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Distribution and abundance of demersal juvenile cod (*Gadus morhua*) on the Northeast Newfoundland Shelf and the Grand Banks (Divisions 2J3KLNOP): implications for stock identity and monitoring

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Abstract

The distributions of juvenile cod in Divisions 2J3KLNO in the autumns of 1995-1998 and in Divisions 3LNOP in the springs of 1996-1998 (plus 1999 for Subdivision 3Ps only) were inferred from catches during resource assessment bottom-trawl surveys. Since autumn 1995 these surveys have been conducted with the Campelen 1800 shrimp trawl, which is far more effective at catching small cod than the Engel 145 Hi-rise trawl that it replaced. In 2J3KL, there was an ontogenetic change from a mainly coastal distribution at ages 0 and 1 to a more mid- and outer shelf distribution by ages 3 and 4. Of those year-classes observed with the autumn surveys, only the 1994 year-class was broadly distributed across the shelf, including much of 2J, by age 1. Subsequent year-classes were distributed almost entirely inshore at age 1, and moved with increasing age onto the Northeast Newfoundland Shelf in 3K and northern 3L, and to a much lesser extent into 2J. In 3P, age 1 cod were distributed mainly toward the coast and on western St. Pierre Bank, age 2 cod were more broadly distributed across the Division, and older fish were concentrated in the northwest and the southeast. The only distinct offshore aggregation of cod of ages 0 and 1 was seen on the plateau of Grand Bank in 3NO. The ontogenetic changes in distribution complicate the interpretation of stock structure and the monitoring of recruitment.

Résumé

Les distributions de la morue juvénile dans les divisions 2J3KLNO au cours des automnes de 1995 à 1998 et dans les divisions 3LNOP au cours des printemps de 1996 à 1998 (et de 1999 pour la subdivision 3Ps exclusivement) ont été déduites à partir des captures réalisées lors des relevés au chalut de fond pour l'évaluation des ressources. Depuis l'automne 1995, les relevés sont effectués à l'aide du chalut à crevettes Campelen 1800 au lieu du chalut Engel 145 à remontée élevée, le premier se révélant beaucoup plus efficace pour capturer les petites morues que le second. Dans 2J3KL, la distribution, surtout côtière aux âges 0 et 1, a connu un changement ontogénique et s'est déplacée davantage vers le centre et le bord extérieur du plateau aux âges 3 et 4. Parmi les classes d'âge observées lors des relevés d'automne, seule celle de 1994 était largement répartie à la grandeur du plateau, qui comprend la majeure partie de 2J, à l'âge 1. Au même âge, les classes d'âge ultérieures étaient presque entièrement réparties le long de la côte et, avec l'âge, elles se sont déplacées vers le nord-est du plateau de Terre-Neuve dans 3K, dans le nord de 3L et, quoique dans une bien moindre mesure, dans 2J. Dans 3P, les morues d'âge 1 étaient surtout réparties près de la côte et sur la partie ouest du banc de Saint-Pierre, celles d'âge 2 étaient plus largement dispersées dans la division, et les poissons âgés étaient concentrés dans le nord-ouest et dans le sud-est. La seule concentration hauturière significative de morues d'âges 0 et 1 a été observée sur la plate-forme du Grand Bank dans 3NO. Les changements ontogéniques dans la distribution compliquent l'interprétation de la structure du stock et la surveillance du recrutement.

Introduction

Ontogenetic changes in distribution have been described for most cod stocks. For the "northern" cod stock, occupying waters off southern Labrador and eastern Newfoundland (NAFO divisions 2J3KL), the historic model has been that of spawning offshore, advection of pelagic stages to the inshore where juveniles of ages 0 and 1 occupy shallow nursery areas, and gradual adoption during ages 2-4 of a seasonal migration between overwintering and spawning areas offshore and summer feeding areas inshore (Templeman 1981; Lear and Green 1984; Lear and Wells 1984). However, it is recognized that spawning also occurs inshore (Hutchings et al. 1993; Smedbol and Wroblewski 1997), so juvenile cod found in shallow coastal waters could come from spawning in both the offshore and the inshore (Wroblewski et al. 1996).

The 2J+3KL cod stock declined dramatically during the late 1980s and early 1990s (Taggart et al. 1994). During the latter half of the 1990s, the densities of cod found offshore during research bottom-trawl surveys were very small and few cod larger than 50 cm were caught. In contrast, cod of commercial size existed in the inshore in sufficient density to enable moderate to high catch rates in sentinel surveys at various times and places from White Bay in central Division 3K to the southern boundary of the stock. It has been hypothesized that at least some of the cod in inshore waters belong to inshore or bay stocks (or substocks) that remain inshore throughout their lives (see review in Lilly et al. 1999).

There has been considerable interest in distinguishing and managing individual components within the 2J+3KL cod stock complex. Indeed, quotas were established for inshore waters alone for an index fishery in 1998 and a commercial fishery in 1999. If a management regime with two or more components or substocks is to be considered, then it will be important to determine if the components are experiencing different recruitment patterns, and if they are, to create a recruitment index for each.

Information on the distribution and relative abundance of young cod in divisions 2J+3KL has been obtained with a variety of gears. For example, mid-water trawls of various sizes have been used to study 0-group cod before they settle (Anderson et al. 1995; Anderson and Dalley 1997); beach seines have been employed to catch demersal age 0 and age 1 cod in shallow coastal waters (Methven and Bajdik 1994; Gotceitas et al. 1997; Grant and Brown 1998; Methven and Schneider 1998); and bottom-trawls of various sizes have been deployed to catch demersal fish of all ages during experimental studies in both the inshore and the offshore (Dalley and Anderson 1997; Methven and Schneider 1998).

The longest time-series of information on relative abundance at age comes from catches during resource assessment bottom-trawl surveys conducted in the offshore during the autumn starting in 1977 in 2J, 1978 in 3K and 1981 in 3L. The surveys in 2J3K and those in 3L from 1985 onward were conducted with an Engel 145 Hi-Lift otter trawl with large, lightweight bobbins in the footgear (McCallum and Walsh 1997). This trawl is very

inefficient at catching small cod, with near zero capture efficiency for individuals under 20 cm (Godø and Walsh 1992). Nevertheless, some age 1 cod (and very few age 0 cod) were caught. A preliminary analysis of the data revealed that the most promising areas for exploratory surveys with a more efficient gear were "... the plateau of the northern Grand Bank and the coastal shelf from the Grey Islands to just north of Belle Isle" (Lilly 1992).

The autumn survey data were examined in detail by Anderson (1993) and Anderson and Gregory (2000). They reported that age 1 cod occurred most frequently in two areas; in the north where they were concentrated on the shoreward side of the survey areas off southern Labrador and the Great Northern Peninsula of Newfoundland, and in the south where they occurred in specific areas over the northern Grand Bank. In the northern part of the area there was a cross-shelf gradient on the Northeast Newfoundland Shelf, declining to zero offshore. The distribution of age 2 cod was similar to that of age 1 cod, but they were found over a broader area, including the outer part of the Northeast Newfoundland Shelf. Cod of ages 3 and 4 were found in four distinct areas; on Hamilton Bank, in deep water on the outer shelf between Belle Isle Bank and Funk Island Bank and between Funk Island Bank and Grand Bank, and on Grand Bank at the southern limit of the survey. These four areas correspond to those recognized as areas of concentration when the total catch (all ages) is examined (Lilly 1994).

The surveys described above did not extend into inshore waters and were conducted with a gear that was inefficient at catching small fish. To overcome these limitations, Dalley and Anderson (1997) used a Campelen 1800 shrimp trawl with rockhopper foot gear to conduct experimental surveys in 1992-1994 at fixed stations on line transects extending from within the bays along the east coast of Newfoundland to the shelf break. They found that age 0 cod were distributed almost exclusively in the inshore, age 1 fish extended further onto shelf areas, and older juveniles were widely distributed on the shelf. They speculated, however, that "offshore distribution of demersal age 0 cod may have been more extensive historically, when the stock was healthier."

Ontogenetic changes in distribution have been examined in less detail for cod on the southern Grand Bank (divisions 3NO) and in the area to the south of Newfoundland (Subdivisions 3Ps and 3Pn). With respect to 3NO cod, Walsh et al. (1995) reported that cod of ages 1 and 2 were most abundant on and around the Southeast Shoal and that older cod were more dispersed.

In the autumn of 1995 the Engel trawl was replaced by the Campelen 1800 shrimp trawl as the standard trawl for multispecies bottom-trawl surveys conducted by Canada in Newfoundland waters. The resultant increase in catches of small cod presented an opportunity to explore the distribution and relative abundance of juvenile cod from southern Labrador (Division 2J) to southwestern Newfoundland (Subdivision 3Pn).

The purpose of this paper is to examine ontogenetic changes in the distribution of juvenile cod in offshore and nearshore waters. Data from autumn surveys in 2J3KLNO are examined together, as are data from spring surveys in 3LNOP. The autumn surveys cover

the stock areas of 2 cod stocks (2J+3KL and 3NO) and the spring surveys cover the stock areas of 2 cod stocks (3NO and 3Ps) and part of the areas of 2 additional stocks (3Pn4RS to the west and 2J+3KL to the north). These geographic scales are broader than those usually considered during assessments of individual stocks and may provide additional insight into stock affinities.

Methods

Bottom-trawl surveys

Stratified-random bottom-trawl surveys have been conducted by Canada during autumn in Divisions 2J, 3K and 3L since 1977, 1978 and 1981 respectively (Lilly et al. 1999) and in Divisions 3NO since 1990 (Stansbury et al. 1999). Surveys have been conducted in spring in Divisions 3LNO since the early 1970s (Lilly et al. 1999; Stansbury et al. 1999), and in winter or spring in Division 3P since the early 1970s (Brattey et al. 1999). Details of the ships employed and trip numbers may be found in the relevant assessment documents cited above.

The survey stratification scheme was based on depth contours (Doubleday 1981; Bishop 1994; Murphy 1996). Set allocation was proportional to stratum area, with the provision that each stratum be allocated at least 2 sets. Additional strata were added to the inshore in Divisions 3K and 3L and Subdivision 3Ps in recent years to provide additional insight into distribution and abundance of cod and other species landward of the standard survey area. For the most part, the new strata on the east coast (divisions 3KL) did not extend into the shallow water where most of the inshore commercial cod fishing occurs.

The Engel 145 Hi-rise trawl was used since the start of the surveys in Divisions 2J and 3K and since the change to the Wilfred Templeman and its sister ship the Alfred Needler in Divisions 3LNOP in the early 1980s. In the autumn of 1995 the Engel trawl was replaced with the Campelen 1800 shrimp trawl with rockhopper footgear. The Campelen trawl was towed at 3.0 knots for 15 min instead of 3.5 knots for 30 min. The selectivities of the two nets were found through comparative fishing experiments in 1995 and 1996 to be markedly different, with the Campelen being far more effective at catching small cod (Warren 1997).

Distribution

The number of stations occupied with the Campelen trawl was 2494 in the autumn and 1708 in the spring (Table 1). For 1999 only data from 3Ps was available at the time of analysis.

The number of cod at length in the catch at each trawl station was converted to number at age by applying an age-length key (ALK) constructed from sampling in the same Division or Subdivision during the same survey. For areas and years where sampling was conducted

in both the offshore and the inshore, an ALK was constructed using data from fish collected both offshore and inshore, and this one ALK was applied to the catches in both the offshore and the inshore. This procedure of applying a divisional ALK to the length composition at each fishing station may result in the catch being assigned to more age groups than actually occurred at that station. At its extreme, the procedure may cause a catch of one fish to be assigned to 2, 3 or even more ages. As a consequence, there will be numerous instances of a catch at age of less than 1. In addition, the procedure will cause each age-group to appear to have been caught at more stations than was actually the case. Nevertheless, the catch at age in each tow, calculated as described here, should reveal broad trends in geographic distribution at age.

The distribution at age is presented in expanding symbol plots, rather than contour plots generated from modelling of the catches, in order to provide visual information on the spatial distribution of fishing stations, among-station variability in the catch, and the relationship between catch and bathymetry.

To examine the average distribution at age, sets were binned into areas of 20' latitude and 30' longitude. The arithmetic mean catch at age was calculated for all sets occurring in each spatial bin, and the mean was plotted at the geographical centre of the bin. Additional plots illustrate the catch at age in each individual tow in specific years and areas.

Results

Distribution at age in 2J3KLNO in autumn 1995

Distribution plots of cod at ages 0-9 in 1995, the first year that the Campelen trawl was deployed, reveal spatial variability in density at each age and differences in distribution among ages (Fig. 1a-e).

The 1995 year-class at age 0 was caught in very small numbers, primarily in 3NO but also in one set near the coast in 3K.

The 1994 year-class at age 1 was broadly distributed, with largest catches in 2J3K and 3N. Catches tended to be small in eastern 3K and in 3L.

The 1993 and 1992 year-classes at ages 2 and 3 had a distribution similar to that of the 1994 year-class, except that they were less abundant on the coastal shelf in 2J3K and more abundant to the east of Belle Isle Bank and in an arc around the southern half of Funk Island Bank.

The 1991 year-class at age 4 had a distribution similar to that of the 1992 year-class, but individual catches tended to be smaller. Catches in Funk Island Deep were small.

The 1990 and 1989 year-classes at ages 5 and 6 were weakly represented in 2J3KL but much stronger in 3NO. These year-classes are recognized as having been relatively strong in the 3NO stock (Stansbury et al. 1999) and in the 3Ps stock to the west (Brattey et al. 1999). The few catches in 3L just south of the Virgin Rocks appear to be a continuation of the distribution in 3NO.

The 1988 year-class at age 7 was weakly represented all over. Largest catches were taken on the southernmost part of the Northeast Newfoundland Shelf in 3L.

The 1987 and 1986 year-classes at ages 8 and 9 were caught in very low numbers. These year-classes were initially strong in the surveys, especially in 3KL, but they disappeared rapidly in the early 1990s (Shelton and Lilly 2000).

Average distribution at age in 2J3KLNO in autumn 1996-1998

Ontogenetic changes in the autumn distribution of cod in 2J3KLNO, including the inshore of 3KL, were explored with plots (Fig. 2 a-c) of the average catch at age in 1996-1998, the only years in which strata in the inshore of 3KL were occupied.

Cod of age 0 were found mainly in three centres of distribution; near shore off the Northern Peninsula in 3K; near shore around the southern Avalon Peninsula in 3L; and on the plateau of Grand Bank in southern Division 3L and Divisions 3N and 3O.

Cod of age 1 were more widely distributed, especially in 2J and 3K. Largest catches were taken off the Northern Peninsula and Strait of Belle Isle in northern 3K, on the Fogo Shelf in southern 3K, and near shore in the bays of 3L and around the Avalon Peninsula. The catches in 3NO are well separated from those in 3L.

Cod of age 2 were more widely distributed than those of age 1, with moderately large average catches occurring on eastern Belle Isle Bank and to the south and east of Funk Island Bank.

Cod of ages 3 and 4 were even more broadly distributed across the shelf in 2J3KL. With increasing cod age, catches tended to decrease toward the coast and increase toward the outer shelf. This was particularly noticeable in 2J3K.

Cod of age 5 were broadly distributed at very low density.

In general, over the period 1996-1998, there was one broad area of distribution of young cod on the southern Labrador Shelf and the Northeast Newfoundland Shelf, including northern Division 3L, and a second area on the southern Grand Bank, mainly within 3N and 3O but possibly extending into southern 3L. Within 2J3KL, the distribution was predominantly coastal at ages 0 and 1. There was a gradual expansion across the shelf with

increasing age. In 2J and northern 3K, this expansion across the shelf was accompanied by a reduction in density toward the coast.

