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Dispersion of eggs, larvae and pelagic juveniles of White Hake (*Urophycis tenuis,* Mitchill 1815) on the Grand Banks of Newfoundland in relation to subsurface currents

by

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ABSTRACT

White hake (*Urophycis tenuis*, Mitchill 1815) is a temperate bottom dwelling fish with the northern extent of its distribution on the southern Grand Banks. There they are found at bottom depths from 50-800 m, associated with 4-8^0C ambient temperatures. They are restricted to a narrow band along the southwest edge and into the Laurentian and Hermitage Channels where local bottom temperatures are warmest (> 4 C^0). We have examined potential dispersion patterns of eggs, larvae and juveniles under climatological monthly-mean circulation fields, M_2 tidal currents and associated turbulent mixing, which was computed from a three-dimensional regional ocean circulation model. Effects of spawning locations (horizontal and vertical) and timing (monthly and yearly) are investigated. The results indicate the spawning below the surface Ekman layer, on the southwest Grand Bank and in the weaker Labrador Current year have higher chances for young juveniles to settle down in the southwest Grand Bank nursery area in fall.

INTRODUCTION

Review of Distribution and 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 and 1974, Bundy *et al.* 2001, Hurlbut and Poirier 2001, Kulka et al. 2005). On the Grand Banks (Fig. 1), white hake 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 distributing in a very similar manner (Kulka *et al.* 2005). The distribution varies seasonally, with concentrations of fish extending onto the shallow (< 80 m) part of the southern Grand Bank and into some coastal locations in the autumn.

From examination of the gonads taken during the spring trawl survey, functionally mature fish were noted in Apr.-May on the outer Grand Banks (Kulka et al. 2005). Further, technical staff on the NL surveys also reported large running females during April and May along the southwest slope suggesting spring spawning along the slope. Summer observations of maturity were not available to determine if spawning extended into that period. However, Markle *et al.* (1982) in addition to indicating the presence of mature fish in the spring in the Gulf of Maine also reported ripening fish during Oct –Nov near the Kennebecasis River suggesting that spawning may be protracted there. Battle (1951) noted 3 sizes of eggs, suggesting serial spawners in the Bay of Fundy. No mature fish were observed in October on the Grand Banks suggesting that spawning was completed there by the fall (Kulka *et al.* 2005). What the full extent of the spawning period on the Grand Banks is unknown since the collection of data on maturity has been restricted to April, May and October.

Eggs, larvae and young juveniles of white hake are pelagic. Although distribution of eggs and larvae has not been described for the Grand Banks, the next stage in the life cycle, pelagic young of the year were observed in Aug.-Sept. over most of the Grand Bank but most densely concentrated over the shallow part of the southern Bank (Kulka *et al* 2005). Ninety-eight percent of observed pelagic fish were taken from an area centred at Lat. 44^{O} 20, Lon. 50^{O} 50’ encompassing only 4% of the Bank just west of the Southeast Shoal. Grand Banks white hake, if similar in their life history attributes to those in the Gulf of St. Lawrence, as described by Nepszy (1968) and Markle et *al.* (1982) suggests that those pelagic fish were spawned in spring/summer. This is consistent with maturity observations from the spring Grand Banks trawl survey described above. 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 eel grass beds (Laurel *et al* 2003) but the large majority were found well off shore on the shallow part of the southern Grand Bank in the autumn at the same geographic location as the high concentrations pelagic juveniles observed in late summer, as described above. The bottom depth at that location was 50-80 m and corresponded to the warmest location on the bank. There, the newly settled juveniles, in the range of 8-15 cm, were largely separated from larger fish indicating initial isolation from the older components. Separation of the youngest juveniles is advantageous given that larger white hake are known to feed on younger white hake (Bowman et al. 2000).

Juveniles larger than 15 cm became increasingly more mixed with larger fish and were located closer to the shelf edge. By the following spring, fish in the range of about 15-30 cm were fully mixed with the larger sizes along the outer bank. Thus, white hake settle onto the shallow part of the Bank in the autumn then move southwest toward the shelf edge over winter becoming increasingly more mixed with older fish. In the Gulf of Maine, white hake settle to the bottom when they reach 5-6 cm TL (Fahey and Able 1989) and juveniles typically occupy shallower areas than the adults (Sosobee 1998). In the Gulf of St Lawrence, Markle et *al.* (1982) noted fish as large as 8 cm prior to settling.

Circulation of the Grand Banks

Mean ocean circulation in the upper water column off Newfoundland are dominated by the inshore and shelf-edge Labrador Current. The shelf-edge Labrador Current bifurcates north of Flemish Pass, with one branch southward through the Flemish Pass and the other eastward along the northern flank of the Flemish Cap. The Flemish Pass branch flows along the southeastern Grand Bank slope with strong retroflection offshore, a portion of which passes around the Tail of the Grand Bank and continues along the southwestern Newfoundland Slope (Petrie and Anderson, 1983). The inshore Labrador Current flows along the eastern and south Newfoundland coast. There are significant cross-shelf exchanges between the inshore and offshore Currents from place to place. For example, the inshore Labrador Current exists from the Avalon Channel, partially steering offshore through Haddock and Halibut Channels and merging with the shelf edge flow. When reaching the Laurentian Channel the shelf-edge current bifurcates, with one branch turning inshore along the eastern flank of the Channel towards Cabot Strait and the other continuing across the Channel (Han et al., 1999).

Over the Grand Bank, the circulation is generally weak. There are indications of the anticyclonic eddies over various banks. For example, an anticyclonic eddy occurs north of the Tail in summer. The eddy over the St. Pierre Bank is seasonally persistent.

There are significant temporal circulation variations in this region. On the seasonal scale, the shelf edge and inshore Labrador Current is stronger in fall/winter and weaker in spring/summer. There are strong vertical shear in the horizontal currents. Studies revealed prominent interannual variability in the Labrador Current (Han and Tang, 2001; Han, 2005). The region is also subject to intensive atmospheric forcing from fall to spring, resulting in significant synoptic variability in the shelf circulation.

Over the lower continental slope, the mean currents are equator-ward but much weaker than the Gulf Stream and the North Atlantic Current. In addition to variations of the Labrador Current strength and pathway, meanders and eddies pinched from the Gulf Stream and the North Atlantic Current can generate prominent temporal and spatial variability in regional hydrography and circulation, resulting in intense shelf/deep-ocean interactions and exchanges of physical, chemical and biological properties.

Purpose

White hake are among the most fecund of fish, Beacham and Nepszy (1980) noting that a 70 cm fish in the Gulf of St. Lawrence produces as many as 4 million eggs, a 90 cm female producing as many as 15 million eggs. Wenner (1983) calculated an average 1,772 eggs per g body weight for the closely related longfin hake, (*Urophycis chesteri*.) Thus, this highly r-selected species has the potential to produce very large number of eggs that are released into the water column. As evidenced in 1999, the species is capable of producing a very large year class from a small spawning biomass (SSB). These progeny remain in the water column, only settling once they have grown into small juvenile fish and thus they spend considerable time, a period of several months over the spring and summer, in the water column (Kulka et al 2005). The population of white hake on the Grand Banks has undergone large fluctuations in abundance from the 1970s on (Kulka *et al.* 2006). The purpose of this paper is to explore how eggs/larvae/pelagic juveniles released into the water column in the spring would be affected by subsurface currents that would influence their location over the next few months and how this might affect recruitment. Variation in the release points and their effects on the final destination are explored.

METHODS

Information on weights, numbers size and maturity of 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 NL Region after 1970 can be found in Doubleday (1981). 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.

Analyses

Analysis of distribution of different stage of white hake 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 Divisions of 3NO, 3NOPs, and Subdivision 3Ps.

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 the fish, each density class covering approximately the same amount of area. The method is further described in Kulka (1998).

Circulation and Dispersion Models

A prognostic finite-element model QUODDY4 (Lynch et al., 1996) was used to compute circulation fields. The model has 3-d nonlinear primitive equations with Boussinesq and hydrostatic approximations, and a level-2.5 turbulence closure scheme. The vertical eddy viscosity for momentum, and vertical diffusivity for temperature, salinity and turbulent kinetic energy and mixing length scale were given a minimum value of 0.0001 m^2/s.

The model's fixed horizontal mesh (Fig. 2) has about 10000 variably spaced nodes (Han and Wang, 2006). It covers the southern Labrador Shelf (SLS), the Newfoundland Shelf, and adjacent deep oceans, with high resolution in shallow areas and those with steep topography. Typical node spacing is 5 km over the shelf. The vertical mesh has

21 variably spaced nodes with minimum spacing of 1 m near the sea surface and seabed, and adjusts to track the movement of the sea surface during the model simulations. The model uses topography for the shelf from a database with about 7-km resolution and topography for deep oceans from etopo5.

Initial temperature and salinity fields are from a monthly mean climatology (Geshelin et al., 1999) for the Northwest Atlantic. The wind stresses are computed from 6-hourly wind data of NCEP-NCAR reanalysis data. The climatological monthly-mean wind stresses have seasonal variations in both magnitude and direction, with the winter stress being stronger and directed more cross-shelf (offshore) than the stresses during the other seasons. The most prominent tidal constituent, the M_2 tide, was also included in the model. See Han and Wang (2006) for more details.

We only consider effects of temporal variability and spatial structure of model circulation and turbulence. The method used is to track numerical drifters released in the model monthly circulation fields. The drifter-tracking method is described by Werner et al. (1993) and Blanton (1995). In addition, estimates of the influence of unmodelled horizontal motions are obtained assuming a random walk process where additional displacements are calculated using externally specified eddy diffusivities in the horizontal directions (e.g. Berg, 1993). The sensitivity of the advective pathways to the effects of unmodeled horizontal current fluctuations is considered using a horizontal random walk. We assume the horizontal diffusivity is homogenous and isotropic ($K = K_x = K_y$). The Smagorinsky formulation in the circulation model indicates that the horizontal eddy viscosity of 130 to 200 m^2/s. Previous studies based on field experiments off the US east coast estimated the eddy mixing coefficients to be 50 - 500 m^2/s (Ketchum and Keen, 1955). In this study we chose a baseline value of 150 m^2/s. A vertical random walk approach based on the model turbulence field is used. In the approach, the Langevin equation is used to derive a Markov equation for the vertical velocity in inhomogeneous turbulence.

RESULTS

Distribution

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). White hake were rarely encountered west of Heritage Bay, namely in Fortune and Placentia Bay or open waters just south of that area. Low densities of small fish, < 30 cm were also taken in St. Mary's Bay and in several bays along the northeast coast of Newfoundland, at depths < 50m, almost exclusively in the autumn. White hake were absent along the outer coast of the Avalon Peninsula. On the Grand Bank, their 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, between 1971 and 2004.

Seasonally, spring vs. autumn, white hake distribute on the Grand Banks in a somewhat different manner (Fig. 3). They occur year round 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. 4, left panels and upper right panel). However, a significant concentration of fish at depths < 100 m on the southern Grand Bank, west of the Southeast Shoal, in the autumn, is not observed in the spring.

