RESTRICTED

International Commission for the Northwest Atlantic Fisheries

Serial No. 3552
(D.c.9)

ICNAF Res.Doc. 75/68
(Revised)

ANNUAL MEETING - JUNE 1975

Linear programming simulations of the effects of by-catch on national catches in ICNAF Subarea 5 and Statistical Area 6

by

B.E. Brown, J.A. Brennan, and J.E. Palmer
National Marine Fisheries Service
Northeast Fisheries Center, Woods Hole, Massachusetts, USA

Abstract

Linear programming simulations of 1975 expected national catches are made using 1973 and 1971 by-catch ratios in directed fisheries and 1975 national species quotas. The expected total catch derived from each set of by-catch ratios is only about 55% of the sum of the species quotas and 70% of the 1975 Total Allowable Catch for all species combined.

Introduction

The control of fishing mortality by means of individual species catch quotas is very difficult to accomplish whenever a significant proportion of the fishing mortality on any given species is generated as a result of the incidental catch or by-catch of that species in fisheries directed toward other species. Since 1973 the catch of all major species in ICNAF Subarea 5 and Statistical Area 6 has been regulated by national quotas, and the estimated by-catch of the major directed fisheries is large. Under these circumstances, attempting to catch the entire quota of a given species by means of a directed fishery for that species may cause the total catch to exceed the allowable catch because of the associated by-catch of that species in the other fisheries.

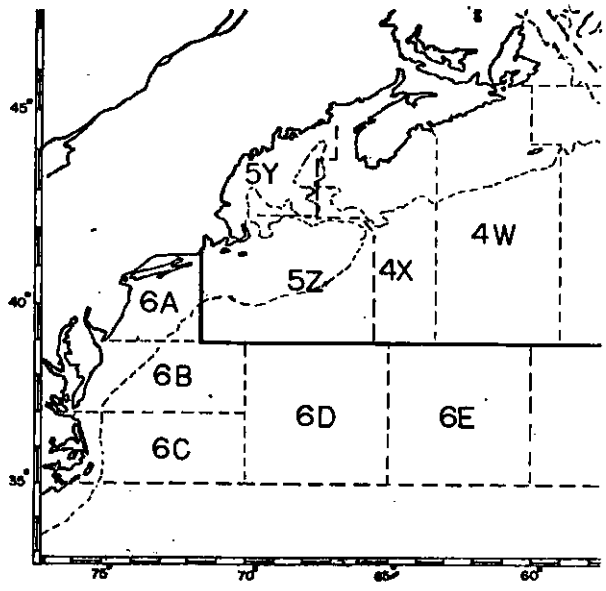

Fig. 1. Map of the southern part of the ICNAF Area and Statistical Area 6.

ICNAF has modified its regulatory measures several times in an attempt to account for by-catches of species under quota restrictions. The initial haddock quota regulations (Subarea 5 and Div. 4X) stated that the directed fishery should cease whenever the accumulated catch (directed catch plus by-catch) reported to ICNAF bi-weekly reached 80% of the quota, anticipating in advance that the catch after closure (a by-catch by definition) would be 20% of the quota. When the yellowtail flounder was added to the list of species under quota, the closure procedures were changed. The Assessments Subcommittee of STACRES first estimated the expected monthly by-catch after closure of directed fisheries. The decision to cease directed fishing was then made when the accumulated total catch reported to ICNAF on a bi-weekly basis plus the expected by-catch during the remainder of the year equaled the quota. With the introduction of national quota allocations in 1972, the procedure again changed, requiring each country to control its directed fishery so that the sum of its directed catch and the estimated by-catches would not exceed its quota allocation.

Despite these procedures it became evident as simulated by Brown *et al.* (1973) that with the by-catch ratios that existed in 1971 the expected total catch in 1973 would be less than the sum of the individual species total allowable catches (TAC) if none of the latter were to be exceeded. The by-catch question was considered in the setting of 1974 and 1975 TAC's (ICNAF 1974 Meeting Proceedings). Anthony and Brennan (1974) applied the linear programming techniques utilized by Brown *et al.* (1973) using 1972 by-catch ratios. The present paper simulates 1975 catches with 1973 by-catch ratios and also with 1971 by-catch ratios. The latter simulation was run to examine the stability of the results using these techniques. Linear programming techniques are used to determine a country's directed catch level considering its national species quotas which would maximize its total catch. A comparison is made between the estimated total values with each country's total quotas for all species combined.

Methods and materials

Data base

Nominal landings and effort for designated main species (or species group) sought categories are submitted annually by almost all countries fishing in Subarea 5 and Statistical Area 6. These data are published in Table 5 of the ICNAF Statistical Bulletin. 1973 and 1971 data were the bases from which the proportions of by-catch and directed catch were estimated. The nominal catches do not include fish caught and discarded at sea.

In 1971 and 1973, the nominal catch and effort (days fished) for finfish only were summarized over months for each of the "main species sought" categories reported in Tables 4 and 5 of the ICNAF Statistical Bulletin, 1971 and 1973, respectively. Catches made with fixed gears as well as catches of menhaden, halibut, and large pelagic fishes, *i.e.*, tuna, billfish, and sharks (other than dogfish), were excluded. In instances where no "main species sought" category was indicated or where landings were attributed to a mixed fishery, the monthly landings were assigned to "species sought" categories according to the species which formed a simple plurality of the catch. The term "fishery" as used in this paper refers to the vessels and associated catch on these "main species sought" categories. The term "species" refers to both individual species and species groups. All reported landings were thus identified by two factors: species and fisheries. Such tabulations were prepared for all nations for which data were available. For Romania, which has had a herring fishery but did not report a directed herring fishery in 1973, values for 1972 (ICNAF Statistical Bulletin 1972) were used for that species fishery. The only countries with an allocated national quota for which 1971 or 1973 data were not available and thus could not be analyzed were Italy (1971 and 1973) and France (1971).