Distribution at age 1 in 2J3KLNO in autumn 1995-1998

The plots of average distribution at age discussed in the previous section might be influenced by annual variability in distribution at age. As an illustration, the distribution of cod at age 1 is shown for the 1994 to 1997 year-classes (Fig. 3 a, b). The 1994 year-class had a stronger representation on the shelf in 2J3K than did any of the three following year-classes.

Distribution of the 1993-1995 year-classes at ages 1-4 in 2J3KL in autumn

The ontogenetic changes in distribution illustrated above might include both year-class effects and year effects. To explore whether the dominant trends in the distributions may be seen in individual year-classes, the distributions of the 1993-1995 year-classes were plotted at ages 1-4 (Fig. 4 a-c). Stations in the new inshore strata were not plotted so as to allow the eye to concentrate on those areas that were surveyed in all years.

The 1993 year-class at age 2 was caught mainly on the outer shelf in 2J and in an arc around southern Funk Island Bank in 3K and northern 3L. The distribution did not change substantially at age 3. Catch rates were very low by age 4.

The 1994 age-class was already well represented on the shelf by age 1, as noted above. With increasing age it expanded into the area to the east of Belle Isle Bank and Funk Island Bank, and declined on the coastal shelf off southern Labrador and northern Newfoundland. The rapid reduction in catch per tow with increasing age is very striking.

The 1995 age-class at age 1was caught mainly on the coastal shelf off southern Labrador and northern Newfoundland and in the southern Funk Island Deep off the Fogo Shelf. With increasing age it became more broadly distributed toward the outer part of the shelf and declined on the coastal shelf off southern Labrador and northern Newfoundland.

These plots of the distribution of individual year-classes are in general agreement with the plots obtained by averaging the data from several year-classes (Fig. 2).

Average distribution at age in 3LNOP in spring 1996-1999

Ontogenetic changes in the spring distribution of cod in 3LNOP, including the inshore of 3Ps, were explored with plots (Fig. 5 a-c) of the average catch at age in 1996-1999. Note that the scaling used in this figure is not appropriate for 3P. (There are too many points that fall within the maximum bin size of 10+ individuals per standard tow.) However, the scale

is kept identical to that used in the comparable plots for the autumn surveys (Fig. 2) to aid a visual comparison of the spring and autumn catches in 3LNO.

Cod of age 1 were found mainly on the southern Grand Bank (Divisions 3N and 3O) and on northwestern St. Pierre Bank and the adjacent inshore area around the tip of the Burin Peninsula. Average catches were small or nil over most of Division 3L.

Cod of age 2 were more broadly distributed from 3Pn across 3Ps and the southern Grand Bank. Average catches were small or nil over most of 3L, but somewhat larger catches occurred in the north at the southern end of the Northeast Newfoundland Shelf.

Cod of ages 3 to 6 were increasingly aggregated in two areas: (1) 3Pn and the Burgeo Bank / Hermitage Channel area of 3Ps and (2) the southern end of the channels in southeastern 3Ps and southwestern 3O. There were also isolated high average catches elsewhere in 3O, in 3N and in northern 3L.

Distribution at ages 1 and 2 in 3LNOP in spring 1996-1999

Because the plots of average distribution at age discussed in the previous section might mask annual variability, the distributions at ages 1 and 2 are illustrated for each year in the period 1996-1999 (Fig. 6 a-d). In 3L there were very small catches at age 1 in each year, but by age 2 somewhat larger catches were taken, especially in the north. In 3NO, catch-at-age varied by age and year. There are insufficient data available to date to determine if distributions tend to be stable between age 1 and age 2 and among years. In 3P the area around the Burin Peninsula was important in each of the years when it was surveyed (1997-1999). The distributions at both age 1 and age 2 seemed to be broader in 1999 than in the previous 3 years.

Distribution of the 1989 and 1990 year-classes in 3LNOP in spring 1996-1999

The 1989 and 1990 year-classes were subjected to low fishing mortality in 3Ps during the years of the moratorium, and by 1996 they comprised a major portion of the 3Ps spawning biomass. During the springs of 1996-1999 these year-classes were caught mainly in 2 areas (Fig. 7 a-d): (1) the outer reaches of Burgeo Bank and Hermitage Channel and (2) the southern ends of the channels in southeastern 3Ps and western 3O, with some additional large catches along the southwestern slope of Grand Bank. In 1999 these year-classes appeared to be more broadly dispersed on the plateau of St. Pierre Bank than they had been in 1996 and 1998. The failure to secure large catches of these year-classes in southeastern 3Ps and western 3O during 1997 is striking. Very few individuals were caught offshore in Division 3L in any year.

Discussion

The distribution of cod at age has been illustrated in the present study by maps that cover broad geographic areas (2J3KLNO in autumn and 3LNOP in spring). These maps do not necessarily represent a synoptic picture of distribution. The autumn surveys, which were conducted with two ships, usually started in mid-October and ended in mid-December. The spring surveys, which were conducted with one ship, started in 3P in early April and progressed to 3O, 3N and finally 3L, finishing in late June. The possibility that cod may move substantially during the period of the survey, and thereby affect the perception of their distribution, has not been investigated.

Cod in 2J3KL

Ontogenetic changes in the distribution of cod on the southern Labrador Shelf and the Northeast Newfoundland Shelf (2J3K and northern 3L) in the autumns of 1995-1998, as reported in the present paper, were similar to those reported from bottom-trawling in 1981-1992 (Anderson 1993; Anderson and Gregory 2000) and 1992-1994 (Dalley and Anderson 1997). In each of these periods demersal juveniles occurred mainly in coastal waters at ages 0 and 1 and moved across the shelf with increasing age. The availability of both spring and autumn surveys in 3L permit finer resolution of the timing of the advance across the shelf. Very few cod were caught in northern 3L (the southernmost Northeast Newfoundland Shelf) at age 0, but with succeeding seasons the cod gradually expanded across the shelf until by the spring of age 2 there was good representation on the northeast slope of Grand Bank.

There remains uncertainty about the historic relative importance of the offshore and the inshore for cod at age 0. Anderson et al. (1995) concluded, from studies of pelagic juvenile cod in the 1980s, that individuals spawned offshore remain offshore and that the offshore was the primary habitat for pelagic 0-group cod. Anderson and Dalley (1997) concluded, from models of circulation and studies of the distribution of pelagic juveniles in 1991-1994, that pelagic juveniles offshore will have originated primarily from offshore spawning and pelagic juveniles inshore will have originated primarily from inshore spawning. Dalley and Anderson (1997) concluded, from the distribution of demersal age 0 cod in 1992-1994, that settlement occurred almost exclusively in the inshore in those years. They stated that "the lack of age 0 demersal cod in the offshore is a result of spawning failure of the offshore components of the stock complex in recent years". They also suggested that "offshore distribution of demersal age 0 cod may have been more extensive historically, when the stock was healthier." However, this presumed greater importance of the offshore in earlier years is not consistent with the distribution of juveniles caught during autumn bottom-trawl surveys in 1981-1992. Age 0 cod were caught infrequently during those surveys, but Anderson and Gregory (2000, p. 351) said the following about the distribution of age 1 cod: "There were two areas where 1-year-old cod occurred most frequently. In the north, they were concentrated on the shoreward side of the survey area off southern Labrador and the northern peninsula of Newfoundland and, in the south, they occurred in specific areas over the Northern Grand Bank. In the northern part of the survey area there

was a clear cross-shelf gradient on the Northeast Newfoundland Shelf declining to zero offshore. This distribution implies high concentrations of cod inshore, beyond the survey boundary." The distributions of cod at ages 1-3 led Anderson and Gregory (2000, p.356) to conclude that "inshore areas along the northeast coast of Newfoundland and off southern Labrador are a primary nursery area of northern cod". Additional nursery areas occurred on the Northern Grand Bank. "The relative importance of nursery areas inshore along the northeast coast and offshore on the Northern Grand Bank remains unresolved" (Anderson and Gregory (2000).

It appears at this point that there is an inconsistency that remains to be resolved. If pelagic juveniles in the offshore on the southern Labrador Shelf and Northeast Newfoundland Shelf remain offshore, as stated by Anderson et al. (1995) and Anderson and Dalley (1997), then what happens to them when it is time to settle and how does the inshore become a major nursery area?

The offshore distribution of the 1994 year-class at age 1 provides both insight and additional uncertainty regarding the importance of the offshore in 2J3K as a nursery area for 2J+3KL cod. Anderson and Dalley (1997) noted that 1994 was the only year in the 1991-1994 period when pelagic juveniles were found in abundance in the offshore. They further noted that this was consistent with the presence of a postspawning concentration of cod in the Hawke Saddle area in June of 1994, as determined by an acoustic study of the area (Rose 1996). Since there had been no observations in Hawke Saddle in June of earlier years, the assumption was apparently made that such concentrations of postspawning cod were not there in 1991-1993. In a continuation of this line of enquiry, J.T. Anderson (DFO, St. John's, pers. comm.) has drawn attention to the small numbers of postspawning cod found in Hawke Saddle in 1995-1996 during additional acoustic studies by G.A. Rose (Memorial University of Newfoundland, St. John's, NF) and the small numbers of pelagic 0-group cod caught offshore in the same years (Anderson et al. 1999). He has concluded that the number of pelagic juveniles caught each year is related to the abundance of postspawning cod in the Hawke Saddle area in June. It is of further interest that the 1994 year-class was also the only year-class caught in relative abundance at age 1 in the offshore bottom-trawl surveys in 2J3K since the Campelen trawl was introduced in 1995. It is not clear if the occurrence of age 1 cod in the offshore in 1994 was a novel event, or if year-classes in the 1980s also were present in the offshore by age 1 but were at such low abundance that they were subsequently swamped by individuals recruiting to the offshore from the inshore. Additional monitoring may help elucidate the importance of offshore spawning for the distribution of pelagic and demersal juveniles in the offshore.

The origin of juvenile fish appearing in the offshore during the mid- to late-1990s is of importance to the elucidation of stock structure and to the monitoring of year-class strength. As discussed above, the 1994 year-class was well represented on the shelf at age 1. Many individuals occurred in 2J. Following Anderson and Dalley (1997), it may be concluded that those individuals in the offshore had resulted from offshore spawning. In contrast, the 1995-1997 year-classes were not well represented on the shelf at age 1. However, they appeared to move with increasing age from the inshore to the offshore,

especially to the Northeast Newfoundland Shelf in 3K and northern 3L. What was the origin of those individuals that migrated onto the shelf? There are several possibilities.

(1) They originated from offshore spawning, were advected to the inshore at some stage in their early life (or swam inshore as pelagic juveniles) and then migrated back to the offshore. This is the historic model of the life history (Lear and Green 1984), and would indicate that some successful spawning was occurring in the offshore.
(2) They originated from inshore spawning of fish that belong to offshore components. These adults may have overwintered inshore or overwintered on the shelf and migrated into coastal waters before spawning. The early life stages are completed inshore before the juveniles move offshore.
(3) They originated from fish that belong to putative inshore substocks, but are spreading across the shelf with age. These fish may mature and spawn in the offshore.
(4) They originated from fish that belong to putative inshore substocks, but are moving onto the shelf for a period before returning to the inshore to spawn.

If there are two or more substocks or components within the 2J+3KL stock, then it might be useful to create a recruitment index for each group, especially if it is expected that the groups have different dynamics and are going to be managed differently. Because fish from the offshore and the inshore may co-occur inshore at early ages, and some fish recruit to the offshore from the inshore, there is no obvious way to use distribution alone to distinguish between individuals belonging to inshore components and individuals belonging to offshore components. Studies of current patterns and the advection of eggs and larvae into and out of bays (Laprise and Pepin 1995; Pepin et al. 1995; Pepin and Helbig 1997) provide additional insight into the complexity of distributions at very early life stages. Recruitment indices derived from deployment of various gears in coastal waters are likely monitoring an unknown and perhaps variable mixture of individuals from both inshore and offshore spawning.

Cod in 3NO and 3Ps

The distribution of cod of ages 1 and 2 on the southern Grand Bank (3NO) appears to be similar to that reported by Walsh et al. (1995), who found that catches from autumn surveys in 1989-1993 tended to be highest on and around the Southeast Shoal.

Aggregations of age 1 cod in 3NO and 3Ps appear to be distinct from those in 2J3KL. At present there is little evidence that juveniles from these southern stocks are migrating in substantial numbers into the 2J+3KL stock area. The plateau of the Grand Bank in the vicinity of the Virgin Rocks may be an area where juveniles from 3NO spill over into 3L. There is also a possibility of movement of cod from 3N into 3L along the eastern edge of Grand Bank.

Spawning populations

The identity of the spawning populations that gave rise to the juveniles caught in the autumn and spring surveys is of considerable interest but difficult to determine at present because of limited bottom-trawl and acoustic surveying during spawning periods, the absence of egg surveys, and inadequate knowledge of the drift patterns of eggs, larvae and juveniles, especially in offshore areas of 3LNOP.

Of particular interest is the distribution of the 1989 and 1990 year-classes, both of which were not particularly strong at the juvenile stage but were protected by moratoria and contributed much of the spawning biomass of the 3Ps and 3NO cod stocks in the mid- to late-1990s. These year-classes were found during spring mainly in two areas; (1) on the outer slopes of Burgeo Bank and the seaward end of the adjacent Hermitage Channel and (2) in the outer ends of the channels in southeastern 3Ps and southwestern 3O. At this time there is no indication that fish from these two year-classes have migrated in detectable numbers to the offshore of 2J3KL. These year-classes (especially the 1990 year-class) were, however, important contributors to the fish found in the inshore of 3KL in 1995-1997, as seen by their prominence in sentinel survey catches (Lilly et al. 1998) and in samples taken in 1995 from the aggregation of cod found in winter/spring in Smith Sound in inner Trinity Bay (3L) (Brattey 1997).

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Table 1. Number of fishing sets made with the Campelen 1800 shrimp trawl during multispecies bottom-trawl surveys during the autumns and springs of 1995-1999. For 1999, age reading was available for 3Ps only. Strata in the inshore of Divisions 3K and 3L were fished during the autumns of 1996-1998. These strata were not fished in 1999.

