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Distribution and Aspects of Life History of White Hake (*Urophycis tenuis,* Mitchill 1815) on the Grand Banks of Newfoundland

by

D. W. Kulka, C. M. Miri and M. R. Simpson

Department of Fisheries and Oceans, P.O. Box 5667
St. John's, NF & LAB Canada A1C 5X1

Abstract

White hake (*Urophycis tenuis,* Mitchill 1815) is a bottom-dwelling fish distributed only in the northwest Atlantic from Cape Hatteras to southern Labrador; with dense concentrations in the Gulf of Maine, on the Scotian Shelf, in the Gulf of St. Lawrence, and on the southern Grand Banks. Over their entire range, white hakes are found at bottom depths from <50 m to about 800 m. They are mainly associated with 4-8°C ambient temperatures. On the Grand Banks, white hakes are restricted to a narrow band along the southwest edge and into the Laurentian and Hermitage Channels, where bottom temperatures are warmest (>4°C). They occupy a wide range of bottom depths along the slope out to 800 m; at depths considerably greater than what is observed in other parts of their range. White hake may be classified as "temperature keepers": maintaining a constant temperature range by changing their depth distribution. The largest year-class since 1977 was observed in 1999; first detected by an IYGPT survey and also observed in a Spanish research survey. An estimated growth rate of about 2.5 cm per month corresponds to the dominant 25-cm mode of white hakes seen in the following year's Canadian spring research survey. There appears to be some geographic separation of white hake life stages in NAFO Div. 3NO and Subdiv. 3Ps. Spawning occurs in spring (and possibly summer) along the slope of the Grand Bank, and young white hakes settle over the shallow part of the Bank. Juveniles occupy the largest area; including the Laurentian Channel where other life stages rarely occur. Assessing white hake only in NAFO Div. 3NO (in isolation from Subdiv. 3Ps fish) could bias results of stock status assessments. The purpose of this paper is to provide information on stage-based distributional dynamics of white hake on the Grand Banks and seasonal movement, in order to help determine the most appropriate management unit for this stock.

Introduction

Review of Biology

White hake (*Urophycis tenuis,* Mitchill 1815; Family Gadidae) is a demersal species distributed in the northwest Atlantic from Cape Hatteras to southern Labrador; with dense concentrations occurring in the Gulf of Maine, on the Scotian Shelf, in the Gulf of St. Lawrence, and on the southern Grand Banks (Musick, 1969, 1974; Bundy *et al.*, 2001; Hurlbut and Poirier, 2001; Kulka and Simpson, 2002). Over their entire range, white hakes are found at depths from less than 50 m to ~800 m. They tolerate ambient water temperatures from 1°C to 21°C, but are mainly associated with 4-8°C (habitat summarized in Scott and Scott, 1988).

Much of the past research on life history and distribution pertains to the southern Gulf of St. Lawrence and Gulf of Maine, and to a lesser extent on the Scotian Shelf (where white hake fisheries were important since the 1960s). Hurlbut and Clay (1990); Clay *et al.* (1992); Fowler *et al.* (1996); and Hurlbut *et al.* (1996), using distributional, morphometric and meristic studies, collectively reported the likelihood of several geographically separate components of white hake; with some overlap from the Gulf of St. Lawrence to the Gulf of Maine. The stock structure of white hake is viewed as complex, fragmented, and possibility associated with fish in adjacent areas (Fowler, 1998; Hurlbut and Poirier, 2001).

A number of studies on age and growth in the Gulf of Maine (Musick, 1969, 1974; Clay and Clay, 1991; NEFSC, 2001) and in the Gulf of St. Lawrence (Hunt, 1982; Beacham, 1983) demonstrated that white hake undergo very fast growth; which is slightly greater in females, and faster in southern areas. For example, Age 2 fish in the Gulf of Maine were found to be 34 cm at 50% maturity, and Age 4+ fish were >60 cm (O'Brien *et al.*, 1993; NEFSC, 2001). In the southern Gulf of St. Lawrence, length at 50% maturity was 44 cm, and Age 4 fish averaged ~46 cm (Hurlbut and Poirier, 2001).

White hake are among the most fecund of fish. Beacham and Nepszy (1980) noted that a 70-cm white hake in the Gulf of St. Lawrence produced 4 million eggs, and a 90-cm female produced 15 million eggs. Wenner (1983) calculated an average of 1 772 eggs per gram of body weight for the closely related longfin hake, (*Uro*) *Phycis chesteri*. Thus, this highly r-selected species has the potential to produce large year-classes from a small spawning stock biomass.

Purpose

In spite of the work cited above, much remains to be learned about white hake stock structure and life history across its entire range. Directed research on aspects of life history or stock structure on the Grand Banks in particular has been very limited where a directed fishery did not commence until about 30 years later than in Gulf of Maine and Gulf of St. Lawrence. Only four previous papers, by Muir (1978), Kulka and DeBlois (1996), Kulka and Mowbray (1998) and Kulka and Simpson (2002) report on hake distribution, abundance and fish sizes in survey and commercial catches.

Interest in white hake in Canada increased when COSEWIC (Committee on the Status of Endangered Wildlife in Canada) focused it attention in terms of risk of extinction following a decline in the abundance of in the Gulf of St. Lawrence and on the Scotian Shelf. At the same time, there was a >10-fold increase in the catch of white hake on the Grand Banks in 2003 attributable to new effort by EU-Spain and EU-Portugal in the NRA (NAFO Regulatory Area) (Kulka *et al.*, 2004). Given this large increase in catches, the Fisheries Commission (FC) of NAFO requested specific information on fishing mortality, abundance and distribution, reference points and conservation measures, size of fish and delineation of fishery areas with respect to white hake in 2004. That advice, to the extent of the available data, was summarized in Kulka *et al.* (2004).

Such stock management units are meant to delineate biological units, but this is not always the case. For example, Bundy *et al.* (2001) noted that, although white hakes on the Scotian Shelf and Bay of Fundy (NAFO Div. 4VWX/5) are managed as a single unit, potentially there is more than one biological unit; including mixing of other populations at the fringe. However, the authors note that substructure within the management unit is considered in stock assessments. Another example is the splitting of a larger population, such as was done for Greenland halibut (*Reinhardtius hippoglossoides*), for the purpose of management across political borders: e.g., Canadian versus international waters. Splitting a biological unit into one or more stock management units can bias the assessments of the parts; if there is seasonal movement across management unit borders, or stages in the life history are not evenly distributed throughout the population range (e.g., white hake).

The 2003 Fisheries Commission request for advice was specific for NAFO Div. 3N and 3O and excluded NAFO Subdiv. 3Ps, which was formerly part of the stock management area for Canadian assessments. In 2004, FC subsequently requested scientific advice for the management of white hake in Div. 3NO. By specifying advice for that area, FC implicitly set the stock management unit for white hake as Div. 3NO. However, this management unit designation was related to divisional overlap with the NRA, but is without biological basis. The Canadian management unit for white hake, Div. 3NO + Subdiv. 3Ps, was previously established based on an observed continuum in distribution over 3LNOPs: encompassing an area of similar physical conditions, shelf edge habitat with no discontinuities in terms of temperature and depth, and no evidence of any biological separation at the Subdiv. 3Ps/Div. 3O line (Kulka and Simpson, 2002).

An initial and fundamental step in examining status of a species, whether to determine appropriate levels of commercial exploitation or extinction risk, is the delineation of biological units. The request for advice from NAFO with regards to white hake on the Grand Banks is in its initial stages. Thus, it is the most appropriate time to define a management unit that will not produce biased results. As noted above, directed research on white hake in Newfoundland waters, the type of information required to delineate biological units and assess stock status, has only recently commenced, and few details of its life history there are published. However, data on size and maturity have been collected from research surveys since the 1980s. The purpose of this paper is to provide information on stage-based distributional dynamics of white hake on the Grand Banks and seasonal movement, in order to determine, if possible, the most appropriate management unit for this stock.

Methods

Survey Data

The Department of Fisheries and Oceans Canada in the Newfoundland and Labrador (DFO - NL) Region undertakes a number of fishery-independent surveys to collect biological information. For this study, survey data were derived from four sources:

1) Standard NL demersal trawl surveys (random stratified, Engel and Campelen trawl gear, Spring and Autumn, post-1970 using Yankee-41.5 to 1983, Engel-145 Hi-lift to 1996, and Campelen-1800 shrimp trawl to date)
2) Special demersal trawl surveys (same gear and effort protocol as standard survey)
3) Juvenile demersal surveys (Yankee-41 shrimp trawl, August-October, 1985-1994)
4) IYGPT pelagic surveys (pelagic trawl at 36 m below surface, August-September, 1996-2000) described below in detail.

Standard and special trawl surveys - Data on white hake have routinely been collected during stratified-random trawl surveys around Newfoundland and Labrador for the purpose of estimating biomass and abundance (STRAP). A summary of the stratified-random survey design (standard sets) adopted by the DFO-NL Region after 1970 can be found in Doubleday (1981). While survey design has remained constant, additional strata have been included in recent years along with modifications to some of the original strata. An accounting of these modifications up to 1994 can be found in Bishop (1994). One of the recent significant changes in the surveys is the addition of shallower and deeper strata after 1993 although sets at depths <50 m were occasionally recorded in earlier years (Table 1). Table 2 enumerates catches of white hake by year and depth and the potential affect of additional shallow and deep strata, introduced since 1996 are discussed.

The most significant alteration in NL survey design was a change in gear in the autumn of 1995, from Engel 145 High Lift Otter (demersal) Trawl to Campelen 1800 Shrimp Trawl. McCallum and Walsh (1996) and Walsh and McCallum (1996) described the geometry and specifications of the two gears. In addition to gear dimensions, the mesh size was different – 160 mm in the bellies and codend for Engel and 40 mm for Campelen. Visual analyses verify that the two gears capture different size ranges and composition of white hake. While size based conversion factors for amounts of fish caught were derived from comparative surveys for the major commercial species, this exercise was not done for "minor" species, including white hake. Thus, the catch rate data and resulting biomass and abundance indices must be considered as separate indices, differently scaled. The change in gear occurred in the autumn of 1995. The change in scale is delineated on the various tables by spatial separations and on the figures. Table 1 enumerates the Engel and Campelen survey sets by NAFO Division, survey season and depth.

In addition to the proportional allocation of the random-stratified sets used for STRAP estimates, extra sets using the same gear and effort (tow time) were done on occasion, apart. These were done primarily to survey redfish, mainly in the vicinity of the Laurentian Channel and for diurnal studies at other locations on the Grand Bank. Those extra sets are particularly useful for delineating autumn distribution of white hake along the southern St. Pierre Banks and Laurentian Channel (NAFO Div. 3Ps), an area not covered by the standard survey in the autumn. Table 1b and 1d show the total sets, standard plus special used for mapping white hake and Table 2 enumerates sets containing white hake catches.

Primarily due to the addition of new strata, the total surveyed area has changed over the years. From 1996 to date, the area surveyed was ~295 000 km^2, in 1994-95 it was 283 000 km^2 and from 1986-1993 was 255 000 km^2. CTD, BT, or XBT gear was used to record bottom temperatures at all tow locations. These data were used to examine the relationship between hake distribution and bottom temperature.

Juvenile surveys: The Grand Bank, within NAFO Div. 3LNO, was surveyed in August to October 1985-1993, using a Yankee-41 shrimp trawl with 38 mm mesh in the bellies and codend (i.e., more efficient at capturing small fish than the Engel gear used for standard Canadian surveys). Only a limited number of white hake were measured during this survey, 73 length frequencies from 1989-1992, and is used as an extra source of information on summer/autumn distribution of juvenile fish. Table 3 enumerates the juvenile survey sets, all of which occurred on the bank at depths of 39-260 m (average 91 m).

IYGPT (Pelagic) surveys: The IYGPT (International Young Gadoids Pelagic Trawl) survey took place on the Grand Banks in 1996-2000. The survey has since been discontinued, but contains some valuable information on the pelagic (newly-hatched) stage of white hake. This short survey series, taking place ~30 m below the surface in August-September on the Grand Banks, covered NAFO Div. 3LNO, but not Subdiv. 3Ps (Dalley and Anderson, 1997, 2000). This survey was used as source of information on recruitment (pelagic young-of-the-year), and is compared to Campelen results after the fish have settled. Table 4 enumerates the sampling effort. White hake captured were measured for total length.

Analyses

Standard sets from the seasonal surveys, spring and autumn (see Table 1a and c) are used to estimate index of abundance (STRAP2) and biomass**,** while a combination of the standard and special sets are used to map the distribution. Eighty-two percent of sets containing white hake were sampled for length by sex in both spring and autumn trawl surveys in Div. 3L, 3N, 3O, and Subdiv. 3Ps (spring only), and those samples were used to estimate numbers at length using STRAP1 (Smith and Somerton, 1981). STRAP estimates biomass (and numbers of fish) by areal expansion within each of a series of pre-defined strata added over the survey area. Estimates based on sets from strata that have been surveyed throughout the years compared to estimates that include deep water and inshore strata (which have been added in recent years) yield very similar results for white hake (refer to Kulka and Mowbray, 1998)**,** and thus no adjustments for these changes are necessary. Therefore, data from the new strata are included in the estimates of recent years.

Stage-based analyses, including a stock recruitment relationship and stage-based distribution**,** integrate information on length and maturity collected for each sex during standard research trawl surveys. The focus of this analysis is on years when a Campelen trawl was used (1996-2004), since it captures a wider range of sizes**;** including small juveniles (recruits). Maturities, recorded for most research survey sets (about 97%), were used to calculate maturity ogives and length at 50% maturity (L_{50} = length at which 50% of the fish were sexually mature) by sex for each Campelen year in the combined Div. of 3NO, 3NOPs, and Subdiv. 3Ps. In addition, for historical interest, white hake maturities available for Engel trawl years (1988-1992) are included here; although a paucity of data only allowed ogives to be calculated for 1989 and applied to other Engel years.

A GIS - SPANS was used to investigate the spatial distribution of white hake with survey data. Potential mapping in SPANS (Anon., 2000) transforms points (kg per tow) to density surfaces (areas of similar kg per tow) by placing a circle around each point and averaging the values of all points that fall within the circle. The circle size selected (12 km diameter) provided complete coverage of the survey area while minimizing gaps in the density surface, and thus maximizing spatial resolution. The study area periphery was isolated using a ‘cookie cut’ technique (referred to as a basemap cut in SPANS). This resulted in a density surface bounded on all sides by either land or the 1000 m depth contour. The resulting map was then post-stratified into 15 classes defining density of fish; each density class covering approximately the same amount of area. The method is further described in Kulka (1998).

Results

Survey Coverage

Standard NL trawl survey sets used as input to STRAP are enumerated in Table 1a and c. Non-standard sets plus standard sets within that area are listed in Table 2b and d. The latter dataset was used for mapping distributions, because it increases the density of sampling.

