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Northwest Atlantic Fisheries Organization

Serial No. N2315

NAFO SCR Doc. 93/121

SCIENTIFIC COUNCIL MEETING - SEPTEMBER 1993

Seasonal Components in Technological Interactions in Gulf of St. Lawrence Shrimp and Groundfish Fisheries

by

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Introduction

The term "technological interactions" has been commonly used to describe the class of multi-species fisheries interactions caused by the co-occurrence of more than one species in the catches of commercial fishing vessels (Anderson 1975, Murawski et al. 1983a, Sinclair 1985a). Fishing effort causes fishing mortality on more than one species at a time. These interactions may lead to sub-optimal fishing mortalities on the stocks involved (Paulik et al. 1967) or to substantial yield losses under single species management regimes where the catches of the interacting species are limited by catch quotas for one particular species.

Technological interactions are determined by the spatial distributions of the fish populations involved and the distribution of fishing effort. Individual fish species exist in discrete populations. Population density varies through space and time and populations of different species overlap to varying degrees through space and time. The joint distribution of the individual species define fishery assemblages (Gabriel and Tyler 1980, Overholtz 1982, Mahon 1985, Rogers and Pikitch 1992). Fishers, on the other hand, exploit these assemblages with the objective of maximizing gain. They go to specific locations where high catch rates are expected, and if these expectations are not met, they will fish elsewhere. Multi-species fishery units may be defined as concentrations of fishing effort which yield unique, homogeneous species composition and which exhibit stability in composition and location relative to the underlying assemblage structure.

The objective of this presentation is to describe the seasonal patterns in distribution of the major groundfish and shrimp fisheries in the Gulf of St. Lawrence (GSL) and to demonstrate how regular seasonal migrations have important implications in the study of technological and biological fisheries interactions in the area. Most previously published studies do not deal specifically with seasonal changes in catch composition, however in the case of the fisheries in question where the main species being exploited undertake extensive seasonal migrations, such considerations are necessary if one is to arrive at fishery unit definitions suitable for fisheries management actions.

The study of technological interactions in the northwest Atlantic groundfish fisheries is of particular current importance. Canada has closed several cod fisheries because of extremely low stock levels. However, fisheries for other species are continuing. The main question is how much cod by-catch may be expected to result from continued fishing for these other species.

Gear Selectivity/Technical Interactions Symposium

Study Area

The Gulf of St. Lawrence is a semi-enclosed sea with two connections to the northwest Atlantic Ocean: the Strait of Belle Isle to the northeast, and the Cabot Strait to the southeast (Figure 5). The Laurentian Channel bisects the GSL and forms a deep water channel between the Atlantic shelf break and the St. Lawrence estuary. Two other channels, the Esquiman Channel and the Anticosti Channel complete the deep water features of the GSL. Intermediate depth Atlantic waters enter via the Cabot Strait and slowly flush the GSL system through this system of channels where depths vary between 200-550 m (Koutitonsky and Bugden 1991). The southern GSL comprises a shallow plateau (the Magdellan Shallows) with depths generally less than 100 m.

The GSL receives considerable freshwater input from the St. Lawrence River drainage system as well as from rivers along its north shore and northeastern New Brunswick. The Gaspé Current dominates the surface circulation of the GSL as the freshwater plume of the St. Lawrence River which exits the estuary and hugs the north shore of the Gaspé Peninsula before spilling over the shallows of the southern GSL. Cold waters from the Labrador Current enter the GSL through the Strait of Belle Isle and influence the surface waters of the northern GSL as well as the intermediate cold layer of the entire system (Petrie et al. 1988).

The waters of the GSL have a typical three layer structure in summer, surface waters over shallow areas may reach 20°C in summer in the southern Gulf but are much colder in the north. However, temperatures cool quickly with depth and dip below 0°C in the 50-75 m range, then increase to 4-6°C at depths greater than 200 m. The surface stratification breaks down in late autumn and the surface waters cool. Ice forms in a northwest-southeast direction beginning in early January. Most of the GSL is ice covered by late January-early February. Breakup occurs first in the northwest and extends along the central part of the GSL. Ice remains the longest over the southern part of the Magdellan Shallows. In normal years breakup begins in late March, however in 1991-92 it was later than normal with significant quantities remaining along the north shore until July and over the Magdellan Shallows into May (Drinkwater 1993).

Fishing Gears

There are four major gear types involved in the mobile gear groundfish and shrimp fisheries in the GSL, otter trawls, seines (Danish and Scottish), midwater trawls, and shrimp trawls. Otter trawls are used for a broad range of species, the predominant ones being cod, redfish, plaice, witch, winter flounder and white hake. Seines are used for the same species with the exception of redfish. The minimum regulated mesh size for otter trawls and seines in 1991-92 was 130 mm except when fishing for white hake and winter flounder where it was 120 mm and when fishig for redfish when there is no minimum mesh size. While shrimp trawls are technically otter trawls, they are dealt with separately here because the minimum mesh size is 40 mm and the species composition of the catch is unique. Midwater trawls are used exclusively for redfish and therefore their fisheries will not be described in this paper.

Methods

The catch data used in this study were obtained from the Gulf, Québec, and Scotia Fundy region statistics branches of the Canadian Department of Fisheries and Oceans (DFO). data were selected for mobile gears fishing in Div. 3P4RSTV. Position data were available to at least a 10' grid of latitude and longitude from the three regions. Appropriate position data were not available for landings in the Newfoundland region of DFO (this includes the south and east coasts of Newfoundland and the coast of Labrador).

Species catches were aggregated by 10' grids, month, and year. For initial visualization of the patterns of catches, monthly maps of catches were produced using various degrees of shading. The shading intervals were selected to correspond with the 25^{th}, 50^{th}, 75^{th} and 90^{th} quantiles of the catches in the non-zero grids for the entire species series. The maps were produced with the ACON mapping software (G. Black, pers comm.) and assembled into an animated movie using the Quicktime® facility on a Macintosh computer. Monthly maps of combined 1991-92 catches of cod, redfish, plaice and shrimp are reproduced here for reference.

Cluster analysis was used to define fishery units based on similarities in catch composition. Individual observations to be grouped consisted of gear/year/month/grid proportional species catch compositions. Fifteen species were used; cod, haddock, redfish, halibut, plaice, yellowtail, witch, winter flounder, Greenland halibut, pollock, white hake, catfish, angler, herring and shrimp. Similarities among observations were calculated as Euclidian distances based on the catch composition and groups were joined using an agglomerative hierarchical approach and Ward's method. The CLUSTER procedure of SAS was used for computations. Separate analyses were performed by gear and year.

A characteristic of cluster analysis is that there are no hard and fast methods for determining at what level of agglomeration to stop. The method proceeds by sequentially joining observations and groups of observations until one group is left. It is up to the researcher to determine where to stop (Gabriel and Murawski 1985). The approach used here was a combination of within and between comparisons of the results of annual analyses. The dendrograms of individual analyses were examined to determine at what level large changes in the similarity index were associated with specific groupings. Principle components analysis was performed on the basic data and plots of the first three components were coded as to the clusters to see if clusters were separate in this multi-dimentional space. A similar approach was used by Rogers and Pikitch (1992) however they used correspondence analysis. The species compositions of groups defined at progressive levels of agglomeration were compared to see if groups with similar species compositions were joined (e.g. with the same species but at different proportions) or if groups with very different species compositions were joined. The latter were kept separate. Finally, the species compositions of groups were compared among years to determine if certain groups dominated.

Once the annual groups were determined, the individual observations were colour-coded and plotted. Monthly maps were produced and assembled into animations as described above and viewed for spatial and seasonal patterns. Unfortunately these coloured maps cannot be reproduced here.

One example area was chosen to examine the importance of seasonal changes in species composition of catches on the feasibility of catching individual single species quotas. The area chosen was west of Cape Breton Island. The species composition data were taken from the seine fleet. Four species dominated the catches, cod, plaice, witch, and white hake.

Linear programming has been used to study problems of this type (Brown et al. 1973, 1979, Brodie 1981, Murawski et al. 1983b, Sinclair 1985b). The basic form of the problem is to maximize (or minimize) an objective function, which is a linear function of a series of unknowns, subject to a set of constraints (Luenberger 1973). In the present case the objective was to maximize the catches of three species, plaice, witch, and white hake. The linear functions were monthly equations of catch rates of the four species. The constraints were that the catches of these species could not exceed their average catches species over the last two years and that the by-catch of cod could not exceed various levels. The problem was to find the series of monthly fishing efforts that satisfied the objective and constraints. The computations were carried out with the SOLVER function in Microsoft Excel v 4.0.

Results

Cod Catches

There are two cod management units in the GSL, in the southern Gulf (Div. 4TVn (Jan.-Apr.)) and in the northern Gulf (Div 3Pn4RS). Both of these stocks are highly migratory and evidence largely from tagging studies has indicated that they spend the winter months at the entrance of the GSL, on the southern and northern sides of the Laurentian Channel respectively (McKenzie 1956, Templeman 1962, 1979, Gascon 1990). The cod reenter the GSL in the spring, become widely distributed during the summer, and exit in early winter. The distribution of cod catches will be discussed separately for each management unit.

