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FINAL REPORT - 2007 Data collection and analysis in support of single and multispecies stock assessments in Chesapeake Bay: The Chesapeake Bay Multispecies Monitoring and Assessment Program

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Progress Report

The Chesapeake Bay Multispecies Monitoring and Assessment Program

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FINAL REPORT

Data collection and analysis in support of single and multispecies stock assessments in Chesapeake Bay:

The Chesapeake Bay Multispecies Monitoring and Assessment Program

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Introduction

Historically, fisheries management has been based on the results of single-species stock assessment models that focus on the interplay between exploitation level and sustainability. There currently exists a suite of standard and accepted analytical frameworks (e.g., virtual population analysis (VPA), biomass dynamic production modeling, delay difference models, etc.) for assessing the stocks, projecting future stock size, evaluating recovery schedules and rebuilding strategies for overfished stocks, setting allowable catches, and estimating fishing mortality or exploitation rates. A variety of methods also exist to integrate the biological system and the fisheries resource system, thereby enabling the evaluation of alternative management strategies on stock status and fishery performance. These well-established approaches have specific data requirements involving biological (life history), fisheries-dependent, and fisheries-independent data (Table 1). From these, there are two classes of stock assessment or modeling approaches used in fisheries: partial assessment based solely on understanding the biology of a species, and full analytical assessment including both biological and fisheries data.

Table 1. Summary of biological, fisheries-dependent and fisheries-independent data requirements for single-species analytical stock assessment models.

Data Category	Assessment Type	Data Description
Biological / Life History	Partial	Growth (length / weight)
		Maturity schedule
		Fecundity
		Partial recruitment schedules
		Longevity
		Life history strategies (reproductive and behavioral)
Fishery-Dependent Data	Analytical	Catch, landings, and effort
		Biological characterization of the harvest (size, sex, age)
		Gear selectivity
		Discards/bycatch
Fishery-Independent Data	Analytical	Biological characterization of the population (size, sex, age)
		Mortality rates
		Estimates of annual juvenile recruitment

Although single-species assessment models are valuable and informative, a primary shortcoming is that they generally fail to consider the ecology of the species under management (e.g., habitat requirements, response to environmental change), ecological interactions (e.g., predation, competition), and technical interactions (e.g., discards, bycatch) (NMFS 1999, Link 2002a,b). However, inclusion of ecological processes into fisheries management plans is now strongly recommended (NMFS 1999, NRC 1999) and in some cases even mandated (NOAA 1996). Multispecies assessment models have been developed to move towards an ecosystem-based approach to fisheries management (Hollowed et al. 2000, Whipple et al. 2000, Link 2002a,b). Although such models are still designed to yield information about sustainability, they are structured to do so by explicitly incorporating the effects of ecological processes among interacting populations.

Over the past several years, the number and type of multispecies models designed to provide insight about fisheries questions has grown significantly (Hollowed et al. 2000, Whipple et al. 2000). This growth has been fueled by the need to better inform fisheries policy makers and managers, however, recent concerns about effects of fishing on the structure of ecosystems have also prompted research activities on multispecies modeling and the predator-prey relationships that are implied. From a theoretical perspective, basing fisheries stock assessments on multispecies rather than single-species models certainly appears to be more appropriate, since multispecies approaches allow a greater number of the processes that govern population abundance to be modeled explicitly. However, this increase in realism leads to an increased number of model parameters, which in turn, creates the need for additional types of data.

In the Chesapeake Bay region, there has been a growing interest in ecosystem-based fisheries management, as evidenced by the recent development of fisheries steering groups (e.g., ASMFC multispecies committee), the convening of technical workshops (Miller et al. 1996; Houde et al. 1998), and the goals for ecosystem-based fisheries management set by the Chesapeake Bay 2000 (C2K) Agreement. In many respects, it can be argued that the ecosystem-based fisheries mandates inherent to the C2K Agreement constitute the driving force behind this growing awareness. The exact language of the C2K agreement, as it pertains to multispecies fisheries management, reads as follows:

1. By 2004, assess the effects of different population levels of filter feeders such as menhaden, oysters and clams on Bay water quality and habitat.

2. By 2005, develop ecosystem-based multispecies management plans for targeted species.

3. By 2007, revise and implement existing fisheries management plans to incorporate ecological, social and economic considerations, multispecies fisheries management and ecosystem approaches.

If either single-species or ecosystem-based management plans are to be developed, they must be based on sound stock assessments. In the Chesapeake Bay region, however, the data needed to perform single and multispecies assessments is either partially available or nonexistent.

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) was developed to assist in filling these data gaps, and ultimately to support bay-specific stock assessment modeling activities at both single and multispecies scales. While no single gear or monitoring program can collect all of the data necessary for both types of assessments, ChesMMAP was designed to maximize the biological and ecological data collected for several recreationally, commercially, and ecologically important species in the bay.

In general, ChesMMAP is a large-mesh bottom trawl survey designed to sample late juvenile-to-adult fishes in Chesapeake Bay. This field program currently provides data on relative abundance, length, weight, age, and trophic interactions for several important fish species seasonally inhabiting the bay. This report summarizes the field, laboratory, and preliminary data.

Among the research agencies in the Chesapeake Bay region, only VIMS has a program focused on multispecies issues involving the adult/harvested components of the exploited fish species that seasonally inhabit the bay. The multispecies research program at VIMS is comprised of three main branches: field data collection (ChesMMAP and the VIMS Seagrass Trammel Net Survey), laboratory processing (The Chesapeake Trophic Interactions Laboratory Services – CTILS, and ChesMMAP), and data analysis and multispecies modeling (The Fisheries Ecosystem Modeling and Assessment Program - FEMAP). In this report, we summarize the field, laboratory, and data analysis activities associated with the 2006 sampling year.

The following Tasks are addressed in this report:

- Task 1 – Analyze existing data for improved design efficiency
- Task 2 – Conduct research cruises
- Task 3 – Synthesize data for single species analyses
- Task 4 – Quantify trophic interactions for multispecies analyses
- Task 5 – Estimate abundance
- Task 6 – Serve as sampling platform for other bay studies

Methods

Task 1 – *Design Efficiency*

See Results section.

Task 2 – *Conduct research cruises*

In 2007, four research cruises were conducted bimonthly from March to November in the mainstem of Chesapeake Bay (a fifth cruise scheduled for the month of September was cancelled due to a funding shortfall). The timing of the cruises was chosen to adequately characterize the seasonal abundances of fishes in the bay. The R/V Bay Eagle, a 19.8m aluminum hull, twin diesel vessel owned and operated by VIMS, served as the sampling platform for this survey. The trawl net is a 13.7m (headrope length) 4-

seam balloon trawl manufactured by Reidar's Manufacturing Inc. of New Bedford, MA. The wings and body of the net are constructed of #21 cotton twine (15.2cm mesh), and the codend is constructed of #48 twine (7.6cm mesh). The legs of the net are 6.1m and connected directly to 1.3m x 0.8m steel-V trawl doors weighing 83.9kg each. The trawl net is deployed with a single-warp system using 9.5mm steel cable with a 37.6m bridle constructed of 7.9mm cable.

For each cruise, the goal was to sample 80 stations distributed in a stratified random design throughout the mainstem of Chesapeake Bay. The Bay was stratified by dividing the mainstem into five regions of 30 latitudinal minutes each (the upper and lower regions being slightly smaller and larger than 30 minutes, respectively). Within each region, three depth strata ranging from 3.0m-9.1m, 9.1m-15.2m, and >15.2m were defined. A grid of 1.9km^2 cells was superimposed over the mainstem, where each cell represented a potential sampling location. The number of stations sampled in each region and in each stratum was proportional to the surface area of water represented. Stations were sampled without replacement and those north of Pooles Island (latitude 39^o 17') have not been sampled since July 2002 due to repeated loss of gear. In the future, sidescan sonar will be used to identify potential sampling locations in this area.

Tows were conducted in the same general direction as the tidal current (pilot tows conducted using the net monitoring gear in November 2001 indicated that the gear performed most consistently when deployed with the current rather than against the current). The net was generally deployed at a 4:1 scope, which refers to the amount of cable deployed relative to depth. For shallow stations, however, the bridle was always deployed beyond the vessel's tow-point, implying that the scope ratio could be quite high. The target tow speed was 6.5 km/h but occasionally varied depending on wind and tidal conditions. Based on data collected from the net monitoring gear, tow speed and scope were also adjusted occasionally to ensure that the gear was deployed properly. Tows were 20 minutes in duration, unless obstructions or other logistical issues forced a tow to be shortened (if the duration of a tow was at least 10 minutes, it was considered complete). Computer software was used to record data from the net monitoring gear (i.e., wingspread and headrope height) as well as a continuous GPS stream during each tow. On occasions when the monitoring gear failed, the trawl geometry was assumed to follow cruise averages and beginning and ending coordinates were taken from the vessel's GPS system.

Task 3 – *Synthesize data for single species analyses*

Once onboard, the catch from each tow is sorted and measured by species or size-class if distinct classes within a particular species are evident. A subsample of each species or size-class is further processed for weight determination, stomach contents, ageing, and determination of sex and maturity stage. In addition, surface and bottom temperature, salinity, and dissolved oxygen readings are recorded at each sampling location.

Single-species assessment models typically require information on (among others) age- length-, and weight-structure, sex ratio, and maturity stage. Data were synthesized to characterize age-, length-, and weight-frequency distributions across a variety of spatial and temporal scales (e.g., by year, season, or region of the bay) for each species. Sex ratio and maturity data are also be available to support sex-specific analyses.

Task 4 – *Quantify trophic interactions for multispecies analyses*

In addition to the population-level information described under Task 3, multispecies assessment models require information on predator-prey interactions across broad seasonal and spatial scales. In general, these procedures involve identifying each prey item to the lowest possible taxonomic level (Hyslop 1980). Several diet indices were calculated to identify the main prey types for each species: %weight, %number, and %frequency-of-occurrence. These indices were coupled with the information generated from Task 3 and age-, length-, and sex-specific diet characterizations were developed for each species. Efforts also focused on characterizing spatial and temporal variability in these diets.

Diet index values were calculated to identify the main prey in the diet of predators in the mainstem Chesapeake Bay. Since trawl collections essentially yield a cluster of fish at each sampling location, the aforementioned indices were calculated using a cluster sampling estimator (Buckel et al. 1999).

The contribution of each prey type to the diet ($\%Q_k$, where Q_k is any of the aforementioned index types) is given by:

$$\%Q_k = \frac{\sum_{i=1}^{n} M_i q_{ik}}{\sum_{i=1}^{n} M_i} \quad , \qquad (1)$$

where

$$q_{ik} = \frac{w_{ik}}{w_i} * 100 \, ,$$

and where n is the number of trawls containing the predator of interest, M_i is the number of that predator collected at sampling site i, w_i is the total weight of all prey items encountered in the stomachs of that predator collected from sampling location i, and w_{ik} is the total weight of prey type k in those stomachs. Accordingly, stomachs collected in the field were processed following standard diet analysis procedures (Hyslop 1980).

Task 5 – *Estimate abundance*

Time-series of relative abundance information can easily be generated from the basic catch data of a monitoring survey. For each species, a variety of relative abundance trends can be generated according to year, season, and location within the Bay. Absolute abundance estimates can be generated for each species by combining relative abundance data with area swept and gear efficiency information. Area swept was calculated for each tow by multiplying tow distance (provided by GPS equipment) by average wingspread (provided by net monitoring gear). Gear efficiency estimates are being derived by comparing the number of fish that encounter the gear (from the hydroacoustic data) with the fraction captured (from the catch data). To develop species-specific efficiency estimates, the hydroacoustic data will be partitioned according to the target strength distribution for each species. These distributions will be determined through ongoing cage experiments.

ChesMMAP utilizes two types of hydroacoustic gear in an effort to convert relative indices of abundance into estimates of total abundance. The equation necessary for this conversion is:

$$N = \frac{cA}{\frac{a}{e}}, \qquad (1)$$

where N is total population size measured in numbers (or biomass), c is the mean number (or weight) of fish captured per tow, a is the area swept by one trawl tow, A is the total survey area, and e is the net efficiency (dimensionless). Given that c is observed and A is easily determined, the hydroacoustic equipment is used to derive estimates of a and e. Estimation of the parameter e for a variety of species is a mid-to-long term goal. Until then, removal of that parameter from Equation 1 results in relative estimates of ‘minimum trawlable abundance.’ These estimates represent the smallest number (or biomass) of fish present within the sampling area that are susceptible to the sampling gear.

Task 6 – *Serve as sampling platform for bay studies*

See Results section.

Results

Task 1 - *Design Efficiency*

A number of approaches to this issue were considered, however, outside factors caused us to defer proceeding with design efficiency analyses until a later date. Specifically, the Chesapeake Bay Fishery Independent Monitoring Workshop recognized that the general concept behind the ChesMMAP program could serve as a model and a platform for future monitoring programs. In anticipation of a larger group focusing on survey designs, it was considered prudent to defer these analyses.

Task 2 – *Conduct Research Cruises*

Throughout six years of sampling, the number of fish collected each year by the ChesMMAP survey was fairly consistent and ranged from approximately 31,000 (in 2003 and 2007) to 48,000 (in 2004 – Table 1). Each year, between 3,900 and 6,000 pairs of otoliths have been collected, the majority of which have been processed for age determination. Similar numbers of stomachs have been collected and processed for diet composition information annually.

Table 1. The number of specimens collected, measured and processed for age determination and diet composition information from ChesMMAP 2002 – 2007.

Year	Fish collected	Fish measured	Otoliths collected	Otoliths processed	Stomachs collected	Stomachs processed
2002	32,019	23,605	5,487	4,433	4,556	2,412
2003	30,924	20,828	3,913	2,934	3,250	2,236
2004	47,622	31,245	5,169	4,070	4,272	3,156
2005	45,204	36,906	6,065	4,793	5,066	3,195
2006	43,957	31,243	5,412	4,058	4,400	2,692
2007	30,893	22,124	4,282	2,952	3,663	2,282

Tasks 3-5 – *Data Summaries*

The data summaries in this report essentially represent biological and ecological profiles of those species well sampled by the ChesMMAP survey. Our intent with these profiles is to maximize the amount of information available to fishery managers. The profiles that follow are organized first by species and then by type of analysis ('Task'). Each Task element (single-species stock parameter summarizations, trophic interaction summaries, and estimates of abundance) is included but is not labeled with a Task number and is not necessarily shown in Task number order (note also that not all analysis types are available for all species).

The species profiles contain the following information (note that some data/analyses may not be available for all species):

1) estimates of abundance, both in numbers and biomass, by year, month, and region within the bay
2) length-frequency data by year
3) age-class distributions by year (for those species where appreciable numbers have been captured and otoliths have been processed)
4) sex-ratio by year and where appropriate, by region, month, and/or by age.
5) statistically determined length-weight relationships for sexes combined and separately
6) sex-specific maturity ogives along with a single diet summary

Species Data Summaries

Atlantic Croaker

Abundance: Atlantic croaker is among the most abundant species in ChesMMAP survey catches, especially during the May and July cruises each year with minimum trawlable number (MTN) estimates typically reaching 30-40 million and minimum trawlable biomass (MTB) between 5-10 million kg (Figure 1). The large majority of fish appear to reside in Regions 4 and 5 (Viriginia). Catches decline in September and November as this summer resident species leaves bay waters. No inter-annual trend in abundance during six years of sampling appears to have developed. Croaker are typically about four times more abundant in mid-depth (30' – 50') and deep stations (>50') than at shallow (10' – 30') stations (Figures 2-7).

Length and Age: Specimens between 14mm and 499mm in length (Figure 8) and between age 0 and 16 (Figure 9) appear in survey data with the large majority of individuals between 150mm and 350mm or ages 2-6 with specimens to age 9 not uncommon.

The length distribution of this species changes considerably year-to-year as year-classes of highly variable abundance move through the stock. For example, a highly abundant 2001 year class seen as a peak in the length-frequency histograms between 2002 and 2006 and as a distinctly abundant year class in the age-frequency figures still in 2007. There appears to evidence of mildly to highly successful year classes in 2003, 2004, and 2005 so the stock should remain plentiful in coming years. The fact that the pattern of year class abundance remains relatively constant from year to year indicates both that the survey gear fishes consistently over time and that laboratory ageing methods don't vary.

Sex, Growth, Maturity: With over 4,000 specimens examined through 2007, no particular geographic or age/size pattern appears to occur in the roughly 1:1 sex ratio of this species (Figure 10). Similarly, males and females appear to have very similar weight-at-length growth and maturity-rate patterns (Figures 11 and 12). About 50% of individuals are mature at 21cm-23cm and 99% are mature at 32mm.

Diet: While the largest single prey type is unidentified material (25.4%) the largest taxonomic category of prey is various types of worms (34.3%). Crustaceans constitute 15.3% of prey with mysids, mantis shrimp, and sand shrimp the most abundant. Fish constitute only 1.0% of the diet of specimens in the survey. It is likely that a large part of the unidentified material is highly digested soft prey types such as worms, mollusks, tunicates, etc. (Figure 13).

Figure 1. Atlantic croaker minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay 2002-2007.

Figures 2 – 7. Abundance (number per hectare swept) of Atlantic croaker in Chesapeake Bay, 2002-2007.

Figure 8. Atlantic croaker length-frequency in Chesapeake Bay, 2002-2007.

Figure 9. Atlantic croaker age-structure in Chesapeake Bay, 2002-2007.

Figure 10. Atlantic croaker sex-ratios in Chesapeake Bay, 2002-2007, by region (A), and age (B).

Figure 11. Atlantic croaker length-weight relationships in Chesapeake Bay, 2002-2007 as calculated by power regression for sexes combined (A), and separately (B).

Figure 12. Atlantic croaker maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Figure 13. Atlantic croaker diet in Chesapeake Bay, 2002-2007 combined.

Black Seabass

Abundance: The survey gear and methodology are not considered particularly effective for this structure-oriented species (locations of known complex bottom structures and other 'hangs' are purposely avoided). However, enough individuals are captured for a certain amount of information to be extracted from survey samples. Catches are typically highest during September and November cruises and are concentrated in Regions 4 and 5 but are not uncommon in Region 3 (Figure 14). As catches of black sea bass are so inconsistent, station-specific abundance maps are not presented.

Length and Age: Specimens captured in the survey tend to be relatively small (<250mm) and young (age-1) though individuals up to 270mm have been sampled (Figure 15) and ageing has not been completed for individuals captured after 2003 (Figure 16). It is possible that an age-1 abundance index could be developed which could serve as validation of YOY abundance estimates from other surveys.

Sex, Growth, Maturity: This species is believed to be a protogynous hermaphrodite (fish begin life as females and later change to males) though they are also documented as being incompletely metagonous (some number of individuals are hatched as both sexes and not all specimens change sex) (Musick and Mercer, 1977). This life history causes the sex ratios of the smaller individuals in survey samples to be predominantly female (Figure 17). As the sample sizes are small and the size range is limited, weight-at-length regressions and the maturity schedule presented (Figures 18, 19) should be considered incomplete.

Diet: Though the sample size is relatively small (132 specimens, 83 clusters of specimens) and the size range of samples is limited, the diet data is probably the most valuable ChesMMAP contribution for this species. Crustaceans (68.3%), dominated by mysids (18.5%), and mud crabs (13.4%), contribute the highest portion of the diet, by weight. Fish constitute 8.9% of the diet with bay anchovy (3.0%) the largest component among identifiable species. A variety of worms (6.2%) molluscs (5.4%) and other components less prominent or unidentifiable taxa constitute the remainder of the diet (Figure 20).

Figure 14. Black sea bass minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay 2002-2007.

Figure 15. Black sea bass length-frequency in Chesapeake Bay, 2002-2007.

Figure 16. Black sea bass age-structure in Chesapeake Bay, 2002-2003.

Figure 17. Black sea bass sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B).

Figure 18. Black sea bass length-weight relationships in Chesapeake Bay, 2002-2007, as calculated by power regression for sexes combined (A) and separately (B).

Figure 19. Black sea bass maturity schedule in Chesapeake Bay, 2002-2007 combined, (females only).

Figure 20. Black sea bass diet in Chesapeake Bay, 2002-2007 combined.

Bluefish

Abundance: Due to the fast-swimming nature of bluefish, this species also is not considered to be well sampled by ChesMMAP though some useful assessment-related information can be generated from survey data (Figure 21). When captured, typically between one and five specimens occur in a tow, though as many as 42 have been captured in a single sampling event. Bluefish are usually captured in either the shallow (10'-30') or mid-depth (30'-50') strata. Catches are usually highest late in the year, presumably as the fish are moving out of the bay. Abundance is typically highest in Regions 4 and 5 but notable exceptions occur (Figures 22-27).

Length and Age: Most individuals sampled in the survey are less than 350mm (Figure 28) and are either age-0 or age-1 (Figure 29). Though the numbers may be too small, it may be possible to use ChesMMAP data to develop an abundance index to validate abundance estimates from other surveys.

Sex, Growth, Maturity: Among the relatively narrow size range of sampled specimens, sex ratios are consistently close to 1:1 (Figure 30). Growth rates of males and females appear to be similar (Figure 31) but size at maturity varies considerably by sex (though caution should be used in using these results due to small sample sizes and limited size range) (Figure 32).