The spring survey covers all NAFO Divisions where white hake were encountered on the Grand Banks; whereas the standard autumn survey does not cover NAFO Subdiv. 3Ps (Table 5). However, the addition of non-standard sets during 1972-1996 extends the coverage into NAFO Subdiv. 3Ps in the Laurentian Channel and outer fringe of St. Pierre Bank: all locations where white hake are observed in significant numbers during the spring survey. Limited sets on the top of St. Pierre Bank in the autumn did not capture white hake. Thus, the non-standard Subdiv. 3Ps autumn sets (from 1972-1996) confirmed that white hake in autumn were distributed similarly to the spring period.

In terms of depth, new deep strata (>700 m) added to the autumn survey after 1996 had little impact on the enumeration or distribution results for white hake, since this species is recorded only occasionally at depths >700 m: 2 sets in the spring; 2 sets in the autumn (Table 2a and b). Catch rates at those depths were very low: <2% of the average catch rate at the main depths of 51-700 m (Table 2b).

However, white hake were occasionally captured in the new shallow coastal strata (introduced in 1995). While these additional shallow strata revealed the presence of white hake in St. Mary’s Bay on the south coast and in Conception and Trinity Bays on the northeast coast, such catches were sporadic and at densities (numbers per tow) far less than at >50 m (Table 2b).

With the change from the Engel 145 trawl (160 mm codend mesh size) to the Campelen 1800 trawl (40 mm codend mesh) in the autumn of 1995, sampling efficiency by size changed significantly; as evidenced by an increase in proportion of small fish captured with the Campelen trawl. Size-based conversion experiments were not conducted for white hake. Thus, stage-based analyses in this paper, comparing first year fish to juveniles and mature adults, were done only for the period when the Campelen gear was used (since autumn 1995). The earlier Engel and Yankee data were used only to examine historical distributions summed over all sizes captured.

Distribution

Male and female white hake distribute in a very similar manner, both covering the extent of the overall distribution and concentrating at the same locations: mainly along the southwest slope of the Grand Bank and the western edge of St. Pierre Bank (Fig. 2). White hake occur consistently and continuously along the southwest portion of the Grand Banks, into the Laurentian Channel, including the western edge of the St. Pierre Bank, in the Burgeo and Hermitage Channels, and nearshore eastward along the southwest coast of Newfoundland as far east as Hermitage Bay (Fig. 3, lower right panel). White hake were rarely encountered west of Heritage Bay, namely in Fortune and Placentia Bays or open waters just south of that area. Of sixty-four research survey sets in Fortune Bay, only 3 sets captured white hake, and at a rate of 0.14 individuals per tow: a much lower rate than the nearshore catches to the west. Low densities of small fish (<30 cm) were also caught in St. Mary’s Bay, and in several bays along the northeast coast of Newfoundland, at depths <50m and almost exclusively in autumn. White hake was absent along the outer coast of the Avalon Peninsula. On the Grand Bank, its distribution extends onto the shelf west of the Southeast Shoal, and sporadically in low densities along the outer edge of the Bank. This pattern is consistent among the years examined: 1971-2004.

With respect to spring *versus* autumn seasons, white hakes distribute on the Grand Banks in a somewhat different manner. They occur throughout the year in high concentrations along the southwest slope, and in some parts of the western extent of St. Pierre Bank; straddling the 100 m contour (Fig. 3, left panels and upper right panel). However, a significant concentration of white hake in the autumn at depths <100 m on the southern Grand Bank, west of the

Southeast Shoal, is not observed to the same extent in the spring. As noted above, low concentrations of white hake were recorded inshore in St. Mary's, Trinity and Notre Dame Bays in autumn, but not in spring.

Combining all seasons, the area occupied by white hake fluctuated without trend between 1972 and 2004; although abundance (and biomass) changed significantly over that same period (compare upper and lower panels of Fig. 4). On average, white hake occupied 21% (12-24%; or 38 000-98 000 km^2) of the area surveyed: the Grand Banks within NAFO Div. 3LNO and Subdiv. 3Ps. Much of the variation between years can be attributed to incomplete coverage during research surveys. Peaks in total area surveyed correspond to peaks in total area occupied by white hake. However, the main area of distribution (i.e., 20% of the area where 66% of the fish were concentrated; corresponding to brown areas in Fig. 3) was very stable: varying by no more than 3% of the mean among year groups, and largely at the same locations. Thus, spatial extent of white hake did not vary with changes in abundance.

White hakes distribute over a fairly wide rang of depths: from the shallowest sets prosecuted at 32 m to the deepest record of 858 m in research surveys. They distribute regularly at 100-600 m in spring, and at 50-500 m in autumn (Fig. 5, lower panel); this pattern is also consistent between years. The major difference between seasons is the significant increase in abundance at 51-100 m in autumn (Fig. 5, middle panel). This is due to the presence of mainly small fish on the shallow part of the Grand Bank west of the Southeast Shoal. Notably, white hake distribute proportionally by depth with respect to the available habitat; especially in autumn.

A significant proportion of white hake biomass distributes deeper than 200 m, due to their preference for warm waters that are restricted to the deeper parts of the southern Grand Banks. The majority of the area (66%) within NAFO Div. 3LNO and Subdiv. 3Ps has associated depths <200 m; whereas a substantial proportion of white hake (58% in 1971-1988; 78% in 1989-1995; 65% in 1996-2001) is distributed at depths greater than 200 m in spring.

On the Grand Banks, white hake were observed over a range of bottom temperatures: from $^{-}0.9$-$^{+}13.0^{o}$C; the latter being the warmest available temperature. In contrast, only 16 fish from 10 592 sets were recorded in sub-zero temperatures. The highest densities corresponded to the warmest available temperature at 5.5+^{o} C (Fig. 6, lower panel). Most of the abundance occurred at 4.0-6.5^{o}C in spring, and at 5.0-7.5^{o} C in autumn (Fig. 6, middle panel).

Unlike what was observed with respect to depth, white hake do not distribute proportionally in the available temperature habitat (Fig. 6, upper panel); but rather concentrate at the warmest locations. Comparing Fig. 7 (spring and autumn bottom temperatures averaged over 1995-2004) to the seasonal distribution illustrated in Fig. 3, shows substantial similarities in spatial patterns. The main concentrations of white hake occur over the western slope of the Grand and St Pierre Banks. Nearshore, the largest concentrations occur on the south coast, but only as far as Hermitage Bay (where the warm water ends). Nearshore records also occur in other bays where the water is marginally warmer than the surrounding waters. Both in terms of temperature and depth, this pattern has been consistent between years (Fig. 8).

An examination of length frequencies indicates that white hake distribute differently by size between NAFO Divisions (Fig. 9). The most obvious difference is in the range of fish <30 cm. In NAFO Subdiv. 3Ps, white hake <30 cm are largely absent. By examining the ratio of number of fish by size in NAFO Div. 3NO versus the entire area of 3NOPs, it becomes apparent that white hake distribute differentially by size between both areas (Fig. 10). Close to 100% of fish <25 cm are found in NAFO Div. 3NO. White hakes in this size range are in their first year (based on modal analysis and on preliminary ageing of otoliths; not presented here). A decreasingly smaller proportion of fish at 26-40 cm is found in NAFO Div. 3NO. About 50% of the total abundance of white hake at 41-57 cm occurs in Div. 3NO. For fish larger than 57 cm, the proportion steadily rises as length increases. This pattern of shifting abundance is consistent over the year examined: 1997-2004 (Fig. 10, lower panel).

An analysis of gonad condition from data collected in 1997-2004 indicates that length at 50% maturity is different between sexes; but similar among years and between areas (Div. 3NO *versus* Subdiv. 3Ps; Fig. 11). Females reach 50% maturity at 56 cm (49-59 cm; 1997-2004), and males do so at 39 cm (36-44 cm; 1997-2004). The exception is a much lower value for females in 1997 (relative to other years). The data source for that year was limited to a single shift (= one sample) on one portion of a survey.

Data on maturity were available only for April, May, and October. Ripe females were observed in April and May during the spring research survey: comprising 39 and 28% of all >56 cm females (Fig. 12, upper panel). The proportion of immature females was highest in October, and the proportion of spent individuals was similar between the three months examined. The smallest white hakes observed (i.e., those newly settled to the bottom; <17 cm), dominated survey catches in November (Fig. 12, lower panel).

Based on the analyses of sexual maturity, observations of modes in the size frequencies, and preliminary information on age, white hakes were assigned to three size-classes corresponding to stages in white hake life history: <25 cm – fish in their first year; 26-56 cm – juveniles older than 1 year and 57+ cm – mature adults. Numbers of fish <25 cm dominated research survey catches on the shallow southern portion of the Grand Bank; exceeding 50% of the mix over areas inside the 100 m contour (Fig. 13). These first year fish also dominated the nearshore locations; but at much lower densities than observed offshore. They were largely absent or in low concentrations along the slope from the southern tip of the Grand Bank to the Laurentian Channel. White hake of 26-66 cm dominated in the Laurentian Channel (NAFO Subdiv. 3Ps), and comprised about 50% of the fish along the slope of the Grand Bank (outer extent of NAFO Div. 3NO). Fish >57 cm reached their highest proportion (30-85% of the mix) along the southwest slope of the Grand Bank (Longitude 51^{o}-56^{o}; mainly NAFO Div. 3O). Occasional large catches of adults were also observed up on the Bank.

Figure 14 further illustrates distribution of the youngest stages of white hake. Pelagic young-of-the-year (YOY), caught at ~30 m below the surface in the IYGPT trawl surveys (August-September 1994-2000) were distributed over much of the sampled locations on the Grand Bank. However, 98% were taken over a small portion of the southern Grand Bank, centered at Latitude 44^{o} and Longitude 51^{o} (just west of the Southeast Shoal; Fig. 14: large hollow squares). Certain sections of the survey area (in NAFO Subdiv. 3Ps and slope waters) were not sampled by the IYGPT survey, and thus it is unknown if pelagic YOY are distributed there. Catches were very small at the western edge of the survey area: along the NAFO Subdiv. 3O/3Ps border. This concentration of pelagic YOY closely corresponds to the location of demersal juveniles caught in the Campelen trawl survey in October-November (Fig. 14, upper panel: coloured areas). This concentration of very small white hakes was observed in all years examined.

Progression of the very large 1999 year-class was readily observed through time with both gears. The mean date of capture of these YOY at 30 m below the surface in the IYGPT survey was September 5. Their sizes were 2.5-7 cm (averaging 6 cm). At the same geographic location, but on the bottom in 52-79 m, dense concentrations of YOY were caught in November 1999 by Campelen trawl. Seventy-two days (10.3 weeks) after being caught in the pelagic survey, on the mean date of capture in the autumn demersal survey (November 15), average size of white hake was 13.4 cm (Fig. 14, lower panel: blue mode). Sets with fish of this size contained almost no larger fish; indicating initial isolation from the older components. One hundred and seventy days (24.3 weeks) later, on the Spring mean survey date of 3 May 2000, a mode of fish averaging 25.7 cm was taken (Fig. 14, lower panel: purple mode). Estimated daily growth rate during that period was 0.57 mm/day. Unlike in autumn of the previous year, these fish were caught in deeper water mainly along the southwest slope of the Grand Bank, and were mixed with larger, juvenile fish (Fig. 14, lower panel: yellow mode). In terms of season, the largest catch rates of <17 cm fish occurred in November, and abundance of 18-25 cm fish peaked in April of the following year (Fig. 12).

Spatial distribution of size-classes of white hake is summarized in Fig. 15; corresponding to 1996-2004 when length measurements of white hake were available from Campelen gear. During that period, fish <17 cm were distributed on the shallow part of the southern Grand Banks and, to a lesser extent, on the inner par of the southwest slope. NAFO Subdiv. 3Ps was not surveyed in autumn 1996-2003; thus white hake lengths were not measured when the fish were settling. Larger, 18-25 cm fish in their first year were distributed further south: primarily along the inner portion of the southwest slope of the Grand Bank. White hake at 26-56 cm (age 2+ juveniles) was the most widely distributed stage occurring over the entire range; but concentrated along the western slope of the Grand and St. Pierre Banks. Fish >57 cm were restricted to the southwest slope of the Grand Bank.

The stage-based distribution shown in Fig. 15 is based on information from 1996-2004. Engel trawl surveys in earlier years did not capture smaller sizes of white hake with the same efficiency as those using Campelen gear; thus research survey data before autumn 1995 were not used in the above analyses. However, a juvenile survey, undertaken during the summer-autumn of 1984-1994 (using a 38 mm codend mesh in a Yankee-41 trawl) captured juvenile white hakes at 5-38 cm. Their distribution during that earlier period was similar to that observed in the 1996-2004 Campelen surveys.

Discussion

On the Grand Banks, white hakes are near the northern limit of their range, concentrating along the southwest slope of the Grand Bank, into the eastern side of the Laurentian Channel, and along the southwest coast of Newfoundland. Males and females distribute in a very similar manner. Distribution varies seasonally, with concentrations of fish extending onto the shallow portion (<80 m) of the southern Grand Bank and into some coastal locations in autumn. Extent of the distribution, areas of high density concentrations and seasonal patterns have been highly consistent over the years observed.

Prior to 1995, DFO - NL Spring research surveys extended over much of the Grand Bank and sampled the main portion of white hake; except for some nearshore areas. Introduced in 1995, coastal strata showed the regular presence of juvenile fish in some bays close to shore, but at much lower concentrations. Small white hakes were observed along parts of the south coast of Newfoundland and in St. Mary's, Trinity and Notre Dame Bays in the Autumn; but not in Conception Bay, along the eastern coast of the Avalon Peninsula, and only rarely in Placentia Bay. Laurel *et al*. (2003) reported the presence of juvenile hake in shallow eelgrass beds (*Zostera marina*) along the northeast coast of Newfoundland in Newman Sound, Bonavista Bay (i.e., much shallower than the minimum depths of offshore research surveys). White hakes among the eelgrass were 12.6 ± 0.5 cm standard length: the size of fish early in their first year (Beacham, 1983). Furthermore, it was noted that white hakes <30 cm (likely up to one-year-olds) are regularly observed in various locations in very shallow water along the northeast coastal shore of Newfoundland (Dr. Robert Gregory, pers. comm.). Similarly, the presence of juvenile white hake has been noted nearshore (<15 m) off the south coast of Newfoundland in the vicinity of St. Mary's Bay (Dr. David Methven, pers. comm.). Nearly all coastal Newfoundland records are comprised of fish <25 cm, the majority <15 cm.

White hake have consistently occupied about 20% of the available area at depths <800 m on the Grand Banks. Although abundance and biomass were observed to fluctuate widely over the last 35 years (Kulka *et al.*, 2005), area occupied was relatively stable. However, Kulka and Simpson (2002) noted a subtle change in distribution at depth during 1989-1995, as compared to distributions before and after. During that time, a greater proportion of white hake biomass occupied >200 m along the southwest slope of the Grand Bank. The authours attributed this shift to colder bottom waters on the bank during that period; thereby restricting white hake distribution onto the bank. Thus, white hake distribution underwent a contraction in the colder waters of the early 1990s; then subsequent expansion during the late 1990s. This subtle reduction in distribution also coincided with a period of declining stock size and low recruitment rates; whereas the recent warm water period coincided with large recruitment in the late 1990s (Kulka and Simpson, 2002).