Southern Gulf, 4Vn and 4Vs

Catches were continuously distributed in southern Subdiv. 4Vn and northern Subdiv. 4Vs along the edge of the Laurentian Channel during the January-March periods of the two years (Figure 1). Catches increased along the Channel edge in a northwesterly direction into Subdiv. 4Vn and 4T in April-May of 1991. In 1992 there was very little catch in 4T in April due to heavy ice coverage. In May of both years there were catches along the Channel edge of Subdiv. 4Vn and Div. 4T, west of Cape Breton in Div. 4T as well as off the Gaspé coast. Catches along the channel edge of Subdiv. 4Vn were smaller during June to September; there was a reduction of catches in Div. 4T west of Cape Breton; and increased catches off Gaspé, Miscou, in the Shediac Valley and in Chaleur Bay. Beginning in October there was a reverse movement with increasing catches along the Channel edge in Div. 4T and western Cape Breton. In November there were large catches off Cape Breton both in Div. 4T and Subdiv. 4Vn. While fishing was not permitted in Subdiv. 4Vn in December of 1992, the 1991 cod catches stretched from the channel edge northeast of the Magdellan Islands in Div. 4T southeast to southern Subdiv. 4Vn. At the same time there were increased catches in northern Subdiv. 4Vs but there was a break in the catch distribution between Subdiv. 4Vn and 4Vs.

Northern Gulf and 3P

The extent of cod catches by mobile gears in Div. 3P are under-represented in these figures because catch data from the DFO Newfoundland Region were not available.

The catches landed in the other 3 regions during January-March were taken from southern Div. 4R, 3Pn and extended into northern Div. 3Ps. Fishing moved into Div. 4R in April and extended in a northeasterly direction along the 200 m contour of the Esquiman Channel and Anticosti areas in May to August. There were increased catches in the Strait of Belle Isle in July-August which may correspond with the entry of cod from the 2J3K area as suggested by tagging data (Gascon 1990). The return migration from northern Div. 4R to the over-wintering grounds begins in November and follows the 200 m depth contour. Catches began to increase in Subdiv. 3Pn in January.

There were no cod catches from Div. 4S during January-March. Catches were recorded first in April west of Anticosti Island, and these were taken mainly as by-catch in the shrimp fishery. Catches were recorded east of Anticosti island in May, and the cod catches increased both east and west of the island through July with an increase in otter trawl fishing. Catches remained high during August to September however the amount taken by otter trawlers decreased while that by shrimp trawlers increased. Catches then decreased considerably in November and December. Over 90% of the cod catch in Div. 4S came from west of Anticosti Island.

Redfish Catches

There is one redfish management unit in the GSL. Originally the unit was defined as including Div. 4RST. However, the unit was recently been enlarged to include catches in Subdiv. 3Pn4VN during January to May (Atkinson and Power 1991). Redfish are also believed to be highly migratory, spending the winter at the entrance of the GSL and the summer in the deep waters of the Gulf. These conclusions are based largely on fishery distribution.

Winter catches of redfish came predominantly from southern Div. 4R and Subdiv. 3Pn (Figure 2). There were small amounts of redfish by-catch in Div. 4V along the edge of the Laurentian Channel. Beginning in April and May, redfish by-catch increased within the GSL as the cod and shrimp fisheries began. Redfish fishing intensified along the southern edge of the Laurentian Channel in Div 4TV during May to July. Directed catches increased in the deep water areas of the GSL south and east of Anticosti Island in July and August and there was also a limited amount of directed fishing west of Anticosti Island. In September, directed redfish fishing in the northern part of Div. 4S was greatly reduced and the fishery was moving southward. There was little redfish catch along the Laurentian Channel edge in Div. 4T in September and the main catches within the GSL came from southern Div 4R and 3Pn in October and November, and these extended into the center of the Laurentian Channel in Div 3P4Vn in December.

Plaice Catches

There is one management unit for plaice in the GSL and it includes only Div 4T. This analysis revealed very little reported catch of plaice from Div 4V, however this is likely because this species has been reported as part of a mixed flounder category during 1991-92 (C. Annand, Department of Fisheries and Oceans, Bedford Institute of Oceanography, pers. comm.).

There were no plaice catches reported from the study area during January to March (Figure 3). Limited catches appeared in northern Div. 4T, west of Anticosti Island, and off southwest Newfoundland in April. Catches increased rapidly in May in the southern GSL west of Cape Breton Island and in the southwest GSL. Catches remained high in these two areas during the summer months with a southerly movement to the eastern end of the Northumberland Straight, Chaleur Bay and the Shediac Valley by September. Catches increased along the Laurentian Channel edge and off Cape Breton in Div 4T in October and by November almost all of the Div 4T catches came from the latter area. The highest catches outside the Div. 4T management unit came from west of Anticosti Island, the head of the Esquiman Channel, and Bay St. George, Newfoundland. The distribution of plaice catches resembled the distribution of cod with the exception of winter catches. However, most of the plaice catch comes from Div. 4T while for cod the catches in the northern and southern parts of the GSL are similar.

Shrimp Catches

There are five shrimp management units in the GSL, Esquiman, Sept-Isle, north-Anticosti, south-Anticosti, and the St. Lawrence Estuary. These units were established based mostly on the fishery distribution.

Little movement is evident for this species on the scale of the study area and in comparison to the other species discussed in detail (Figure 4). Catches are clearly grouped within the defined management units and catches simply increase and decrease seasonally within those units.

Results of Cluster Analysis

Otter Trawl Fishery Distribution

A total of 10 fishery units were defined using cluster analysis in both 1991 and 1992 for the otter trawls. The species compositions of these groups were very similar between years (Figure 6). Most of the fisheries had an average catch composition dominated by one species, these being redfish, cod, pollock, plaice, haddock, witch, winter flounder, and yellowtail.

The main fishery groups within the GSL were redfish, cod, plaice, winter flounder, and witch. Where cod and redfish accounted for the majority of the catches in the GSL, the distribution of grids classified as being directed for these species reflected the distribution of their single species catches. The grids classified as being plaice directed were located in the eastern portion of the Northumberland Straight, Chaleur Bay, and the Shediac Valley in July to October. The winter flounder grids were located in the western portion of the Northumberland Strait in the summer months. The witch fishery grids were found along the edges of deep water channels in Div. 4T, in St. Georges Bay Newfoundland, and in western Div. 4S.

The pollock, haddock, and yellowtail fisheries were found outside the GSL proper. The pollock classified grids were found along the edge of the Laurentian Channel in Div. 4V. It was interesting to note that during April, 1991, the fishery designation in this area changed from cod to pollock to redfish as the depth increased down the channel slope. The haddock classified grids were found on Banquereau Bank in Subdiv. 4Vs and along the Laurentian Channel edge in Subdiv. 3Ps. The yellowtail grids were found over the shallow areas of Banquereau Bank.

Seine Fishery Distribution

The seiner fleet was not active during January to March and fished mostly in the southern GSL and Subdiv. 4Vn. There were eight fishery units defined in the two years, and seven of these had very similar species compositions (Figure 7). These seven fisheries were cod, cod mixed, witch, plaice, redfish, white hake, haddock. The last groups were winter flounder in 1991 and pollock in 1992.

Within the GSL the seine fisheries took a more diverse list of species. Of particular interest were the monthly differences in species composition in the area west of Cape Breton Island (Figure 8). The pattern of species composition in the landings was similar between years. When the fishery began in April the catches were dominated by cod. As the percentage cod decreased that of white hake increased. This was accompanied by an increase in the percentage of plaice. By August the percentage of witch increased. Towards the end of the fishing year cod became abundant again as they passed through the area in November en route to Subdiv. 4Vn. Monthly trends in catch per day were examined and these confirmed that the pattern in catch composition was driven by changes in the abundance of these species in the area (Figure 9, Table 1). These data were used in the following linear programming analysis of changes in technological interactions.

Analysis of Technological Interactions off western Cape Breton

The solutions to the linear programming problems reflected the seasonal changes in species composition in the western Cape Breton area. Where the cod catch constraint was the most limiting, the LP solution placed the fishing effort in August and July when the cod catch rates were the lowest (Table 2). As the cod catch constraint was increased the effort allocations shifted to October and July. When the cod catch was not limited then the three other species catch constrains became binding and effort was allocated to June, October and November. The witch catch constraint was realized at all levels of cod quota (Figure 10). The white hake constraint was met at a 1250 t cod quota. All three species catch constraints were realized at a cod quota of 1750 t.

Discussion

This analysis of the catches of the major commercial groundfish and shrimp fisheries in the GSL indicates the importance of considering seasonal changes in species distribution when modeling technical or biological interactions.

The interactions between cod and redfish have a strong seasonal component. Both species are highly migratory. In the winter months both are fished at the entrance to the GSL and are found in close proximity to each other. They were generally separated along a depth gradient, with cod found at shallower depths. However, in certain circumstances, and in particular in Subdiv. 3Pn, these two species were fished together and the depth separation actually reversed. During the summer months the two species were separated to a much greater extent. Cod become distributed in the shallower, inshore areas. This is most noticeable in the southern GSL. Redfish became distributed in the deeper channels. Only on the edges if the channels are the two species caught together. Around Anticosti Island, cod are found to a much greater extent on the western side while redfish are more abundant on the eastern side.

