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Distribution of witch flounder (*Glyptocephalus cynoglossus* L.) and white hake (*Urophycis tenuis* M.) in the Gulf of St. Lawrence in relation to management units

by

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Abstract

In the Gulf of St. Lawrence, white hake is presently managed within NAFO (North Atlantic Fisheries Organization) Division 4T and the management unit for witch flounder is 4RS. The boundaries of the 4R, 4S and 4T divisions follow the axes of the Laurentian and Esquiman channels. Regression analyses based on data from summer groundfish surveys indicated that hake in the northern Gulf preferred depths of about 200 to 300 m. In winter, hake moved to deeper channel waters where their maximum abundance was at depths of 350 to 450 m. Distribution maps of the northern and southern Gulf indicated that hake concentrated during summer in areas east and west of Prince Edward Island, off northwestern Cape Breton, and on the southern slope of the Laurentian Channel. During winter, hake were distributed in the eastern part of the Laurentian Channel, uniformly across the 4RST boundaries and outside the Gulf into NAFO divisions 3Pn and 4Vn. Regression analyses on witch data from summer surveys of 4RS indicated depth preferences of approximately 210 to 310 m. In winter, witch abundance increased with depth as they sought the deepest channel waters of the eastern Gulf. Maps of the winter distribution of witch suggested that their distribution in the Gulf extended uniformly into 3Pn and 4Vn. These results contradict previous studies that differentiate 4RS and 3Pn witch on the basis of genetic and meristic characters. This study confirms previous investigations that suggest that the existing management units for white hake (4T) and witch flounder (4RS) do not circumscribe their seasonal distributions and therefore may not account for all removals from these stocks.

Résumé

Dans le Golfe du St-Laurent, les unités de gestion sont les divisions 4T de l'OPANA pour la merluche blanche et 4RS pour la plie grise. Les limites des divisions 4R, 4S et 4T correspondent aux axes des chenaux Laurentien et Esquiman. Des analyses de régression, basées sur les relevés estivaux des poissons de fond, indiquent que la merluche dans le nord du golfe préfère les profondeurs d'environ 200 à 300 m. En hiver, la merluche se déplace vers les eaux profondes des chenaux où l'abondance maximale est enregistrée aux profondeurs de 350 à 450 m. Les cartes de distribution des relevés du golfe en été indiquent des concentrations de merluche dans les secteurs à l'est et à l'ouest de l'Ile du Prince Édouard, au nord-ouest du Cap Breton, et sur la partie sud du chenal Laurentien. En hiver, la merluche se trouve dans la partie est du chenal Laurentien où elle se distribue à travers les limites de 4RST et à l'extérieur du golfe dans les divisions 3Pn et 4Vn. Les analyses de régression sur la plie grise lors des relevés d'été en 4RS indiquent que cette espèce préfère des profondeurs d'environ 210 à 310 m. En hiver, l'abondance de la plie grise augmente en relation avec la profondeur et les plies occupent l'eau profonde des chenaux dans l'est du golfe. Les cartes de distribution du golfe indiquent que la plie grise se distribue en hiver de façon continue avec le 3Pn et le 4Vn. Ces résultats contredisent des analyses génétiques et méristiques qui indiquent une séparation des stocks de plie grise entre 4RS et 3Pn. Cependant, notre étude confirme d'autres études qui indiquent que les unités de gestion pour la merluche blanche (4T) et la plie grise (4RS) ne correspondent pas aux limites de leur distributions saisonnières. En conséquence, les unités de gestion ne comptabilisent pas toutes les prises provenant de ces stocks.

Introduction

The management of fisheries requires knowledge of the stock structure of the resources being exploited. The practical difficulties of knowing the spatial limits of fish populations, and their seasonal distribution relative to commercial fishing fleets, often require defining management units in arbitrary ways. Management units in the Gulf of St. Lawrence were established in the 1960's by the International Commission for the Northwest Atlantic Fisheries (ICNAF) to reflect sectors bounded by the Laurentian and Esquiman channels. The three resulting divisions, 4R, 4S and 4T (Figure 1), correspond to hydrographic zones within the Gulf, each separated by deep channels that are potential barriers to fish movements.

The fishery for white hake in NAFO Division 4T has been the third most important groundfish resource in the southern Gulf of St. Lawrence. Landings have averaged about 5800 t annually since 1960, representing the most important fishery for this species in the NAFO convention area. Northern Gulf (4RS) landings of witch peaked in 1976 at 5341 t, but began to decline by the early 1980's. The fishery for witch flounder in 4RS began in the 1950's as a localized seiner fleet exploiting St. George's Bay off western Newfoundland. A winter fishery by otter trawlers developed during the 1960's in the Esquiman Channel.

Stock identity and the adequacy of management units have been longstanding issues for both of these resources in the Gulf of St. Lawrence. White hake in 4T comprise two stock components: a shallow southern component that occurs off the eastern and western coasts of Prince Edward Island (the "Strait" component); and an offshore component occupying the slope of the Laurentian channel (the "Channel" component)(Koeller and LeGresley 1981, Clay and Hurlbut 1989, Hurlbut 1990, Hurlbut and Clay 1990a). Scott (1981) suggested that the channel component may form a continuum with the concentrations of hake to the east, along the slope of the Laurentian Channel in 4Vn. Clay (1991) indicated that 4T hake probably mix with hake from the north in divisions 4R and 4S when they overwinter along the Laurentian Channel. Bowering (1978) questioned whether witch flounder fished in 4T off northern Cape Breton should be considered as part of the stocks managed within 4RS. Lafleur and Lussiaà-Berdou (1982) suggested that 4RS witch comprise two stocks and Tallman and Forest-Gallant (1991) noted significant catches of witch in research surveys at the boundary of 4RS and 4T.

The purpose of this study was to examine the adequacy of current Gulf management units for white hake and witch flounder based on research survey data. Ideally, management units should circumscribe the stock, defined by Larkin (1972) as a population sharing a common gene pool, sufficiently discrete to be considered as a self-perpetuating system that can be managed. The genetic component to this definition of the stock is not within the scope of this study. We address the ecological component, that of discreteness, by predicting that hake and witch should concentrate within appropriate management units. Since the boundaries of the management units in the Gulf of St. Lawrence correspond to deep zones, hake and witch should concentrate at intermediate depths, distant from the unit boundaries.

Methods

Data sources

Data for this study originated from groundfish surveys conducted by the Quebec and Gulf regions of the Department of Fisheries and Oceans (DFO). Survey designs are described in detail by Koeller (1981), Schwab and Hurtubise (1987), and Hurlbut and Clay (1990b). Since 1984, the Quebec Region has conducted annual surveys of 4RS in January and August. Groundfish surveys of the southern Gulf (4T) have been conducted every September since 1971. Most of these surveys were based on a stratified random survey design, with depth as the main stratifying variable. From 1984 to 1987, the Gulf Region surveyed 4T using a fixed station design with stations that were initially randomly selected. Although every effort was made to maintain common sampling procedures in the surveys, some changes were required as research vessels were changed or when the survey objectives were modified to cover other resources such as redfish and shrimp. Table 1 summarizes the important characteristics of the surveys that contributed to this study. Catches were standardized to a common tow distance of 1.75 NM.

Analysis of abundance-depth relation

To compare the depth distribution of fish of similar size, we first established size groupings that were common to summer and winter surveys. Stratified mean length frequencies of hake and witch from each survey were computed. Length frequencies varied between surveys (Table 2), partly due to differences in vessels and gear, so fish size could not be grouped similarly across all years. Size groups were instead standardized between each August survey and the following January survey by interpolating between the corresponding size quartiles. Three size groups were established based on the first quartile, the second and third quartiles combined, and the fourth quartile.

The abundance-depth relation was first examined graphically. Mean catch per standard tow was calculated in 10-m intervals for each species. These values were then smoothed across depths by a running average of three.

The abundance of each size group in relation to depth was analyzed separately for each survey by regressing the catch per unit of effort (CPUE) on the mean depth (m) of each tow. The analysis was performed using a Poisson regression model, described by Swain (1993) in a similar analysis of cod abundance in relation to hydrographic variables. The model used was of the form:

$$E[Y_i] = \mu_i = \exp(\beta_0 + \beta_1 X_i + \beta_2 X_i^2)$$

$$Var[Y_i] = \phi\mu_i$$

where Y_i is the number of fish of a given size group in tow *i* of a particular survey; X_i is the depth of tow *i*; β_o, β_1, β_2 are coefficients of the regression; and ϕ is a parameter for extra-Poisson variation. This probability model was chosen because the mean and variance tends to be positively related in survey data (Smith 1990, Swain 1993). Significant effects of depth on the abundance of hake and witch were tested by examining the change in scaled deviance in models with and without the tested depth terms (McCullagh and Nelder 1989). The overall effect of depth in the model was tested by removing both depth terms from the regression model. The X_i and X_i^2 terms were then removed separately to test the contribution of the linear and quadratic terms to the model.

Regressions with significant linear and quadratic terms ($P<0.05$) were then examined to determine the depth at which maximum abundance of fish occurs for that particular size group and survey. The depth of maximum CPUE was calculated from the derivative of the regression model set to zero ($f' = 0 = -\beta_1/2\beta_2$).

Analysis of seasonal change in geographical distribution

We describe the geographic distribution of witch and white hake in the Gulf of St. Lawrence during summer (combining August and September surveys) and during winter (January surveys). For comparability, ten summer surveys of the Lady Hammond (five DFO Gulf Region surveys and five Quebec Region surveys conducted between 1985 and 1989, all using a Western IIA trawl) were analyzed. Catches from three fixed-station surveys (Gulf Region) were incorporated in this analysis in order to include all of the available information on distribution. The analysis of winter distributions was limited to five surveys of the Quebec Region, conducted between 1986 and 1990 aboard the Gadus Atlantica. For these surveys, a Western IIA trawl was used for the years 1986-88 and an Engels-145 trawl was used for the years 1989-90.

Plots of the geographical distribution of witch and hake were made with ACON software (Version 7.14, Black 1993). The catches at individual stations were represented by expanding circles (kilograms per standard tow). The expanding circle plots for each species were scaled identically for all surveys.

Results

White hake

During August surveys, hake abundance consistently peaked in the 200 to 300-m depth range (Figure 2). The distribution of hake shifted in January to deeper water; however, peak abundance was less clearly defined and more variable across depth than during August surveys.

Poisson regression analyses of the hake abundance data generally supported the patterns observed in Figure 2. Of the 30 regression analyses performed (5 years, 3 size groups, 2 surveys per year), only two regressions failed to provide significant quadratic models (Table 3). Quadratic models accounted for between 10 and 29% of the total deviance in August surveys and 23-52% of total deviance in January surveys.

Hake tended to occupy deeper water in winter than in summer. The quadratic term accounted for most of the deviance in August surveys, whereas the linear term was stronger in January surveys (Table 4), indicating that hake tended to seek the deepest available waters in winter. The depth of maximum abundance, based on Poisson regressions with significant quadratic terms, was 200-300 m in summer and 350-450 m in winter (Table 7). Hake of smaller size tended to occupy slightly shallower depths.