Season	Area	1995	1996	1997	1998	1999	Total
Autumn	2J	84	117	117	118		436
	3K	131	155	155	152		593
	3L	166	179	171	170		686
	3KL inshore		52	54	53		159
	3N	90	67	74	90		321
	3O	81	58	73	87		299
	Total	552	628	644	670		2494
Spring	3L		188	158	155		501
	3L inshore				8		8
	3N		82	71	88		241
	3O		86	81	93		260
	3Ps		141	127	144	140	552
	3Ps (inshore)		7	31	32	35	105
	3Pn		13	13	15		41
	Total		517	481	535	175	1708

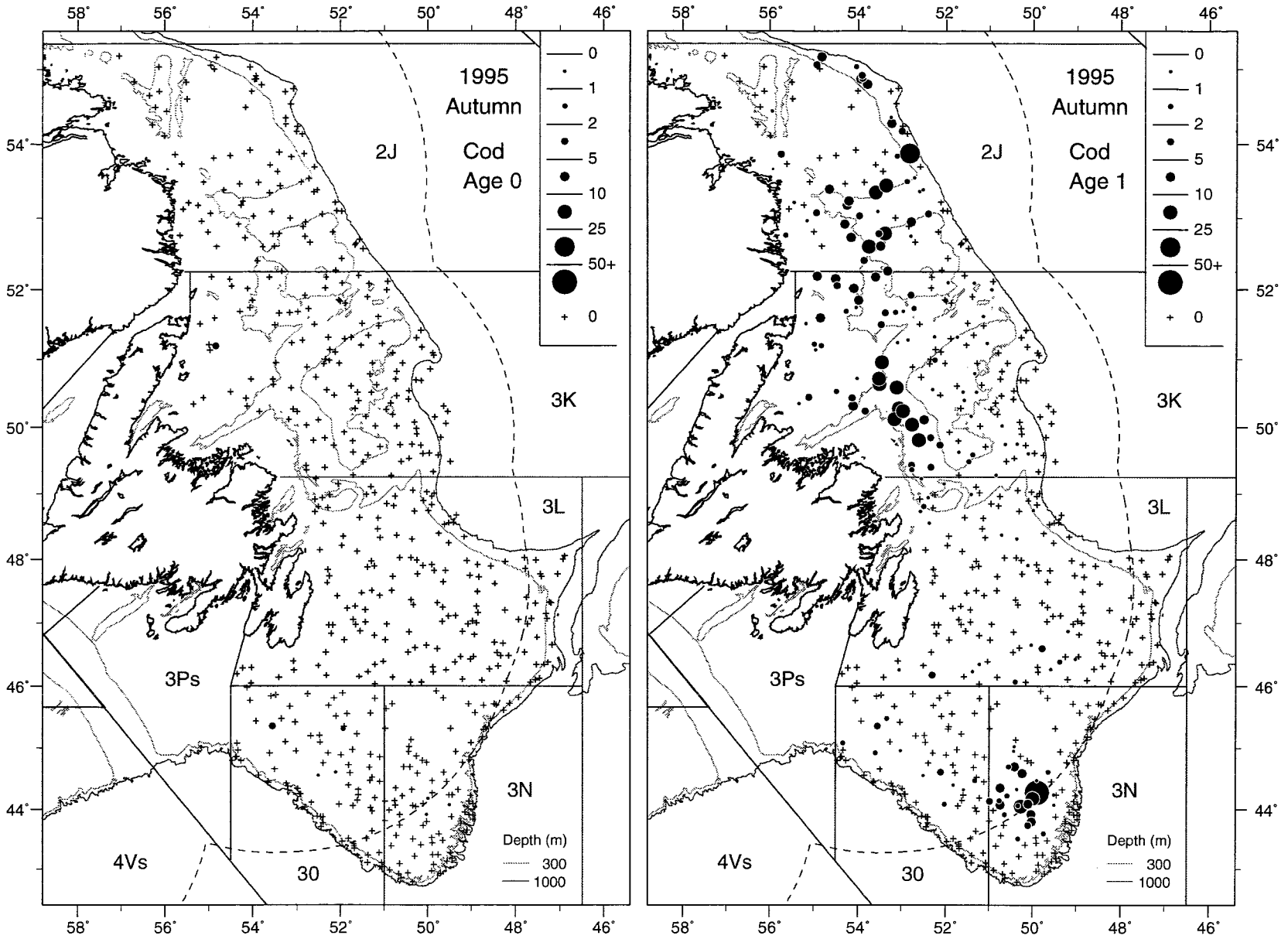


Fig. 1a. Geographic distribution (number per tow) of cod of ages 0 and 1 in Divisions 2J3KLNO during autumn 1995.

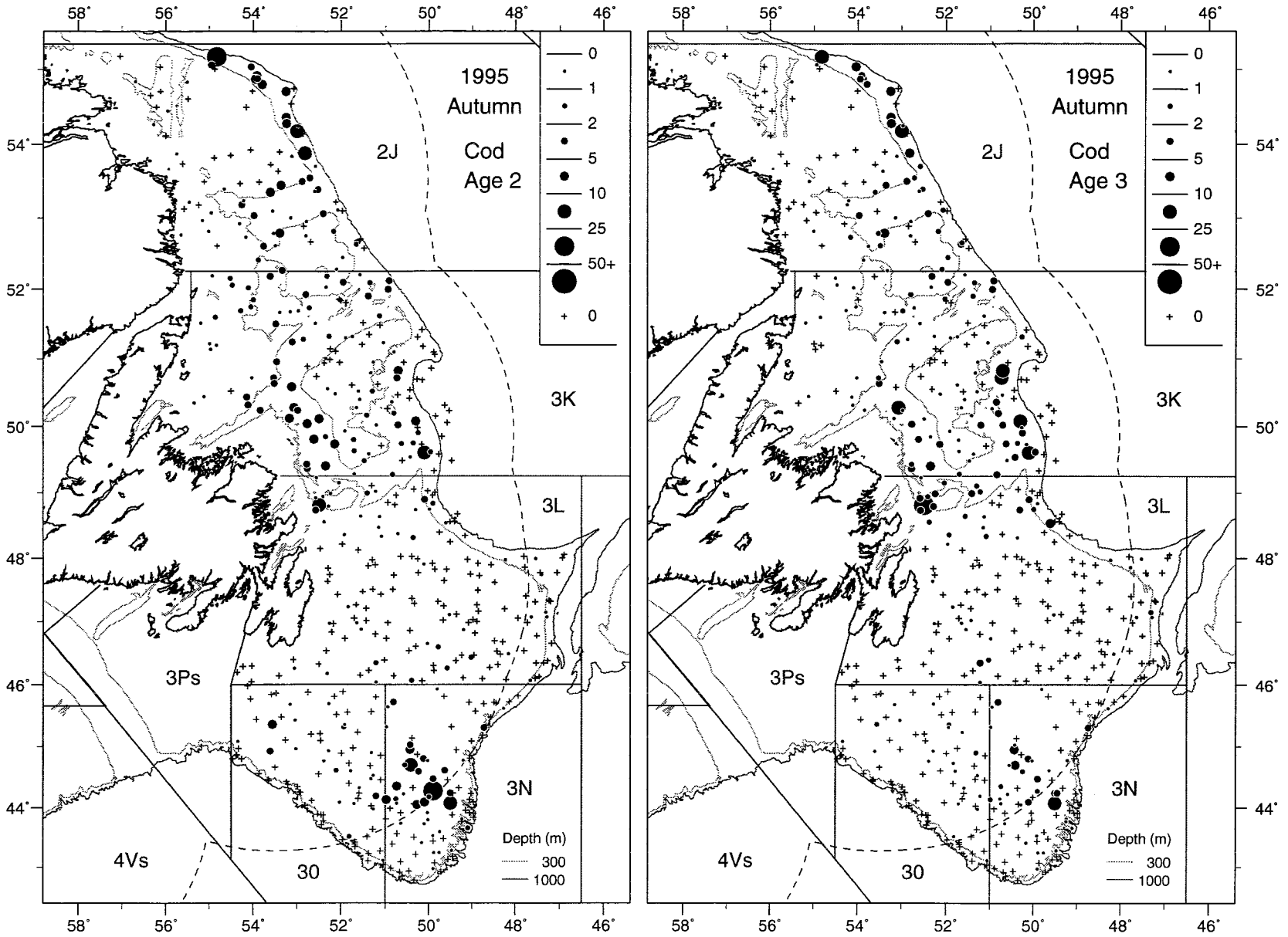


Fig. 1b. Geographic distribution (number per tow) of cod of ages 2 and 3 in Divisions 2J3KLNO during autumn 1995.

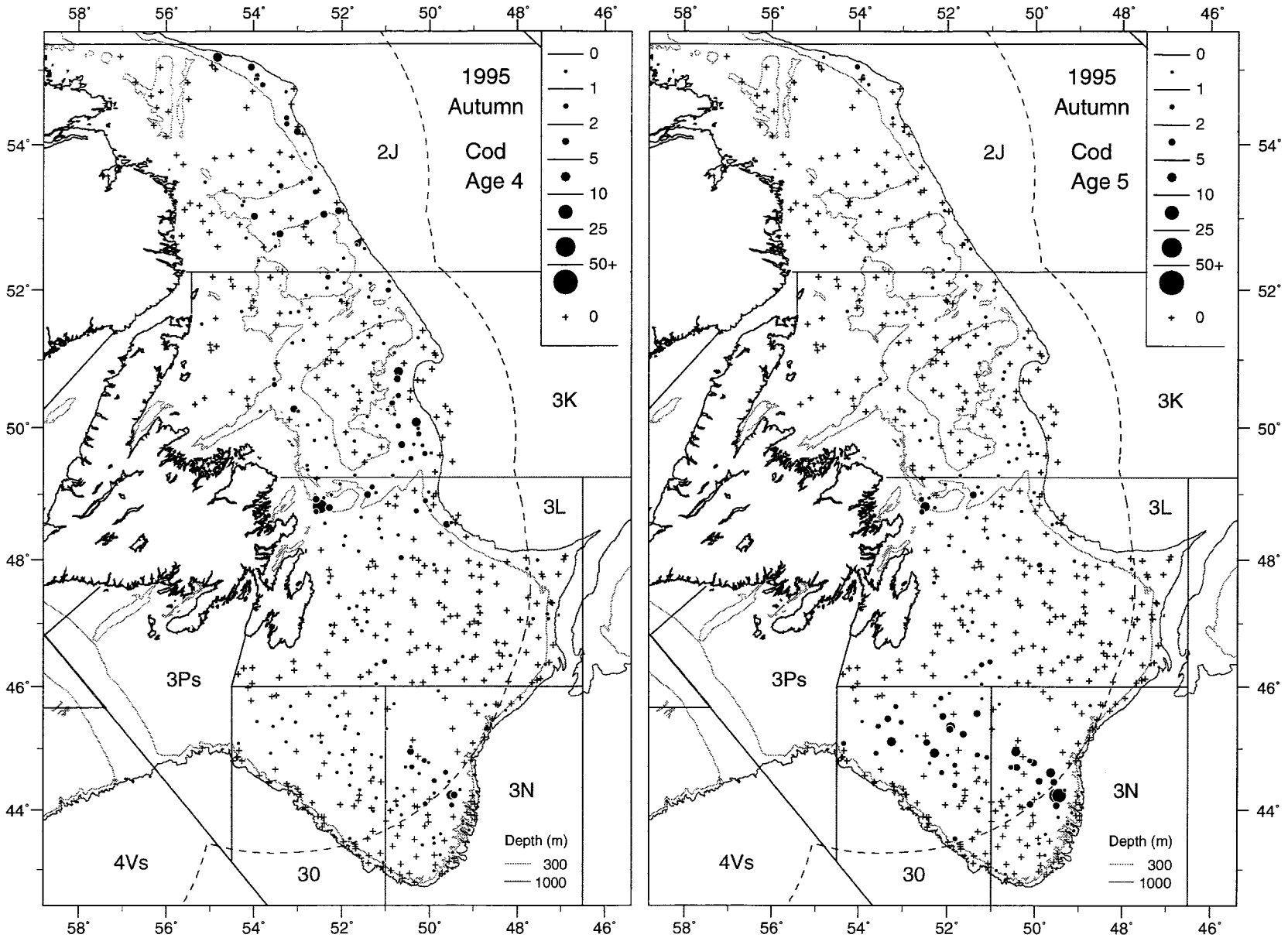


Fig. 1c. Geographic distribution (number per tow) of cod of ages 4 and 5 in Divisions 2J3KLNO during autumn 1995.

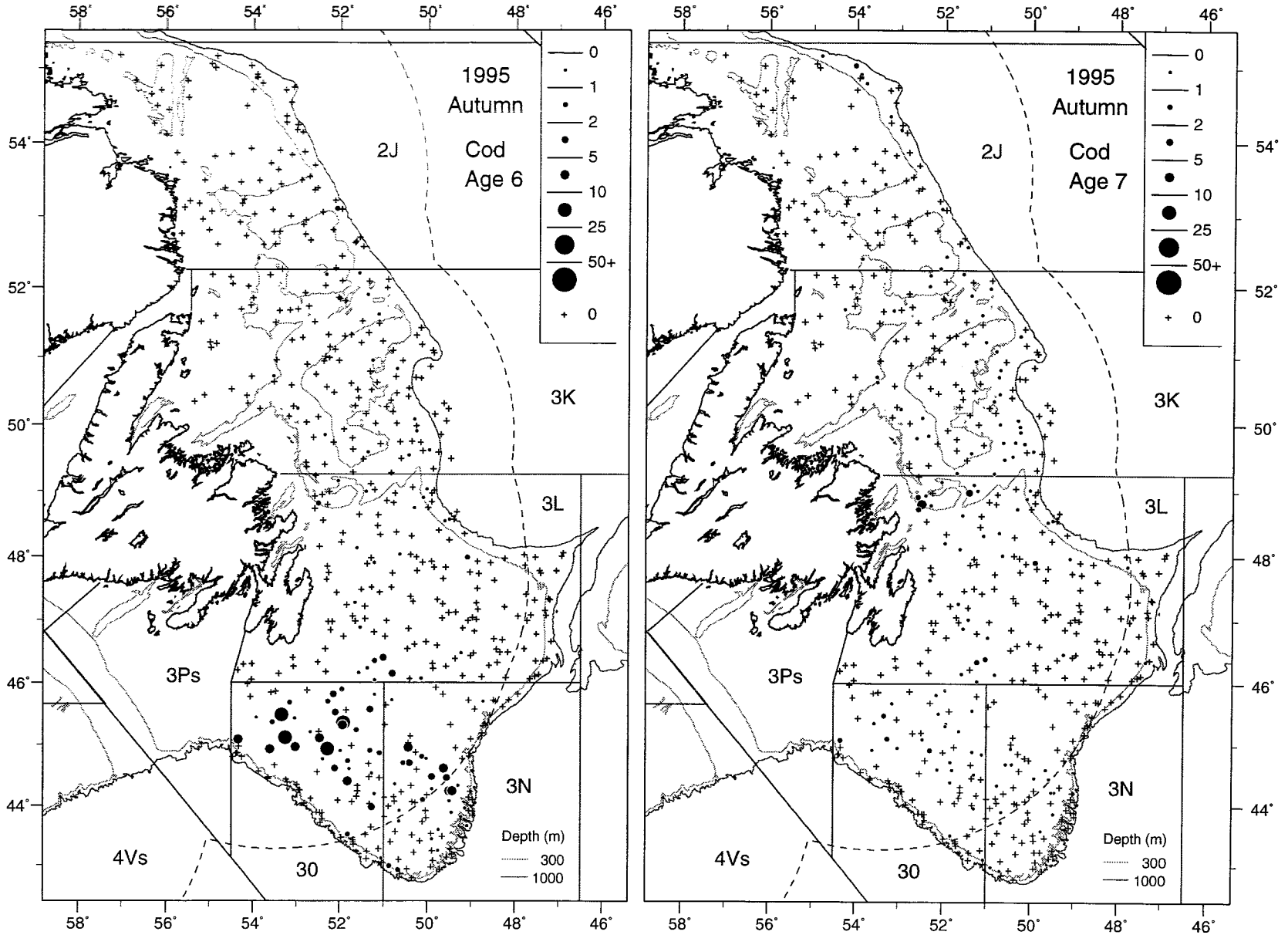


Fig. 1d. Geographic distribution (number per tow) of cod of ages 6 and 7 in Divisions 2J3KLNO during autumn 1995.