White hake distribute over a fairly wide range of depths from the shallowest sets prosecuted in the survey at 32 m to the deepest record at 858 m (Fig. 4). They distribute regularly between 100 and 600 m in the spring and 50-500 m in the autumn (Fig. 4, lower panel) and this pattern is consistent among years. The major difference between seasons is the significant increase in abundance in 51-100 m in autumn (Fig. 4, 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 by depth proportionally with respect to the available habitat particularly in the autumn.

On the Grand Banks, white hake were observed over a range of bottom temperature from -0.9- , 13.0^O C, the latter value being the warmest available temperature (Fig. 5). Only 16 fish from 10,592 survey sets were recorded in sub-zero temperatures. The highest densities and majority of the biomass occurred where the temperature was warmest, in 5.5+ C^O (Fig. 5b, lower panel). Most of the abundance occurred within 4.0-6.5 ^{O}C in the spring and 5.0-7.5 ^{O}C in the autumn (Fig. 7, middle panel). Both in terms of temperature and depth, the correlation with white hake distribution has been consistent among years.

Based on the analyses of sexual maturity, observations of modes in the size frequencies and preliminary information on age, white hake were assigned to three size classes corresponding to stages in white hake life history: < 25 cm – animals in their first year; 26-56 cm –juveniles older than 1 year and 57+ cm – mature adults (see Kulka *et al* 2005). Based on spring survey data corresponding to the spawning time, mature females (> 57 cm) reached their highest proportion (30-85% of the mix) along the southwest slope of the Grand Bank (mainly NAFO Div. 3O) from Lon. 51^{O} to Lon. 56^{O} (Fig. 6). It is from these locations that it is expected that the eggs would be released. These mature females inhabit a wide range of depths from about 80-450 m (Fig. 7), However, the adult females were most densely concentrated from about 100-270 m. This range of depths was consistent over time but with inter-annual fluctuations where, within the range, the fish were most densely concentrated.

Numbers of fish < 17 cm (newly settled YOY) dominated the survey catches on the shallow southern portion of the Grand Bank in the autumn when settling of the juveniles occurred (Fig. 8, coloured areas). These locations correspond closely with YOY observed in the water column in the IGYPT surveys Aug.-Sept. 1994-2000 (Fig. 8, black squares) These first year fish also dominated nearshore locations along the south coast and to a lesser extent along the northeast coast but at much lower densities than observed offshore. They were largely absent or in low concentration along the slope from the southern tip of the Grand Bank to the Laurentian Channel.

The progression of the very large 1999 year class was particularly easy to follow through time in the two gears. The mean date of capture of these YOY at 30 m below the surface in the IGYPT survey was Sep. 5. Their size was 2.5-7 (average 6) cm. At the same geographic location, but on the bottom in 52-79 m, dense concentrations of YOY were taken in Nov. of 1999 in the Campelen trawl. On Nov. 15, mean date of capture in the autumn demersal survey and 72 days (10.3 weeks) after being taken in the pelagic survey, average size of the fish was 13.4 cm (Fig. 9, 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, in the spring, mean survey day on May 3 2000, a mode of fish averaging 25.7 cm was taken (Fig. 9, lower panel, purple mode).

Model Circulation Fields

The circulation model generated 12 monthly-mean circulation fields and the M_2 tidal current fields. There are strong seasonal variations in the near-surface circulation. For example the Labrador Current is much stronger in December than in July (Fig. 10). The spatial variability is significant, with the dominant flow along the shelf edge, and along the coast. Cross-shelf advective exchanges are clearly evident, for example, the offshore flow on the northeastern Newfoundland Shelf. The cross-slope exchanges are also revealed, especially along the southeastern Grand Bank slope where the Labrador Current retroreflects northeastward. Significant vertical shears and strong near-bottom currents are evident in the shelf edge Labrador Current (Fig. 11). There is also substantial spatial variability in tidal currents, e.g. with stronger currents over the Southeast Shoal.

Dispersion Model Results

The dispersion experiments in this study treat eggs, lava and juveniles as neutrally buoyant particles. We assume they have no behavior and passively follow the water movement under monthly mean circulation, M_2 tidal currents and turbulent mixing effects. Three release regions are considered geographically: the SW slope region from the 100-m to 500-m isobath and from 56^{o}W to 50^{o}W (4862 particles); the SW Grand Bank region (1317 particles), and the Laurentian Channel region (1698 particles) (see Fig. 12). We have considered three positions in the vertical: 50 m with high spawning adult population, 30 m below the surface Ekman layer, and 1 m below the sea surface within the Ekman layer. The release times are April 1, May 1st and June 1st. The ending time is September 30.

Effects of horizontal release positions

Numerical experiments were carried for the 50-m releases from the three geographical areas (Fig. 13). The results indicate that relatively high percentage of drifters from the SW Bank release can be available for settle-down in the nursery region at the end of early summer (Fig. 14). The availability from the SW slope release is low. None is available from the Laurentian Channel release. These results are consistent with the pattern of the model circulation. The subsurface current along the shelf edge is relatively strong, which has more capacity to carry the drifters downstream. Over the south Grand Bank, the flow is relative weak.

Effects of vertical release positions

The results from the 1-m, 30-m and 50-m releases indicate that the more particles released near the surface (1m) are carried away by the ocean currents from the SW nursery region than those at the subsurface at the end of late summer (Fig. 15). The horizontal currents have substantial shear in the vertical. In general, surface currents are stronger than those at depth. The simulation results suggest the seasonal wind-driven surface Ekman dynamics plays an important role in affecting the drifter trajectory and destination. The differences between the 50- and 30-m (both below the surface Ekman layer) releases are not as significant.

Effects of Release time

Earlier studies have suggested a spring spawning of the mature adult white hake. The results at the 50 m release started at Aril 1, May 1 and June 1 indicate that juveniles from the late spring spawning have relatively higher chances to settle in the SW Grand Bank nursery ground (Fig. 16). There is persistent westward flow in the model circulation fields along the shelf edge during the spring and summer. The longer the eggs, larvae and juveniles in the ocean currents before their settlement in the nursery region, the farther they can be carried downstream by advection and to offshore by entrainment.

The 1999 Scenario: A consequence of the weak Labrador Current

As indicated earlier, there was significant interannual variability in the shelf edge Labrador Current. The interannual variability may have profound impacts on the destination of the eggs and lava and the first year juveniles since the major spawning area is located in the shelf-edge. Previous studies have suggested that the shelf-edge Labrador Current was intensified off central Labrador in 1995/96 (Han and Tang, 2001). The Labrador Current pulse passed the southwest Newfoundland Slope in 1997 and intruded onto the Scotian Shelf in late 1997 and early 1998 (Han, 2002). The flow through the Flemish Pass was much weaker in 1998/1999 (Han et al., 2007).

To show potential impacts of the weakened Labrador Current in the 1999 on egg and lava distribution and their final settlement of young-of-the-year juveniles, we have released drogues under the reduced (by 50%) monthly mean currents. The distribution pattern at the 50-m release indicates that there are significant increases of the particles that are available to settle over the south Grand Bank nursery area (Fig. 17 and 18). More particles can reach the shallow portion of the Grand Bank, providing a high chance for the young of the year juveniles to reach inshore bays along northern Avalon.

CONCLUDING REMARKS

Growth rate of demersal juveniles was calculated as a mean of 1.02 mm day $^{-1}$ (~3 cm month $^{-1}$) in the first summer post settlement 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 fish. The estimate of growth of newly settled fish calculated by Kulka *et al.* (2005) was lower, at 1.8 cm month $^{-1}$. Thus, from their release into the water column as eggs in the spring (April and probably other months in the spring, see Kulka *et al.* 2005) to settlement mainly in shallow areas in the autumn was a period of about 20 weeks during which time they were subject to transport by midwater currents.

The present particle tracking study under the model monthly-mean circulation fields, tidal currents and associated mixing indicates that a weaker Labrador Current can increase the likelihood of the juvenile settlement on the southern shallow extent of the Grand Bank, the "nursery area" in the fall. This area corresponds to location where the large majority of the very large 1999 year class settled. The SW slope (an identified major spawning location in spring) spawning has much lower availability for the fall settlement than the Grand Bank spawning. Nevertheless, the species is capable of producing a very large numbers of eggs in spring. As a result, it can maintain a sufficient number of small juveniles settling into the nursery area in fall. The simulated results also suggest that juveniles from the late spring spawning have higher potential to settle there.

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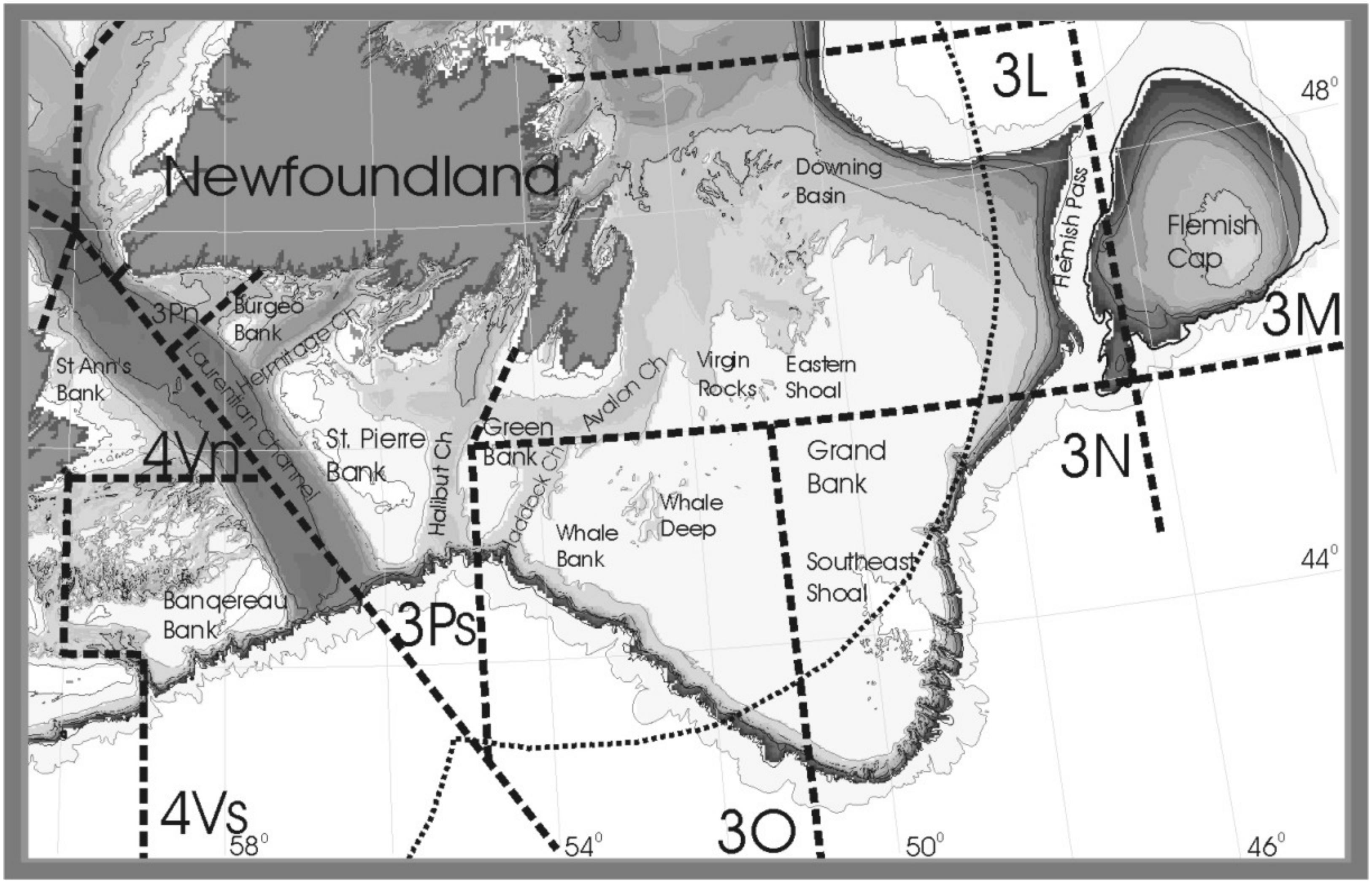


Figure 1. Map of the Grand Banks showing various banks, basins and NAFO Divisions. Thick dotted lines delineate NAFO Divisions. The thin dotted curved lines shows the 200 mile limit delineating Canadian territory from the NAFO Regulatory Area.

