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Longliner-Otter Trawler Interactions in Cod Fisheries on the Scotian Shelf: Implications of Differences in Partial Recruitment

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Abstract

The implications of quota transfers from fixed gear (longliner) to mobile gear (otter trawl) sectors on subsequent catches by fixed gear in the 4Vn (M-D) cod management unit were examined. Gear specific partial recruitment (PR) estimates indicated that longline PR was flat topped with full recruitment-at-age 10 while otter trawl PR was dome-shaped with full recruitment-at-age 7. In a two gear fishery simulation, yield-per-recruit was found to be highest for a pure longline fishery and it declined as the percentage of longline effort decreased. Thus, if recruitment is uneffected by the percentage of longline effort, long-term average catch (at $F_{0.1}$) would be higher for the pure longline fishery than a pure otter trawl fishery. If otter trawl effort is added to a pure longline fishery, longline catch-per-unit-effort was strongly affected due to a reduction in the overall biomass and the interception of young fish by otter trawlers. If longline effort is added to a pure otter trawl fishery, the effect on otter trawl catch-per-unit-effort is much less severe. This is because the longline effort reduces the biomass of older fish with low PR to the otter trawls. These results indicate that increases in otter trawl effort will have serious effects on longline success.

Résumé

On a examiné les implications du transfert de contingents de secteurs de pêche à l'engin fixe (palangre) aux secteurs de pêche à l'engin mobile (chalut à panneaux) sur les prises ultérieures au moyen des engins fixes dans l'unité de gestion de la morue 4Vn (M-D). Des estimations de recrutement partiel (RP) spécifique à l'engin donnent une courbe à sommet plat pour le RP palangre avec recrutement complet à l'âge de 10 ans et une courbe en forme de dôme pour le RP chalut avec recrutement complète à l'âge de 7 ans. Lors d'une simulation de la pêche à chacun des engins, on a constaté que le rendement par recrue était le plus élevé pour la pêche exclusivement à la palangre et qu'il diminuait à mesure que diminuait l'effort de pêche à la palangre. Ainsi, si le recrutement n'est pas influencé par le pourcentage d'effort de pêche à la palangre, les prises moyennes à long terme (à $F_{0,1}$) seraient plus élevées pour la pêche exclusivement à la palangre que pour la pêche exclusivement au chalut. Si un effort de pêche au chalut est ajouté à une pêche exclusivement à la palangre, les prises par unité d'effort à la palangre sont fortement influencées en raison d'une réduction de la biomasse globale et de l'interception de jeunes poissons par les chaluts à panneaux. Si un effort de pêche à la palangre est ajouté à une pêche exclusivement au chalut à panneaux, l'effet sur les prises par unité d'effort au chalut est beaucoup moins prononcé, en raison du fait que l'effort de pêche à la palangre réduit la biomasse de poissons plus vieux, ce qui donne un faible RP pour les chaluts à panneaux. Ces résultats indiquent que des accroissements de l'effort de pêche au chalut à panneaux auraient des effets sérieux sur le succès de la pêche à la palangre.

Introduction

Within Groundfish Management Plans (GMP) on Canada's east coast total allowable catches (TACs) are allocated among fleet sectors defined by vessel size and the type of gear used. The current sectors are fixed gear < 65, mobile gear < 65', fixed gear 65-100', mobile gear 65-100', and vessels greater than 100'. The fixed gear component is dominated by longlines but it also includes traps, weirs, gillnets, and handlines. The mobile gear component is dominated by otter trawls but it also includes Danish and Scottish seines. Vessels greater than 100' are almost exclusively otter trawlers.

Allocations are made on the basis of equity among the fleet sectors taking into account the dependence of coastal communities and fleet sectors on the resource (Principle 3 of GMP, Anon. 1986). Principle 8 of the GMP has been interpreted, within the Atlantic Groundfish Advisory Committee (AGAC), to mean that a gear sector quota that is not likely to be caught within the fishing year will be sub-allocated to other gear sectors. Little consideration is given to biological factors such as gear selectivity or fishing patterns when allocations and mid-season sub-allocations are made.

Catch projections used to formulate TAC advice are based upon specific partial recruitment (PR) parameters as well as population estimates and target fishing mortalities. It is clear from catch-at-age data that longlines catch older fish, on average, than otter trawls. Adjustments to the relative participation of each gear will affect the partial recruitment pattern for the total fishery. Implicit in the sub-allocation process is the assumption that a ton of mobile gear fish is equivalent, with respect to fishing mortality-at-age, to a ton of fixed gear fish. Clearly this is not the case and some consideration of gear specific PR should be given when TACs are allocated.

This issue has recently been raised with respect to 4Vn (M-D) cod (Smith and Sinclair, 1986). Specifically the ADM Atlantic Fisheries Service has asked whether annual transfers of quota from the small fixed gear vessels to small mobile gear vessels have contributed to a decline in the fixed gear catch. It is not possible to fully quantify these effects for this stock due to the lack of relevant data. Rather, the object of this paper is to examine interactions between longliners and otter trawlers using data from an adjacent management unit, 4VsW cod.

Allocation and Catch Profile

Over the 10 years that GMPs have been in place the proportional allocation of the 4Vn (M-D) cod TAC has changed in favour of the inshore fixed gear fleet (Table 1). From 1977 to 1980 the fixed gear allocations were designated as allowances and were therefore not restrictive. Since then they have been regulated quotas. In 1977 and 1978 about 35% of the TAC was allocated to fixed gear. This increased to about 80% for the 1981-84 period but has fallen to 60% in 1985-1986. However, this is well above the 1977-78 level and the increased proportion allocated to fixed gear indicates the desire to promote the inshore small vessel fixed gear fishery in the area.

The fixed gear fleet has had varying success in meeting its allocations. Between 1977-80 it exceeded its allowances by 2.2 to 3.6 times. In 1981, the first year that quotas were imposed for fixed gear catches, the fleet again exceeded its allocation by 1.3 times. This was despite a 2,000 t increase in quota due to a mid-season increase in TAC based on biological advice. Since then the fixed gear fleet has failed to catch its quota and there were mid-season reallocations to the mobile gear of 1,100 t and 650 t in 1984 and 1985, respectively. The mobile gear catches were close to its quotas from 1978 to 1983. But in 1984 and 1985 the quotas were exceeded by 1.3 and 1.5 times respectively despite transfers. In the past three years catch and effort by longliners has been stable while that by otter trawlers has been increasing (Smith and Sinclair, 1986).

Methods

Fishing Patterns

Two factors contribute to PR for a specific gear, the selectivity of the gear, and the availability of fish of a given age to that gear. To examine possible availability differences the distribution of fishing effort by longliners and otter trawlers in 1984 and 1985 was investigated. Log records from vessels fishing for cod in Subdivision 4Vn between May and December were obtained from DFO Statistics Branch. Fishing locations and depths fished, whether daily or set by set, were compared.

Partial Recruitment

Only two years of full catch-at-age data are available for 4Vn (M-D) cod, namely 1984 and 1985. Due to this short time series no sequential population analysis (SPA) has been attempted. For the purposes of this analysis partial recruitment parameters were estimated using data from a sequential population analysis (SPA) of 4VsW cod (Sinclair and Annand, 1986) since these two management units are adjacent and similar vessels fish both areas.

Partial fishing mortalities by gear (k) and age (i) were calculated as:

$$F_{ik} = F_i \frac{C_{ik}}{C_i} \qquad (1)$$

where F = fishing mortality
C = catch numbers.

These partial Fs were decomposed into age and year effects as

$$F_{ijk} = S_{ik} F_{jk} \qquad (2)$$

where S_{ik} = partial recruitment at age i for gear k
F_{jk} = fully recruited fishing mortality in year j for gear k,

using a multiplicative analysis (O'Boyle, pers. comm.). The years 1982-84 and ages 3 to 10 were used. Input data are given in Table 2. PR estimates for 4Vn (M-D) cod obtained from ratios of commercial catch-at-age to survey mean catch-per-tow-at-age. Due to the short time series and the uncertainties associated with this method of calculation these estimates were used for comparative purposes only.