A second example of strong seasonal changes in species overlap concerns shrimp, cod and redfish. The shrimp were fished almost exclusively in the northern part of the GSL. Cod and redfish, both potential shrimp predators, are most abundant in this area only in summer.

The distribution of cod catches indicates that some modification of the current management unit definitions may be necessary. In the Div. 4TVn area during 1991-92 the winter migration out of Div. 4T began in November and was well advanced in December. There was a continuous distribution of catches from the southern portion of Subdiv. 4Vn well into Subdiv. 4Vs in January. There was very little catch in Subdiv. 4Vn during February and March when catches were high in the northern portions of Subdiv. 4Vs. The distribution of catches in May and June indicates that the return migration to Div. 4T may have been ongoing during these months. The catch distribution in the Div. 3Pn4RS and Subdiv. 3Ps indicates that northern Gulf cod moved into northern Subdiv. 3Ps during February and March. If this is the case, it is possible that the research vessel abundance surveys for the Div. 3Pn4RS stock, which is conducted in January, and that for Subdiv. 3Ps cod, which has been conducted in February, may be biased. A large proportion of the Div. 3Ps research survey abundance estimates come from the strata in this area.

A specific example was presented of how seasonal migrations of a dominant species can affect the catch composition of fisheries in a given area. The area west of Cape Breton was chosen as an example, however several others exist. For example; off southwest Newfoundland where in winter months cod and redfish are found in close proximity to each other; along the edge of the Laurentian Channel in Div. 4V where cod, pollock, and redfish are separated over a short distance but along a depth gradient.

The use of animations of catch and cluster maps was very effective for visualizing these seasonal movements and to focus attention on areas where species composition changed seasonally. Future projects will be focused on displaying not only changes in species composition but also species densities. Research is warranted into developing methods of accounting for the area fished as well as the mean fish density in a fishery in the development of stock abundance indices from commercial catch rate data. Another avenue of research possible with these spatially referenced catch and effort data is to investigate factors which may control how fishers allocated their effort to alternative fisheries and areas. Both annual and seasonal research vessel abundance survey data are available for this area and these would be useful in mapping the entire distribution of the exploited populations to compare with the areas fished.

Acknowledgments

I wish to thank G. Black for his help and advice in using the ACON mapping program, L. Currie for drawing many maps of species catches, and G. Lamoureux for doing the cluster analysis and devising innovative ways to display the results. I am grateful to the many fishers who have completed fishing logbooks giving positions, species and quantities of captures at sea, and to all those in the Gulf, Québec, and Scotia Fundy regions of DFO who code, keypunch, and maintain the enormous amount of information analyzed here.

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Table 1: Average monthly catch rates (kg/day) for 1991-92 for the four species used in the linear programming simulation of seine fisheries off western Cape Breton.

Month	Cod	Plaice	Witch	White Hake
Apr	1131	104	0	0
May	3284	574	135	65
Jun	1345	450	146	395
Jul	547	393	110	249
Aug	193	400	459	95
Sep	330	314	351	37
Oct	777	704	210	112
Nov	3514	623	43	184
Dec	758	4	0	0

Table 2: Fishing effort allocations by month resultinf from a linear programming simulation of the seine fishery off western Cape Breton.

	Cod Catch Constraint								
Month	250 t	500 t	750 t	1000 t	1250 t	1500 t	1750 t	2000 t	None
Apr	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0	891
Jul	183	682	1181	1680	1918	1778	1672	1608	0
Aug	778	658	538	418	274	96	0	2	0
Sep	0	0	0	0	0	0	0	0	0
Oct	0	0	0	0	189	654	912	924	1126
Nov	0	0	0	0	0	0	36	114	258
Dec	0	0	0	0	0	0	0	0	0

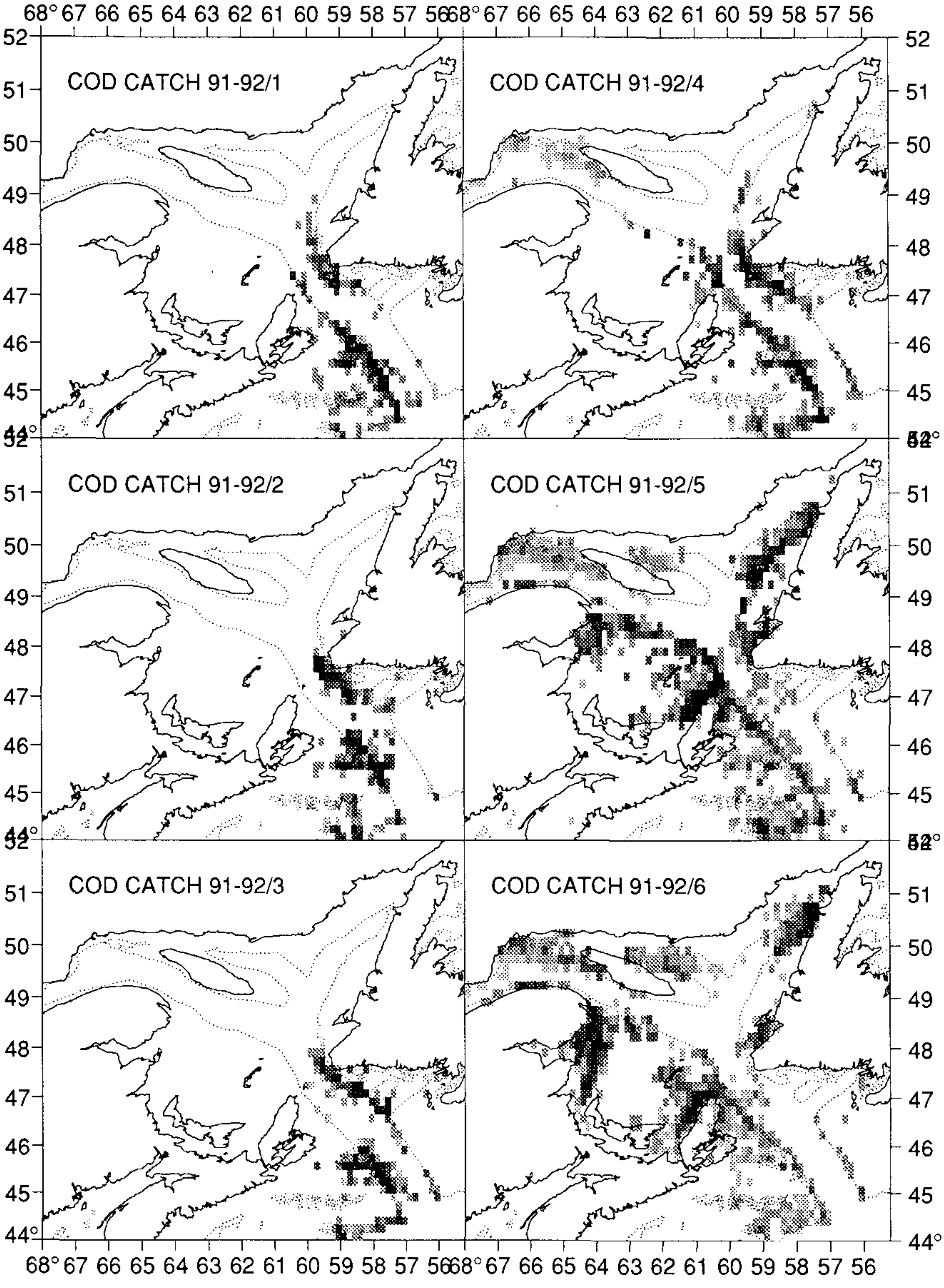

Figure 1: Cod catches 1991-92. Shading intervals are 0.5, 10, 50, and 100 t.

