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Yield Projections for the Transboundary Cod and Haddock Resources on Eastern Georges Bank

by

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[1]La présente série documente les bases scientifiques des évaluations des ressources halieutiques sur la côte atlantique du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

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ABSTRACT

The transboundary nature of the eastern Georges Bank haddock and cod stocks warrants the quantification and evaluation of the effectiveness of unilateral harvest controls by Canada. Deterministic yield projection simulations were conducted to investigate the response of yield in the Canadian fishery for various exploitation rates by Canada and the USA using available information on distribution and seasonal migration between the two jurisdictions.

The distribution of haddock and cod from 1985 to 1990 in relation to the international boundary was investigated using results from bottom trawl surveys made by Canada in the spring and by the USA in the spring and fall. Results showed that a seasonal migration of haddock and cod occurs within the 5Zjm management unit. Haddock and cod migrated onto the bank and a portion of the population spread across the international boundary into USA territory during October to March. During April to September, a migration eastward occurred so that almost all of the haddock and a significant proportion of the cod stock were found in Canadian territory. Instantaneous rates of migration and fishing mortality were calculated using a model that incorporated the migratory nature of the stocks.

Deterministic yield projection simulations were conducted using a two compartment population model comprised of the Canadian and USA portions of eastern Georges Bank and incorporated half-year time increments to accommodate seasonal differences in migration rates and fishing mortality rates. The results for haddock suggest that unilateral management actions by Canada can achieve desired objectives for yield and catch rates. Because cod were more widely distributed across the international boundary and migration into USA territory is greater than that exhibited by haddock, the benefits associated with a unilateral management strategy by Canada would be more difficult to achieve. For cod, consistent conservation measures by both countries appear necessary for stock rebuilding.

RÉSUMÉ

Étant donné le caractère transfrontalier des stocks d'aiglefin et de morue de l'est du banc Georges, il y a lieu de quantifier et d'évaluer l'efficacité des mesures unilatérales prises par le Canada pour régir la pêche. En se servant des renseignements dont on disposait sur la distribution et sur les migrations saisonnières d'un pays à un autre, on a effectué des projections déterministiques simulées du rendement afin d'établir comment le rendement dans la pêche canadienne réagissait à divers taux d'exploitation par les Canadiens et les Américains.

On a étudié la distribution de l'aiglefin et de la morue de 1985 à 1990 de part et d'autre de la frontière internationale en se fondant sur les résultats de relevés de recherche au chalut à panneaux réalisés par le Canada au printemps et par les États-Unis au printemps et en automne. Ces résultats dénotaient une migration saisonnière de l'aiglefin et de la morue au sein de l'unité de gestion 5Zjm. Ces deux espèces migraient vers le banc, une partie de la population se disséminant au-delà de la frontière, c'est-à-dire du côté américain, d'octobre à mars. D'avril à septembre, elles migraient vers l'est; si bien que la majeure partie de l'aiglefin et une proportion importante du stock de morue se trouvaient alors en territoire canadien. On a calculé les taux instantanés de migration et de mortalité par pêche au moyen d'un modèle qui tenait compte du caractère migratoire des stocks.

Les projections déterministiques simulées du rendement ont été réalisées à l'aide d'un modèle de population à deux compartiments représentant les secteurs canadien et américain de l'est du banc Georges; elles progressaient par tranche de demi-année pour tenir compte des différences saisonnières dans les taux de migration et de mortalité par pêche. Comme la morue était répartie sur une plus vaste surface de part et d'autre de la frontière et que sa migration en territoire américain est plus importante que celle de l'aiglefin, les avantages qui découleraient d'une stratégie canadienne unilatérale de gestion seraient plus difficiles à réaliser. Par conséquent, en ce qui concerne la morue, des mesures de conservation uniformes par les deux pays semblent nécessaires au rétablissement des stocks.

INTRODUCTION

The International Court of Justice decision in 1984 established the maritime boundary between Canada and the USA on Georges Bank. A subsequent evaluation of accumulated evidence on stock structure and consideration of practical matters relating to statistics led to the definition of an eastern Georges Bank management unit (Gavaris and Van Eeckhaute 1990, Hunt 1989).

The Canadian Atlantic Fisheries Scientific Advisory Committee has provided recommendations on advised catch for Canada which were consistent with Canadian management strategies and targets (i.e. $F_{0.1}$). Considering the transboundary nature of these stocks, the implications of restricting catches by Canada need to be quantified and evaluated with respect to a harvest strategy. Deterministic projection simulations were conducted to investigate the response of yield in the Canadian fishery for various exploitation rates by Canada and the USA using available information on distribution and seasonal migration between the two jurisdictions.

DISTRIBUTION

Van Eeckhaute et al (*in prep.*) and Hunt and Buzeta (*in prep.*) investigated the distribution of haddock and cod respectively in relation to the international boundary using results from bottom trawl surveys. Canada has conducted a bottom trawl survey in the spring since 1986 and the USA has conducted bottom trawl surveys in the spring since 1968 and in the fall since 1963. Abundance estimates on the Canadian and USA portions of unit areas 5Zjm were readily obtained for the Canadian surveys as the strata boundaries used since 1987 incorporated the international boundary. The1986 Canadian survey results were not used as different strata boundaries were employed in that year. For the USA surveys, several strata were bisected by the boundary. When tows were conducted in strata sections, the sections were treated in the same manner as entire strata since tow location was chosen at random. Abundance for strata sections where no tows were conducted were either assigned a zero abundance in areas where fish did not typically occur (eg. haddock on the USA side of strata 17 or 18) or were estimated using a multiplicative model. Subsequent computations required commercial statistics resolved as to location of capture in relation to the international boundary. As these are only available since 1985, only survey data since then were used (Tables 1 and 2). Strata where abundance was derived using the multiplicative model contributed only from 0.1% to 7% of the total abundance for any year.

Employing the length/age sampling results, the proportion of the total 5Zjm haddock abundance at age occurring in Canada was summarized in Table 3. At the beginning of the spring/summer period the proportion of 5Zjm haddock in Canadian territory ranges from 0.48 to 1.00. It is unlikely that all of the haddock are on the Canadian side and the value of 1.00 is probably a statistical artifact. To reflect this and to facilitate computations with the conventional exponential population models, values of 1.00 were replaced by 0.99. About 70% of the proportions are 0.80 or greater. The average spring/summer proportion for age 2 is 0.84. At the beginning of the fall/winter period almost all of the haddock are in Canadian territory and the average proportion is 0.98. The biomass contour maps (Fig. 1) display this seasonal shift in distribution.