During summer, white hake were found in 4T in areas east and west of PEI, off northwestern Cape Breton, and on slope water of the Laurentian channel between Quebec and Cape Breton, south of the 4T-4S boundary (Figure 3). Hake were seldom caught in the shallow, central zone adjacent to the Magdalen Islands. The distribution of hake across the 4R and 4S divisions appeared to be continuous. Coverage of 3Pn in summer surveys was restricted to one year (1987, Figure 3), but it suggested a continuous distribution with 4R hake to the north. In all of the summer surveys (1985-1989), most hake were caught in the 4T management unit. The winter surveys (Figure 4) indicated that hake occupy deep channel water in areas that correspond to channel boundaries. These data also suggested that hake increasingly occupy the eastern portion of the Gulf in winter and that their distribution is continuous with divisions outside of the Gulf, including 3Pn and possibly 4Vn (Figures 4 and 5).

Witch flounder

Mean catches of witch flounder in summer and winter surveys (Figure 6) indicated a marked difference in their seasonal distribution. In August, witch of all size groups occupied intermediate depths, usually 150-300 m. Witch of the first two size groups, but particularly the smallest group (<30 cm length), tended to peak in abundance in a second depth range, usually >400 m (years 1988-91, Figure 6). In winter, witch of the two larger size groups (>30 cm length) increased sharply in abundance with increasing depth (Figure 6).

Poisson regressions of witch abundance accounted for less of the total deviance during August than during January. Of the 15 regressions conducted on witch data from August surveys, three regressions were not significant ($P>0.05$), four regressions produced significant negative linear relations, and the remaining eight regressions were significant quadratic models (Table 5). Regressions based on January surveys of witch accounted for a larger part of the deviance. All of these regressions were significant; 10 of the 15 regressions conducted on January surveys accounted for >60% of the total deviance and nine regressions were linear relations. The strength of the quadratic term varied across the August surveys, tending to dominate in the latter three years (1990-92) of the surveys that we examined (Table 6). The linear term clearly accounted for the largest part of the total deviance in all but one of the regressions conducted on the January survey data (Table 6).

Witch occupied deeper water in winter than in summer (Table 7). The August surveys resulted in few regressions with significant quadratic terms. These indicated a depth of maximum witch abundance at roughly 210-310 m (Table 7); however, four of the 15 regressions resulted in significant linear models with negative slopes. In winter, witch clearly preferred the deepest available water, evidenced by the number of significant linear models with positive slope (Table 7).

Distribution maps of witch flounder during summer surveys indicated concentrations in 4S west of Anticosti Island, in western 4T and throughout the Laurentian Channel, north and west of Cape Breton, and in northern 4R (Figure 7). Some of these concentrations were centred within NAFO divisions; however, the distribution maps generally indicated that the summer distribution of witch was dispersed across the boundaries of management units. The summer surveys also suggest that witch in 4T were of a similar magnitude of abundance to witch in the 4RS management unit. During winter, witch tended to occupy channel waters coincident with the 4RST boundaries (Figure 8). Witch appeared to be distributed uniformly into 3Pn in winter. The January 1994 survey results suggest that witch may be found continuously on both sides of the channel, extending into 4Vn (Figure 9).

Discussion

The results of this study indicate that the current Gulf management units do not circumscribe the seasonal distributions of white hake and witch flounder. Both species appeared to occupy the deeper, eastern portion of the Gulf in winter and their distributions were continuous with NAFO divisions outside of the Gulf, including 3Pn and 4Vn.

White hake

Our observation that white hake in the Gulf of St. Lawrence select deeper water in winter is consistent with other studies. Clay (1991) inferred the annual migration of white hake in the southern Gulf from six seasonal surveys of the area conducted between September 1986 and September 1987. His analysis indicated that as the shallow waters of the southern Gulf cool in the fall, the inshore ("strait") component, which had been acclimated to warmer waters, migrates to the deep (> 200 m), relatively warm water of the Laurentian Channel. He suggested that this is the probable overwintering area for three groups of white hake: strait and channel stock components from the southern Gulf and hake from the northern Gulf (NAFO divisions 4R and 4S).

In a limited tagging study of white hake conducted off eastern Prince Edward Island, Kohler (1971) documented a similar movement of fish from the inshore component, out of the shallows in winter to the deeper, warmer slope waters of the Laurentian Channel. His data indicated that at least a portion of the fish from the inshore component returned, although substantial mixing could have occurred with both the channel component and hake from the northern Gulf (Clay and Hurlbut 1989). It should be noted that no fish from the Laurentian Channel or outside the Gulf were tagged in Kohler's study.

The definition of management units may be further complicated by complex stock structure, as appears to be the case in Gulf white hake. Hurlbut (1990) and Hurlbut and Clay (1990a) conducted an analysis of morphological characters of 4T white hake that confirmed the identity of the strait and channel components of southern Gulf hake and questioned the validity of this management unit. A subsequent preliminary study using protein electrophoresis, however failed to demonstrate genetic differences between these two components, possibly due to inadequate numbers of polymorphic loci (Clay et al. 1992).

Hake migrating from the southern Gulf to overwinter along the Laurentian Channel and outside NAFO Division 4T may be vulnerable to harvest in a mixed fishery with hake by-catch, occurring in the northern Gulf and beyond (divisions 4R, 4S, 3Pn and possibly 4Vn). In response to this concern, Clay and Hurlbut (1990) explored the potential for such a differential exploitation of 4T hake by estimating the proportion of landings that could be attributed to the strait and channel components and by examining the catches of hake in neighbouring areas/divisions. Their analysis revealed the following:

1. Of the total landings attributed to 4T, the majority (83-89%) come from unit areas that represent only the inshore strait component; most of the remainder were composed of strait component fish from unit areas that overlap deep and shallow water areas.

2. Landings from the southern Gulf fishery were an order of magnitude greater than the sum of those in the surrounding Divisions 4R and 4S and sub-divisions 3Pn and 4Vn.

3. The International Observer Program data showed no large scale discarding of white hake from the deep water fisheries of the Laurentian or Esquiman channels.

Witch flounder

Our analyses of the seasonal distribution of witch flounder in the Gulf of St. Lawrence partly confirm other studies. Powles and Kohler (1970) noted significant movements of witch from their summer distribution on the Scotian Shelf to wintering sites located offshore in slope waters. Although they considered that most witch in the Gulf of St. Lawrence wintered in nearby channels, they also suggested possible overwintering movements outside of the Gulf. Bowering and Brodie (1984) reviewed data from surveys between 1976 and 1981 in the Gulf of St. Lawrence. They observed winter concentrations of witch flounder in the lower Esquiman Channel and the eastern Laurentian Channel, but discounted the possibility of movements outside of the Gulf, as reported by Powles and Kohler (1970), due to the effects of seasonal changes in availability.

Powles and Kohler (1970) proposed a model of the life cycle of witch flounder with spatially segregated life stages. Juvenile witch (10-30 cm) were proposed to occupy deeper waters than adult stages during the summer. This pattern was supported elsewhere by Markle (1975); however, Walsh (1987) suggested that the pattern observed by Powles and Kohler (1970) was biased due to gear selectivity and the depth of sampling. Our results suggest that the smallest size group of witch (<30 cm) tended to peak at greater depths than larger size groups (Figure 6).

Overwintering witch in 4RS have been described by Bowering and Brodie (1984) as pre-spawning concentrations. Biochemical analyses of the witch stocks (Fairbairn 1981) indicate considerable differentiation, including separation between 4RS and 3Pn witch collected during winter surveys. Similar stock differentiation has been found based on meristic characters (Bowering and Misra 1982).

Distributional data are useful in defining management units; however, they should be used in concert with biological data, including the analysis of heritable traits. Further analyses are required that incorporate the distribution of juvenile and maturing life stages, stock components, as well as fleet dynamics. For white hake, witch and other species which exhibit a continuous distribution between the Gulf of St. Lawrence (4RST) and Cabot Strait (3Pn and 4Vn), the existing management units may not account for all catches from these stocks.

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Table 1. Details of the research surveys included in this study.
Abbreviations for trawl types: WIIA - Western IIA; E-145 - Engels 145;
U.R.I. - University of Rhode Island.

Year	Month	Research Vessel	Mission #	DFO Region	Trawl Type	Survey Design
1985	Aug.	Lady Hammond	H140	Que.	WIIA	Random
1985	Sept.	Lady Hammond	H141	Gulf	WIIA	Fixed (Initially Randomly Selected)
1986	Aug.	Lady Hammond	H158	Que.	WIIA	Random
1986	Sept.	Lady Hammond	H159	Gulf	WIIA	Fixed (Initially Randomly Selected)
1987	Aug.	Lady Hammond	H177	Que.	WIIA	Random
1987	Sept.	Lady Hammond	H179	Gulf	WIIA	Fixed (Initially Randomly Selected)
1988	Jan.	Gadus Atlantica	G148	Que.	WIIA	Random
1988	Aug.	Lady Hammond	H188	Que.	WIIA	Random
1988	Sept.	Lady Hammond	H192	Gulf	WIIA	Random
1989	Jan.	Gadus Atlantica	G162	Que.	E-145	Random
1989	Aug.	Lady Hammond	H203	Que.	WIIA	Random
1989	Sept.	Lady Hammond	H204	Gulf	WIIA	Random
1990	Jan.	Gadus Atlantica	G177	Que.	E-145	Random
1990	Aug.	Alfred Needler	N141	Que.	WIIA	Random
1991	Jan.	Gadus Atlantica	G194	Que.	E-145	Random
1991	Aug.	Alfred Needler	N155	Que.	U.R.I.	Random
1992	Jan.	Gadus Atlantica	G211	Que.	E-145	Random
1992	Aug.	Alfred Needler	N177	Que.	U.R.I.	Random
1993	Jan.	Gadus Atlantica	G227	Que.	E-145	Random
1994	Jan.	Alfred Needler	N197	Gulf	WIIA	Random

Table 2. Length categories (cm) of hake and witch from surveys conducted by the Quebec Region. Abbreviations for Vessels: LH - *Lady Hammond*; AN - *Alfred Needler*; GA - *Gadus Atlanticus.*

Species	Vessel	Year	Min	Quartiles 25%	50%	75%	Max
Hake	LH	1988	23	40	47	55	94
		1989	23	38	45	54	80
	AN	1990	22	34	40	48	80
		1991	18	32	40	46	78
		1992	26	36	44	52	66
		1993	24	36	42	46	64
	GA	1987	24	40	48	57	99
		1988	16	25	36	48	87
		1989	20	35	38	43	57
		1990	19	30	40	51	81
		1991	16	27	38	48	79
		1992	20	38	40	46	88
		1993	20	30	36	40	70
Witch	LH	1988	9	29	34	38	58
		1989	9	31	35	40	55
	AN	1990	8	18	28	36	58
		1991	8	18	24	32	60
		1992	8	22	26	36	50
		1993	8	20	26	28	52
	GA	1987	11	34	39	45	69
		1988	11	34	38	45	62
		1989	9	33	37	43	60
		1990	15	33	38	43	59
		1991	6	31	36	42	65
		1992	12	36	40	44	60
		1993	14	32	38	42	58

Table 3. Coefficients of Poisson regression models (above), and corresponding standard errors (below), relating white hake CPUE to depth (m). Regression models include intercept (β_o), linear (β_1) and quadratic (β_2) terms, with percent of total deviance accounted for by the model. Hake from August surveys and corresponding following January survey were divided into length intervals as indicated. NS: not significant (P >0.05).