Diet: Diet data presented here are consistent with previous studies in showing that bluefish are highly piscivorous (Figure 33). Bay anchovy constitute 49.2% of the diet of sampled specimens and all fish species together represent 81.6%. Atlantic menhaden represent only 5.1% of the diet from survey data but once again the size range of sampled individuals is truncated. Crustaceans (mainly mysids) represent 15.4% and Loligo squid 2.4% of the diet of observed fish.

Figure 21. Bluefish minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figures 22 – 27. Abundance (number per hectare swept) of bluefish in Chesapeake Bay, 2002-2007.

Figure 28. Bluefish length-frequency in Chesapeake Bay, 2002-2007.

Figure 29. Bluefish age-structure in Chesapeake Bay, 2002-2007.

Figure 30. Bluefish sex-ratios in Chesapeake Bay, 2002-2007, by year.

Figure 31. Bluefish length-weight relationships in Chesapeake Bay, 2002-2007, as calculated by power regression for sexes combined (A) and separately (B).

Figure 32. Bluefish maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Figure 33. Bluefish diet in Chesapeake Bay, 2002-2007 combined.

Butterfish

Abundance: Butterfish abundance follows a generally predictable annual pattern, building from near-zero during March, low but increasing abundance through the spring and summer, with maximum catches generally occurring during the September and November cruises (Figure 34). Most butterfish are captured in Regions 4 and 5 (Virginia) but the species is common in the northern regions (2 and 3) during some cruises (assumed to follow patterns of salinity). Catches are usually highest in the mid-depth (30’-50’) depth strata (Figures 35-40). No inter-annual trend in abundance is apparent during 2002-2007 in either numbers or biomass.

Length and Age: This program (and others) has found butterfish extremely difficult to age. Otoliths are no longer removed and saved for this species. Yearly length frequency diagrams (Figure 41) appear to reveal at least two year classes of varying strength present in the Chesapeake Bay fish during any given year, however this will require further analysis.

Sex, Growth, Maturity: Sex ratios during early years of the survey (data not shown) were roughly 1:1. As neither otoliths (see above) nor stomachs (see below) are presently analyzed for this species, dissections are not performed to determine sex and maturity. A combined-sex weight-at-length analysis is presented (Figure 42).

Diet: Analyses of butterfish stomachs from early program years revealed a high percentage of generally unidentifiable gelatinous zooplankton and other unidentifiable items (Figure 43). It was determined that further analyses of butterfish diets was not an efficient use of resources and the determination was made to discontinue preservation and analysis of butterfish stomachs.

Figure 34. Butterfish minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figures 35 – 40. Abundance (number per hectare swept) of butterfish in Chesapeake Bay, 2002-2007.

Figure 41. Butterfish length-frequency in Chesapeake Bay, 2002-2007.

Figure 42. Butterfish length-weight relationship in Chesapeake Bay, 2002-2007, as calculated by power regression.

Figure 43. Butterfish diet in Chesapeake Bay, 2002-2003 combined.

Northern Kingfish

Abundance: Catches of this summer resident of the lower Chesapeake Bay are uneven. Considering cruises occurring after fish enter the bay sometime in mid-late spring each year, there does not appear to be either an intra-annual or inter-annual trend in abundance (Figure 44). When present is survey catches, numbers are generally small (85% of catches contain 5 or fewer individuals) though as many as 46 specimens have been captured in a single tow. On average, the highest catches occur in the deep (>50’) strata (Figures 45-50). Differentiating this species from its close relative the southern kingfish can be difficult and so it is likely that some specimens are misidentified in our data.

Length and Age: Due to the relatively small number of specimens captured during any particular year, it is difficult to interpret length frequencies (Figure 51) and age frequencies (Figure 52) generated from ChesMMAP data. Age-classes are apparent in the length diagrams and indeed specimens up to age-7 have been captured. Apparently abundant year-classes (e.g. 2002) do seem to track through the stock from year to year.

Sex, Growth, Maturity: Sex ratios across years and regions (Figure 53) appear to remain roughly at 1:1 and no differences in growth rates between sexes are immediately apparent (Figure 54). Likewise, estimated size at 50% maturity (Figure 55) is approximately equal at 21cm-22cm.

Diet: The majority (53.1%) of prey items in northern kingfish stomachs are crustaceans, primarily small shrimps and crabs. Molluscs and worms constitute 15.6% and 12.5% of the diet, respectively, with fish comprising an additional 7.4% (Figure 56).

Figure 44. Northern kingfish minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figures 45 – 50. Abundance (number per hectare swept) of northern kingfish in Chesapeake Bay, 2002-2007.

Figure 51. Northern kingfish length-frequency in Chesapeake Bay, 2002-2007.

Figure 52. Northern kingfish sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B).

Figure 53. Northern kingfish length-weight relationships in Chesapeake Bay, 2002-2007, as calculated by power regression for sexes combined (A) and separately (B).

Figure 54. Northern kingfish maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Figure 55. Northern kingfish diet in Chesapeake Bay, 2002-2007 combined.

<u>Northern Puffer</u>

Abundance: Typical patterns of abundance for this species in the survey are for minimal numbers in spring and early summer, reaching a peak during the November cruise, perhaps as the summer residents are out-migrating toward offshore wintering grounds. Catches are consistently highest in Regions 4 and 5, though the species is common into Region 3 (Figure 57). As catches in the survey are spotty, estimates of abundance for this species should be treated as of unknown reliability.

Length and Age: Specimens between approximately 50mm and 270mm have been captured though most individuals measured between 100mm and 250mm. The length composition varies year to year likely as a result of varying year classes entering and leaving the bay stock (Figure 58). However, as this is not a high priority species, ageing of otoliths has not been completed.

Sex, Growth, Maturity: While survey samples exhibit temporal and geographical variation, no pattern of significant differentiation from a 1:1 sex ratio is apparent (Figure 59). The largest individuals captured (over 250mm) are females and length-weight regressions suggest that there may be differential growth between sexes (Figure 60). The size at which 50% of females reach maturity is about 145mm and 99% are mature at approximately 250mm (Figure 61). The maturity regression for males does not yet appear to be reliable.

Diet: Crustaceans (40.0%), primarily small crab species, molluscs (16.4%), and worms (13.0%), constitute the majority of identifiable items in the stomachs of this species. Unidentifiable material constitutes a significant (13.7%) portion of prey items examined.

Figure 57. Northern puffer minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figure 58. Northern puffer length-frequency in Chesapeake Bay, 2002-2007.

Figure 59. Northern puffer sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B).

Figure 60. Northern puffer length-weight relationships in Chesapeake Bay, 2002-2007, as calculated by power regression for sexes combined (A) and separately (B).

Figure 61. Northern puffer maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Figure 62. Northern puffer diet in Chesapeake Bay, 2002-2007 combined.

Scup

Abundance: Survey catches of scup are typically rare during spring through early summer and nearly always reach a peak in September before declining again in November as fish leave bay waters (Figure 63, Figures 64-69). The species is most abundant in Region 5 and is rarely captured north of Region 4. No trend in abudnace over the six survey years is apparent, though it is significant that no 2007 data are available due to cancellation of the September cruise. Scup are typically most abundant in shallow strata (10'-30') and mid-depth strata (30'-50') and are rarely captured in waters over 50'.

Length and Age: Most specimens captured in the survey are less than 200mm (Figure 70). While otoliths have not been processed (preparation of otoliths from all ChesMMAP years has just been completed so age data will be available for the next annual report), data from other survey sources indicates that the most fish captured are either age-0 or age-1. While the length-frequency figure for 2007 may be misleading due to cancellation of the September cruise, there may be evidence of larger than normal young-of-year abundance in 2007.

Sex, Growth, Maturity: Due to the large number of small, immature specimens captured by the survey, the sex of many individuals cannot be determined using macroscopic examination. While higher percentages of females than males are identified, this may be the result of the fact that females can often be more easily recognized at small sizes. Therefore, sex ratios presented must be interpreted carefully (Figure 71). Length-weight regressions indicate similar growth rates between sexes, at least over the relatively narrow size range available to the survey (Figure 72). Likewise, while requiring careful interpretation maturity rates appear to be similar between males and females with both reach 50% maturity at 170mm-180mm (Figure 73).

Diet: Worm species constitute a near majority (49.8%) of identifiable items in scup stomachs (Figure 74) but unidentifiable prey (likely largely constituted of worms and other soft-bodied prey) also make up a large portion (25.2%). Crustaceans (15.6%) are also a major prey source, primarily small shrimp (mysids and skeleton shrimp).

Figure 63. Scup minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figures 64 – 69. Abundance (number per hectare swept) of scup in Chesapeake Bay, 2002-2007.

Figure 70. Scup length-frequency in Chesapeake Bay, 2002-2007.

Figure 71. Scup sex-ratios in Chesapeake Bay, 2002-2007, by year (A) and month (B).

Figure 72. Scup length-weight relationships in Chesapeake Bay, 2002-2007, as calculated by power regression for sexes combined (A) and separately (B).

Figure 73. Scup maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Figure 74. Scup diet in Chesapeake Bay, 2002-2007 combined.

Spot

Abundance: Spot are typically among the most abundant species in the survey during all cruises except March. Likewise the species is well distributed throughout the bay (Figure 75). Abundances (numbers) during 2005-2007 appear to be somewhat higher than during 2002-2004, though peak annual biomass estimates remained relatively constant throughout all survey years. The species appears to invade the bay earlier and remain abundant later in the fall during recent years compared to early survey years. Whether this is environmentally related or a result of increased overall abundance is unknown. Catches are usually considerably higher at mid-depth (30'-50') and deep (>50') stations than at shallow (10'-30') stations (Figures 76-81).

Length and Age: Individuals between 100mm and 250mm are most common in the survey, with a smaller number of specimens up to 300mm occasionally captured (Figure 82). The largest individuals are most often captured in Regions 2 or 3. Nearly all fish in the survey are either age-0 or age-1 (Figure 83). The oldest fish captured were age-4.

Sex, Growth, Maturity: Inter-annual and intra-annual examination of sex ratios indicate nearly exactly 1:1 sex ratios (Figure 84). A small number of specimens cannot be identified as to sex due to their small size and state of maturity. Likewise, weight-at-length appears to be nearly identical between the sexes (Figure 85) and size at 50% maturity is very similar at approximately 190mm for females and about 210mm for males (Figure 86). Nearly all individuals of both sexes are mature at approximately 280mm.

Diet: A small number of stomachs for this species have been examined but due to the small soft-bodied nature of the most common prey types, combined with the anatomy and physiology of spot, identification of prey is extremely difficult. No diet data are presented here.

Figure 75. Spot minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figures 76 – 81. Abundance (number per hectare swept) of spot in Chesapeake Bay, 2002-2007.

Figure 82. Spot length-frequency in Chesapeake Bay, 2002-2007.

Figure 83. Spot age-structure in Chesapeake Bay, 2002-2007.

Figure 84. Spot sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B).

Figure 85. Spot length-weight relationships in Chesapeake Bay, 2002-2007, as calculated by power regression for sexes combined (A) and separately (B).

Figure 86. Spot maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Striped Bass

Abundance: Intra-annual patterns of abundance for striped bass typically follow a similar pattern. Large numbers of spawning migrants are captured during the March cruise, followed by lower numbers in May as the spawners leave the bay then lower catches in July and September and higher numbers again in November as fish school before leaving the bay for offshore wintering grounds. Most striped bass are captured in Regions 1 – 3 (Maryland waters) but the species occurs regularly in samples from all bay locations (Figure 87). No inter-annual trend is yet apparent in ChesMMAP data but efforts are currently underway to compare young-of-year seine survey indices to later abundance from ChesMMAP data. Those results will be formally reported elsewhere. Considering data from all cruises pooled together no pattern is apparent in catch rates among depth strata though cruise-specific differences do occur (Figures 88 – 93). Catch rates in March are highest in deep (>50') strata, perhaps as fish use deeper channels as migration routes. In all other cruises, catch rates are highest in the shallow strata (10' – 30'), perhaps partially a response to low oxygen levels in deep water over large portions of the species' range of highest abundance.

Length and Age: Most specimens captured in the survey are about 60mm and less (ages 1 – 7). The largest individuals approach 1000mm and are captured during spring spawning. Due to the relatively long-lived nature of this species, the varying life history scenarios for different portions of the stock and associated variable growth rates, along with variable young-of-year recruitment, it is difficult to differentiate year-classes within length-frequency histograms (Figure 94). Age distribution figures however (Figure 95) readily reveal year-class strength (high peaks during one year tend to follow into succeeding years, as do low abundances) and this phenomenon is being used in attempting to validate results of young-of-year seine surveys. Specimens up to age-16 have been captured.

Sex, Growth, Maturity: A slight preponderance (~60:40) of male fish is consistently present in survey samples. This is likely the result of differential migration habits between sexes as males tend to reside in the bay for several more years than females (Figure 96). The sex ratio is nearly exactly 1:1 however with all March cruises combined, as females return to the bay to spawn. Age specific patterns are also present: up to age-3 the sex ratio is close to even, between ages 4 and 6 a declining percentage of females is present as those fish migrate to coastal waters, followed by several age-classes exhibiting an overall male:female ratio again of approximately 60:40. A very similar relationship of weight to length between sexes is apparent in ChesMMAP samples though the very largest individuals captured (> ~950mm) are all females (Figure 97). A significant sex-related difference is observed in size at maturity with 50% of males reaching maturity at approximately 220mm but females not reaching that rate of maturity until about 360mm. For both sexes, virtually all individuals are mature at about 600mm (Figure 98).

Diet: Results of diet analyses from this study differ appreciably from those presented previously using specimens from Chesapeake Bay (Figure 99). While fish comprise the largest taxonomic group in the diet (41.3%), this survey consistently finds that bay anchovy contributes the highest proportion by weight (17.2%), with Atlantic menhaden a distant second (9.1%). Further, crustaceans such as mysids and amphipods constitute 19.7% and 5.8% respectively, a sharp contrast to previous studies; and worms make up another 15.1%. These differences from previous diet studies are likely the result both of sampling methodological differences (the broad temporal and geographic scale of

ChesMMAP as well as the trawl gear used) and analytical/mathematical differences in calculating percentages in the diet. In brief, this study calculates fish diets using cluster-sampling theory and analytical methods whereas previous studies are thought to have used the assumption of simple random sampling of fish. This is discussed thoroughly in a paper recently submitted for publication in the primary literature.

Figure 87. Striped bass minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figures 88 – 93. Abundance (number per hectare swept) of striped bass in Chesapeake Bay, 2002-2007.

Figure 94. Striped bass length-frequency in Chesapeake Bay, 2002-2007.

Figure 95. Striped bass age-structure in Chesapeake Bay, 2002-2007.

Figure 96. Striped bass sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B), age (C).

Figure 97. Striped bass length-weight relationships in Chesapeake Bay, 2002-2007 as calculated by power regression for sexes combined (A) and separately (B).

Figure 98. Striped bass maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Figure 99. Striped bass diet in Chesapeake Bay, 2002-2007 combined.

Summer Flounder

Abundance: The typical intra-annual pattern of abundance for summer flounder is an increasing monthly pattern throughout the period of the year sampled by the survey, with highest catches (in numbers) in September or November. Biomass estimates however, tend to reach a high level in May and remain relatively constant for the rest of the year (Figure 100). This interesting pattern likely results as more numerous but smaller individuals become available to the survey. Summer flounder are most abundant in Regions 4 and 5 but are common in Regions 2 and 3 as well. No inter-annual trend in abundance is readily apparent but development of overall or age-specific abundance indices from ChesMMAP data is a priority for this species (as well as others). The highest catches of summer flounder often occur along the eastern portions of Regions 4 and 5 but this is not an absolute (Figures 101-105). A slightly higher catch rate is exhibited for mid-depth (30' – 50') and deep (>50') stations than in shallow (10' – 30') waters.

Length and Age: Fish which measure between approximately 200mm and 500mm are most prevalent in survey samples though fish as large as 760mm have been captured (Figure 107). In several years a large number of fish under 300mm (likely age-0) can be differentiated in length-frequency graphs. Most fish in the survey are age-5 and under and the oldest fish yet captured was a single individual at age-12. In age classes older than age-2 it appears to be more difficult, compared to other species, to follow abundance trends of particular year classes in successive years (Figure 108). This could be the result of differential migration patterns among different sized fish or of fishery preferences and/or regulations.

Sex, Growth, Maturity: Considered on either a yearly or geographic basis there is a consistent pattern in ChesMMAP samples of a predominance of female fish at a 60:40 ratio or greater (Figure 109). Most interestingly however, when age-specific sex ratios are calculated, age-0 specimens exhibit a nearly perfect 1:1 sex ratio, age-1 fish show approximately a 3:2 female-to-male proportion, and for all fish age-3 and older there is about a 9:1 female preponderance. This pattern could have profound management implications and analyses are presently being performed to evaluate possible implications of this phenomenon. Males and females show nearly identical length-to-weight relationships (Figure 110) though very few males greater than about 450mm are captured and all specimens over about 600mm are female. The 50% maturity rate for both sexes is reached at about 310mm (Figure 111) but, analyses not presented here show that size-at-age for males is considerably smaller than for females.

Diet: Fish comprise a slight majority (50.2%) of summer flounder diets in the survey, with the primary prey being bay anchovy (18.3%), weakfish (10.8%), and spot (6.5%) (Figure 112). Crustaceans constitute just slightly less of the diet (45.2%) with the main prey types being mysids (22.8%), mantis shrimp (10.9%), and sand shrimp (7.5%). The high prevalence of fish in summer flounder stomachs, especially for larger individuals, leads to the conclusion that this species should be considered a top predator in Chesapeake Bay along with striped bass, bluefish, and weakfish (Latour et al. 2008).

Figure 100. Summer flounder minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figures 101 – 106. Abundance (number per hectare swept) of summer flounder in Chesapeake Bay, 2002-2007.

Figure 107. Summer flounder length-frequency in Chesapeake Bay, 2002-2007.

Figure 108. Summer flounder age-structure in Chesapeake Bay, 2002-2007.

Figure 109. Summer flounder sex-ratios in Chesapeake Bay, 2002-2007, by month (A), region (B), age (C).

Figure 110. Summer flounder length-weight relationships in Chesapeake Bay, 2002-2007, as calculated by power regression for sexes combined (A) and separately (B).

Figure 111. Summer flounder maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Figure 112. Summer flounder diet in Chesapeake Bay, 2002-2007 combined.

Weakfish

Abundance: Weakfish is among the most abundant species in survey samples over most seasons and locations. Catches are typically small in March but fish have begun to invade the bay by May and remain abundant in the survey throughout the rest of the year. Peak catches are usually in September and decline somewhat in November as fish begin their late fall out-migration (Figure 113). After reaching a peak in 2004 it appears that abundance may have declined over the last three years. Catches are typically highest in mid-depth (30' – 50') and deep (>50') stations than at shallow ones (10' – 30') (Figures 114 – 119).

Length and Age: Most weakfish captured by the survey are between 100mm and 350mm. Minimum and maximum sizes found during the six survey years are 23mm and 616mm respectively (Figure 120). With only a few exceptions most fish captured over 400mm were sampled during the first two years of the survey (2002 and 2003). Likewise, the age structure of Chesapeake Bay weakfish has compressed over the past six years with few individuals older than age-2 captured in recent years and almost none older than age-3 (Figure 121).

Sex, Growth, Maturity: No significant deviation from a 1:1 sex ratio over survey years, regions, or fish age is observed (Figure 122). Weight-at-length regressions between sexes are very similar, though the few specimens captured greater than ~500mm are all females (Figure 123). As noted in other studies, this species matures early in its life cycle, reaching 50% maturity for both species at approximately 200mm (Figure 124).

Diet: Fish (54.4%), primarily bay anchovy (31.7%) comprise a majority of prey types in the weakfish diet (Figure 125). Notably, weakfish account for 5.2% of prey, by weight. The relatively low percent of Atlantic menhaden seen in the survey stomach samples (3.4%), when compared to earlier studies, may be due to the truncation of the size range of weakfish in Chesapeake Bay. Crustaceans (38.9%) constitute most of the remainder of the diet with mysids (30.5%) contributing the largest share by a large margin.

Figure 113. Weakfish minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figures 114 – 119. Abundance (number per hectare swept) of weakfish in Chesapeake Bay, 2002-2007.

Figure 120. Weakfish length-frequency in Chesapeake Bay, 2002-2007.

Figure 121. Weakfish age-structure in Chesapeake Bay, 2002-2007.

Figure 122. Weakfish sex-ratios in Chesapeake Bay, 2002-2007, by year (A), region (B), age (C).

Figure 123. Weakfish length-weight relationships in Chesapeake Bay, 2002-2007, as calculated by power regression for sexes combined (A) and separately (B).

Figure 124. Weakfish maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Figure 125. Weakfish diet in Chesapeake Bay, 2002-2007 combined.

