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By-Catches in Five Grand Bank Groundfish Fisheries

by

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ABSTRACT

A linear programming technique was used to analyse the ratios of by-catch species to main species in five directed groundfish fisheries in NAFO Div. 3L, 3N, and 3Ø. Operating within allowable catch levels for 1981, the analysis provided the directed catch as well as the total catch for each species, based on yearly fishing patterns over the period 1976-79. The results showed that although the predicted directed catches for each species in 1981 varied considerably with each of the four fishing patterns, the total catch permitted for each species would be taken regardless of the fishing pattern used.

RESUME

La programmation linéaire a servi à analyser les rapports entre les prises fortuites et celles de l'espèce visée dans cinq pêcheries dirigées des divisions 3L, 3N et 3Ø de l'OPANO. Cette analyse, menée dans les limites de prises fixées pour 1981, a donné les quantités capturées de l'espèce cible ainsi que le total de chaque espèce, fondées sur le régime annuel de pêche pendant la période 1976-79. Les résultats démontrent que, en dépit des fortes variations des prises dirigées prédites pour chaque espèce en 1981 à chacun des quatre régimes de pêche, les prises totales admissibles de chaque espèce auraient été atteintes, quel que soit le régime de pêche adopté.

INTRODUCTION

In considering problems of by-catch, 5 directed fisheries by Canadian trawlers in NAFO Div. 3L, 3N and 3O combined were examined: cod, redfish, American plaice, witch and yellowtail. Only offshore fisheries i.e., those conducted using trawl nets, were considered. By-catch ratios were calculated for each of the 4 years 1976-1979. The linear programming model used by Brown et. al., (1973, 1975) is used for each of the 4 years' by-catch ratios to maximize total catch of all 5 species for 1981, the constraints being that the "allocation"[1] for each species not be exceeded.

MATERIALS AND METHODS

Catches for 1976, '77, '78 and '79 separately, for areas Div. 3LNO, for all trawl gear, by main species, were determined from ICNAF statistics (Tables 1, 2, 3, 4). From these, by-catch ratios were derived (Tables 5, 6, 7, 8). These were calculated, for each directed fishery, by dividing the catch of each species in the fishery by the catch of the directed species. The column headed "R" gives the sum of the ratios within each fishery i.e., the sum of the catch of the 5 species in the fishery divided by the catch of the main species.

Two methods were used to calculate the "allocations" for the Div. 3LNO trawl fisheries. The first method used the ratio of the Div. 3LNO catch by trawl in the 5 fisheries (Tables 1-4) to the Div. 3LNO catch by all gears for each year. These ratios were multiplied by the Canadian allocation for 1981 for each species to give an "allocation" for trawl gears for each species in the model for each year. For cod and witch, the portion of the Div. 2J3KL allocation which would theoretically be caught in Div. 3L was determined from catch ratios in Div. 2J3KL and Div. 3L in each year and this was added to the Div. 3NO allocation (Table 10) before the ratios were applied. The "allocations" calculated by this method appear in Table 11. The second method involved the use of the actual 1981 Canadian allocations (Table 9). For redfish, American plaice, and yellowtail, the 1981 Div. 3LNO allocations were used directly as the Div. 3LNO "allocations" for the model (Table 17). For cod and witch, the Div. 3L portion of the Div. 2J3KL allocation was determined, and this was added to the Div. 3NO allocation. This was done for each species by taking the ratio of the Div. 3L catch to the Div. 2J3KL catch in a year and multiplying this by the Div. 2J3KL Canadian offshore allocation to produce a Div. 3L offshore "allocation". This was then divided by the Div. 2J3KL total Canadian allocation for that year and the resulting figure was multiplied by the 1981 Canadian allocation for Div. 2J3KL to produce the 1981 Div. 3L offshore "allocation". Results of these computations appear in Table 16.

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[1]"allocation" is used throughout this paper to mean an amount allowed to be caught. It is not a true allocation, although it is calculated from such.

The by-catch ratios and R values were used in the linear programming model (Glicksman 1963; Llewellyn 1964). A value, S, which is the total catch of all species, was maximized so that none of the individual species "allocations" was exceeded (Appendix I). The solution to the set of equations gave the directed catches for each species, from which the total catches for each species were calculated. Program ZX3LP from IMSL was used in solving the linear programming setup. Results from the linear programming simulations appear in Tables 12-15 and 18-21.