White hake is a temperate species, associated primarily with 5-11^{o}C ambient temperatures over its entire range in the northwest Atlantic (habitat summarized in Scott and Scott 1988). However, most of the Grand Banks is covered by bottom water <5^{o}C throughout the year. As a result, white hakes are largely confined there to areas associated with the warmest bottom temperatures: 3.5-8^{o}C. They are observed only infrequently and at much lower concentrations where water temperatures are colder: along the outer (eastern) shelf edge of the Grand Bank, nearshore in the bays along the north and east coast of Newfoundland, and rarely on the south coast of Labrador (Scott and Scott, 1988). However, it appears that white hakes in their first year are more tolerant of low temperatures (including those <0^{o}C). IYGPT research data indicate that temperatures at 36 m depth averaged 0.8^{o}C; with 50% of survey sets capturing white hakes at <0^{o}C. No white hakes >1 year old were found by IYGPT in temperatures <0^{o}C.

White hakes occupy a wide range of depths on the Grand Banks: near shore to about 800 m (considerably deeper than at other locations throughout its range). In the Gulf of Maine, most trawl catches are taken at depths of approximately 110+ m, and as shallow as 27 m (Sosebee, 1998). In the Gulf of St. Lawrence and Scotian Shelf, white hakes are reported to occur mainly at depths of 50-200 m (Hurlbut and Poirier, 2001; Fowler, 1998). On the Grand Banks, about 50% of abundance distributes deeper than 200 m, in order to avoid colder water that occurs in the shallower depths. White hakes on the Grand Banks can be classified as "temperature-keepers" (sensu Perry and Smith, 1994): they maintain a presence within a narrow range of temperatures (warmest); thereby avoiding the large expanse of cold water. This is in contrast to another closely distributed Grand Banks species: yellowtail flounder, which is a depth-keeper that tolerates a wide range of temperature variation, while maintaining a shallow distribution (Perry and Smith, 1994).

Although location, extent of occurrence, and seasonal distribution of this stock as a whole is similar between years, white hake on the Grand Banks distributes differently at various stages of its life history. The Grand Banks spawning ground, indicated by the presence of mature female fish (>56 cm), is located in a narrow band along the continental slope. Mature fish do not distribute into the Laurentian Channel, onto shallow parts of the bank, nor into coastal locations. Fahey and Able (1989) speculated that the Gulf of Maine white hake population may be sustained primarily by a spawning component located on the continental slope of the Georges Bank; similar to what is observed on the Grand Banks.

From examination of gonads, functionally mature fish were noted in April-May on the outer Grand Banks. Technical staff on DFO - NL spring research surveys also reported large ripe and running females during April and May along the southwest slope; indicating spring spawning along the slope. Given that NL standard research surveys are not conducted in NAFO Div. 3NO and Subdiv. 3Ps during summer months, observations on maturity were not possible at that time. However, several NL Fisheries Observers reported that no ripe or running females were seen in July or August; suggesting that white hake spawning did not extend into that period (pers. comm.). In addition to noting the presence of mature white hakes in spring in the Gulf of Maine, Markle *et al*. (1982) also reported ripening fish during October–November near the Kennebecasis River; suggesting that spawning may be protracted there. However, no mature fish were observed in October on the Grand Banks. Battle (1951) noted three sizes of eggs in mature females, which possibly denotes serial spawners in the Bay of Fundy; but this aspect has not been examined in the Grand Banks stock. Timing of the complete annual spawning period for white hake on the Grand Banks remains unknown, because standardized collection of maturity data has been restricted to April, May, October, and November.

White hake eggs and larvae are pelagic. Although distribution of these early stages has not been described for the Grand Banks, pelagic young-of-the-year (i.e., the next stage in its life cycle: YOY) were observed in August-September over most of the Grand Banks; but most densely concentrated over the shallow part of the southern Bank. Ninety-eight percent of observed pelagic fish were caught in an area centered at Latitude 44°20’ and Longitude 50°50’: encompassing only 4% of the Bank just west of the Southeast Shoal. If the life history attributes of Grand Banks white hake are similar to those of white hake in the Gulf of St. Lawrence (as described by Nepszy in 1968 and Markle *et al.* in 1982), then those pelagic YOY observed on the Grand Banks were probably spawned in Spring of that year. Further south in the Gulf of Maine, pelagic juveniles (just prior to settling) were found earlier in May-June (Fahay and Able, 1989).

Newly-settled Grand Banks juveniles were observed in coastal waters; sometimes associated with eelgrass beds (Laurel *et al.*, 2003). However, the largest portion was found offshore on the southern Grand Bank in autumn: at the same geographic location as the high concentrations of pelagic juveniles observed in late summer (as described above). The bottom depth at this location was 50-80 m, and corresponded to the warmest area inside the 100 m contour on the bank. Newly-settled juveniles of 8-15 cm length were separated from larger fish at this location. Geographic separation of the youngest juveniles is advantageous; given that larger white hakes are known to feed on younger ones (Bowman *et al.*, 2000).

Juveniles larger than 15 cm became increasingly more mixed with larger fish as they moved toward the shelf edge. By the following spring, year-1 fish of 15-30 cm length were fully mixed with larger white hakes along the outer bank. Thus, white hakes settle onto the shallow part of the Bank in autumn, then move southwest towards the shelf edge during autumn and winter; becoming increasingly mixed with older fish. In the Gulf of Maine, white hakes settle to the bottom when they reach 5-6 cm total length (Fahey and Able, 1989), and juveniles typically occupy shallower areas than adults do (Sosebee, 1998). In the Gulf of St Lawrence, Markle *et al*. (1982) reported white hakes as large as 8 cm before settling.

In their first summer after settling, growth rate of demersal juveniles was calculated as a mean of 1.02 mm day $^{-1}$ (~3 cm month $^{-1}$) in the Gulf of Maine (Fahay and Able, 1989). Markle *et al.* (1982) reported an early growth rate of 0.1-0.22 mm day $^{-1}$ for the pelagic stage, and 2.5 cm/month in newly-settled white hakes. For Grand Banks white hake, estimate of growth of newly-settled fish is lower: 1.8 cm month $^{-1}$. Consistently higher water temperatures in the Gulf may explain the difference in growth rates between both areas.

Older juveniles (18-56 cm) occupied the greatest area of all life stages: extending over most of their entire range from the southwest coast of Newfoundland, into the Laurentian Channel, and along the southwest slope of the Grand Banks. White hakes in the Laurentian Channel were almost exclusively juveniles >25 cm. Fish of that size were rarely found nearshore, or on the shallow part of the Grand Bank. As the fish matured, they moved to spawning grounds along the continental slope of St. Pierre Bank, and the southwest slope of the Grand Bank to reproduce.

Geographic separation of white hake life stages has also been reported from other areas. Macdonald *et al.* (1984) noted that white hake <15 cm were found nearshore in depths of about 1 m in the Bay of Fundy. Hurlbut and Clay (1990), and Hurlbut and Poirier (2001) suggest spatial structure in the life stages of white hake in the southern Gulf of St. Lawrence. McAllister (1960) reported newly-settled fish hiding in the sand; in very shallow water where older white hakes were not present. Similarly in the Gulf of Maine, Sosebee (1998).indicated that depth distribution of white hake varies with age: juveniles typically occupy shallower areas than adults do, and spawning likely occurs on the slope.

White hakes from various surrounding stock components mix in the Laurentian Channel, and white hake in NAFO Subdiv. 3Pn/Div. 4R may be an extension of the Grand Banks stock. Kulka and Deblois (1996) noted that white hake may be contiguous with those located in the eastern Gulf of St. Lawrence. Based on pre-1980s DFO - NL research surveys, Grand Banks - NAFO Subdiv. 3Ps hakes (mainly older juvenile) extend northward along the Laurentian Channel into NAFO Subdiv. 3Pn and Div. 4R; with no apparent discontinuity in distribution. In 1990-2002, DFO - Quebec research surveys indicate a distribution pattern similar to that described by Kulka and Deblois (1996) in Subdiv. 3Pn/Div. 4R, and that the majority of white hakes sampled in these surveys are older juveniles (Bourdages 2002). Fish <20 and >60 cm were rarely recorded in the Quebec surveys. This range of sizes (primarily older juveniles) is similar to that observed in the NL surveys along the Laurentian Channel to the south in NAFO Subdiv. 3Ps. White hakes also extend southwest across the Laurentian Channel, where there appears to be limited mixing with Scotian Shelf and Gulf of St. Lawrence fish. Hurlbut and Poirier (2001) also suggested that there is mixing of Gulf of St. Lawrence and Scotian Shelf white hakes in this area.

Conclusion

From a biological perspective, this spatial analysis strengthens earlier arguments that white hake on the Grand Banks form a single biological unit; but with a degree of geographic separation in life history stages. Adults concentrate along the southwest slope of the Grand Bank, spawning occurs in spring (and possibly summer) and eggs are dispersed into the water column. Young white hakes settle mainly over the southern shallow part of the Bank following a pelagic stage. Older juveniles occupy the largest area encompassing nearly the entire extent of occurrence; including the Laurentian Channel where other life stages rarely occur. Thus, continuity in the distribution and the results of this staged spatial analysis indicates that white hake on the Grand Banks (NAFO Div. 3LNOPs) are likely part of the same population.

Further, white hake in NAFO Subdiv. 3Pn and Div. 4R (part of DFO - Quebec jurisdiction and thus not a part of this study) may be an extension of the same biological unit as on the Grand Banks. Early NL surveys suggest continuity in the concentration that straddle the NAFO Subdiv line between 3Ps and 3Pn (Burgeo bank). As well, there appears to be a considerable mixing/overlap of the populations of the Grand Banks, the Gulf of St. Lawrence, and the Scotian Shelf, in the Laurentian Channel. White hake are found across the entire width of the Laurentian Channel, where they mix with fish on the Scotian Shelf and also with the channel component of the Gulf of St. Lawrence. What degree of genetic mixing that occurs between these biological units is unknown. However, there is a spawning concentration on the southwest slope of the Grand Banks and adults are largely absent from the Laurentian Channel, where mixing occurs.

From a fisheries management perspective, in the northwest Atlantic, combinations of NAFO Divisions usually delineate management units for fish stocks; including white hake. Given the evidence presented here, assessing white hake only in NAFO Div. 3NO (i.e., isolated from Subdiv. 3Ps fish - as requested by Fisheries Commission of NAFO) could bias results of stock status assessments; especially given the likelihood of a single spawning component for this stock on the Grand Banks, and geographic separation of white hake life stages that results in different proportion of the population to occur within different NAFO Divisions between years. Thus, the most appropriate approach for assessing Grand Banks white hake is to analyze a combined unit (i.e., Div. 3LNO + Subdiv. 3Ps). Furthermore, white hakes in NAFO Subdiv. 3Pn and Div. 4R may be an extension of the Grand Banks stock. However, 3Pn/4R are surveyed using different gears and at a different time of year, as compared to 3LNOPs research surveys. If Subdiv. 3Pn and Div. 4R white hakes are part of the Grand Banks stock, then it should be noted that not all of the juvenile fish in the population are accounted for when assessing the Grand Banks - 3LNOPs stock.

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Table 1a. Count of sets in the Engel and Campelen **Spring** time series by year, depth interval, and NAFO Division. **Only standard sets** used for STRAP are included.

Year	3L 0-50	3L 51-700	3L 701-800	3L 801+	3L Total	3N 0-50	3N 51-700	3N 701-800	3N 801+	3N Total	3O 0-50	3O 51-700	3O 701-800	3O 801+	3O Total	3Ps 0-50	3Ps 51-700	3Ps 701-800	3Ps 801+	3Ps Total	Total
1971		60			60		25			25											85
1972		38			38	1	44			45		1			1	1	43			44	128
1973		33			33	3	46			49		47			47	1	54			55	184
1974		74			74	1	36			37							81			81	192
1975		55			55	1	22			23		35			35		62			62	175
1976		64			64	2	30			32		46			46	3	114			117	259
1977		102			102	3	45			48		40			40	2	100			102	292
1978		95			95	7	79			86		89			89	1	105			106	376
1979		141			141	5	85			90		90			90	1	80			81	402
1980		115			115	4	77			81		59			59	4	77			81	336
1981		81			81	3	52			55		22			22	3	68			71	229
1982		103			103	4	57			61		77			77	5	87			92	333
1983																8	163			171	171
1984		37			37	3	58			61		57			57	8	87			95	250
1985		220	1		221	5	80			85		93			93	6	106			112	511
1986		211			211	9	92			101		102			102	7	138			145	559
1987		181			181	5	86			91		100			100	8	127			135	507
1988		160			160	5	72			77		84			84	11	141			152	473
1989		205			205	8	87			95		101			101	9	148			157	558
1990		156			156	7	80			87		93			93	4	105			109	445
1991		143			143	5	88			93		116			116	7	157			164	516
1992		177	1		178	4	121			125		91			91	9	138			147	541
1993		181			181	3	82			85		81			81	16	263			279	626
1994		152	2	6	160	5	65		5	77		77		2	81	8	162			172	490
1995		151			151	6	83			89		85			85	15	149			164	489
1996		188			188	8	74			82		88			88	7	141			148	506
1997		158			158	4	67			71		82			82	12	146			158	469
1998		162	1		163	5	83			88		93			93	14	163			177	521
1999	2	175			177	8	73		1	82		86			86	13	160		2	175	520
2000		134			134	5	84			89		83			83	14	157			171	477
2001	2	152			154	7	76			83		79			79	10	163			173	489
2002	2	143	1		146	6	80			86		79			79	15	162			177	488
2003		156			156	8	76			84		78			79	17	159			176	495
2004	2	148	1		151	8	71			79		79			79	18	159			177	486
Total	8	4351	7	6	4372	158	2276		6	2442		2333		2	2338	257	4165		2	4426	13578

Table 1b. Count of sets in the Engel and Campelen **Spring** time series by year, depth interval, and NAFO Division. The data used for mapping, **both standard and special sets** are included.