The national restraints (TAC's) needed for each species and country to simulate the 1975 fishery were derived from several different sources. The proposed 1975 national quota allocations for Member Countries in Subarea 5 and Statistical Area 6 (ICNAF Meeting Proceedings 1974) was the main basis. For species in which a country was not allocated a quota, individual country quotas were proportioned from the "Others" allocation category for each individual species. This apportionment was based on the 1973 nominal catch for each particular species and the catch of that species in all countries who constituted the "Others" group in the same situation. The quota for "other groundfish" and "other pelagic" was proportioned from the "other fish" TAC for each country. The quotas for "American plaice and witch" were proportioned from the "other flounder" TAC for each individual country. Each country's national quota allocation for "pollock" was set by ICNAF for Div. 4VWX plus Subarea 5. This simulation is based on setting each

country's pollock quota for Subarea 5 and Statistical Area 6 as a percentage of the 1975 national quota allocations for pollock. The percentage for Subarea 5 was determined by an average percent of the nominal "pollock" catches in Div. 4VWX and Subarea 5 during 1971, 1972, and 1973. In this paper, the catch limitations described above will all be referred to as "quotas."

Analytical methods

For each country, the catch of each species in a fishery in 1973 was first expressed as a percentage of the total catch (column total) for that species (CH percent in Appendix I, Tables 1-11). Similar tables using 1971 data can be found in Brown *et al.* This indicates the extent to which a given country's catch of a species was in a directed fishery or in a by-catch.

For both the 1971 and 1973 catch data, within each fishery the catch of each species was expressed as a proportion of the catch of the main species sought (CH ratio (r) in Appendix Tables 1-11). This computation showed the by-catch as a proportion of the main species sought catch in a given fishery. These CH ratios (r) and the quota restraints were then used to simulate the 1975 fishery of each country using linear programming techniques.

Linear programming is a decision model for which the effectiveness of an allocation scheme distributed over several variables is measured by the maximum value of some linear function of those variables, when those variables are subject to linear constraints. The solution used in this paper was devised using the Simplex Algorithm (Hadley, 1963. p. 132f) computed using a Honeywell Computer program LINPRO: a description of this use of linear programming is given in Appendix II of Brown *et al.* (1973). In this analysis the linear constraints were that no country would exceed its national allocation for any species. The output of the LINPRO program includes the vector X of directed catches of the species along with the resultant total catches of the species and the overall total catch.

Results and Discussion

The results of each country's simulation are given in Appendix Tables 12 through 32. As would be expected, in each case the sum of the species quota allocations exceeded the country maximum catch as determined by the linear programming model in every instance. Table 1 lists the percentage of the sum of a country's TAC's, the predicted total catches, using 1973 by-catch ratios (Table 1A), and 1971 by-catch ratios (Table 1B). In general, the percentages derived from 1973 by-catch ratios were equal to or greater than those derived from 1971 fishing patterns. The exceptions to this trend were Canada and Japan, each of whom would take a smaller percentage under their 1973 fishing regime. Poland, USA, France, and FRG were the only countries predicted to take greater than 80% of the sum of their species TAC's by 1971 or 1973 fishing patterns.

Closer inspection of the results using 1973 by-catches reveals the species which are the limiting factors in a country's inability to take the sum of its species quotas at present. In Appendix Tables 12-22 these are the species which are caught in significant amounts as by-catch and for which a species quota is met. The most frequent species whose catch is limiting is yellowtail flounder. The next major grouping consisted of those species regulated by ICNAF in the "other fish" category and appearing in these tabulations in the "other fish," "other groundfish," and "other pelagic" groupings. Others with potential for being limiting are "other flounder" and herring. Haddock, of course, has traditionally been limiting and is still a critical factor in fisheries which take groundfish.

The sum of the linear programming estimates over countries using 1973 and 1971 data is presented in Tables 2A and 2B, respectively. In each case the sum of the maximum catches determined by the linear programming runs is only about 55% of the sum of the species quotas. The simulated directed fisheries catch levels comprise only 77% of the total using 1973 by-catch ratios, and 69% using 1971 by-catch ratios, the rest being taken as by-catch. The highest percentages of TAC's which were caught in directed fisheries were for redfish, herring, mackerel, and "other pelagics" using 1973 by-catch ratios, and for redfish, silver hake, herring, and "other pelagics" using 1971 by-catch ratios.

Table 1A. Comparison of maximum catches from linear programming simulation using 1973 by-catch ratios, with sum of species "quotas."

Country	Maximum catch Sum of species quotas
Bulgaria	.19
Canada	.45
France	.89
Federal Republic of Germany	.98
German Democratic Republic	.40
Japan	.65
Poland	.95
Romania	.07
Spain	.71
USSR	.27
USA	.86

Table 1B. Comparison of maximum catches from linear programming simulation using 1971 by-catch ratios, with sum of species "quotas."

Country	Maximum catch Sum of species quotas
Bulgaria	.19
Canada	.75
France	-
Federal Republic of Germany	.87
German Democratic Republic	.64
Japan	.26
Poland	.94
Romania	.02
Spain	.10
USSR	.27
USA	.88

Table 2A. Sum of individual country's linear programming simulation of 1975 catches, maximizing total catch ('000 tons), and using 1973 by-catch ratios.