RESULTS AND DISCUSSION

The linear programming model showed, for both sets of simulations, that except for the total "allocations" derived from the 1977 data, the total "allocations" would be caught using the corresponding fishing patterns. For the 1977 data, the total predicted 1981 catch from the "catch method" simulations represented 99.94% of the total "allocation" and the total predicted 1981 catch from the "allocation method" simulations represented 99.97% of the total "allocation".

The increases in the 1981 total "allocations" using the "catch method" over the 4 years' data were due primarily to the increases in the predicted catch of cod. This was because the percentage of the total cod catch taken by trawl fisheries increased in each year. The "allocations" for the other species remained fairly stable over the 4 year range, the greatest difference being a 17.3% decrease in 1977-based witch "allocation" over the 1976-based one.

The differences in the 1981 total "allocations" using the "allocation method" were due primarily to the differences in the ratios of the Div. 3L offshore "allocation" to the Div. 2J3KL total allocation for cod (Table 16). For the 1976 data, which gave a 1981 Div. 3LNO "allocation" of 42,749 MT for cod, this ratio is highest, while for the 1978 data, which gave an "allocation" of 29,464 MT, the ratio was lowest. Witch did not have a great effect on the total 1981 "allocation" as its "allocations" range from 3,385 MT for the 1977 data to 4,456 MT for the 1976 data. "Allocations" for the other species were the same for each year's data, this being due to the fact that all the catch for these species was allocated to offshore fisheries. This was alright for redfish and yellowtail where there are no inshore fisheries, but was not the case for American plaice, where the inshore fishery takes a portion of the total allocated catch.

The increases in the directed catches of cod in the 4 "catch method" simulations were consistent with the increases in the "allocations" for cod in Div. 3L. Because of the low by-catch of redfish in any of the other fisheries (with the exception of the 1979 witch fishery, where total catches were negligible anyway), the directed catches of redfish showed little variation. The predicted directed catches of American plaice showed almost no difference in the 4 simulations. The total amounts of American plaice caught in the other fisheries were approximately equal in each of the 4 years, although the amounts caught in the individual fisheries showed some variation between years. The low directed catch for witch predicted by the 1976 data was due to the higher by-catch ratio of witch in the American plaice fishery that year (0.0429) compared to the other 3 years (0.0175, 0.0170, 0.0252). The reasons

for the changes in the predicted directed catches of yellowtail are the differences in the yellowtail by-catch ratios in the cod and American plaice fisheries in the 4 years. For the 1977 data, which predicted the lowest directed catch of yellowtail, the by-catch ratios of yellowtail in both the cod and American plaice fisheries were higher than in the other 3 years.

For the "allocation method" simulations, much of the above reasoning is also true, as both sets of simulations used the same by-catch ratios. The lower ratios of directed catch to total catch for cod in the 1978 and 1979 based simulations were due to the higher by-catch ratios of cod in the other fisheries in those years, particularly in the American plaice fishery. Conversely, the higher directed-to-total ratio for cod in the 1976 simulation was due to the much lower by-catches of cod in the other fisheries. Other trends which were noticeable in the "catch method" simulations are also present in the "allocation method" simulations because of the identical by-catch ratios.

The model used shows how a maximum amount ($\leq$ total "allocation") of several species can be caught using a known fishing pattern, in such a way that none of the individual "allocations" is exceeded. It predicts what the directed catch of each species in the model should be, based on the known fishing pattern. Some considerations to be made when applying the model:

A. It may not be correct to classify certain fisheries as being directed at one species. Some fisheries result in consistently high by-catches of other species. Thus, to say that a particular amount of effort is directed at a species may be misleading. The model classifies catches in terms of species caught in a directed fishery and therefore the directed catches predicted by the model may not be the result of a true directed fishery. An accurate assessment of by-catch ratios is therefore essential when using a model such as this.

B. The model predicts directed catch and total catch for each species based on the fishing pattern of a previous year. It is doubtful if this concept would be of any use in trying to regulate by-catches within fisheries from a practical viewpoint. Perhaps some sort of ongoing method, on a vessel by vessel basis, could be used in trying to control by-catches. Another possibility would be to break the yearly by-catch ratios into monthly ones. This would also involve the determining of "monthly allocations", based on either a monthly catch pattern or a division of the total allocation into month by month portions.

Some other considerations which apply to the model as it is used here i.e., for 5 Canadian Div. 3LNO groundfish fisheries conducted by trawl gears, are as follows:

A. Stocks of certain species overlap within the area, e.g. Div. 2J3KL cod and Div. 3NO cod. This presented some problems in determining "allocations".