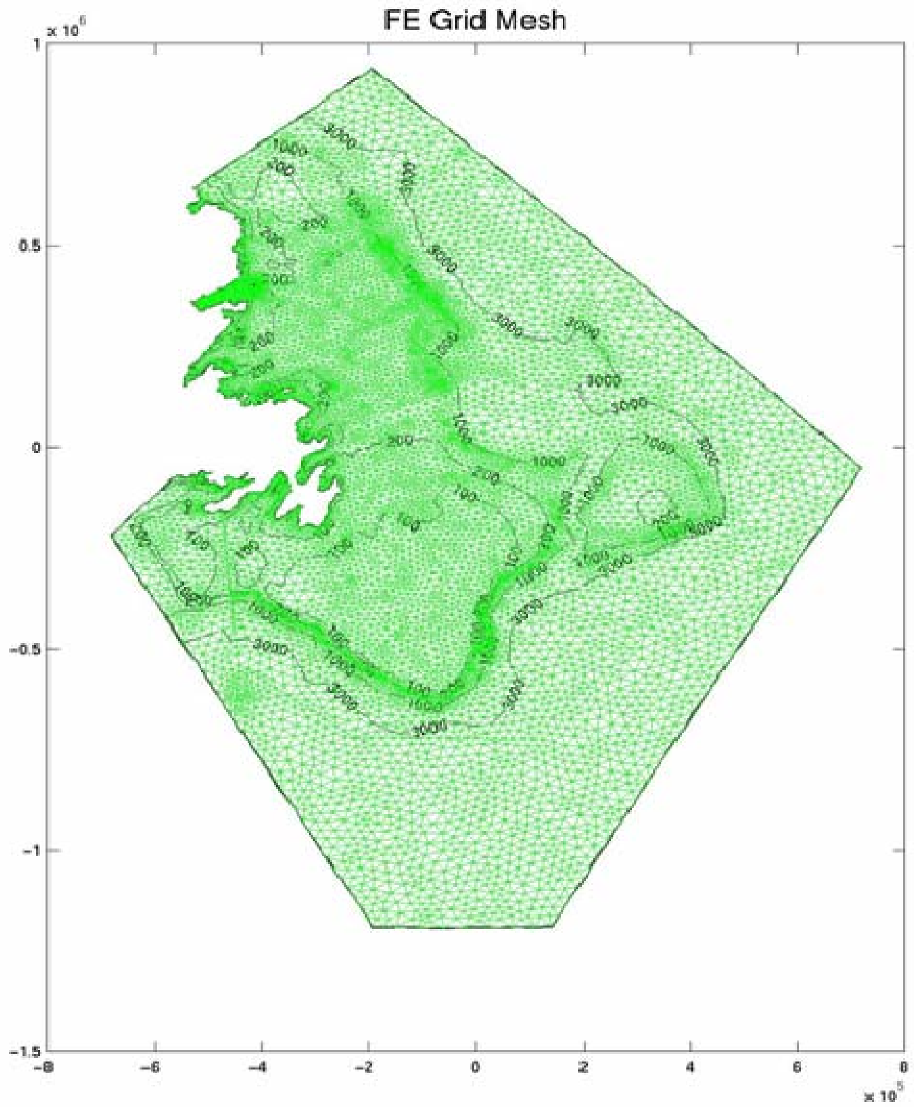


Figure 2. The horizontal finite-element grid (slns2) used in the numerical model. The depth contours and coordinates are in meters. The model origin is at 48.5°N 49.75°W.

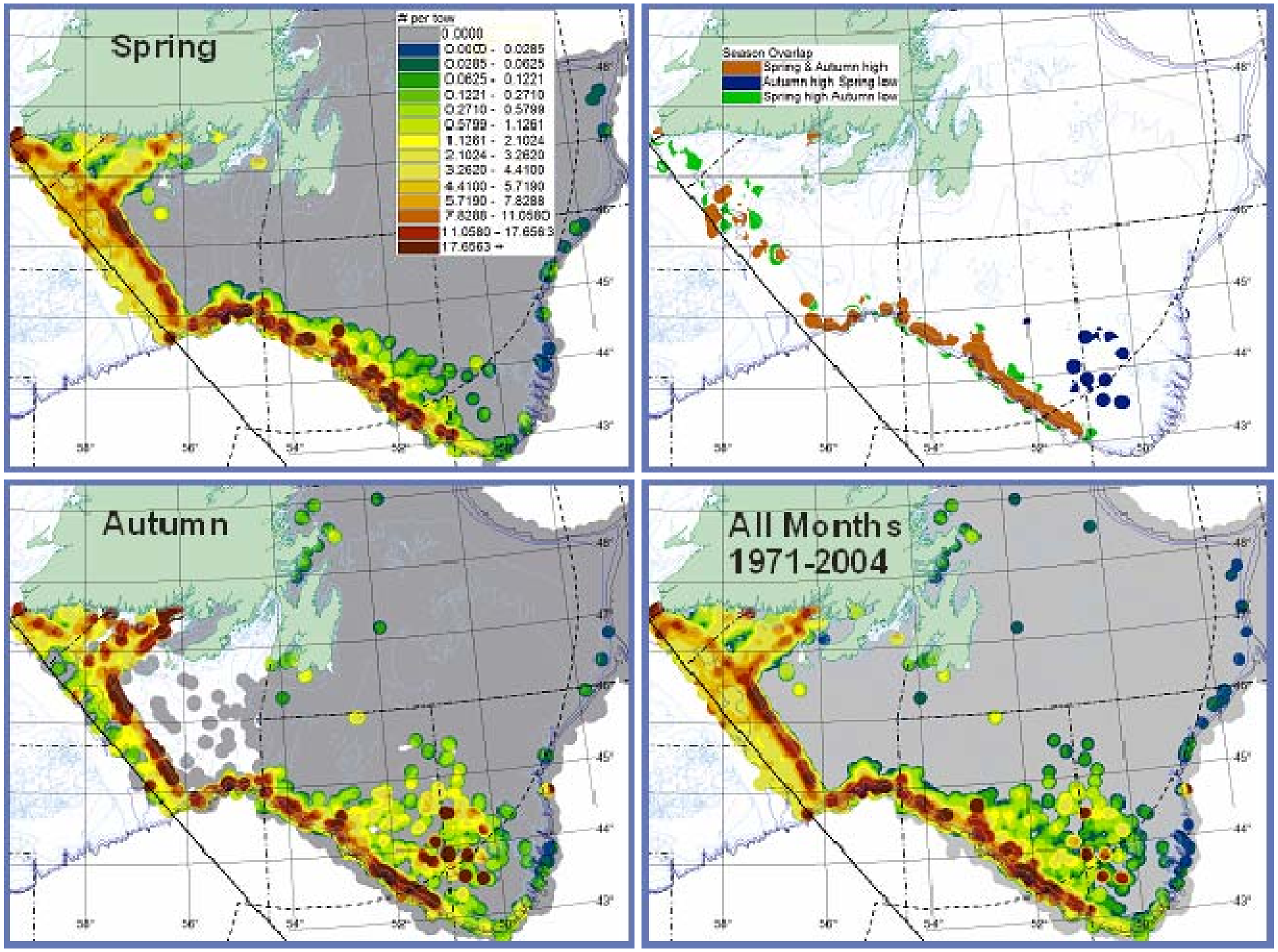


Figure 2. Distribution of white hake on the Grand Banks (NAFO Div. 3LNOP) based on NL surveys carried out between 1971 and 2004. Grey areas depict locations that are surveyed but without catches, blue - low density to red – high concentrations. Upper left: July-January, lower left: February-June. Upper right: seasonal overlap. Lower right: Long term annual (all months) average distribution, 1971-2004.