White Perch

Abundance: White perch are extremely abundant in survey samples throughout each year in Regions 1 and 2 and are common into Region 3 (Figure 126). Estimates of numerical and biomass abundance are higher in 2006 and 2007 than in previous survey years, (except for a single cruise in September 2004 when a small number of very large catches resulted in the highest abundance estimates of the survey). Due to this species' concentration in the shallow waters of Region 1 (Figures 127-132), catches are highest in the shallowest strata (10' – 30'), followed by the mid-depth strata (30' – 50'), and this species is rare in samples from the deepest stations (>50').

Length and Age: All white perch of sizes greater than approximately 150mm are well sampled in the survey (Figure 133). Due to the relatively small maximum size, long life, and slow growth rates it is difficult to separate year-classes of this species using length-frequency. The peak of abundance in 2007 samples was at a smaller size then during previous years. This species is not well sampled by the survey until approximately age-2 (Figure 134). Past that age however, the survey appears to well represent all age classes. The species age distribution appears to be regulated by the relative success of each year-class. Year-class specific peaks in abundance can be easily followed during successive years in survey samples (e.g. 1993, 1996, 200, 2003 year-classes).

Sex, Growth, Maturity: Over each year and most age-classes fish from the survey consistently exhibit roughly a 7:3 female-to-male sex ratio (Figure 134). Whether this represents a true stock dynamic or whether males are less available to the survey is unknown. Weight-at-length in survey samples is nearly identical for male and female speciemens (Figure 135). Females reach 50% maturity at approximately 135mm and

99% maturity at about 210mm (Figure 137). The maturity regression for males does not appear to be reliable.

Diet: Unidentified material represents the largest single item in white perch stomachs (21.5%) but crustaceans (33.8%) are the largest identifiable taxon in white perch samples with amphipods (18.6) the primary prey followed by mud crabs (5.1%) and copepods (4.9%). Worms (19.9%), primarily *Nereis* clam worms (12.9%) and other polychaetes (5.9%), are the second most abundant prey, followed by bivalve molluscs (16.9%). Notably, a small number of bay anchovy (1.1%) are present in white perch stomachs (Figure 138).

Figure 126. White perch minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.

Figures 127 – 132. Abundance (number per hectare swept) of white perch in Chesapeake Bay, 2002-2007.

Figure 133. White perch length-frequency in Chesapeake Bay, 2002-2007.

Figure 134. White perch age-structure in Chesapeake Bay, 2002-2007.

Figure 135. White perch sex-ratios in Chesapeake Bay, 2002-2007, by year (A), age (B).

Figure 136. White perch length-weight relationships in Chesapeake Bay, 2002-2007, as calculated by power regression for sexes combined (A) and separately (B).

Figure 137. White perch maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

Figure 138. White perch diet in Chesapeake Bay, 2002-2007 combined.

Water Quality

Figures 138 – 149. Interpolated bay-wide water temperature values 2002-2007, surface and bottom.

Figures 150 – 161. Interpolated bay-wide salinity values 2002-2007, surface and bottom.

Figures 162 – 173. Interpolated bay-wide dissolved oxygen values 2002-2007, surface and bottom.

Task 6 – *Serve as sampling platform for bay studies*

Since its inception, ChesMMAP has strived to be not just a state-of-the-art monitoring survey, but equally, a research platform from which numerous projects can benefit. We have participated in fish disease, tagging, and habitat related studies that otherwise either could not have been conducted, or would have had very substantially increased costs. For example, since 2003 ChesMMAP personnel have been collecting additional samples from striped bass to support a mycobacteriosis prevalence study conducted by scientists in the Fisheries and Environmental and Aquatic Animal Health (EAAH) Departments at VIMS. Specifically, spleen samples from these striped bass were analyzed histologically for the presence of granulomas, which are evident in diseased fish. The apparent prevalence data set derived from these samples is the most comprehensive apparent prevalence data set collected for striped bass in the bay. Subsequent modeling of those prevalence data has shown 1) the force-of-infection (rate of which disease-negative fish become disease positive) is age-dependent, 2) covariates sex and season are significant explanatory variables, and 3) that there is appreciable disease-associated mortality.

In 2006, ChesMMAP personnel collected 536 striped bass tissue samples to support a trophic ecology project led by members of the Center for Quantitative Fisheries Ecology (CQFE) at Old Dominion University. Stable isotope analysis is being used to investigate the trophic interactions and position of striped bass; ultimately these data will be compared to data from traditional stomach content analysis to provide a more comprehensive description of the predatory impacts of striped bass.

The costs associated with conducting both the disease monitoring and stable isotope studies in the absence of a sampling platform such as the ChesMMAP trawl survey would likely have been prohibitive.

In addition to the aforementioned striped bass projects, ChesMMAP also supported the Environmental Protection Agency's National Coastal Assessment (NCA) program by sampling 11 additional sites during 2006 and 2007 surveys. At each of these stations, up to 10 specimens of each of a number of species of interest were sacrificed for chemical and pathological analysis. Overall, about 200 specimens were taken for this effort. Again, by contracting the ChesMMAP survey to conduct this relatively small amount of sampling, the cost of obtaining the resulting information was reduced substantially. And finally, ChesMMAP's sampling efforts supported four master's theses and a doctoral dissertation in 2007.

Literature Cited

Buckel, J.A., D.O. Conover, N.D. Steinberg, and K.A. McKown. 1999a. Impact of age-0 bluefish (*Pomatomus saltatrix*) predation on age-0 fishes in Hudson River Estuary: evidence for density-dependant loss of juvenile striped bass (*Morone saxatilis*). Canadian Journal of Fisheries and Aquatic Sciences 56:275-287.

Hollowed, A.B., N. Bax, R. Beamish, J. Collie, M. Fogarty, P. Livingston, J. Pope, and J.C. Rice. 2000. Are multispecies models an improvement on single-species models for measuring fishing impacts on marine ecosystems? ICES Journal of Marine Science 57:707-719.

Houde, E.D., M.J. Fogarty and T.J. Miller (Convenors). 1998. STAC Workshop Report: Prospects for Multispecies Fisheries Management in Chesapeake Bay. Chesapeake Bay Program, Scientific Technical Advisory Committee.

Hyslop, E.J. 1980. Stomach content analysis – a review of methods and their application. Journal of Fish Biology 17:411-429.

Latour, R.J., J. Gartland, C.F. Bonzek, and R.A. Johnson. 2008. The trophic dynamics of summer flounder (Paralichthys dentatus) in Chesapeake Bay. Fishery Bulletin 106:47-57.

Link, J.S. 2002a. Ecological considerations in fisheries management: when does it matter? Fisheries 27(4):10-17.

Link, J.S. 2002b. What does ecosystem-based fisheries management mean? Fisheries 27:18-21.

NMFS (National Marine Fisheries Service). 1999. Ecosystem-based fishery management. A report to Congress by the Ecosystems Principles Advisory Panel. U. S. Department of Commerce, Silver Spring, Maryland.

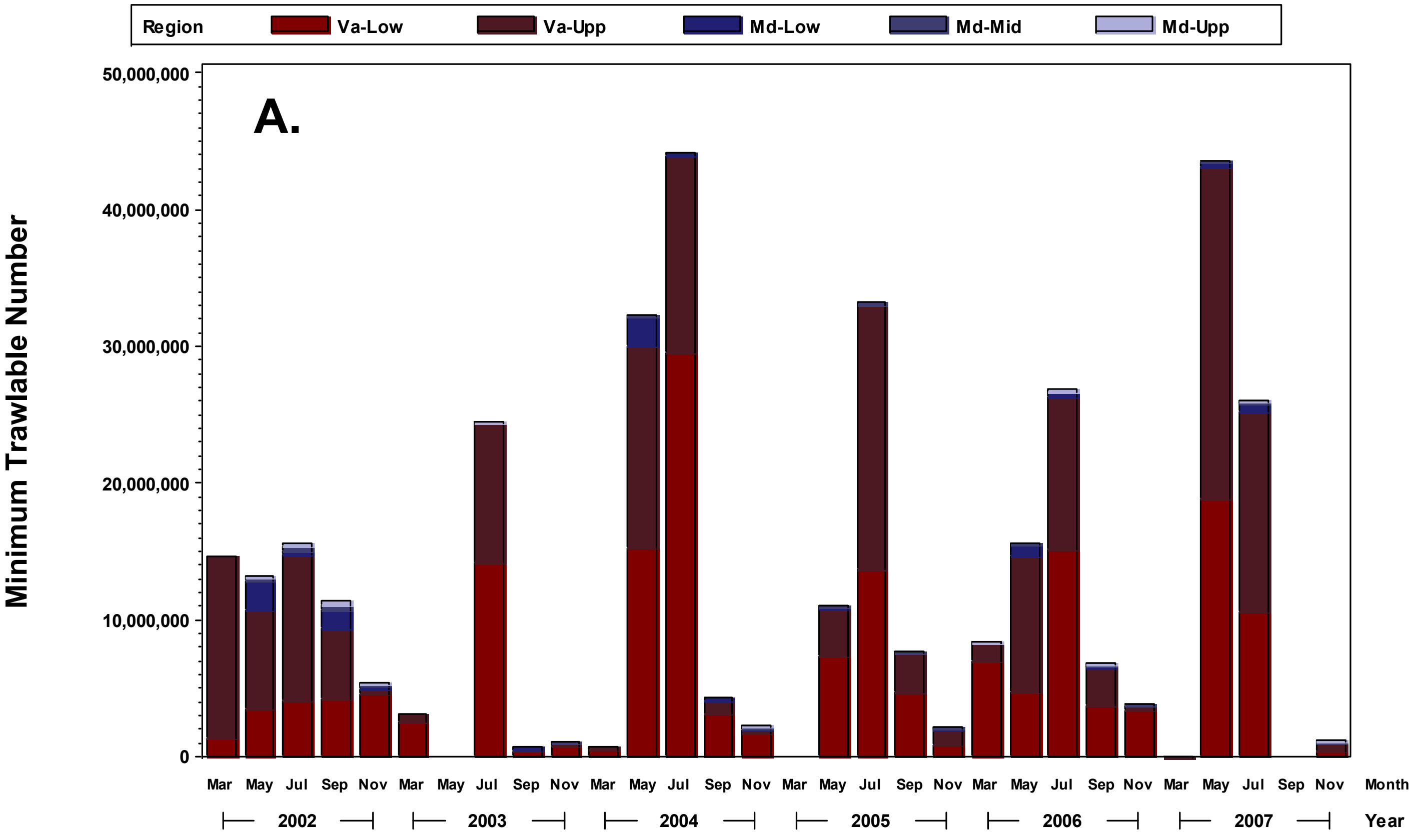
Miller, T.J., E.D. Houde, and E.J. Watkins. 1996. STAC Workshop Report: Prospectives on Chesapeake Bay fisheries: Prospects for multispecies fisheries management and sustainability. Chesapeake Bay Program, Scientific Technical Advisory Committee.

Musick, J.A. and L.P. Mercer. 1977. Seasonal distribution of black seabass Centriprisis striata, in the Mid-Atlantic Bight with comments on the ecology and fisheries of the species. Trans. Am. Fish Soc. 106:1.

NOAA (National Oceanic and Atmospheric Administration). 1996. Magnuson-Stevens Fishery Management and Conservation Act amended through 11 October 1996. NOAA Technical Memorandum NMFS-F/SPO-23. U. S. Department of Commerce.

Whipple, S. J., J. S. Link, L. P. Garrison, and M. J. Fogarty. 2000. Models of predation and fishing mortality in aquatic ecosystems. Fish and Fisheries 1:22-40.

Figure 1. Atlantic croaker minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay 2002-2007.



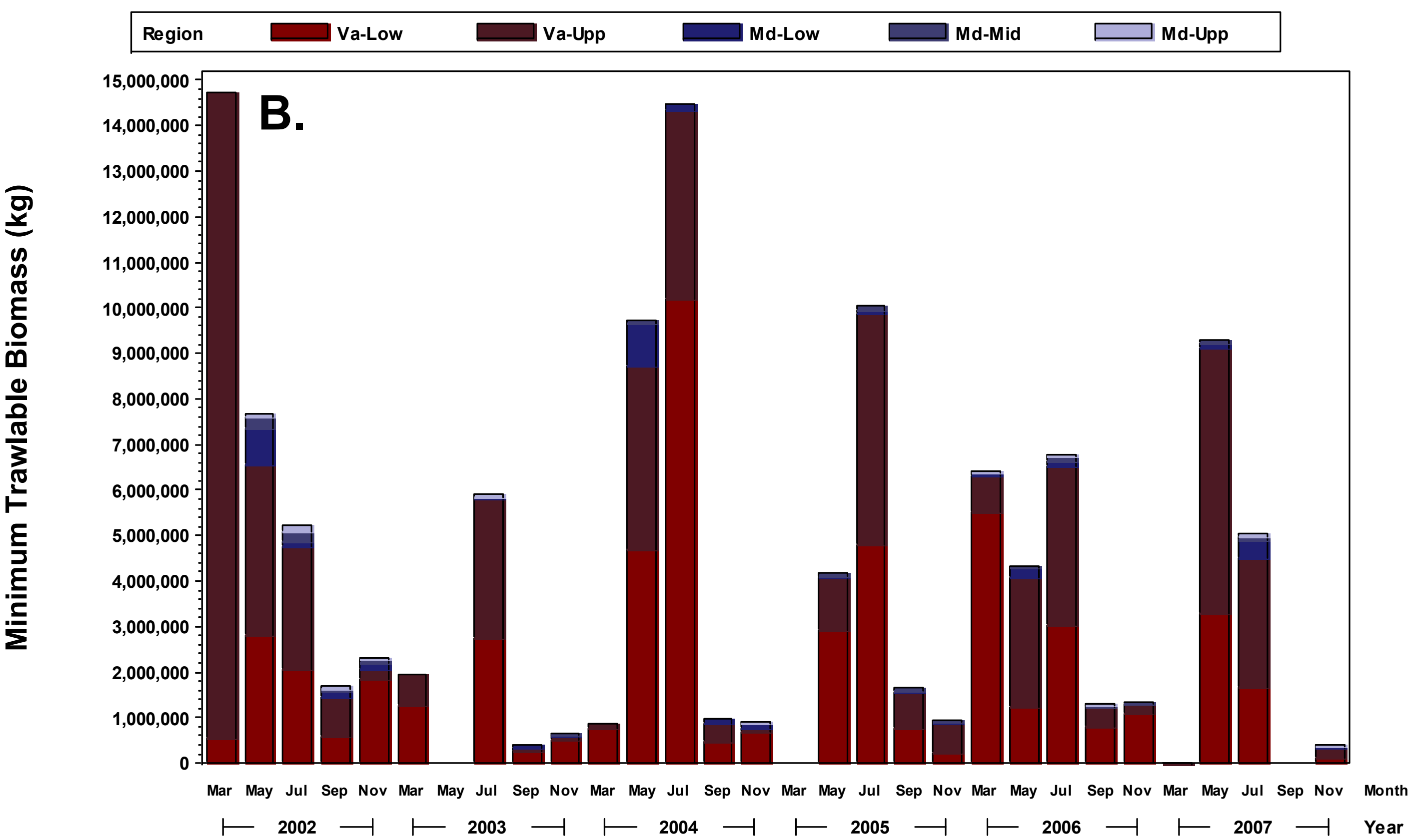


Figure 2. Abundance (number per hectare swept) of Atlantic croaker in Chesapeake Bay, 2002.

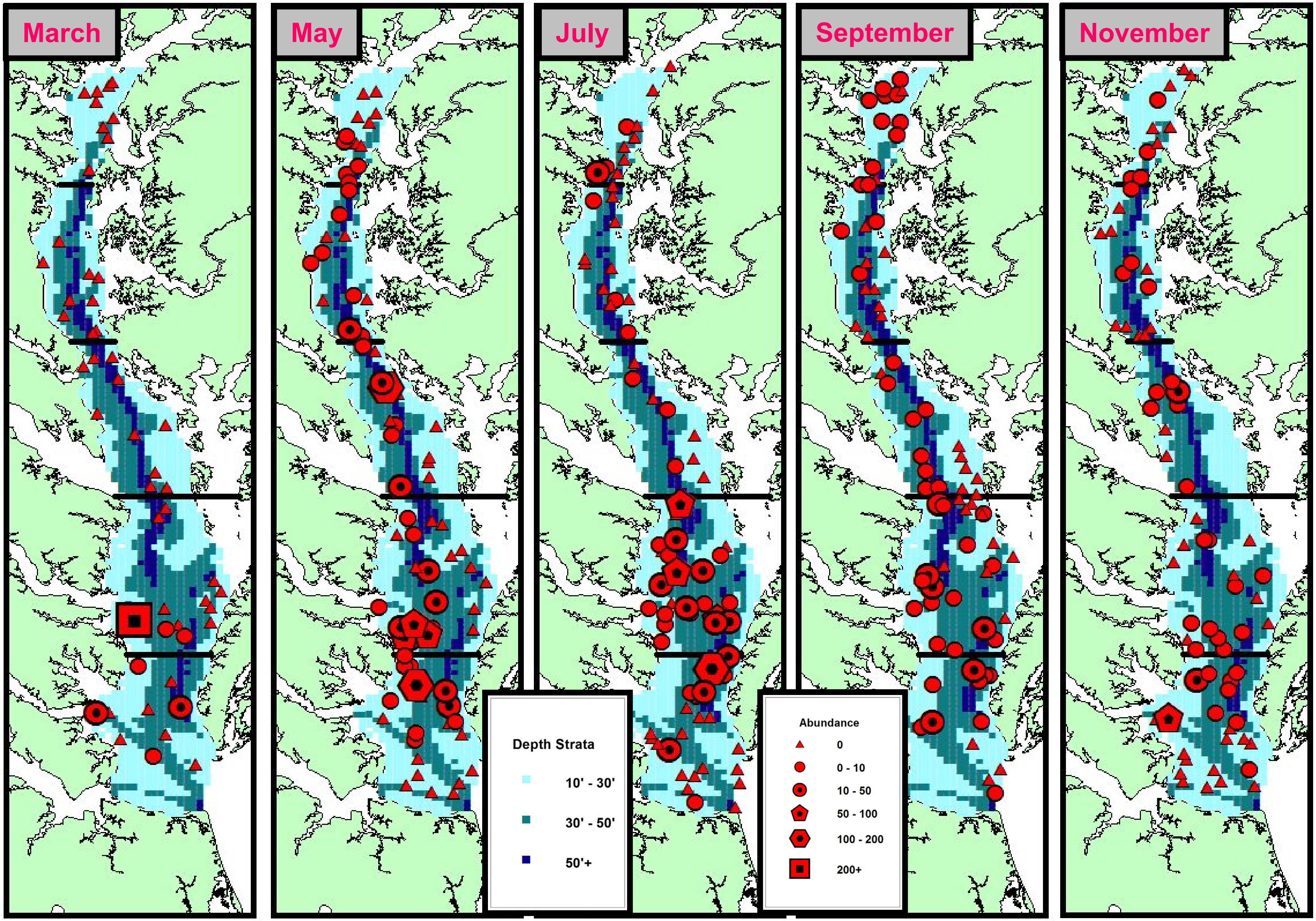


Figure 3. Abundance (number per hectare swept) of Atlantic croaker in Chesapeake Bay, 2003.

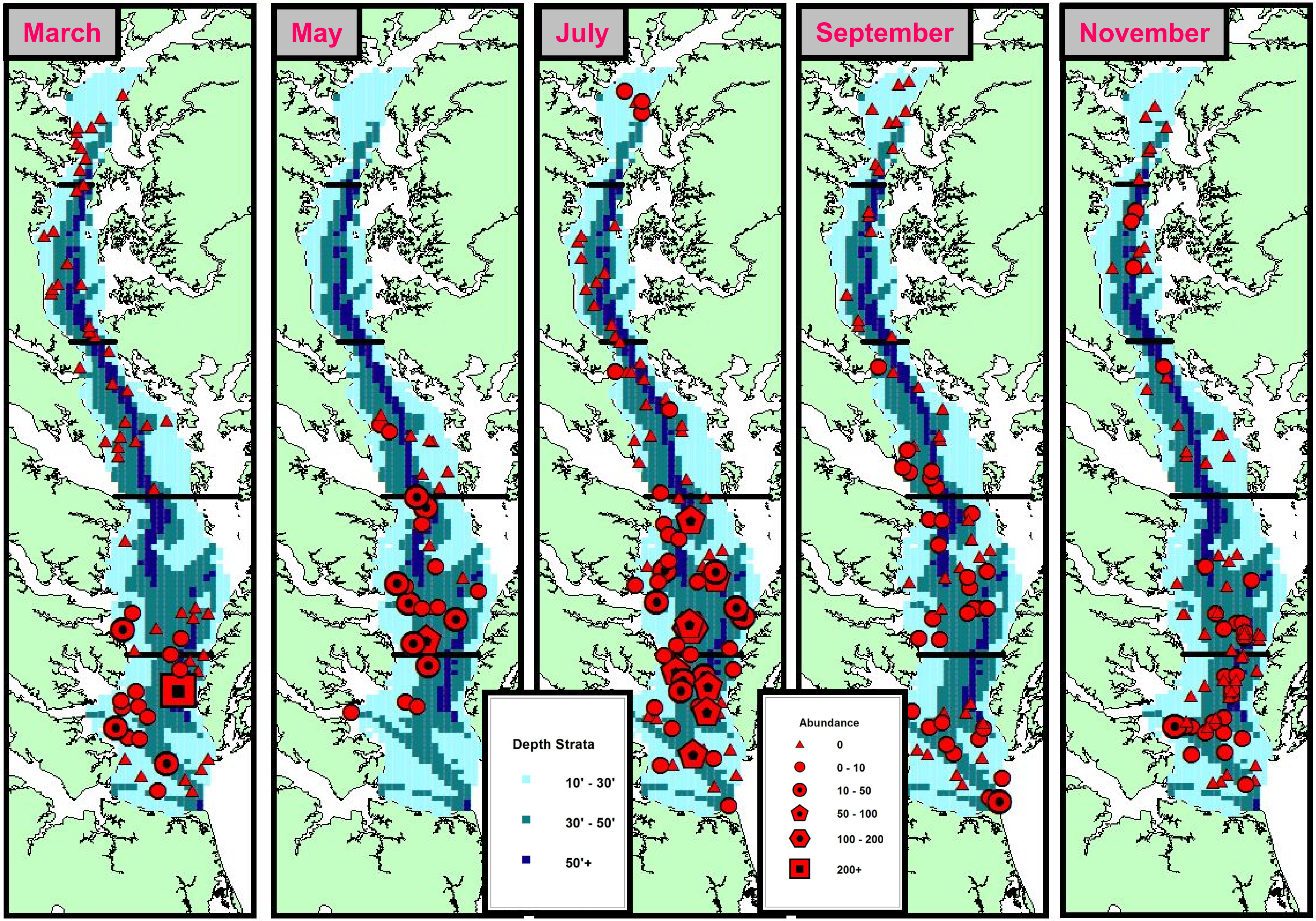


Figure 4. Abundance (number per hectare swept) of Atlantic croaker in Chesapeake Bay, 2004.