B. Offshore fisheries only were considered. Of the 5 species considered, only cod and witch were caught in any significant (>10%of total catch) quantities by inshore fisheries. Therefore, only by-catches occurring in the Div. 3LNO trawl fisheries were examined.

C. "Allocations" used in this model are based on catches or actual allocations in the 5 fisheries examined. By-catches of the species concerned occur in other fisheries in the area, but the total catches are not significant. Changes in other fisheries resulting in higher catches of the 5 species concerned could have an effect on the results, in which case the model would have to be expanded to include those fisheries.

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Table 1. Catches (MT) by Canadian vessels, 1976, Div. 3LNO, trawl gears.

Directed fishery	Species caught: Cod	Redfish	American plaice	Witch	Yellowtail
Cod	1,059	25	367	41	111
Redfish	199	9,773	227	25	32
American plaice	2,649	57	40,852	1,752	2,763
Witch	37	0	563	1,291	55
Yellowtail	236	0	1,928	191	4,886

Table 2. Catches (MT) by Canadian vessels, 1977, Div. 3LNO, trawl gears.

Directed fishery	Species caught: Cod	Redfish	American plaice	Witch	Yellowtail
Cod	2,949	51	1,032	23	511
Redfish	174	11,765	81	43	54
American plaice	4,029	65	34,924	611	5,517
Witch	57	5	316	2,559	16
Yellowtail	646	2	2,194	66	5,191

Table 3. Catches (MT) by Canadian vessels, 1978, Div. 3LNO, trawl gears.

Directed fishery	Species caught: Cod	Redfish	American plaice	Witch	Yellowtail
Cod	8,116	80	1,846	97	427
Redfish	80	4,737	13	24	7
American plaice	6,150	42	39,175	665	5,213
Witch	28	0	180	474	9
Yellowtail	898	8	3,050	95	9,428

Table 4. Catches (MT) by Canadian vessels, 1979, Div. 3LNO, trawl gears.

Directed fishery	Species caught				
	Cod	Redfish	American plaice	Witch	Yellowtail
Cod	12,724	374	3,095	240	499
Redfish	741	9,661	228	89	45
American plaice	4,865	67	34,535	872	3,699
Witch	5	19	0	33	0
Yellowtail	1,769	21	3,987	102	13,238

Table 5. By-catch ratios, 1976. Derived from catches in Table 1. Div. 3LNO.

Directed fishery	Species caught: Cod	Redfish	American plaice	Witch	Yellowtail	R
Cod	1.0000	0.0236	0.3466	0.0387	0.1048	1.5137
Redfish	0.0204	1.0000	0.0232	0.0026	0.0033	1.0495
American plaice	0.0648	0.0014	1.0000	0.0429	0.0676	1.1767
Witch	0.0287	0.0000	0.4361	1.0000	0.0426	1.5074
Yellowtail	0.0483	0.0000	0.3946	0.0391	1.0000	1.4820

Table 6. By-catch ratios, 1977. Derived from catches in Table 2. Div. 3LNO.

Directed fishery	Species caught: Cod	Redfish	American plaice	Witch	Yellowtail	R
Cod	1.0000	0.0173	0.3499	0.0078	0.1733	1.5483
Redfish	0.0148	1.0000	0.0069	0.0037	0.0046	1.0300
American plaice	0.1154	0.0019	1.0000	0.0175	0.1580	1.2928
Witch	0.0223	0.0020	0.1235	1.0000	0.0063	1.1541
Yellowtail	0.1244	0.0004	0.4227	0.0127	1.0000	1.5602

Table 7. By-catch ratios, 1978. Derived from catches in Table 3. Div. 3LNO.

Directed fishery	Species caught: Cod	Redfish	American plaice	Witch	Yellowtail	R
Cod	1.0000	0.0099	0.2275	0.0120	0.0526	1.3020
Redfish	0.0169	1.0000	0.0027	0.0051	0.0015	1.0262
American plaice	0.1570	0.0011	1.0000	0.0170	0.1331	1.3082
Witch	0.0591	0.0000	0.3797	1.0000	0.0190	1.4578
Yellowtail	0.0952	0.0008	0.3235	0.0101	1.0000	1.4296

Table 8. By-catch ratios, 1979. Derived from catches in Table 4. Div. 3LNO.