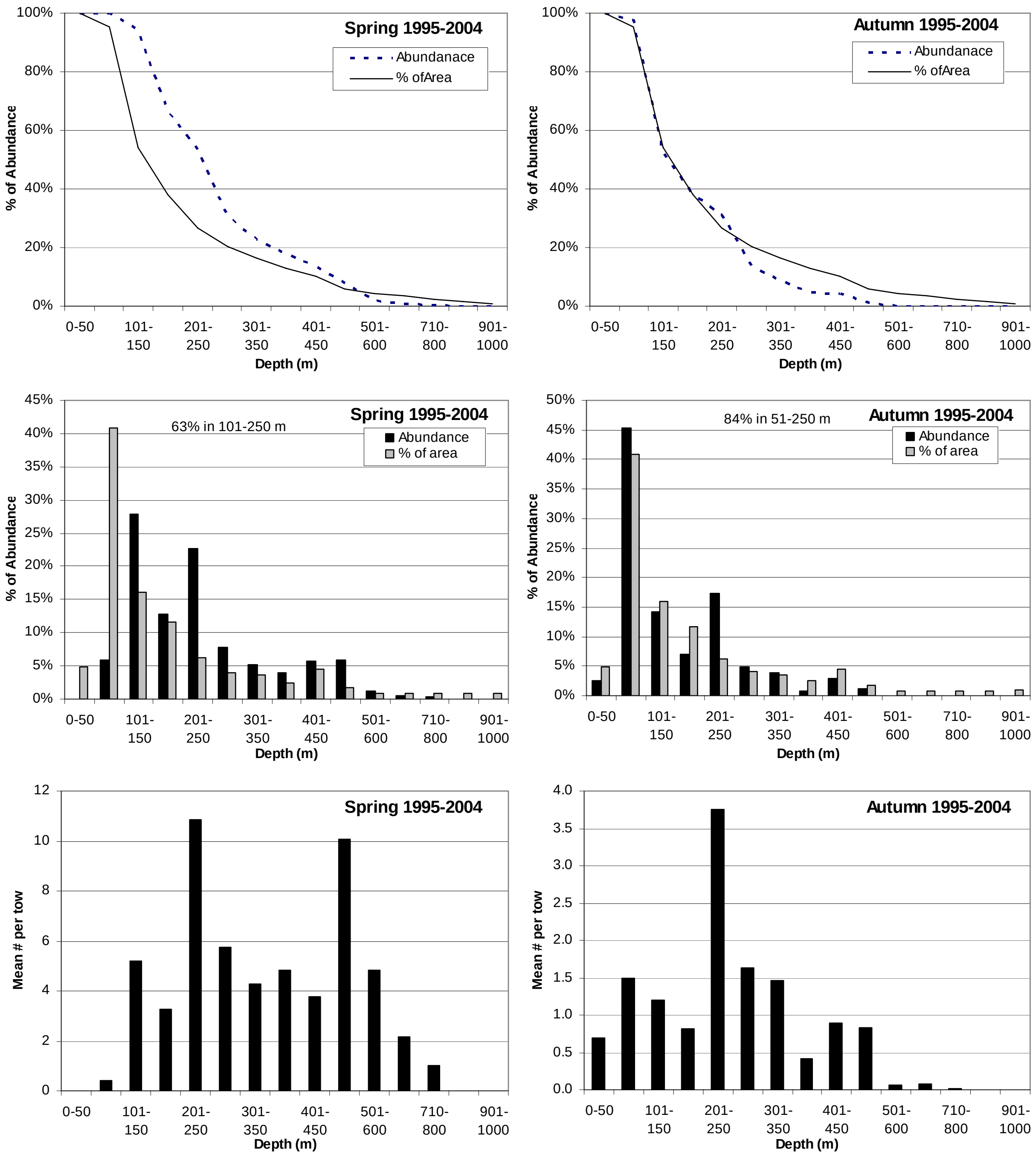


Figure 3. Distribution of white hake by depth from spring and autumn surveys1996-2004. Upper and middle panel: distribution of abundance at depth in relation to available habitat. Lower panel: Density (kg per tow by depth range.

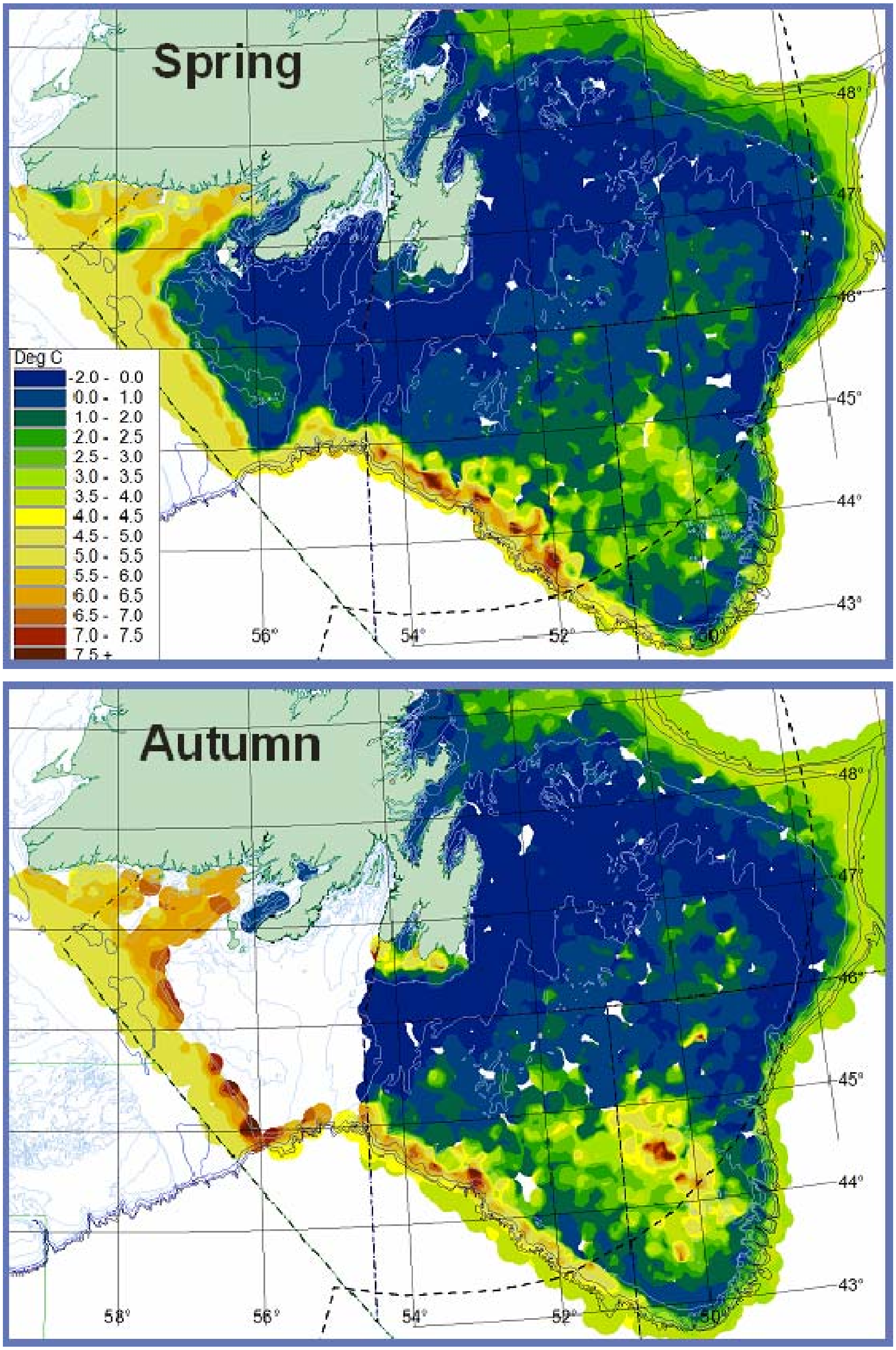


Figure 4a. Bottom temperatures on the Grand Banks, by season, averaged over 1995-2004.

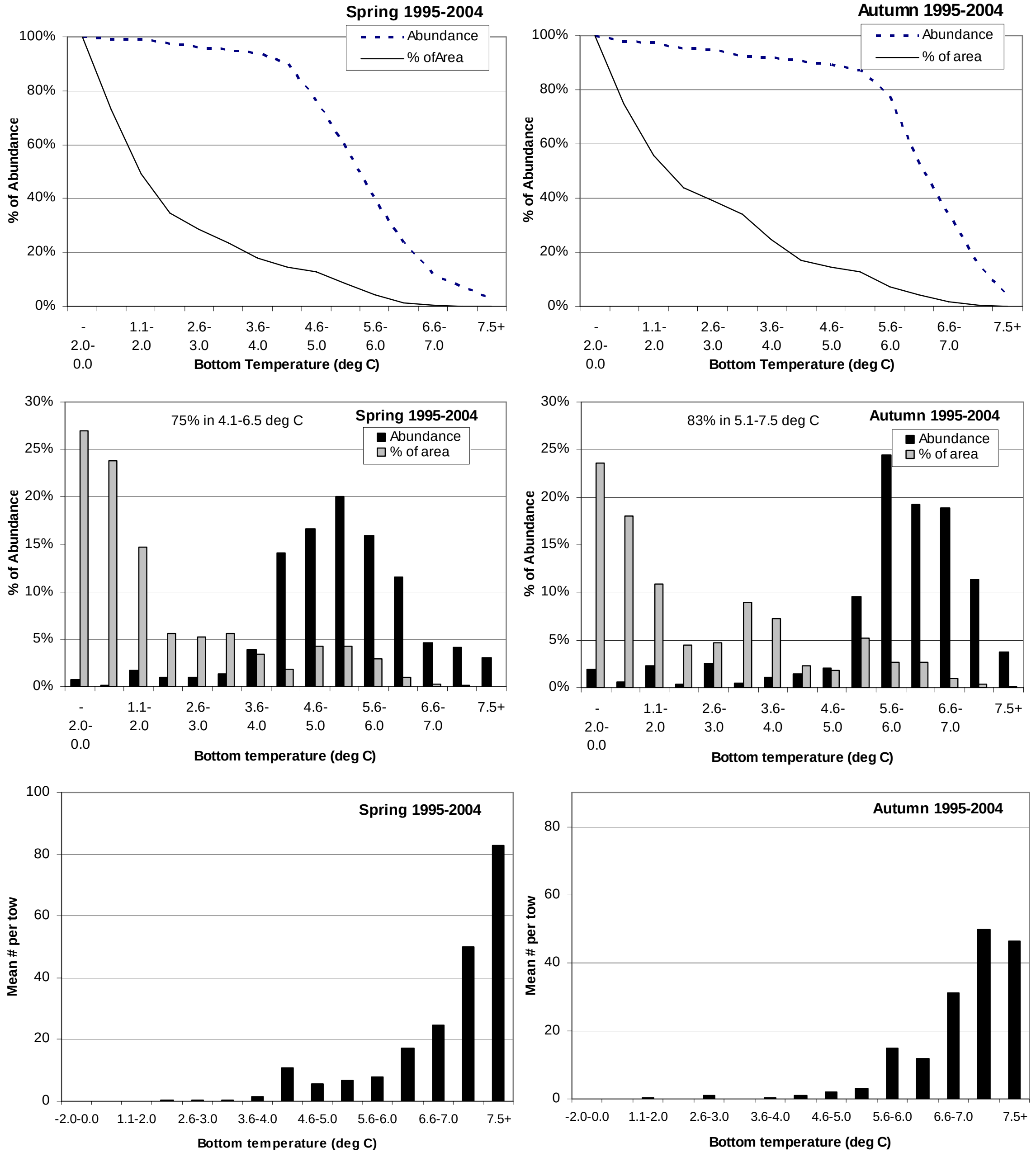


Figure 4b. Distribution of white hake by bottom temperature from spring and autumn surveys1996-2004. Upper and middle panel: distribution of abundance at temperature in relation to available habitat. Lower panel: Density (kg per tow by temperature range.