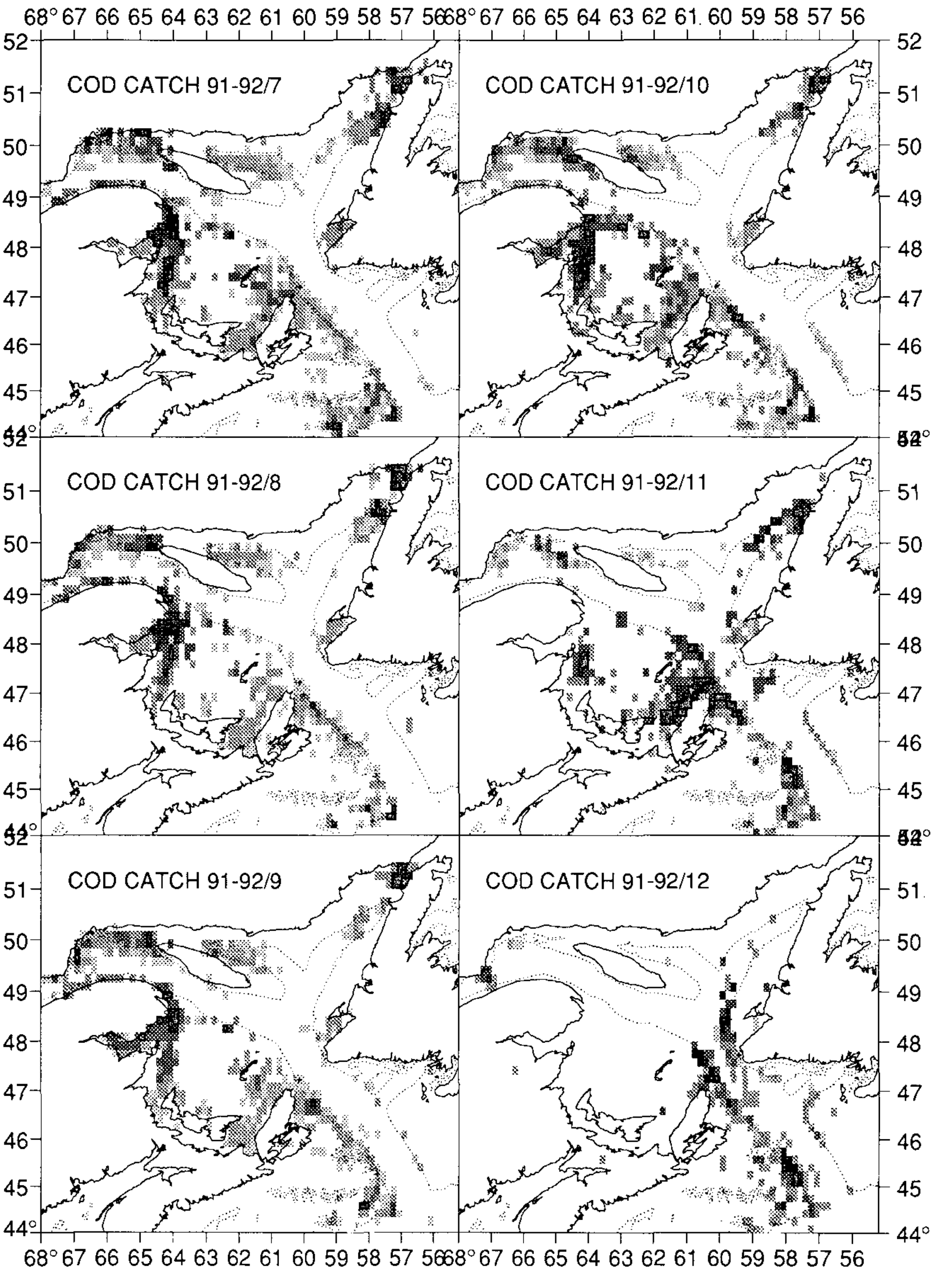

Figure 1: con't

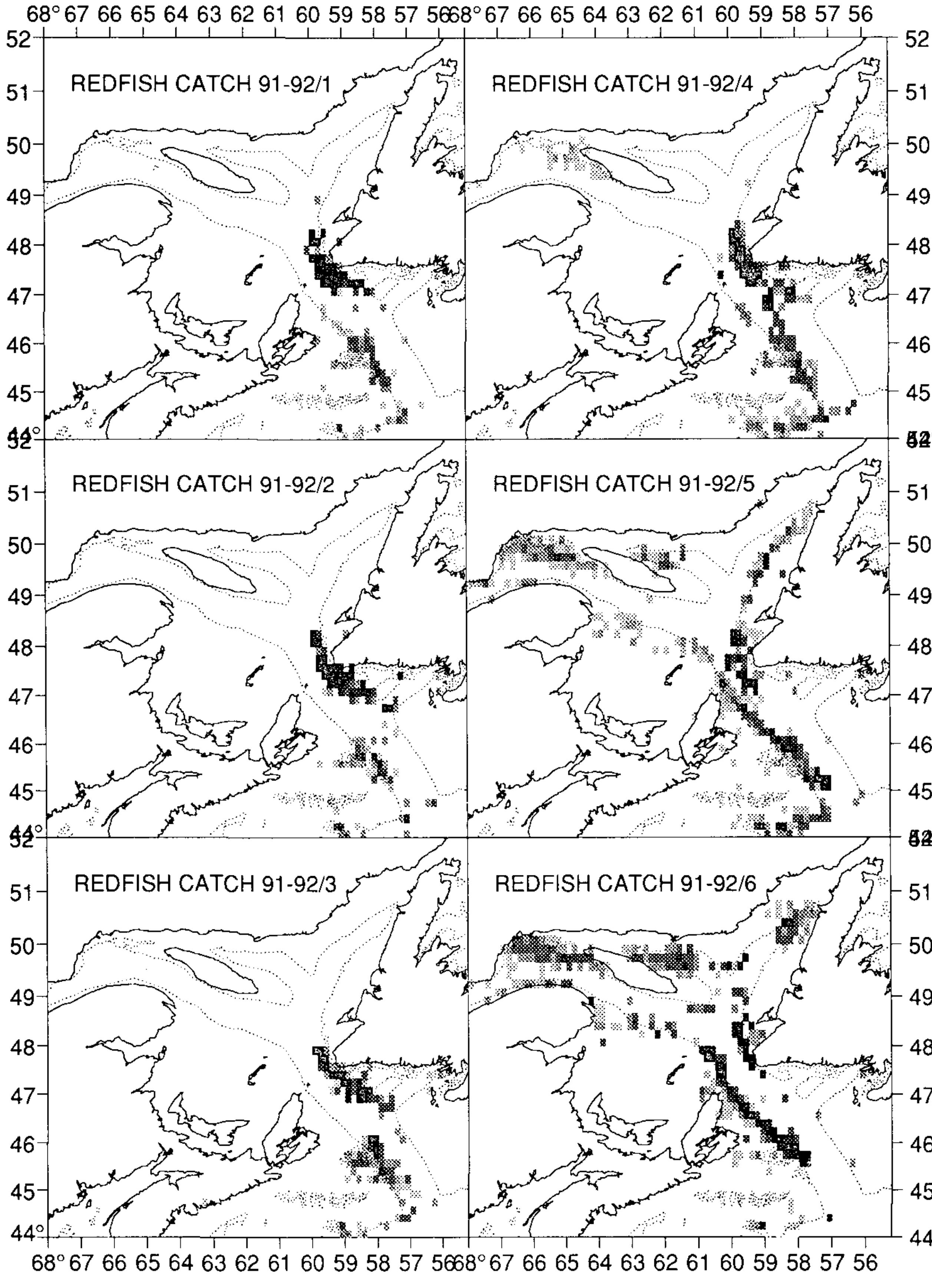

Figure 2: Redfish catches 1991-92. Shading intervals are 0.2, 1.5, 10, and 50 t.