Yield Per Recruit

The current management strategy for Canadian east coast groundfish fisheries is to maintain fishing mortality at $F_{0.1}$. A series of Thompson and Bell yield per recuirt (Y/R) analyses (Rivard, 1982) were run using variable input PR patterns computed for different proportions of longline effort in a two gear fishery.

A partial recruitment vector for ages i and gear k (S_{ik}) represents the relative vulnerability of different ages to fishing by that gear. If q is the catchability coefficient for the stock and P_k is the fishing power of gear k then,

$$v_{ik} = q\, P_k S_{ik} \qquad (3)$$

is a vector of age specific vulnerabilities (Ricker, 1975; p. 3). If two gears with the same fishing power (i.e. generate the same fully recruited fishing mortality (F) per unit effort) fish the same stock simultaneously with effort proportions equal to θ_k ($\sum_k \theta_k=1$), then the resulting fishery wide vector of age specific vulnerabilities (v_i) is equal to

$$v_i = \sum_k v_{ik}\, \theta_k \qquad (4)$$

The fishery wide PR vector (S_i) is then

$$S_i = v_i/\max[v_i] \qquad (5)$$

where $\max[v_i]$ = the fishery wide fully recruited vulnerability (v).

The same PR vector may be calculated from individual gear specific PR vectors as:

$$Q_i = \sum_k S_{ik}\, \theta_k \qquad (6)$$

$$S_i = Q_i/\max[Q_i] \qquad (7)$$

Equation 7 is a necessary standardization if both gears do not have full recruitment at the same age. By combining equations 5 and 7 it may be easily shown that

$$\max[Q_i] = \frac{v}{q} \qquad (8)$$

or the ratio between the fishery wide vulnerability (the F per unit effort for the entire fishery) and the catchability coefficient (the F per unit effort for one particular gear). If the two gears do not have full recruitment at the same age, then $\max[Q_i] < 1$.

Equations 6 and 7 were used to estimate combined PR vectors for Y/R calculations.

A 15 year age span was used similar to that used for 4VsW cod (Sinclair and Annand, 1986). Weight at age and natural mortality (0.2) were held constant. Y/R was computed for 100%, 80%, 60%, 40%, 20%, 0% longline effort fisheries. Comparisons were made with respect to $F_{0.1}$, F_{max}, yield per recruit, gear specific fully recruited fishing mortality, and catch per standardized unit of effort for each level of longline participation.

To estimate gear specific fully recruited fishing mortalities (F_k), the following was considered. Since

$$\theta_k = \frac{E_k}{E} \tag{9}$$

where E = total effective fishing effort
E_k = effective fishing effort for gear k

and since $E = F/v$ and $E_k = F_k/q$, substituting for E and E_k and rearranging gives

$$F_k = \frac{\theta_k \; F \; q}{v} \tag{10}$$

where F = the population fully recruited fishing mortality.

From Equation 8 q/v may be replaced giving

$$F_k = \frac{\theta_k \; F}{\max[Q_i]} \tag{11}$$

By assuming gear specific catchabilities of 1, then $E_k = F_k$. Thus the total fishing effort is the sum of the gear specific efforts.

Catch Projections

Catch projections were carried out to determine gear specific yields and fishable biomass for hypothetical two gear fisheries of various proportions of longline effort fishing at $F_{0.1}$, and to investigate the implications of adding either otter trawler or longliner effort to pure longline or otter trawler fisheries respectively. In all cases recruitment was held constant at 1000 units and thus possible effects of different effort proportions on subsequent recruitment were not considered. Projections were carried out for 15 years to get a stable age distribution. In the former case, where $F_{0.1}$ catches were projected, the beginning population was 1000 units at age 1 and 0 units for ages 2-15. Partial recruitment was estimated using Equations 6 and 7, and projections were made using the corresponding $F_{0.1}$. In the latter case the initial population used was the stable age distribution corresponding to either a 100% longline or 100% otter trawler fishery. The fishing mortality used corresponded to $F_{0.1}$ for the respective gear plus F = 0.2 for the additional gear. The function MPROJECT from Rivard (1982) was used for the projections.

Yearly catch weight (Y_k) by gear was calculated as:

$$Y_k = \sum_i W_i C_i S_{ik} \theta_k / Q_i \qquad (12)$$

where W_i = weight at age i
C_i = total catch numbers at age i

Fishable biomass by gear was:

$$B_k^f = \sum_i B_i S_{ik} \qquad (13)$$

where B_i = the mean population biomass at age i.

Results

Fishing Patterns

The locations of logbook positions for longliners and otter trawlers fishing cod in Subdivision 4Vn (M-D) in 1984 and 1985 are given in Figure 1. The number of locations plotted for each gear does not accurately represent the intensity of fishing because many of the otter trawl locations were set by set while those for longlines were daily. In addition, tonnage class 1 information was not available from logs and there are several tonnage class 1 longliners in the area.

The areas fished by both gears are quite similar with otter trawler activity concentrated along the edge of the Laurentian Channel. Both gears fished the Sydney Bight area, west of 60° longitude. In the eastern area the longliners tended to fish along the 100 m contour while the otter trawler activity tended to be further offshore. The seasonal depth distribution of fishing is given as mean depth by month for each year separately in Figure 2. Both gears showed a tendency to fish deeper waters in the early and late periods of the fishery. In 1984 the mean depths were very similar while in 1985 the otter trawlers tended to fish deeper waters.

Smith and Sinclair (1985) observed that older fish were more abundant in deeper strata from research vessel survey results for Subdivision 4Vn. However, the results for 1985 were contrary to this (Smith and Sinclair, 1986). Nevertheless, the two gears appear to fish the same general areas with the otter trawlers tending to fish slightly deeper waters. This suggests that slightly older fish may be available to this gear than the longlines. However, this is highly spectulative given the available data.

Partial Recruitment

Analysis of partial F matrices for 4VsW cod indicated radically different PR patterns for the two gears (Table 4, Figure 3). For otter trawls the pattern is dome-shaped with full recruitment at ages 6-7. PR then dropped to 45% by age 10. For longlines recruitment was full at ages 9-10. For the purposes of further work the PR vectors were extended to age 15, with the otter trawl PR set at 0.45 and the longline PR at 1.00 for ages 11-15.

For comparative purposes PR was estimated for 4Vn cod using ratios of commercial and research survey catch at age for 1984. The gear specific patterns were similar to those estimated for 4VsW cod for both gears with those for longlines being the most alike (Figure 4). For the otter trawls the 4Vn vector was lower at ages 4, 5, 9, and 10. The PR vectors calculated for 4VsW cod were used for further work because they were based on a larger data set.

The combined PR vectors computed for various levels of longliner effort in hypothetical two gear fisheries are shown in Figure 5. For 100%, 80%, and 60% longline effort full recruitment was at age 9 and was relatively flat topped. For lower proportions of longline effort full recruitment was at age 7 and the curves became progressively more dome shaped. The variability in PR for ages 4-6 was higher for the higher proportions of longline effort. These results indicate the sensitivity of combined PR patterns to the relative amount of effort by the respective gears.

Yield Per Recruit

The results of the yield per recruit calculations are summarized in Table 5. $F_{0.1}$ varied from 0.26 for the 100% longline fishery down to 0.21 at 40% longline, then increased to 0.27 for 0% longline. The gear specific levels of effective fishing effort are also given in Table 5. Since neither gear exhibited full recruitment at the same age the sum of the gear specific effective effort was always greater than the $F_{0.1}$ values for mixed fisheries (Figure 6). The total effort varied little from 0.26 to 0.27. The highest yield per recruit was found for the 100% longline fishery (0.638 kg). It declined steadily to 0.562 kg for the 0% longline fishery. Given the virtually constant total effort and the decreasing trend in yield per recruit with decreasing longline participation, the catch per total effort trend also decreased in the same direction. However, the trend in fishable biomass (Y/F) varied inversely to the trend in $F_{0.1}$. This illustrates the difference between CPUE and fishable biomass in a multigear fishery where the gears do not have full recruitment at the same age.