Directed fishery	Species caught					
	Cod	Redfish	American plaice	Witch	Yellowtail	R
Cod	1.0000	0.0294	0.2432	0.0189	0.0392	1.3307
Redfish	0.0767	1.0000	0.0236	0.0092	0.0047	1.1142
American plaice	0.1409	0.0019	1.0000	0.0252	0.1071	1.2751
Witch	0.1515	0.5758	0.0000	1.0000	0.0000	1.7273
Yellowtail	0.1336	0.0016	0.3012	0.0077	1.0000	1.4441

Table 9. 1981 Canadian Allocations (MT)

Species	Division	(MT)
Cod	2J3KL	185,000
	3NØ	9,800
Redfish	3LN	8,000
	3Ø	7,500
American plaice	3LNØ	54,200
Witch	2J3KL	3,000
	3NØ	3,000
Yellowtail	3LNØ	20,500

Table 10. Amount of 1981 Div. 2J3KL Canadian Allocations (MT) allowed for Div. 3L, based on yearly catches.

	Year			
Species	1976	1977	1978	1979
Cod	109,829	106,134	98,316	96,244
Witch	2,089	534	635	1,516

Table 11. 1981 Canadian "allocations" (MT) for trawl fisheries in Div. 3LNØ, based on yearly catches.

Species	Year 1976	1977	1978	1979
Cod	12,672	18,903	27,223	30,188
Redfish	15,039	14,731	15,025	15,385
American plaice	49,814	49,068	49,330	48,535
Witch	3,738	3,092	3,109	3,432
Yellowtail	20,337	20,489	20,490	20,500
Totals	101,600	106,283	115,177	118,040

Table 12. Linear programming simulation of 1981 catches, based on 1976 pattern. "Catch method" used. Catches in MT. Div. 3LNO.

Species sought	1981 "allocation" for trawl fisheries	Directed catch	Total catch
Cod	12,672	8,988	12,672
Redfish	15,039	14,772	15,039
American plaice	49,814	39,347	49,814
Witch	3,738	1,013	3,738
Yellowtail	20,337	16,643	20,337
Totals	101,600	80,763	101,600

Table 13. Linear programming simulation of 1981 catches, based on 1977 pattern. "Catch method" used. Catches in MT. Div. 3LNO.

Species sought	1981 "allocation" for trawl fisheries	Directed catch	Total catch
Cod	18,903	12,628	18,903
Redfish	14,731	14,429	14,731
American plaice	49,068	39,142	49,007
Witch	3,092	2,102	3,092
Yellowtail	20,489	12,036	20,489
Totals	106,283	80,337	106,222

Table 14. Linear programming simulation of 1981 catches, based on 1978 pattern. "Catch method" used. Catches in MT. Div. 3LNO.

Species sought	1981 "allocation" for trawl fisheries	Directed catch	Total catch
Cod	27,223	19,297	27,223
Redfish	15,025	14,779	15,025
American plaice	49,330	39,569	49,330
Witch	3,109	1,987	3,109
Yellowtail	20,490	14,148	20,490
Totals	115,177	89,780	115,177

Table 15. Linear programming simulation of 1981 catches, based on 1979 pattern. "Catch method" used. Catches in MT. Div. 3LNO.

Species sought	1981 "allocation" for trawl fisheries	Directed catch	Total catch
Cod	30,188	21,396	30,188
Redfish	15,385	13,612	15,385
American plaice	48,535	38,344	48,535
Witch	3,432	1,817	3,432
Yellowtail	20,500	15,491	20,500
Totals	118,040	90,660	118,040

Table 16. Calculation of "allocations" for 1981 Divisions 3LNO trawl fisheries for cod and witch

Year	Species	Ratio of 3L total catch to 2J3KL total catch	2J3KL offshore allocation MT	3L offshore "allocation" MT	2J3KL total allocation MT	1981 3L offshore "allocation" MT	1981 3LNO offshore "allocation" MT
1976	Cod	0.5937	24,000	14,248	80,000	32,949	42,749
	Witch	0.6963	4,600	3,203	6,600	1,456	4,456
1977	Cod	0.5737	17,750	10,183	67,750	27,806	37,606
	Witch	0.1779	6,500[1]	1,156	9,000	385	3,385
1978	Cod	0.5314	20,000	10,629	100,000	19,664	29,464
	Witch	0.2117	6,500	1,376	9,000	459	3,459
1979	Cod	0.5202	30,000	15,607	130,000	22,210	32,010
	Witch	0.5056	6,500	3,286	9,000	1,095	4,095

[1]Estimated. Based on 1976, 1978 and 1979 figures.