Species sought	Total allowable catch restraint	Directed catch	Total catch
Cod	45.0	14.6	31.1
Haddock	6.0	1.0	5.4
Redfish	25.0	19.0	22.1
Silver hake	175.0	78.9	86.2
Red hake	45.0	38.2	24.3
Pollock	22.6	12.6	20.0
American plaice	2.7	-	2.4
Witch	4.3	-	3.9
Yellowtail	20.0	11.8	20.0
Other flounder	18.0	11.8	17.5
Other groundfish	41.5	11.7	26.9
Herring	166.0	98.7	110.9
Mackerel	285.0	113.2	136.6
Other pelagic	21.4	20.7	20.7
Other fish	48.8	2.8	25.8
Squid	66.2	29.5	46.0
Total	992.5	464.5	599.8

Table 2B. Sum of individual country's linear programming simulation of 1975 catches, maximizing total catch ('000 tons), and using 1971 by-catch ratios.

Species sought	Total allowable catch restraint	Directed catch	Total catch
Cod	45.0	1.7	16.6
Haddock	6.0	0.0	5.1
Redfish	25.0	16.3	21.9
Silver hake	175.0	36.7	50.3
Other flounder	45.0	8.1	33.7
Other groundfish	109.1	35.4	55.4
Herring	166.0	128.5	166.0
Other pelagic	306.4	156.2	181.8
Other fish	115.0	10.9	38.4
Total	992.5	393.8	569.2

Referring to the individual country linear programming output tables in the Appendix, it is obvious that under 1973 and 1971 by-catch ratios, national patterns ran the gamut from almost a total mixed fishery by the USSR, and to a somewhat lesser extent by the German Democratic Republic, to very specific species fisheries of the Federal Republic of Germany and Poland.

A summary of the 1973 catches, the 1974 and 1975 total allowable catches, and the linear program estimates of total catch by country, is presented in Table 3. It is obvious that the overall TAC of 923,500 MT for 1974 and 850,000 MT for 1975 would not be attained without exceeding certain species TAC's unless by-catch was reduced. The expected catches of 599,964 MT (1973) and 565,016 MT (1971) are only 71% and 67%, respectively, of the 1975 total TAC. On a country basis, and using the results derived from the 1973 by-catches, it can be seen that the country total TAC's were set for 1974 at approximately appropriate levels for Spain and the USA, too low for the Federal Republic of Germany, Japan, and Poland, and too high for the other countries. In fact, summing the national total TAC's rather than the linear program estimates of country catch, when the former are limiting, to obtain an overall estimated catch, results in an expected total catch of 557,016 MT, only 66% of the overall TAC. The analagous expected total catch derived from 1971 by-catch ratios is 551,426 MT, only 64% of the overall TAC. By-catch may be reduced through actions initiated by fishing fleets or by regulations such as the closure to bottom trawling by larger vessels in the Southern New England and Middle Atlantic areas, adopted by ICNAF at the Fifth Special Commission Meeting, November 1974 (ICNAF Summ.Doc. 75/1).

Table 3. Comparison of linear programming estimates of maximum total catch by overall country TAC's.

Country	1973 nominal catch of species regulated by the Total TAC	Sum of species TAC's	1975 Total TAC	Linear programming estimate of total catch	
				1973 by-catch ratios	1971 by-catch ratios
Bulgaria	37,291	30,620	24,650	5,735	5,989
Canada	16,799	24,457	26,000	11,107	17,687
France	3,623	5,220	2,950	4,620	4,620*
Federal Republic of Germany	38,278	30,290	24,850	29,648	26,370
German Democratic Republic	150,853	100,860	82,850	39,940	63,650
Italy	3,915		4,150	No estimate available	No estimate available
Japan	32,898	45,720	21,250	29,650	11,896
Poland	190,552	153,000	129,250	144,700	144,270
Romania	7,142	7,240	3,850	454	124
Spain	22,195	20,700	14,800	14,630	2,040
USSR	449,037	351,440	301,800	95,240	93,790
USA	203,093	224,600	211,600	224,200	199,200
Total	1,155,676	994,147	850,000	599,924	569,636*

*Due to absence of by-catch ratios for 1971 data, estimate of total catch of France is that derived from 1973 by-catch ratios.

It should be noted, however, that despite the above potential for change as well as the inadequacies of the reporting to ICNAF which may combine more than one directed fishery under a mixed category, there are other factors which work in the opposite direction. The first is the inadequate recording of by-catch noted during international inspections (ICNAF Comm.Doc. 74/41). Some of this is discard and never reported (Lopez-Veiga, 1974) and some is apparently utilized in the fisheries but not accurately reported on logbooks. Both the lack of reporting and any underestimates of by-catch can cause the by-catch ratios used in this analysis to be underestimated.

Literature Cited

Anthony, V.A., and J.A. Brennan. 1974. An example of the by-catch problem on directed fisheries for 1975. Annu. Meet. int. Comm. Northw. Atlant. Fish., Summary Document 74/47 (Revised), Serial No. 3386.

Brown, B.E., J.A. Brennan, E.G. Heyerdahl, and R.C. Hennemuth. 1973. Effect of by-catch on the management of mixed species fisheries in Subarea 5 and Statistical Area 6. Int. Comm. Northw. Atlant. Fish., Redbook 1973, Part III.

Hadley, G. 1962. Linear programming. Addison-Wesley, Reading, Mass.

ICNAF. 1972. Stat. Bull. int. Comm. Northw. Atlant. Fish., Vol. 21.

1973. Stat. Bull. int. Comm. Northw. Atlant. Fish., Vol. 22.

1974a. Int. Comm. Northw. Atlant. Fish. Meet. Proceedings 1974.

1974b. Memorandum of the USA concerning Subarea 5-Statistical Area 6 problems. Int. Comm. North. Atlant. Fish. Comm.Doc. 74/41, Serial No. 3418.

1975. Proceedings of the Fifth Special Commission Meeting, November 1974. Int. Comm. North. Atlant. Fish., Summary Document 75/1, Serial No. 3420.