Values of F_{max} varied from 0.56 at 100% longline to 0.39 for 40% longline, and increased to 0.50 for 0% longline (Table 5). The total effort for both gears went from 0.56 for 100% longline to 0.49 at 40% and 20% longline than back to 0.50 for 0% longline. Yield per recruit was highest (0.695 kg) at 100% longline and declined to 0.603 kg at 0% longline. Catch per total effort increased from 1.25 units at 100% longline to 1.31 at 60% longline, then decreased to 1.20 at 0% longline. Fishable biomass varied inversely with F_{max} as was seen in the $F_{0.1}$ case.

In both the $F_{0.1}$ and F_{max} scenarios the population fully recruited fishing mortalities varied from 30% to 40% depending on the mix of gears. However, the sum of the effective fishing efforts for both gears varied from 6% to 13%. Thus the total effective effort required to achieve target fishing mortalities over the entire spectrum of gear combinations varied little.

Long Term Catches at $F_{0.1}$

In this hypothetical example the long term total catch, assuming constant recruitment of 1000 units, would be 638 kg in a 100% longline fishery (Table 6). This declined to 562 kg as the proportion of longline effort was reduced to 0. This decline in total catch at $F_{0.1}$ with decreasing longline participation indicates that there is not a ton for ton trade off between longline and otter trawl catch in the long term (Figure 7).

Mean population biomass was 4,167 kg in the 0% longline fishery and 5,567 kg in a 100% longline fishery, an increase of 34%. Fishable biomass for longlines increased from 1,584 kg to 2,478 kg or by 56%. Fishable biomass for otter trawls increased by 50% from 2,064 kg to 3,090 kg. In all cases the fishable biomass for otter trawls was higher than that for longlines (Figure 8).

Implications of Adding Effort to a Stable Fishery

The effects of adding otter trawl effort to a pure longline fishery being exploited at $F_{0.1}$ are illustrated in Figure 9a. The additional otter trawl effort was equivalent to a fully recruited fishing mortality of 0.2. Fishing mortalities, PR, and recruitment were held constant for 15 years until a new stable age distribution was established. The increased effort resulted in an increase in total catch from 638 kg to 1,183 kg in the first year. Subsequently, catch by both gears declined as the population biomass was reduced. The longline catch fell 55% from 602 kg in year 2 to 275 kg in year 15. The otter trawl catch fell 36% from 581 t in year 2 to 373 kg in year 15. The total catch in year 15 was 646 kg, 1% higher than the original figure. The catch at age for the pure longline fishery peaked at age 8 while that for the 2 gears peaked at age 5 (Figure 10).

The addition of longline effort to a pure otter trawl fishery resulted in catch increasing from 562 kg to 831 kg in the first year (Figure 9b). Again catches by both gears declined with the otter trawler catch going from 538 kg in year 2 to 453 kg in year 15, a decline of 16%. The longline catch declined 38% from 293 kg to 181 kg. The final total catch was 634 kg, an increase of 13% from the original value. The catches at age for the pure otter trawler and the mixed fishery were very similar (Figure 10). Both peaked at age 5 and slightly more older fish (6 and above) were taken in the combined fishery.

The addition of otter trawl effort to a longline fishery clearly has different implications than the addition of longline effort to an otter trawl fishery. In the former case the younger ages (4-6) were not heavily exploited by longlines and these age groups were at a high abundance. The entry of otter trawlers resulted in high catch rates and apparent good fishing conditions. Continued fishing with otter trawls reduced the abundance of these age groups before they reached the longlines, thus the large decline in longline catch (55%) for the same effort. In the alternate case the new entrants (longliners) exploited older age groups which were only lightly exploited by otter trawls. Consequently, the catch by the otter trawls declined by a much smaller amount, only 16%.

It should be noted that since recruitment was held constant in all simulations, possible stock-recruitment effects were not considered.

Discussion

The main question being addressed here is whether annual quota transfers from the small fixed gear vessels to small mobile gear vessels contributed to a recent decline in the fixed gear catch of cod in 4Vn (M-D). If this question was considered in the context of an $F_{0.1}$ based regulatory system the answers would be yes. If the longlines were the only gear and they were fishing at $F_{0.1}$, the introduction of otter trawl effort would automatically call fo a reduction in longline effort to maintain $F_{0.1}$. It would also reduce the longline catch rates because of a reduction of the biomass of young fish before they reach the longline fishery provided both gears exploit the same population. Both of these factors would lead to a reduced longline catch. In addition the results indicated that increased otter trawl effort would result in a reduced long term average total catch at $F_{0.1}$.

It is only recently that fishing mortalities have been estimated for 4Vn (M-D) cod. These rough initial estimates indicate that F is approximately twice $F_{0.1}$ (Smith and Sinclair, 1986). Thus the $F_{0.1}$ scenario is not a realistic one. Rather a situation where effort by one gear is added to a pure fishery by another gear may be more relevent.

If otter trawl effort was added to a longline fishery and there was no change in longline effort the results indicated a large decline in longline catch (55% in this sample). This is due to two factors, a reduction in the overall biomass level due to increased fishing effort, and the interception of younger fish before they become available to the longliners. The resulting catch would be composed of relatively younger, smaller fish. To the extent that a quota reallocation from fixed to mobile gear would lead to increased otter trawler effort, the answer to the main question would again be yes.

In the opposite senario, adding longline effort to an otter trawl fishery, the results are quite different. The otter trawl catch decreased for the same amount of effort, but by a much smaller amount (15% in this example). This was because the longlines would be catching fish which for the most part were no longer available to the otter trawls.

These observations have biological implications for the way in which TACs are allocated. Specifically a shift of allocations from fixed gear to mobile gear is likely to have a greater effect on the fixed gear fishery than would a reallocation from mobile to fixed on the mobile gear fishery. If an $F_{0.1}$ strategy is followed there does not appear to be any biological advantage to any of the hypothetical fisheries. However, if for other reasons a longline fishery was considered desirable, then shifts in allocations from fixed to mobile gear would have adverse biological implications to the fixed gear in terms of catch rates and age composition.

It was observed that the sum of effective fishing effort in mixed gear fisheries is greater than the standardized effort required to generate the population fully recruited fishing mortality. This has important implications regarding the use of aggregated catch rates series for calibrating sequential population analyses. A standard calibration procedure is to relate fishable biomass (B^f) to a commercial catch rate index. From the catch equation the formal definition of fishable biomass is:

$$B^f = \frac{Y}{F} \tag{14}$$

By rearranging this equation and substituting for F and B^f, yield may be expressed as:

$$Y = \sum_k E_k \sum_i S_{ik} B_i \tag{15}$$

By expanding Equation 13 fishable biomass may be expressed as:

$$B^f = \sum_i B_i S_i \tag{16}$$

Substituting for S_i from Equations 6 and 7 this becomes:

$$B^f = \frac{\sum_k \theta_k \sum_i S_{ik} B_i}{\max[Q_i]} \tag{17}$$

If Equations 15 and 17 are combined fishing mortality may be expressed as

$$F = \max [Q_i] \sum_k E_k \tag{18}$$

Only when the gears are fully recruited at the same age ($\max [Q_i] = 1$) will catch per standardized effort be an unbiased estimate of fishable biomass. Thus when constructing aggregated catch rate indices using methods such as the multiplicative analysis of Gavaris (1980), care should be taken in using only gears with similar partial recruitment patterns. Based on the results of this analysis longline and otter trawler catch rate data should not be combined for 4VsW cod.

Further Research

The analysis presented here was general in nature and used several simplifying assumptions. Due to a lack of specific data on partial recruitment and fishing mortalties for 4Vn (M-D) cod, similar data from an adjacent stock (4VsW cod) were used. The catch projections were based on fixed recruitment and constant fishing effort assumptions. In order to more fully investigate the dynamics of these gear interactions, it may be important to use simulation methods which allow for variable recruitment and gear specific effort levels. Slight modifications to a model proposed by Allen and McGlade (1986) may allow such an investigation. Specific areas of interest would include investigation of the effects of recruitment variation on gear composition in the fishery and the subsequent economic viability of each gear type. Further consideration of the importance of age segregation in the population on partial recruitment is also warrented.

