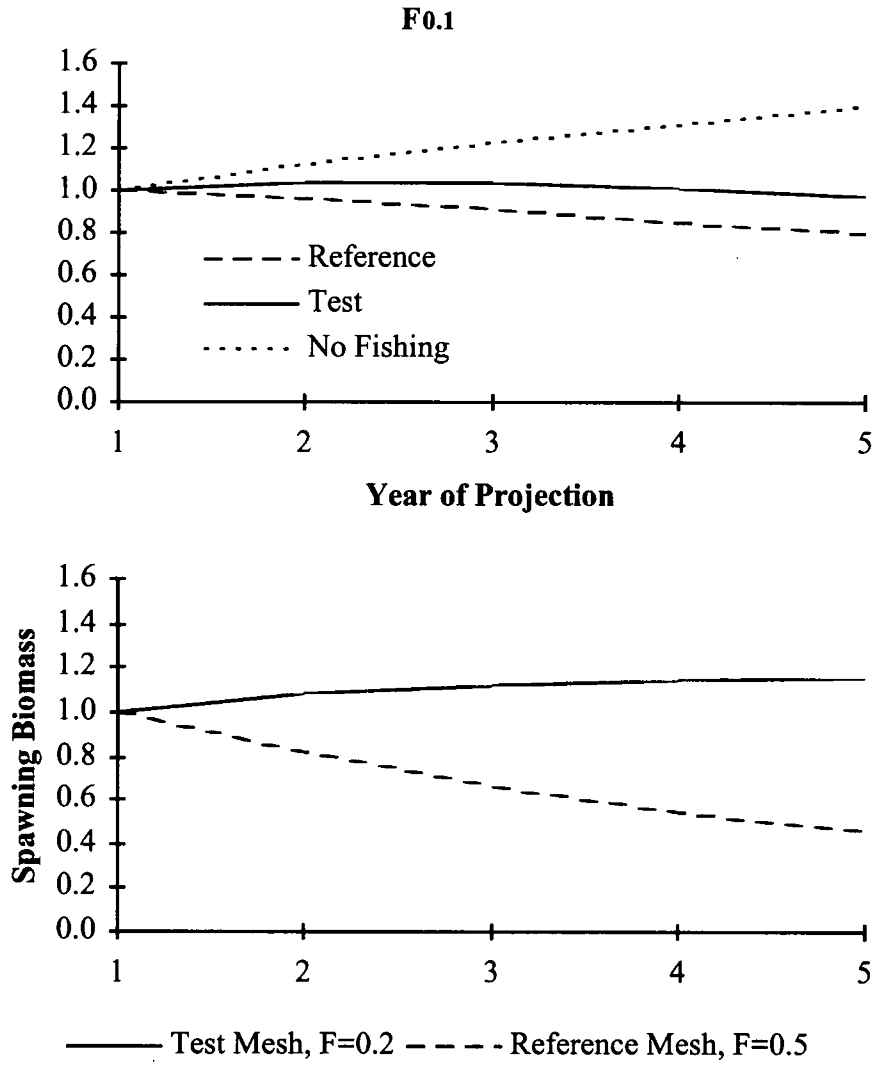

Figure 5: Trends in spawning stock biomass estimated for a five year period and two otter trawl codend mesh sizes, 130 mm diamond (reference) and a mesh with an L05 of 47 cm (Test). Three scenarios are presented. The upper panel is if the population was fished at $F_{0.1}$ corresponding to each mesh size. The lower panel is if the population is fished at F=0.2 by the test mesh and if the population is fished at F=0.5 by the 130 mm mesh size. All values are scaled to the 1996 beginning of year estimates.