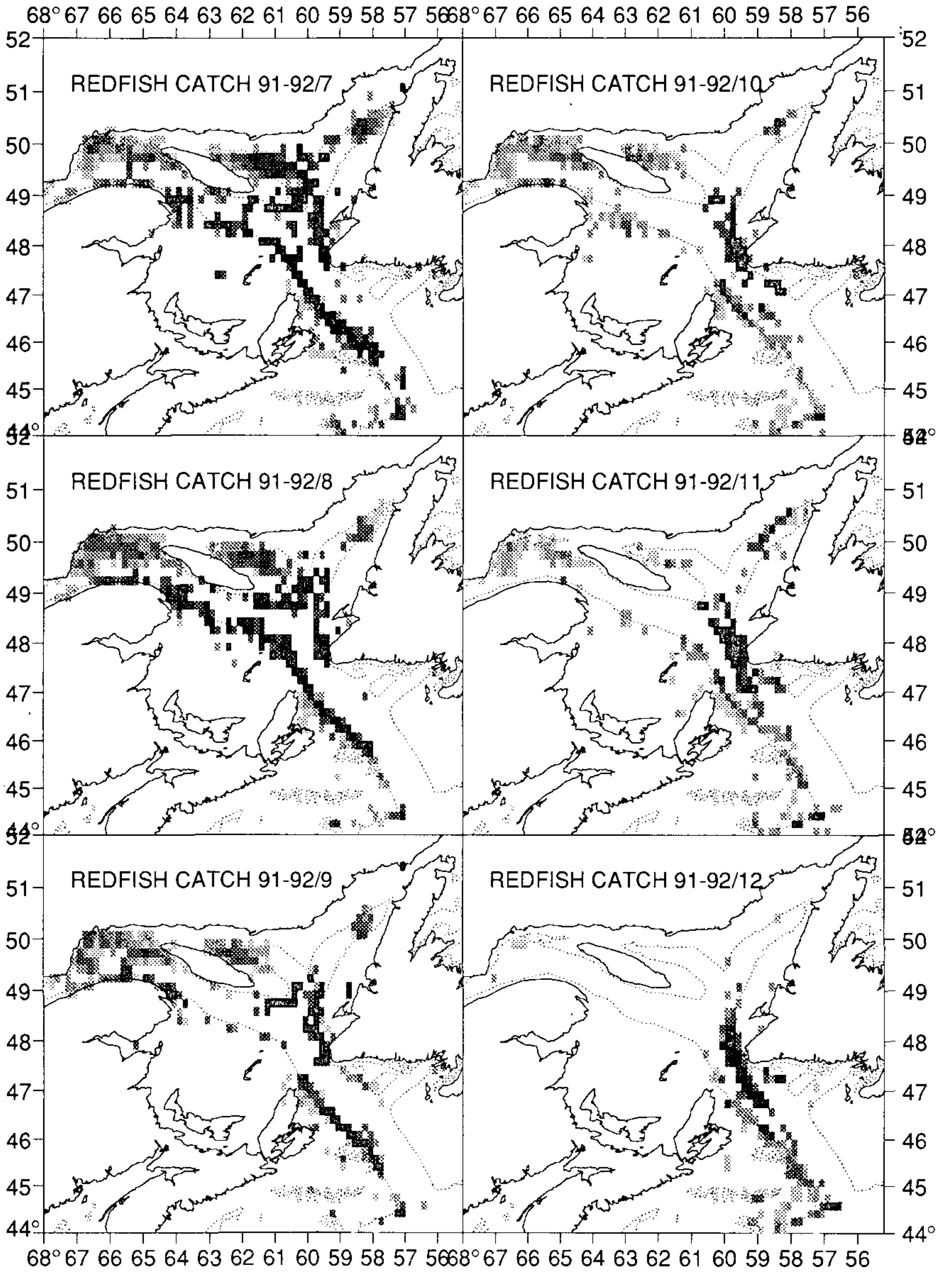

Figure 2: con't

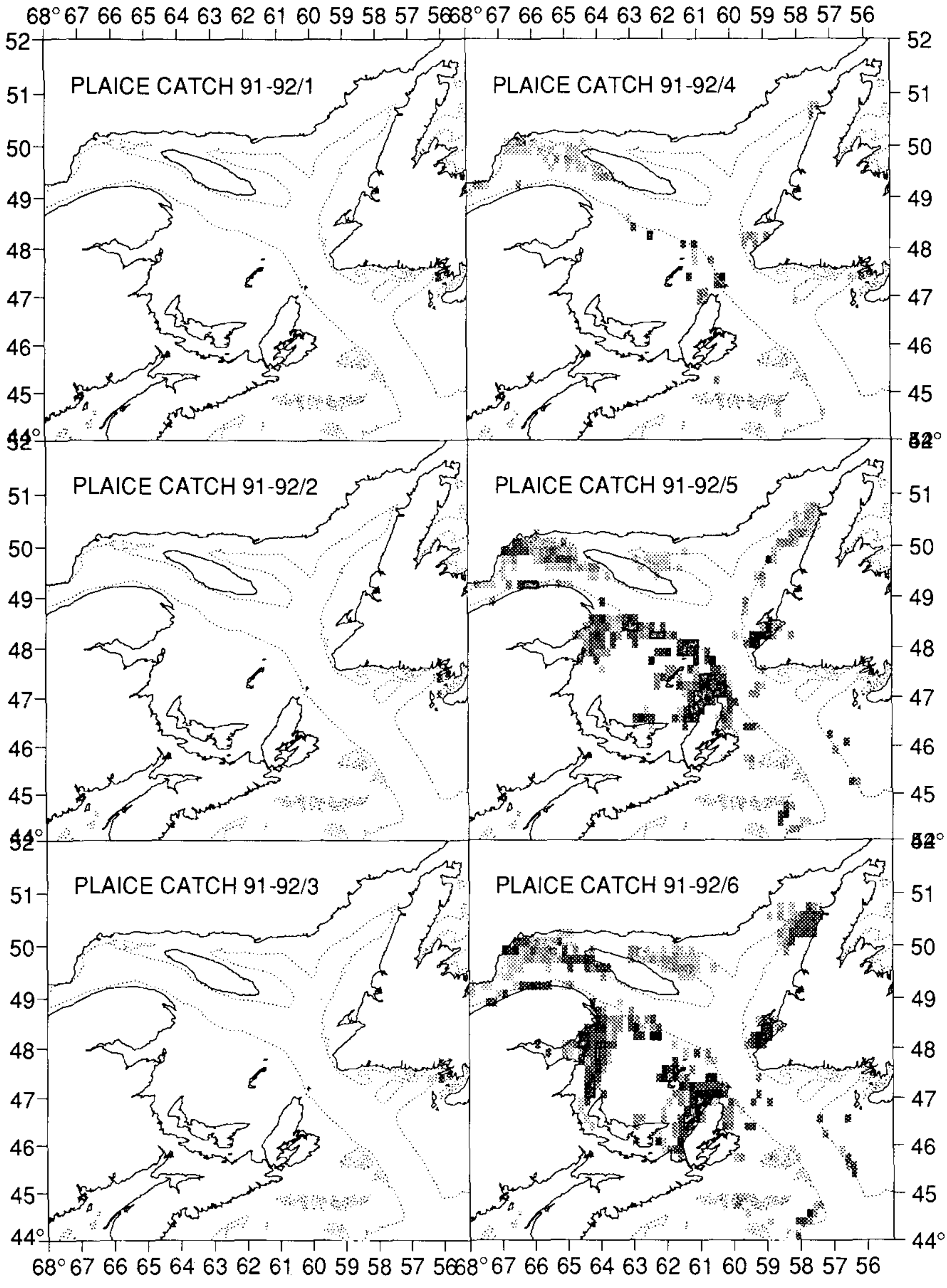

Figure 3: Plaice catches 1991-92. Shading intervals are 0.2, 1, 5, and 10 t.