The proportion at age of 5Zjm cod (Table 4) on the Canadian side of the international boundary during the spring/summer period for 1985-90 ranges from 0.48 to 1.00 (mean= 0.69). Only 29% of the proportions are 0.80 or greater and there is a marked increase in 1990. The average proportion for age 2 cod is 0.65. In the fall/winter period almost all of the cod are in Canadian territory with proportions ranging from 0.72-1.00 (mean= 0.95). As with haddock, proportions of 1.00 were replaced by 0.99 for subsequent computations. However, there are a number of years in which no cod at some ages were found in either the Canadian or USA zone of 5Zjm. The cohorts involved were present in adjacent spring periods and this could be an indication of movement out of the management unit or an artifact of low sampling intensity for age composition. For those ages with no population estimate, the weighted mean of observed ages was used for the analysis. Biomass contour maps (Fig. 2) display this seasonal shift in distribution.

RATES OF MIGRATION AND FISHING MORTALITY

Sequential population analysis was calculated on the basis of two 6-month time periods, from April to September and from October to March. The abundance for the terminal age/year of each cohort considered was taken from the recent assessment (Gavaris and Van Eeckhaute 1992, Hunt and Buzeta 1992) and a constant annual natural mortality rate of 0.2 was assumed. The results from spring and fall surveys were used to characterize the distribution at the beginning of April and the beginning of October respectively. We use a to index age (a = 2 - 8) and p to index period (p = spring/summer or Apr.-Sep. and fall/winter or Oct.-Mar.). The number of fish migrating were determined in the following manner.

The population abundance on the Canadian side of 5Zjm was computed from :

$$N_{Can,p,a} = N\, R_{Can,p,a}$$

where N was the 5Zjm population abundance from the sequential population analysis and $R_{Can,p,a}$ was the proportion occurring on the Canadian side.

The number of fish dying due to natural mortality in 5Zjm over some period p, can be obtained from :

$$_{M}N_{p,a} = N_{p,a} - N_{p+1,a+.5} - {}_{F}N_{p,a}$$

where $_{F}N_{p,a}$ is the total 5Zjm commercial catch in period p and the number of fish dying on the Canadian side is obtained by multiplying this result by the fraction of the population occupying the Canadian side on average during the period :

$$_{M}N_{Can,p,a} = {}_{M}N_{p,a}\, \bar{N}_{Can,p,a} / (\bar{N}_{Can,p,a} + \bar{N}_{USA,p,a})$$

Where $\bar{N}$ is the average population abundance during the period. The number of fish migrating during any period can then be calculated from :

$${}_{E}N_{p,a} = N_{Can,p,a} - N_{Can,p+1,a+.5} - {}_{F}N_{Can,p,a} - {}_{M}N_{Can,p,a}$$

where ${}_{F}N_{Can,p,a}$ is the Canadian commercial catch at age during the period. ${}_{E}N_{p,a}$ will be positive when the net direction of migration is towards the USA side and negative when it is towards the Canadian side.

Instantaneous rates of migration and fishing mortality were calculated relative to the average abundance on the Canadian or USA sides respectively. For the Canadian side, calculations were done as follows :

$$E_{Can,p,a} = 2{}_{E}N_{p,a}\,(0.5Z_{Can,p,a}) / N_{Can,p,a}\,(1 - \exp -(0.5Z_{Can,p,a}))$$

and

$$F_{Can,p,a} = 2{}_{F}N_{p,a}\,(0.5Z_{Can,p,a}) / N_{Can,p,a}\,(1 - \exp -(0.5Z_{Can,p,a}))$$

respectively where :

$$Z_{Can,p,a} = 2\ln\,(N_{Can,p+1,a+.5} \,/\, N_{Can,p,a})$$

and similarly for the USA side. All instantaneous rates of migration and fishing mortality are reported on an annual basis, i.e. units of year^{-1}, which introduces the multipliers 2 and 0.5 in the equations.

There did not appear to be any consistent difference in haddock migration rates between age groups during 1985-90. The direction of net migration for ages 2 to 8 combined was toward the USA side during fall/winter and toward the Canadian side during spring/summer except during the spring/summer of 1985 when migration was very low. During the fall/winter period the net migration rates, relative to the population on the Canadian side, for ages 2 to 8 combined ranged from 0.05 to 0.95 with an average of 0.45 (Table 5a). The net migration rate, relative to the population on the USA side, for ages 2 to 8 during the spring/summer season ranged from -0.86 to -6.20 between 1986 and 1990 with an average of -3.83 (-2.72 when 1985 was included)(Table 5b). Migration and fishing mortality rates could not be calculated when no haddock were caught on the USA side during the fall survey.

Haddock appear to be fully recruited to the commercial fishery by age 3 (Table 6). Canada fished haddock at much higher rates during the spring/summer period than during the fall/winter period. The Canadian spring/summer fishing mortality rate for ages 3 to 8 combined ranged from 0.3 to 0.9 with an average of 0.54 (Table 6a). In fall/winter they range from 0.04 to 0.12 with a mean of 0.09. A less pronounced but similar pattern was observed for the USA where values ranged from 1.05 to 9.67 (mean of 3.89) during spring/summer and from 0.79 to 4.22 (mean of 2.02) in fall/winter(Table 6b). Fishing mortality rates in excess of 2 to 3 correspond to an exploitation rate close to 100% and indicate that the number of fish being caught is about equal to the average number available during the period. More or fewer fish could inhabit a zone at the beginning or end of the period because migration is occurring simultaneously.

The direction of net migration for cod is similar to that of haddock, with movement toward the USA side during fall/winter and toward the Canadian side during spring/summer (Table 7). The exception appears to be during spring/summer of 1990. During the fall/winter period the mean net migration towards the USA side is 0.91 , and the total migration rates for ages 2 and older, based on the population size on the Canadian side range from 0.54 to 1.53 (Table 7a). The mean migration rate towards the Canadian side during the reciprocal 1986-1990 spring/summer season is -1.39, based on the population size on the USA side (Table 7b).

Canadian fishing mortalities for cod during the spring/summer period range from 0.3 to 2.72 (mean= 0.54) and 0.02 to 0.34 (mean is 0.07) during the fall/winter period (Table 8a). The pattern of higher fishing mortalities during the spring/summer period was not observed for the USA where values ranged from 0.07 to 9.08 (mean= 1.76) during spring/summer and from 0 to 7.02 (mean= 1.83) in fall/winter (Table 8b).