Lopez-Veiga, E.C., and A. Vazquez. 1974. Some observations on board two Spanish pair trawlers. Annu. Meet. int. Comm. North Atlant. Fish., Research Document 74/88, Serial No. 3324.

Table 1. 1973 nominal landings for Bulgaria (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

Species sought		Species caught											
		Cod	Redfish	Silver hake	Red hake	Yellow-tail	Other groundfish	Herring	Mackerel	Other pelagic	Other fish	Squid	
Herring	CH Ratio (R)	0.006	0.064	0.060	0.050	0.010	0.000	1.000	0.243	0.049	0.000	0.000	
	CH Percent	7.50	100.00	2.00	6.70	5.60	0.00	29.30	.40	10.50	0.00	0.00	
Mackerel	CH Ratio (R)	0.001	0.000	0.048	0.011	0.003	0.007	0.039	1.000	.007	0.026	0.013	
	CH Percent	92.50	0.00	98.00	93.30	94.40	100.00	70.70	99.60	89.50	100.0	100.0	

Table 2. 1973 nominal landings for Canada (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

Species sought		Species caught											
		Cod	Haddock	Redfish	Pollock	American Plaice	Witch	Yellow-tail	Other flounder	Other groundfish	Herring	Mackerel	Other pelagic
Cod	CH Ratio (R)	1.000	0.214	0.009	0.081	0.003	0.002	0.004	0.011	0.125	0.000	0.000	0.000
	CH Percent	72.33	31.20	62.86	11.00	26.09	50.00	90.91	71.05	38.86	.00	.00	.00
Haddock	CH Ratio (R)	0.549	1.000	0.002	0.126	0.015	0.004	0.001	0.004	0.059	0.000	0.000	0.000
	CH Percent	13.85	50.87	5.71	5.96	52.17	30.00	9.09	7.89	6.37	0.00	0.00	0.00
Other groundfish	CH Ratio (R)	1.087	0.700	0.027	3.472	0.012	0.005	0.000	0.019	1.000	0.000	0.000	0.000
	CH Percent	13.81	17.93	31.43	83.03	21.74	20.00	0.00	21.05	54.78	0.00	0.00	0.00
Herring	CH Ratio (R)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.006	0.000
	CH Percent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00	0.00
Other pelagic	CH Ratio (R)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
	CH Percent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00

Table 3. 1973 nominal landings for France (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

		Species caught		
Species sought		Other groundfish	Herring	Squid
Herring	CH Ratio (R)	0.000	1.000	0.000
	CH Percent	0.00	100.00	0.00
Squid	CH Ratio (R)	0.023	0.000	1.000
	CH Percent	1.00	0.00	100.00

Table 4. 1973 nominal landings for Federal Republic of Germany (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

		Species caught								
Species sought		Cod	Silver hake	Pollock	Other groundfish	Herring	Mackerel	Other pelagics	Other fish	Squid
Pollock	CH Ratio (R)	0.005	0.027	1.000	0.065	0.000	0.000	0.000	0.000	0.000
	CH Percent	100.00	96.67	99.08	8.61	0.00	0.00	0.00	0.00	0.00
Other groundfish	CH Ratio (R)	0.000	0.000	0.000	1.000	0.000	0.083	0.000	0.000	0.500
	CH Percent	0.00	0.00	0.00	2.95	0.00	0.13	0.00	0.00	0.73
Herring	CH Ratio (R)	0.000	0.000	0.000	0.000	1.000	0.010	0.008	0.010	0.000
	CH Percent	0.00	0.00	0.92	0.12	100.00	22.13	53.45	97.62	0.24
Mackerel	CH Ratio (R)	0.000	0.000	0.000	0.000	0.000	1.000	0.094	0.000	0.080
	CH Percent	0.00	0.00	0.00	0.00	0.00	59.66	18.53	0.00	4.45
Squid	CH Ratio (R)	0.000	0.001	0.000	0.463	0.000	0.178	0.084	0.005	1.000
	CH Percent	0.00	3.33	0.00	88.31	0.00	18.07	28.02	2.38	94.58

Table 5 1973 nominal landings for German Democratic Republic (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

		Species caught									
Species sought		Cod	Redfish	Silver hake	Pollock	Other groundfish	Herring	Mackerel	Other pelagic	Other fish	Squid
Pollock	CH Ratio (R)	0.004	0.002	0.000	1.000	0.000	0.042	0.009	0.000	0.000	0.000
	CH Percent	5.33	5.71	0.00	94.62	0.00	0.06	0.01	0.00	0.00	0.00
Herring	CH Ratio (R)	0.001	0.001	0.003	0.001	0.000	1.000	0.008	0.000	0.211	0.005
	CH Percent	44.00	91.43	76.29	4.43	0.00	95.55	0.61	8.15	86.67	97.76
Mackerel	CH Ratio (R)	0.000	0.000	0.001	0.000	0.000	0.031	1.000	0.003	0.010	0.000
	CH Percent	34.66	0.00	20.62	0.32	50.00	4.02	99.06	89.63	5.48	2.24
Other fish	CH Ratio (R)	0.011	0.000	0.006	0.006	0.001	0.204	0.225	0.006	1.000	0.000
	CH Percent	16.00	2.86	3.09	0.63	50.00	0.37	0.31	2.22	7.84	0.00

Table 6. 1973 nominal landings for Japan (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