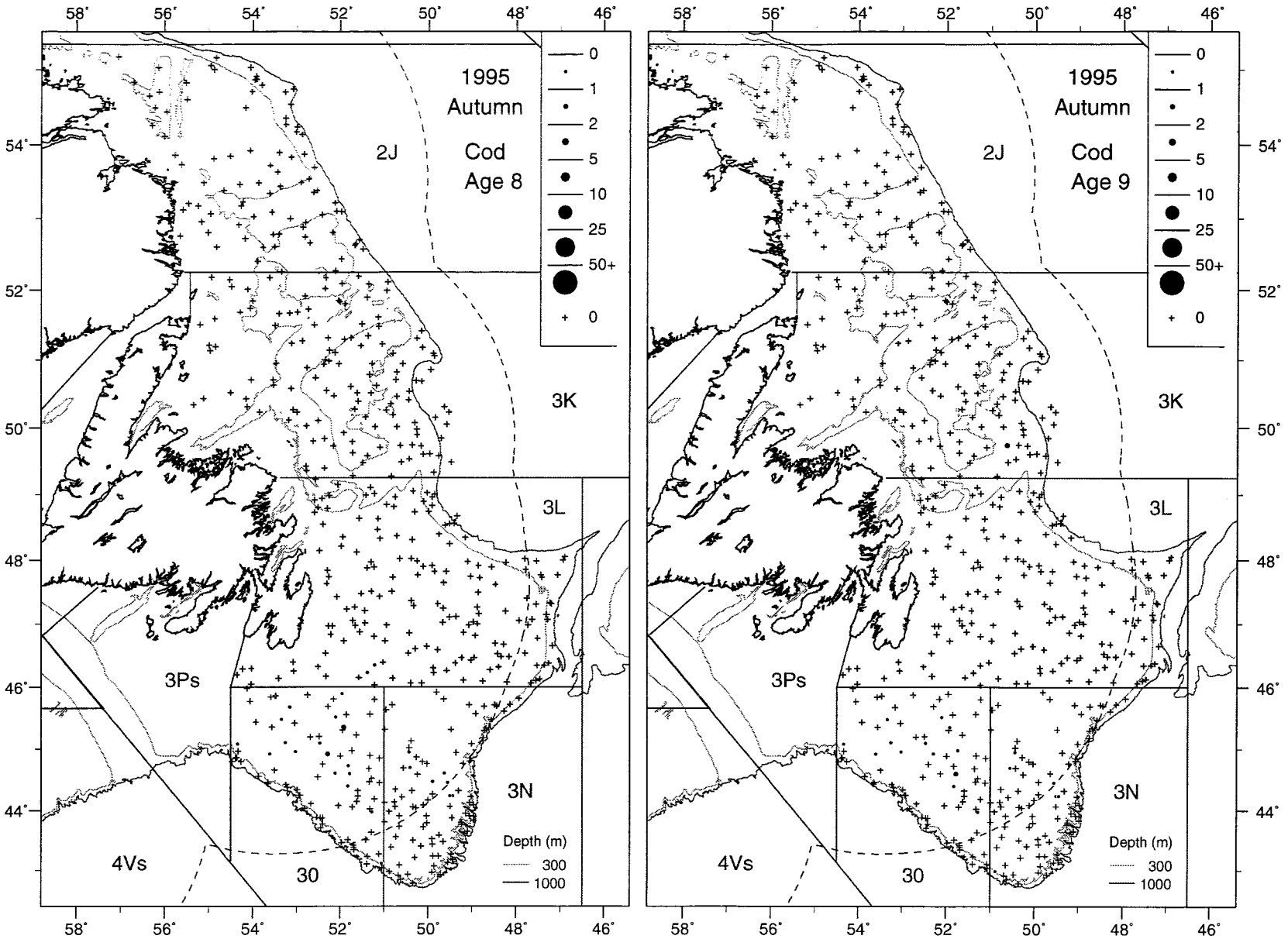


Fig. 1e. Geographic distribution (number per tow) of cod of ages 8 and 9 in Divisions 2J3KLNO during autumn 1995.

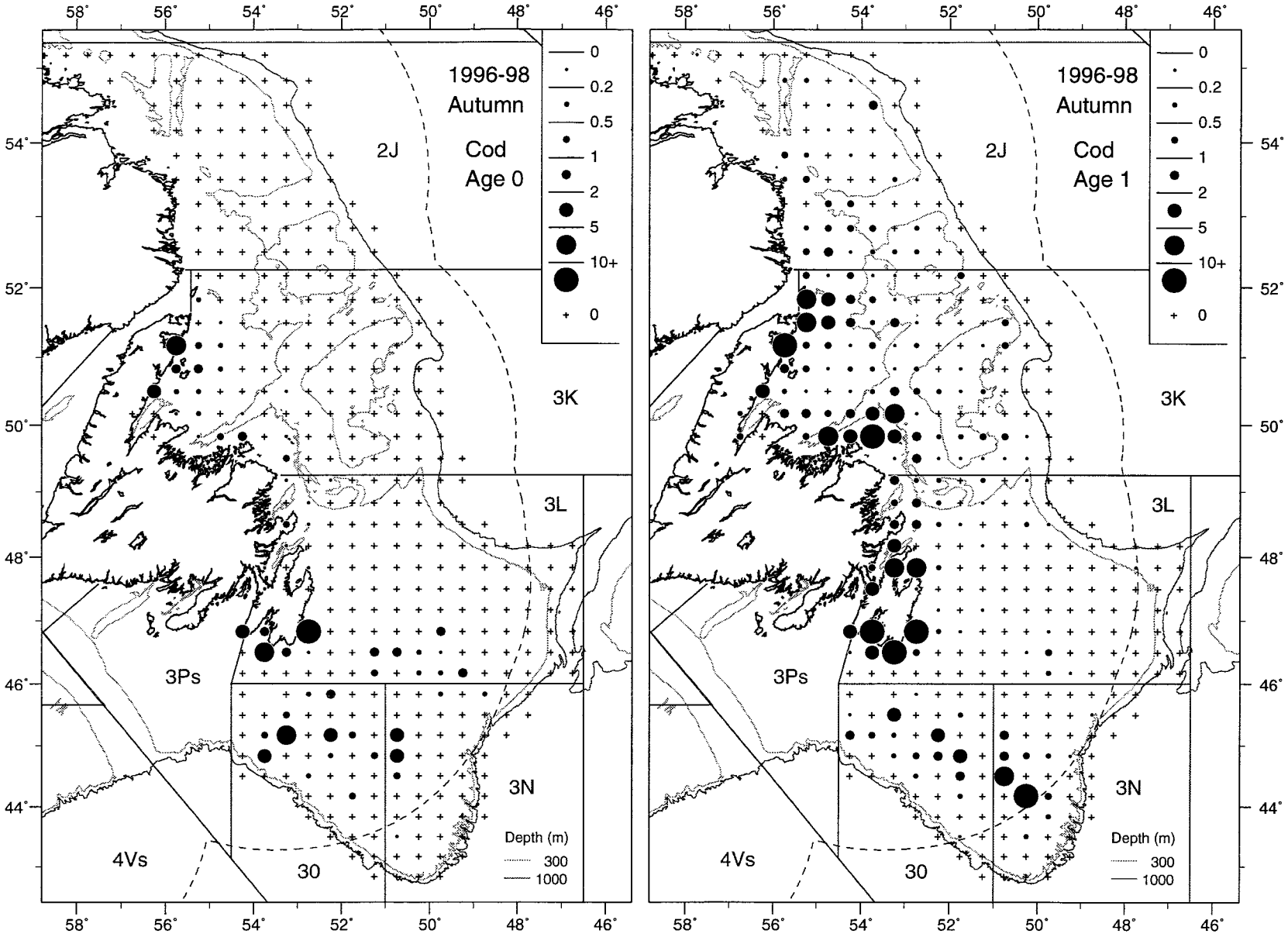


Fig. 2a. Average distribution (mean number per tow in areas of 20 min latitude and 30 min longitude) of cod of ages 0 and 1 in Divisions 2J3KLNO during the autumns of 1996-1998.

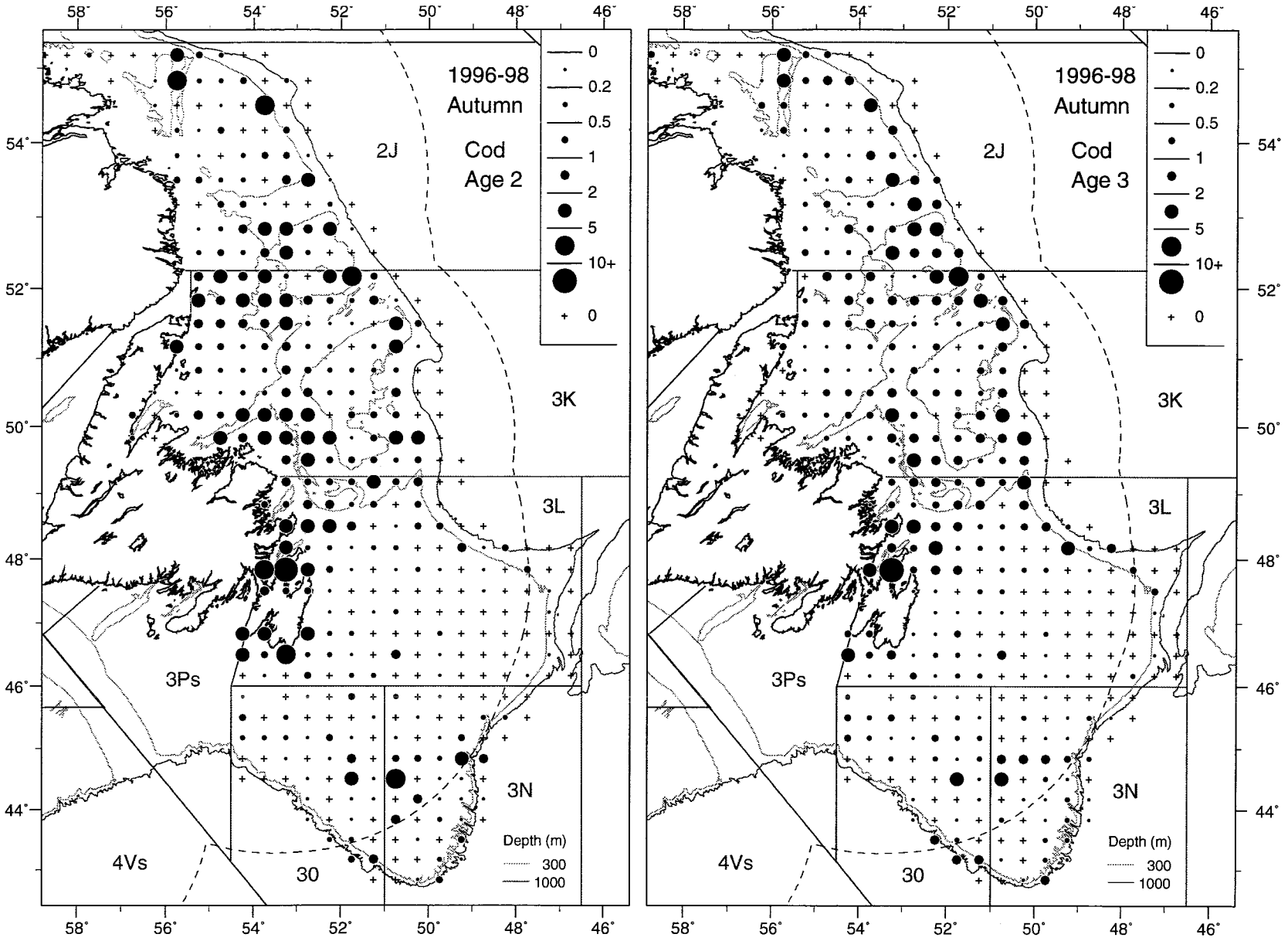


Fig. 2b. Average distribution (mean number per tow in areas of 20 min latitude and 30 min longitude) of cod of ages 2 and 3 in Divisions 2J3KLNO during the autumns of 1996-1998.

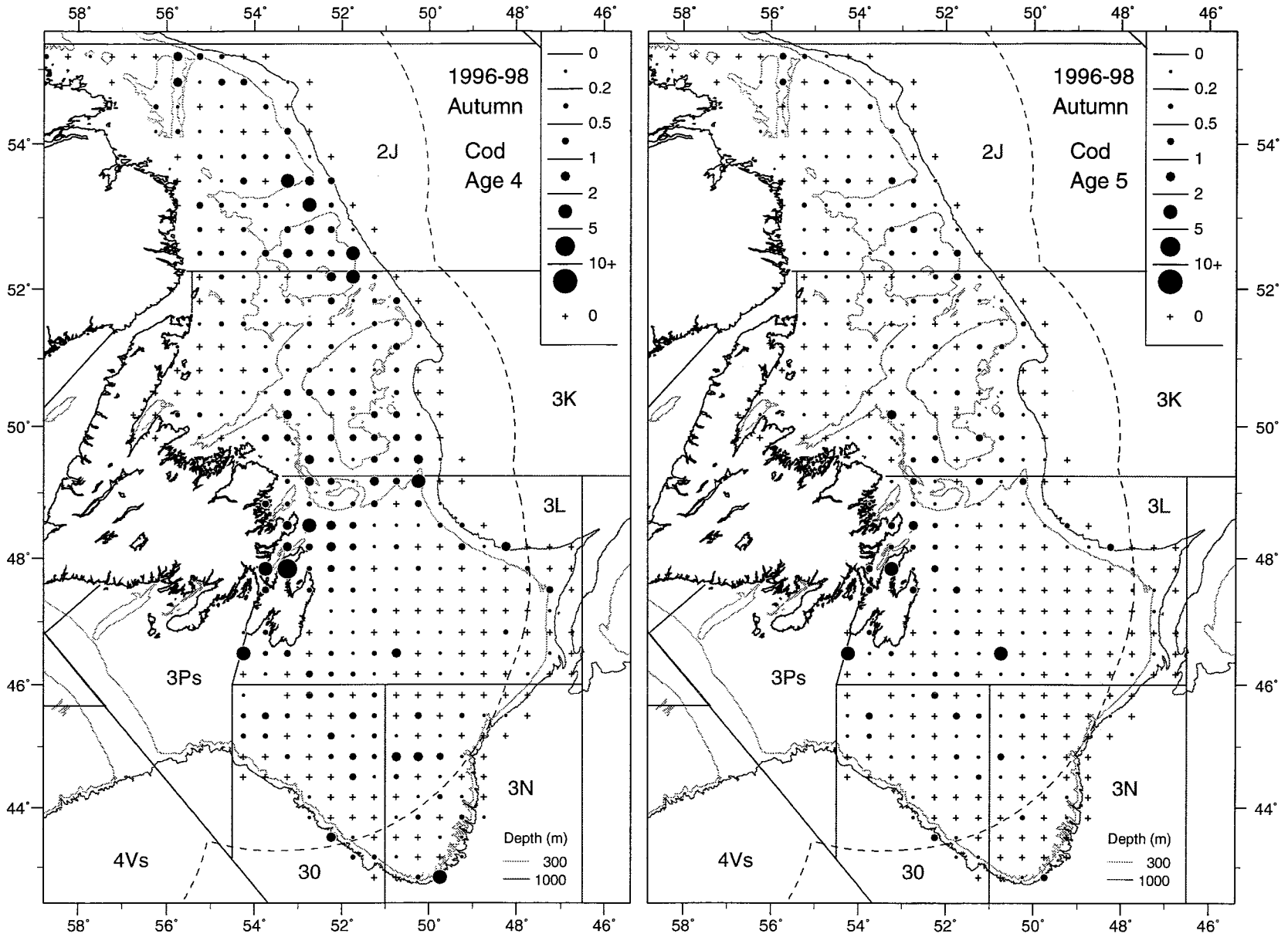


Fig. 2c. Average distribution (mean number per tow in areas of 20 min latitude and 30 min longitude) of cod of ages 4 and 5 in Divisions 2J3KLNO during the autumns of 1996-1998.