	Size	August survey				January survey			
Year	Group (cm)	β_o	β_1	β_2	% Dev	β_o	β_1	β_2	% Dev
1988-89	<39	-12.150 0.1175	0.1175 0.0244	-2.567e-04 5.295e-05	23	-10.890 3.3400	0.0513 0.0196	-6.140e-05 2.787e-05	23
	39-48	-5.139 1.6420	0.0573 0.0142	-1.222e-04 3.000e-05	15	-21.770 5.5870	0.1218 0.0334	-1.709e-04 4.880e-05	25
	>48	-7.403 1.7770	0.0713 0.0142	-1.390e-04 2.797e-05	22	-20.980 5.4430	0.1191 0.0324	-1.654e-04 4.706e-05	26
1989-90	<35	-15.840 3.4710	0.1391 0.0283	-2.850e-04 5.734e-05	29	-13.390 3.1080	0.0718 0.0178	-9.518e-05 2.468e-05	28
	35-52	-8.876 2.0930	0.0877 0.0167	-1.736e-04 3.261e-05	28	-7.983 2.2050	0.0402 0.0129	-4.902e-05 1.804e-05	23
	>52	-6.811 1.9640	0.0621 0.0152	-1.190e-04 2.883e-05	16	-12.490 3.3550	0.0608 0.0183	-7.190e-05 2.441e-05	32
1990-91	<33	-4.749 1.6160	0.0416 0.0122	-7.950e-05 2.254e-05	10	-10.310 3.1620	0.0497 0.0175	-5.884e-05 2.355e-05	23
	33-47	-3.470 1.3780	0.0366 0.0098	-6.320e-05 1.693e-05	10	-16.170 3.3570	0.0792 0.0174	-9.225e-05 2.213e-05	48
	>47	-7.127 1.8910	0.0613 0.0139	-1.126e-04 2.527e-05	16	-18.040 3.7320	0.0936 0.0195	-1.136e-04 2.506e-05	45
1991-92	<36	-8.016 2.4620	0.0734 0.0192	-1.417e-04 3.674e-05	14	-22.010 6.5240	0.1264 0.0352	-1.697e-04 4.665e-05	27
	36-45	-4.668 1.4030	0.0391 0.0101	-6.360e-05 1.774e-05	13	-17.730 4.9750	0.0946 0.0258	-1.179e-04 3.291e-05	30
	>45	-8.137 1.7860	0.0631 0.0130	-1.085e-04 2.315e-05	21	-28.920 5.5840	0.1465 0.0276	-1.750e-04 3.375e-05	52
1992-93	<24	-10.430 0.8361	0.0205 0.0195	NS	37	-4.918 0.8208	0.0056 0.0021	NS	6
	24-45	-7.045 1.8770	0.0642 0.0141	-1.161e-04 2.627e-05	19	-16.270 3.8750	0.0777 0.0197	-8.745e-05 2.470e-05	43
	>45	-7.399 1.6400	0.0596 0.0125	-1.091e-04 2.346e-05	20	-39.260 8.4460	0.1851 0.0408	-2.141e-04 4.898e-05	47

Table 4. The percent contribution of linear and quadratic terms to total deviance in Poisson regressions of hake CPUE on depth. Size groups correspond to ordered length groups shown in Table 2.

Year	Size Group	August survey Linear	August survey Quadratic	January survey Linear	January survey Quadratic
1988-89	1	1.6	21.1	18.5	4.4
	2	1.4	13.8	10.2	14.9
	3	0.1	22.1	11.4	14.4
1989-90	1	1.5	27.4	13.3	14.9
	2	1.1	26.6	16.6	6.2
	3	0.3	15.6	24.3	7.3
1990-91	1	0.5	9.2	17.1	5.5
	2	0.1	9.5	36.4	11.7
	3	0.1	16.0	28.8	15.8
1991-92	1	0.5	13.3	4.2	22.7
	2	4.5	8.2	13.7	16.7
	3	4.4	16.2	27.1	24.4
1992-93	1	36.5	0.3	5.6	0.6
	2	3.7	15.0	35.3	7.8
	3	3.6	15.9	33.6	13.8

Table 5. Coefficients of Poisson regression models (above), and corresponding standard errors (below), relating witch flounder CPUE to depth (m). Regression models include intercept (β_o), linear (β_1) and quadratic (β_2) terms, with percent of total deviance accounted for by the model. Witch from August surveys and corresponding following January survey were divided into length intervals as indicated. NS: not significant (P >0.05).

	Size	August survey				January survey			
Year	Group (cm)	β_o	β_1	β_2	% Dev	β_o	β_1	β_2	% Dev
1988-89	<33	NS	NS	NS		-1.267 0.4051	0.0068 0.0011	NS	23
	33-41	2.232 0.2318	-0.0039 0.0009	NS	8	-3.363 0.4699	0.0138 0.0011	NS	62
	>41	1.200 0.2643	-0.0042 0.0011	NS	7	-5.096 0.5692	0.0168 0.0013	NS	67
1989-90	<33	NS	NS	NS		-1.891 0.4408	-0.0081 0.0011	NS	33
	33-41	1.627 0.3088	-0.0035 0.0012	NS	5	-6.710 1.8390	0.0322 0.0097	-2.542e-05 1.246e-05	70
	>41	0.971 0.3738	-0.0054 0.0016	NS	7	-4.454 0.5457	0.0146 0.0012	NS	66
1990-91	<26	-5.577 1.8370	0.0486 0.0125	-7.887e-05 2.073e-05	12	-6.938 2.7240	0.0405 0.0166	-5.687e-05 2.426e-05	8
	26-38	NS	NS	NS		-2.878 0.5182	0.0124 0.0012	NS	61
	>38	-1.295 1.165	0.0157 0.0093	-3.719e-05 1.805e-05	6	-4.919 0.0169	0.0169 0.0014	NS	72
1991-92	<28	-2.379 1.1460	0.0343 0.0090	-6.469e-05 1.739e-05	10	-8.040 2.4560	0.0407 0.0137	-5.072e-05 1.856e-05	18
	28-37	-4.295 1.3910	0.0421 0.0108	-7.972e-05 2.080e-05	11	-10.210 3.167	0.0471 0.0151	-4.139e-05 1.781e-05	66
	>37	-3.749 1.1670	0.0346 0.0093	-6.674e-05 1.812e-05	9	-9.250 3.2550	0.0425 0.0153	-3.346e-05 1.789e-05	69
1992-93	<28	-9.485 2.7750	0.0753 0.0193	-1.233e-04 3.315e-05	19	-6.285 2.0990	0.0295 0.0119	-3.227e-05 1.626e-05	19
	28-38	-4.010 1.1990	0.0435 0.0106	-9.486e-05 2.307e-05	11	-5.026 0.4773	0.0162 0.0011	NS	76
	>38	-12.830 4.3870	0.1050 0.0331	-1.959e-04 6.185e-05	12	-6.939 0.6451	0.0201 0.0014	NS	75

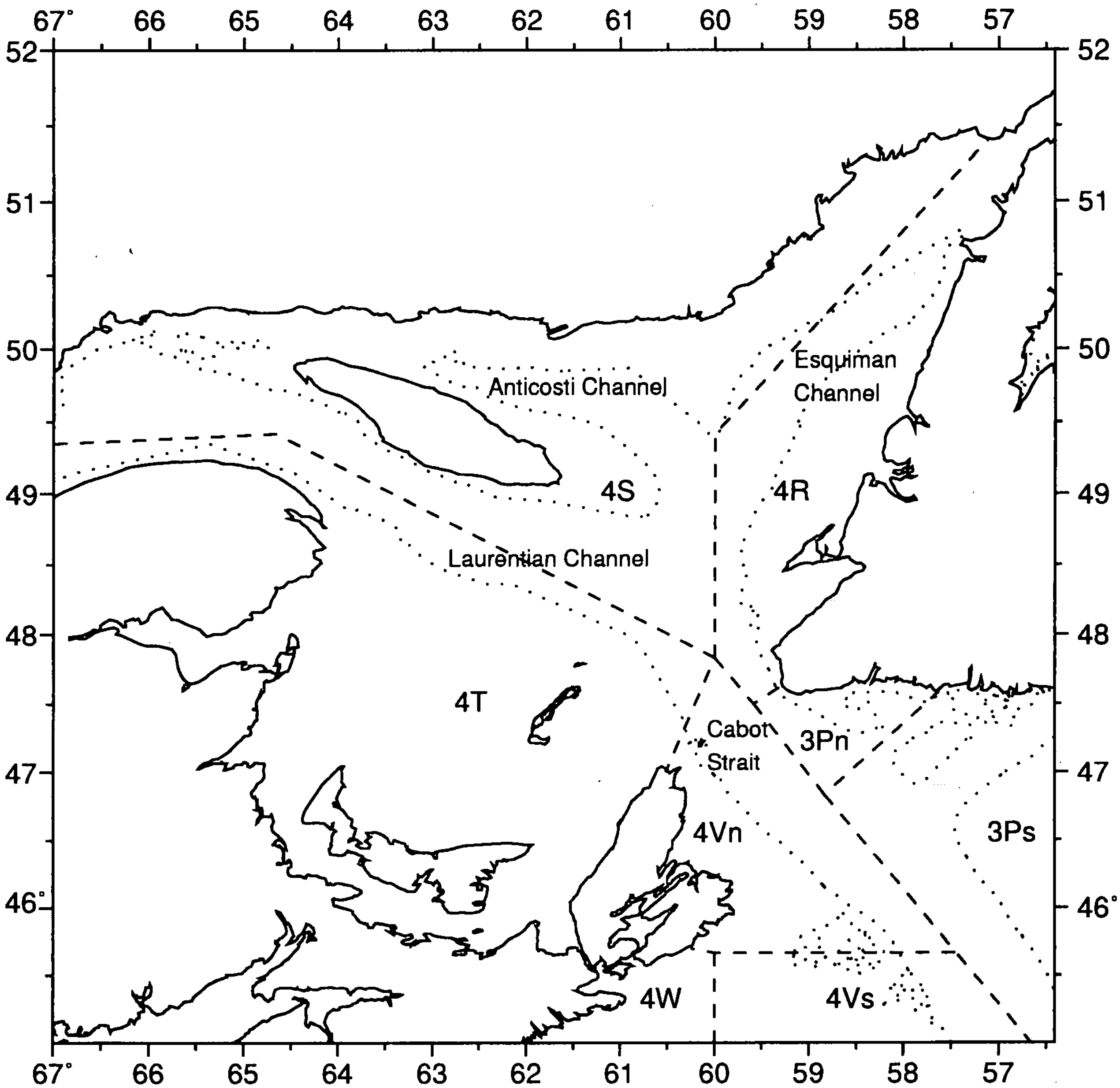
Table 6. The percent contribution of linear and quadratic terms to total deviance in Poisson regressions of witch CPUE on depth. Size groups correspond to length intervals shown in Table 2.