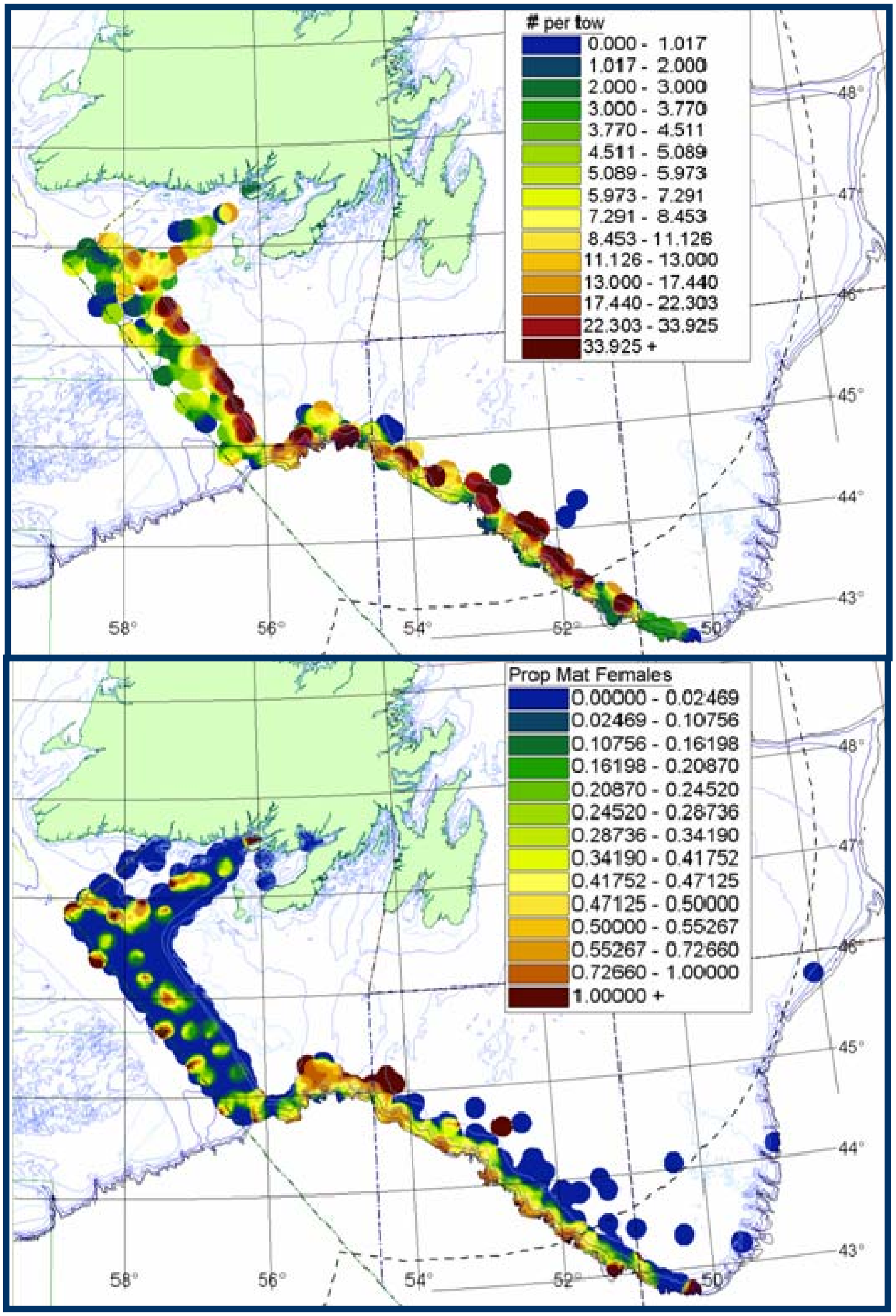


Figure 5. Upper panel: Distribution of mature females (> 57 cm). Lower Panel: Proportion by number of mature females in the total survey catches. Data are from 1995-2004 spring trawl surveys.

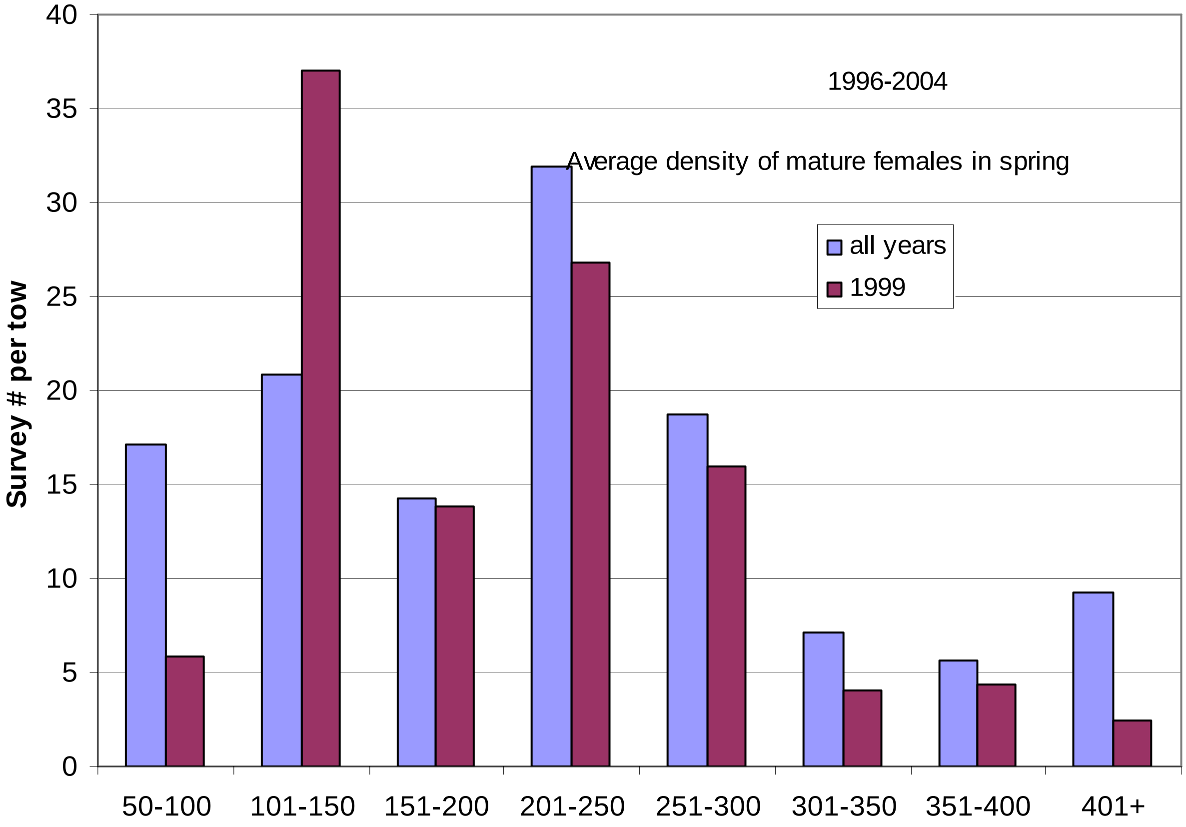
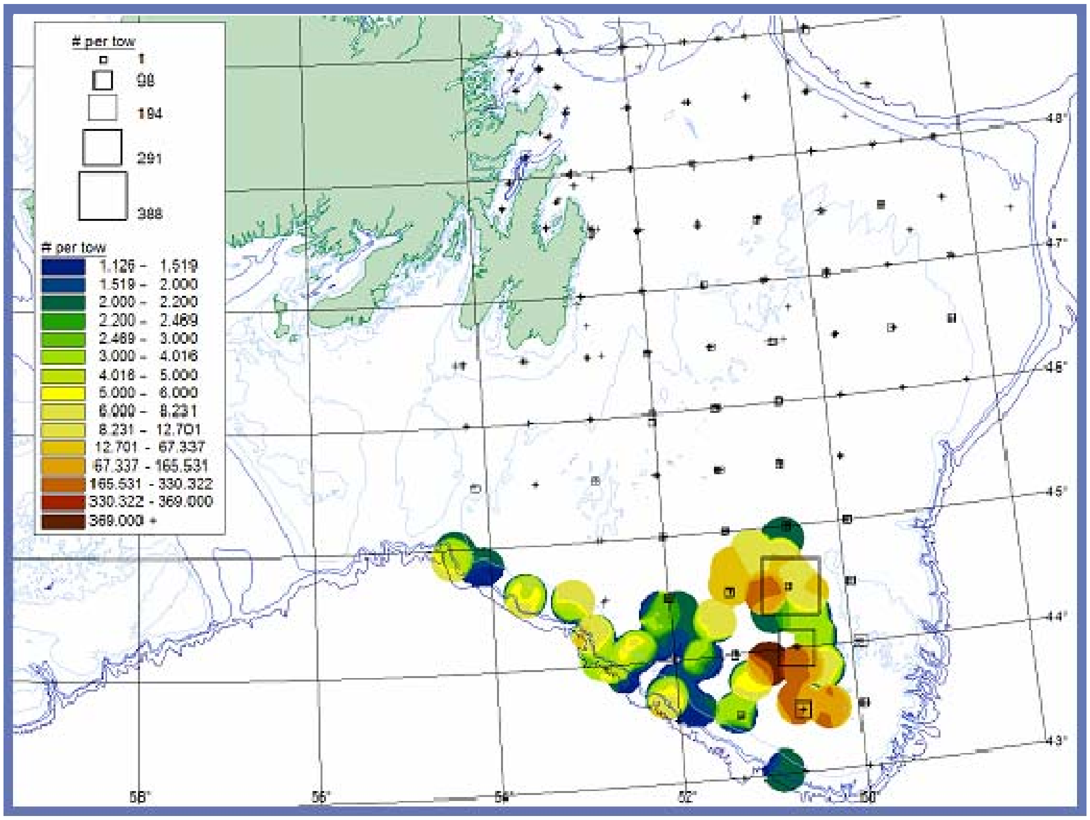


Figure 6. Density of mature females (> 57 cm TL) by depth intervals in the spring 1995-2004 surveys.



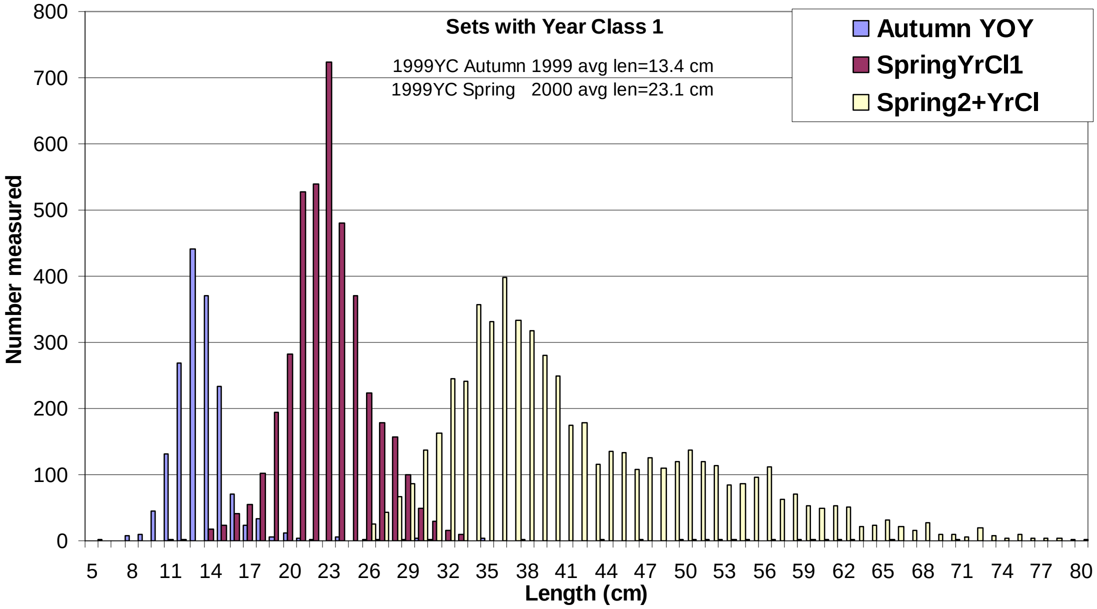


Figure 7. Upper: Colour surface depicts the density of newly settled white hake from the Campelen autumn survey data superimposed by the pelagic (~ 30 cm below surface) YOY from the IGYPT survey. Lower: Cumulative length frequencies for sets containing 1999 year class white hake in the autumn of 1999 and spring of 2000. Fish of other year classes found in those sets are included (as Spring 2+ YrCl)
Embed the YOY Lenfreq into the corner of this raph.