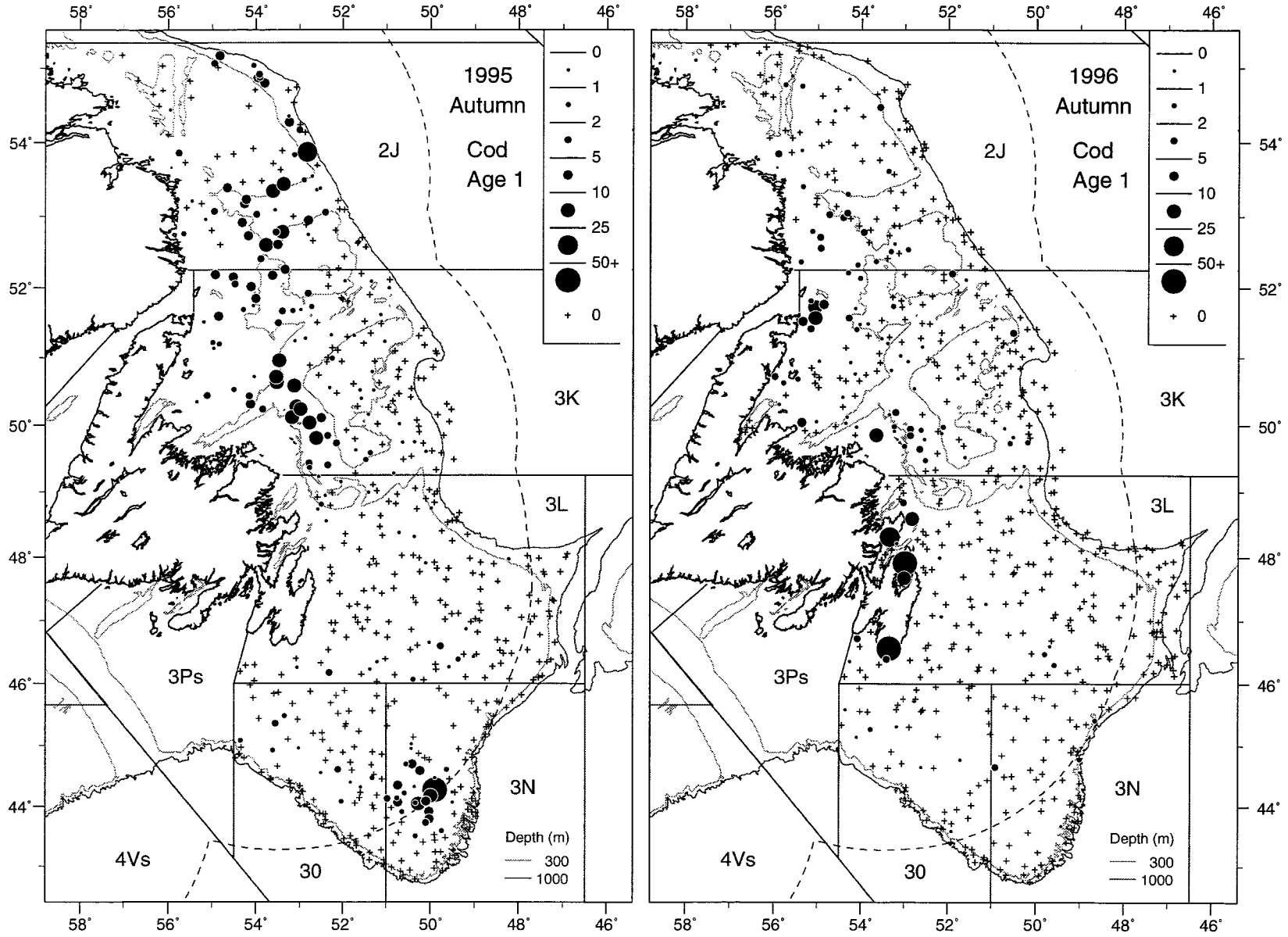


Fig. 3a. Geographic distribution (number per tow) of age-1 cod in Divisions 2J3KLNO during the autumns of 1995 and 1996.

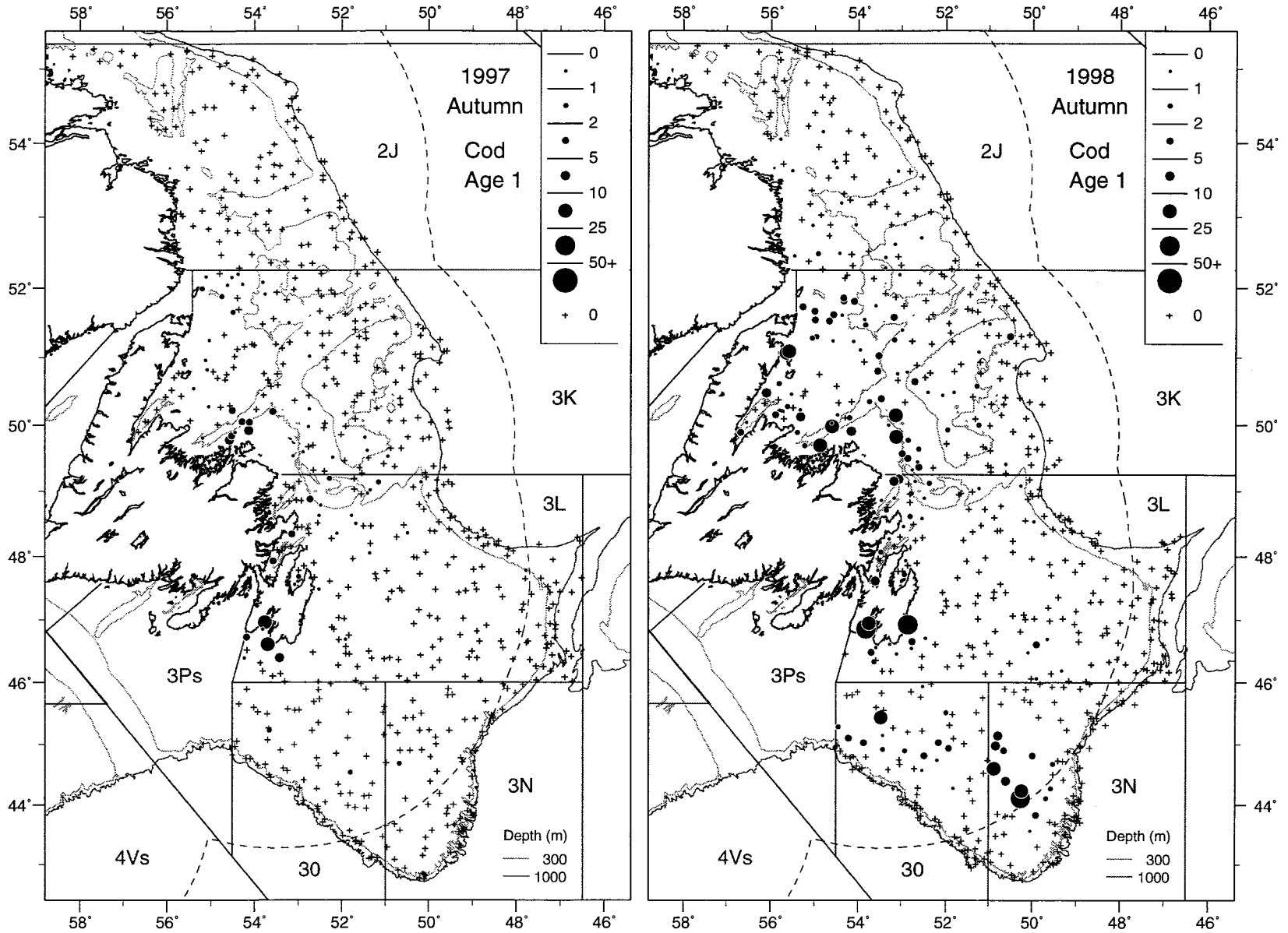


Fig. 3b. Geographic distribution (number per tow) of age-1 cod in Divisions 2J3KLNO during the autumns of 1997 and 1998.

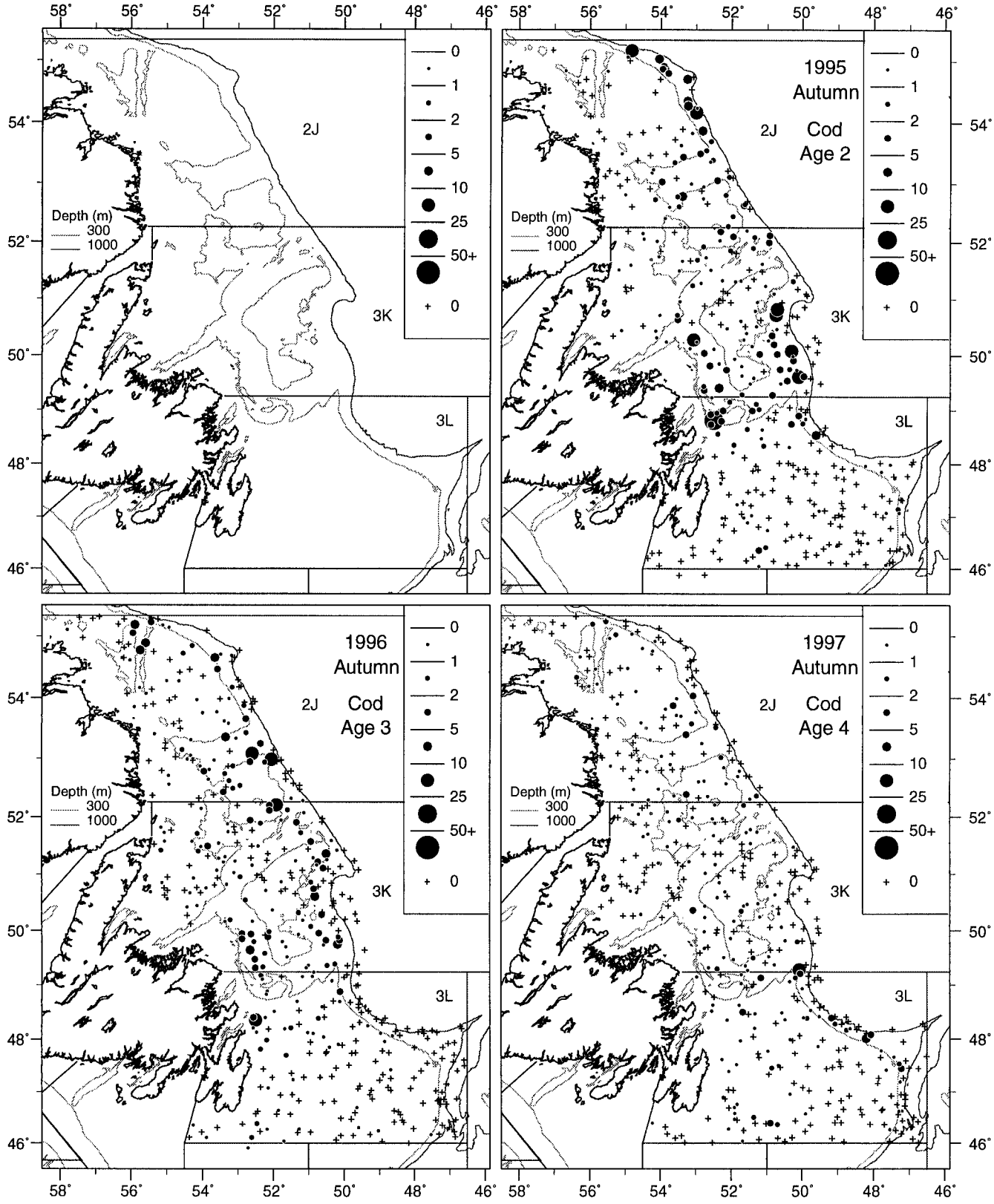


Fig. 4a. Geographic distribution (number per tow) of the 1993 year-class at ages 2-4 in Divisions 2J3KL during the autumns of 1995-1997.

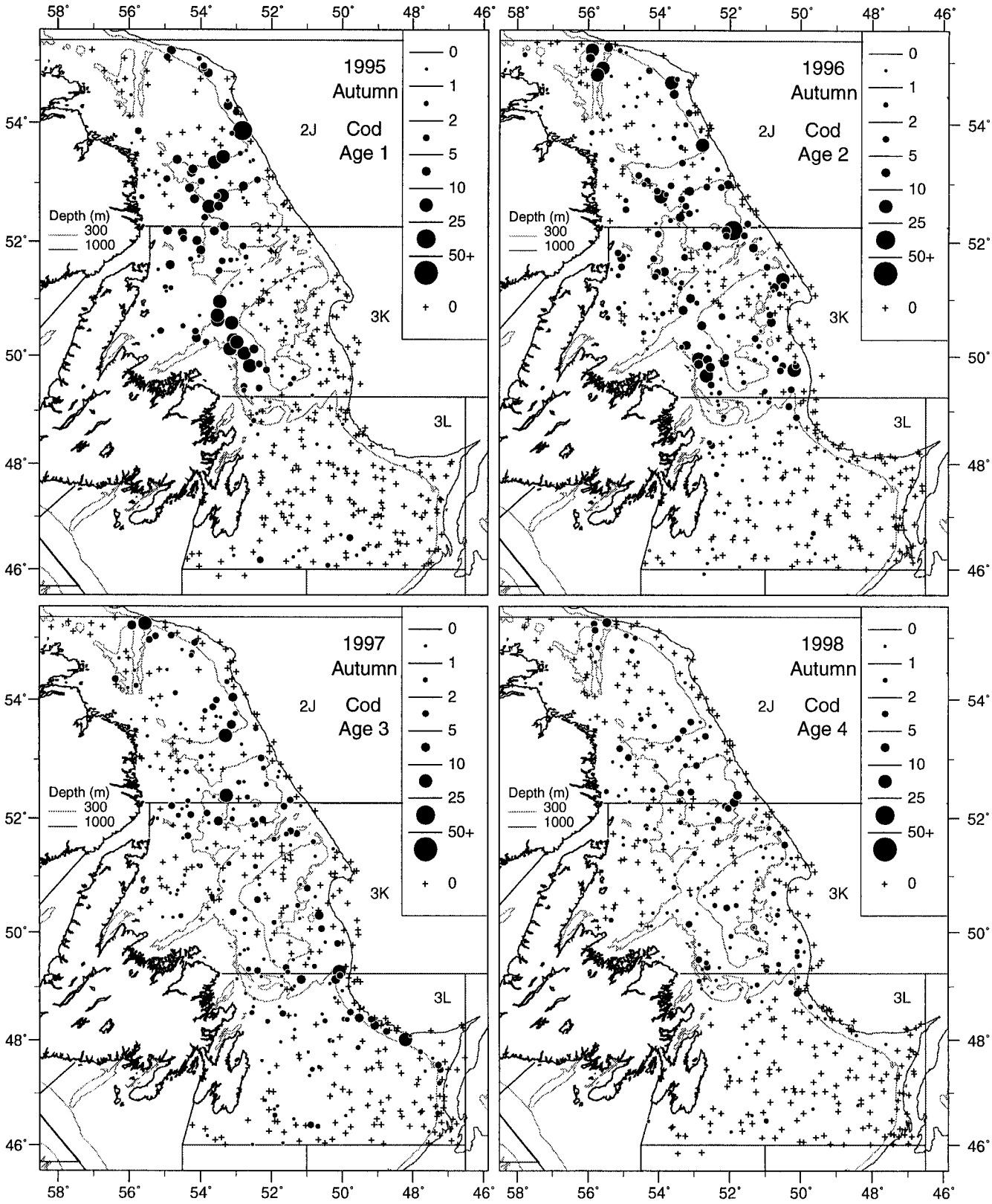


Fig. 4b. Geographic distribution (number per tow) of the 1994 year-class at ages 1-4 in Divisions 2J3KL during the autumns of 1995-1998.