	3L					3N					3O					3Ps					
Year	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**Total**
1971		63			63		42			42		8			8					0	113
1972		38			38	1	44			45		1			1	1	43			44	128
1973		33			33	3	46			49		47			47	1	54			55	184
1974		73			73	1	42			43					0		170			170	286
1975		55			55	1	22			23		35			35		62			62	175
1976		64			64	2	30			32		46			46	3	114			117	259
1977		102			102	3	45			48		40			40	2	100			102	292
1978		324	1		325	16	183			199		182			182	1	110			111	817
1979		278			278	5	85			90		122			122	1	80			81	571
1980		185		3	188	4	113			117		91			91	6	105			111	507
1981		142			142	3	53			56		68			68	3	103			106	372
1982		121		1	122	4	69			73		194		2	196	5	118			123	514
1983		225			225	1	18		1	20		83			83	8	187			195	523
1984		439	10	3	452	4	70	2		76		57			57	8	87			95	680
1985		442	1		443	6	113			119		110			110	6	106			112	784
1986		220			220	24	137			161		125			125	7	179			186	692
1987		407	1		408	6	89			95		155			155	8	127			135	793
1988		227			227	7	72			79		84			84	11	141			152	542
1989		237			237	11	88			99		101			101	9	148			157	594
1990		312	3		315	7	114			121		132			132	4	105			109	677
1991		236			236	5	129			134		132			132	7	157			164	666
1992		192	4	10	206	20	121			141		91			91	9	138			147	585
1993		255	10	16	281	3	129	1	1	134		109		1	110	16	263	2		281	806
1994		152	2	6	160	5	65	2	5	77	4	127	3	5	139	8	222	2	2	234	610
1995		160			160	6	83			89		95		2	97	15	352	1	1	369	715
1996		196			196	8	122			130		216		1	217	7	195	1	1	204	747
1997		161			161	4	67			71		90			90	12	200			212	534
1998		162	1		163	5	83			88		93			93	14	182			196	540
1999	2	199			201	8	73		1	82		86			86	13	160		2	175	544
2000		160			160	5	84			89		84			84	16	235			251	584
2001	5	202			207	7	76			83		85			85	10	164			174	549
2002	3	177	1		181	6	86			92		80			80	15	243			258	611
2003	3	189			192	8	76			84		78	1		79	17	159			176	531
2004	2	148	1		151	8	71			79		79			79	18	159			177	486
Total	**15**	**6576**	**35**	**39**	**6665**	**207**	**2740**	**5**	**8**	**2960**	**4**	**3126**		**11**	**3145**	**261**	**4968**		**6**	**5241**	**18011**

Table 1c. Count of sets in the Engel and Campelen **Autumn** time series by year, depth interval, and NAFO Division. **Only standard sets** used for STRAP are included.

	3L					3N					3O					3Ps					
Year	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**All**
1971					0					0					0					0	0
1972					0					0					0					0	0
1973					0					0					0					0	0
1974					0					0					0					0	0
1975					0					0					0					0	0
1976					0					0					0					0	0
1977					0					0					0					0	0
1978		44			44		7			7					0					0	0
1979					0					0					0					0	51
1980					0					0					0					0	0
1981		99			99	2	71			73					0					0	0
1982		121			121					0					0					0	172
1983		126			126					0					0					0	121
1984		209			209					0					0					0	126
1985		231	1		232					0					0					0	209
1986		141	1		142					0					0					0	232
1987		165			165					0					0					0	142
1988		189			189					0					0					0	165
1989		174			174					0					0					0	189
1990		161			161	3	77			80		91			91					0	174
1991		219			219	3	64			67		83	1		84					0	332
1992		215			215	2	32			34		54			54					0	370
1993		153			153	5	65			70		75			75					0	303
1994		199	1		200	3	72			75		75			75					0	298
1995		177	1	4	182	9	87			96		80	1		81					0	350
1996		180		31	211	13	70		1	84		61			61					0	359
1997	2	172	3	28	205	9	90	1		100		81			81					0	356
1998	2	171	4	27	204	11	90		21	122		84	2	10	96					0	386
1999		142	3	25	170	6	62			68		75			75					0	422
2000	2	144		30	176	6	64	2	22	94		76	2	22	100					0	313
2001	2	172	2	29	205	7	63	1	23	94		74	1	22	97					0	370
2002	2	174	1	29	206	6	64		24	94		75	3	21	99					0	396
2003	2	172	4	27	205	5	64	1		70		75	2	6	83					0	399
2004	1	142			143	6	61			67					0					0	358
Total	**13**	**4092**	**21**	**230**	**4356**	**96**	**1103**	**5**	**91**	**1295**	**0**	**1059**	**12**	**81**	**1152**	**0**	**0**	**0**	**0**	**0**	**6593**

Table 1d. Count of sets in the Engel and Campelen **Autumn** time series by year, depth interval, and NAFO Division. The data used for mapping, **both standard and special sets** are included.

	3L					3N					3O					3Ps					
Year	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**0-50**	**51-700**	**701-800**	**801+**	**Total**	**All**
1971		36			36	2	8			10		6			6					0	0
1972		12			12	6	30			36		2			2		2			2	52
1973		9			9					0					0		32			32	52
1974					0					0					0		29			29	41
1975		4			4					0					0					0	29
1976		55			55		3			3					0		10			10	4
1977		48			48		11			11		25			25		64			64	68
1978		44			44		7			7					0	1	119			120	148
1979	2	114	1		117		12			12		3			3	2	89			91	171
1980		41			41					0					0					0	223
1981	1	183	1		185	2	114			116		25			25					0	41
1982		135			135					0		4			4		2			2	326
1983		145			145					0					0					0	141
1984		209			209					0					0					0	145
1985		464	1		465		70			70					0					0	209
1986		355	3	3	361					0					0					0	535
1987		165			165					0					0	1	47			48	361
1988		206			206	12	8			20					0	11	141			152	213
1989		214			214		24			24		56			56	9	148			157	378
1990		248			248	3	93			96		91			91	4	105			109	451
1991		284			284	3	64			67		83	1		84	7	157			164	544
1992		295			295	2	33			35		54			54	9	138			147	599
1993		199	1	1	201	5	65			70		75			75	8	133	1		142	531
1994		293	1		294	3	72			75		85			85					0	488
1995		371	22	33	426	9	95			104		152	1		153		28			28	454
1996		201	1	36	238	13	124		1	138		91			91		100			100	711
1997	2	172	3	28	205	9	90	1		100		81			81					0	567
1998	2	171	4	28	205	11	90		21	122		84	2	10	96					0	386
1999		142	3	25	170	6	62			68		75			75					0	423
2000	2	144		30	176	6	64	2	22	94		76	2	22	100					0	313
2001	2	172	2	29	205	7	63	1	23	94		74	1	22	97					0	370
2002	2	174	1	29	206	6	64		24	94		75	3	21	99					0	396
2003	2	172	4	27	205	5	64	1		70		75	2	6	83					0	399
2004	1	142			143	6	61			67					0					0	358
Total	**16**	**5619**	**48**	**269**	**5952**	**116**	**1391**	**5**	**91**	**1603**	**0**	**1292**	**12**	**81**	**1385**	**52**	**1344**	**1**	**0**	**1397**	**10127**

Table 2a. Count of sets containing white hake by seasonal research vessel survey. Data include non-standard sets using for species mapping.

Spring	0-50	51-700	701-800	801+	Total
1971		2			2
1972		23			23
1973		22			22
1974		114			114
1975		40			40
1976		81			81
1977		84			84
1978		146			146
1979		68			68
1980		78			78
1981		95			95
1982		95			95
1983		112			112
1984		43			43
1985		70			70
1986		98			98
1987		78			78
1988		51			51
1989		20			20
1990		16			16
1991		34			34
1992	2	23			25
1993		81			81
1994		119	1		120
1995		171			171
1996		131			131
1997		113			113
1998		73			73
1999		85			85
2000		143			143
2001		102			102
2002		152			152
2003		86	1		87
2004		91			91
Total	2	2740	2		2744

Autumn	0-50	51-700	701-800	801+	Total
1971		6			6
1972					
1973		23			23
1974					
1975					
1976					
1977		50			50
1978		54			54
1979		29			29
1980					
1981	1	19			20
1982		2			2
1983					
1984					
1985					
1986					
1987		12			12
1988		61			61
1989		79			79
1990		53			53
1991		66			66
1992		64			64
1993		72			72
1994		22			22
1995	1	78			79
1996	1	67			68
1997	1	22			23
1998	1	28		1	30
1999		54			54
2000	2	49			51
2001	1	51			52
2002	1	44			45
2003	2	43	1		46
2004					
Total	11	1048	1	1	1061

Table 2b. Proportion of total sets with white hake and average catch rate of white hake by depth.

Depth (m)	Sets with White hake	Total sets	Percent with White hake	# White hake per tow	Season
< 51	11	184	6.21%	0.342	autumn
< 51	2	487	0.46%	0.004	spring
51-700	1048	9646	11.24%	1.530	autumn
51-700	2740	17457	16.51%	2.345	spring
>700	1	507	1.77%	0.002	autumn
>700	2	110	0.39%	0.045	spring

Table 3. Count of sets in the Juvenile survey by month and NAFO Division. Avg num refers to Average number of white hake captured per standard tow.

	3L						3N						3O													
	August		September		October		August		September		October		August		September		October		3L		3N		3O		All areas	
Year	Set Count	Avg num	Set Count	Avg num	Set Count	Avg num	Set Count	Avg num	Set Count	Avg num	Set Count	Avg num	Set Count	Avg num	Set Count	Avg num	Set Coun	Avg num	Set Count	Avg num	Set Count	Avg num	Set Count	Avg num	Set Count	Avg num
1985	9	0.00	18	0.00					47	0.02					4	0.00			27	0.00	47	0.02	4	0.00	78	0.01
1986	19	0.00					23	0.00	42	0.02			7	0.00	24	1.83			19	0.00	65	0.02	31	1.42	115	0.39
1987											47	0.06					2	0.00			47	0.06	2	0.00	49	0.06
1988	21	0.00	9	0.00			20	0.00	53	0.04			5	0.00	36	0.28			30	0.00	73	0.03	41	0.24	144	0.08
1989	5	0.00	79	0.00			62	0.03	27	0.30			16	0.00	44	7.80			84	0.00	89	0.11	60	5.72	233	1.52
1990			51	0.02			71	0.03	19	0.00			9	0.00	52	1.02			51	0.02	90	0.02	61	0.87	202	0.28
1991			71	0.00			49	0.00	29	1.45			3	0.00	68	4.72			71	0.00	78	0.54	71	4.52	220	1.65
1992			125	0.00			55	1.09	15	0.00			22	0.09	42	4.10			125	0.00	70	0.86	64	2.72	259	0.90
1993			127	0.00					77	0.00			57	5.26	8	1.38			127	0.00	77	0.00	65	4.78	269	1.16
1994			18	0.00	78	0.00			63	0.22					47	4.30			96	0.00	63	0.22	47	4.30	206	1.05
	54	0.00	498	0.00	78	0.00	280	0.23	372	0.18	47	0.06	119	2.54	325	3.56	2	0.00	630	0.00	699	0.19	446	3.27	1775	0.90

Table 4. Number of sets, average number of young-of-the-year white hake per set, and average weight of fish per set taken in IYGPT trawls, 1996-2000. Average trawl depth was 30 m below the surface.

Year	# of Sets	Average Number per set	Average Weight (kg)
1996	125	0	0.000
	7	1	0.010
	4	2	0.010
	1	3	0.010
	2	5	0.010
	1	11	0.010
	1	12	0.010
	1	18	0.010
	1	23	0.010
Total	**143**	**0.64**	**0.001**
1997	133	0	0.000
	2	1	0.010
	1	2	0.030
Total	**136**	**0.03**	**0.000**
1998	107	0	0.000
	5	1	0.014
	2	2	0.025
	1	3	0.010
Total	**115**	**0.10**	**0.001**
1999	95	0	0.000
	6	1	0.010
	2	2	0.005
	3	3	0.010
	1	5	0.010
	1	14	0.030
	1	16	0.030
	1	17	0.030
	1	21	0.020
	1	54	0.140
	1	91	0.230
	1	277	0.610
	1	465	0.790
Total	**115**	**8.51**	**0.017**
2000	24	0	0.000

Table 5. Biomass, abundance and mean weight of white hake from Spring research vessel surveys, 1971-2004. Surveys were conducted with an Engel trawl (1971- Autumn 1995) and Campelen trawl (Spring 1996-2004). Spring surveys: NAFO Subdiv. 3Ps was not surveyed in 1971; NAFO Div. 3O was not surveyed in 1972, 1974, 1983; and NAFO Div. 3N was not surveyed in 1983.