	Size	August survey		January survey	
Year	Group	Linear	Quadratic	Linear	Quadratic
1988-89	1	1.2	0.2	23.3	4.3
	2	8.2	1.4	62.0	0.4
	3	7.4	0.2	66.5	0.8
1989-90	1	0.2	0.5	33.2	1.9
	2	5.2	2.1	65.6	1.3
	3	7.4	0.0	66.0	0.8
1990-91	1	1.1	10.5	2.0	5.8
	2	1.3	0.6	61.4	0.2
	3	2.9	2.7	71.7	0.0
1991-92	1	0.8	8.7	10.3	7.8
	2	0.8	10.1	63.1	2.3
	3	0.6	8.7	68.1	1.3
1992-93	1	6.7	11.8	16.8	2.6
	2	0.1	10.9	75.5	0.0
	3	1.4	11.0	75.1	0.0

Table 7. Depth of maximum CPUE, based on significant Poisson regressions. NS indicates non-significant relation of CPUE to depth; "+/-" indicates the sign of the slope in significant linear relations of CPUE with depth.

	Size	Hake		Witch	
Year	Group	August	January	August	January
1988-89	1	229	417	NS	+
	2	235	356	-	+
	3	257	360	-	+
1989-90	1	244	377	NS	-
	2	252	410	-	634
	3	261	423	-	+
1990-91	1	261	422	308	356
	2	290	429	NS	+
	3	272	412	212	+
1991-92	1	259	372	265	402
	2	307	401	264	569
	3	291	419	259	636
1992-93	1	+	+	305	458
	2	277	444	229	+
	3	273	432	268	+

Figure 1. Map of the Gulf of St. Lawrence with NAFO Divisions and Subareas.



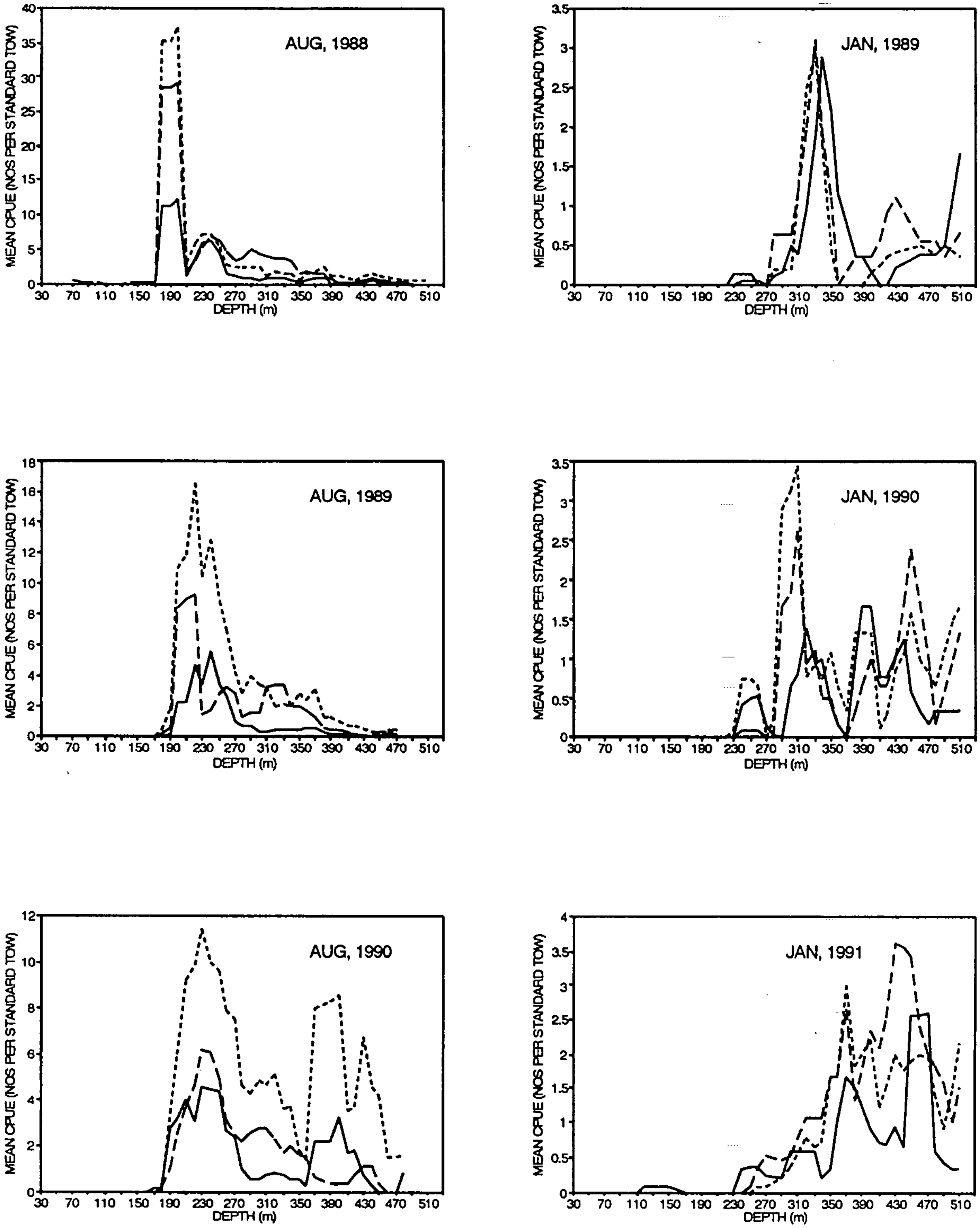


Figure 2. Continued next page.

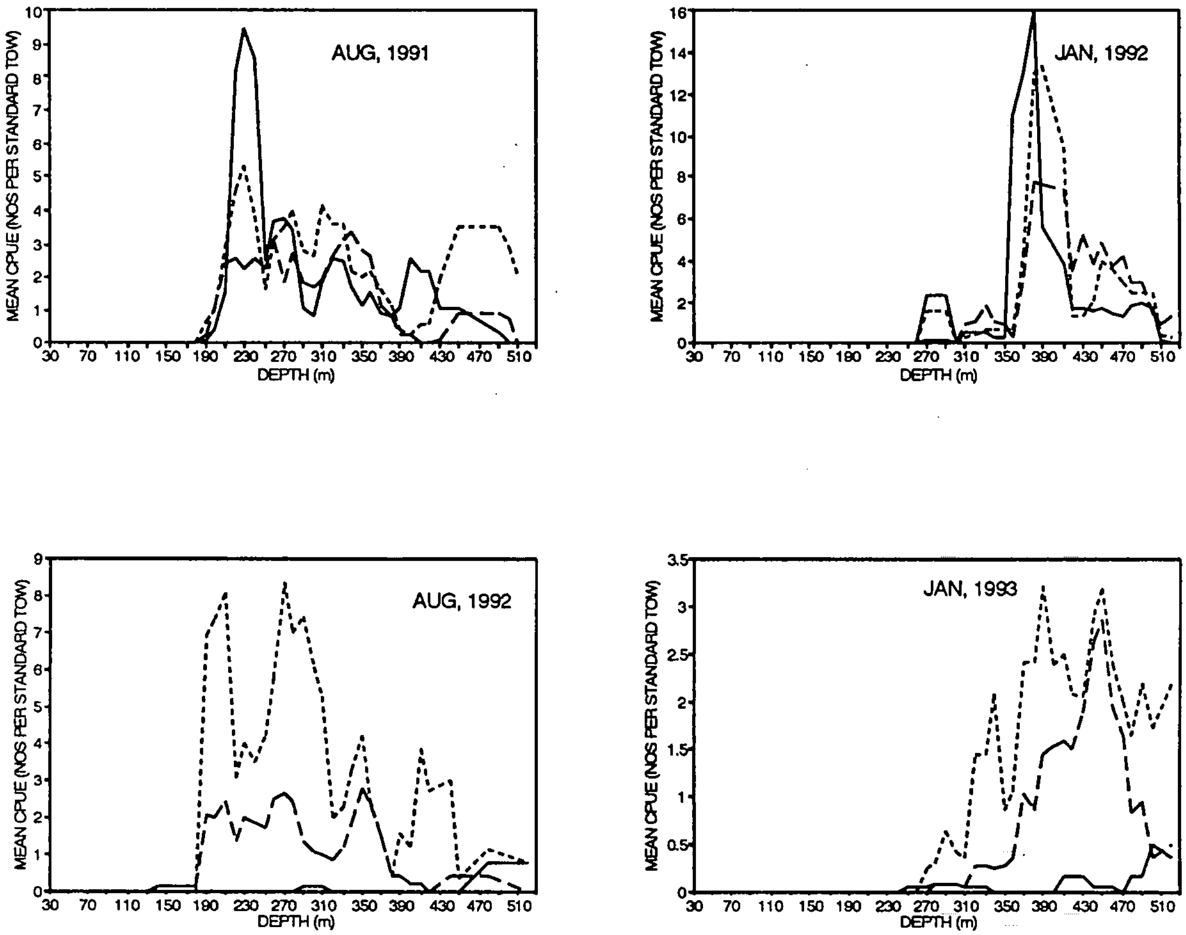


Figure 2. Mean CPUE of white hake in 10-m depth intervals, smoothed by a running average of three. Catch data are presented by size categories corresponding to the first quartile of length frequencies (solid line), second and third quartiles (dotted line), and fourth quartile (dashed line). Length intervals are equivalent for corresponding August and January surveys (intervals are listed in Table 3).

Figure 3 (continued on next page).

WHITE HAKE CATCH (kg)
Gulf/Quebec LADY HAMMOND Surveys - Aug./Sept.

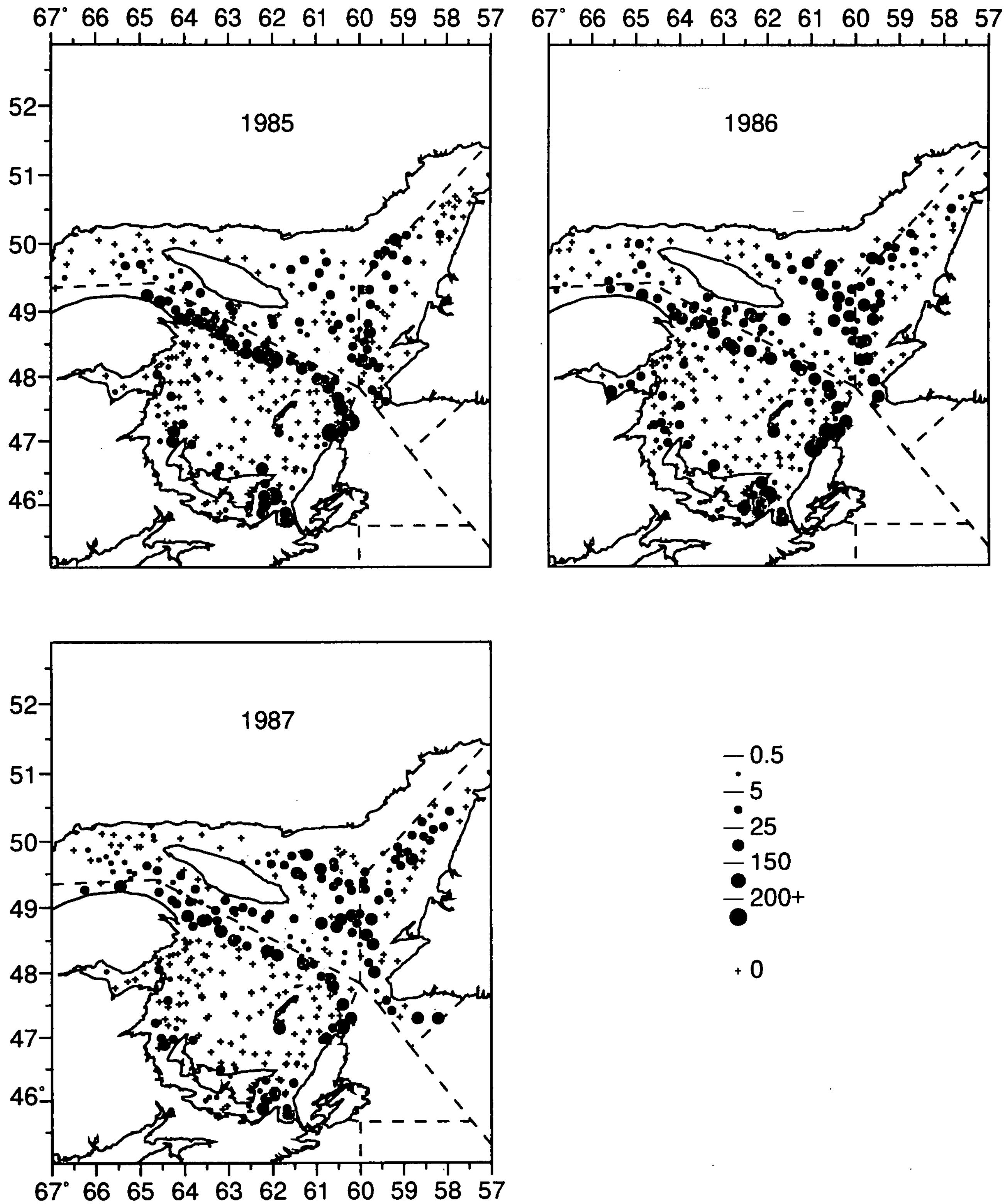


Figure 3 - Continued.