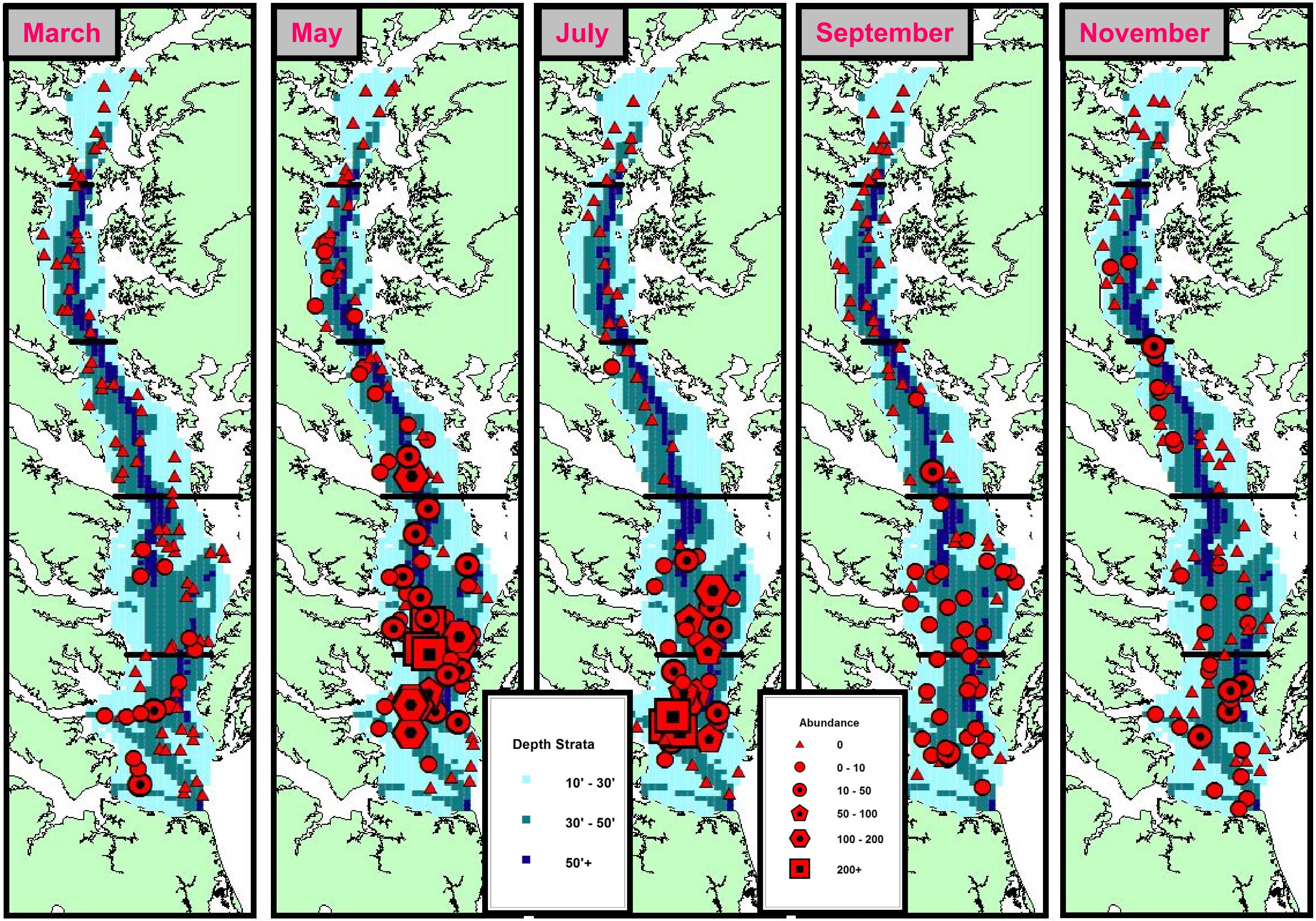


Figure 5. Abundance (number per hectare swept) of Atlantic croaker in Chesapeake Bay, 2005.

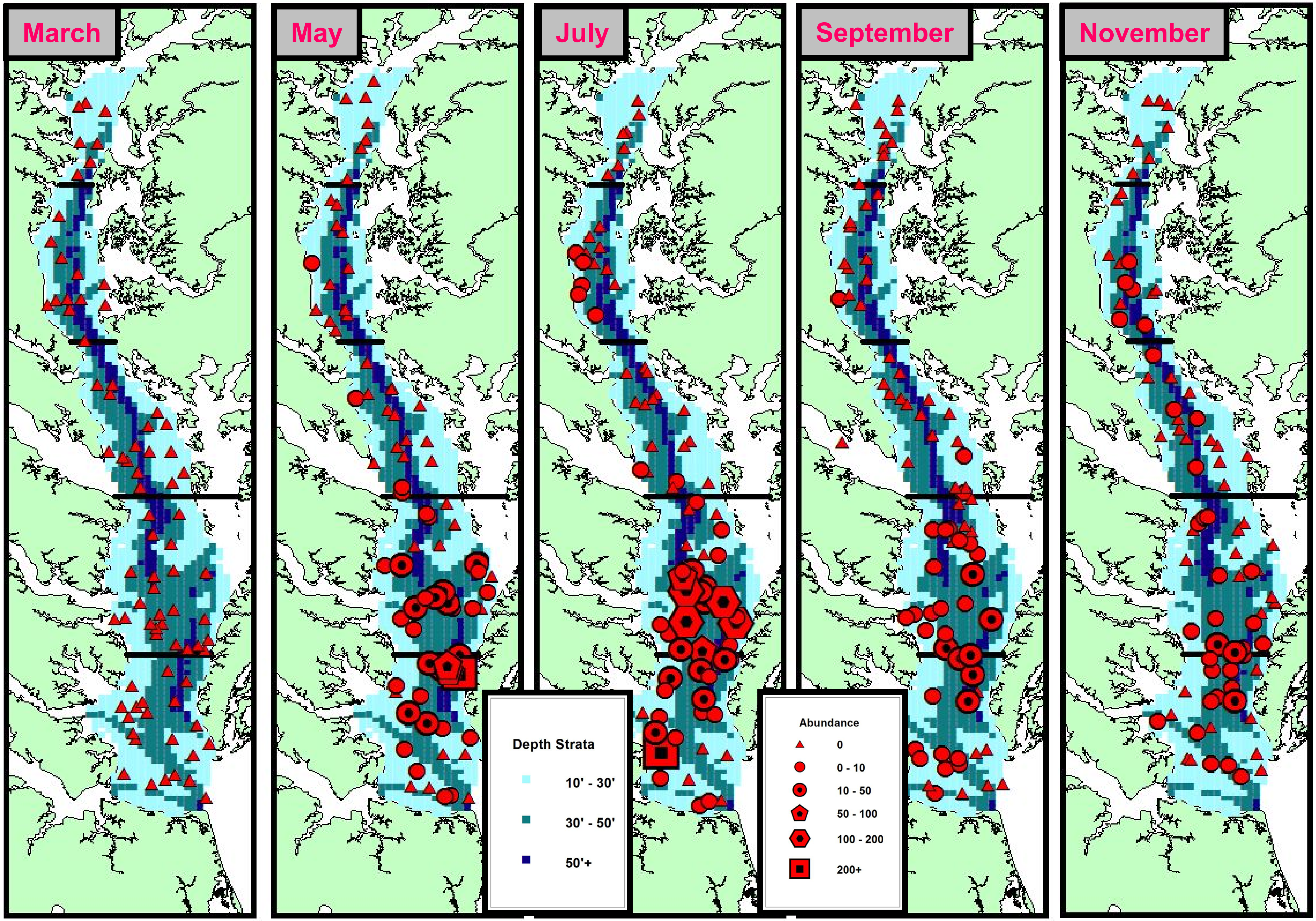


Figure 6. Abundance (number per hectare swept) of Atlantic croaker in Chesapeake Bay, 2006.

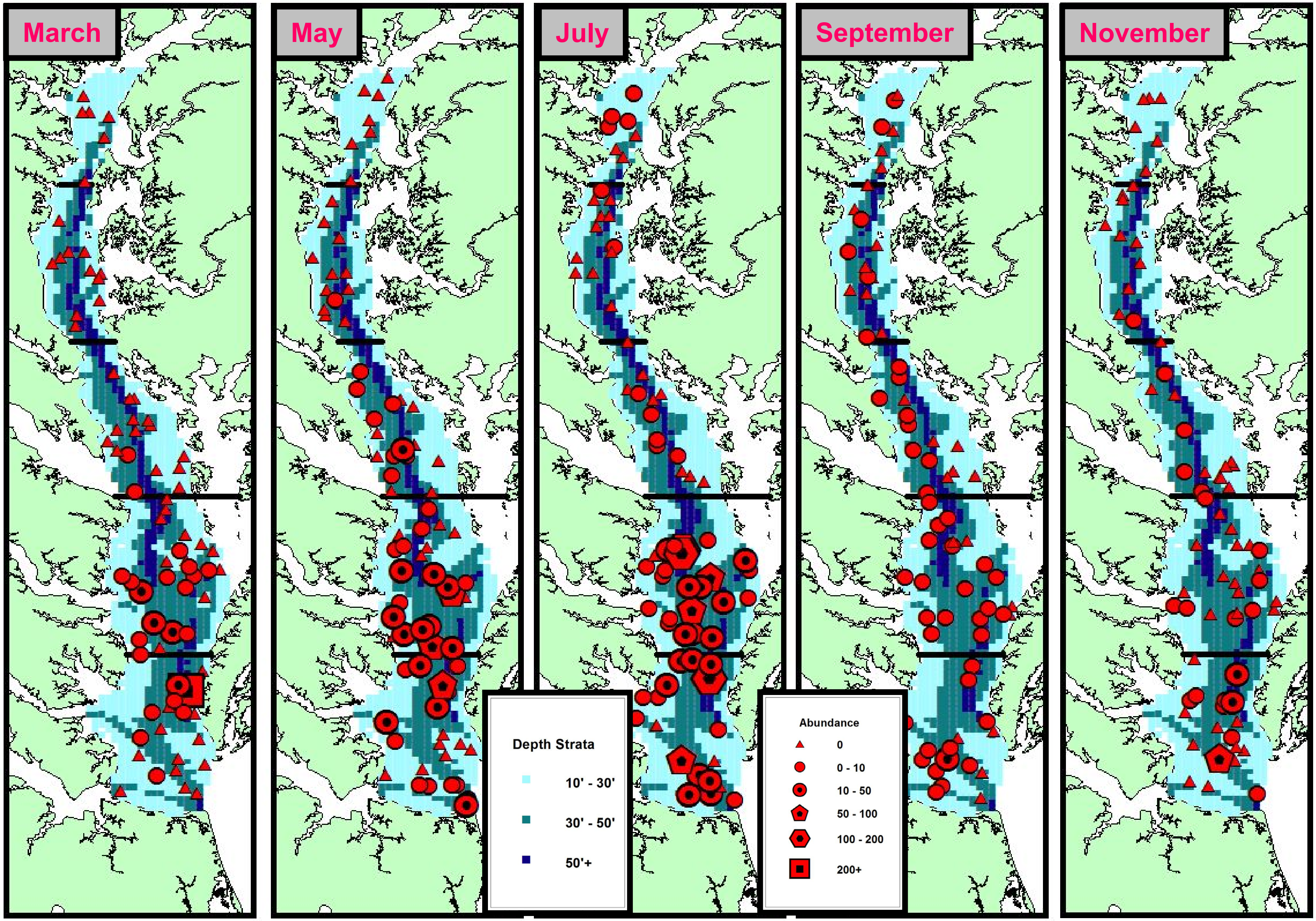


Figure 7. Abundance (number per hectare swept) of Atlantic croaker in Chesapeake Bay, 2007.

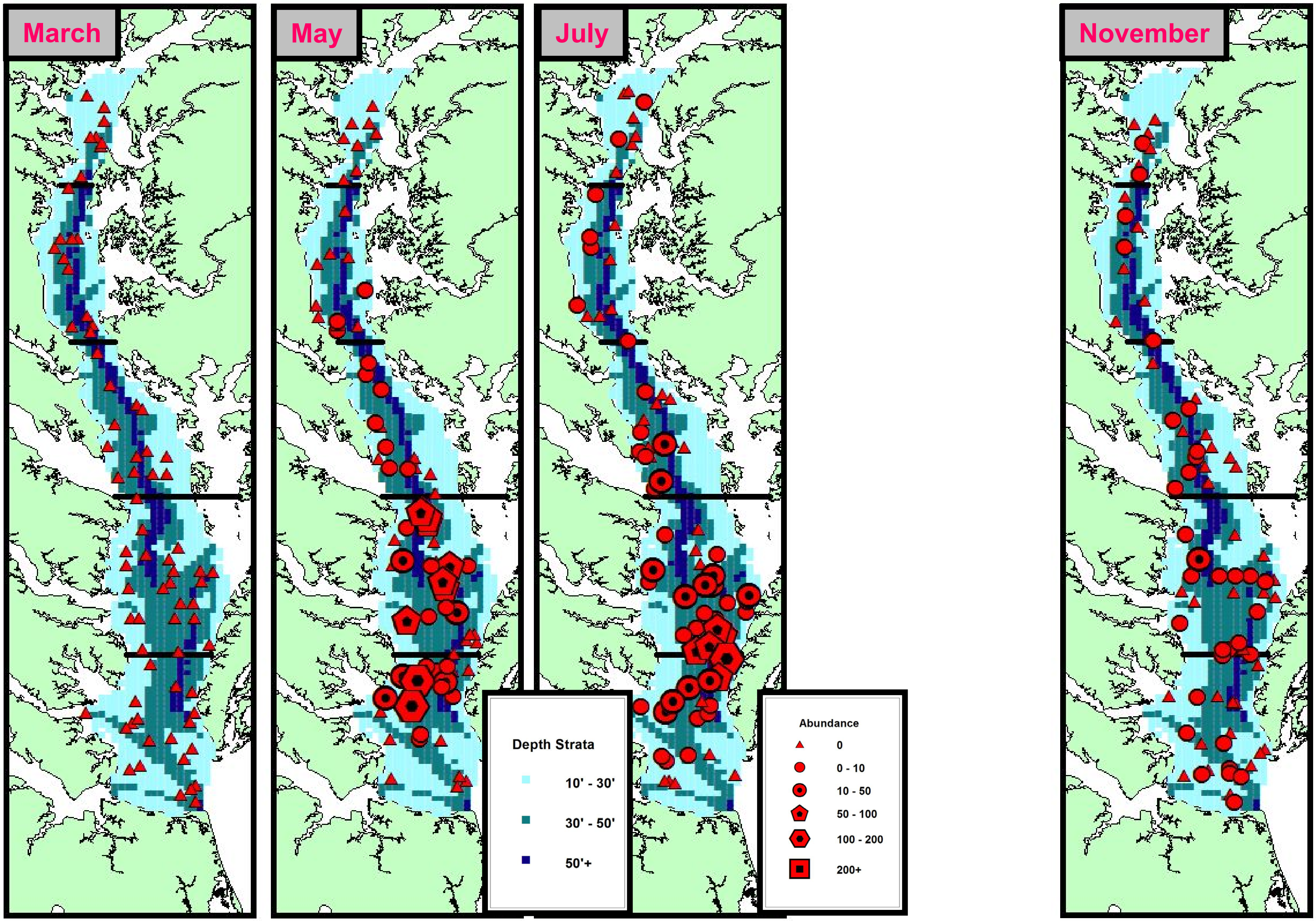


Figure 8. Atlantic croaker length-frequency in Chesapeake Bay 2002-2007.

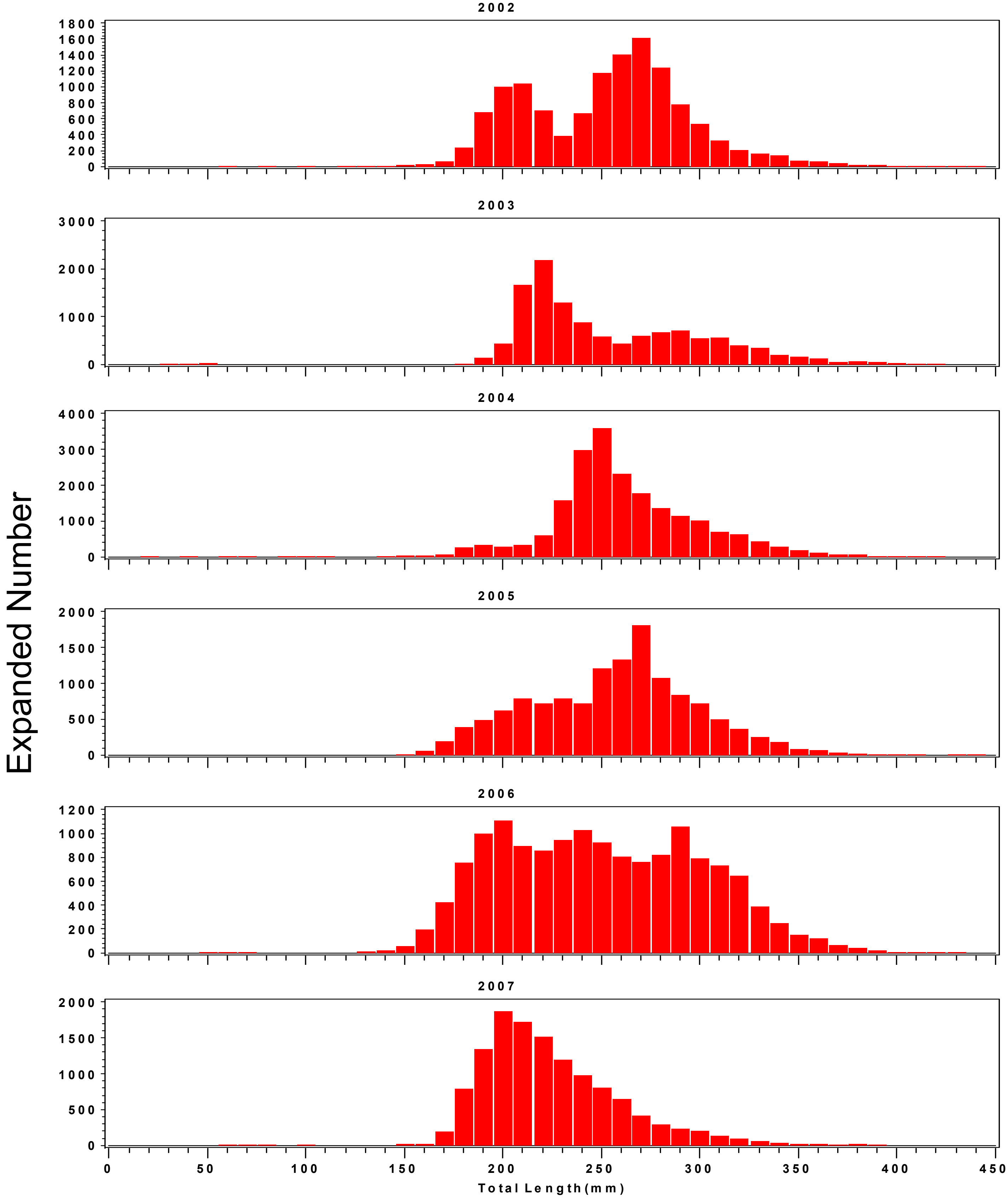


Figure 9. Atlantic croaker age-structure in Chesapeake Bay, 2002-2007.