Canadian RV Surveys																								
	Biomass (tonnes)								Abundance (thousands)								Mean weight (kg)							
	3N		3O		3Ps	3NO	3NO	3NOPs	3N		3O		3Ps	3NO	3NO	3NOPs	3N		3O		3Ps	3NO	3NO	3NOPs
Year	Spring	Autumn	Spring	Autumn	Spring	Spring	Autumn	Spring	Spring	Autumn	Spring	Autumn	Spring	Spring	Autumn	Spring	Spring	Autumn	Spring	Autumn	Spring	Spring	Autumn	Spring
Engel series																								
1971	0		0			0			0		0			0										
1972	354		0		2,707	354		3,061	61		0		1,556	61		1,617	5.80				1.74	5.80		1.89
1973	36		1,532		465	1,568		2,033	11		327		247	338		585	3.25		4.69		1.88	4.64		3.47
1974	0		0		5,051	0		5,051	0		0		2,055	0		2,055					2.46			2.46
1975	0		3,173		4,499	3,173		7,672	0		1,080		2,646	1,080		3,726			2.94		1.70	2.94		2.06
1976	110		5,623		4,783	5,733		10,516	32		1,413		3,856	1,445		5,301	3.43		3.98		1.24	3.97		1.98
1977	50		1,339		7,084	1,389		8,473	43		466		3,935	509		4,444	1.17		2.87		1.80	2.73		1.91
1978	0		6,188		6,754	6,188		12,942	0		4,362		4,058	4,362		8,420			1.42		1.66	1.42		1.54
1979	165		1,978		6,310	2,143		8,453	34		1,065		3,078	1,099		4,177	4.85		1.86		2.05	1.95		2.02
1980	0		1,385		3,968	1,385		5,353	0		1,015		2,053	1,015		3,068			1.36		1.93	1.36		1.74
1981	139		96		7,448	234		7,682	29		93		4,743	122		4,865	4.78		1.03		1.57	1.92		1.58
1982	0		1,058		4,356	1,058		5,415	0		400		1,340	400		1,740			2.65		3.25	2.65		3.11
1983	0		0		2,545	0		2,545	0		0		1,508	0		1,508					1.69			1.69
1984	258		3,531		2,559	3,789		6,349	57		1,085		1,179	1,142		2,321	4.53		3.25		2.17	3.32		2.74
1985	46		2,878		5,303	2,924		8,227	9		1,315		3,045	1,324		4,369	5.16		2.19		1.74	2.21		1.88
1986	356	0	2,438	0	11,105	2,794	0	13,899	70	0	574	0	4,186	644	0	4,830	5.09		4.25		2.65	4.34		2.88
1987	44	0	2,752	0	9,866	2,796	0	12,662	95	0	1,114	0	4,438	1,209	0	5,647	0.46		2.47		2.22	2.31		2.24
1988	32	0	5,432	0	13,005	5,464	0	18,469	63	0	690	0	5,533	753	0	6,286	0.51		7.87		2.35	7.26		2.94
1989	0	0	925	0	6,884	925	0	7,809	0	0	251	0	4,130	251	0	4,381			3.69		1.67	3.69		1.78
1990	0	0	754	1784	3,988	754	1,784	4,742	0	0	236	863	2,941	236	863	3,177			3.19	2.07	1.36	3.19	2.07	1.49
1991	0	0	1,039	2805	4,591	1,039	2,805	5,630	0	0	1,118	2,047	3,800	1,118	2,047	4,918			0.93	1.37	1.21	0.93	1.37	1.14
1992	0	22	606	471	3,008	606	493	3,614	0	63	574	448	2,699	574	511	3,273		0.35	1.06	1.05	1.11	1.06	0.96	1.10
1993	0	0	522	748	2,731	522	748	3,253	0	0	301	490	2,559	301	490	2,860			1.73	1.53	1.07	1.73	1.53	1.14
1994	0	0	1,079	1445	2,433	1,079	1,445	3,512	0	0	886	1,341	2,274	886	1,341	3,160			1.22	1.08	1.07	1.22	1.08	1.11
1995	0		334		2,334	334		2,668	0		189		2,104	189		2,293			1.77		1.11	1.77		1.16
Campelen series																								
1995		94		4099			4,193			306		5,409			5,715			0.31		0.76			0.73	
1996	4	6	2,020	3960	6,282	2,024	3,966	8,306	75	143	2,982	3,850	8,089	3,057	3,993	11,146	0.05	0.04	0.68	1.03	0.78	0.66	0.99	0.75
1997	4	72	2,221	4192	8,507	2,225	4,264	10,732	91	64	2,987	5,361	12,432	3,078	5,425	15,510	0.04	1.13	0.74	0.78	0.68	0.72	0.79	0.69
1998	7	171	2,205	2896	4,007	2,212	3,067	6,219	79	2,036	2,249	5,079	4,765	2,328	7,115	7,093	0.09	0.08	0.98	0.57	0.84	0.95	0.43	0.88
1999	20	3,028	12,194	4043	8,236	12,214	7,071	20,450	29	83,220	26,010	11,583	8,654	26,039	94,803	34,693	0.69	0.04	0.47	0.35	0.95	0.47	0.07	0.59
2000	30	1,165	15,900	9551	10,294	15,930	10,716	26,224	716	2,875	104,360	22,750	11,743	105,076	25,625	116,819	0.04	0.41	0.15	0.42	0.88	0.15	0.42	0.22
2001	269	946	14,908	10739	8,092	15,177	11,685	23,269	517	1,077	39,384	18,207	13,792	39,901	19,284	53,693	0.52	0.88	0.38	0.59	0.59	0.38	0.61	0.43
2002	96	2,753	10,808	11384	10,118	10,904	14,137	21,022	105	2,126	11,334	13,434	15,098	11,439	15,560	26,537	0.91	1.29	0.95	0.85	0.67	0.95	0.91	0.79
2003	2	**906**	7,981	**13374**	5,762	7,983	14,280	13,745	35	**748**	7,250	**10,628**	6,904	7,285	11,376	14,189	0.06	**1.21**	1.10	**1.26**	0.83	1.10	**1.26**	0.97
2004	33	**1,847**	10,369	**2237**	6,622	10,402	4,084	17,024	53	**2,084**	8,477	**1,492**	6,977	8,530	3,576	15,507	0.62	**0.89**	1.22	**1.50**	0.95	1.22	**1.14**	1.10

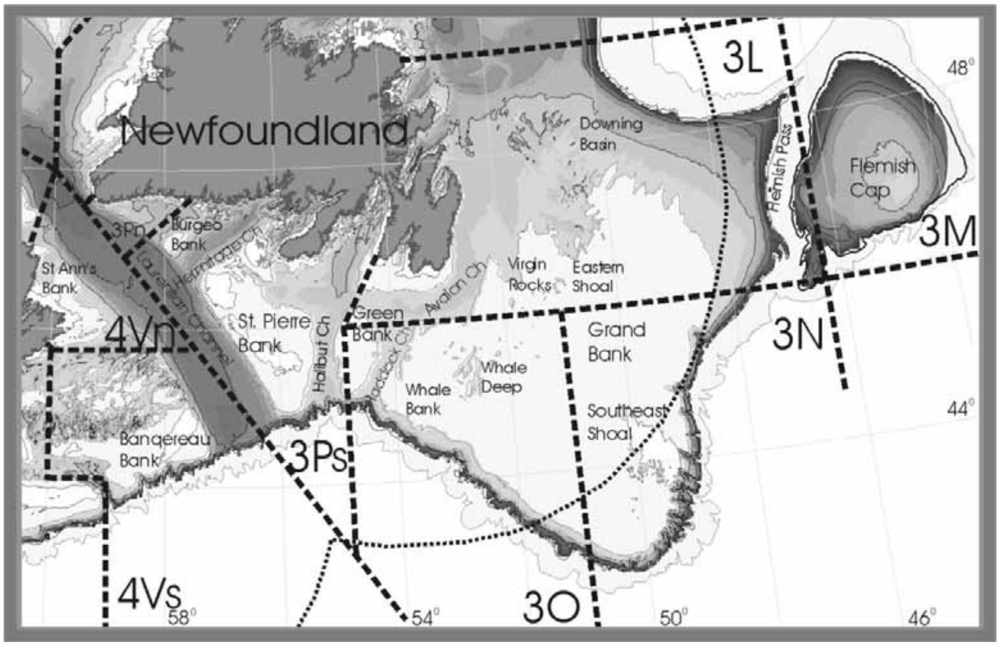

Fig.1. Map of the Grand Banks showing various banks, basins, and NAFO Divisions. Thick dotted lines delineate NAFO Divisions. The thin dotted curved line shows Canada's 200-mile-limit: delineating Canadian territory from the NAFO Regulatory Area.

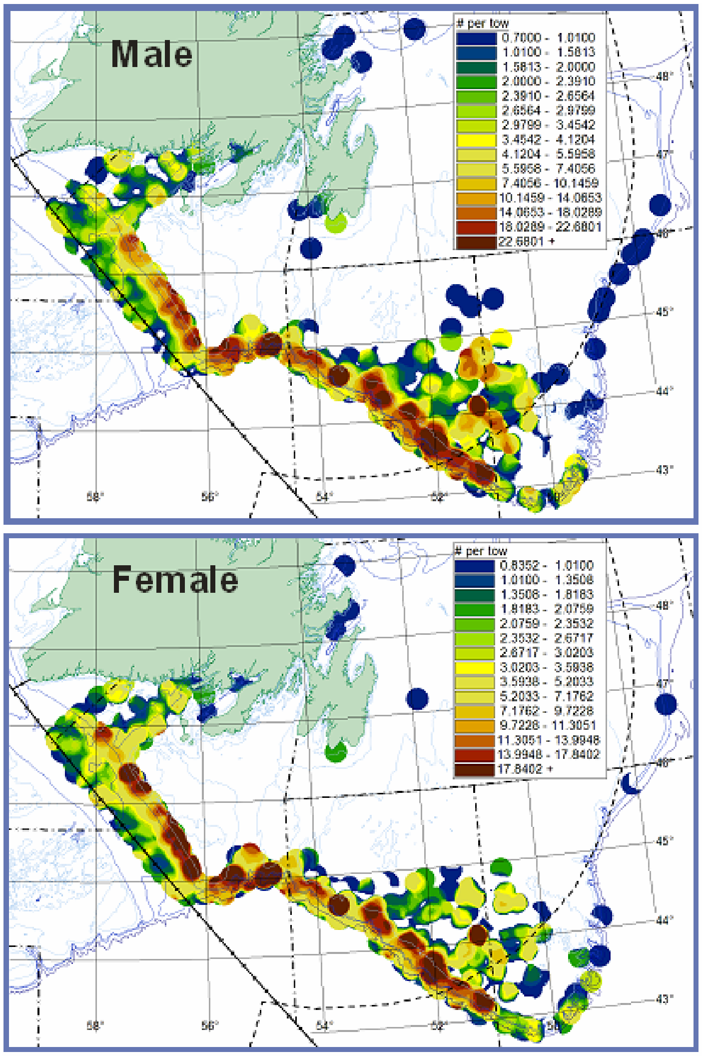

Fig. 2. Distribution of male and female white hake; based on research vessel survey data from all seasons, 1995-2004.

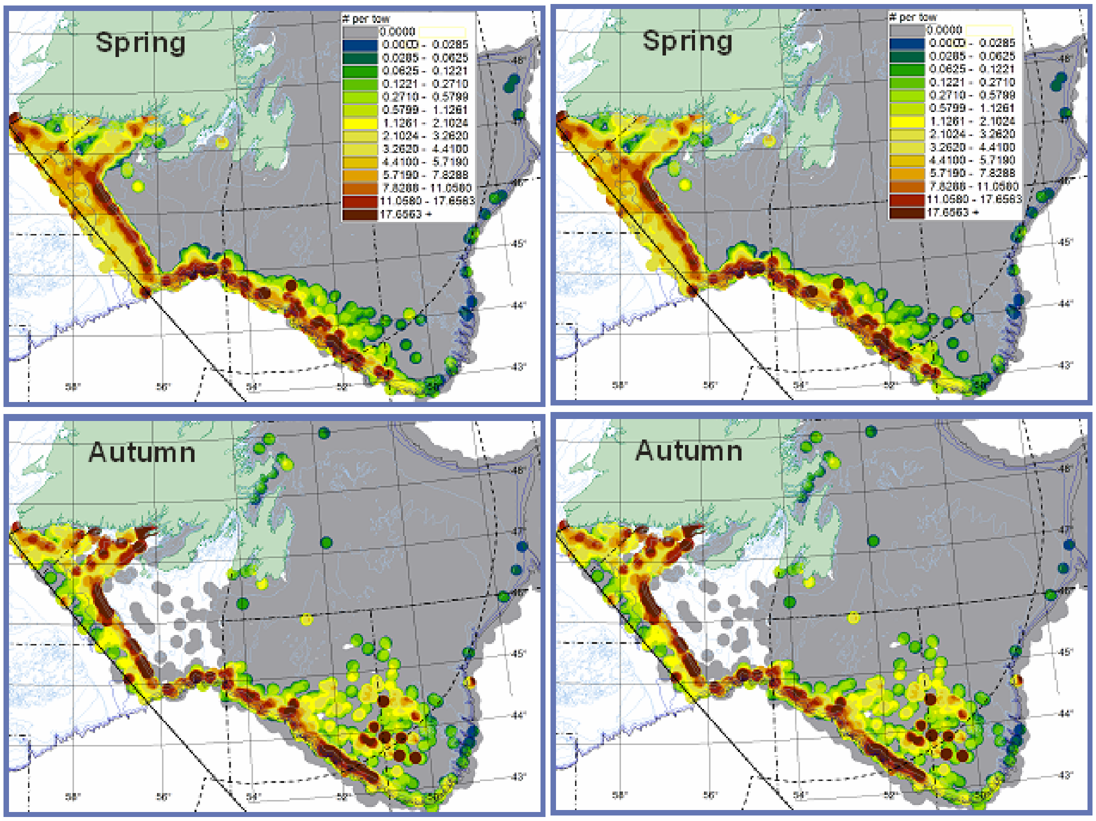

Fig. 3. Distribution of white hake on the Grand Banks (NAFO Div. 3LNO and Subdiv. 3Ps); based on seasonal research vessel surveys, 1971-2004. Grey areas depict locations that are surveyed but without catches of white hake; blue areas = low density; red areas = high concentrations. Upper left panel: July-January. Lower left panel: February-June. Upper right panel: seasonal overlap. Lower right panel: long term annual (all months) average distribution, 1971-2004.

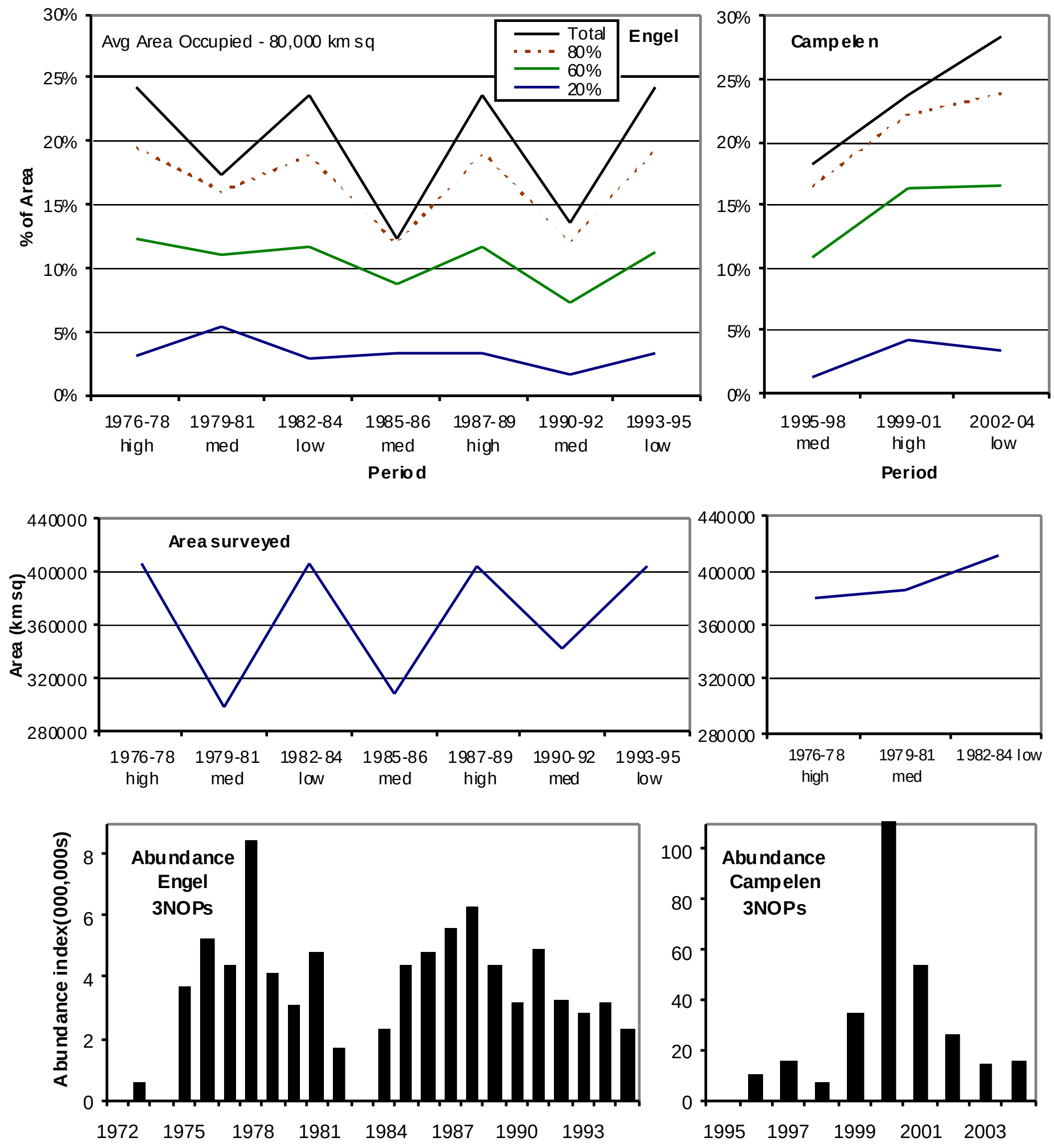

Fig. 4. Upper panel: Percent of total surveyed area occupied by white hake on the Grand Banks. 20% refers to 29% of the area where the density (kg per tow) of white hake was greatest. Middle panel: Total area surveyed during the spring research vessel survey. Lower panel: Abundance of white hake in NAFO Div. 3NO and Subdiv. 3Ps; based on spring surveys, 1972-2004.