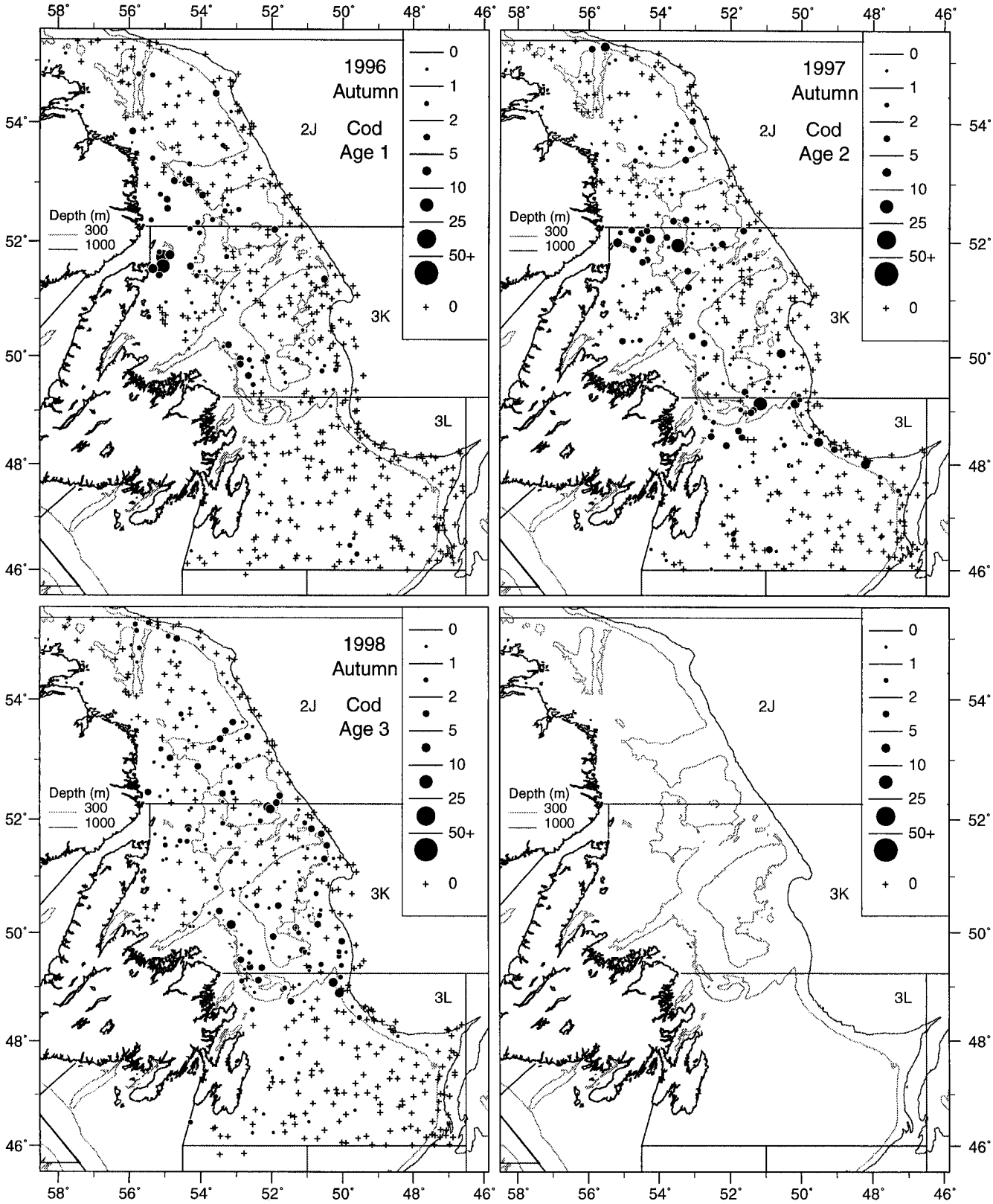


Fig. 4c. Geographic distribution (number per tow) of the 1995 year-class at ages 1-3 in Divisions 2J3KL during the autumns of 1996-1998.

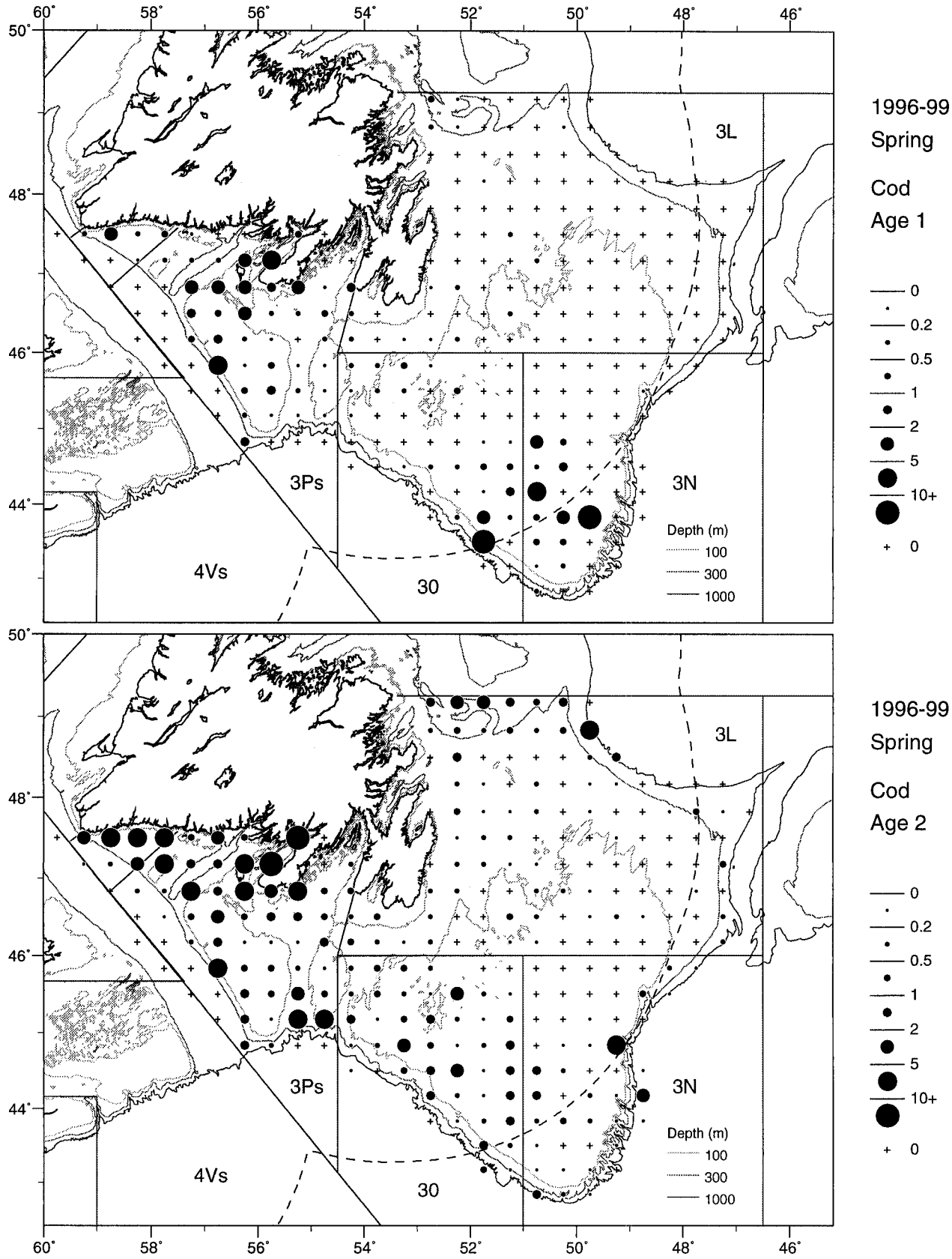
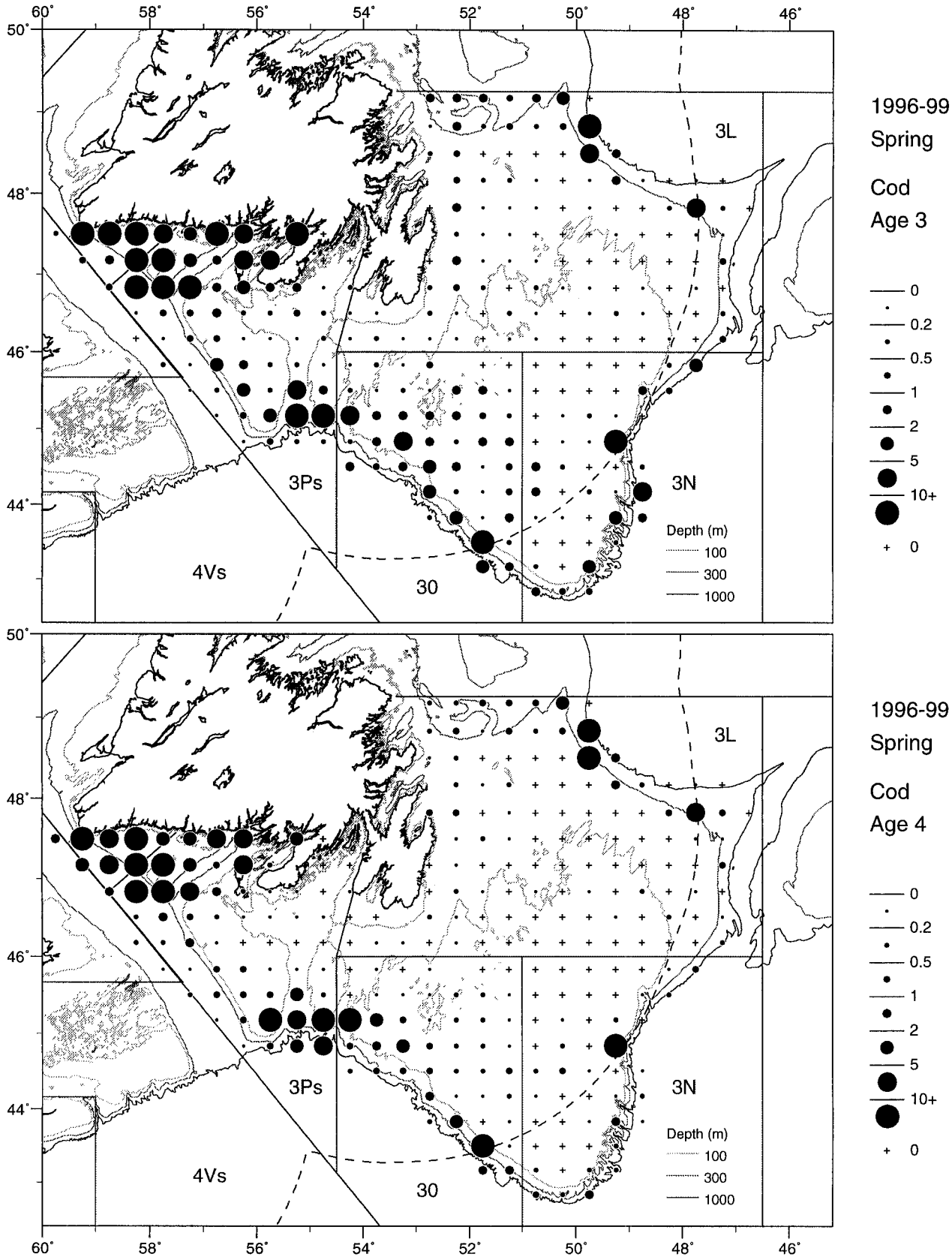


Fig. 5a. Average distribution (mean number per tow in areas of 20 min latitude and 30 min longitude) of cod of ages 1 and 2 in Divisions 3LNOP during the springs of 1996-1999. The 1999 data are for 3Ps only.



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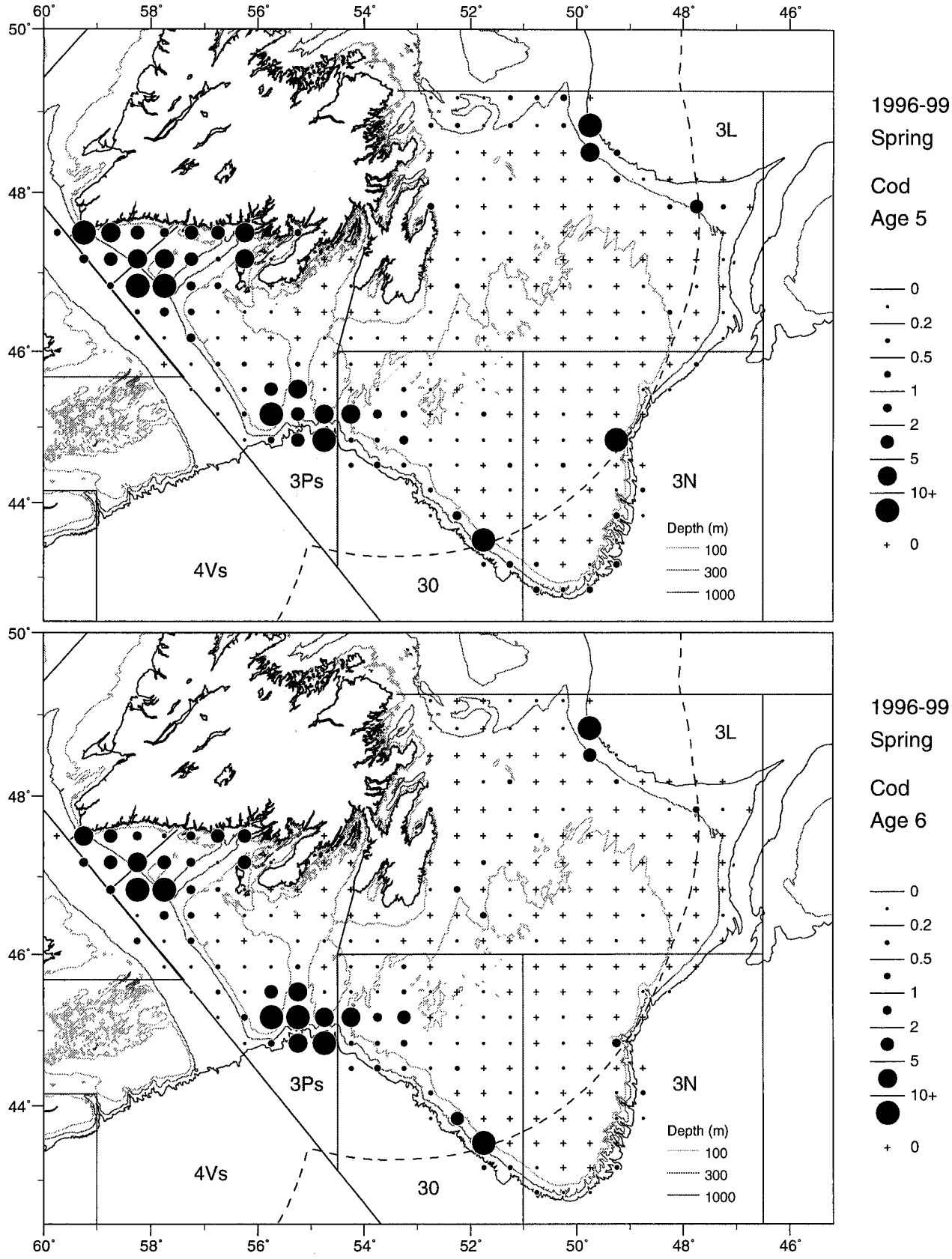