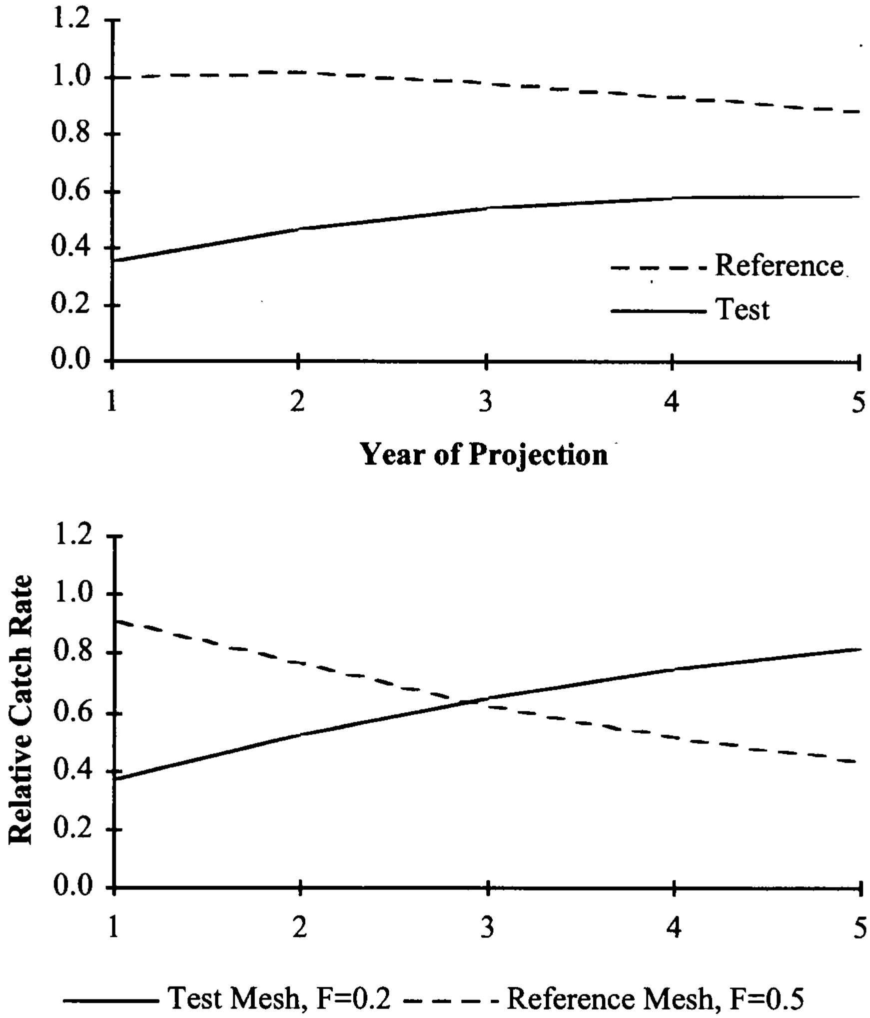

Figure 6: Trends in catch rates estimated for a five year period and two otter trawl codend mesh sizes, 130 mm diamond (reference) and a mesh with an L05 of 47 cm (Test). Three scenarios are presented. The upper panel is if the population was fished at $F_{0.1}$ corresponding to each mesh size. The lower panel is if the population is fished at F=0.2 by the test mesh and if the population is fished at F=0.5 by the 130 mm mesh size. All values are scaled to the 1996 130 mm catch rate at $F_{0.1}$.

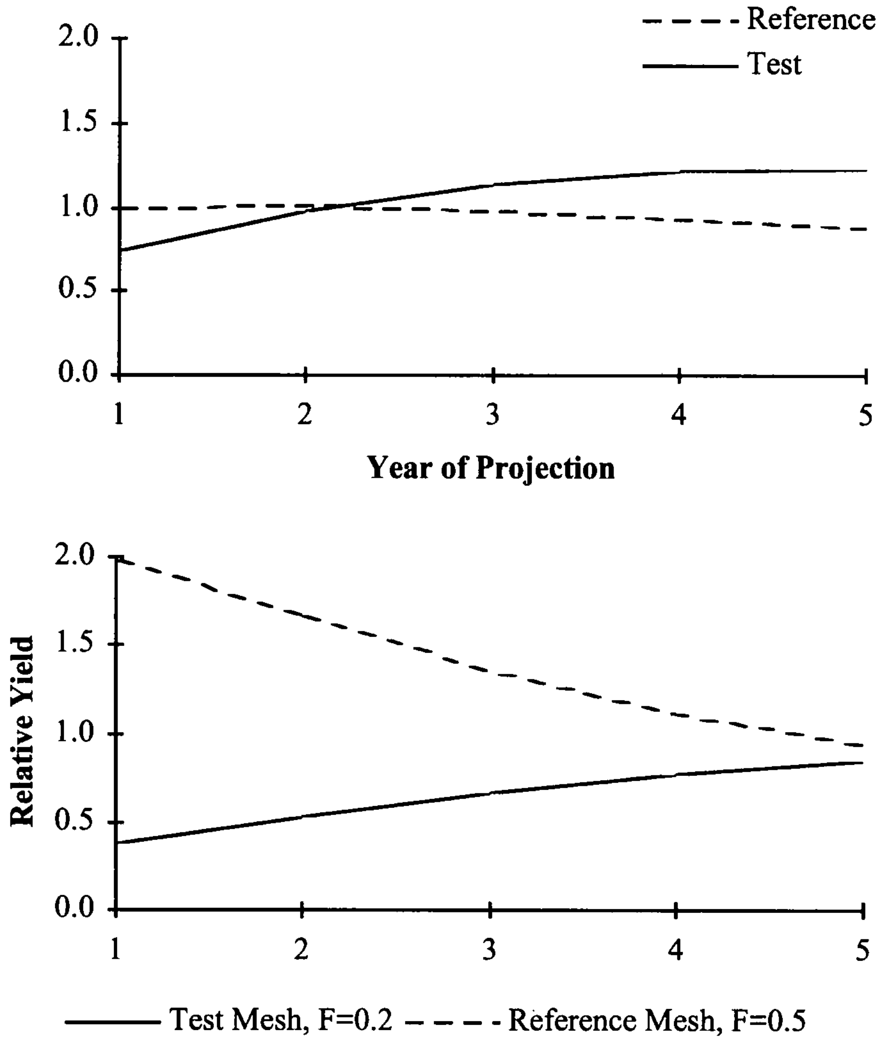

Figure 7: Trends yield estimated for a five year period and two otter trawl codend mesh sizes, 130 mm diamond (reference) and a mesh with an L05 of 47 cm (Test). Three scenarios are presented. The upper panel is if the population was fished at $F_{0.1}$ corresponding to each mesh size. The lower panel is if the population is fished at F=0.2 by the test mesh and if the population is fished at F=0.5 by the 130 mm mesh size. All values are scaled to the 1996 130 mm yield at $F_{0.1}$.