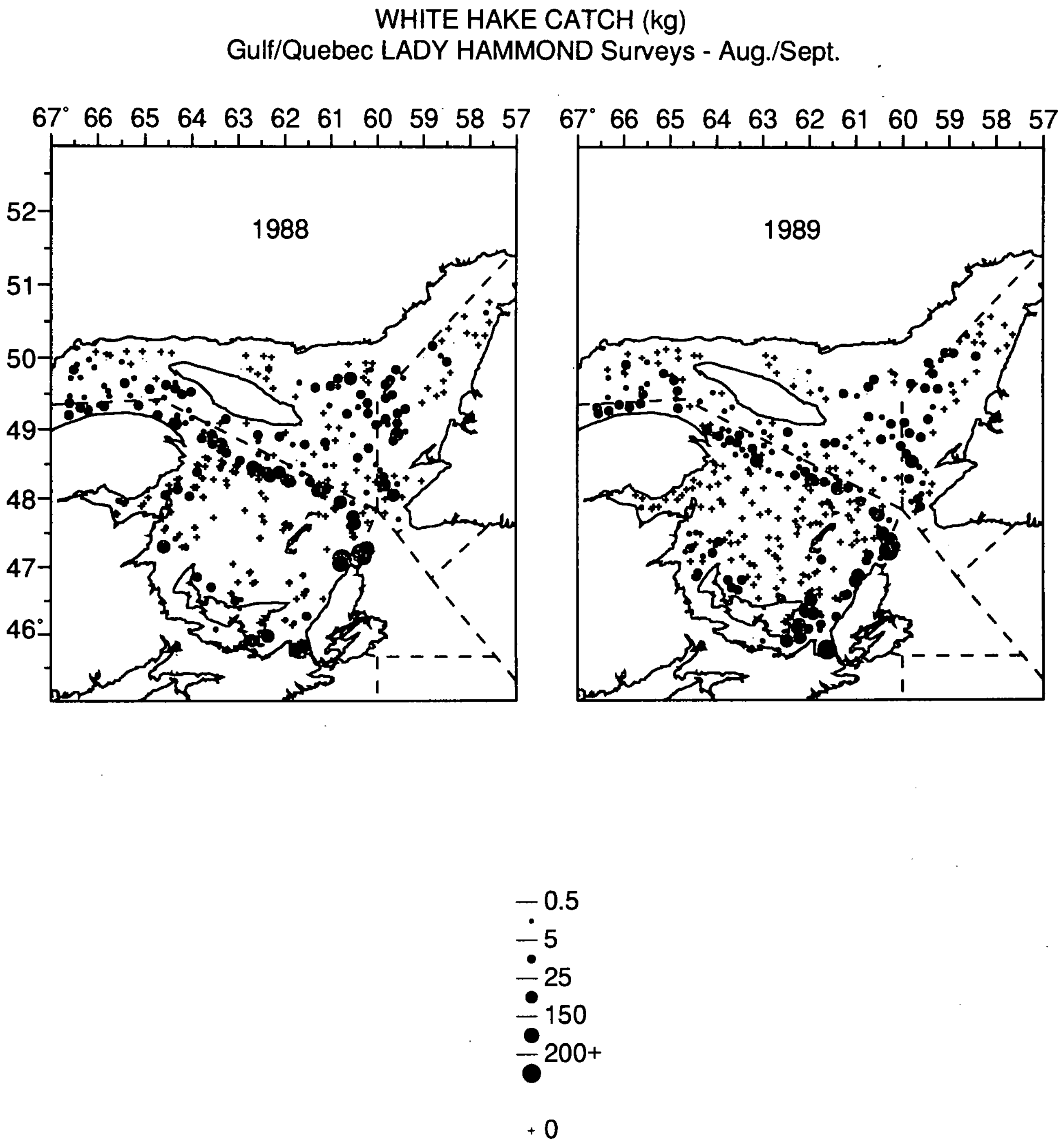


Figure 4 (continued on next page).

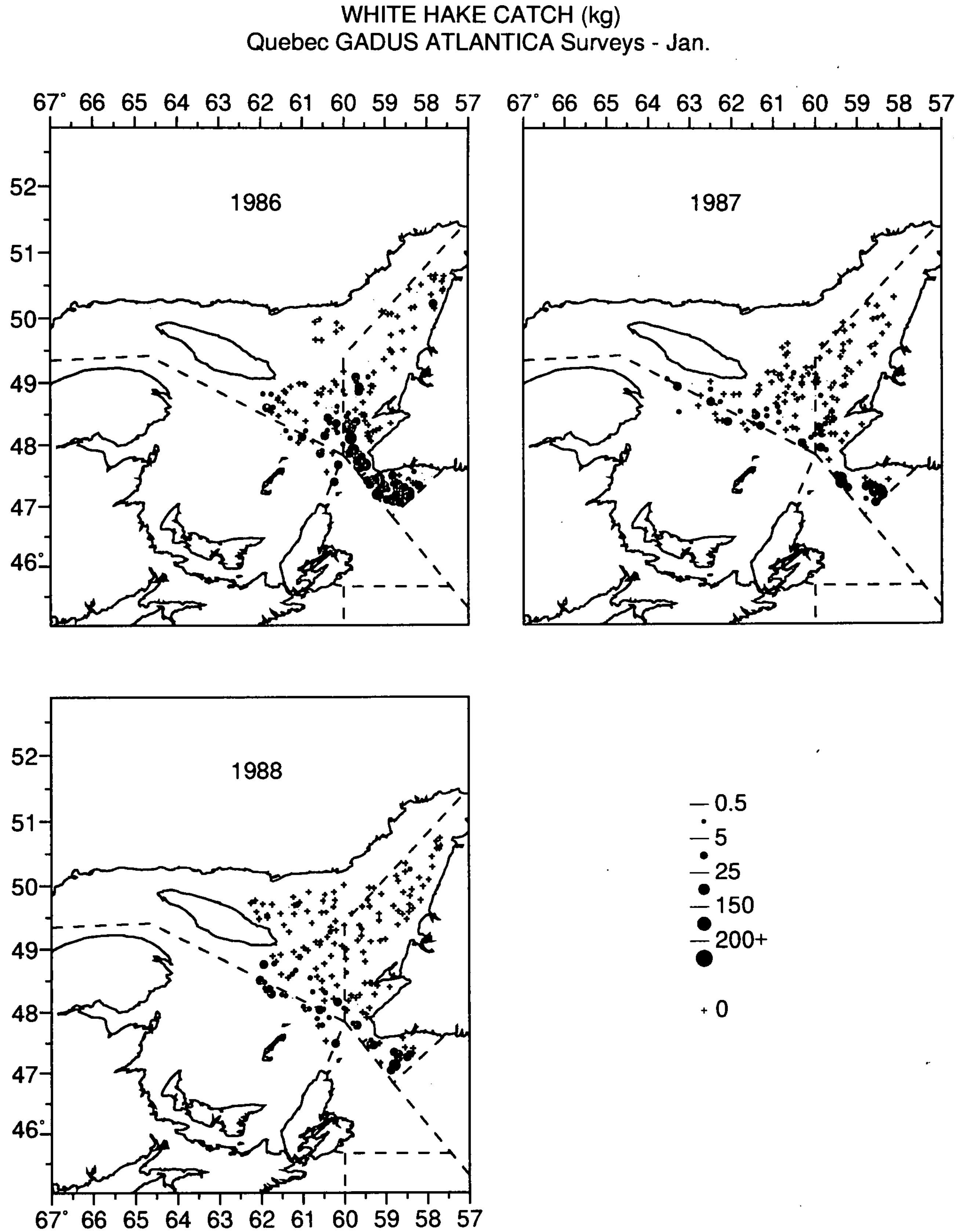


Figure 4 - Continued.

WHITE HAKE CATCH (kg)
Quebec GADUS ATLANTICA Surveys - Jan.