YIELD PROJECTION MODEL

A two compartment population model was considered comprising of the Canadian and USA portions of Georges Bank. The model also incorporated half year time increments, April-September and October-March, to accommodate seasonal differences in migration rates and fishing mortality rates. All instantaneous rates are reported as annual rates. Projected yield was computed for deterministic simulations with constant recruitment. As with a standard yield projection, the transboundary yield projection model requires partial recruitment to the fishery and the average weight at age of fish caught. Long-term average values used in yield per recruit analyses for haddock (Gavaris 1989) and cod (Hunt 1990) were employed here for both Canadian and USA fisheries:

Haddock

Age	2	3	4	5	6	7	8	9	10	11	12	13	14
PR	0.5	1	1	1	1	1	1	1	1	1	1	1	1
Wt(kg)	.95	1.34	1.9	2.3	2.75	3.15	3.6	3.8	3.9	4	4.1	4.2	4.3

Cod

Age	2	3	4	5	6	7	8	9	10	11	12
PR	0.378	1	1	1	1	1	1	1	1	1	1
Wt(kg)	1.39	2.25	3.58	5.01	6.45	8.33	10.34	10.95	13.72	16.50	17.87

The simulations were done using a constant recruitment of 1000 fish, making the results equivalent to a yield per recruit analysis. For each simulation the following were kept constant:

- the proportion of Canadian to USA population abundance for age 2 at the beginning of the spring/summer period
- the instantaneous rate of emigration from the Canadian side during the fall/winter period
- the instantaneous rate of emigration from the USA side during the spring/summer period

- the ratio of spring/summer to fall/winter instantaneous fishing mortality rate for both Canada and the USA (an average for 1985 to 1990)

The yield was computed for a range of annual fishing mortality rates during the spring/summer period of between 0 and 1 for Canada and between 0 and 2 for USA.

The Canadian yield was derived as follows:

$$Y_{Can,a,p} = \frac{W_a F_{Can,a,p} t\, N_{Can,a,p}(1-\exp[-(E_{Can,a,p}+F_{Can,a,p}+M)t]}{(E_{Can,a,p}+F_{Can,a,p}+M)t}$$

where W is weight
M is natural mortality rate (M = 0.2 assumed)
t is time increment (t = 0.5 yr).

To ensure that the same number of fish that emigrated from one compartment immigrated into the other compartment and that the migration rates did not imply more fish emigrating than were present, only emigration rates (designated by a positive sign in the tables) were input and the corresponding immigration rates (designated by a negative sign) for the other compartment were computed. That is, given the emigration rate from the USA side in the spring/summer, the number of migrants, ${}_EN_{a,p}$, was obtained from :

$${}_EN_{a,p} = \frac{E_{USA,a,p} t\, N_{USA,a,p}\, (1-\exp[-(E_{USA,a,p}+F_{USA,a,p}+M)t]}{(E_{USA,a,p}+F_{USA,a,p}+M)t}$$

The immigration rate to the Canadian side for the same season was obtained by solving for $E_{Can,a,p}$ using a Newton-Raphson technique (Press et al 1988) in the equation :

$${}_EN_{a,p} = \frac{E_{Can,a,p} t\, N_{Can,a,p}\, (1-\exp[-(E_{Can,a,p}+F_{Can,a,p}+M)t]}{(E_{Can,a,p}+F_{Can,a,p}+M)t}$$

Similarly, given the emigration rate from the Canadian side during the fall/winter, the corresponding immigration rate to the USA side was derived.

The analysis for haddock assumed that the proportion of the age 2 population on the Canadian side was 80% and that the emigration rates from the Canadian and USA sides were 0.5 and 3.0 respectively. The Canadian F's for the fall/winter period were set to 20% of the F's in the spring/summer period. The USA F's for the fall/winter period were set to 25% of the F's used during the spring/summer period.

The yield to the Canadian fishery decreases somewhat as the USA fishing mortality rate increases (Fig. 3). For any given USA fishing mortality rate, yield is asymptotic in relation to increasing

Canadian fishing mortality rate. That is, increases in Canadian yield are marginal for fishing mortality rates in excess of 0.6. Using an heuristic approach, an equivalent harvest strategy approximating the Canadian $F_{0.1}$ level, conditional on each USA exploitation rate, was considered to be that rate which achieves 85% of the asymptotic yield (taken as Canadian spring/summer F = 1.0). Over the range of spring/summer F's examined for the USA fishery (0.2-2.0), the Canadian spring/summer F's that would give 85% of the asymptotic yield increased from 0.37 to 0.49.

Two other scenarios were considered for haddock representing extreme conditions, which establish bounds for "worst case" situations. One assumed that no haddock returned to Canada after migrating to the USA side. The corresponding Canadian spring/summer F which achieved 85% of asymptotic yield was closer to 0.6. This yield surface does not reach an asymptote as quickly. The second scenario assumed that only 60%, about the lowest observed, of age 2 haddock were in Canadian territory at the beginning of the spring/summer period and migration to the USA was 50% greater, about the highest observed, than that used above while migration to Canada remained unchanged. For similar Canadian and USA fishing mortality rates the Canadian yield was generally less than half that obtained in the original projections. The yield continued to increase even at very high Canadian fishing mortality rates, precluding computation of any meaningful reference level.

The analysis for cod assumed that the proportion of the age 2 population on the Canadian side was 60% and that the emigration rates from the Canadian and USA sides were 1.2 and 2.04 respectively. The Canadian F's for the fall/winter period were set to 10% of the F's in the spring/summer period. The USA F's for the fall/winter period were set to 125% of the F's used during the spring/summer period. The yield to the Canadian fishery increases rapidly at first as effort by both countries increases, but reaches a maximum and then declines (Fig 4). The influence of the USA exploitation rate is apparent, with a general decrease in yield to Canada as USA exploitation increases.

DISCUSSION

The results indicate a seasonal migration of haddock and cod to the northeast and to areas of greater bottom depth through the spring and summer (April-September) and a return onto the bank in the autumn and winter (October-March). This movement does not appear to be related to relative densities or abundance but is presumably associated with spawning activity (Colton 1955). The analyses suggested that a fraction of the populations migrated between Canadian and USA territory, as opposed to the entire populations circulating over their range and making them susceptible to each of the fisheries at some time during the year. The majority of haddock landings from the USA side of 5Zjm since 1985 occurred during the first half of the year and there were virtually no landings during the second half (Gavaris and Van Eeckhaute 1992). The continued presence of haddock on the Canadian side during the second half of the year is substantiated by high Canadian landings during that period. Canadian landings are low during the first half of the year because of the spawning closure. The continued occurrence of haddock and cod on the USA side despite high exploitation suggests mixing and redistribution.

The net migration is towards the USA side during autumn-winter and towards the Canadian side during spring/summer. The rate of movement balances out on average and there is no net annual migration. Roughly 15-20% of the total haddock stock and 20-27% of the total cod stock aged 2 and older shift between the Canadian and United States sides during this seasonal migration.

In the case of haddock, if Canada and the USA adopted a consistent $F_{0.1}$ harvest strategy for the entire stock, the yield per recruit analysis indicated a fishing mortality rate of about 0.25 (Gavaris 1989). The results from the transboundary yield projections suggest that in the absence of a consistent management strategy and under average conditions observed during the late 1980s, the kinds of benefits associated with an $F_{0.1}$ strategy can be approximately achieved by the Canadian fishery if the Canadian fishing mortality rate was maintained below 0.5 during the spring/summer and below 0.1 during the fall/winter. This exploitation is in addition to any exerted by the USA.