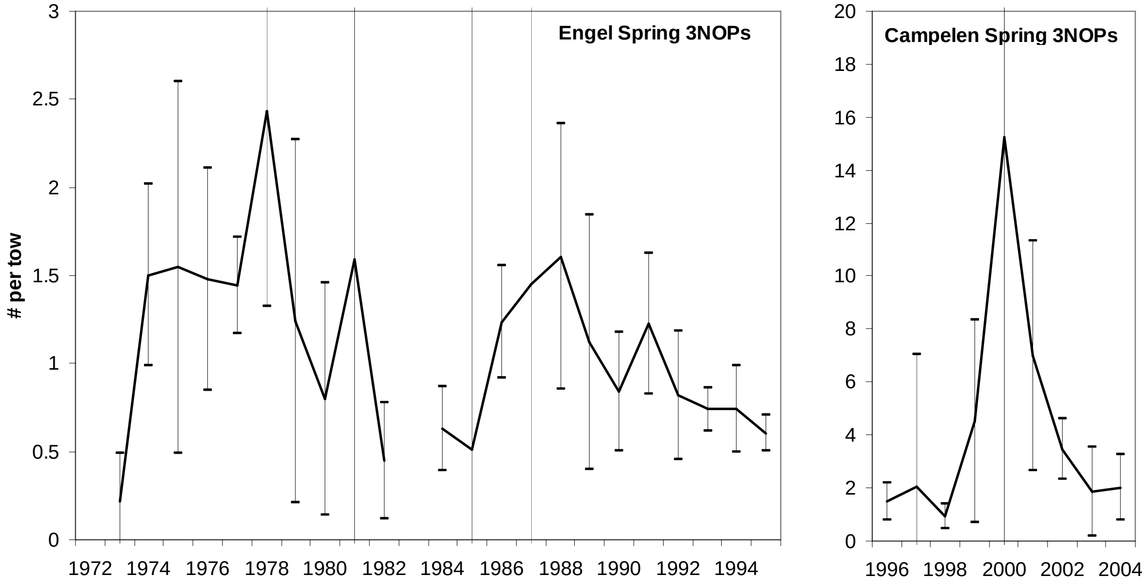


Figure 8. Upper panel: Percent of total area surveyed occupied by white hake on the Grand Banks. 20% refers to 29% of the area where the density (kg per tow) of white hake is greatest. Middle panel: Total area surveyed during the Spring survey. Lower Panel: Abundance of white hake in NAFO Div 3NOPs based on spring surveys.

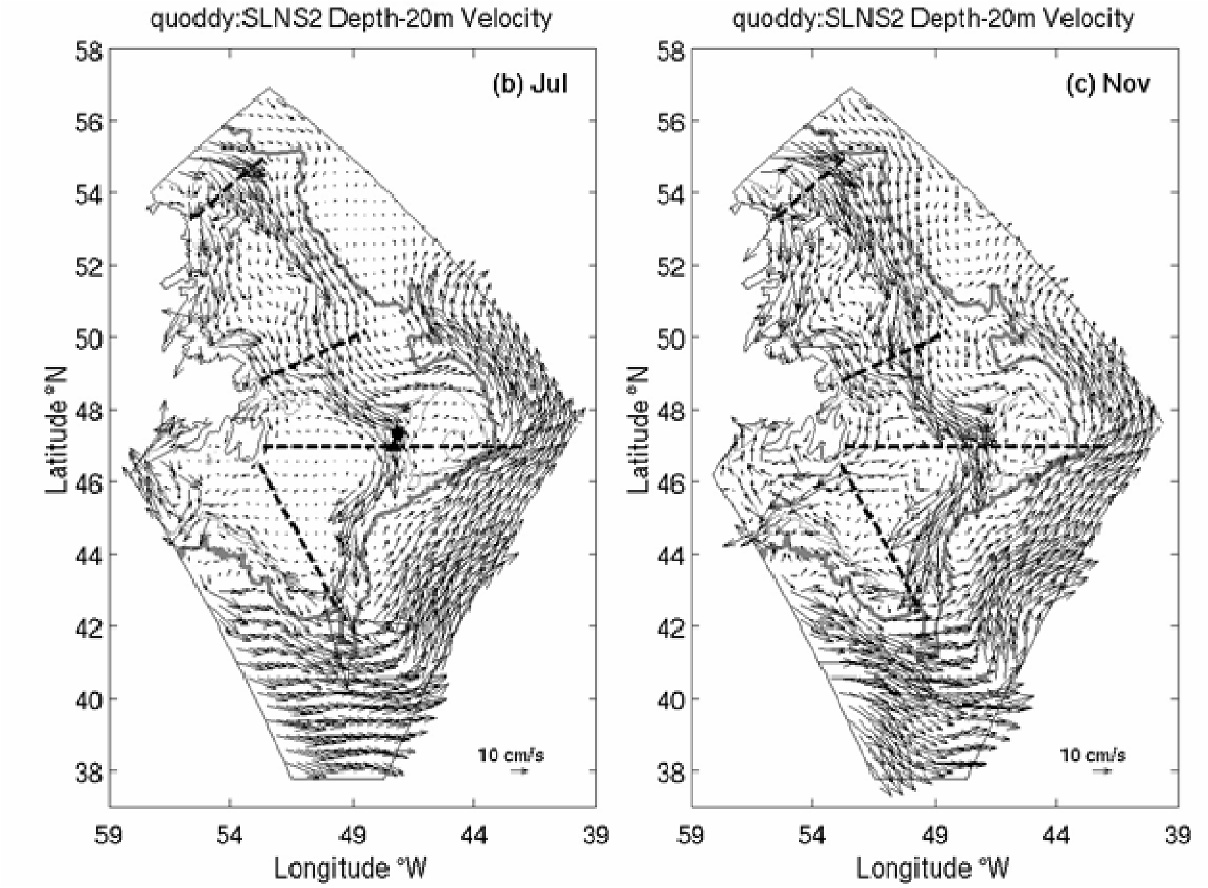


Figure 10. Model circulation fields at the 20-m depth for July and November, representing summer and fall respectively. The model fields have been subsampled for clarity of presentation. The 200-, 1000-, and 3000-m isobaths are depicted as the grey lines.

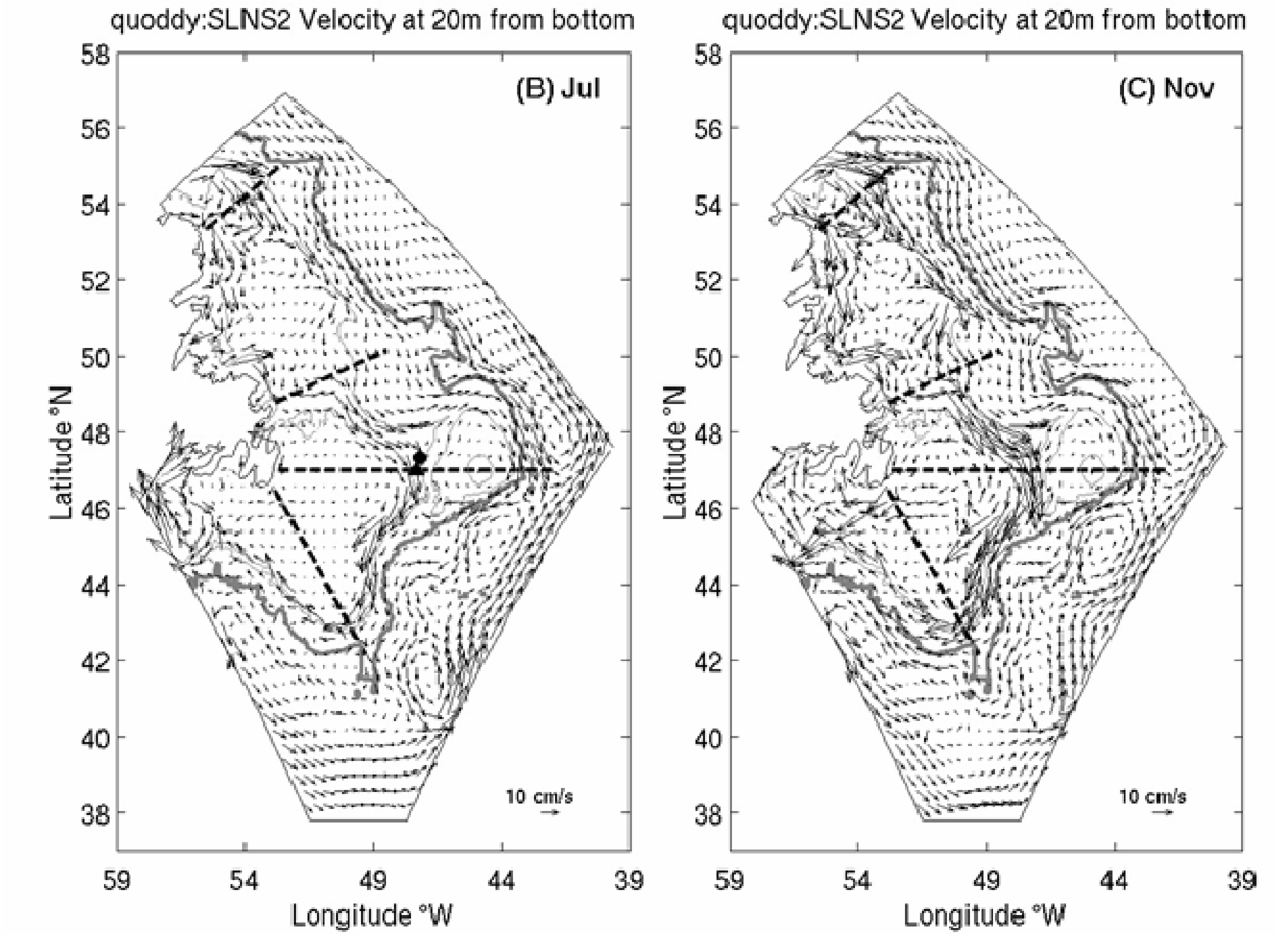


Figure 11. Same as Fig. 10, but at the 20 m above the sea bed.