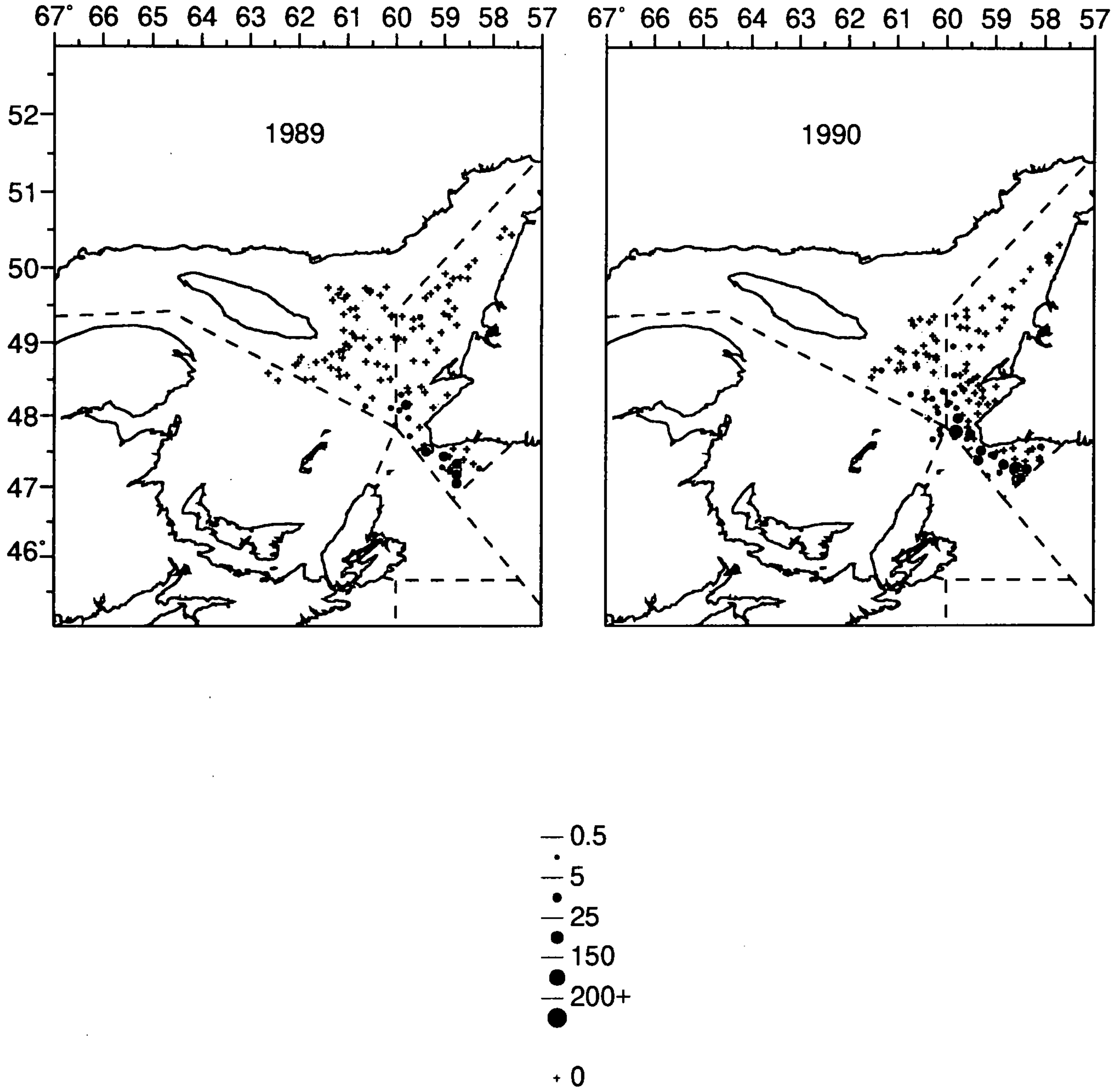
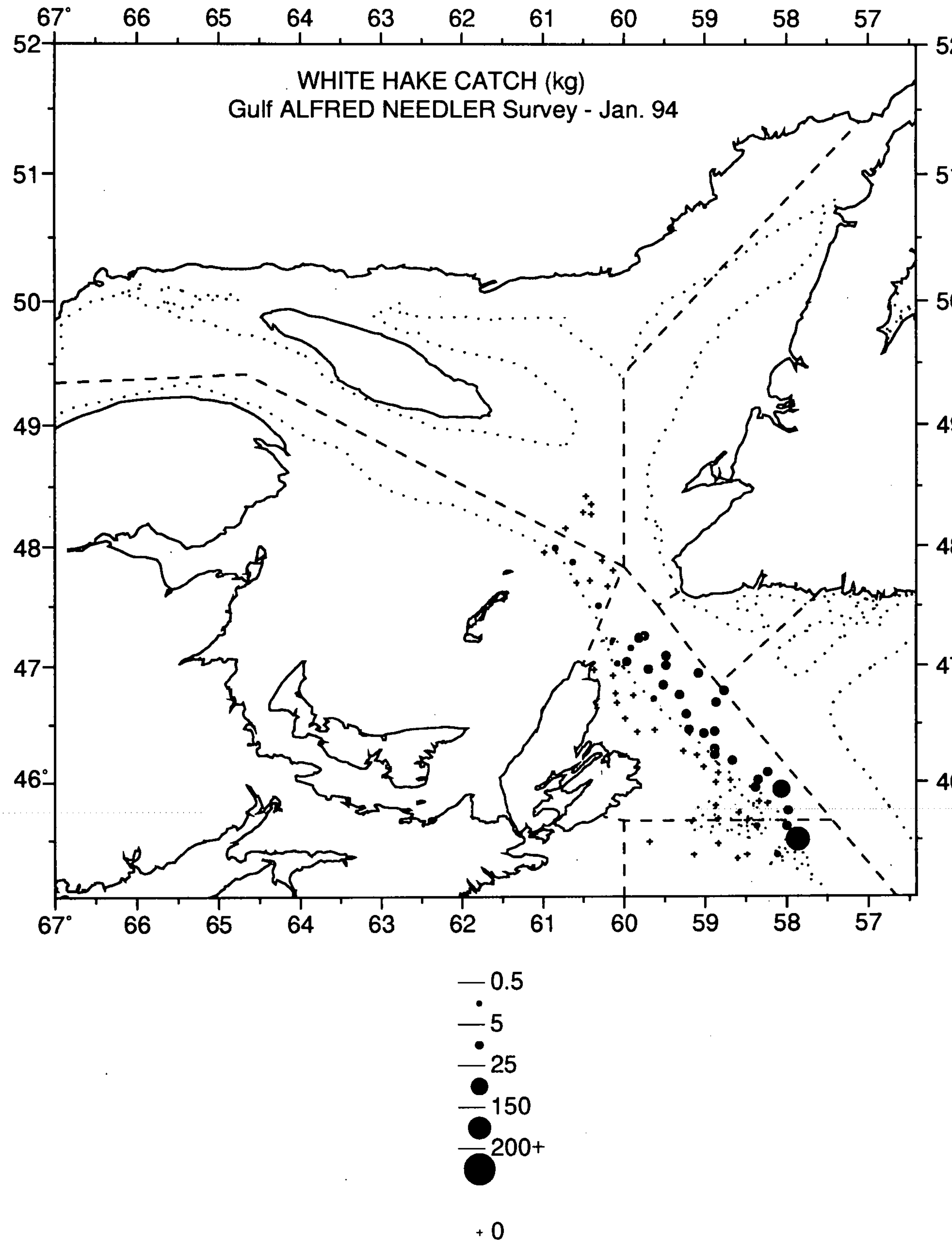


Figure 5.


WHITE HAKE CATCH (kg)
Gulf ALFRED NEEDLER Survey - Jan. 94
67° 66 65 64 63 62 61 60 59 58 57
52 51 50 49 48 47 46°
0.5
5
25
150
200+
0

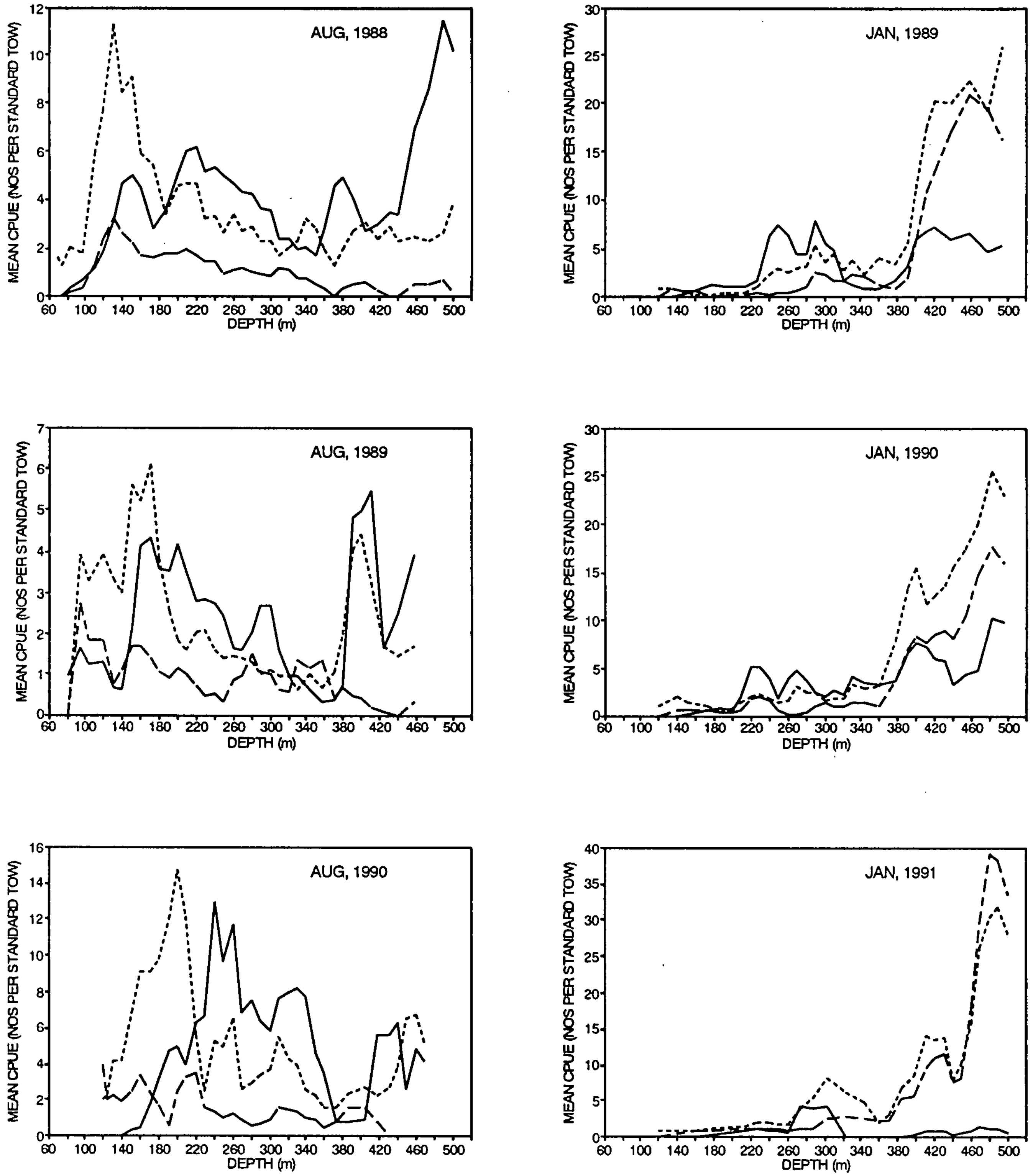


Figure 6. Continued next page.