If none of the haddock migrating to the USA return to Canada, then a higher fishing mortality rate by Canada is indicated to approximate an $F_{0.1}$ harvest strategy. If the distribution of haddock changes, approaching the 60% to 40% split used in the "worst case" scenario and migration from Canada is greater than migration to Canada, the results suggest that unilateral actions by Canada are unlikely to be effective in achieving management objectives related to conservation or yield optimization.

The analysis suggests that unilateral management actions by Canada can have beneficial effects on haddock yield and catch rates, however, it may be profitable and perhaps necessary to pursue consistent measures by both countries to achieve a recovery of Georges Bank haddock from its present depressed state.

For cod, the present distribution of the stock relative to the international boundary and the extent of migration suggests that the benefits associated with a unilateral $F_{0.1}$ management strategy by Canada would be more difficult to achieve. Stock rebuilding under such a plan could be offset by high or even increased exploitation rates outside of the area under Canadian jurisdiction without consistent conservation measures by both countries. In addition, the number of zero population estimates at some ages during the fall/winter period may be an indication of movement of cod out of the management unit. Further analysis is required to assess the extent of cod distribution relative to the present stock unit area unit and implications for management of the resource.

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REFERENCES

Colton J. B. 1955 Spring and summer distribution of haddock on Georges Bank. Spec. Sci. Rep. U.S. Fish. Wildl. Serv. No. 156, 65p.

Gavaris, S. 1989. Assessment of eastern Georges Bank haddock. CAFSAC Res. Doc. 89/49, 27p.

Gavaris, S. and L. Van Eeckhaute. 1990. Assessment of haddock on eastern Georges Bank. CAFSAC Res. Doc. 90/86, 37p.

Gavaris, S. and L. Van Eeckhaute. 1992. Assessment of haddock on eastern Georges Bank. CAFSAC Res. Doc. 92/29, 32p.

Hunt , J.J. 1989. Status of the Atlantic cod stock on Georges Bank in unit areas 5Zj and 5Zm 1978-88. CAFSAC Res. Doc. 89/47, 26p.

Hunt, J. 1990. Status of the Atlantic cod stock on Georges Bank in unit areas 5Zj and 5Zm, 1978-89. CAFSAC Res. Doc. 90/80, 37p.

Press, W.H., B.P. Flannery, S.A. Teukolsky and W.T. Vetterling. 1988. Numerical Recipes in C. The Art of Scientific Computing. (Cambridge: Cambridge University Press). 735p.

Table 1. Haddock abundance in 5Zj,m on the Canadian and USA sides of the international boundary by strata or strata sections as estimated from the fall and spring USA surveys. Values in parentheses were estimated using a multiplicative model.

	Stratum											
	16		17		18		19	20	21		22	
Year	Can.	USA	Can.	USA	Can.	USA	USA	USA	Can.	USA	Can.	USA
USA Fall Survey												
1985	5314617	7230989	587675	(0)	323565	0	0	0	568377	(118754)	24934	(127490)
1986	6844583	0	892396	(0)	357672	0	0	0	2273508	40365	12467	0
1987	80525	179340	270766	(0)	114966	(0)	135271	102699	315765	0	311675	0
1988	2536522	143472	493357	(0)	740892	(0)	0	0	1178856	(64988)	361543	0
1989	851949	47346	1189861	(0)	(336212)	4803	0	102699	1378841	16146	573482	16401
1990	563672	915351	1204372	93192	344898	(0)	0	0	1164752	(102366)	170424	(109887)
USA Spring Survey												
1985	9133089	573888	251612	31064	38322	0	108217	0	1936692	(54654)	87269	(43736)
1986	6313121	1520803	29021	0	0	0	432868	0	1305162	4037	0	(18588)
1987	5991023	114778	135528	0	6387	0	0	1871518	126306	(12352)	24934	(9841)
1988	1417231	1893830	29021	0	0	(0)	54109	0	568377	0	0	0
1989	4167948	5021520	391784	93192	153288	(0)	27054	0	1631453	0	797888	(41877)
1990	14623249	1721664	43532	0	(0)	(0)	0	0	1291058	16146	12467	(22524)

Table 2. Cod abundance in 5Zj,m on the Canadian and USA sides of the international boundary by strata or strata sections as estimated from the fall and spring USA surveys. Values in parentheses were estimated using a multiplicative model.

	Stratum											
	16		17		18		19	20	21		22	
Year	Can.	USA	Can.	USA	Can.	USA	USA	USA	Can.	USA	Can.	USA
USA Fall Survey												
1985	1288392	0	65297	(7766)	8559	0	0	17117	926244	(285)	12467	(229)
1986	1489703	71736	116084	(7766)	31935	0	0	0	284189	50445	0	0
1987	805245	0	29021	(7766)	134127	(4803)	0	0	199985	1140	12467	229
1988	845507	0	154682	(7766)	140514	(4803)	212	17117	203563	(285)	473746	458
1989	2523638	0	20314	31064	(12774)	0	0	102699	820989	285	12467	344
1990	1108017	18651	174126	0	12774	(4803)	0	0	1101599	285	29048	229
USA Spring Survey												
1985	2668582	526542	106507	15532	76644	0	8207	787359	347342	(60790)	105970	(22305)
1986	966294	573888	9577	15532	6387	0	11300	308097	768362	428	74802	(11809)
1987	1127343	373027	241745	0	6387	0	1906	342330	63153	(20425)	37401	(7435)
1988	2319106	516499	159616	0	12774	(1489)	5560	136932	442071	6840	124670	0
1989	2963302	659971	43532	0	12774	(672)	9002	770243	189459	0	0	(6123)
1990	4831470	532281	174126	0	(33085)	(1537)	2648	205398	112202	1995	187005	(13668)

Table 3. Proportion of 5Zj,m haddock on Canadian side of international boundary at beginning of spring-summer (April to September-SS) and fall-winter (October to March-FW) periods as determined from Canadian and USA spring surveys and USA fall surveys.

AGE	1985		1986		1987		1988		1989		1990	
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW
2	0.97	0.86	0.88	0.99[a]	0.83	0.99[a]	0.62	0.93	0.82	0.99[a]	0.89	0.93
3	0.97	0.92	0.90	0.99[a]	0.97	0.99[a]	0.66	0.97	0.83	0.99	0.81	0.95
4	0.99	0.99	0.94	0.99[a]	0.98	0.99[a]	0.62	0.98	0.80	0.99[a]	0.81	0.96
5	0.97	0.99[a]	0.90	0.99[a]	0.89	0.99[a]	0.54	0.98	0.69	0.94	0.64	0.97
6	0.84	0.99[a]	0.82	0.99[a]	0.99[a]	0.99[a]	0.48	0.99	0.48	0.91	0.52	0.98
7	0.82	0.99[a]	0.94	0.99[a]	0.97	0.99[a]	0.50	0.99	0.51	0.99[a]	0.74	0.99[a]
8	0.89	0.99[a]	0.86	0.99[a]	0.96	0.99[a]	0.52	0.99[a]	0.49	0.99[a]	0.84	0.99[a]

[a]actual value was 1.00 but an upper limit of 0.99 was used to facilitate calculations

4.Proportion of 5Zj,m cod on Canadian side of international boundary at beginning of spring-summer (April to September-SS) and fall-winter (October to March-FW) periods from 1985 to 1990 as determined from Canadian and USA spring surveys and USA fall surveys.