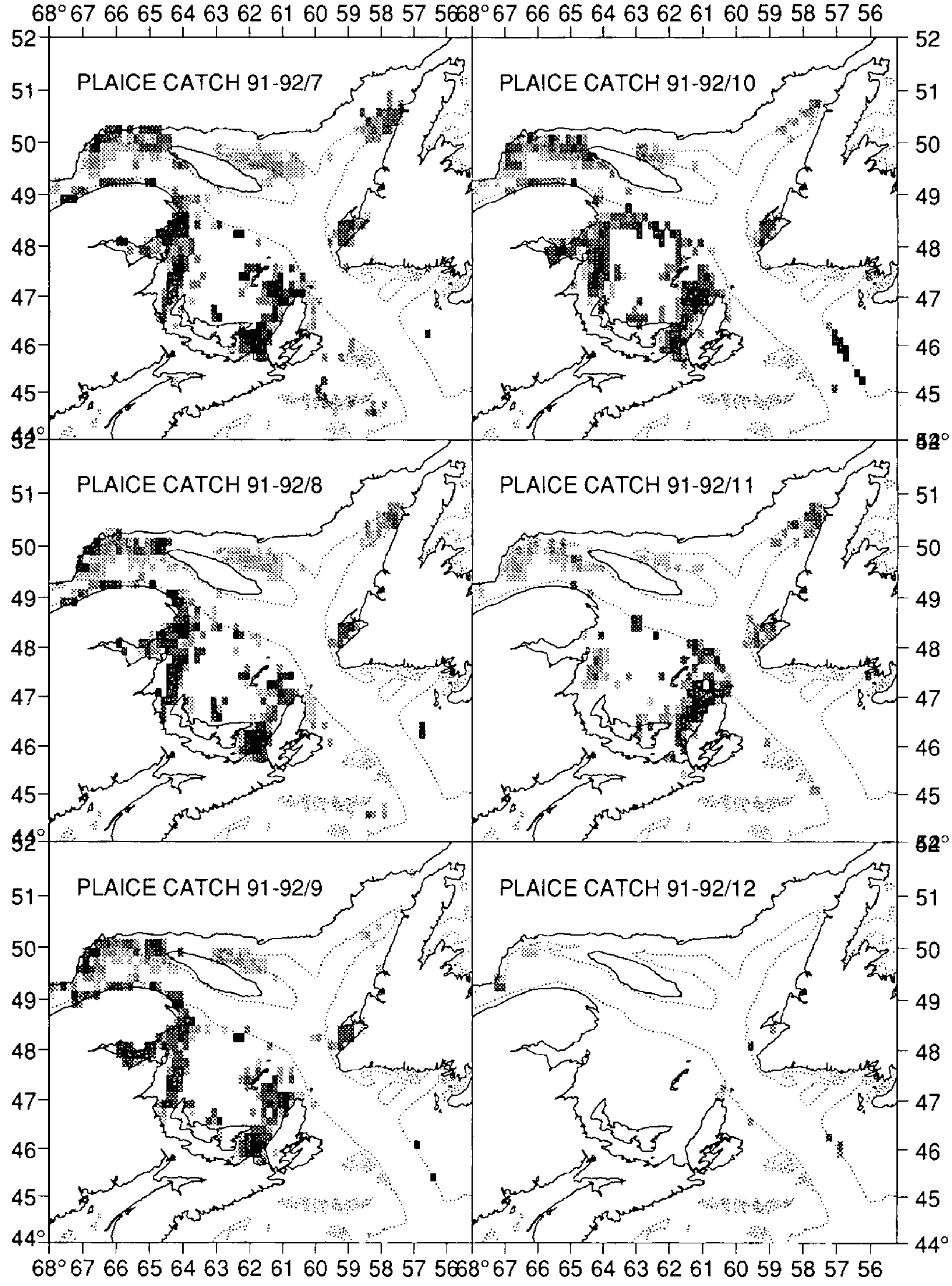

Figure 3: con't

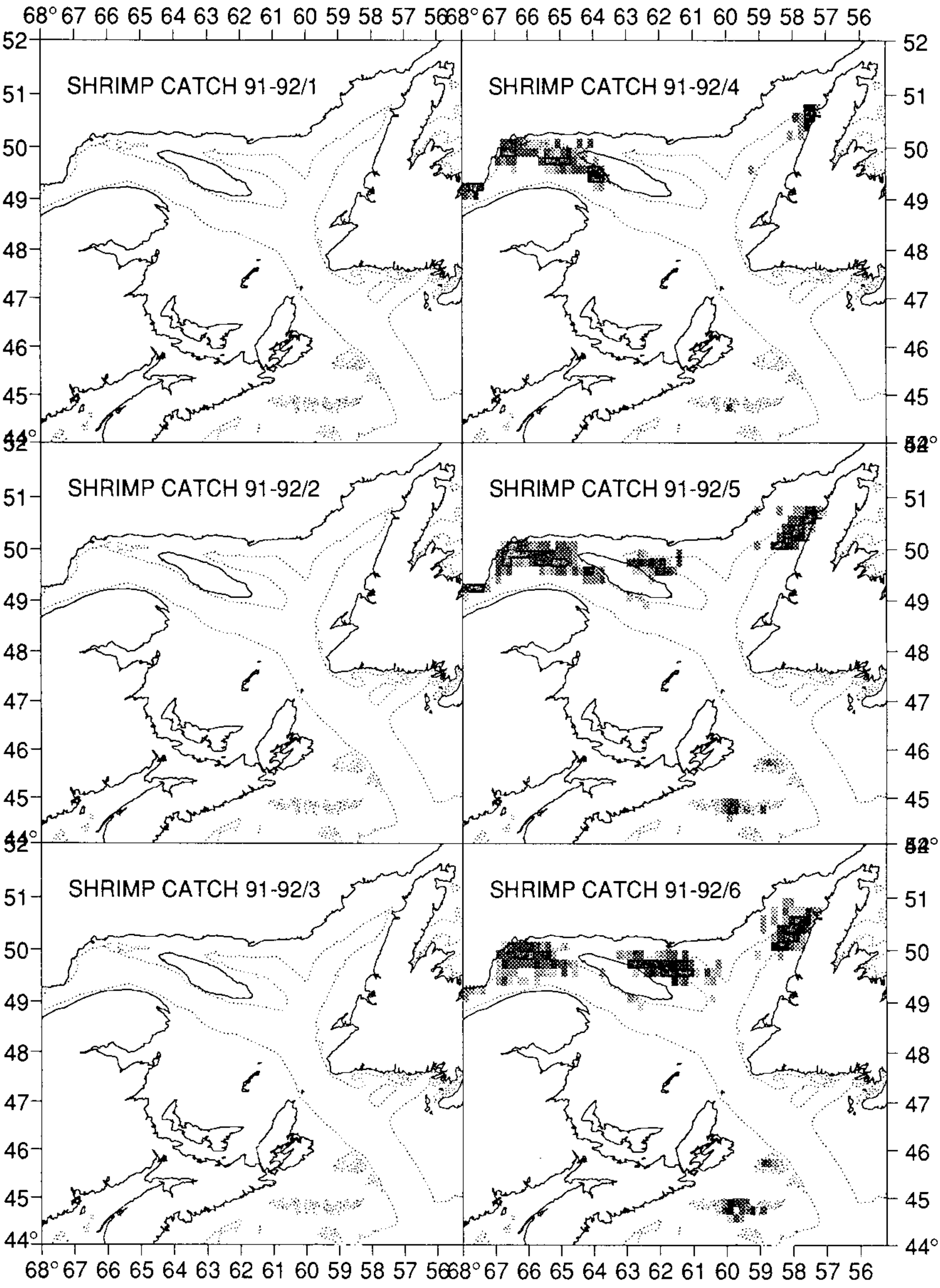

Figure 4: Shrimp catches 1991-92. Shading intervals are 2.5, 10, 30, and 75 t.