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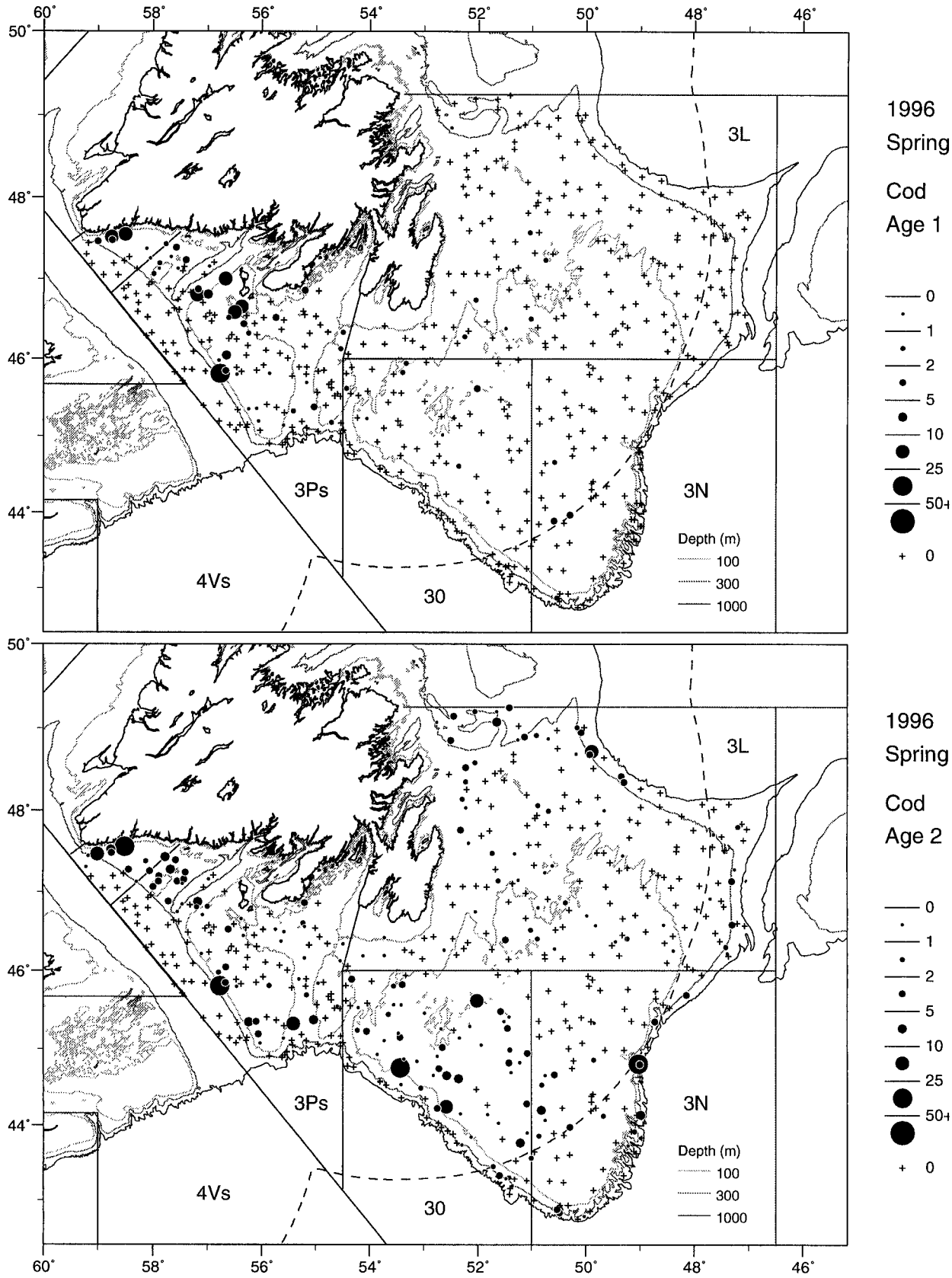
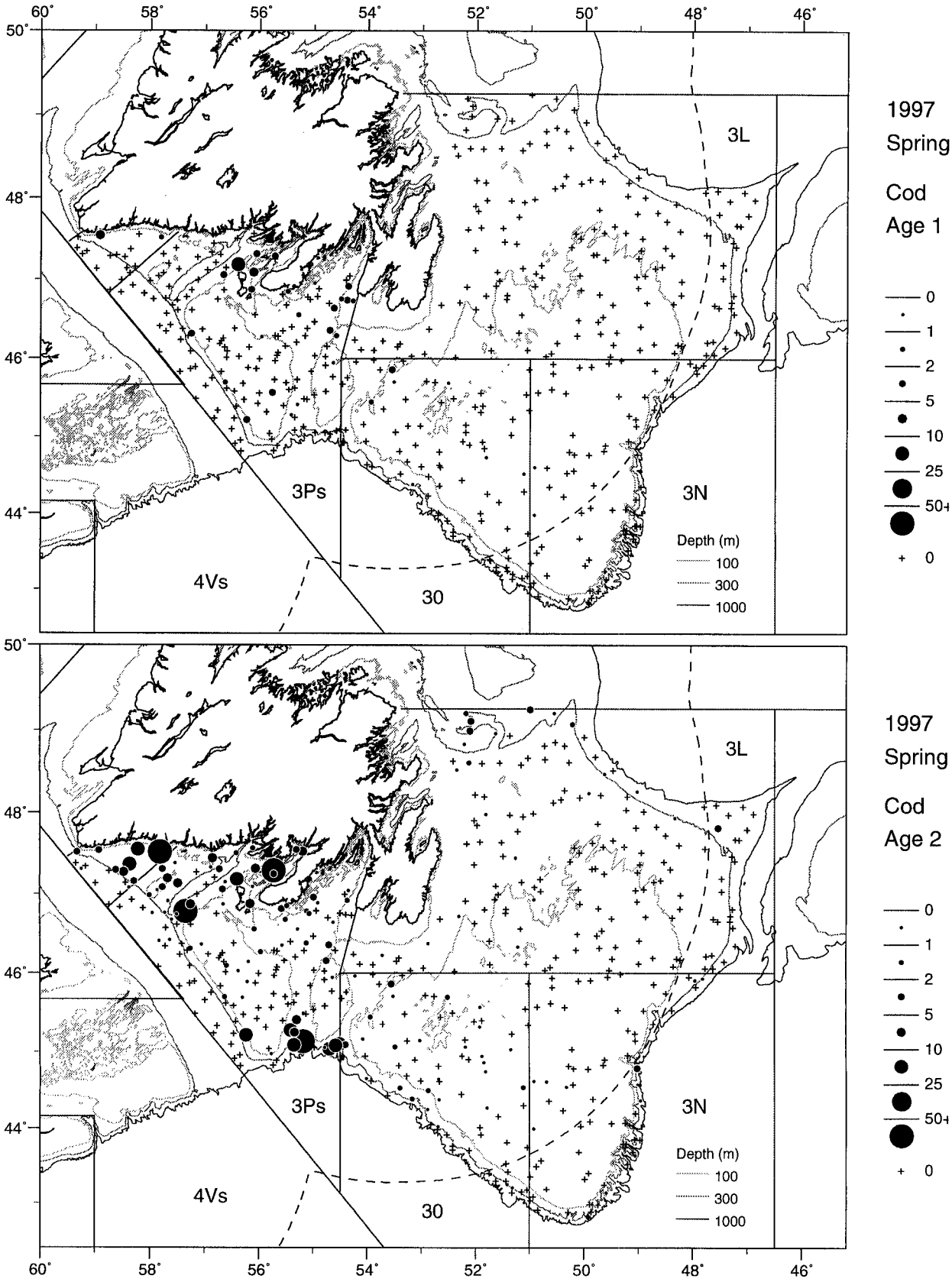


Fig. 6a. Geographic distribution (number per tow) of cod of ages 1 and 2 in Divisions 3LNOP during the spring of 1996.



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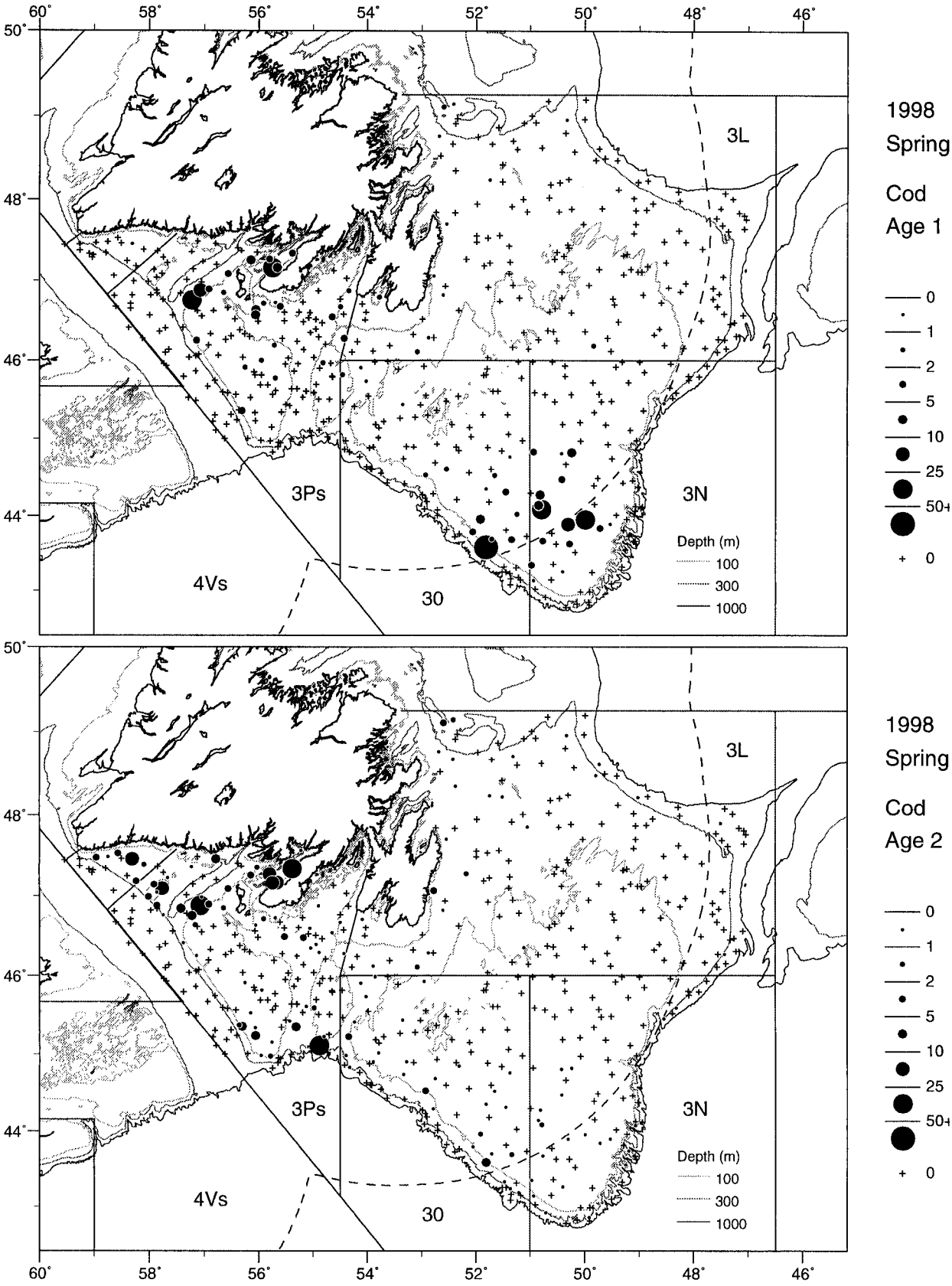

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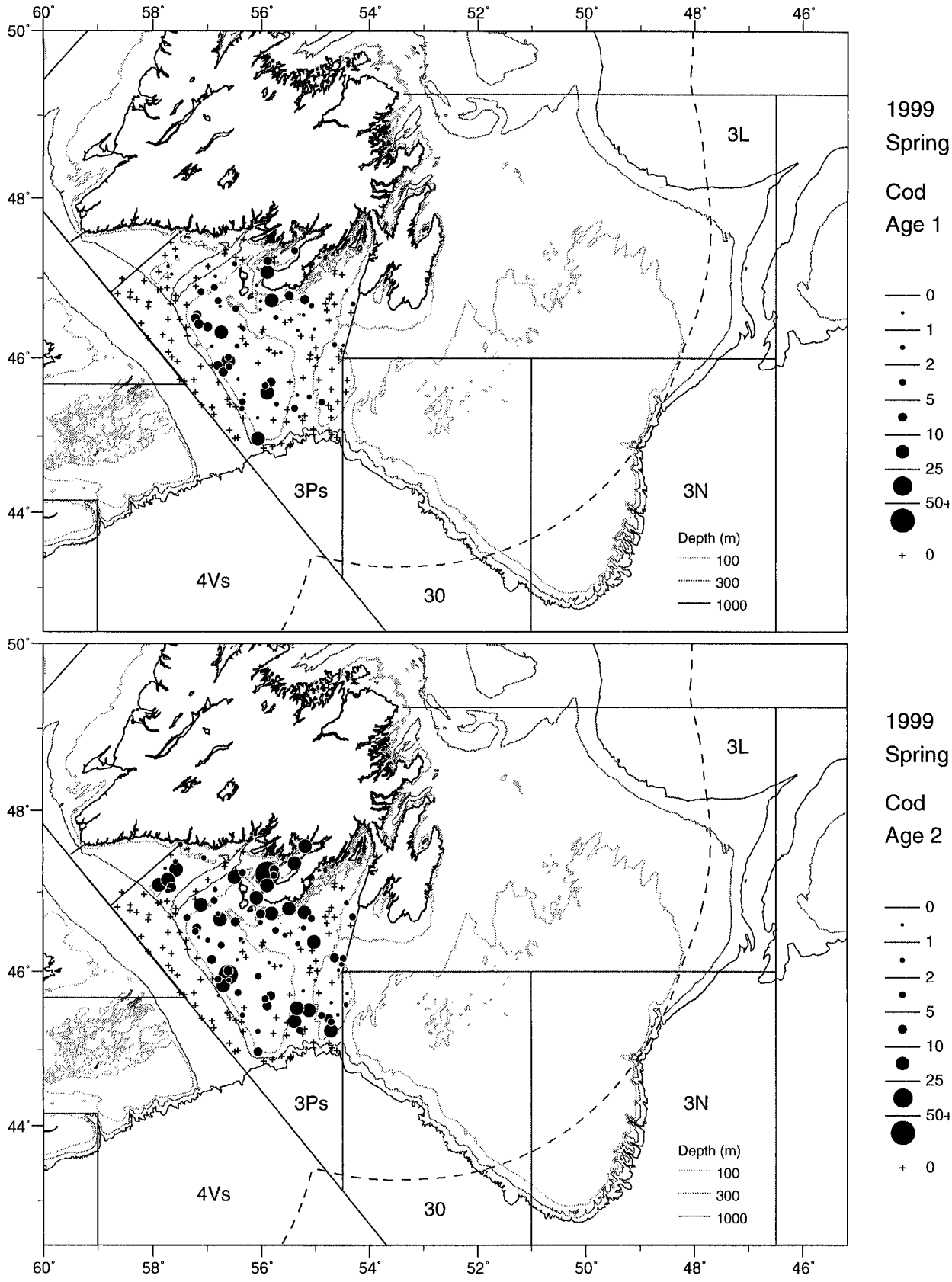


Fig. 6d. Geographic distribution (number per tow) of cod of ages 1 and 2 in Divisions 3LNOP during the spring of 1999.