AGE	1985		1986		1987		1988		1989		1990	
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW
2	0.62	0.98	0.49	0.99	0.72	0.97	0.66	0.95	0.57	0.98	0.86	0.94
3	0.65	0.99[a]	0.51	0.72	0.66	0.92	0.78	0.95	0.66	0.98	0.87	0.99
4	0.63	0.98	0.45	0.77[b]	0.71	0.93	0.79	0.95	0.67	0.98	0.81	0.99
5	0.52	0.99[b]	0.50	0.77[b]	0.83	0.96[b]	0.71	0.92	0.75	0.98	0.83	0.99[a]
6	0.48	0.96	0.52	0.99[a]	0.82	0.96[b]	0.88	0.98[b]	0.62	0.99[a]	0.83	0.99
7	0.77	0.99[b]	0.99[a]	0.77[b]	0.72	0.96[b]	0.84	0.90	0.61	0.98[b]	0.69	0.99[a]
8	0.72	0.99[b]	0.80	0.77[b]	0.64	0.96[b]	0.40	0.99[a]	0.71	0.98[b]	0.86	0.99[b]

[a]actual value was 1.00 but an upper limit of 0.99 was used to facilitate calculations
[b]no actual value because no cod were caught during survey so average value was used

Table 5a. Annual instantaneous migration rates for 5Zj,m haddock ages 2 to 8 on the Canadian side of the international boundary relative to the population on that side during the spring-summer (Apr-Sept:SS) and fall-winter (Oct-Mar:FW) periods. -ve values indicate migration into Canadian territory, +ve values indicate migration into USA territory.

AGE	1985		1986		1987		1988		1989		1990
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS
2	0.23	-0.06	-0.23	0.09	-0.41	0.79	-0.89	0.23	-0.42	0.41	-0.10
3	0.17	0.13	-0.02	0.08	-0.02	0.95	-0.93	0.45	-0.35	0.56	-0.32
4	0.19	0.28	-0.01	0.24	0.16	1.30	-0.92	0.81	-0.45	0.93	0.03
5	0.15	0.55	0.11	0.06	-0.10	1.55	-0.95	1.43	-0.37	1.23	-0.78
6	-0.16	0.44	-0.18	0.12	0.20	1.54	-1.41	1.36	-1.28	0.45	-0.73
7	0.03	0.57	0.14	0.12	0.42	1.54	-1.16	1.43	-1.24	0.52	-0.54
8	0.00	-	-0.09	-	0.36	-	-1.17	-	-1.19	-	-0.27
$Mean_{2-8}$[a]	0.19	0.05	-0.04	0.09	-0.19	0.95	-0.95	0.66	-0.47	0.52	-0.38

[a]mean rate, ages 2 to 8 combined

Table 5b. Annual instantaneous migration rates for 5Zj,m haddock ages 2 to 8 on the USA side of the international boundary relative to the population on that side during the spring-summer (Apr-Sept:SS) and fall-winter (Oct-Mar:FW) periods. -ve values indicate migration into Canadian territory, +ve values indicate migration into USA territory.

AGE	1985		1986		1987		1988		1989		1990
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS
2	3.02	-0.42	-4.96	4.83	-6.12	7.19	-3.63	1.87	-7.85	7.96	-1.07
3	3.55	1.76	-0.33	4.86	-1.01	7.57	-5.50	4.86	-5.41	8.61	-2.63
4	20.55	7.16	-0.40	5.55	9.98	8.81	-5.22	6.29	-7.73	10.52	0.24
5	8.01	8.96	2.46	6.20	-2.05	9.12	-4.50	7.34	-1.78	4.36	-4.16
6	-2.55	15.10	-2.52	6.03	19.66	9.62	-7.50	9.60	-3.20	2.27	-3.28
7	0.48	11.22	4.42	5.43	20.17	10.08	-6.80	9.46	-6.67	8.95	-5.37
8	0.10	-	-1.66	-	14.41	-	-6.17	-	-5.78	-	-4.00
Mean$_{2-8}$[a]	2.86	0.40	-0.86	5.07	-3.99	7.81	-5.16	5.61	-6.20	7.41	-2.96

[a]mean rate, ages 2 to 8 combined

Table 6a. Annual Canadian instantaneous fishing mortality rates for 5Zj,m haddock ages 3 to 8 relative to the population on the Canadian side of the international boundary during the spring-summer (Apr-Sept:SS) and fall-winter (Oct-Mar:FW) periods.

AGE	1985		1986		1987		1988		1989		1990
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS
3	0.46	0.18	0.58	0.04	0.24	0.03	1.07	0.05	0.28	0.14	0.44
4	0.33	0.12	0.28	0.03	0.65	0.12	0.40	0.06	0.51	0.13	0.61
5	0.27	0.09	0.41	0.07	0.27	0.10	0.64	0.10	0.40	0.18	0.98
6	0.21	0.07	0.31	0.05	0.32	0.07	0.61	0.05	0.69	0.08	0.23
7	0.18	0.06	0.19	0.06	0.31	0.08	0.18	0.02	0.25	0.03	0.61
8	0.20	-	0.15	-	0.32	-	0.47	-	0.36	-	0.92
Mean$_{3-8}$[a]	0.30	0.12	0.51	0.04	0.52	0.09	0.90	0.06	0.49	0.12	0.54

[a]mean rate, ages 3 to 8 combined

Table 6b. Annual USA instantaneous fishing mortality rates for 5Zj,m haddock ages 3 to 8 relative to the population on the USA side of the international boundary during the spring-summer (Apr-Sept:SS) and fall-winter (Oct-Mar:FW) periods.

AGE	1985		1986		1987		1988		1989		1990
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS
3	1.81	2.64	5.05	3.27	1.64	0.30	0.55	0.86	0.43	3.05	0.58
4	20.72	2.61	3.53	0.76	12.30	1.35	0.85	1.19	1.00	1.20	4.09
5	10.58	3.44	7.75	6.33	3.17	1.42	3.03	0.57	2.00	0.57	2.09
6	3.31	11.75	3.75	3.72	20.05	2.06	2.18	0.75	0.83	0.36	4.11
7	6.77	6.24	8.54	2.61	23.25	2.64	2.51	0.50	1.44	3.57	1.79
8	5.26	-	3.99	-	17.98	-	2.15	-	2.68	-	2.49
Mean$_{3-8}$[a]	5.20	4.22	5.01	2.82	9.67	1.26	1.27	0.79	1.05	1.00	1.16

[a]mean rate, ages 3 to 8 combined

Table 7a. Annual instantaneous migration rates for 5Zj,m cod ages 2 to 8 on the Canadian side of the international boundary relative to the population on that side during the spring-summer (Apr-Sept:SS) and fall-winter (Oct-Mar:FW) periods. -ve values indicate migration into the Canadian side, +ve values indicate migration into the USA side.