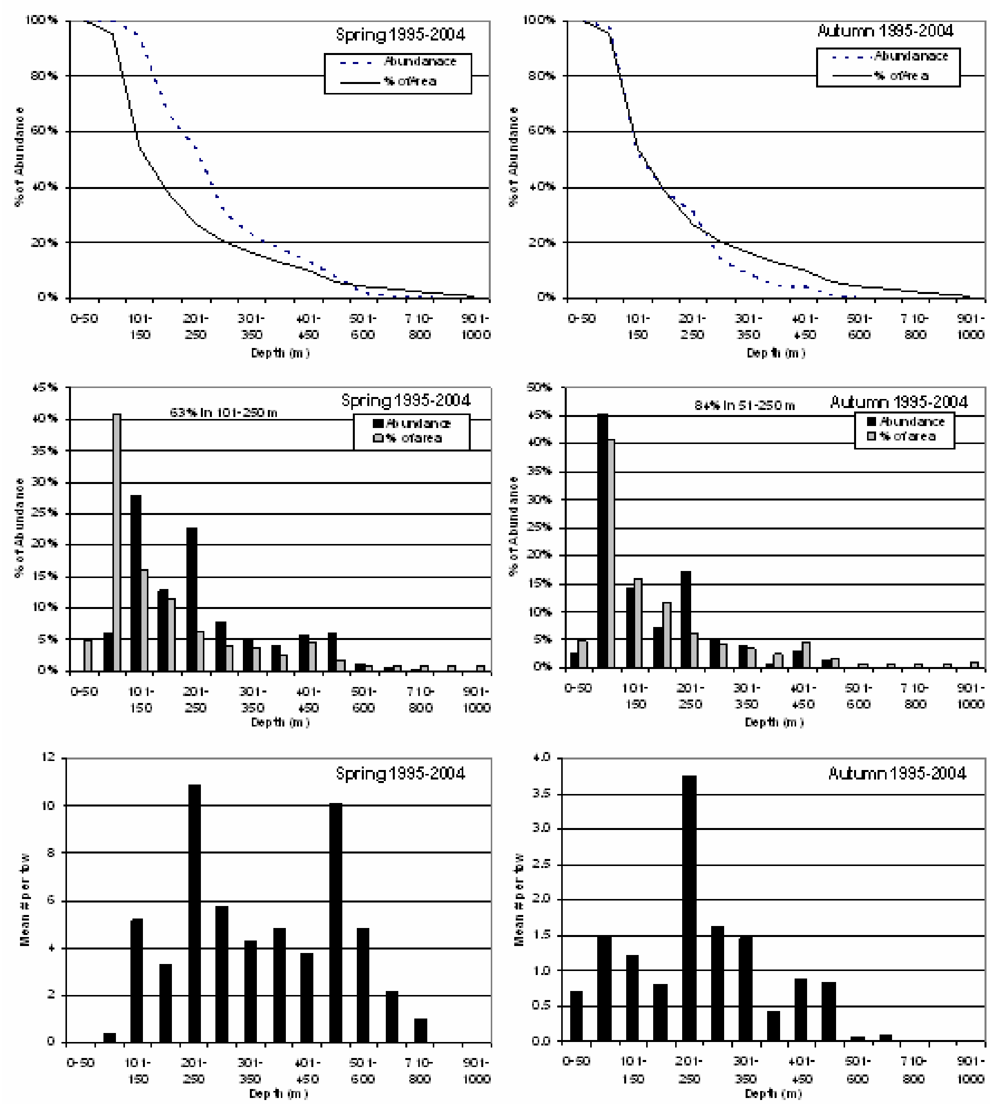

Fig. 5. Distribution of white hake by depth from spring and autumn surveys, 1995-2004. Upper and middle panel: distribution of abundance at depth in relation to available habitat. Lower panel: density (kg per tow) by depth range.

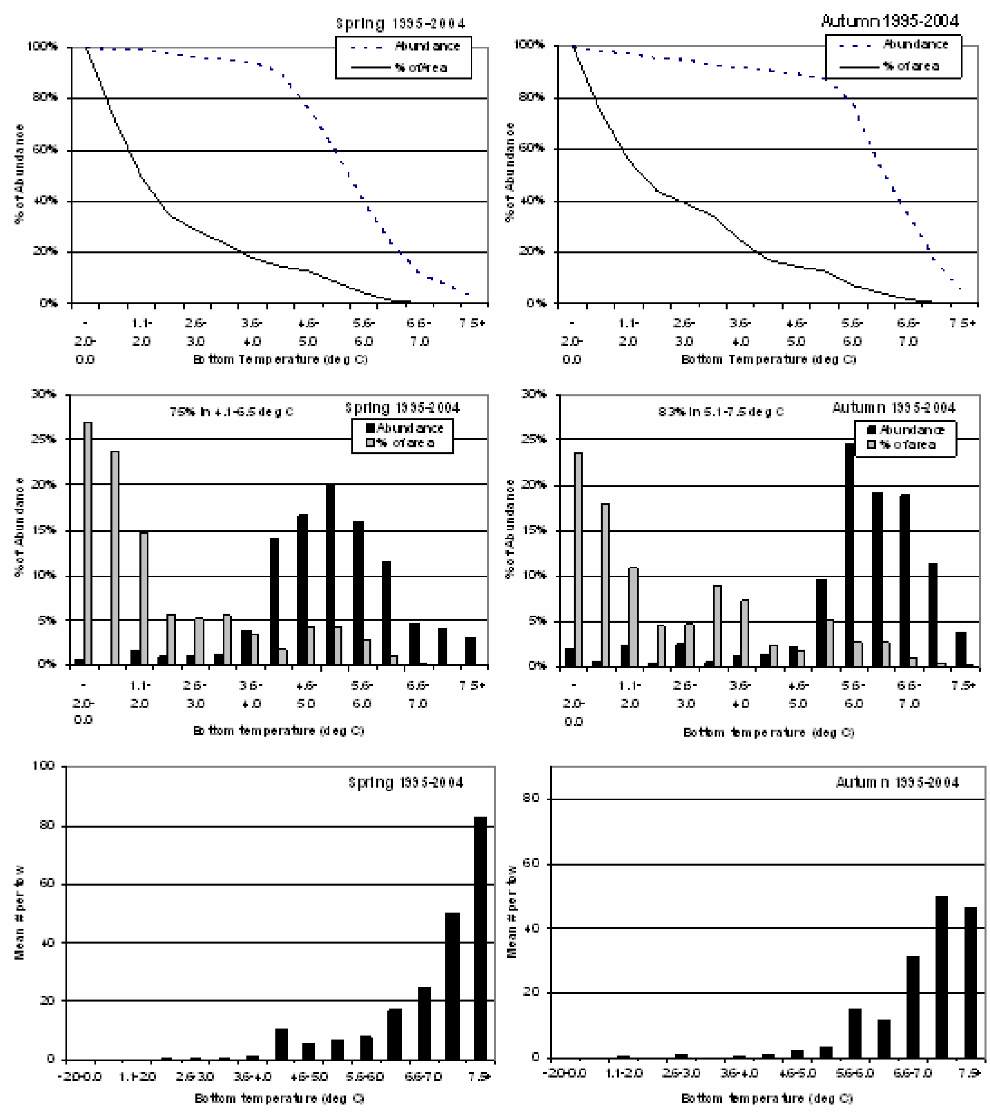

Fig. 6. Distribution of white hake by bottom temperature from spring and autumn surveys, 1995-2004. Upper and middle panel: distribution of abundance at temperature in relation to available habitat. Lower panel: density (kg per tow) by temperature range.

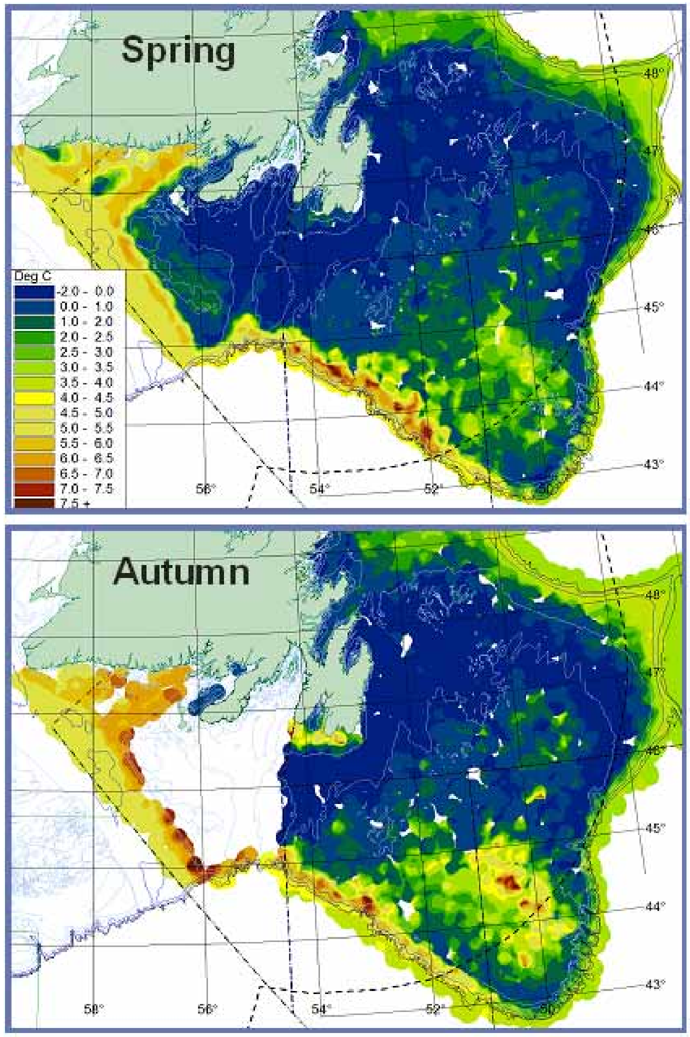

Fig. 7. Bottom temperatures on the Grand Banks by season, averaged over 1995-2004.

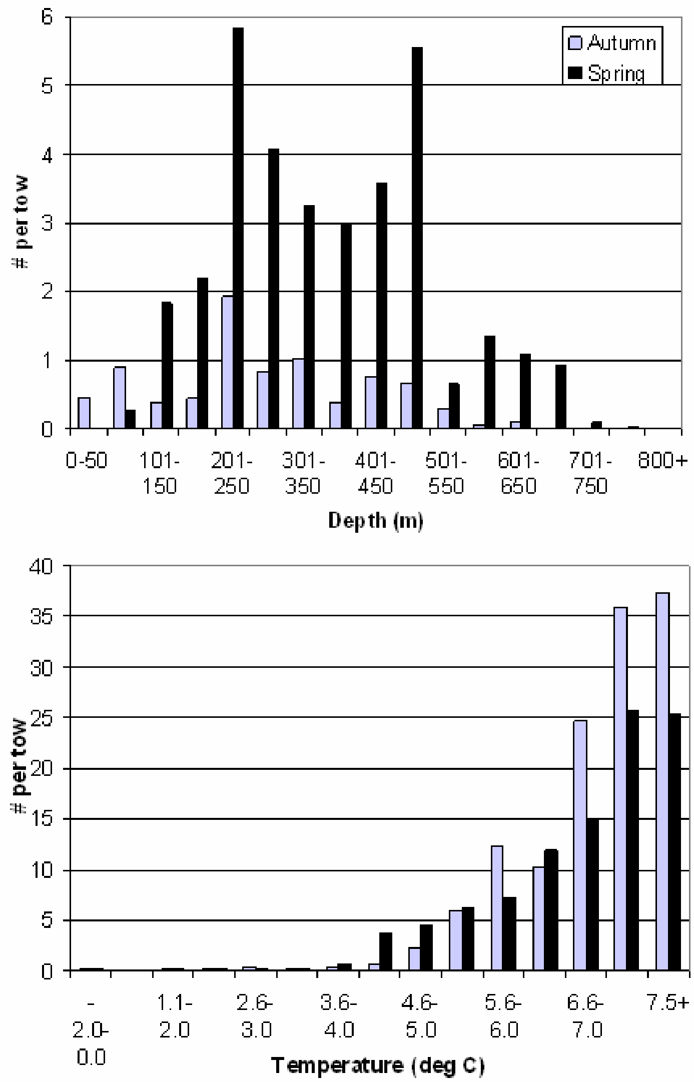

Fig. 8. Long term distribution of white hake relative to bottom depth and temperature, 1971-2004.