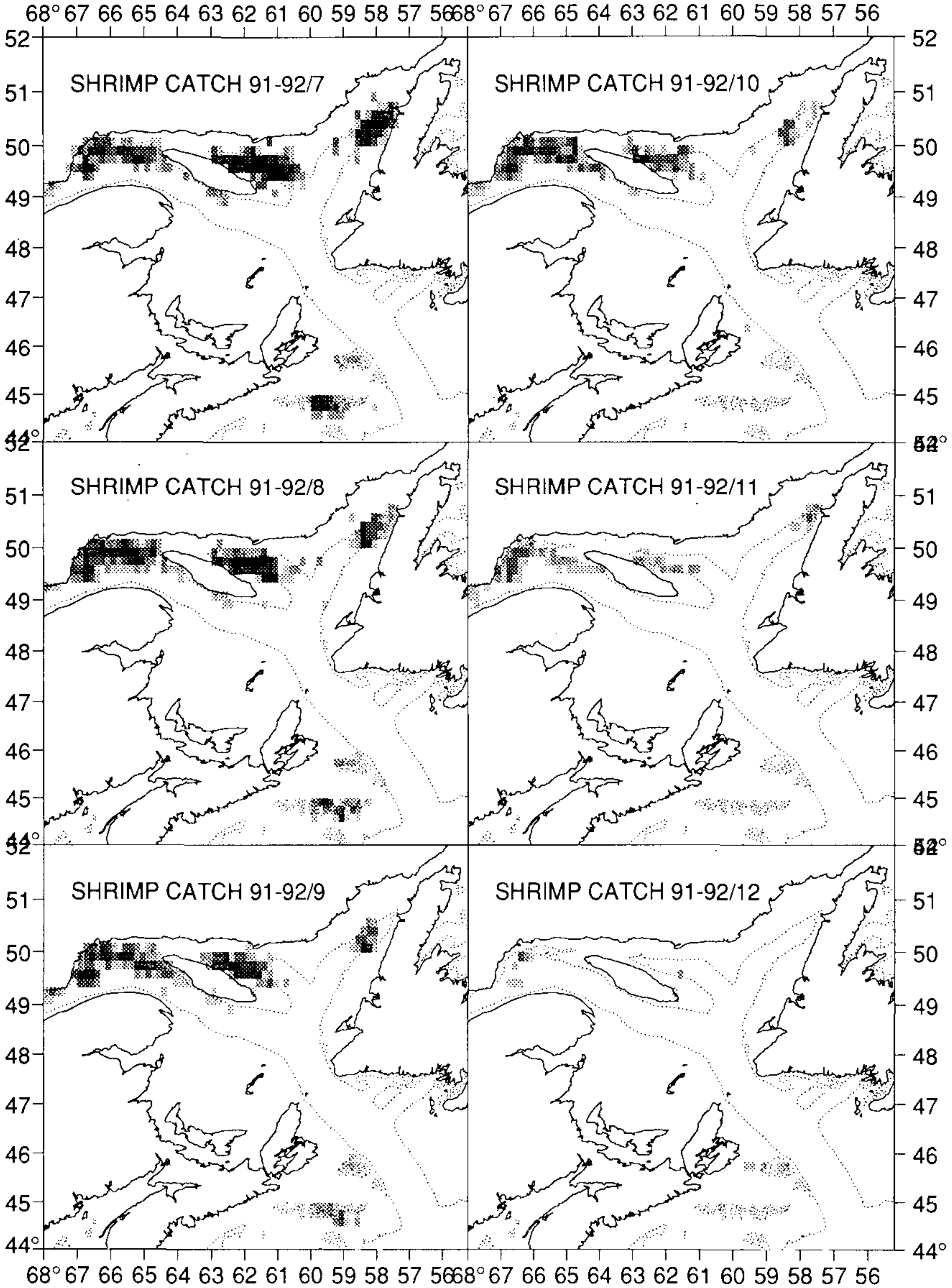

Figure 4: con't

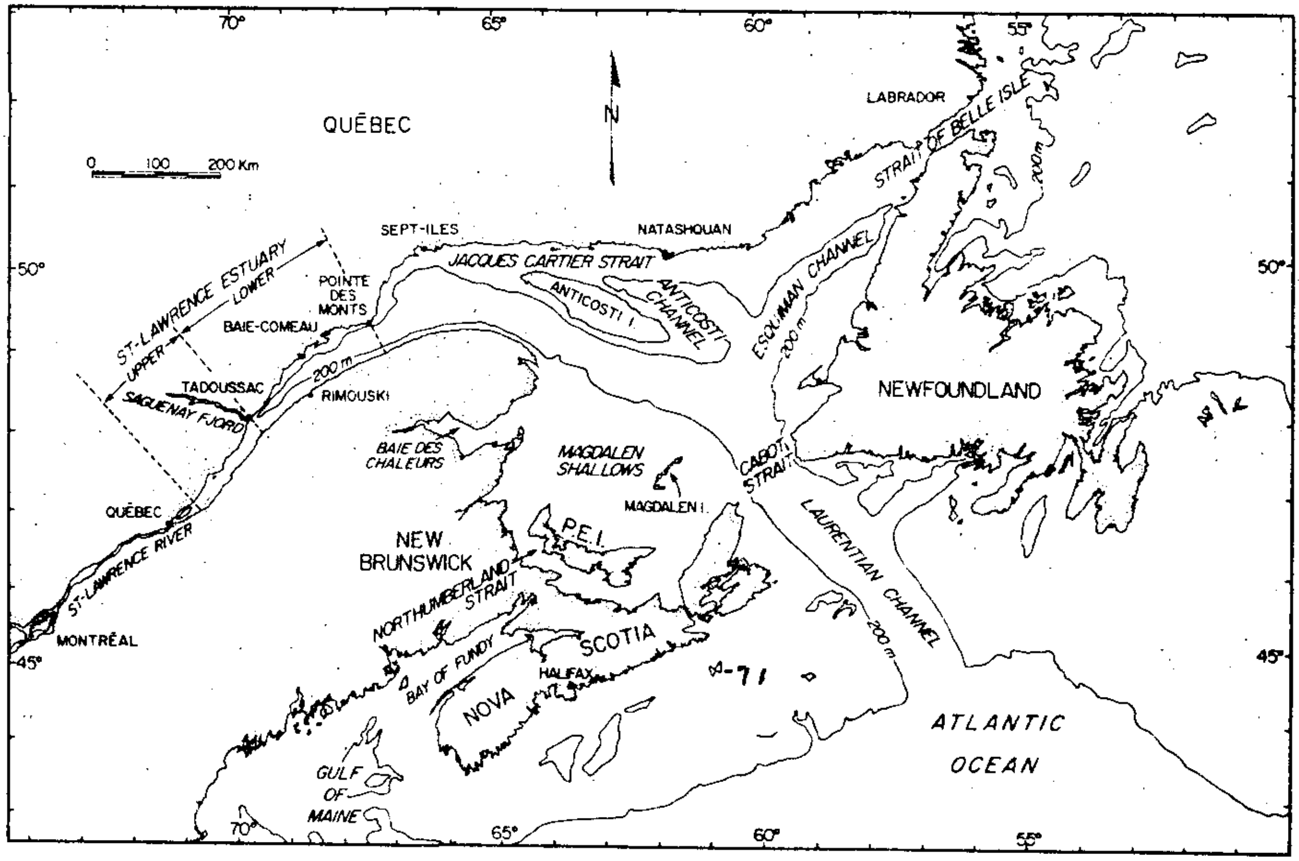

Figure 5. The Gulf of St. Lawrence (from Koutitonsky and Bugden 1991).

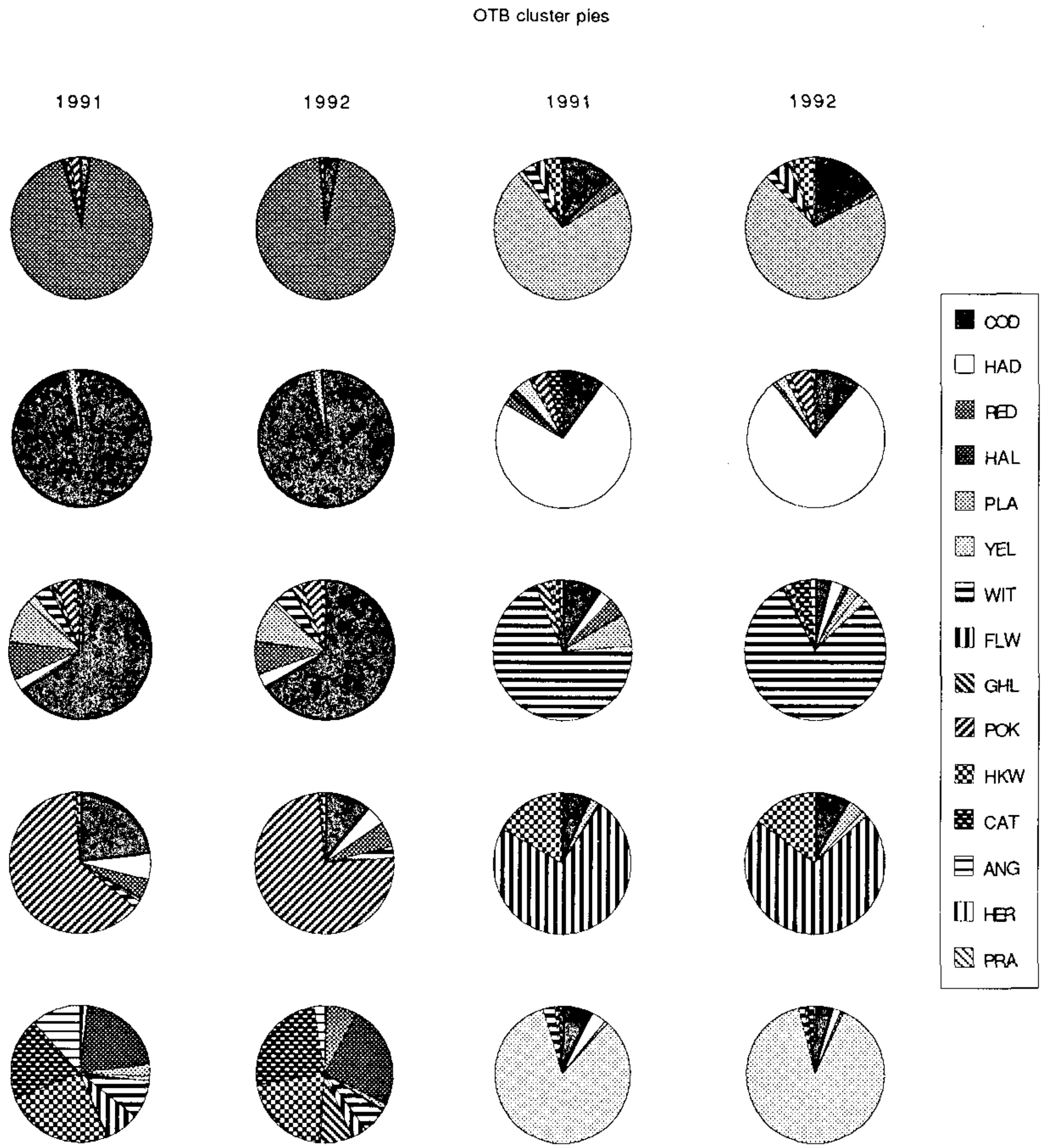

Figure 6: Catch composition of cluster groups from separate annual analyses of 1991-92 otter trawl catches. The main species in each group going down columns are: redfish, cod, cod mixed, pollock, mixed, plaice, haddock, witch, winter flounder, yellowtail.