AGE	1985		1986		1987		1988		1989		1990
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS
2	-0.75	1.55	-1.28	1.00	-0.37	0.75	-0.53	0.95	-0.88	0.59	0.87
3	-0.68	1.81	-0.58	0.26	-0.52	0.89	-0.08	1.05	-0.41	1.02	0.20
4	-0.72	1.77	-1.24	0.14	-0.36	0.96	-0.03	0.88	-0.33	0.74	0.23
5	-1.19	1.80	-0.78	0.17	-0.06	0.62	-0.22	1.06	-0.35	0.65	-0.04
6	-1.37	0.27	-1.26	0.95	-0.05	0.72	0.17	1.10	-0.69	0.96	-0.21
7	-0.30	0.69	0.73	0.65	-0.39	2.10	0.12	0.66	-0.54	0.53	-0.61
8	-0.40	-	0.28	-	-0.62	-	-2.07	-	-0.58	-	-0.11
$Mean_{2-8}$[a]	-0.77	1.53	-0.83	0.54	-0.37	0.80	-0.19	1.01	-0.70	0.67	0.18

[a]mean rate, ages 2 to 8 combined

Table 7b. Annual instanteous migration rates for 5Zj,m cod ages 2 to 8 on the USA side of the international boundary relative to the population on that side during the spring-summer (Apr-Sept:SS) and fall-winter (Oct-Mar:FW) periods. -ve values indicate migration into Canadian terriroty, +ve values indicate migration into the USA side.

AGE	1985		1986		1987		1988		1989		1990
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS
2	-4.47	8.47	-6.00	8.40	-2.43	6.74	-2.75	5.29	-5.01	10.24	7.24
3	-6.38	13.50	-0.92	0.65	-2.16	5.97	-0.58	6.01	-2.84	14.30	3.48
4	-4.09	8.89	-1.89	0.54	-1.83	5.40	-0.19	6.09	-2.12	9.81	2.66
5	-6.16	12.38	-1.32	0.65	-0.62	8.02	-1.01	4.33	-2.98	9.02	-0.46
6	-4.57	12.10	-6.40	10.71	-0.45	7.90	2.63	7.37	-4.69	9.62	-3.25
7	-3.45	10.40	9.91	1.60	-2.39	7.34	-0.82	3.06	-2.90	8.09	-5.13
8	-3.76	-	1.04	-	-3.13	-	-7.31	-	-4.14	-	-1.96
$Mean_{2-8}$[a]	-4.74	9.28	-1.83	2.02	-2.24	6.43	-1.20	5.57	-4.21	10.51	2.55

[a]mean rate, ages 2 to 8 combined

Table 8a. Annual Canadian instantaneous fishing mortality rates for 5Zj,m cod ages 3 to 8 relative to the population on the Canadian side of the international boundary during the spring-summer (Apr-Sept:SS) and fall-winter (Oct-Mar:FW) periods.

AGE	1985		1986		1987		1988		1989		1990
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS
3	0.72	0.07	0.58	0.03	0.59	0.07	0.32	0.05	0.11	0.02	0.58
4	0.51	0.14	1.04	0.07	0.48	0.07	0.38	0.08	0.52	0.05	2.72
5	0.67	0.17	0.60	0.05	0.32	0.06	0.28	0.07	0.74	0.11	1.26
6	0.68	0.15	0.76	0.09	0.40	0.13	0.20	0.09	0.57	0.07	1.14
7	0.12	0.04	0.21	0.04	0.76	0.34	0.35	0.14	0.78	0.04	0.50
8	0.44	-	0.09	-	0.30	-	1.43	-	1.03	-	0.24
$Mean_{3-8}$[a]	0.59	0.11	0.61	0.04	0.51	0.08	0.32	0.06	0.43	0.05	0.8

[a]mean rate, ages 2 to 8 combined

Table 8b. Annual USA instantaneous fishing mortality rates for 5Zj,m cod ages 3 to 8 relative to the population on the USA side of the international boundary during the spring-summer (Apr-Sept:SS) and fall-winter (Oct-Mar:FW) periods.

AGE	1985		1986		1987		1988		1989		1990
	SS	FW	SS	FW	SS	FW	SS	FW	SS	FW	SS
3	1.84	1.01	0.31	0.17	0.40	3.13	1.42	1.14	1.94	7.02	5.80
4	0.59	1.92	0.18	0.50	0.54	1.50	1.52	1.87	2.74	3.05	9.08
5	0.86	3.41	0.39	0.50	0.67	3.46	0.90	0.66	1.12	1.87	3.68
6	0.44	5.80	0.69	1.78	1.18	3.28	3.42	0.00	1.58	0.60	1.15
7	0.53	1.37	1.00	0.34	0.97	1.52	0.86	0.00	2.72	1.13	0.31
8	1.31	-	0.07	-	0.44	-	0.86	-	0.53	-	0.00
$Mean_{3-8}$ [a]	0.98	2.02	0.31	0.25	0.52	2.14	1.33	1.06	2.30	3.68	5.14