		Species caught											
Species sought		Cod	Redfish	Silver hake	Red hake	Pollock	Other flounder	Other groundfish	Herring	Mackerel	Other pelagic	Other fish	Squid
Other groundfish	CH Ratio (R)	0.000	0.000	0.000	0.000	0.000	0.044	1.000	0.000	0.000	0.000	0.000	0.067
	CH Percent	0.00	0.00	0.00	0.00	0.00	3.08	26.47	0.00	0.00	0.00	0.00	0.02
Herring	CH Ratio (R)	0.000	0.015	0.011	0.000	0.000	0.001	0.000	1.000	0.000	0.057	0.038	0.012
	CH Percent	0.00	83.33	3.95	0.00	0.00	1.54	0.00	94.19	0.00	0.74	30.01	0.12
Mackerel	CH Ratio (R)	0.000	0.000	0.000	0.000	0.813	0.000	0.000	0.000	1.000	0.813	0.062	0.875
	CH Percent	0.00	0.00	0.00	0.00	92.86	0.00	0.00	0.00	3.59	0.10	0.05	0.09
Other pelagic	CH Ratio (R)	0.000	0.015	0.020	0.000	0.000	0.003	0.003	0.007	0.017	1.000	0.055	0.334
	CH Percent	0.00	16.67	41.67	100.00	7.14	50.77	15.29	4.01	35.20	76.37	25.58	20.41
Other fish	CH Ratio (R)	0.005	0.000	0.012	0.000	0.000	0.000	0.002	0.025	0.000	0.407	1.000	0.447
	CH Percent	100.00	0.00	1.54	0.00	0.00	0.00	0.59	0.87	0.00	1.93	29.03	1.69
Squid	CH Ratio (R)	0.000	0.000	0.020	0.000	0.000	0.002	0.008	0.001	0.023	0.215	0.071	1.000
	CH Percent	0.00	0.00	52.85	0.00	0.00	44.61	57.65	0.93	61.21	20.86	42.34	77.66

Table 7. 1973 nominal landings for Poland (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

Species sought		Species caught										
		Cod	Redfish	Silver hake	Red hake	Pollock	Other groundfish	Herring	Mackerel	Other pelagic	Other fish	Squid
Red hake	CH Ratio (R)	0.000	0.000	0.000	1.000	.031	0.000	0.047	0.000	0.172	0.031	0.000
	CH Percent	0.00	0.00	0.00	40.51	10.00	0.00	.01	0.00	.36	0.02	0.00
Pollock	CH Ratio (R)	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.250	0.000
	CH Percent	0.00	0.000	0.00	0.00	40.00	0.00	0.0	0.00	0.00	0.02	0.00
Herring	CH Ratio (R)	0.004	0.000	0.000	0.000	0.000	0.012	1.000	0.258	0.034	0.039	0.024
	CH Percent	33.49	0.00	2.33	2.53	10.00	22.50	83.02	9.00	44.96	18.27	10.86
Mackerel	CH Ratio (R)	0.003	0.000	0.001	0.000	0.000	0.012	0.075	1.000	0.006	0.056	0.027
	CH Percent	66.51	100.00	41.11	18.99	5.0	60.70	16.08	89.82	19.88	67.71	30.77
Other pelagic	CH Ratio (R)	0.000	0.000	0.000	0.142	0.025	0.039	0.025	0.352	1.000	0.167	0.000
	CH Percent	0.00	0.00	0.00	25.32	35.00	.55	0.01	0.08	9.14	0.54	0.00
Other fish	CH Ratio (R)	0.000	0.000	0.092	0.167	0.000	0.017	0.033	0.317	0.125	1.000	0.000
	CH Percent	0.00	0.00	3.21	12.66	0.00	0.10	0.01	0.03	0.49	1.37	0.00
Other shell-fish	CH Ratio (R)	0.000	0.000	0.034	0.000	0.000	0.057	0.080	0.231	0.144	0.197	1.000
	CH Percent	0.00	0.00	53.35	0.00	0.00	15.15	0.87	1.06	25.18	12.07	58.36

Table 8. 1973 nominal landings for Romania (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

Species sought		Species caught									
		Haddock	Redfish	Silver hake	Yellow-tail	Other groundfish	Herring	Mackerel	Other pelagic	Other fish	Other shellfish
Herring	CH Ratio(R)*	0.007	0.007	0.020	0.016	0.000	1.000	0.223	0.035	0.000	0.000
	CH Percent	100.00	100.00	46.15	100.00	0.00	87.37	7.23	17.52	0.00	0.00
Mackerel	CH Ratio(R)	0.000	0.000	0.008	0.000	0.064	0.051	1.000	0.058	0.010	0.026
	CH Percent	0.00	0.00	53.85	100.00	100.00	12.63	92.77	82.48	100.00	100.00

*Ratios derived from 1972 nominal landings.

Table 9. 1973 nominal landings for Spain (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

Species sought		Species caught					
		Cod	Haddock	Red hake	Pollock	Other groundfish	Squid
Cod	CH Ratio (R)	1.000	0.065	0.001	0.134	0.008	0.000
	CH Percent	100.000	100.00	100.00	100.00	52.67	0.00
Squid	CH Ratio (R)	0.000	0.000	0.000	0.000	0.003	1.000
	CH Percent	0.00	0.00	0.00	0.00	47.31	100.000

Table 10. 1973 nominal landings for USSR (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