Table 17. 1981 Canadian "allocations" for trawl fisheries in Divisions 3LNO based on yearly allocations

Species	Year 1976	1977	1978	1979
Cod	42,749	37,606	29,464	32,010
Redfish	15,500	15,500	15,500	15,500
American Plaice	54,200	54,200	54,200	54,200
Witch	4,456	3,385	3,459	4,095
Yellowtail	20,500	20,500	20,500	20,500
Totals	137,405	131,191	123,123	126,305

Table 18. Linear programming simulation of 1981 catches, based on 1976 fishing pattern. "Allocation method" used to determine "allocations". Catches in MT in Div. 3LNO.

Species sought	1981 "allocation" for trawl fisheries	Directed catch	Total catch
Cod	42,749	39,533	42,749
Redfish	15,500	14,519	15,500
American Plaice	54,200	34,274	54,200
Witch	4,456	872	4,456
Yellowtail	20,500	13,955	20,500
Totals	137,405	103,153	137,405

Table 19. Linear programming simulation of 1981 catches, based on 1977 fishing pattern. "Allocation method" used to determine "allocations". Catches in MT in Div. 3LNO.

Species sought	1981 "allocation" for trawl fisheries	Directed catch	Total catch
Cod	37,606	31,749	37,606
Redfish	15,500	14,869	15,500
American Plaice	54,200	38,959	54,156
Witch	3,385	2,289	3,385
Yellowtail	20,500	8,759	20,500
Totals	131,191	96,625	131,147

Table 20. Linear programming simulation of 1981 catches, based on 1978 fishing pattern. "Allocation method" used to determine "allocations". Catches in MT in Div. 3LNO.

Species sought	1981 "allocation" for trawl fisheries	Directed catch	Total catch
Cod	29,464	20,852	29,464
Redfish	15,500	15,234	15,500
American Plaice	54,200	44,211	54,200
Witch	3,459	2,244	3,459
Yellowtail	20,500	13,453	20,500
Totals	123,123	95,994	123,123

Table 21. Linear programming simulation of 1981 catches, based on 1979 fishing pattern. "Allocation method" used to determine "allocations". Catches in MT.in Div. 3LNO.

Species sought	1981 "allocation" for trawl fisheries	Directed catch	Total catch
Cod	32,010	22,454	32,010
Redfish	15,500	13,394	15,500
American Plaice	54,200	43,950	54,200
Witch	4,095	2,326	4,095
Yellowtail	20,500	14,850	20,500
Totals	126,305	96,974	126,305

APPENDIX I

Example of the linear programming model used by Brown et al., (1973)

3 species A, B, C.

Directed fisheries occur for each. By-catches of other 2 species occur in each of the 3 fisheries. Catches are broken down by main species as follows:

Species Sought	Species Caught A	B	C
A	x_1	x_2	x_3
B	y_1	y_2	y_3
C	z_1	z_2	z_3

Where x, y & z represent the catches in MT. From this, a table of ratios is calculated. Within each fishery, each species is given as its proportion to the directed species. The table is as follows:

Species Sought	Species Caught A	B	C
A	1.00	$\frac{x_2}{x_1}$	$\frac{x_3}{x_1}$
B	$\frac{y_1}{y_2}$	1.00	$\frac{y_3}{y_2}$
C	$\frac{z_1}{z_3}$	$\frac{z_2}{z_3}$	1.00

Values for R_1, R_2, and R_3 are obtained by adding across the above table so that:

$$R_1 = 1.00 + \frac{x_2 + x_3}{x_1}$$

$$R_2 = 1.00 + \frac{y_1 + y_3}{y_2}$$

$$R_3 = 1.00 + \frac{z_1 + z_2}{z_3}$$

If we let the predicted directed catch for species A, B, and C, be equal to A', B', and C' respectively, then we can formulate the problem as follows:

Maximize a value S equal to $R_1A'+R_2B'+R_3C'$ so that

Total catch of Species A = $1.00A'+\frac{y_1}{y_2}B'+\frac{z_1}{z_3}C' \leq$ "allocation" for Species A

Total catch of Species B = $\frac{x_2}{x_1}A'+1.00B'+\frac{z_2}{z_3}C' \leq$ "allocation" for Species B

Total catch of Species C = $\frac{x_3}{x_1}A'+\frac{y_3}{y_2}B' + 1.00C' \leq$ "allocation" for Species C.