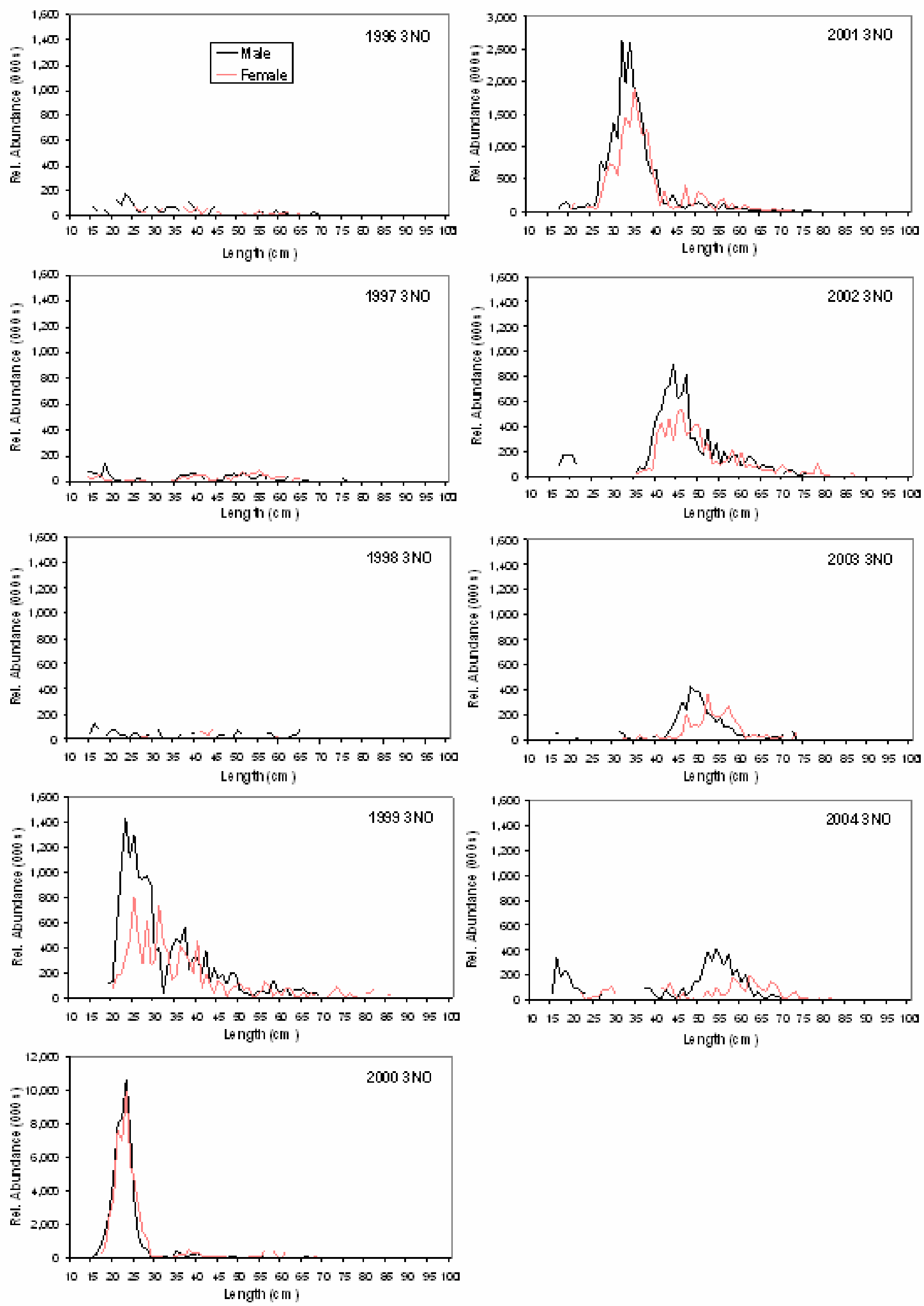

Fig. 9a. Relative abundance at length of white hake from spring research vessel surveys in NAFO Div. 3NO, 1996-2004.

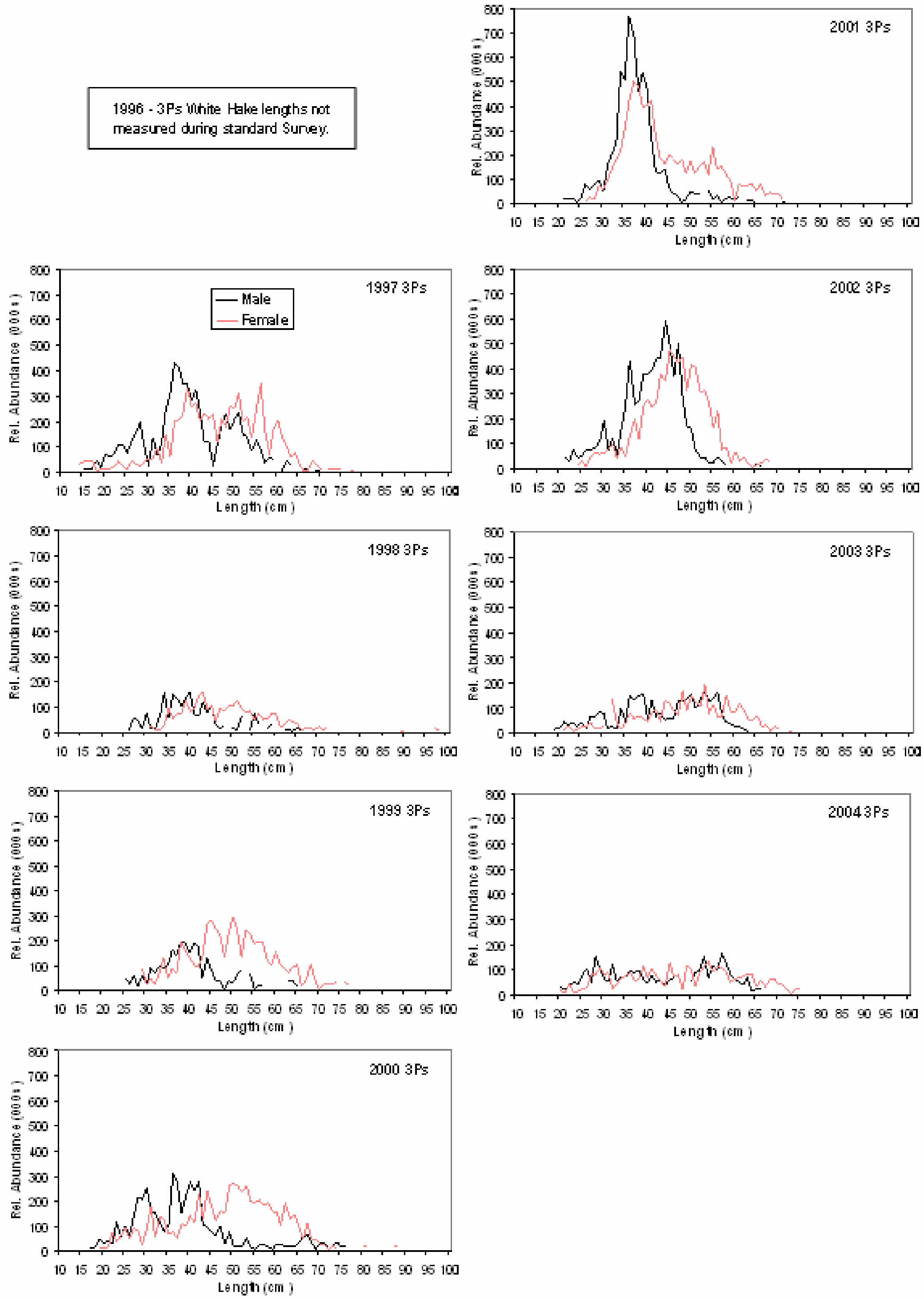

Fig. 9b. Relative abundance at length of white hake from spring research vessel surveys in NAFO Subdiv. 3Ps, 1996-2004.

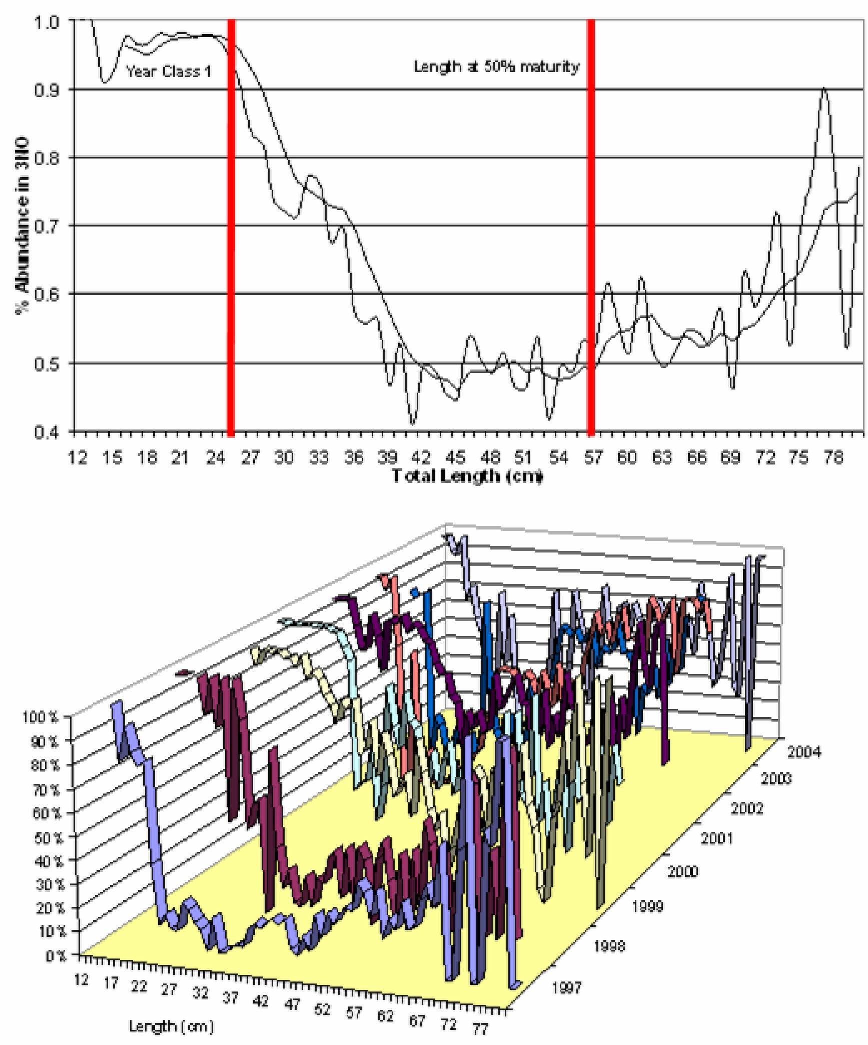

Fig. 10. Distribution by size of white hake (males and females combined) in NAFO Div. 3NO *versus* 3NOPs; expressed as percent of relative abundance. Upper panel: All years combined. Thick red vertical lines delineate first year fish from juveniles from mature fish. The thin black line is a 5-cm running average. Lower panel: Individual years.

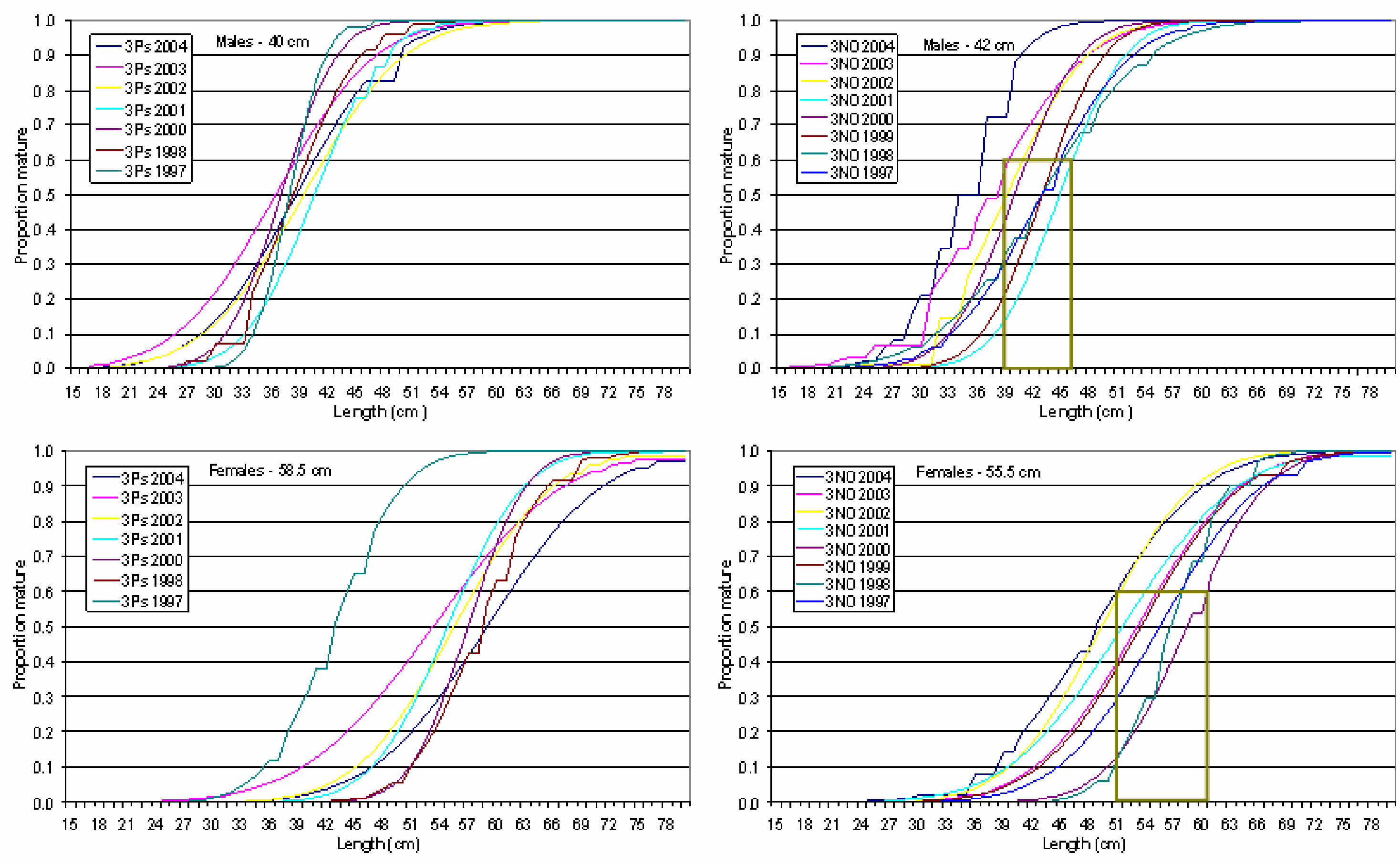

Fig. 11a. Annual maturity ogives for white hake males and females in NAFO Div. 3NO *versus* Subdiv. 3Ps, 1997-2004.

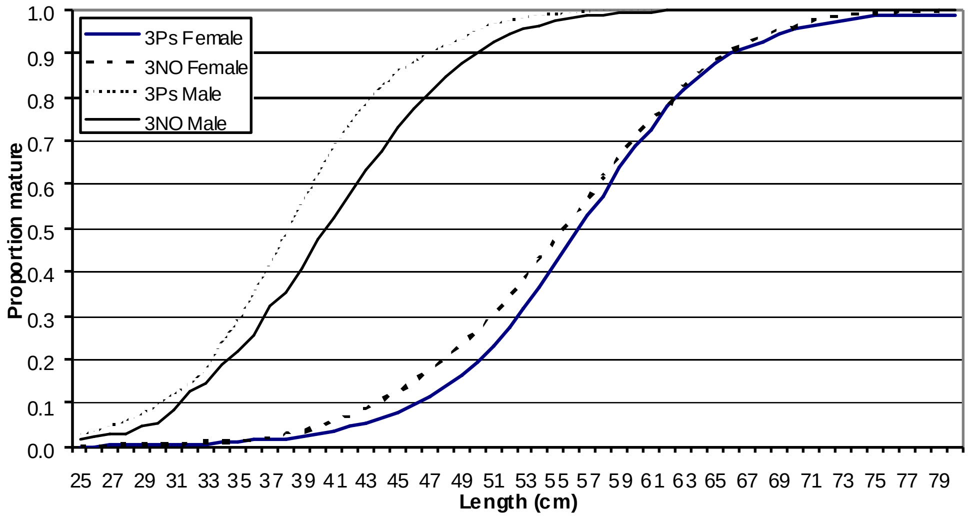

Fig. 11b. Averaged maturity ogives for white hake in NAFO Div. 3NO *versus* Subdiv. 3Ps, 1997-2004.