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Table 1. Allocations to and catches by fixed and mobile gears in the 4Vn (M-D) cod management unit. Percentages are in brackets.

Year	Initial Allocation		Final Allocation		Catch		TAC	
	Fixed	Mobile	Fixed	Mobile	Fixed	Mobile	Initial	Final
1977	1250(38)	2000(62)	1250(38)	2000(62)	2754(35)	5167(65)	3300	
1978	1000(29)	2500(71)	1000(29)	2500(71)	3623(65)	1926(35)	3500	
1979	2300(68)	1100(32)	2300(68)	1100(32)	5472(86)	902(14)	3400	
1980	3600(73)	1300(27)	3600(73)	1300(27)	8479(83)	711(17)	5000	
1981	6100(80)	1300(20)	8100(82)	1800(18)	10603(85)	1821(15)	7500	10000
1982	8600(83)	1800(17)	10400(75)	3450(25)	8684(72)	3350(28)	10500	14000
1983	11100(80)	2800(20)	11100(80)	2800(20)	6179(60)	3200(34)	14000	
1984	11100(80)	2800(20)	10000(72)	3900(28)	6191(58)	4566(42)	14000	
1985	8000(67)	3900(33)	7350(62)	4550(38)	6416(51)	6090(49)	12000	
1986	7900(66)	4000(34)	7900(66)	4000(34)	2077(37)	3477(63)	12000	

1. From 1977 to 1980 the fixed gear allocations were designated as allowances.

2. 1986 is catch to date.

TABLE 2: INPUT DATA FOR THE ESTIMATION OF PR FOR LONGLINERS AND OTTER TRAWLERS IN 4VsW COD. A) CATCH AT AGE BY GEAR, B) F AT AGE BY GEAR.

A)

	LONGLINE			OTTER TRAWL			TOTAL		
AGE	82	83	84	82	83	84	82	83	84
3	80	18	4	2000	2412	367	2500	3048	421
4	385	246	137	6323	7028	5371	7664	8251	6210
5	764	564	409	8209	6114	7997	9953	7368	9371
6	419	902	462	2873	4705	5017	3449	5967	6113
7	539	401	540	1755	1460	3104	2408	1938	4102
8	555	387	273	665	576	950	1273	999	1294
9	390	246	166	247	323	386	674	576	569
10	190	115	114	109	112	171	304	229	293
11	110	85	80	43	55	64	156	140	149
12	45	31	39	20	18	21	67	50	61
13	41	18	28	15	3	6	57	22	35
14	45	14	12	5	2	5	51	16	17
15	16	5	2	2	1	0	19	6	2

B)

	LONGLINE			OTTER TRAWLER			TOTAL		
AGE	82	83	84	82	83	84	82	83	84
3	.001	.000	.000	.025	.038	.009	.032	.048	.011
4	.008	.004	.003	.128	.118	.114	.156	.138	.131
5	.023	.017	.010	.244	.183	.197	.296	.220	.230
6	.033	.044	.022	.225	.229	.236	.270	.290	.287
7	.087	.049	.044	.284	.180	.251	.390	.239	.332
8	.152	.107	.053	.182	.159	.183	.348	.277	.249
9	.196	.112	.073	.124	.147	.170	.338	.262	.250
10	.221	.092	.080	.127	.089	.120	.354	.183	.206
11	.346	.166	.093	.135	.107	.075	.490	.273	.173
12	.355	.177	.117	.158	.103	.063	.530	.285	.183
13	.872	.268	.265	.319	.045	.057	1.219	.328	.332
14	1.528	1.466	.321	.170	.209	.134	1.719	1.676	.455
15	.255	.250	.300	.032	.050	.000	.300	.300	.300

Table 3. Average weights at age for 4VsW cod, 1982-84.

AGE	WEIGHT AT AGE
1	.400
2	.635
3	.701
4	1.044
5	1.456
6	1.981
7	2.491
8	3.170
9	3.993
10	5.105
11	6.368
12	6.140
13	9.935
14	11.167
15	11.255

Table 4. Partial recruitment estimates for 4VsW cod, derived from an analysis of partial F's, and 4Vn (M-D) cod, derived from ratios of commercial catch to survey numbers at age.

	Longline		Otter Trawl	
Age	4VsW	4Vn	4VsW	4Vn
1	0	0	0	0
2	0	0	0	0
3	0	0	.09	.01
4	.04	.07	.51	.26
5	.13	.14	.88	.53
6	.27	.30	.98	1.00
7	.49	.66	1.00	.90
8	.81	.73	.74	.85
9	.99	.91	.62	.20
10	1.00	.98	.47	.32
11		1.00		.16
12		.27		.02

Table 5. Summary of yield per recruit calculations at different levels of longliner participation.

% Longline	F	Effort: Longline	Effort: Otter Trawl	Total Effort	Yield Per Recruit	Fishable Biomass[1]	CPUE[2]
$F_{0.1}$							
100	.2578	.2578	0	.2578	.6384	2.48	2.48
80	.2374	.2064	.0516	.2580	.6198	2.61	2.40
60	.2196	.1558	.1039	.2597	.6031	2.75	2.32
40	.2089	.1051	.1576	.2627	.5879	2.81	2.24
20	.2397	.0534	.2136	.2670	.5742	2.40	2.15
0	.2726	0	.2726	.2726	.5616	2.06	2.06
F_{MAX}							
100	.5583	.5583	0	.5583	.6951	1.25	1.25
80	.4731	.4113	.1028	.5142	.6704	1.42	1.30
60	.4201	.2981	.1987	.4969	.6499	1.55	1.31
40	.3913	.1968	.2952	.4920	.6322	1.62	1.28
20	.4443	.0990	.3959	.4949	.6167	1.39	1.25
0	.5036	0	.5036	.5036	.6029	1.20	1.20

1. Fishable biomass is calculated as Y/R ÷ F

2. CPUE is calculated as Y/R ÷ total effort

% Longline	Max [Qi]
100	1.0000
80	.9201
60	.8455
40	.7954
20	.8977
0	1.0000

Table 6. Summary of stable age dist. catches for $F_{0.1}$ conditions under different mixes of longline and otter trawler effort.

	Percent Longline					
	100	80	60	40	20	0
Total Catch	638	620	604	587	574	562
Longline Catch	638	471	327	201	93	0
(%)	(100)	(76)	(54)	(34)	(16)	(0)
Trawler Catch	0	149	277	386	481	562
(%)	(0)	(24)	(46)	(66)	(84)	(100)
Mean Population Biomass	5567	5261	4970	4693	4424	4167
Longline Exploitable Biomass	2478	2285	2096	1922	1749	1584
Trawler Exploitable Biomass	3090	2875	2662	2455	2254	2064