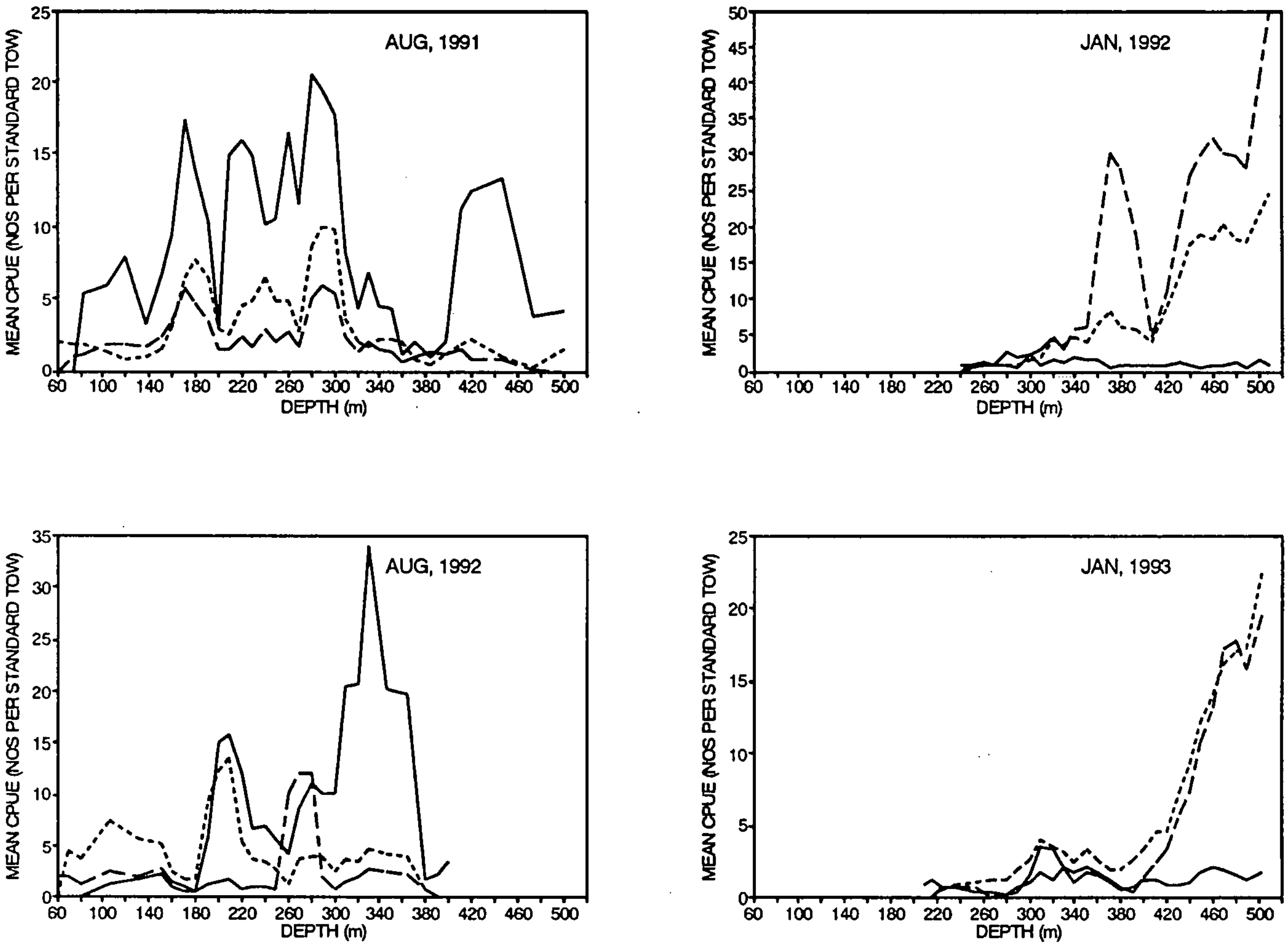


Figure 6. Mean catch of witch flounder in 10-m depth intervals, smoothed by a running average of three. Catch data are presented by size categories corresponding to the first quartile of length frequencies (solid line), second and third quartiles (dotted line), and fourth quartile (dashed line). Length intervals are equivalent for corresponding August and January surveys (intervals are listed in Table 5).

Figure 7 (continued on next page).

WITCH CATCH (kg)
Gulf/Quebec LADY HAMMOND Surveys - Aug./Sept.

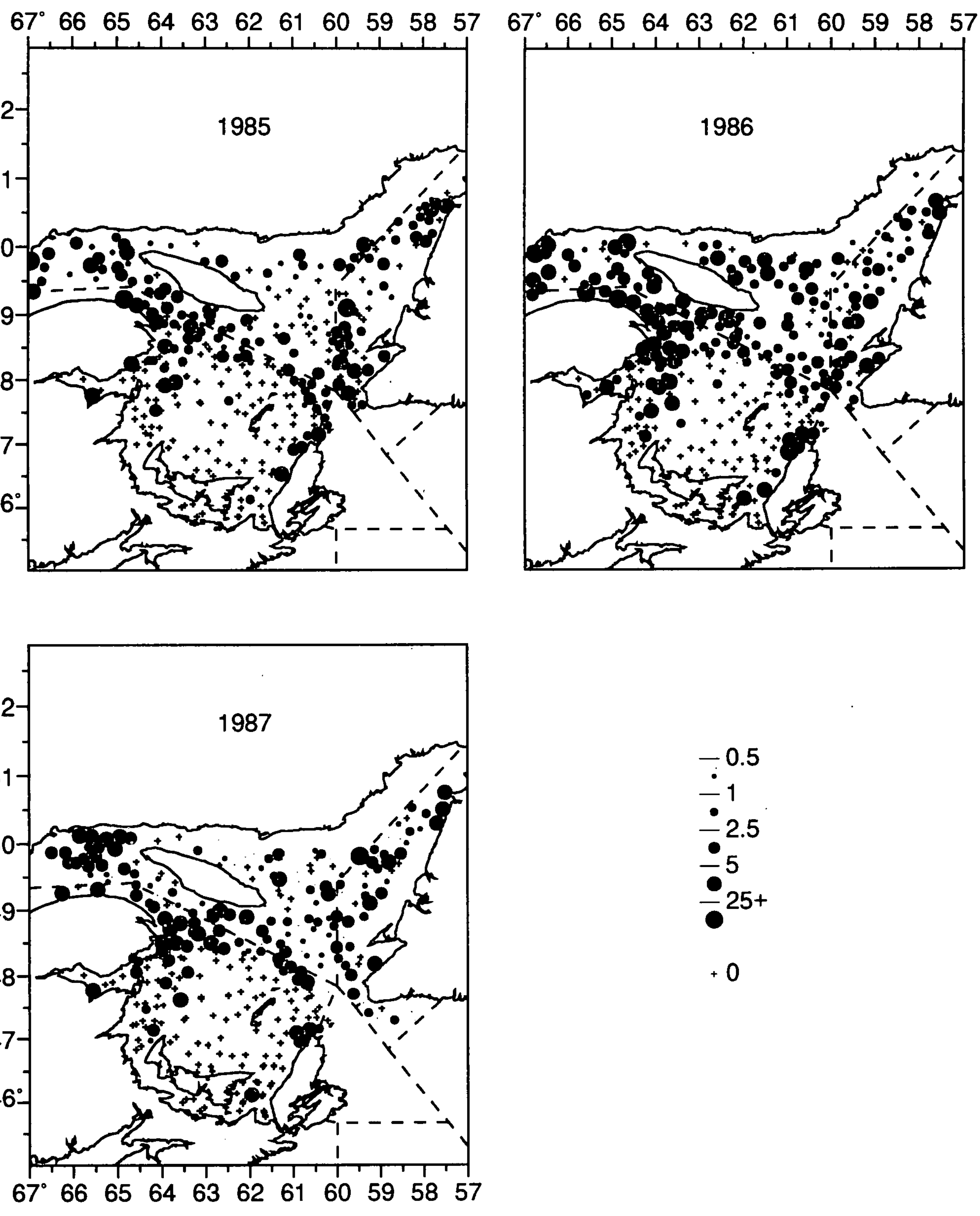


Figure 7 - Continued.

WITCH CATCH (kg)
Gulf/Quebec LADY HAMMOND Surveys - Aug./Sept.

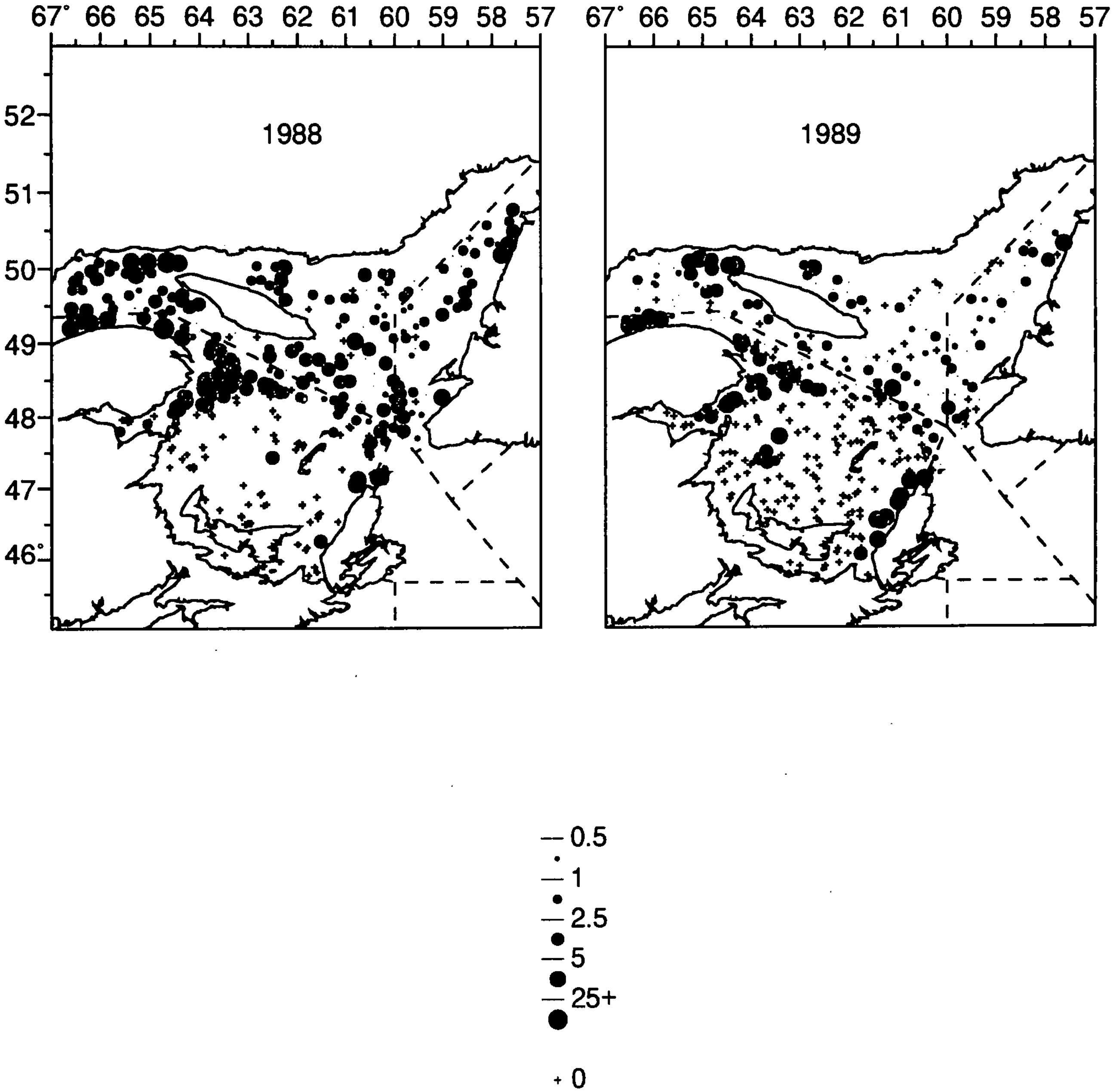


Figure 8 (continued on next page).