[a]mean rate, ages 2 to 8 combined

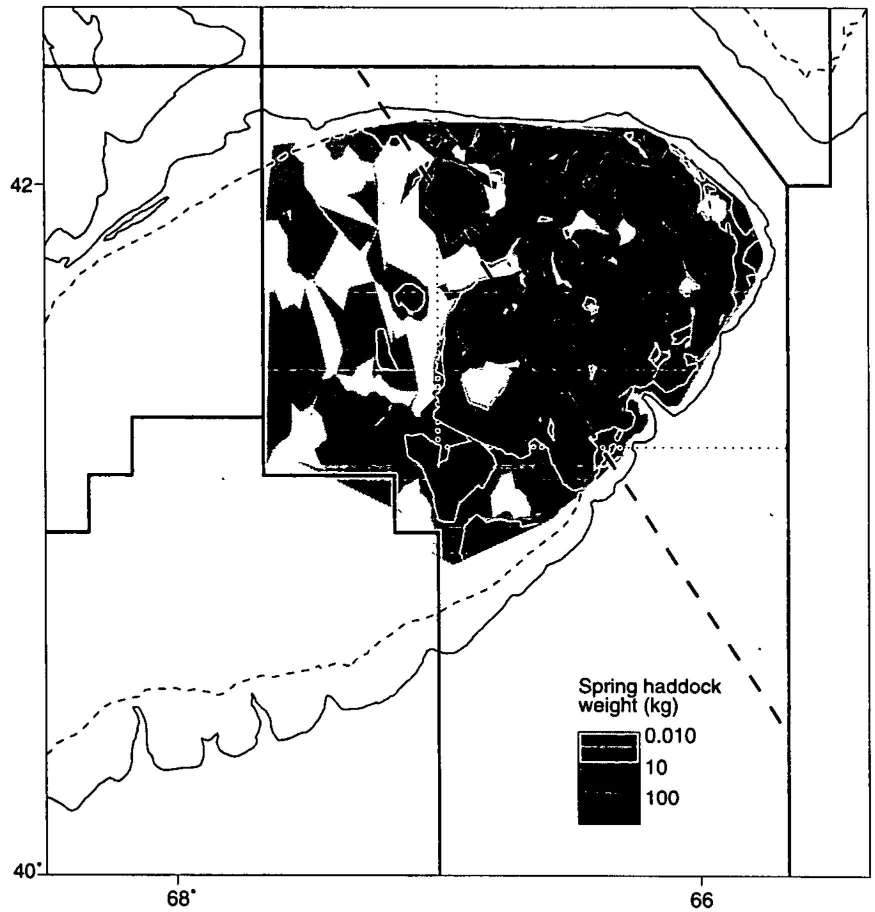


Fig. 1a. Composite distribution of haddock biomass on eastern Georges Bank from the Canadian spring surveys since 1987.

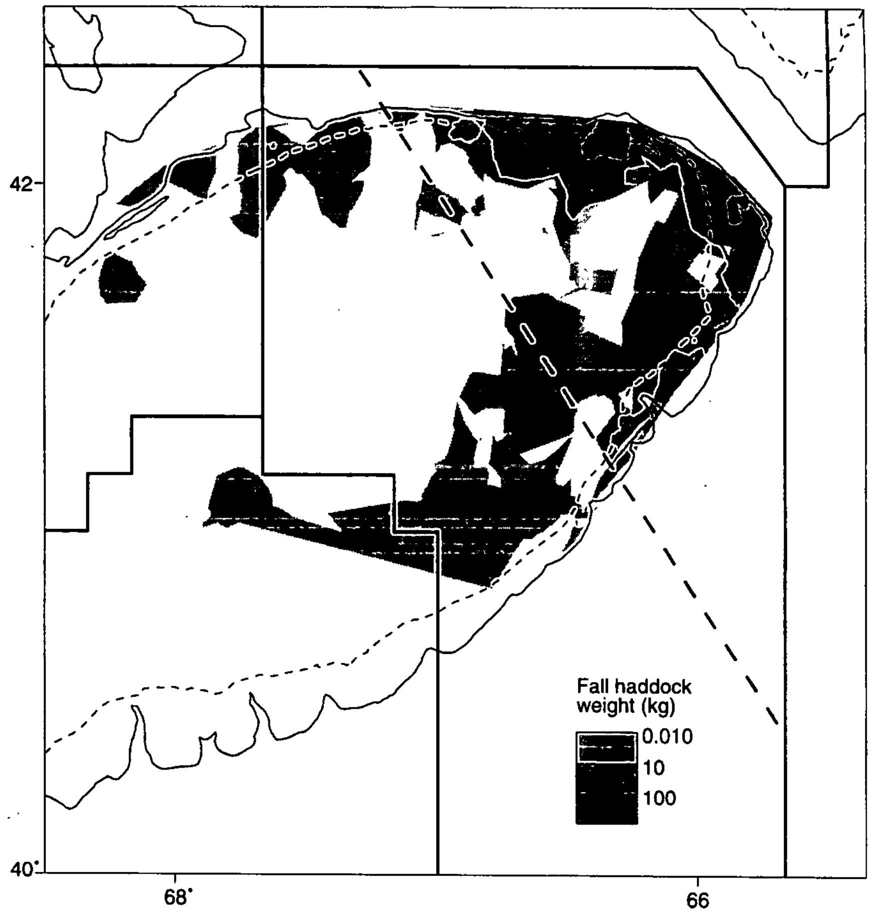


Fig. 1b. Composite distribution of haddock biomass on eastern Georges Bank from the USA fall surveys since 1985.

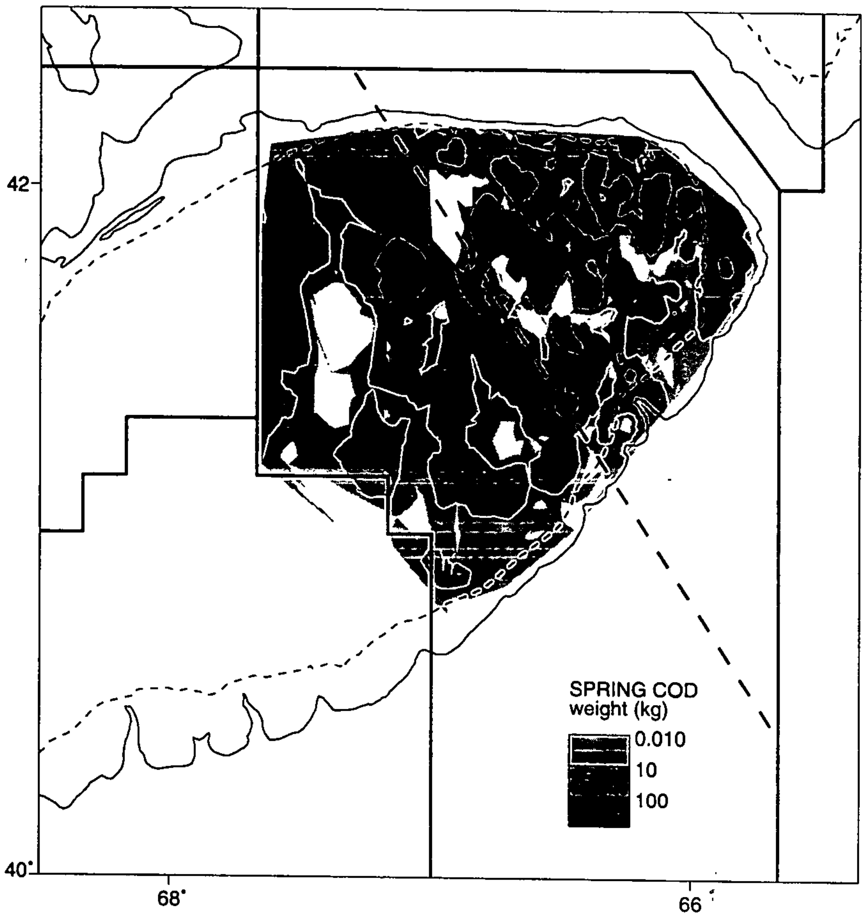


Fig. 2a. Composite distribution of cod biomass on eastern Georges Bank from the Canadian spring surveys since 1987.