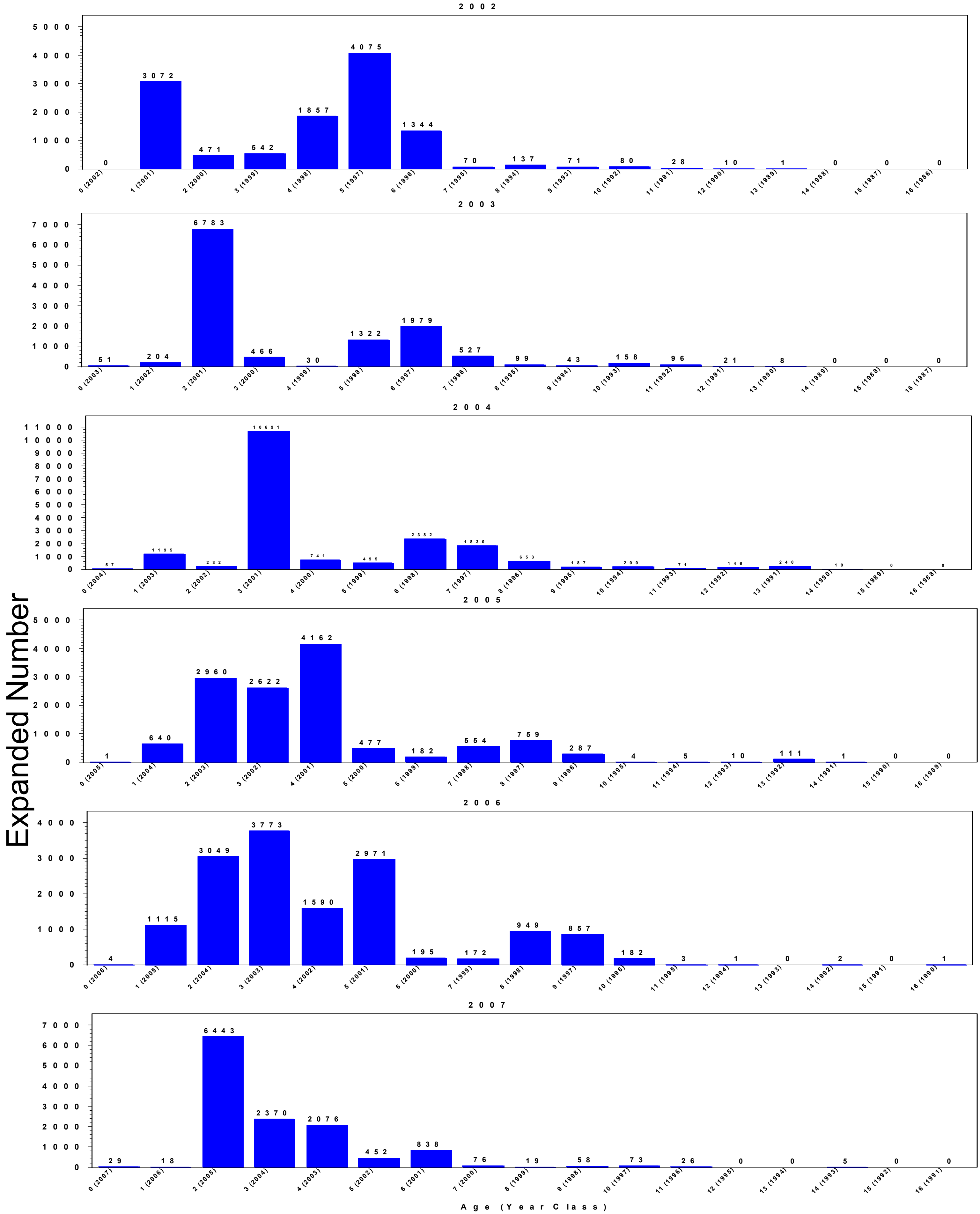


Figure 10. Atlantic croaker sex-ratios in Chesapeake Bay, 2002-2007, by region (A), age (B).

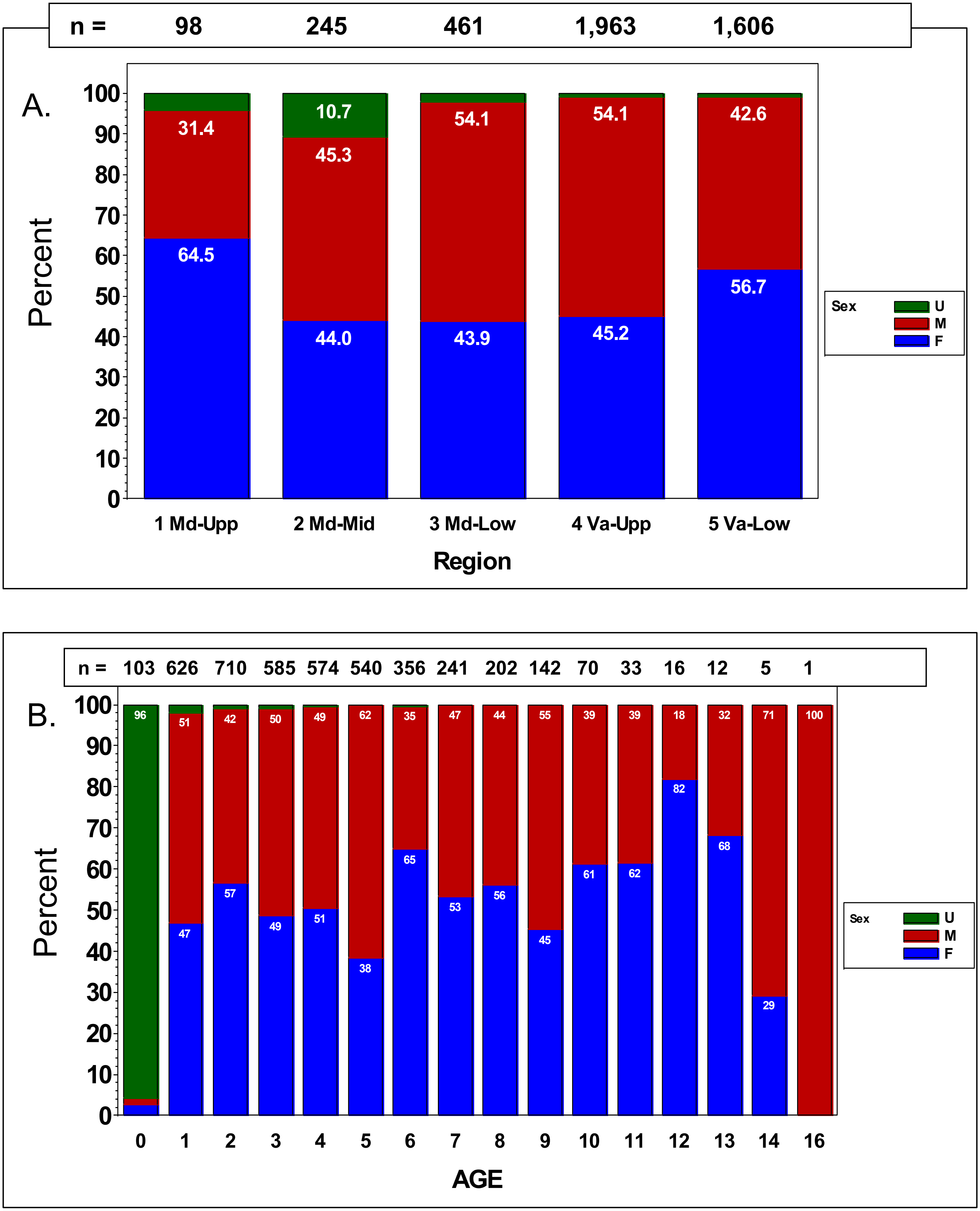


Figure 11. Atlantic croaker length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).

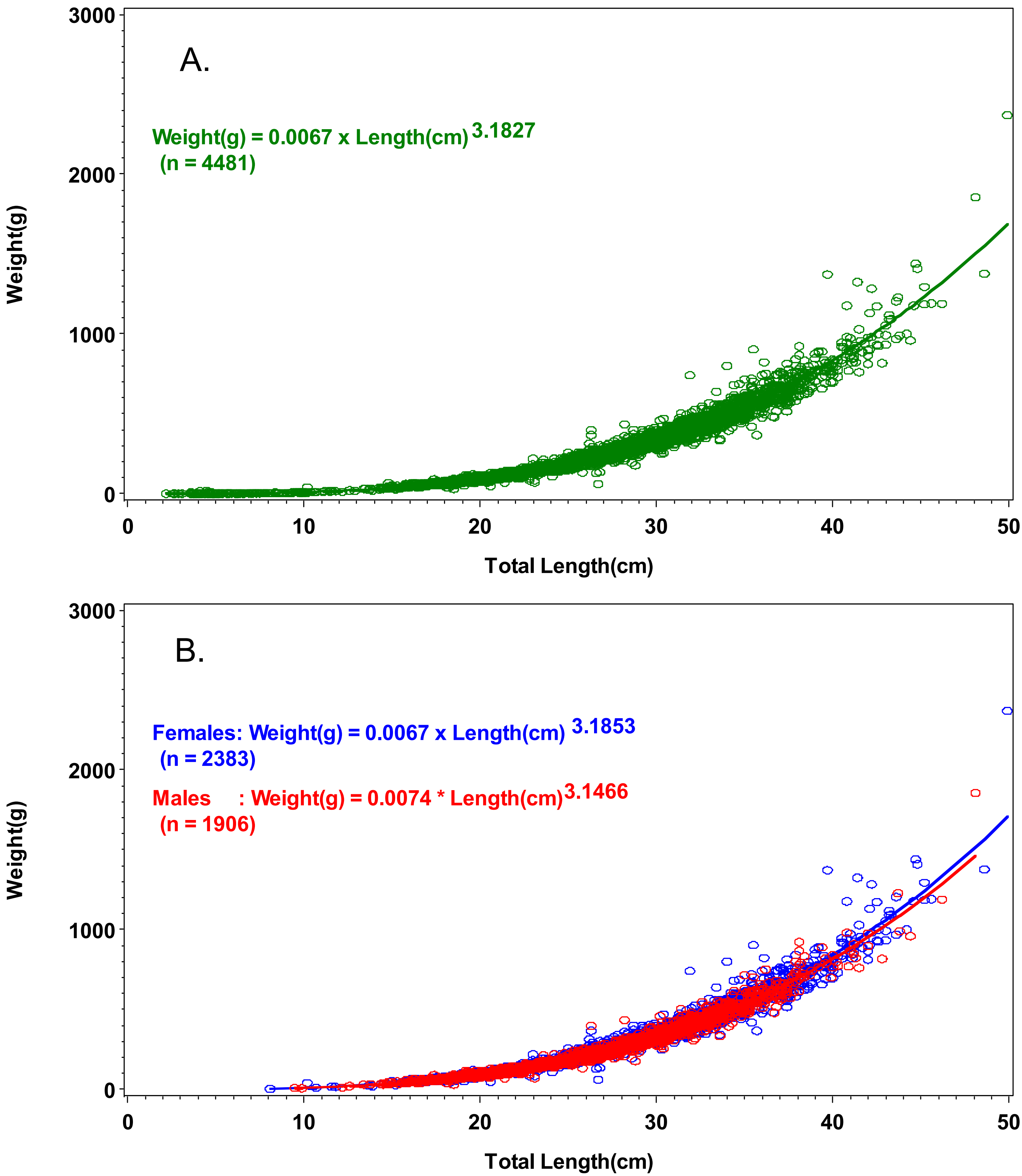


Figure 12. Atlantic croaker maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

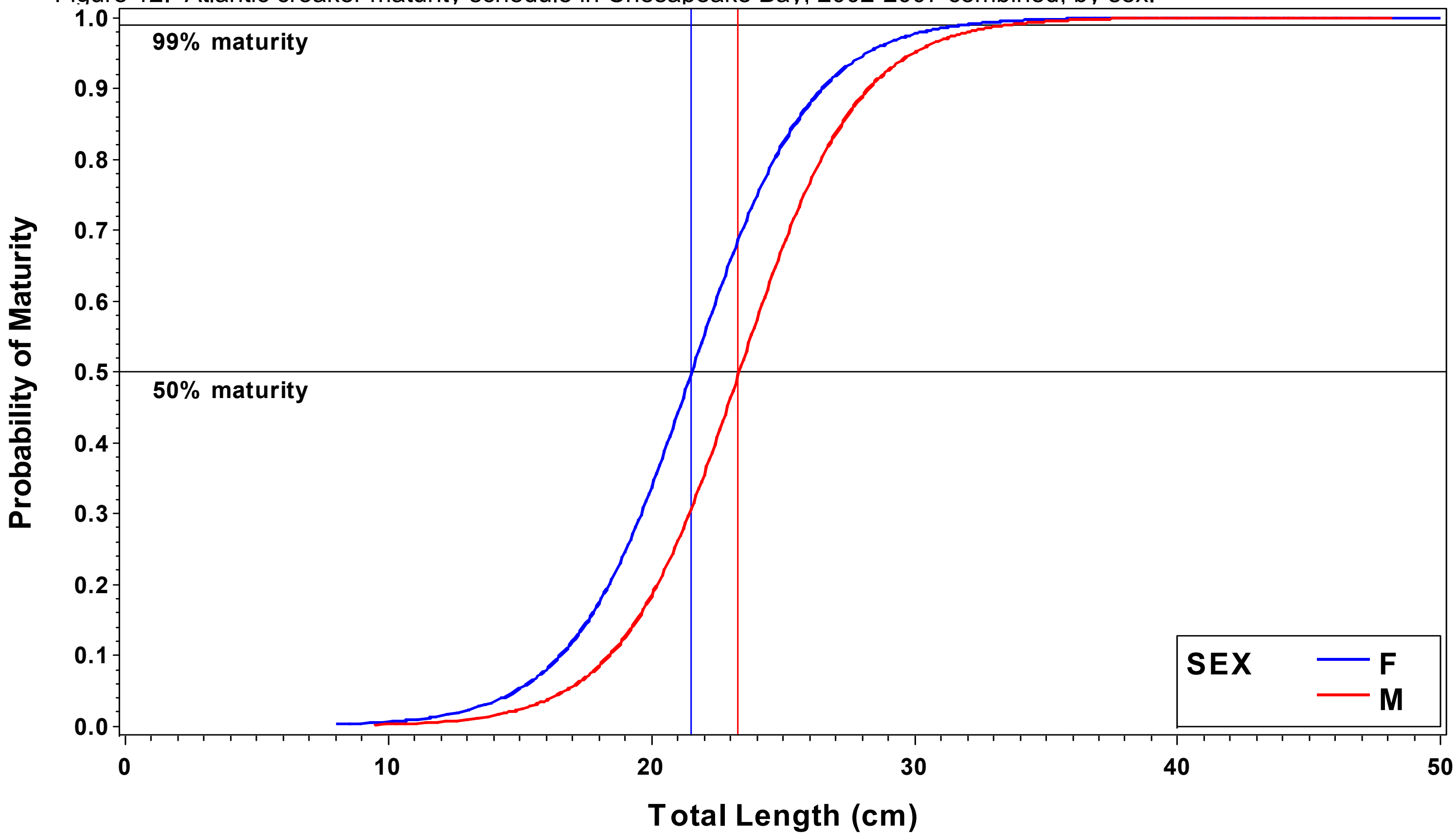
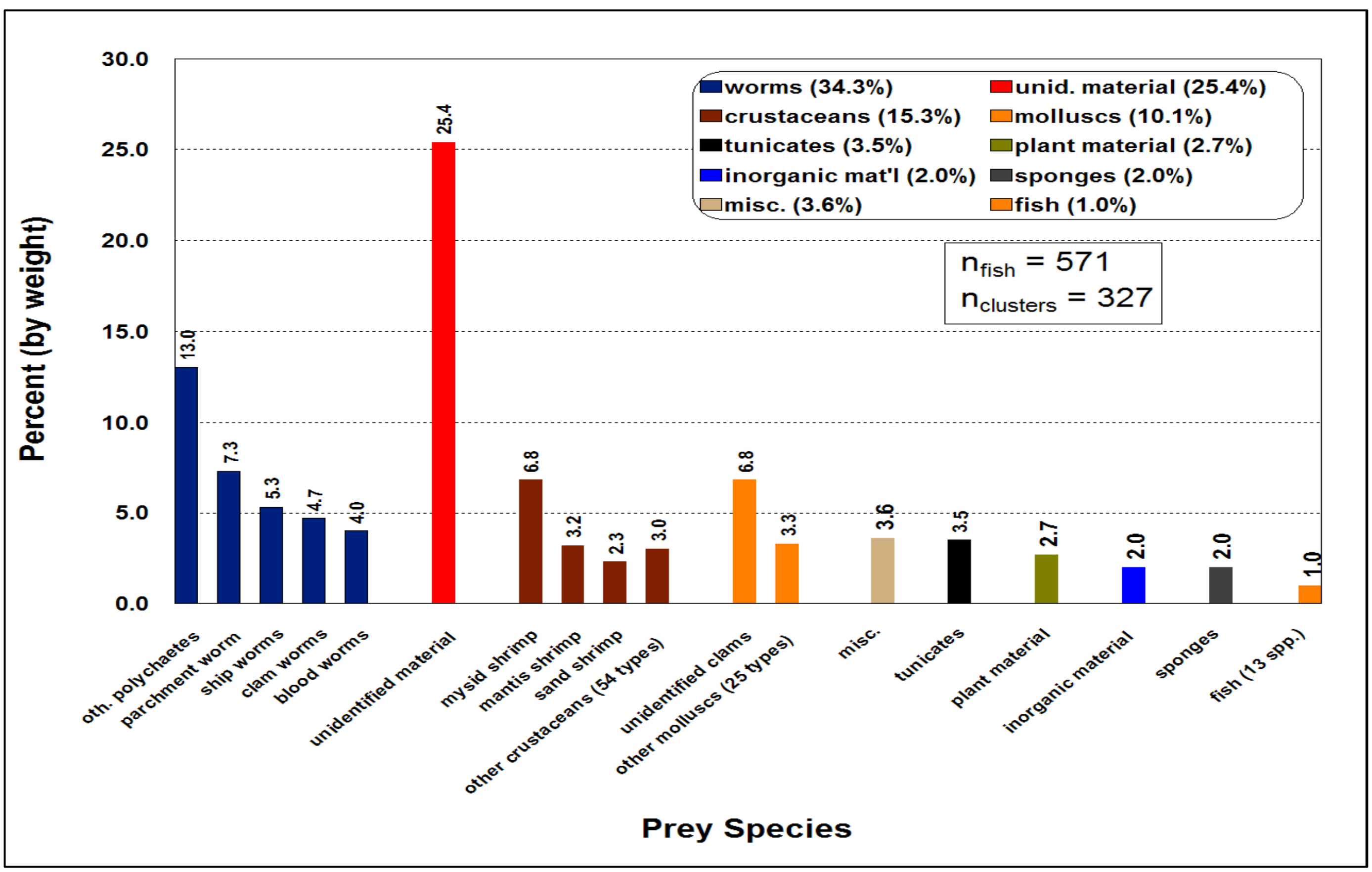
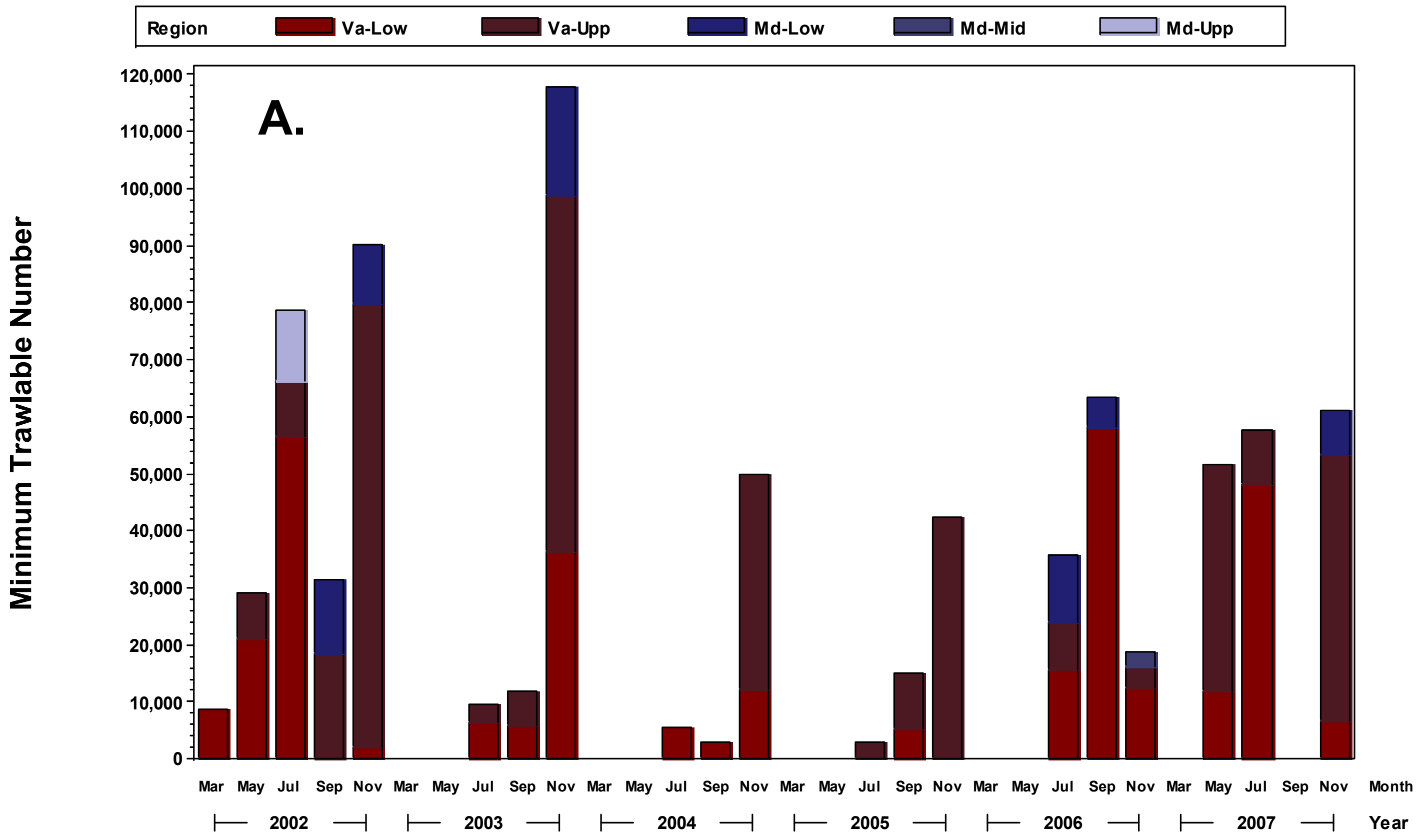


Figure 13. Atlantic croaker diet in Chesapeake Bay 2002-2007 combined*.