Species sought		Species caught															
		Cod	Haddock	Redfish	Silver hake	Red hake	Pollock	American Plaice	Witch	Yellow-tail	Other flounder	Other groundfish	Herring	Mackerel	Other pelagic	Other fish	Squid
Silver hake	CH Ratio (R)	0.005	0.001	0.034	1.000	0.236	0.003	0.001	0.001	0.002	0.004	0.062	0.069	0.303	0.006	0.188	0.073
	CH Percent	14.68	6.81	52.78	71.98	31.03	8.79	9.62	14.65	27.43	22.58	12.66	10.73	16.95	19.49	49.26	66.50
Red hake	CH Ratio (R)	0.020	0.000	0.019	0.410	1.000	0.009	0.003	0.004	0.007	0.011	0.117	0.118	0.237	0.002	0.107	0.032
	CH Percent	19.65	0.83	11.00	10.84	48.27	9.81	18.12	19.59	40.30	20.70	7.94	6.73	4.88	2.74	10.29	10.81
Other groundfish	CH Ratio (R)	0.494	0.000	0.000	0.571	0.101	0.000	0.002	0.012	0.035	0.058	1.000	0.164	0.148	0.036	0.031	0.000
	CH Percent	20.56	0.00	0.00	0.62	0.20	0.00	0.67	2.39	8.21	4.67	0.46	0.39	0.13	1.93	0.12	0.00
Herring	CH Ratio (R)	0.011	0.000	0.000	0.187	0.140	0.000	0.003	0.002	0.004	0.007	0.100	1.000	0.227	0.001	0.110	0.000
	CH Percent	3.49	0.00	0.00	1.55	2.11	0.00	7.16	3.34	6.90	4.09	21.15	17.94	1.46	0.21	3.31	0.02
Mackerel	CH Ratio (R)	0.010	0.005	0.017	0.147	0.094	0.017	0.002	0.003	0.001	0.005	0.051	0.301	1.000	0.003	0.082	0.017
	CH Percent	36.14	91.20	35.78	14.58	16.80	70.46	51.68	50.00	14.55	39.26	75.19	63.76	76.13	16.19	29.11	21.08
Other pelagic	CH Ratio (R)	0.000	0.000	0.000	0.092	0.299	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.055	1.000	0.061	0.001
	CH Percent	0.00	0.00	0.00	0.11	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	57.41	0.26	0.02
Other fish	CH Ratio (R)	0.068	0.003	0.010	0.147	0.245	0.126	0.024	0.026	0.006	0.056	0.675	0.099	0.250	0.020	1.000	0.059
	CH Percent	5.47	1.16	0.44	0.31	0.94	10.94	12.75	10.03	2.61	8.70	0.53	0.45	0.41	2.01	7.64	1.57

Table 11. 1973 nominal landings for USA (ICNAF Subarea 5 and Statistical Area 6), expressed as percentages of species catch distribution over fisheries (CH Percent) and ratios of by-catch to main species sought within fisheries (CH Ratio). See text for explanation.

Species sought		Species caught															
		Cod	Haddock	Redfish	Silver hake	Red hake	Pollock	American plaice	Witch	Yellowtail	Other flounder	Other groundfish	Herring	Mackerel	Other pelagic	Other fish	Squid
Cod	CH Ratio (R)	1.000	0.075	0.013	0.002	0.000	0.052	0.009	0.004	0.035	0.088	0.056	0.000	0.000	0.000	0.001	0.000
	CH Percent	52.91	25.45	1.26	0.11	0.00	10.31	7.75	1.93	1.44	10.63	4.33	0.00	0.00	0.37	0.50	0.25
Haddock	CH Ratio (R)	0.343	1.000	0.006	0.000	0.000	0.087	0.000	0.006	0.056	0.045	0.017	0.000	0.000	0.000	0.000	0.003
	CH Percent	0.58	10.96	0.01	0.00	0.00	0.55	0.00	0.09	0.07	0.17	0.04	0.00	0.00	0.00	0.00	0.06
Redfish	CH Ratio (R)	0.039	0.006	1.000	0.001	0.000	0.066	0.005	0.007	0.000	0.000	0.046	0.000	0.000	0.000	0.000	0.001
	CH Percent	1.94	1.85	90.59	0.09	0.00	12.41	3.84	3.49	0.00	0.03	3.33	0.00	0.00	0.00	0.00	0.69
Silver hake	CH Ratio (R)	0.054	0.003	0.010	1.000	0.022	0.010	0.007	0.006	0.004	0.016	0.058	0.014	0.002	0.008	0.009	0.025
	CH Percent	3.27	1.29	1.13	81.49	8.45	2.22	7.06	3.68	0.18	2.25	5.15	0.68	2.93	9.79	6.72	20.12
Red hake	CH Ratio (R)	0.023	0.000	0.000	0.241	1.000	0.000	0.000	0.000	0.148	0.132	0.357	0.011	0.001	0.096	0.216	0.077
	CH Percent	0.20	0.00	0.00	3.02	60.32	0.00	0.00	0.00	1.06	2.80	4.85	0.08	0.31	17.44	26.38	9.40
Pollock	CH Ratio (R)	0.168	0.054	0.045	0.028	0.008	1.000	0.007	0.021	0.007	0.004	0.130	0.001	0.000	0.000	0.001	0.005
	CH Percent	1.64	3.39	0.81	0.37	0.50	36.55	1.07	1.98	0.05	0.10	1.87	0.01	0.00	0.00	0.13	0.63
Yellowtail	CH Ratio (R)	0.091	0.014	0.001	0.001	0.000	0.001	0.010	0.020	1.000	0.053	0.004	0.000	0.000	0.001	0.000	0.003
	CH Percent	10.26	10.00	0.10	0.16	0.28	0.41	18.80	22.01	86.96	13.80	0.65	0.00	0.00	1.12	0.25	4.60
Other flounder	CH Ratio (R)	0.492	0.074	0.063	0.013	0.003	0.014	0.125	0.230	0.423	1.000	0.072	0.000	0.000	0.003	0.005	0.002
	CH Percent	11.19	10.83	0.11	0.38	0.37	1.18	45.82	50.41	7.40	52.03	2.39	0.01	0.00	1.40	1.38	0.56
Other groundfish	CH Ratio (R)	0.344	0.108	0.063	0.197	0.088	0.188	0.019	0.033	0.070	0.148	1.000	0.023	0.003	0.017	0.069	0.041
	CH Percent	17.90	36.23	5.95	13.92	29.80	36.58	15.66	16.36	2.82	17.66	76.39	0.99	5.25	17.07	47.30	28.26
Herring	CH Ratio (R)	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.002	0.006	0.000	0.000
	CH Percent	0.09	0.00	0.03	0.06	0.00	0.00	0.00	0.04	0.00	0.00	0.08	98.11	9.72	13.71	0.00	0.50
Mackerel	CH Ratio (R)	0.000	0.000	0.000	0.018	0.014	0.018	0.000	0.000	0.004	0.016	0.148	0.059	1.000	0.087	0.024	0.164
	CH Percent	0.00	0.00	0.00	0.05	0.21	0.16	0.00	0.00	0.01	0.08	0.52	0.11	78.24	4.10	0.75	5.23
Pelagic	CH Ratio (R)	0.003	0.000	0.000	0.125	0.003	0.000	0.000	0.000	0.003	0.006	0.030	0.000	0.064	1.000	0.107	0.189
	CH Percent	0.00	0.00	0.00	0.26	0.03	0.00	0.00	0.00	0.00	0.02	0.07	0.00	3.24	30.60	2.20	3.91
Other fish	CH Ratio (R)	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.160	1.000	0.000
	CH Percent	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	3.45	14.26	0.00
Squid	CH Ratio (R)	0.000	0.000	0.000	0.015	0.002	0.000	0.000	0.000	0.000	0.091	0.110	0.000	0.005	0.025	0.005	1.000
	CH Percent	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.40	0.32	0.00	0.31	0.93	0.12	25.74