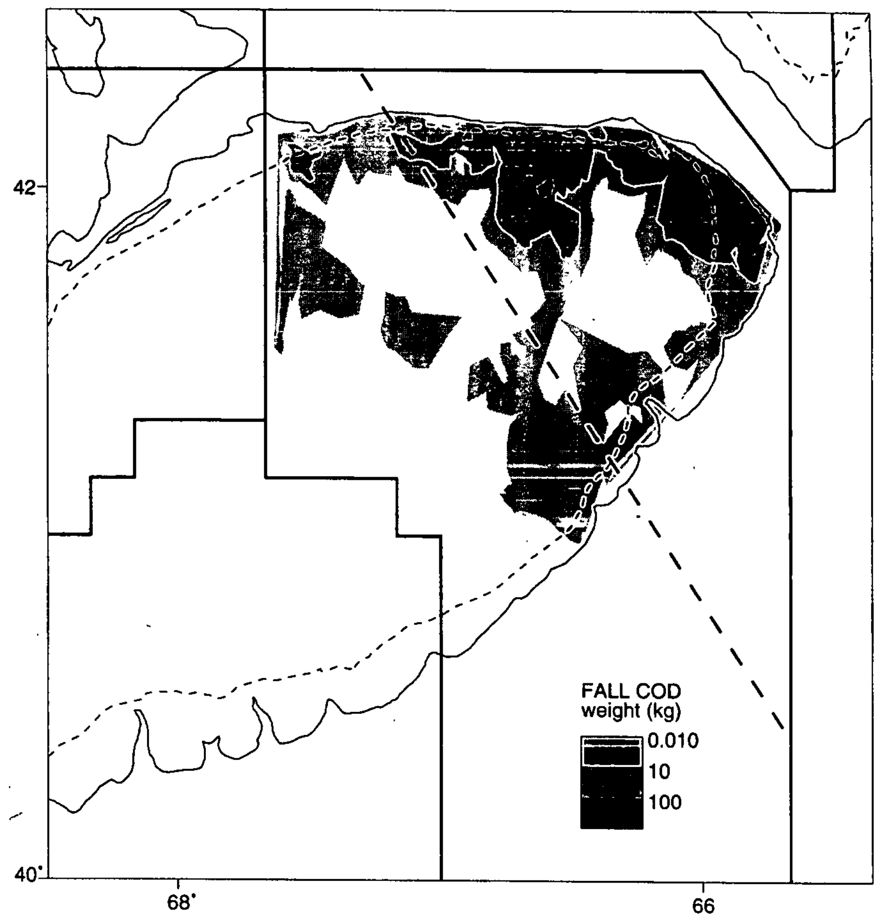
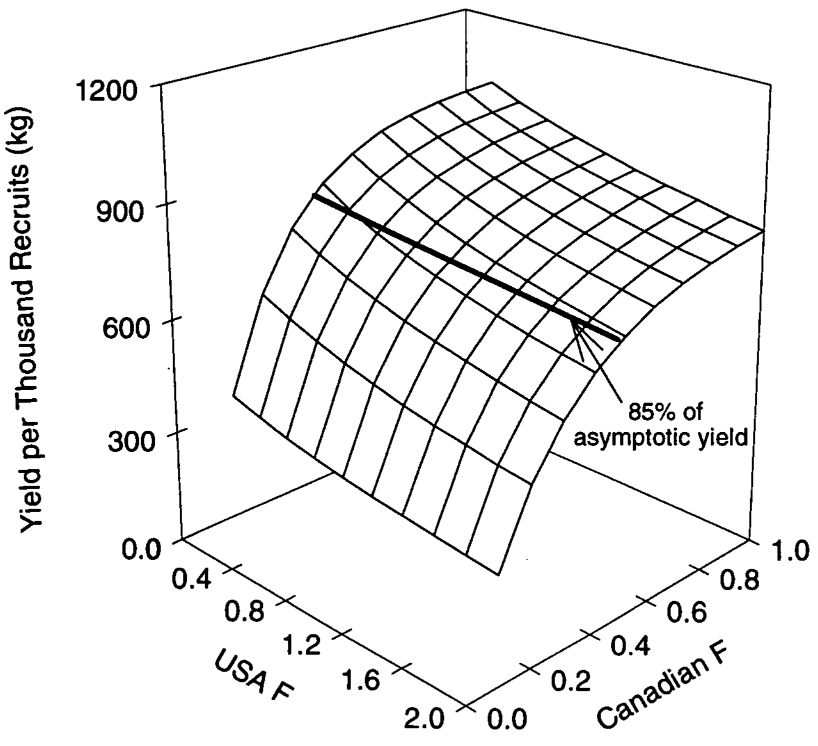


Fig. 2b. Composite distribution of cod biomass on eastern Georges Bank from the USA fall surveys since 1985.



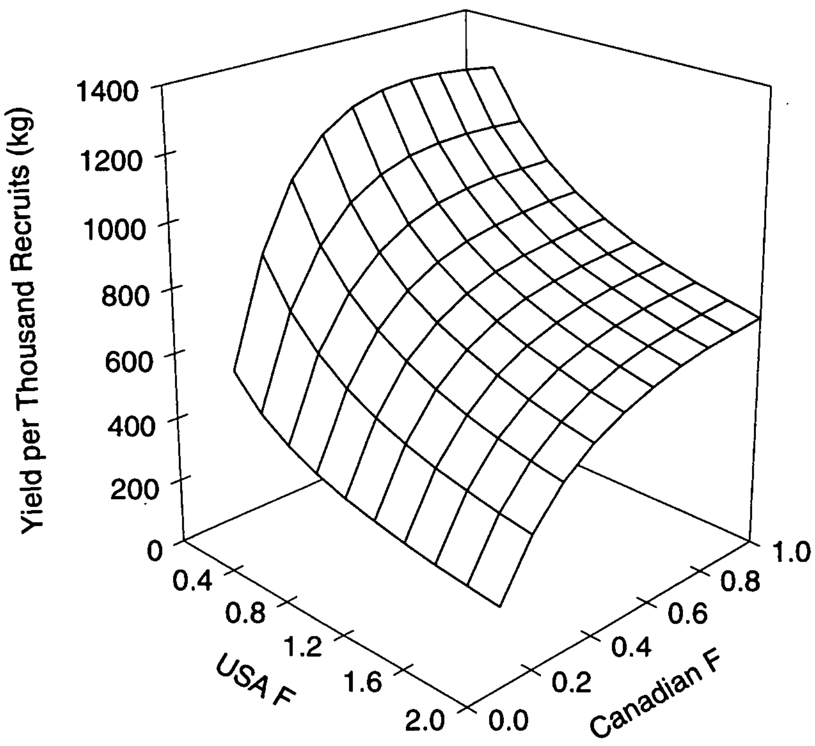


Fig. 3. Yield to the Canadian fishery per thousand recruits for Georges Bank haddock in relation to Canadian and USA fishing mortality.

Fig. 4. Yield to the Canadian fishery per thousand recruits for Georges Bank cod in relation to Canadian and USA fishing mortality.