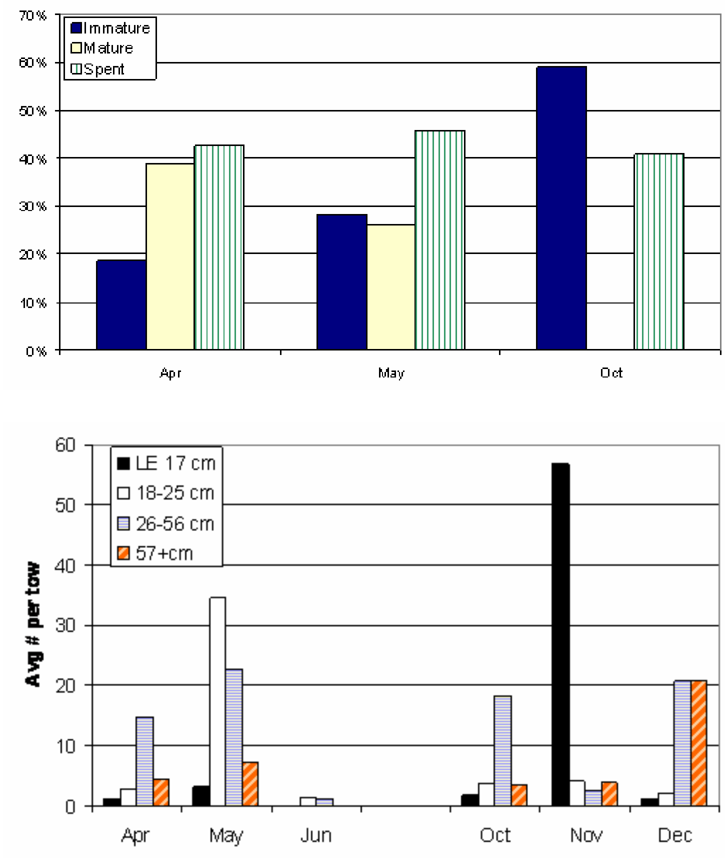

Fig. 12. Upper panel: state of maturity in females >57 cm during months surveyed. Lower panel: Survey average number per tow by month and maturity stage.

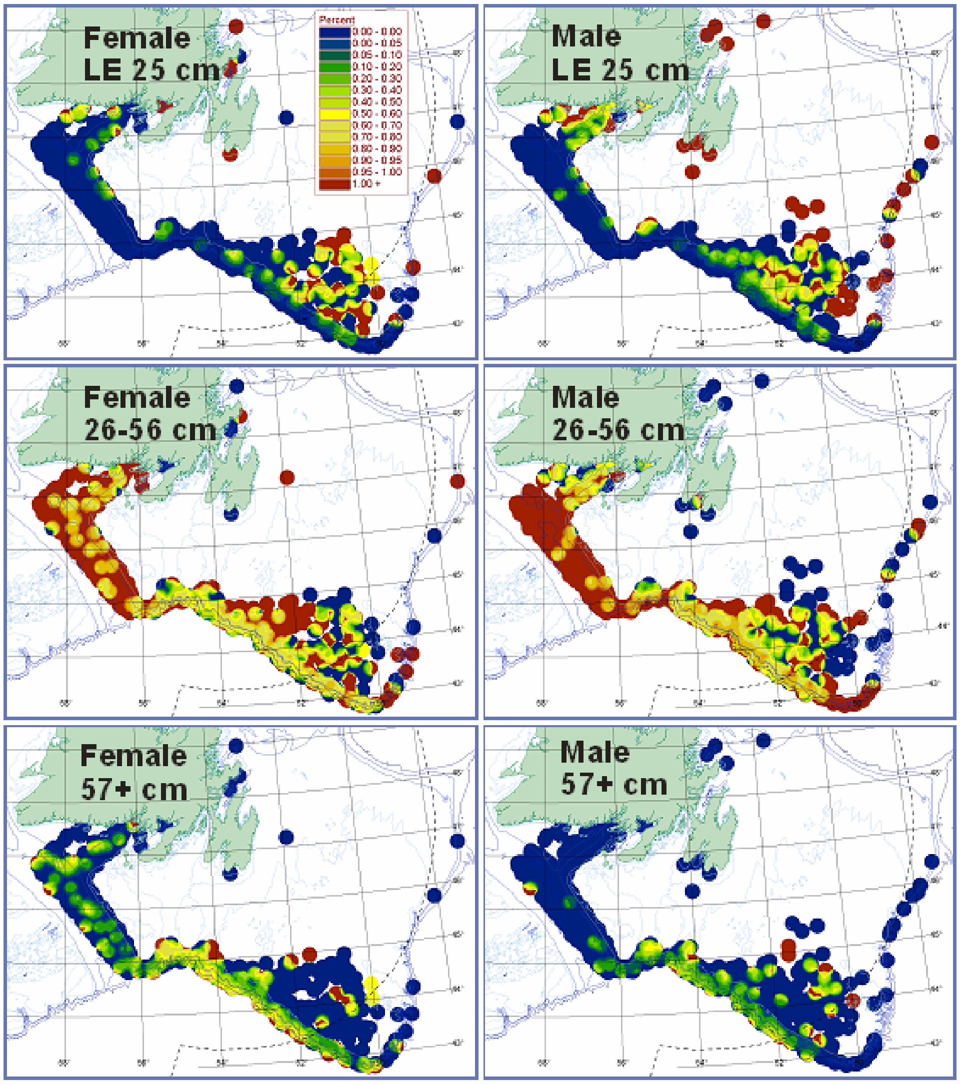

Fig. 13. Spatial depiction of proportion of white hake size classes, spring and autumn combined, 1996-2004 (Campelen surveys). Individuals < 25 cm correspond to fish in their first year; 26-56 cm to juveniles; and 57+ cm to mature adults.

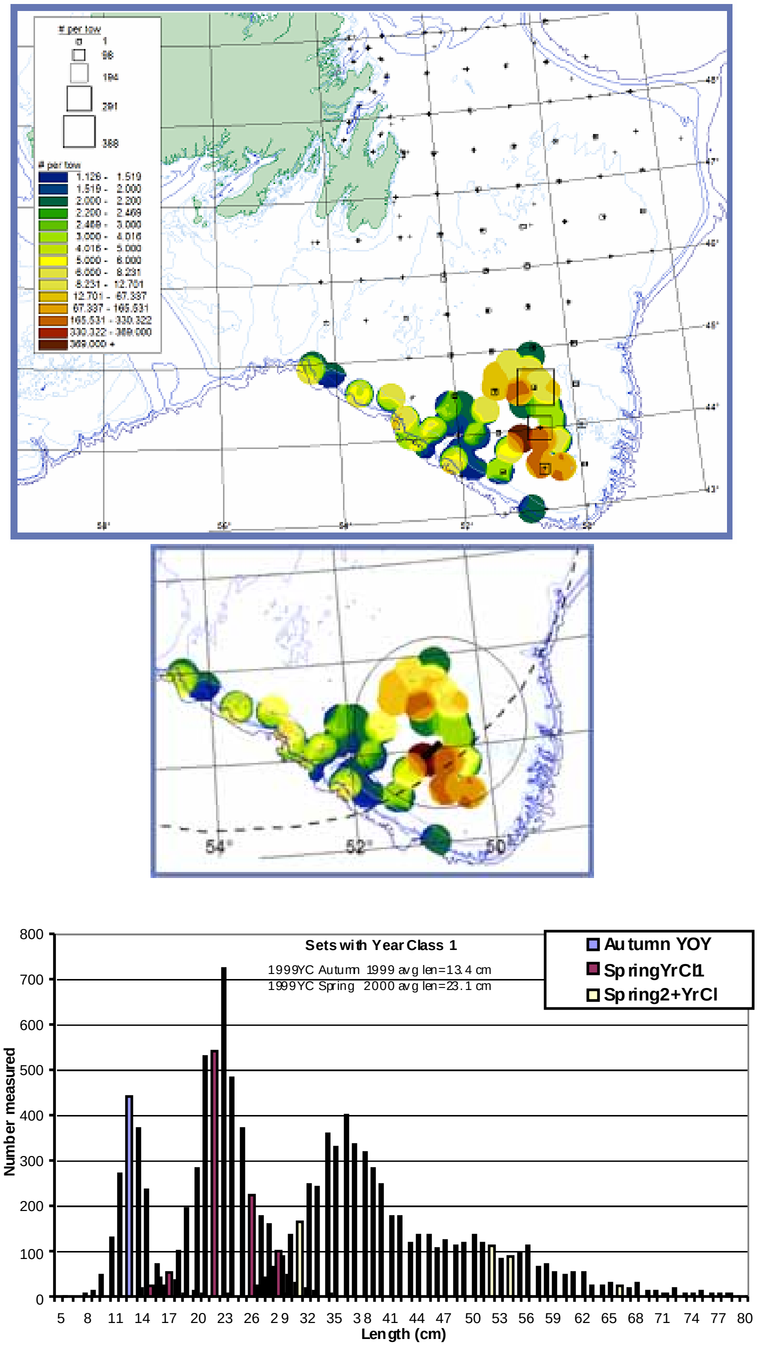

Fig. 14. Upper panel: coloured surface depicts the density of newly settled white hake from the Campelen Autumn research survey data; overlayed by the pelagic YOY from the IYGPT survey (~30 cm below surface). Lower panel: cumulative length frequencies for sets containing the 1999 year-class white hake in autumn 1999, and spring 2000. Fish of other year-classes found in those sets are included (as spring 2+ year-class).

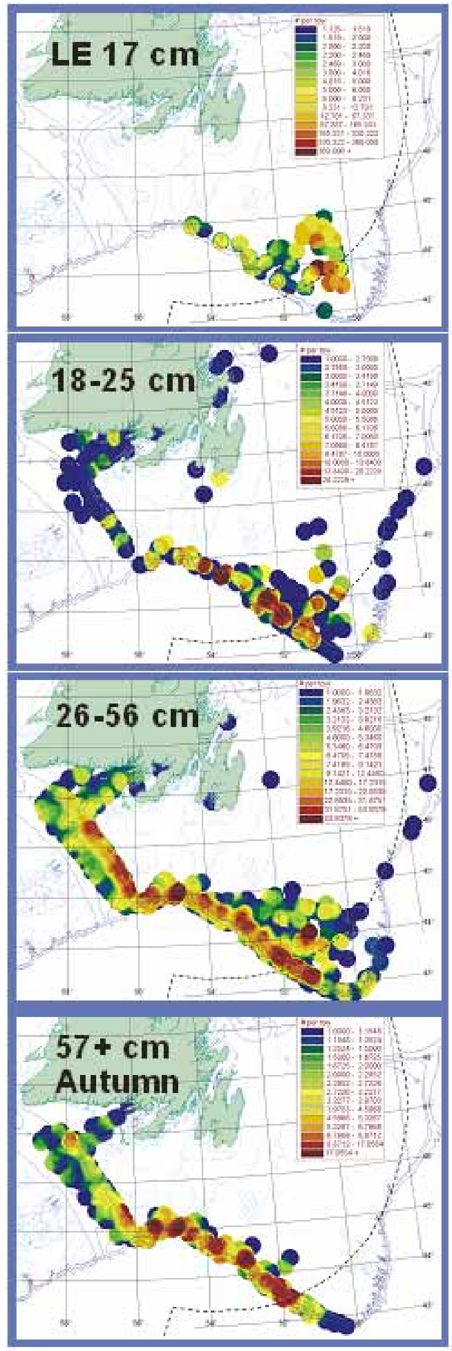

Fig. 15. Distribution of different size groups of white hake; based on research vessel survey data from all months, 1996-2004.

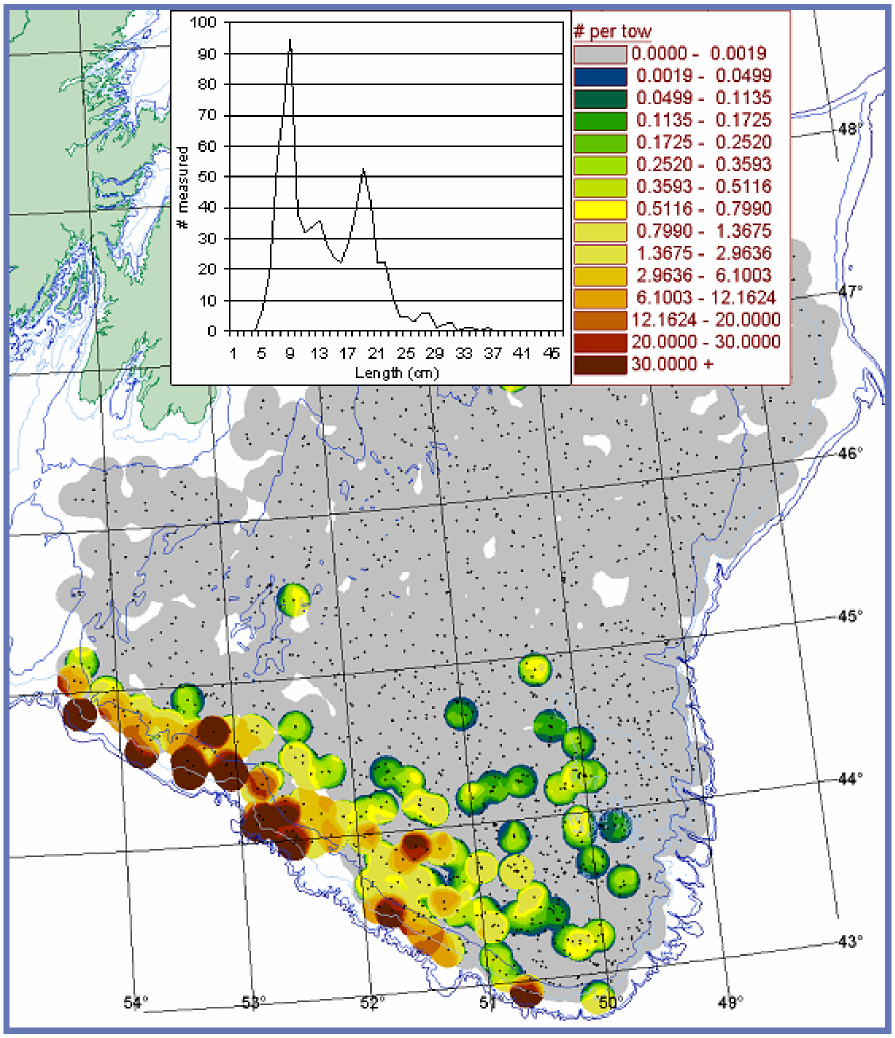

Fig. 16. Distribution of juvenile white hake from the Yankee-41 juvenile trawl survey, 1984-1994. Embedded graph summarizes the size structure of fish caught.