Table 12. Linear programming simulation of 1975 Bulgaria's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	0.7	-	0.005
Redfish	0.5	-	0.0
Silver hake	2.0	-	0.2
Red hake	1.9	-	0.06
Yellowtail	0.02	-	0.02
Other groundfish	0.7	-	0.04
Herring	1.1	0.0	0.2
Mackerel	18.8	5.2	5.2
Other pelagic	0.7	-	0.04
Other fish	2.5	-	0.1
Squid	1.7	-	0.07
Total	30.62		5.735

Table 13. Linear programming simulation of 1975 Canada's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	4.8	0.4	1.2
Haddock	1.2	0.3	0.8
Redfish	0.5	-	0.02
Pollock	3.4	-	2.0
American plaice	0.01	-	0.01
Witch	.005	-	0.005
Yellowtail	.002	-	0.002
Other flounder	0.03	-	0.6
Other groundfish	0.6	0.5	0.6
Herring	6.4	6.4	6.4
Mackerel	7.5	-	0.04
Other pelagic	0.01	0.01	0.01
Total	24.457		11.107

Table 14. Linear programming simulation of 1975 France's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Other groundfish	0.02	-	0.02
Herring	1.8	1.8	1.8
Squid	3.4	0.7	2.8
Total	5.22		4.62

Table 15. Linear programming simulation of 1975 Federal Republic of Germany's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	0.09	-	0.008
Silver hake	0.500	-	0.04
Pollock	1.6	1.6	1.6
Other groundfish	0.7	0.2	0.7
Herring	24.3	24.3	24.3
Mackerel	1.4	1.0	1.4
Other pelagic	0.4	-	0.4
Other fish	0.3	-	0.2
Squid	1.0	0.8	1.0
Total	30.29		29.648

Table 16. Linear programming simulation of 1975 German Democratic Republic's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	1.3	-	0.03
Redfish	0.7	-	0.02
Silver hake	3.1	-	0.06
Pollock	3.5	3.5	3.5
Other groundfish	<0.001	-	0
Herring	31.7	13.0	13.8
Mackerel	56.3	19.3	19.5
Other pelagic	0.06	-	0.06
Other fish	2.9	0	2.9
Squid	1.3	-	0.07
Total	100.86		39.94

Table 17. Linear programming simulation of 1975 Japan's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	0.05	-	0
Redfish	0.5	-	0.1
Silver hake	7.3	-	0.4
Red hake	0.01	-	0
Pollock	0.7	-	0.3
Other flounder	0.06	-	0.05
Other groundfish	0.1	0	0.1
Herring	1.1	1.1	1.1
Mackerel	0.8	0.3	0.8
Other pelagic	9.3	5.9	9.3
Other fish	1.5	0.2	1.5
Squid	24.3	13.6	16.0
Total	45.72		29.65

Table 18. Linear programming simulation of 1975 Poland's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	0.5	-	0.4
Redfish	0.4	-	0
Silver hake	5.3	-	0.1
Red hake	0.8	0.7	0.8
Pollock	0.9	0.7	0.7
Other groundfish	1.4	-	1.4
Herring	38.4	32.1	38.4
Mackerel	90.0	81.3	90.0
Other pelagic	2.2	0.3	2.2
Other fish	6.3	0	6.3
Squid	6.8	1.4	4.4
Total	153.0		144.7

Table 19. Linear programming simulation of 1975 Romania's catches maximizing total catch ('000).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Haddock	0.005	-	0.002
Redfish	0.300	-	0.003
Silver hake	0.500	-	0.007
Yellowtail	0.005	-	0.005
Other groundfish	0.015	-	0.013
Herring	2.000	.300	0.300
Mackerel	3.8	.040	0.110
Other pelagic	0.013	-	0.013
Other fish	0.002	-	0.00
Squid	0.600	-	0.001
Total	7.240		0.454

Table 20. Linear programming simulation of 1975 Spain's catches maximizing total catch ('000).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	7.1	1.3	1.3
Haddock	0.3	-	0.09
Red hake	0.02	-	<0.001
Pollock	0.2	-	0.2
Other groundfish	0.1	-	0.04
Squid	13.0	13.0	13.0
Total	20.7		14.63

Table 21. Linear programming simulation of 1975 USSR catches maximizing total catch ('000 tons).