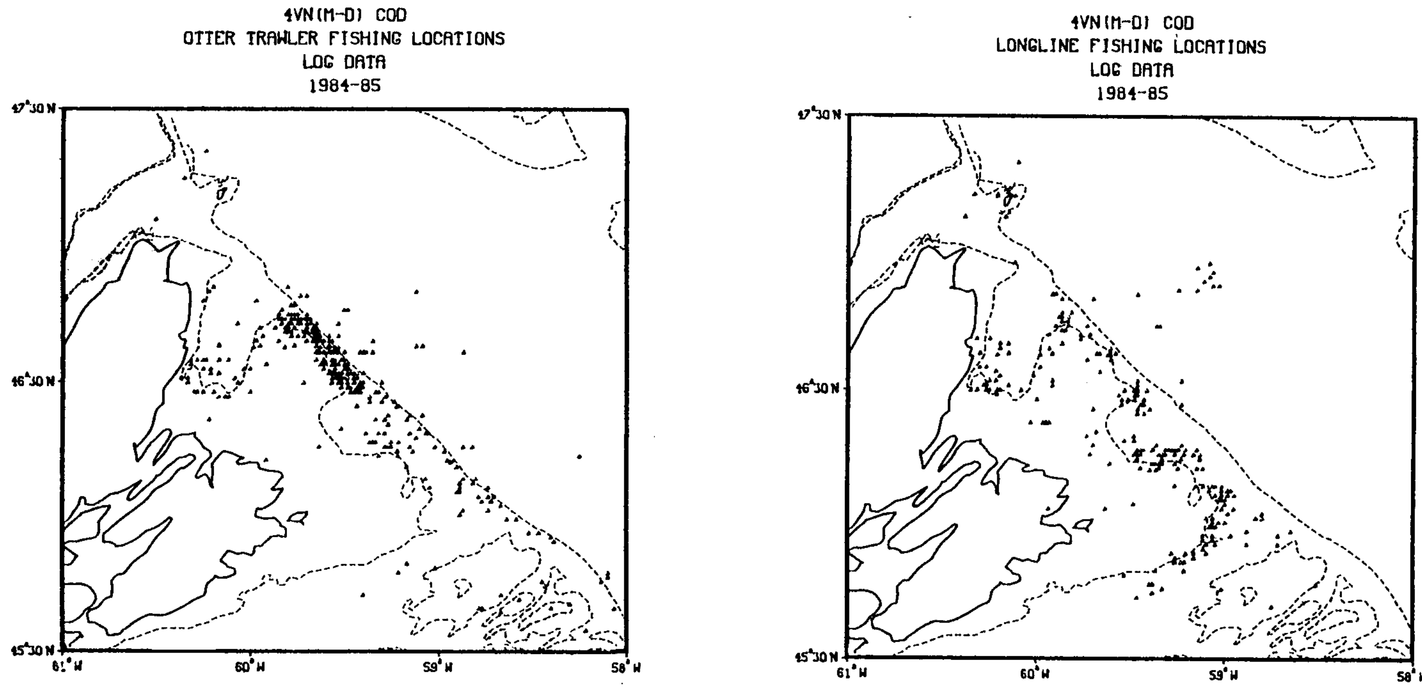

Figure 1. Distribution of otter trawler and longline fishing locations for 4Vn (M-D) cod in 1984-85.

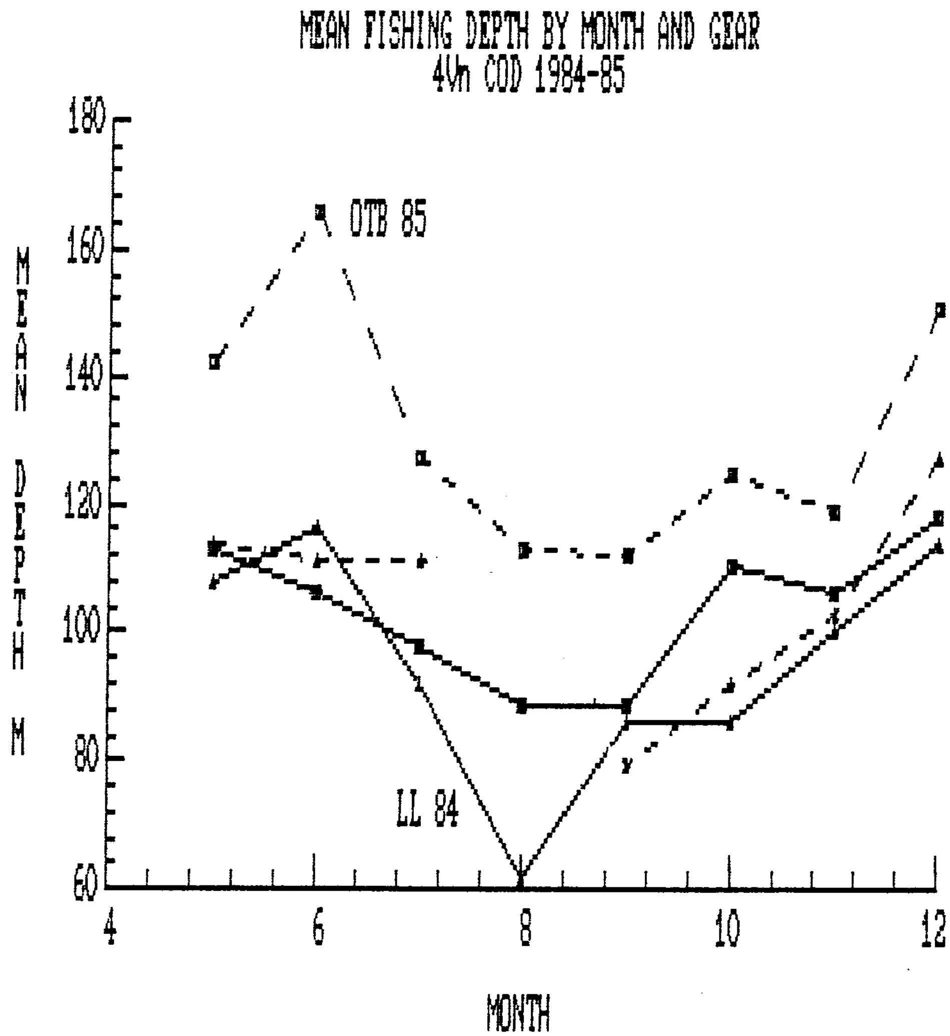

Figure 2. Mean fishing depth by month and gear for 4Vn cod, 1984-85. Data from log records. The solid line is for longliners, the dashed for otter trawlers.

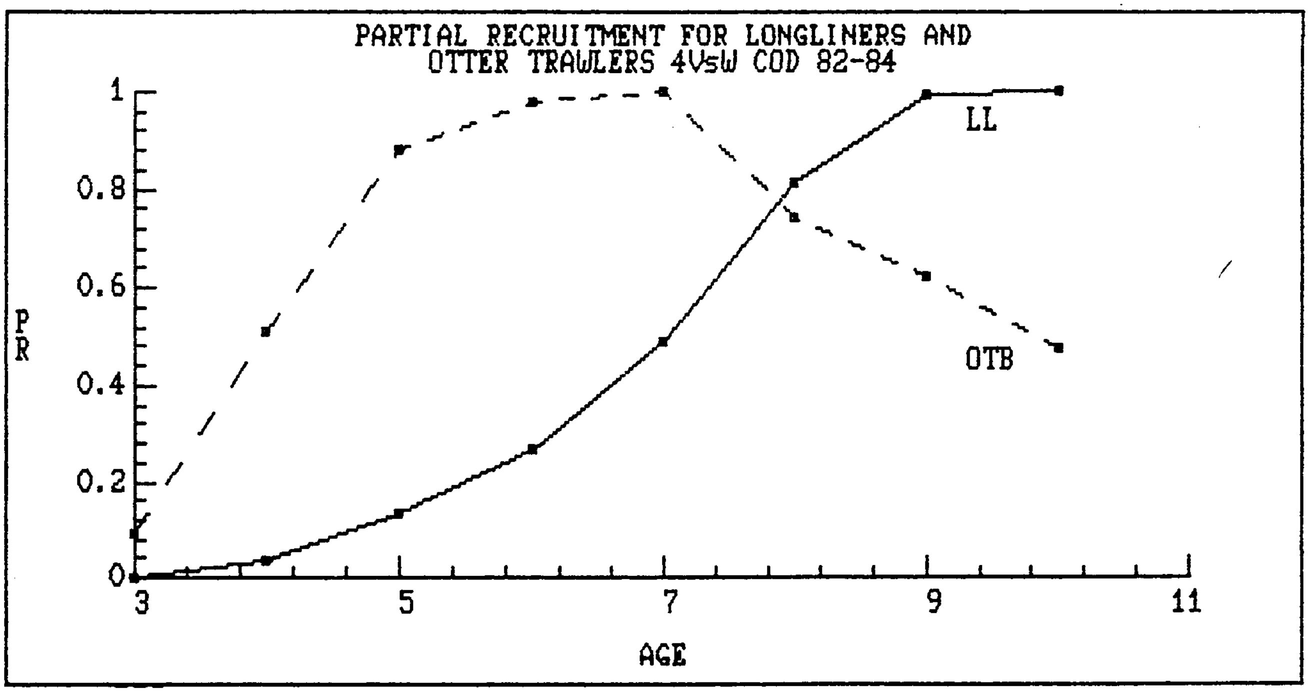

Figure 3. Estimated partial recruitment vectors for otter trawlers and longliners fishing cod in 4VsW.