*All samples not analyzed.

Figure 14. Black sea bass minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay 2002-2007 (Note: abundance estimates for this species not considered reliable).



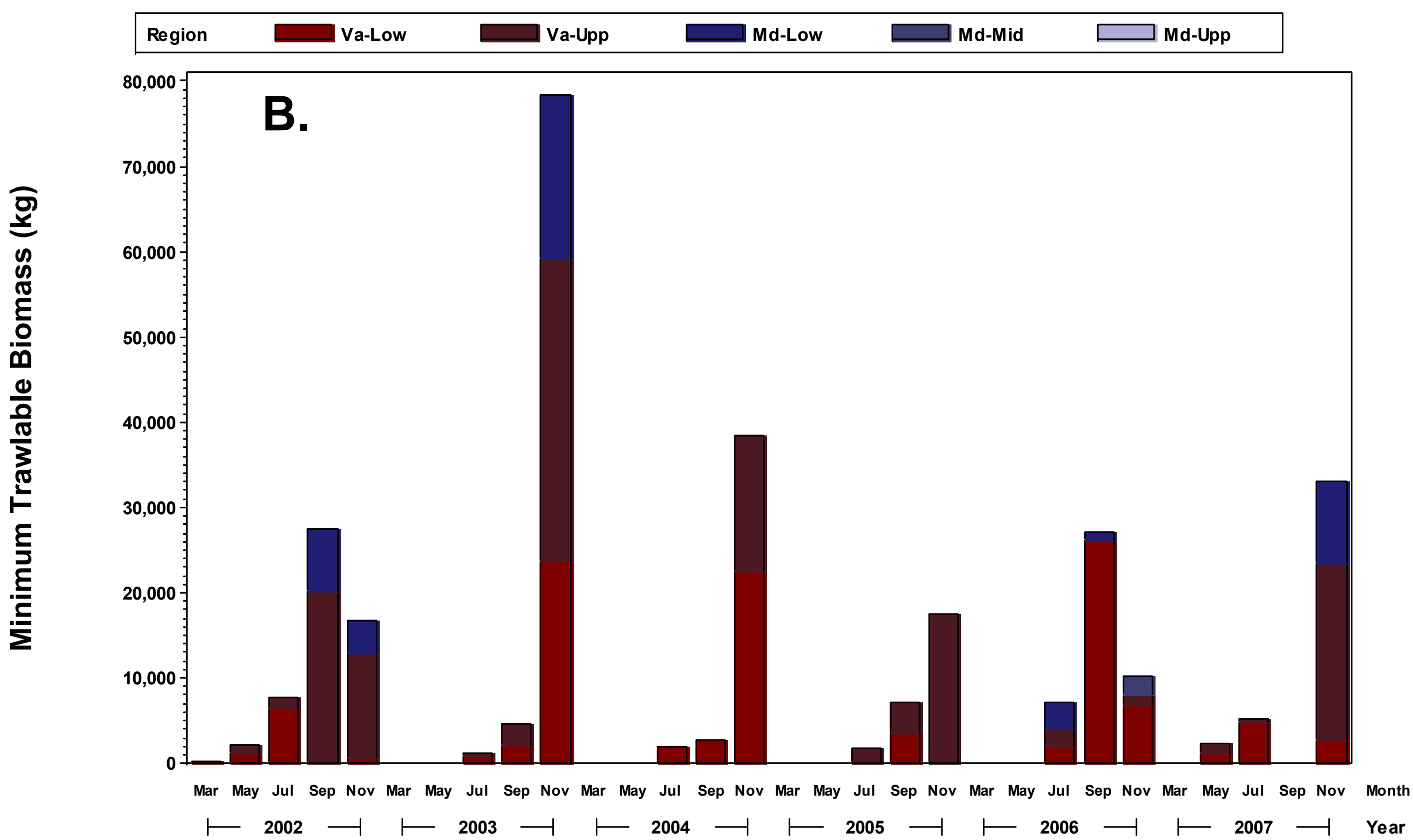


Figure 15. Black sea bass length-frequency in Chesapeake Bay, 2002-2007.

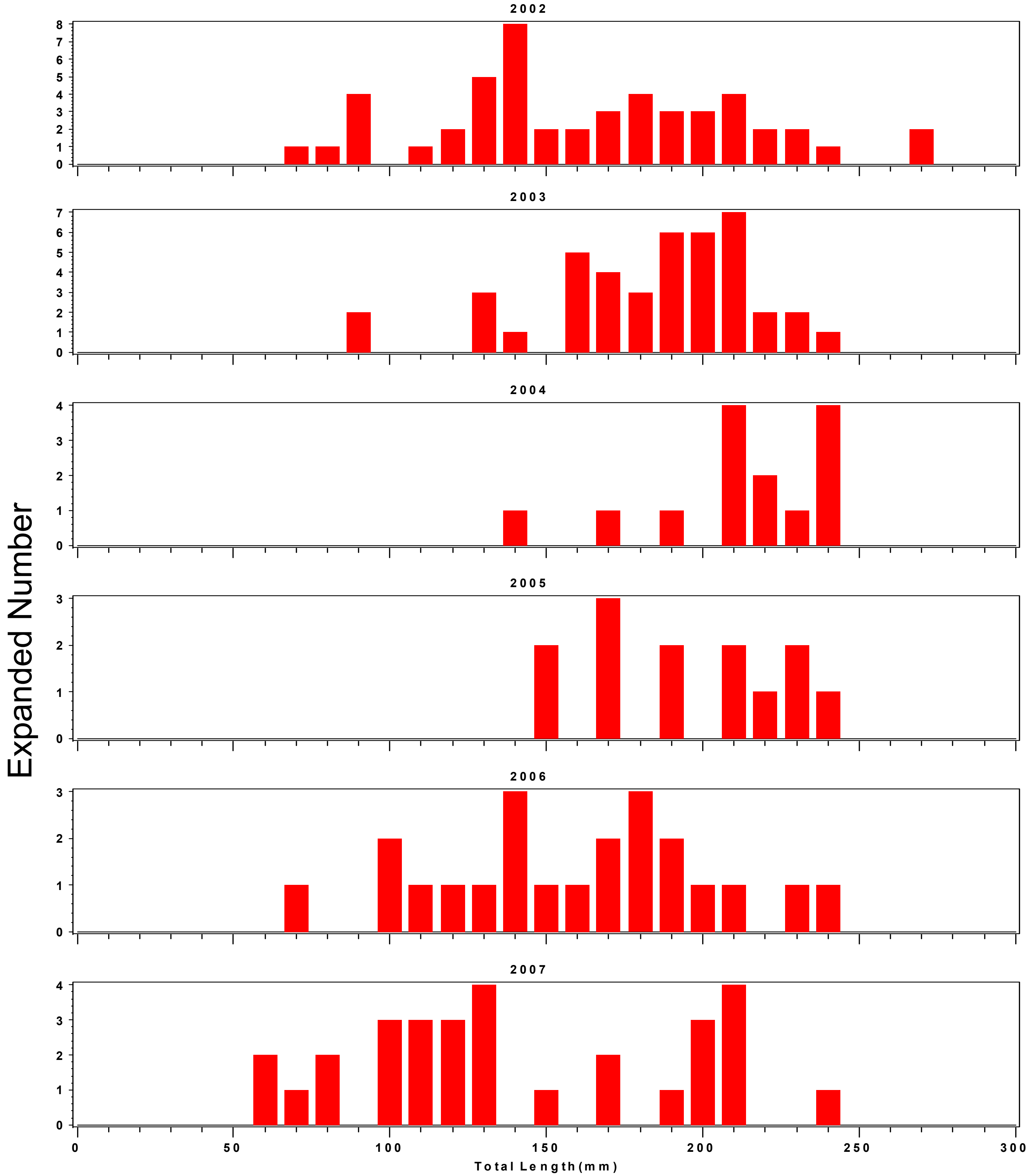


Figure 16. Black seabass age-structure in Chesapeake Bay 2002-2003 (2004-2007 ages not yet assigned).

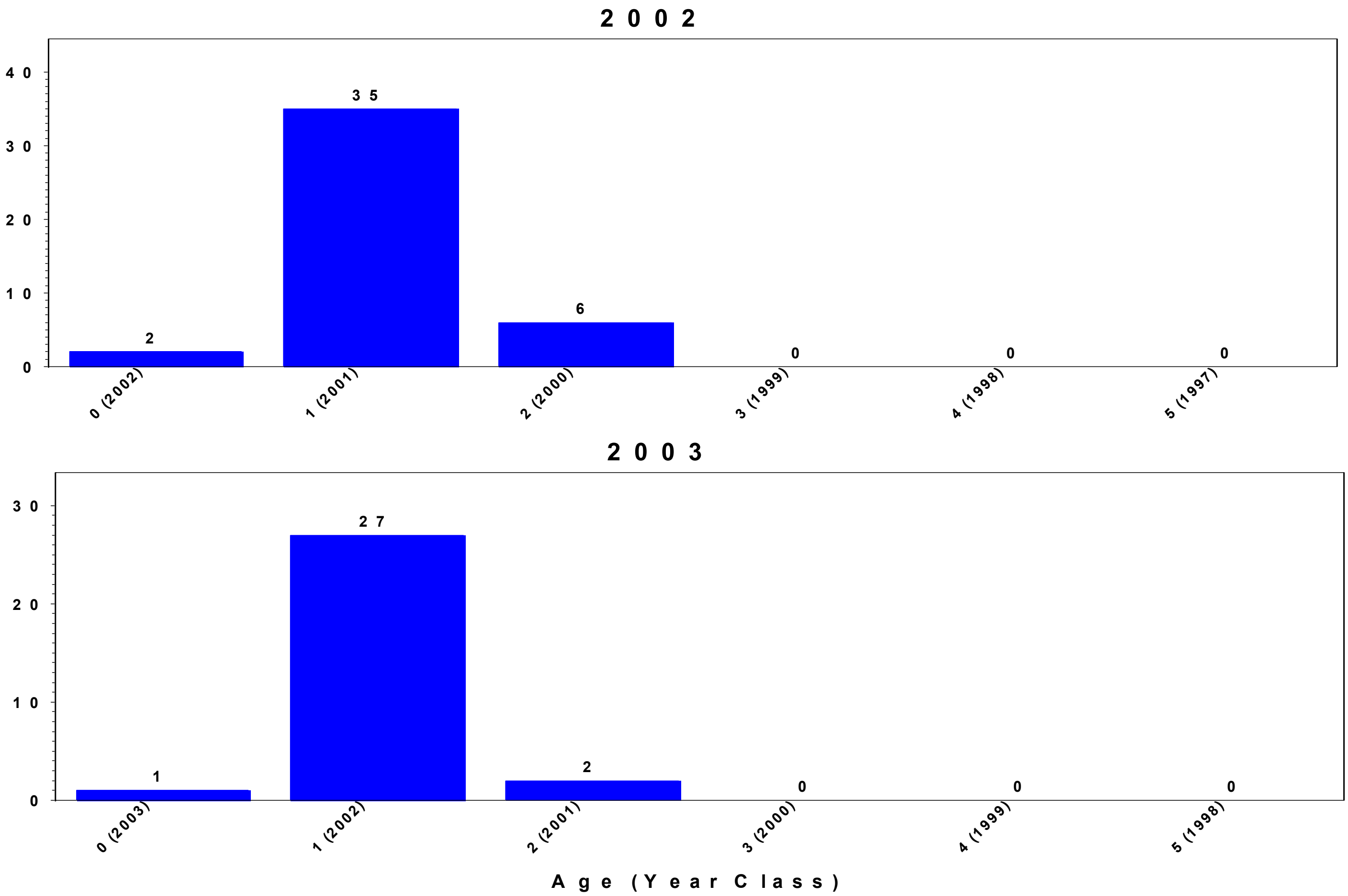
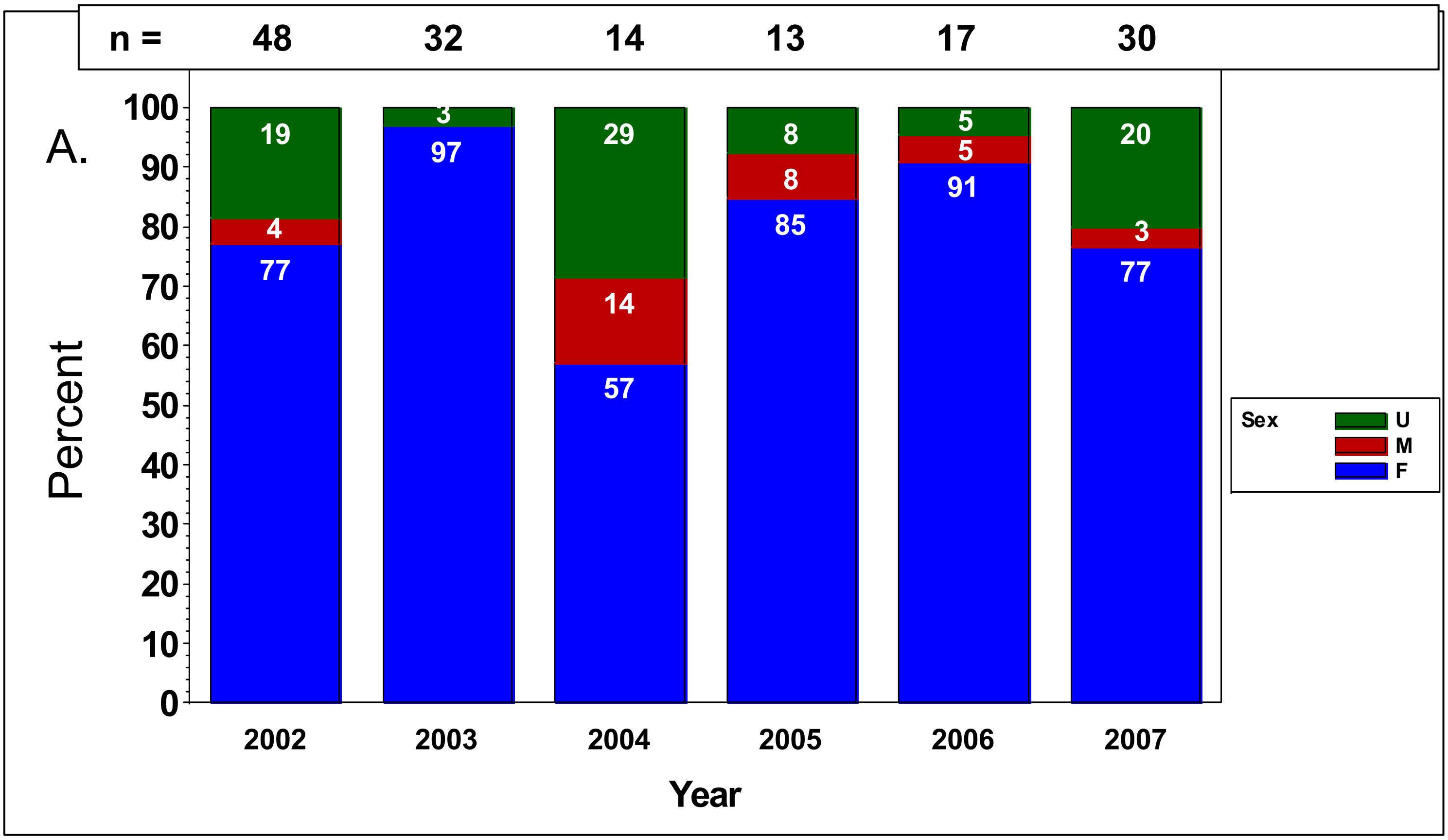


Figure 17. Black sea bass sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B).



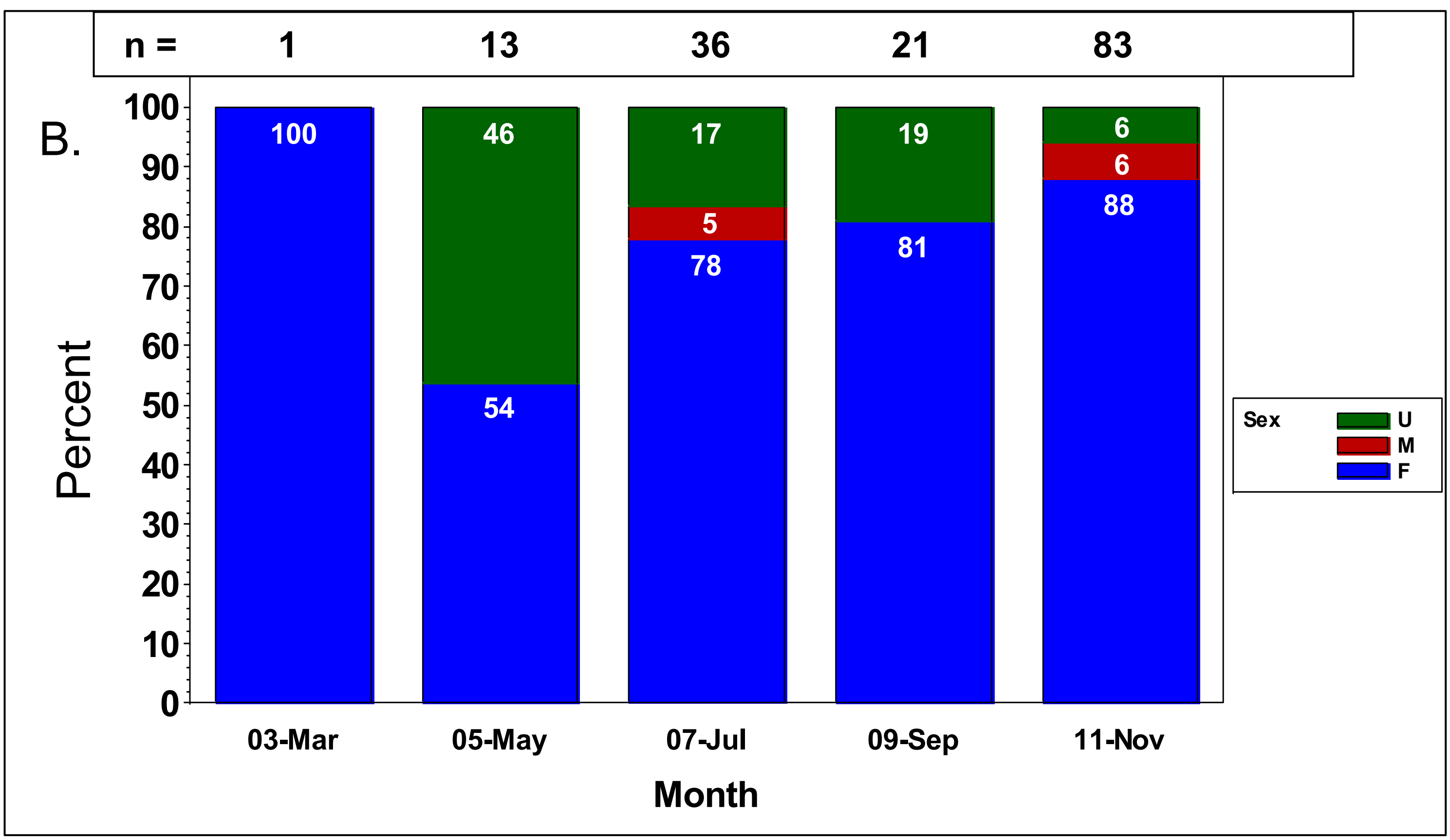


Figure 18. Black sea bass length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).