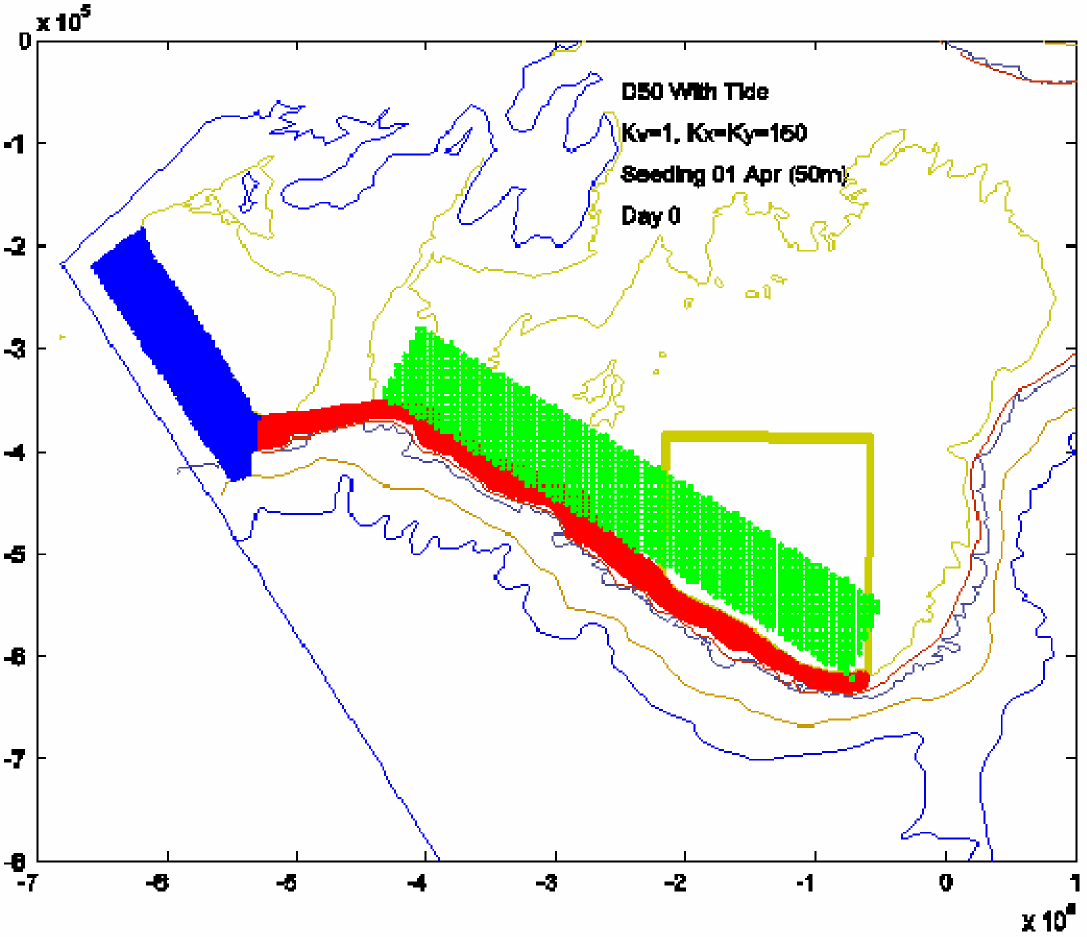


Figure 12. Horizontal distribution of particles at the start of tracking. Green: Southwest Grand Bank (Bank); Red: Southwest Slope (Slope); Blue: Laurentian Channel (LC). The nursery area on the SW Grand Bank is depicted as the area from the 100-m isobath to 45°N and from 52°W to 50°W.

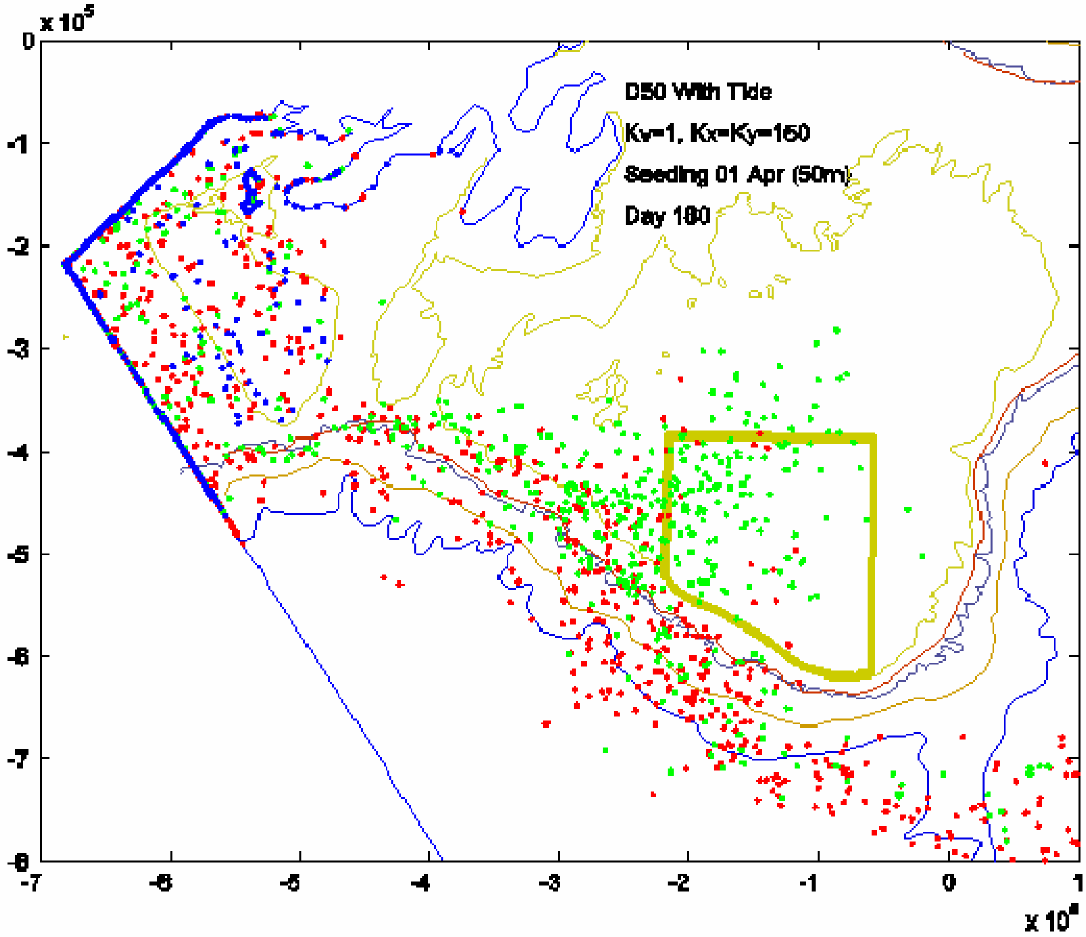


Figure 13. Snapshot of the simulated particle distribution at the end of September. The particles are released at the 50-m depth on April 1.

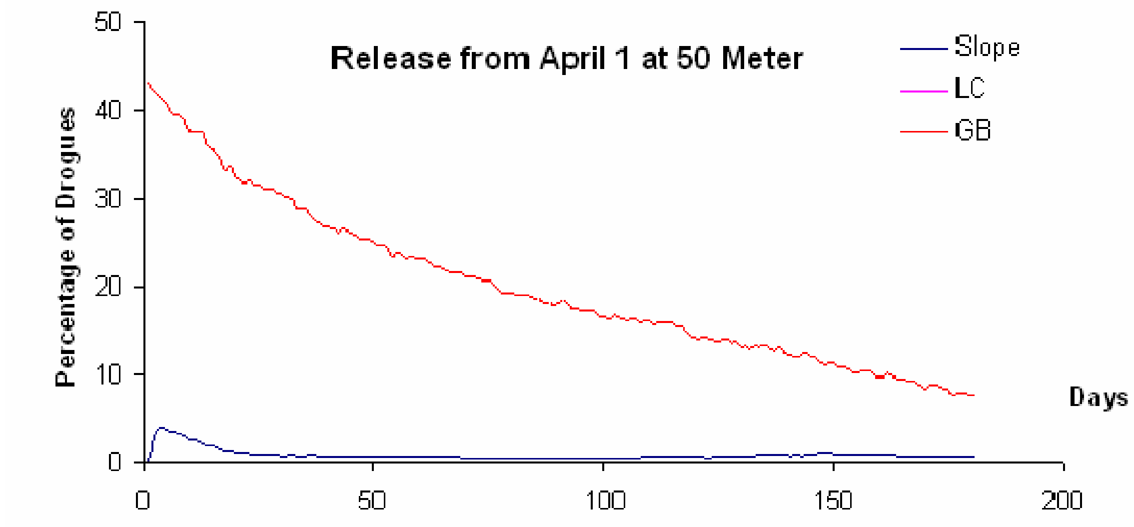
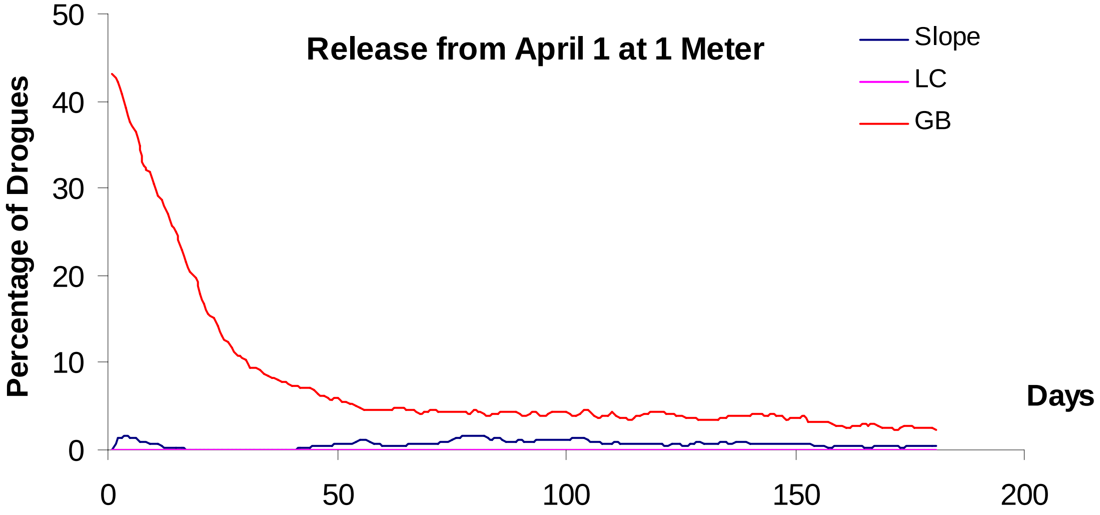


Figure 14. The temporal evolution of the percentage of particles within the nursery area for the three release regions. The particles are released at the 50-m depth on April 1. The percentage of particles at a given time is defined as the ratio of the number of particles within the Grand Bank nursery area and the total number of particles initially released for each geographical region.