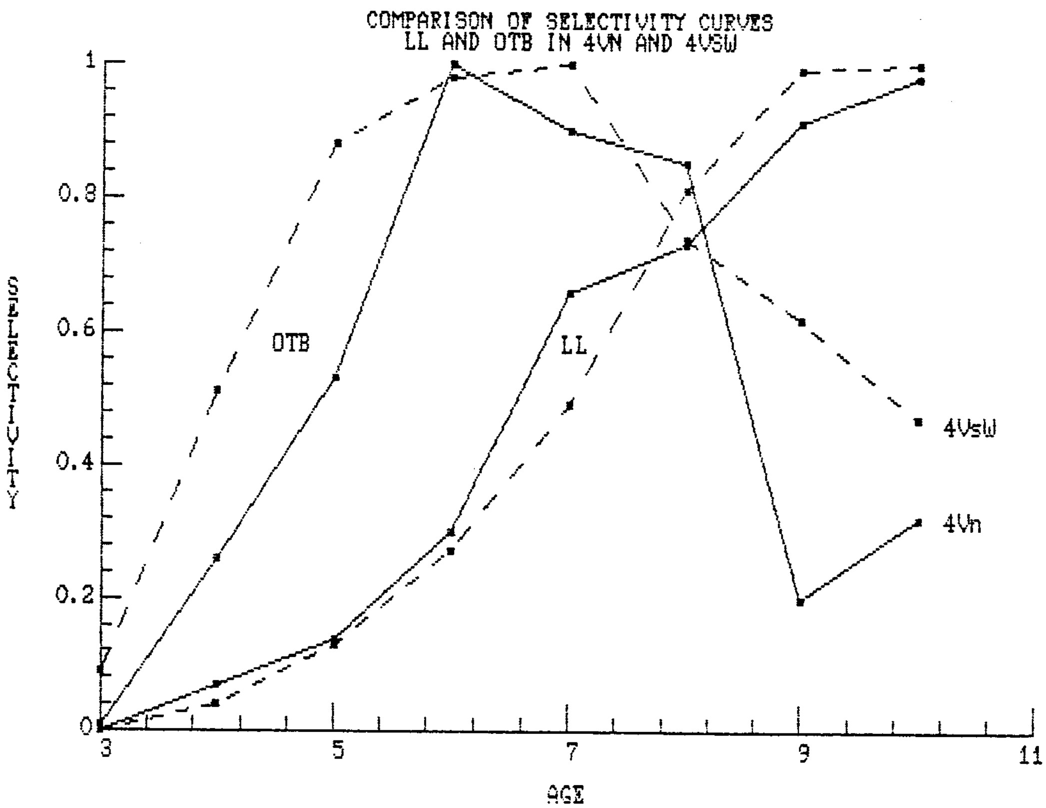

Figure 4. Comparison of partial recruitment curves for longliners and otter trawlers fishing cod in 4Vn and 4VsW.

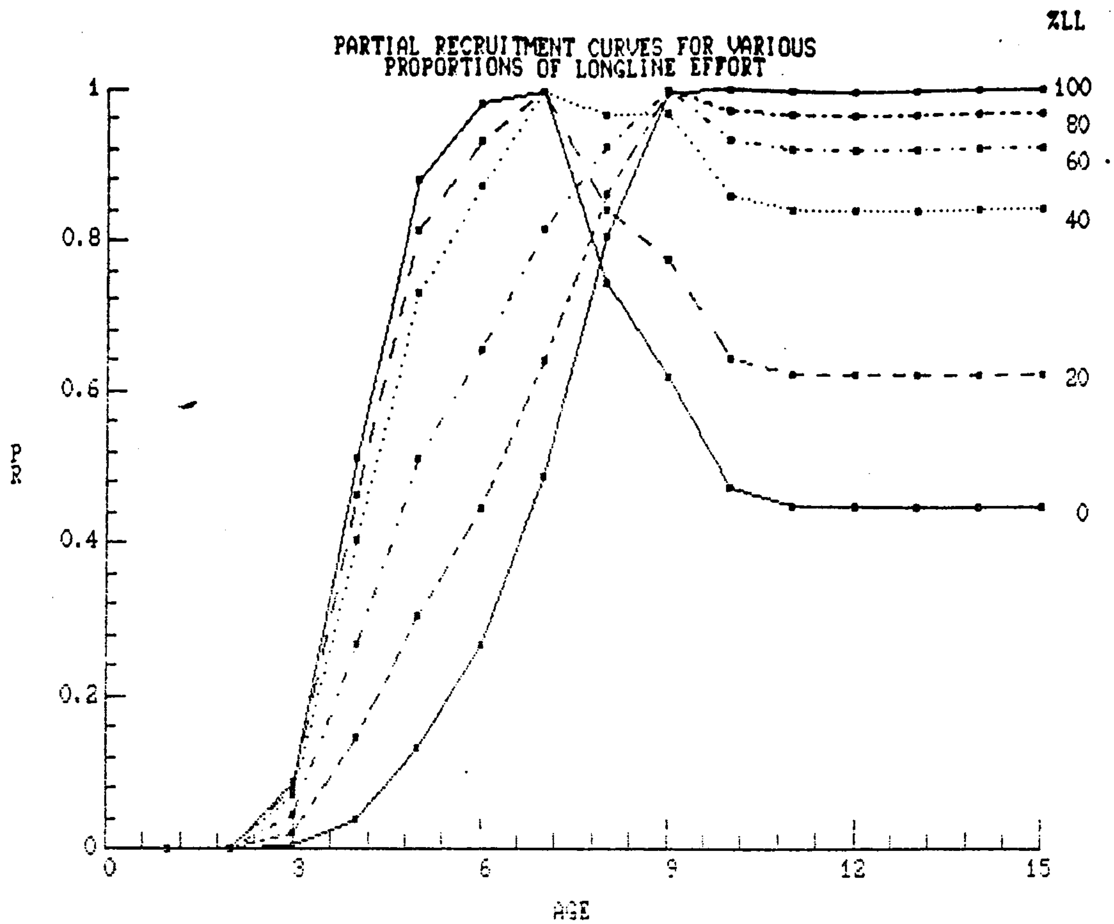

Figure 5. Comparison of partial recruitment curves calculated for various levels of longline participation.