Species Sought	Total allowable catch constraint	Directed catch	Total catch
Cod	2.5	-	0.2
Haddock	0.05	-	0.05
Redfish	1.4	-	1.4
Silver hake	113.3	41.4	42.4
Red hake	30.4	0	11.5
Pollock	0.8	-	0.2
American plaice	0.2	-	0.05
Witch	0.2	-	0.05
Yellowtail	0.09	-	0.09
Other flounder	0.6	-	0.2
Other groundfish	16.7	0	2.9
Herring	42.1	2.0	5.4
Mackerel	101.3	1.7	14.9
Other pelagic	4.4	4.2	4.4
Other fish	28.9	0	8.4
Squid	8.5	-	3.1
Total	351.44		95.24

Table 22. Linear programming simulation of 1975 USA catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraints	Directed catch	Total catch
Cod	28.0	12.9	28.0
Haddock	4.5	0.7	4.5
Redfish	20.6	19.0	20.6
Silver hake	43.0	37.5	43.0
Red hake	11.9	9.9	11.9
Pollock	11.5	6.8	11.5
American plaice	2.5	-	2.3
Witch	4.1	-	3.9
Yellowtail	19.9	12.0	19.9
Other flounder	17.3	11.6	17.3
Other groundfish	21.1	11.0	21.1
Herring	19.2	18.0	19.2
Mackerel	4.7	4.4	4.7
Other pelagic	4.3	1.8	4.3
Other fish	6.4	2.8	6.4
Squid	5.6	2.3	5.6
Total	224.6		224.2

Table 23. Linear programming simulation of 1975 Bulgaria's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	0.70	-	0.002
Haddock	0.04	-	0.000
Redfish	0.50	-	0.004
Silver hake	2.00	0.00	0.142
Other flounder	0.02	-	0.020
Other groundfish	2.60	0.00	0.231
Herring	1.10	1.00	1.100
Other pelagic	19.50	3.60	3.650
Other fish	4.20	0.00	0.810
Total	30.66 *	4.60	5.989

Table 24. Linear programming simulation of 1975 Canada's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	4.80	0.00	0.72
Haddock	1.20	0.00	0.35
Redfish	0.50	0.00	0.05
Other flounder	0.047	0.00	0.047
Other groundfish	4.00	1.39	2.61
Herring	6.40	0.00	6.40
Other pelagic	7.51	0.00	7.51
Total	24.457	1.39	17.687

Table 25. Linear programming simulation of 1975 Federal Republic of Germany's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	0.09	-	0.00
Silver hake	0.50	-	0.00
Other groundfish	2.30	-	0.27
Herring	24.30	24.30	24.30
Other pelagic	1.80	1.27	1.80
Other fish	1.30	-	0.00
Total	30.29	25.57	26.37

Table 26. Linear programming simulation of 1975 German Democratic Republic's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	1.30	-	0.00
Redfish	0.70	-	0.00
Silver hake	3.10	-	0.00
Other groundfish	3.50	0.56	3.50
Herring	31.70	30.43	31.70
Other pelagic	56.36	19.98	24.25
Other fish	4.20	0.00	4.20
Total	100.86	50.97	63.65

Table 27. Linear programming simulation of 1975 Japan's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	0.05	-	0.004
Redfish	0.50	-	0.001
Silver hake	7.3	-	0.100
Other flounder	0.06	-	0.021
Other groundfish	0.81	-	0.800
Herring	1.10	1.08	1.100
Other pelagic	10.10	9.76	9.760
Other fish	25.80	0.00	0.110
Total	45.72	10.84	11.896

Table 28. Linear programming simulation of 1975 Poland's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	0.50	-	0.14
Redfish	0.40	-	0.09
Silver hake	5.30	-	0.09
Other groundfish	3.10	-	0.25
Herring	38.40	26.09	38.40
Other pelagic	92.20	85.92	92.20
Other fish	13.10	1.37	13.10
Total	153.00	113.38	144.27

Table 29. Linear programming simulation of 1975 Romania's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Haddock	0.005	-	0.001
Silver hake	0.500	0.000	0.010
Other flounder	0.005	-	0.005
Other groundfish	0.315	-	0.000
Herring	2.000	0.000	0.010
Other pelagic	3.813	0.070	0.073
Other fish	0.602	-	0.025
Total	7.240	0.070	0.124

Table 30. Linear programming simulation of 1975 Spain's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraints	Directed catch	Total catch
Cod	7.10	1.70	1.70
Haddock	0.30	-	0.30
Redfish	0.02	-	0.00
Pollock	0.20	-	0.00
Other groundfish	0.10	-	0.04
Other fish	13.00	-	0.00
Total	20.72	1.70	2.04

Table 31. Linear programming simulation of 1975 USSR's catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	2.50	-	0.26
Haddock	0.05	-	0.00
Redfish	1.40	-	1.15
Silver hake	113.30	0.00	7.04
Other flounder	1.09	-	1.09
Other groundfish	47.9	0.00	3.24
Herring	42.1	38.01	42.01
Other pelagic	105.7	27.80	33.62
Other fish	37.4	0.00	5.38
Total	351.44	65.81	93.79

Table 32. Linear programming simulation of 1975 USA catches maximizing total catch ('000 tons).

Species sought	Total allowable catch constraint	Directed catch	Total catch
Cod	28.00	0.00	13.80
Haddock	4.50	0.00	4.50
Redfish	20.60	16.30	20.60
Silver hake	43.00	36.70	43.00
Other flounder	43.80	8.10	32.60
Other groundfish	44.50	33.50	44.50
Herring	19.20	5.80	19.20
Other pelagic	9.00	7.80	9.00
Other fish	12.00	8.90	12.00
Total	224.60	117.10	199.20