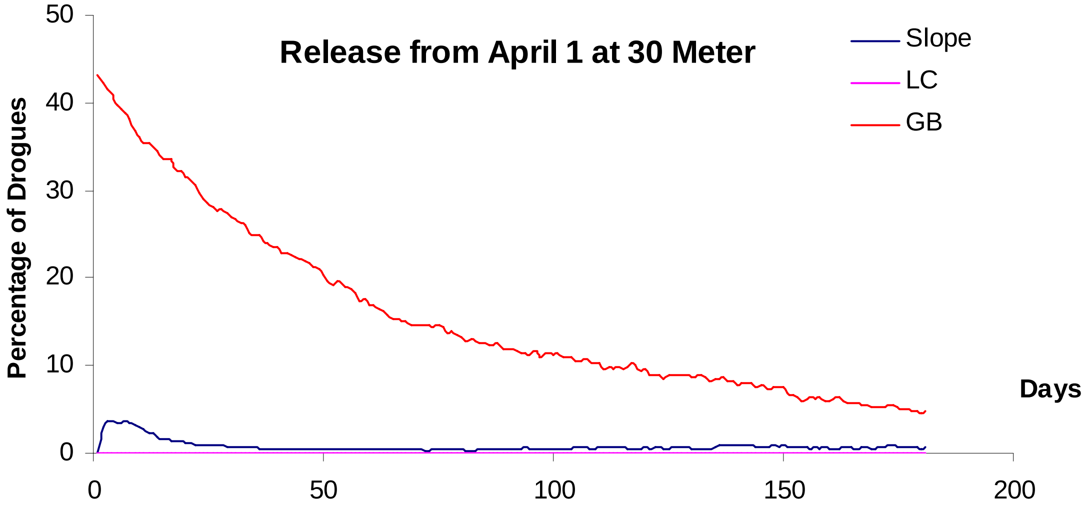
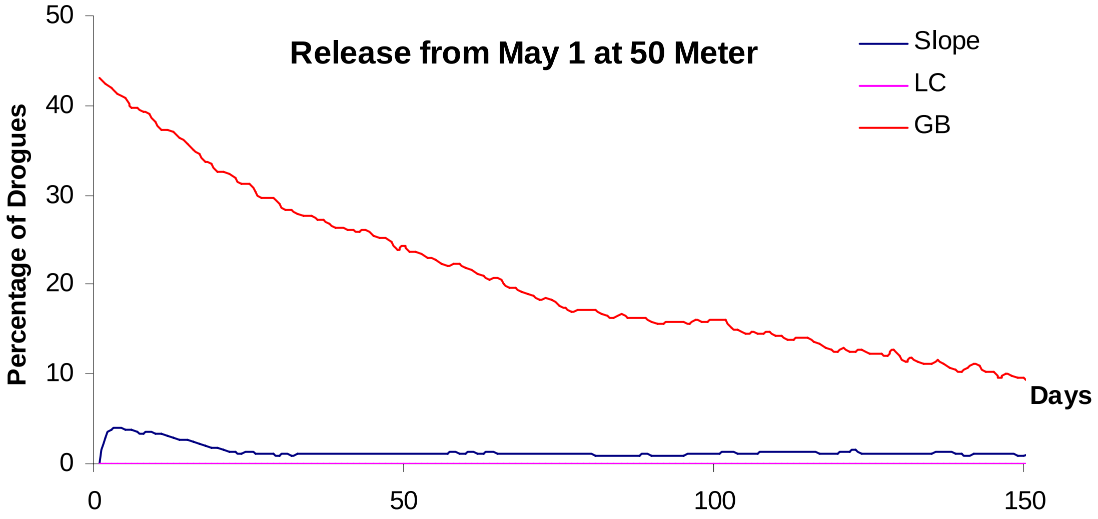


Figure 15. Same as Fig. 14, but released at the 1- and 30-m depth respectively.



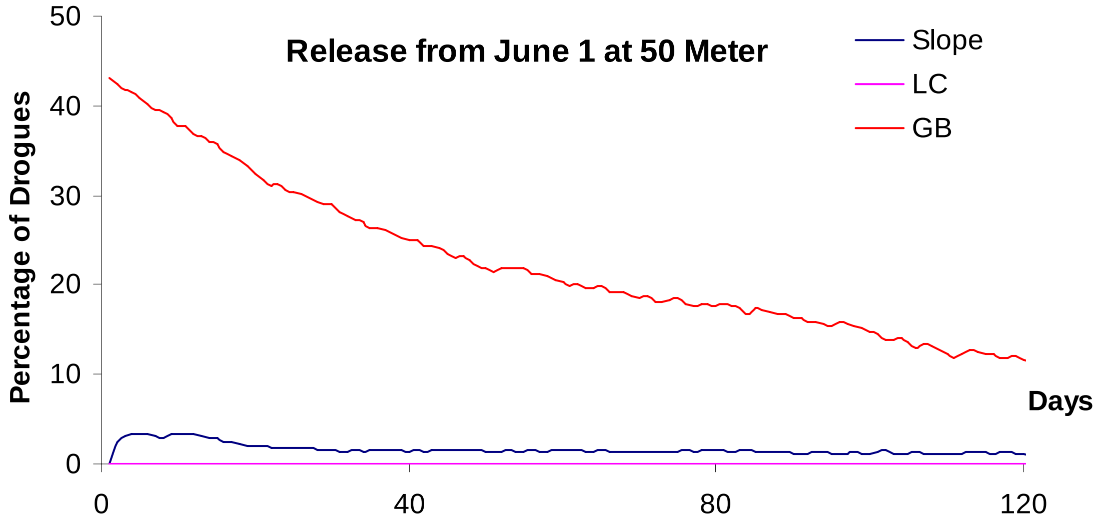


Figure 16. Same as Fig. 14, but released on May 1 and June 1 respectively.

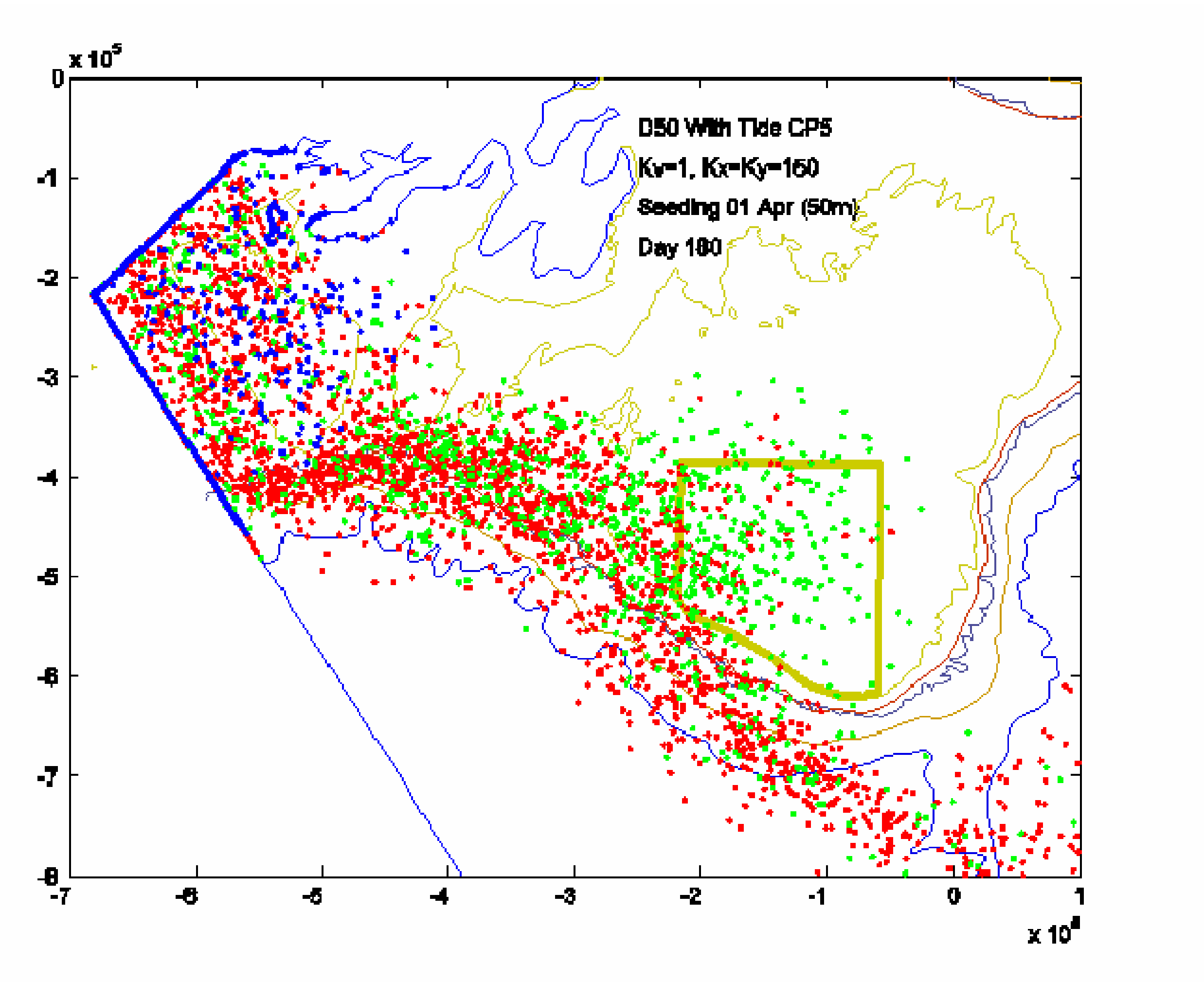


Figure 17. Same as Fig. 13, but with the horizontal and vertical currents reduced by 50%.

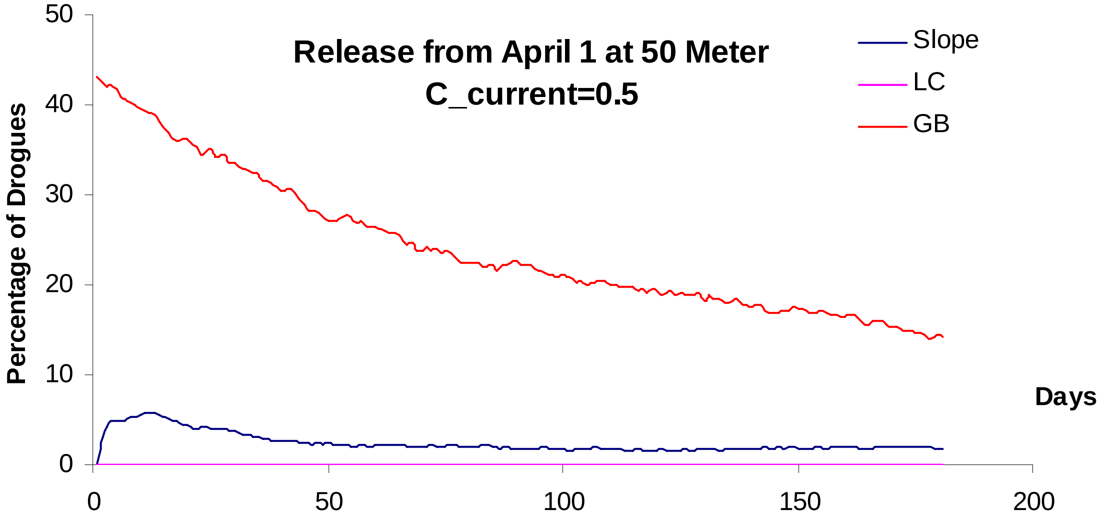


Figure 18. Same as Fig. 14, but with the horizontal and vertical currents reduced by 50%.