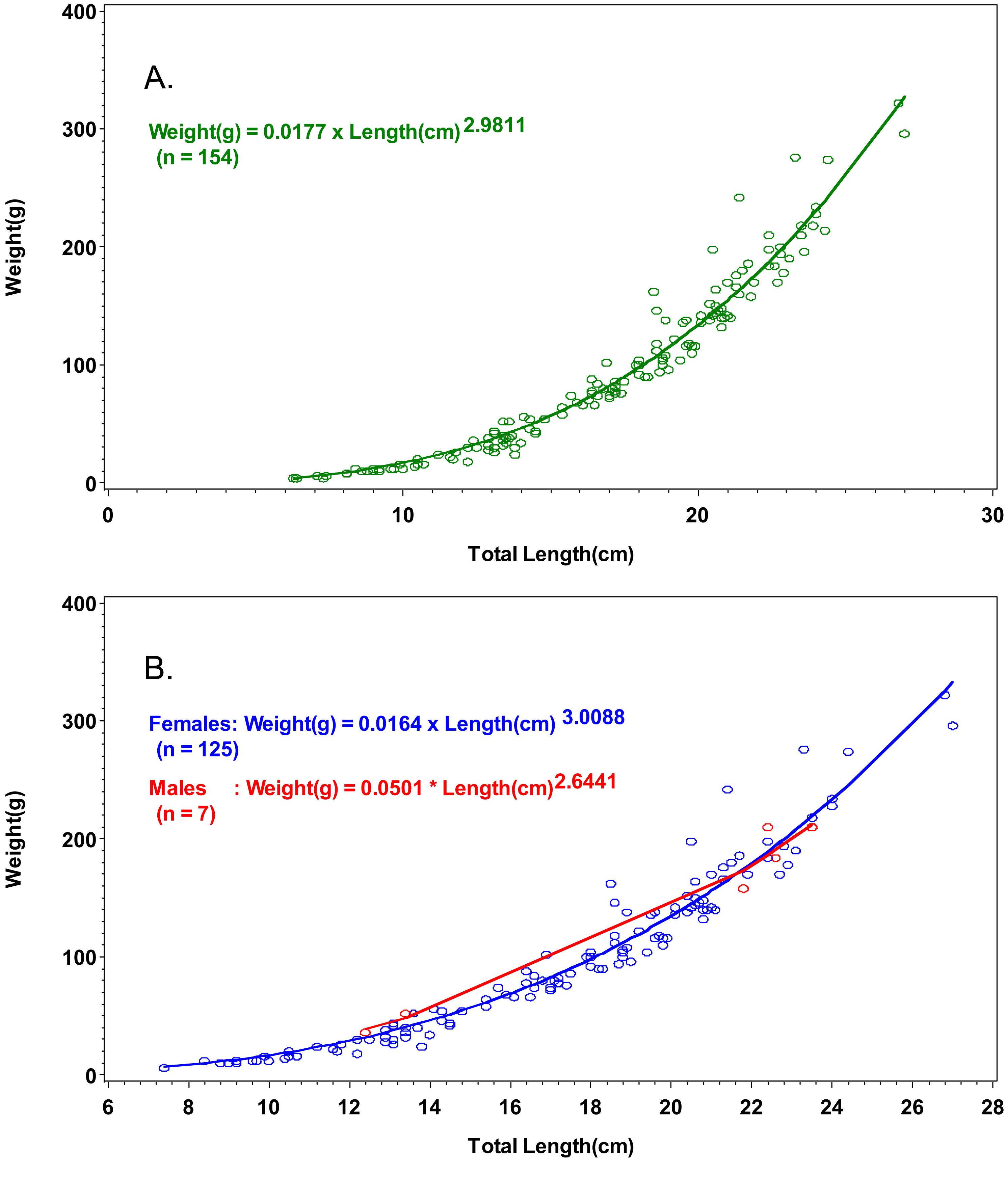


Figure 19. Black sea bass maturity schedule in Chesapeake Bay, 2002-2007 combined, (females only).

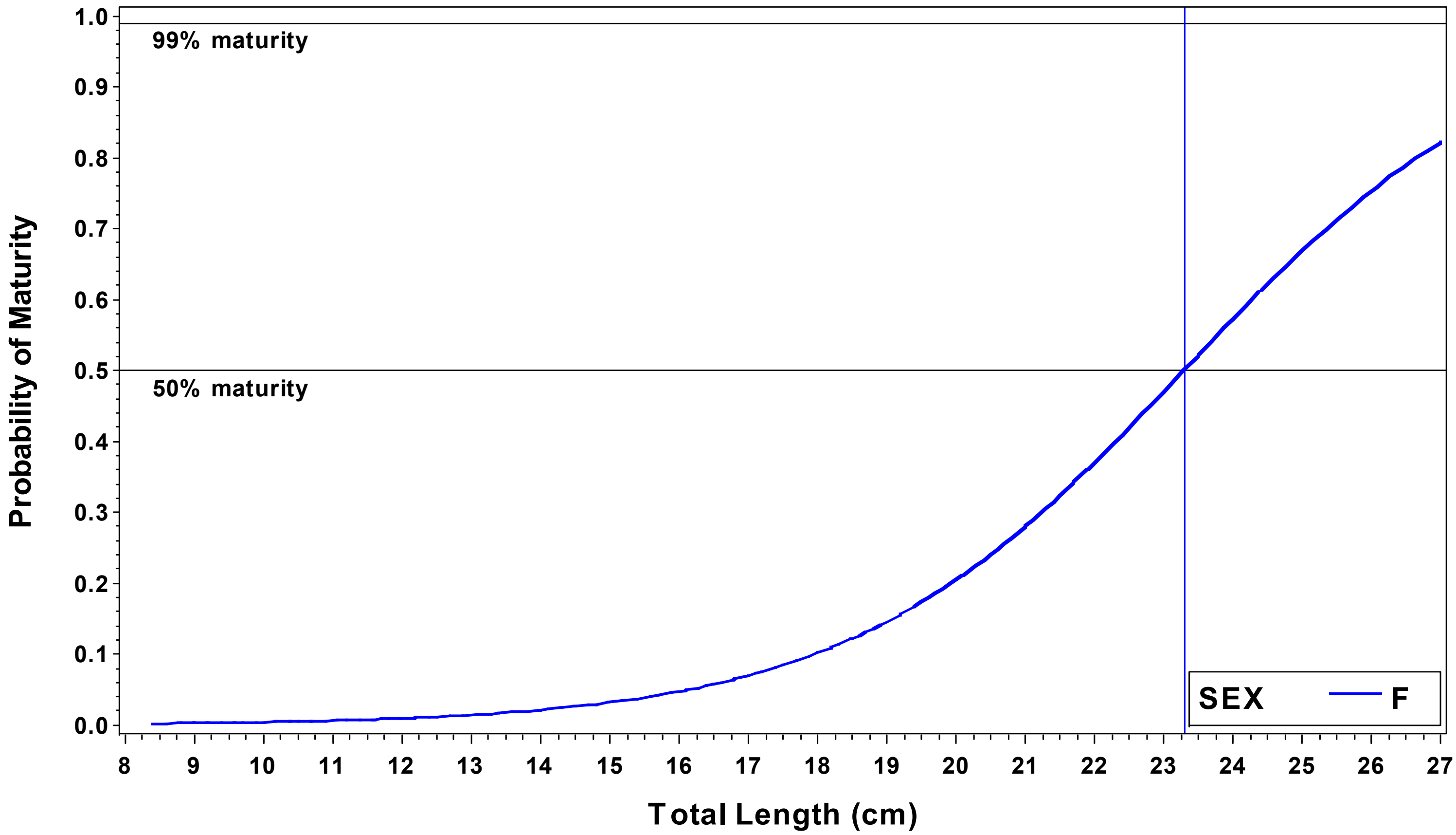


Figure 20. Black sea bass diet in Chesapeake Bay, 2002-2007 combined.

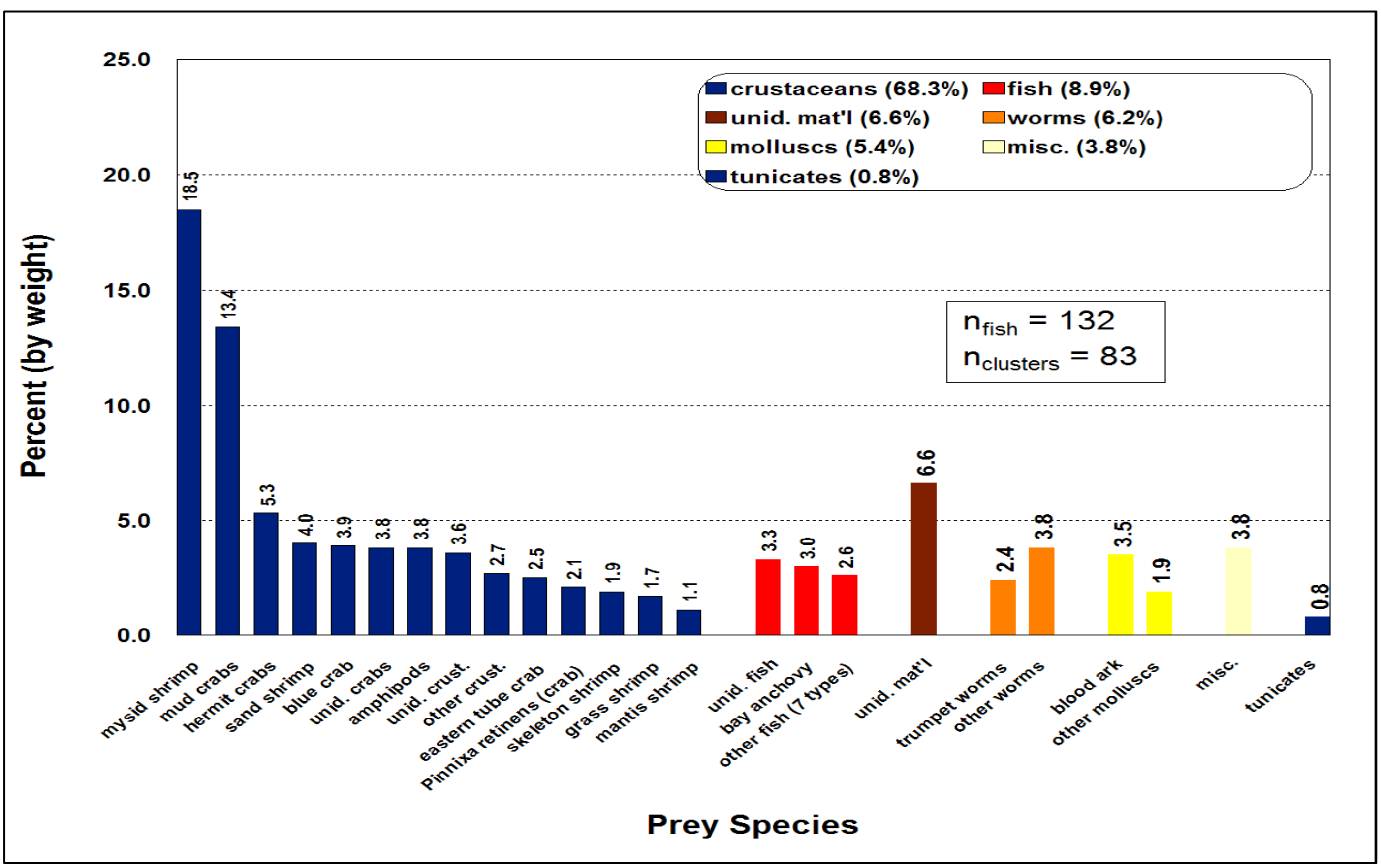
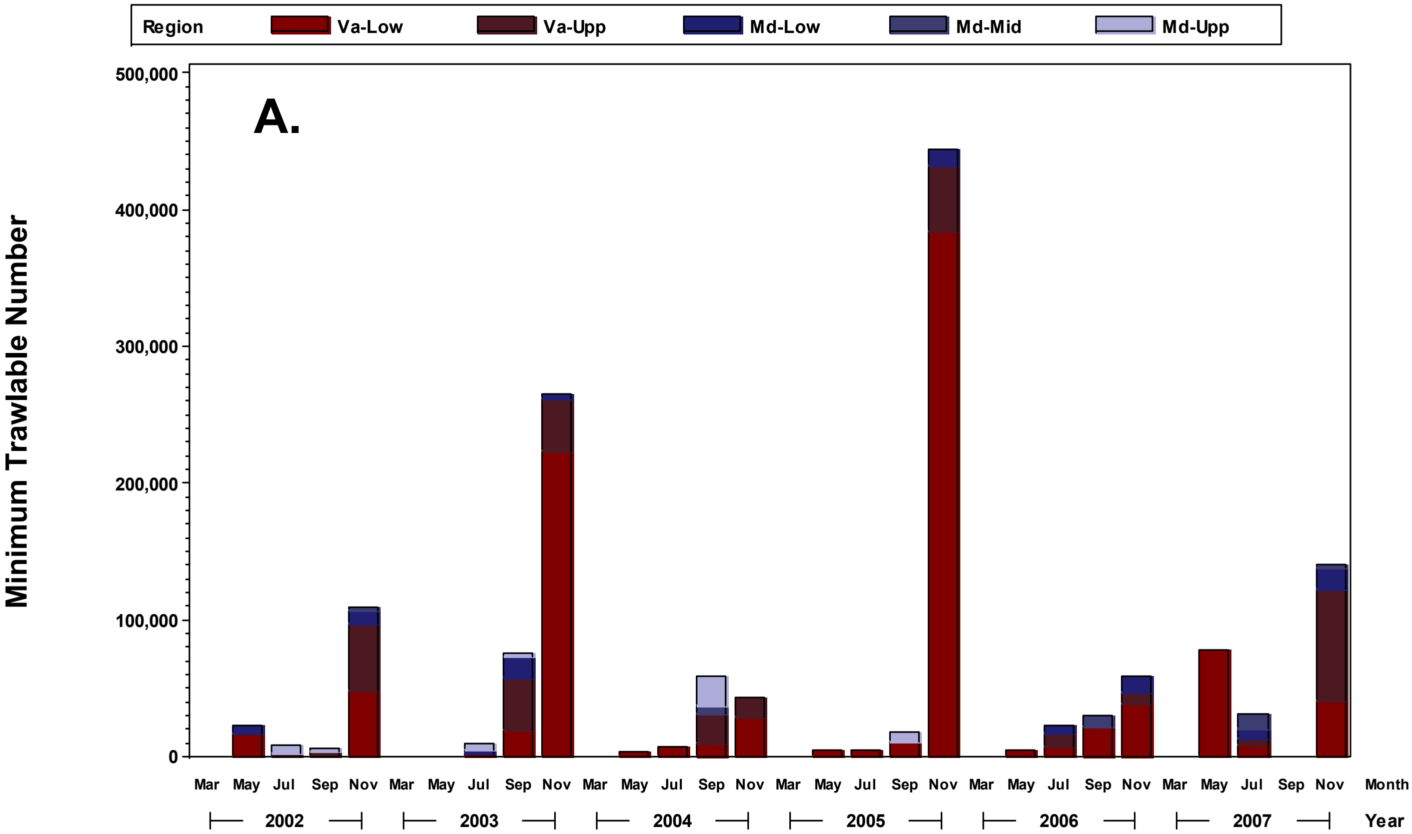


Figure 21. Bluefish minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007 (Note: abundance estimates for this species not considered reliable).



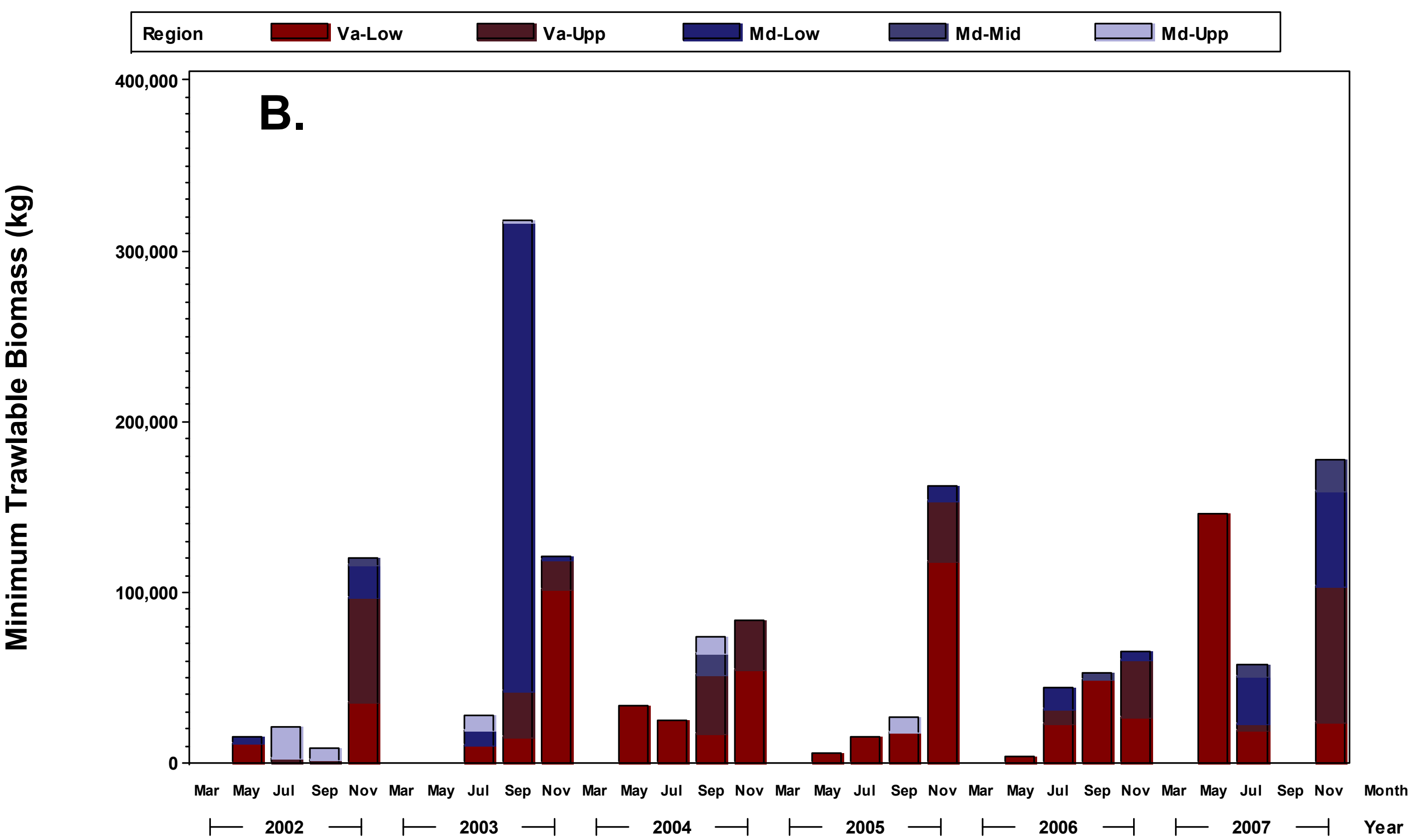


Figure 22. Abundance (number per hectare swept) of bluefish in Chesapeake Bay, 2002.

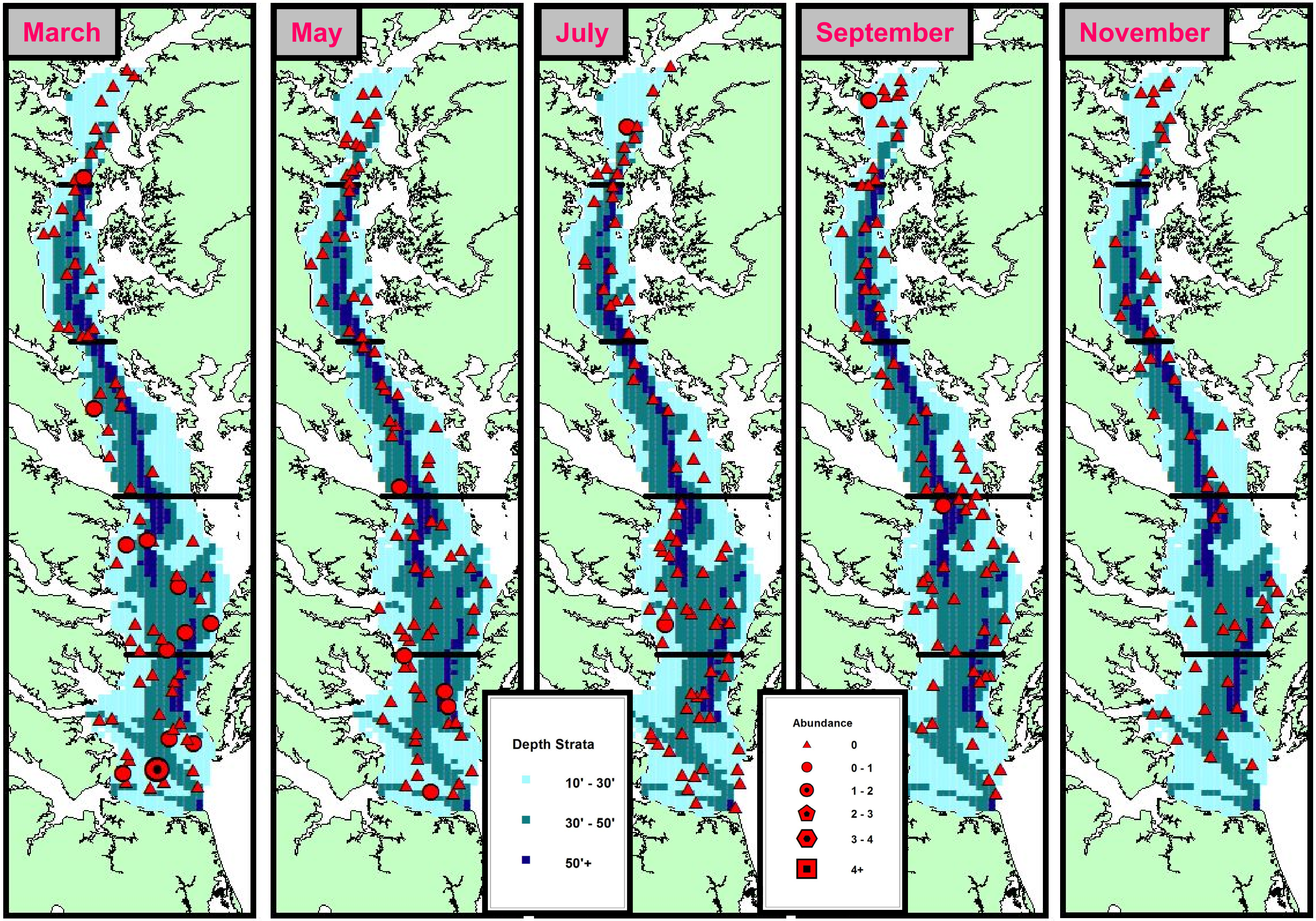


Figure 23. Abundance (number per hectare swept) of bluefish in Chesapeake Bay, 2003.