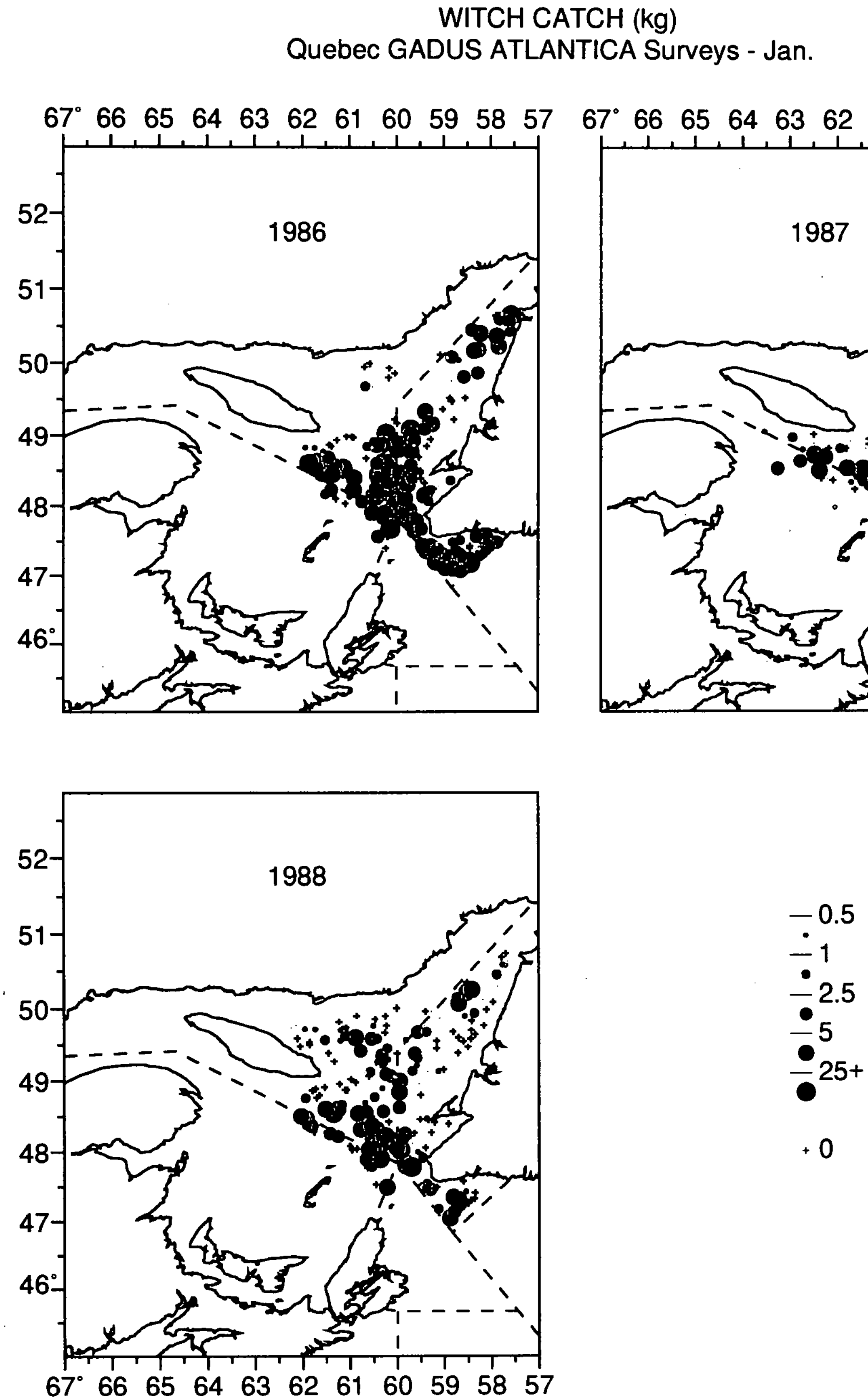


Figure 8 - Continued.

WITCH CATCH (kg)
Quebec GADUS ATLANTICA Surveys - Jan.

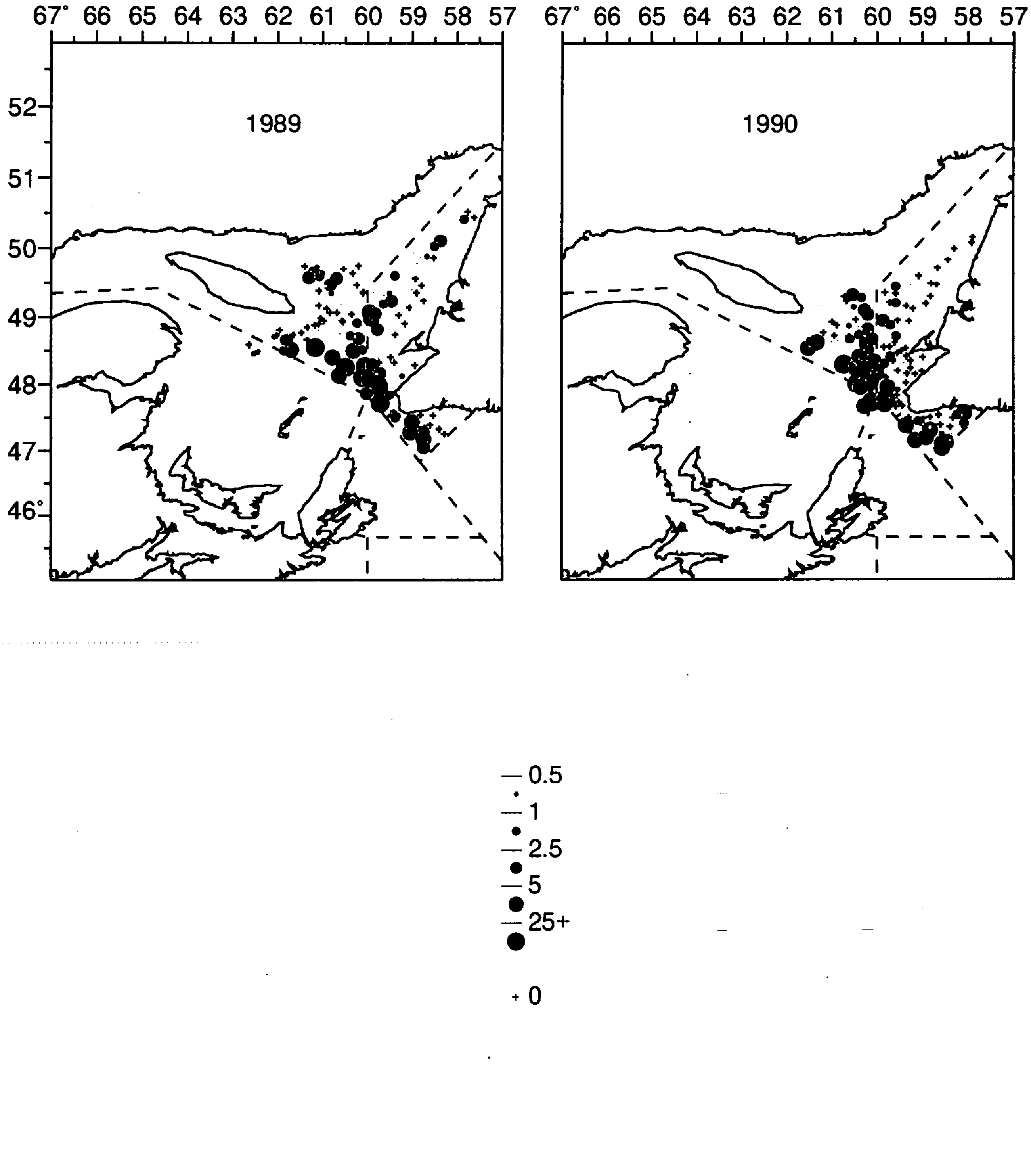
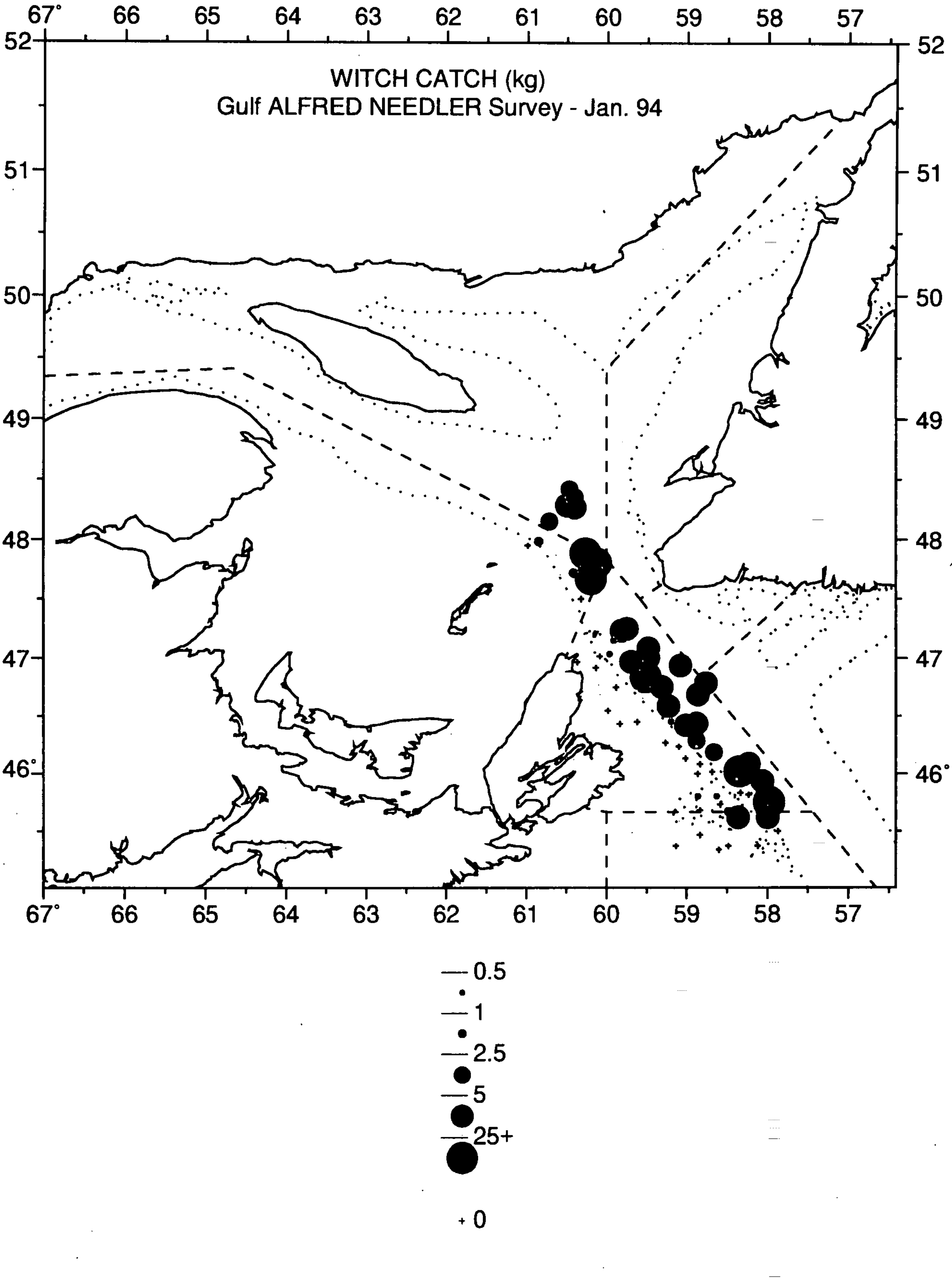


Figure 9.



WITCH CATCH (kg)
Gulf ALFRED NEEDLER Survey - Jan. 94
67° 66 65 64 63 62 61 60 59 58 57
52 51 50 49 48 47 46°
0.5
1
2.5
5
25+
0