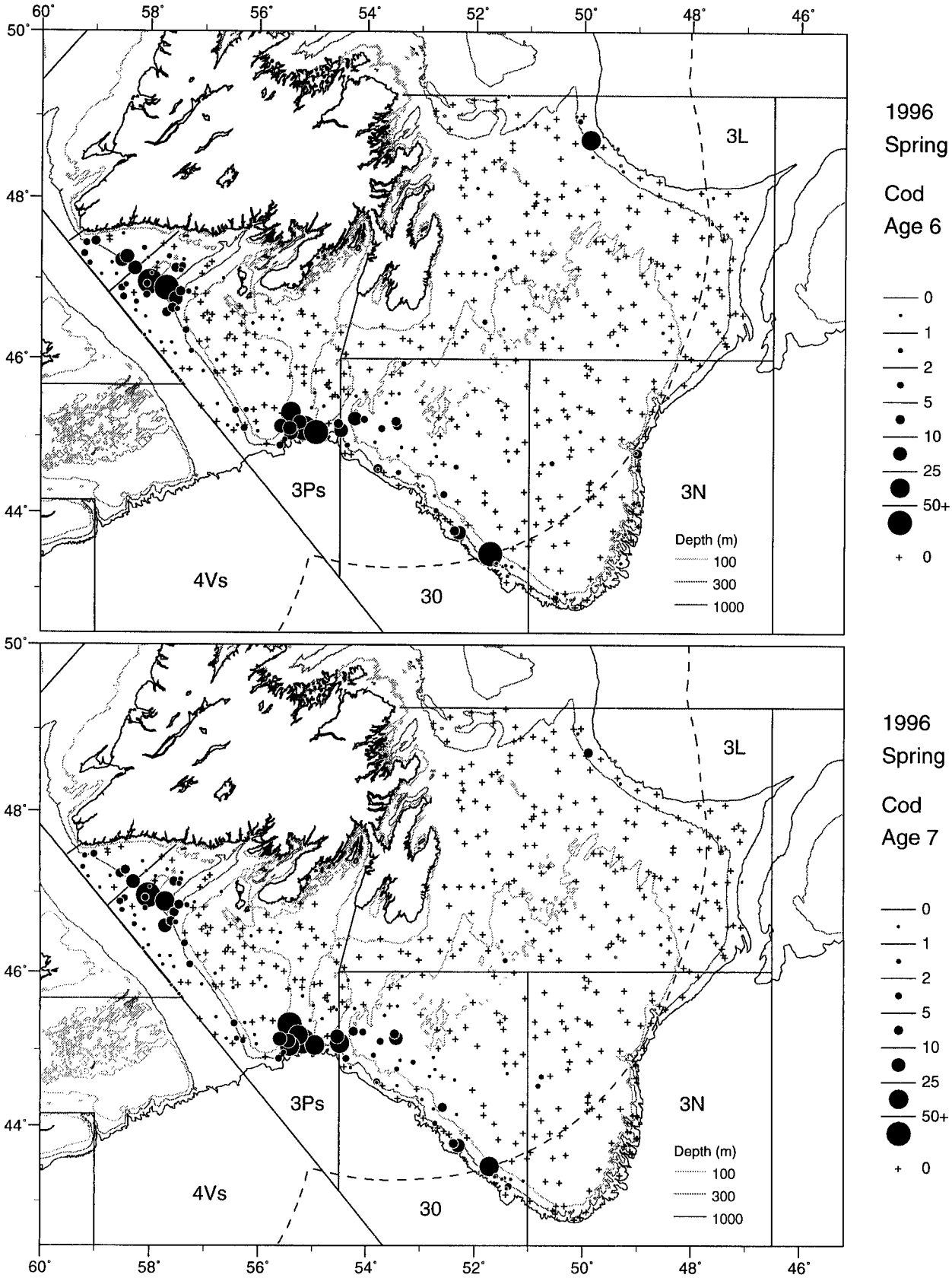


Fig. 7a. Geographic distribution (number per tow) of the 1990 and 1989 year-classes at ages 6 and 7 respectively in Divisions 3LNOP during the spring of 1996.

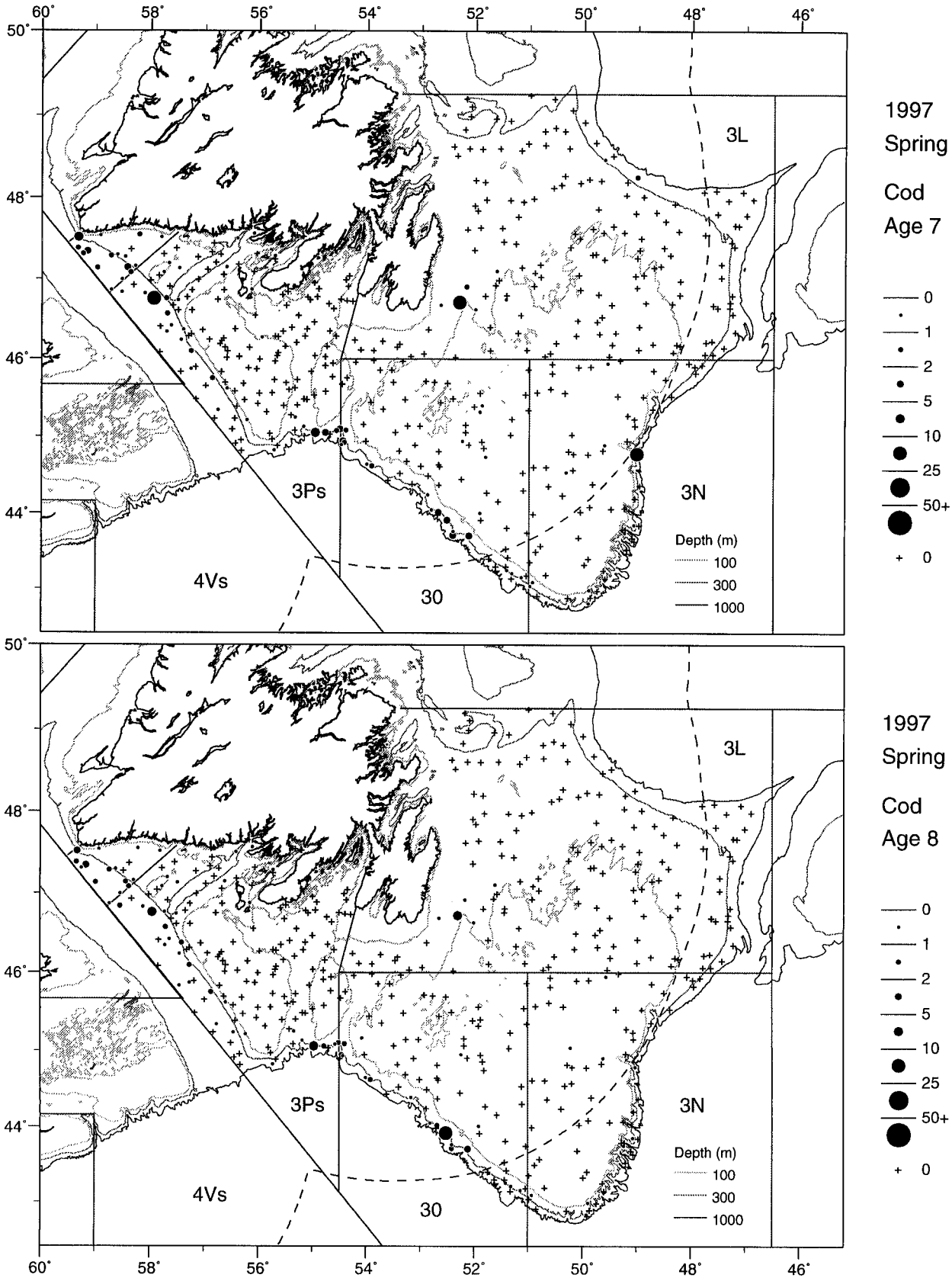
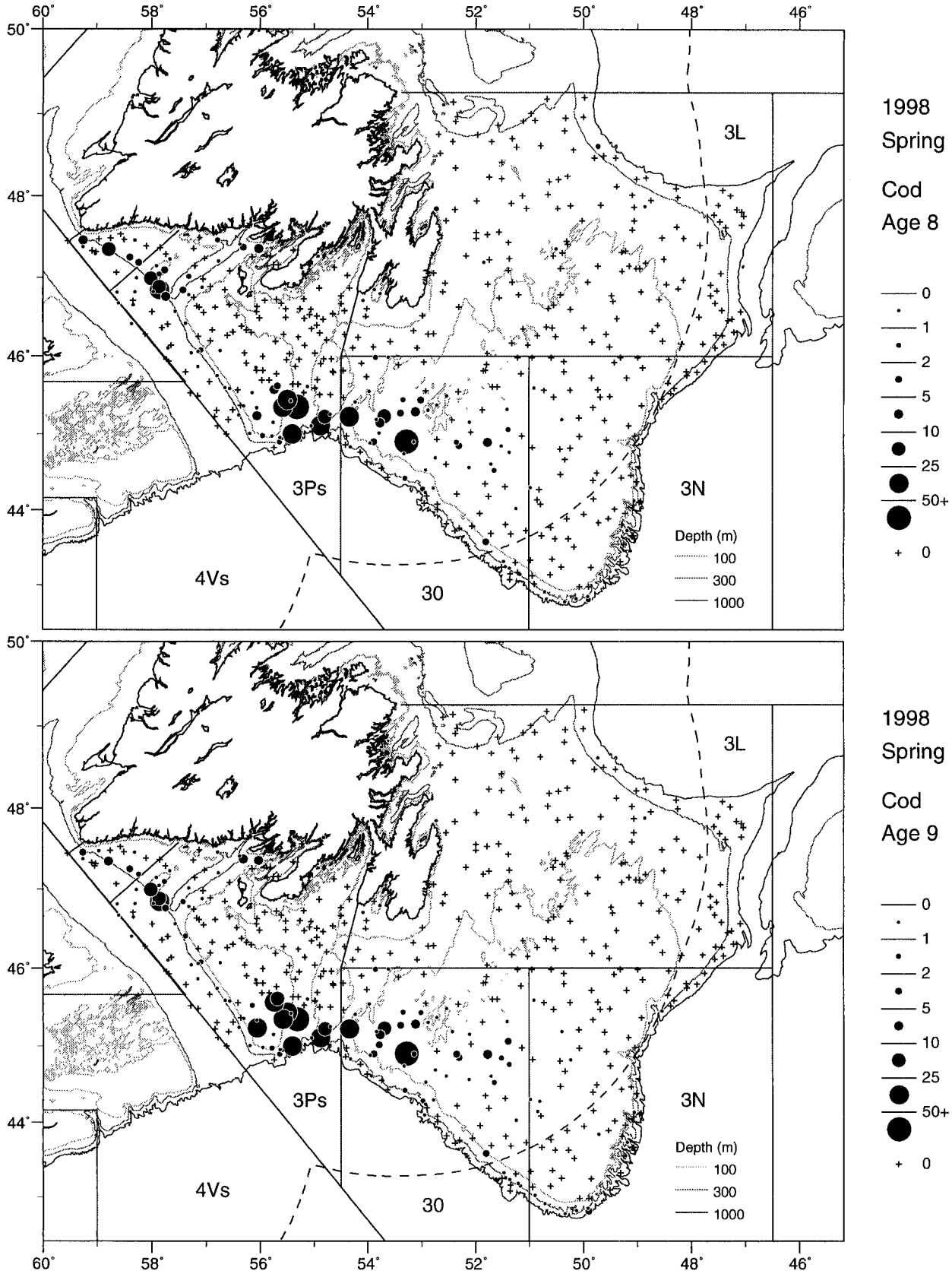


Fig. 7b. Geographic distribution (number per tow) of the 1990 and 1989 year-classes at ages 7 and 8 respectively in Divisions 3LNOP during the spring of 1997.



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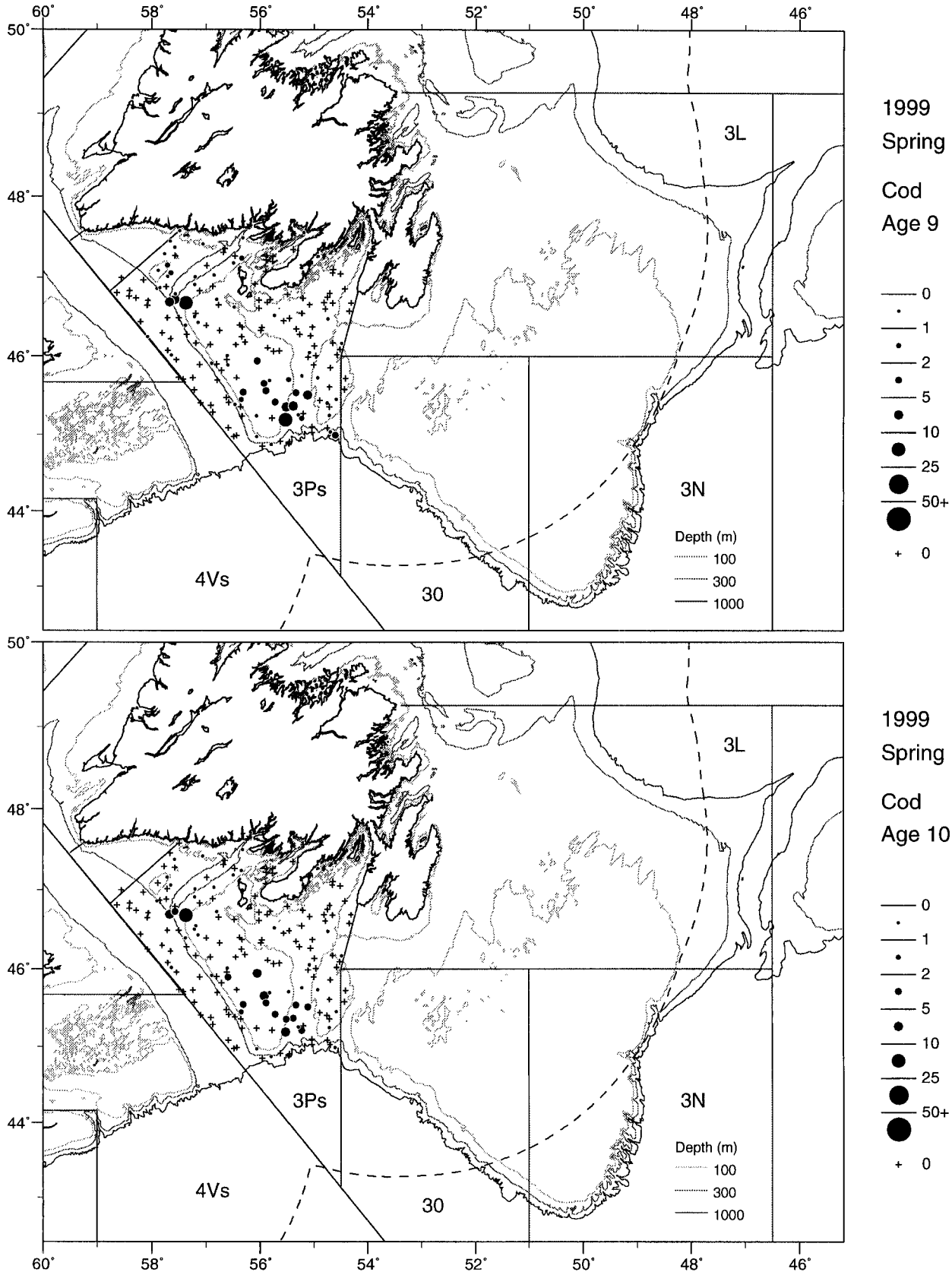

Fig. 7d. Geographic distribution (number per tow) of the 1990 and 1989 year-classes at ages 9 and 10 respectively in Divisions 3LNOP during the spring of 1999.