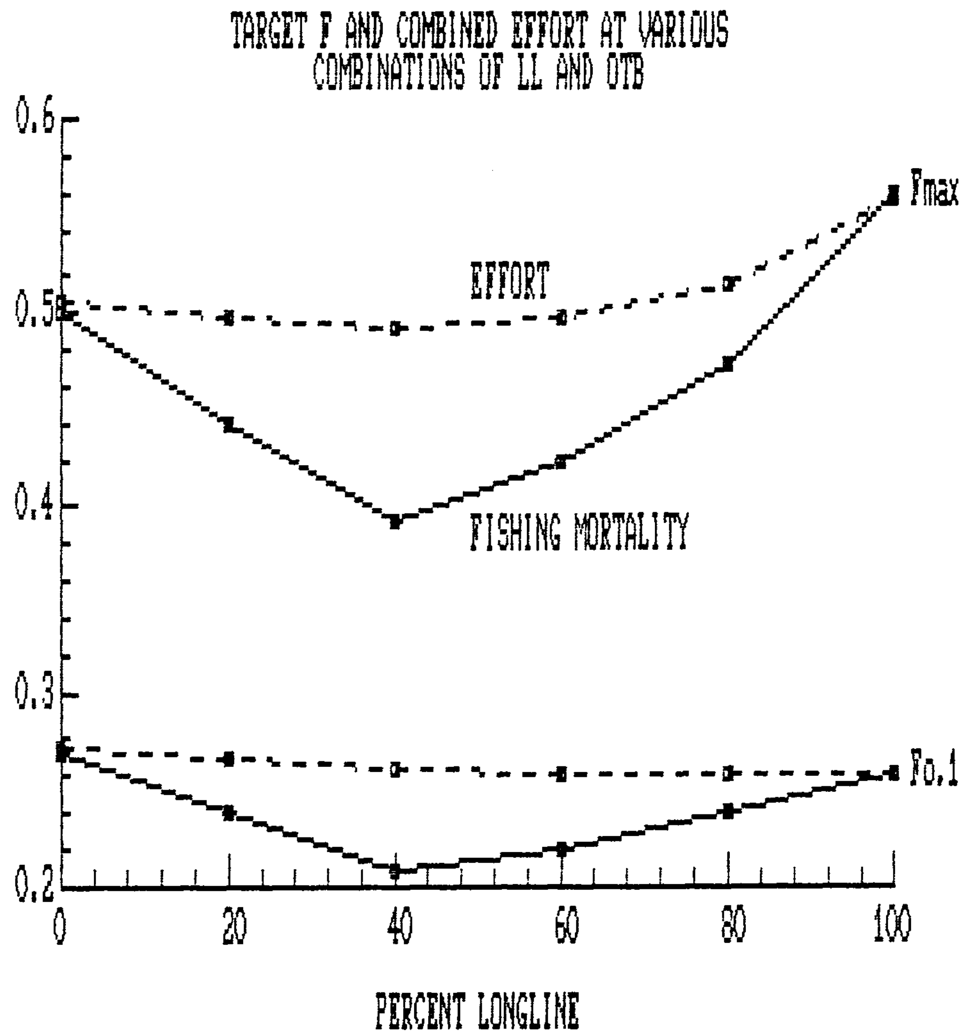

Figure 6. Comparison of target fishing mortalities and the associated standardized fishing efforts at different levels of longline participation.

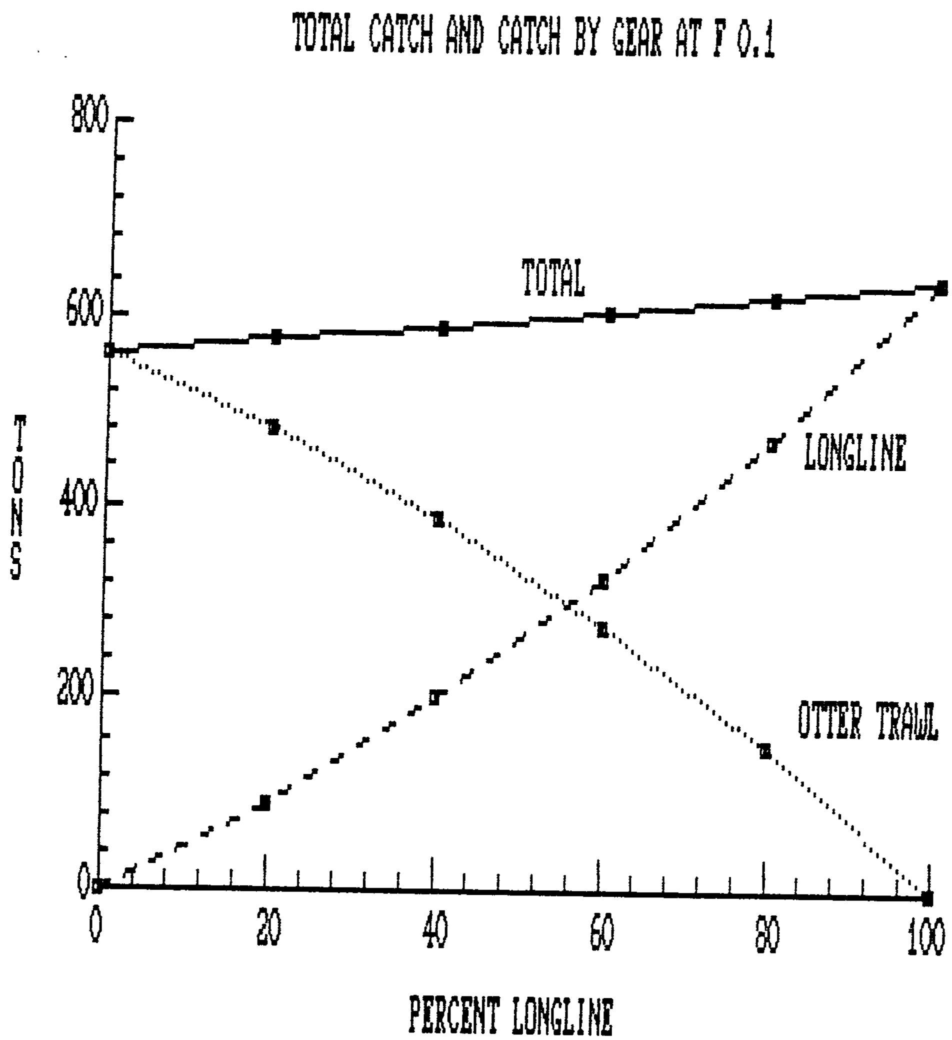

Figure 7. Long term average catch by gear and in total at $F_{0.1}$ for different levels of longline effort.

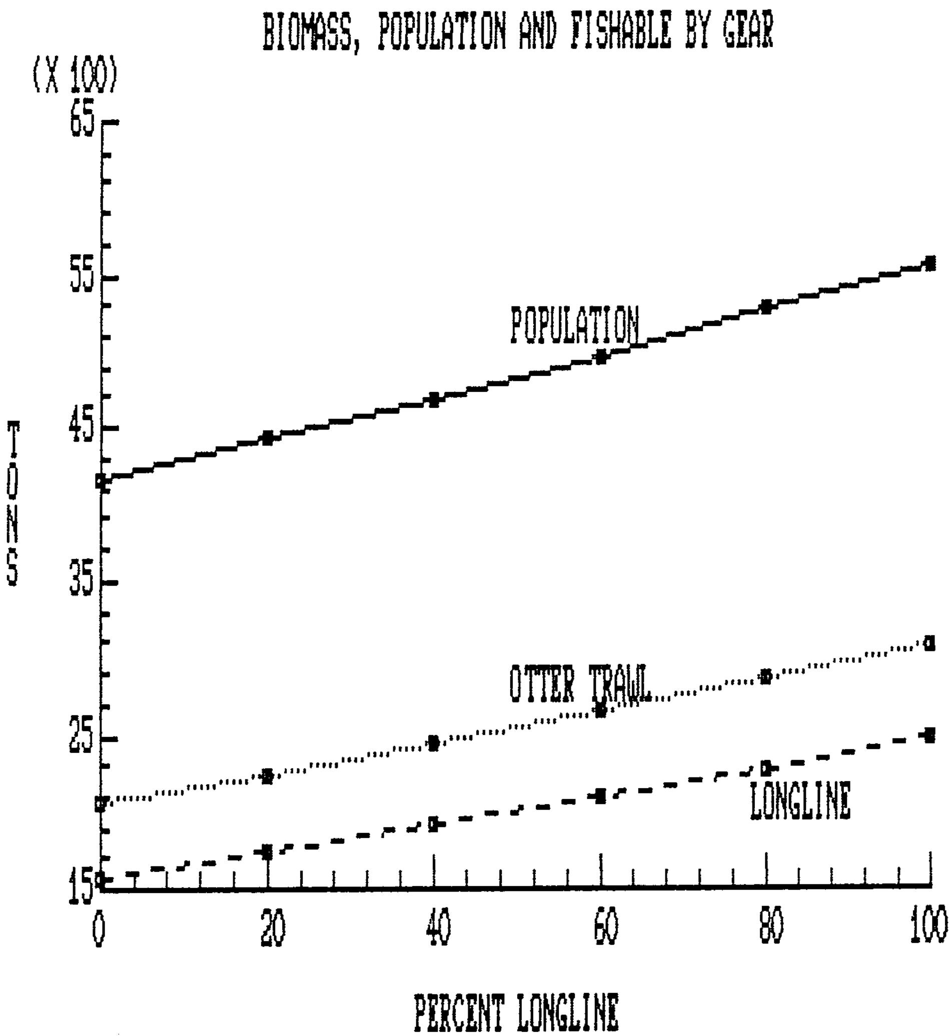

Figure 8. Population mean biomass and gear specific fishable biomass at different levels of longline participation.