SNU cluster pies

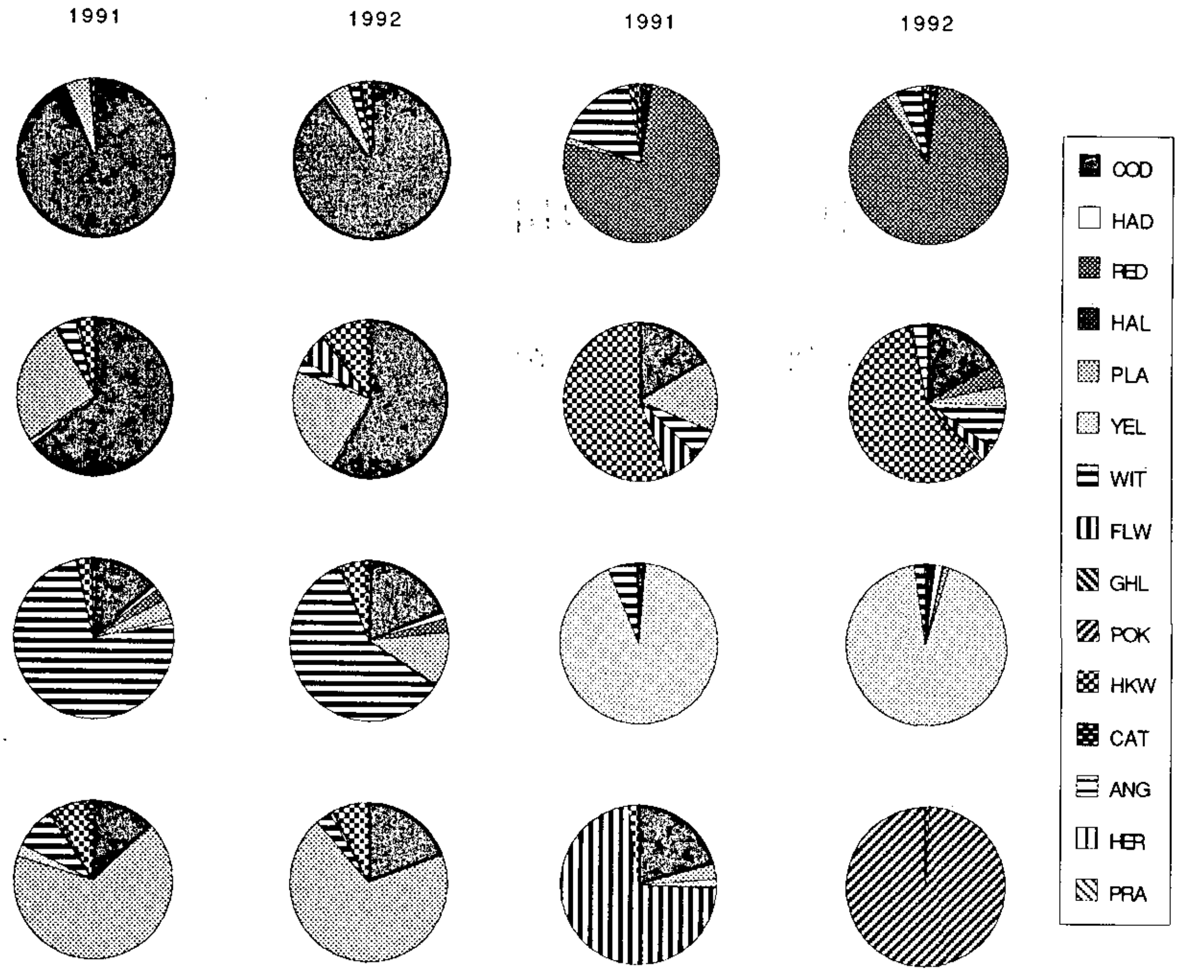

Figure 7: Catch composition of cluster groups from separate annual analyses of 1991-92 otter trawl catches. The main species in each group going down columns are: cod, cod mixed, witch,plaice,redfish,white hake, haddock, while the last group was winter flounder in 1991 and pollock in 1992.

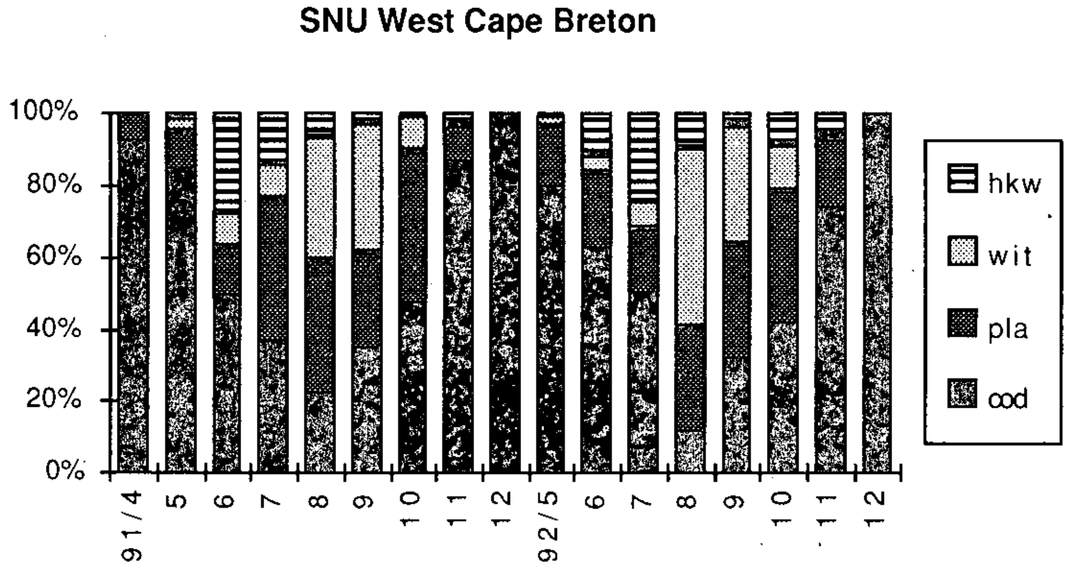

Figure 8: Monthly catch composition, 1991-92, for the seine fishery off western Cape Breton.

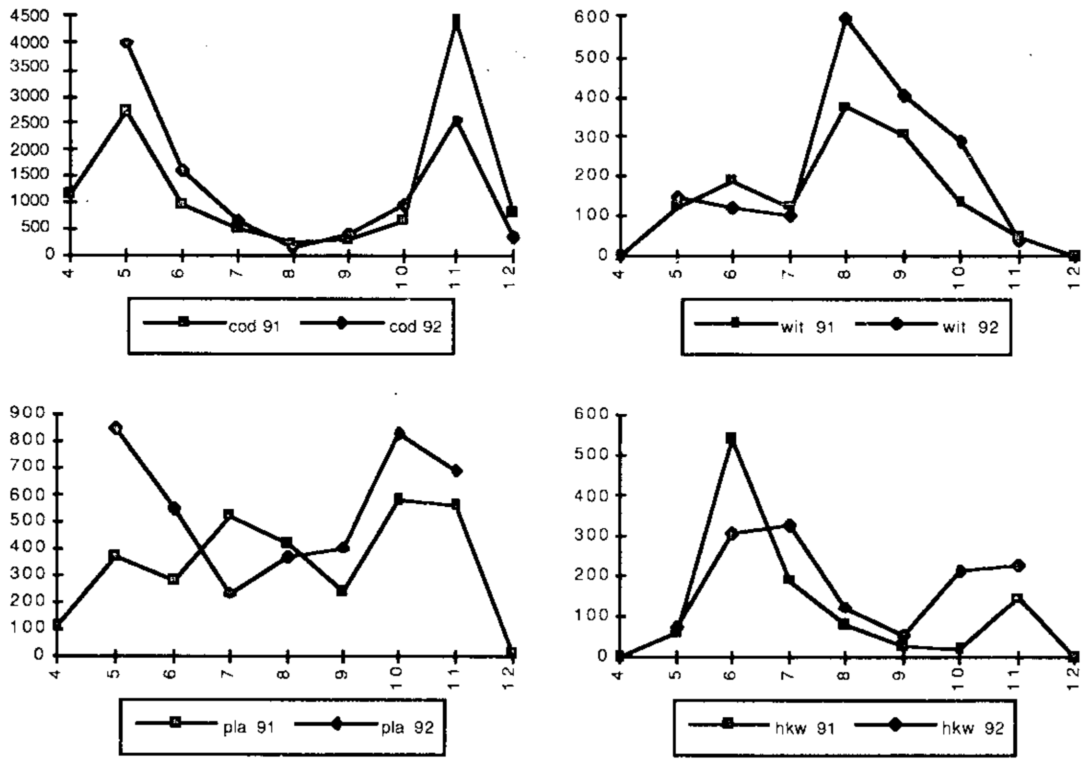

Figure 9: Monthly catch rates (kg/day) for cod, plaice, witch and white hake in the 1991-92 seine fisheries off western Cape Breton.

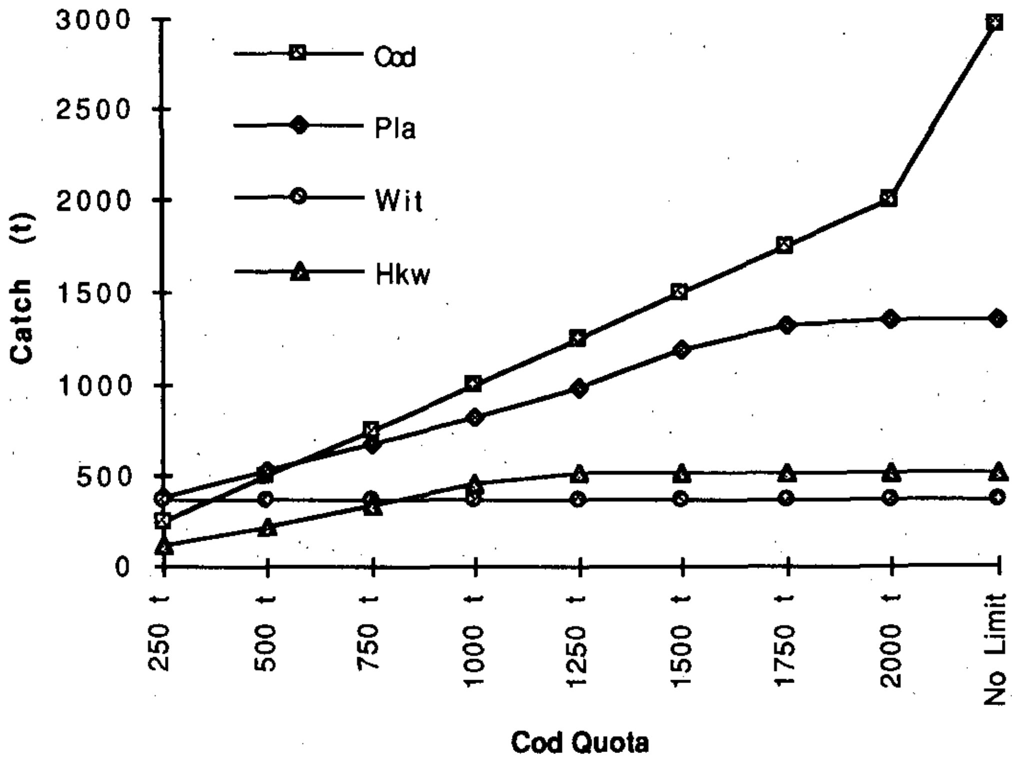

Figure 10. Catches of cod, plaice, witch, and white hake resulting from linear programming simulations of the seine fishery off western Cape Breton.