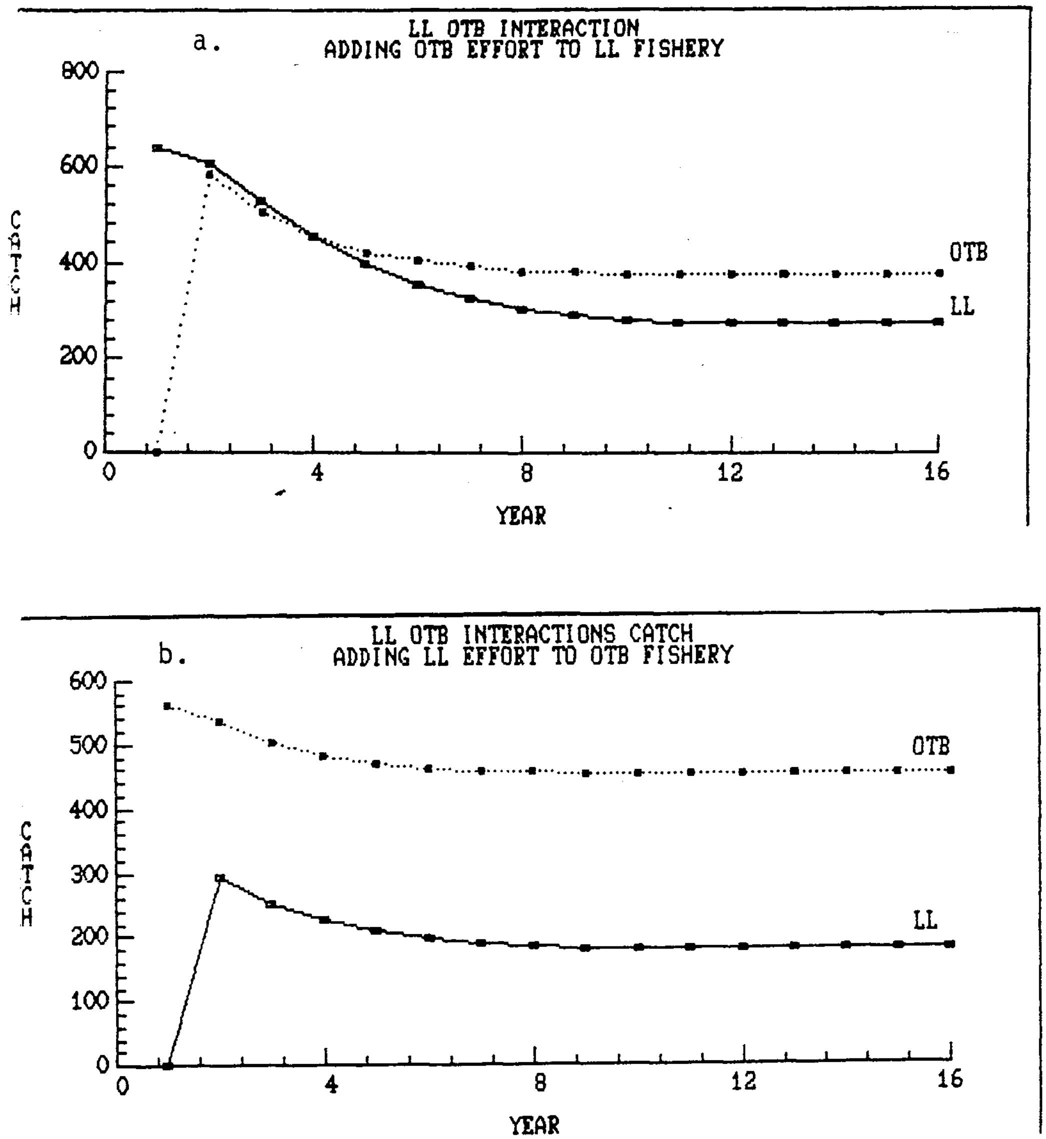

Figure 9. Catch by gear following the addition of effort by one gear to a pure fishery at $F_{0.1}$ by another.

a) Addition of otter trawler effort to a longline fishery.

b) Addition of longline effort to an otter trawler fishery.

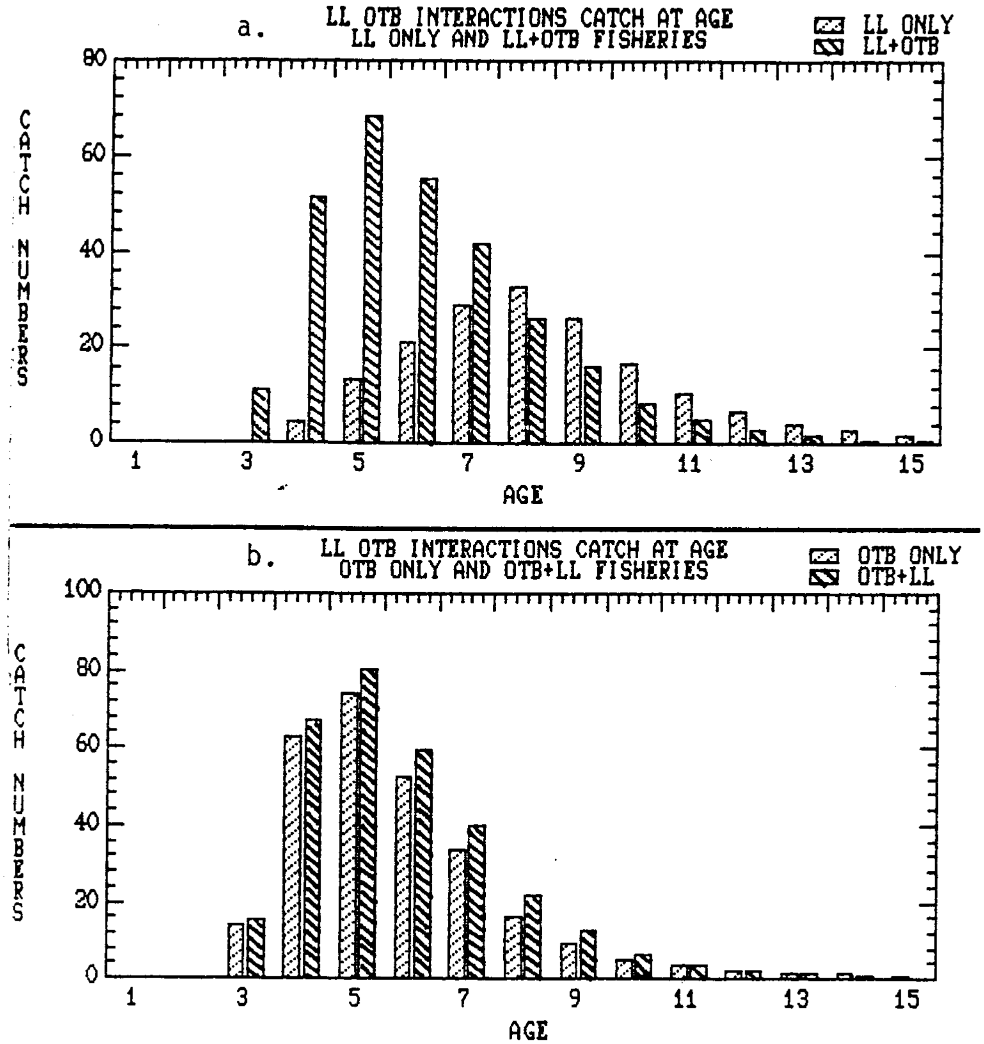

Figure 10. Catch at age before and after (15 years) the addition of effort by one gear to a pure fishery at $F_{0.1}$ by the other.

a) Addition of otter trawler effort to a longline fishery.

b) Addition of longline effort to an otter trawler fishery.