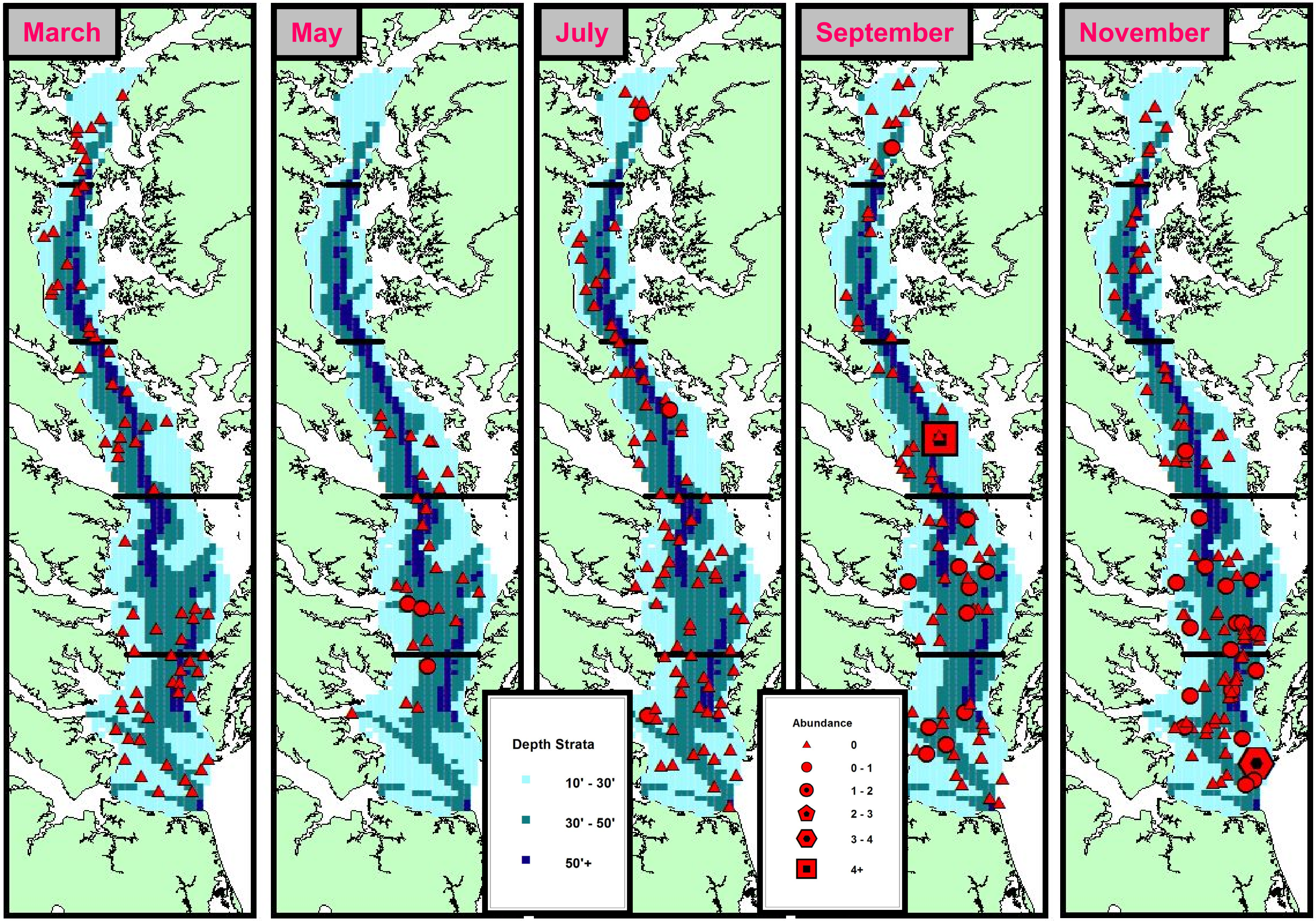


Figure 24. Abundance (number per hectare swept) of bluefish in Chesapeake Bay, 2004.

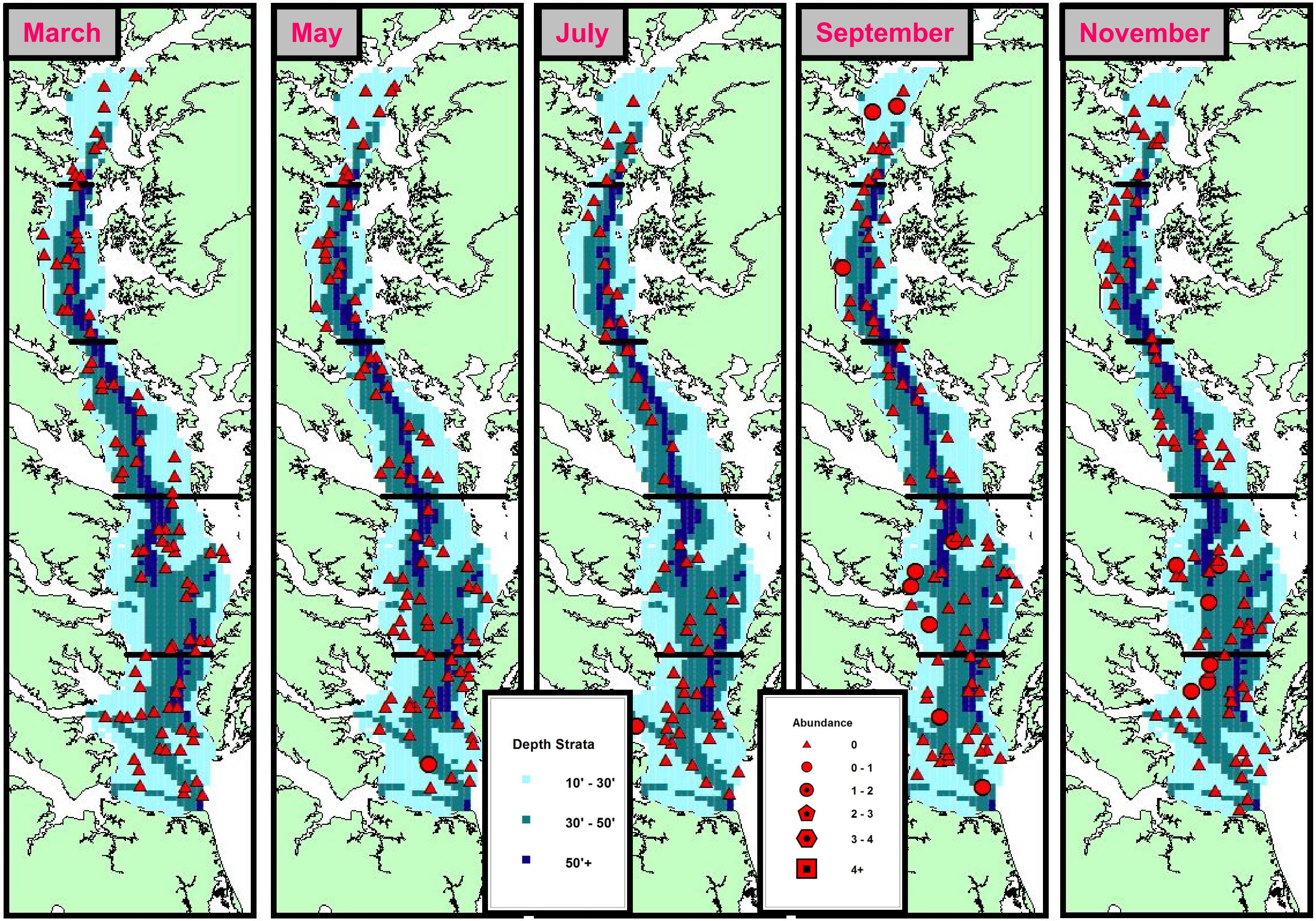


Figure 25. Abundance (number per hectare swept) of bluefish in Chesapeake Bay, 2005.

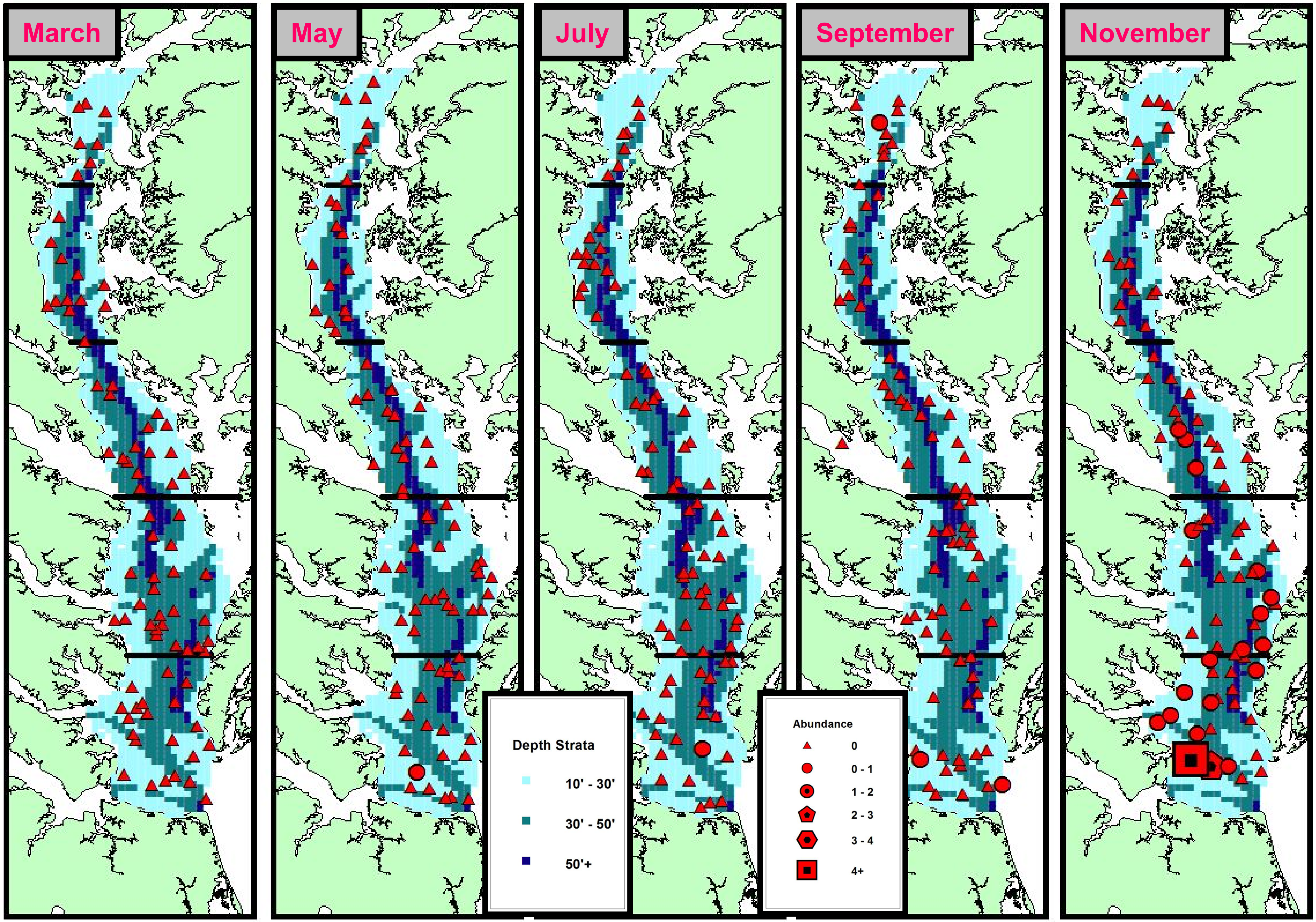


Figure 26. Abundance (number per hectare swept) of bluefish in Chesapeake Bay, 2006.

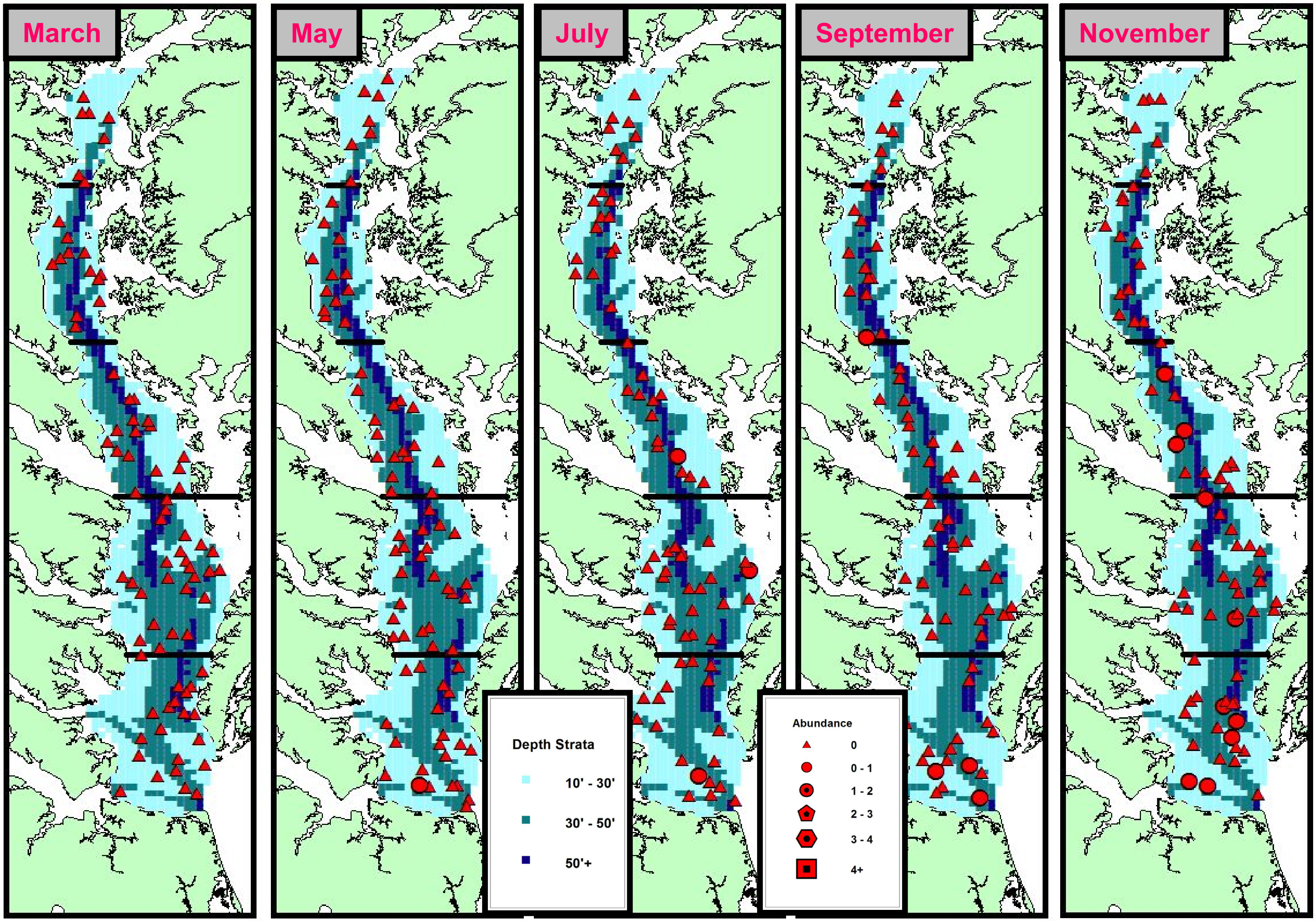


Figure 27. Abundance (number per hectare swept) of bluefish in Chesapeake Bay, 2007.

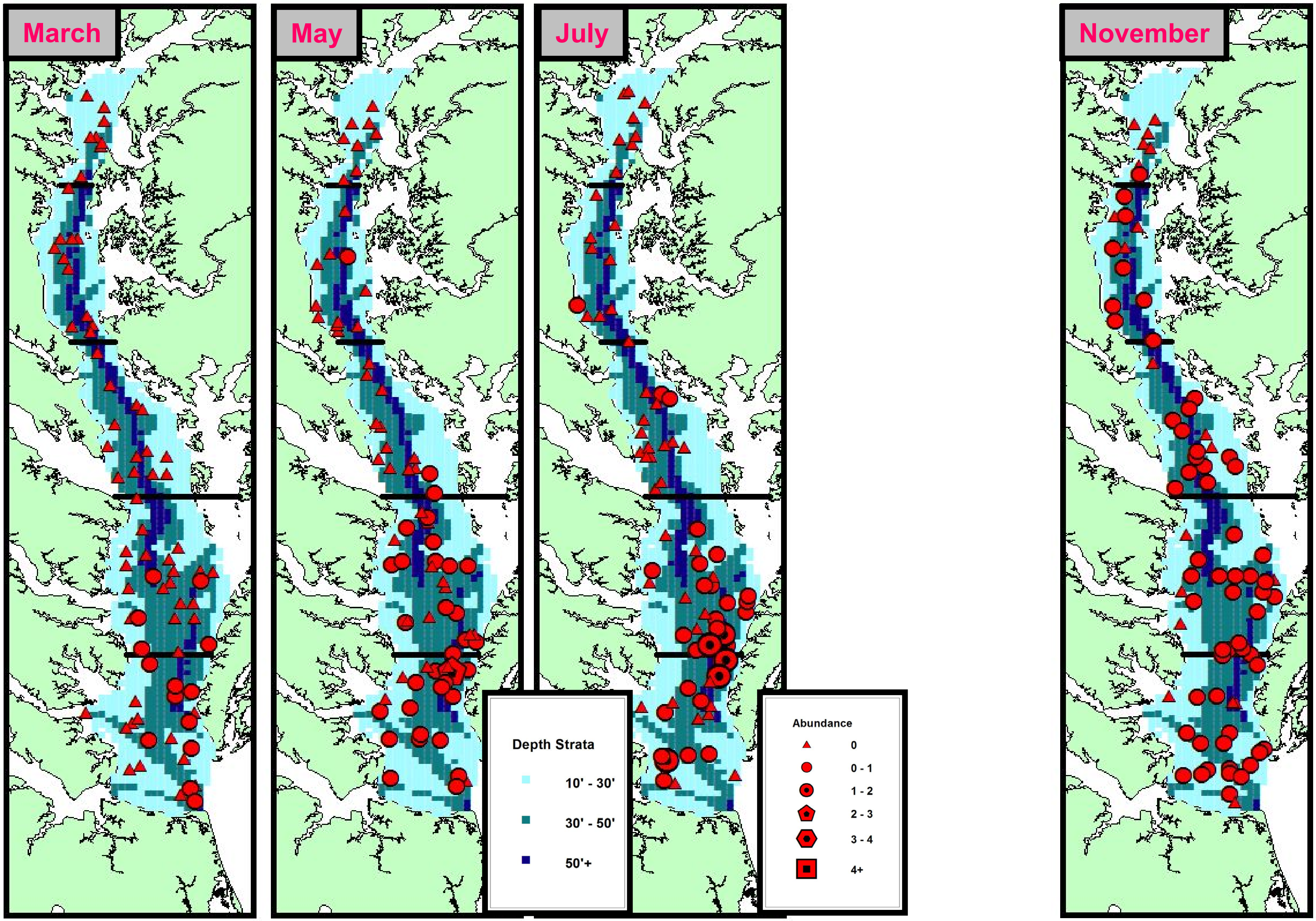


Figure 28. Bluefish length-frequency in Chesapeake Bay, 2002-2007.

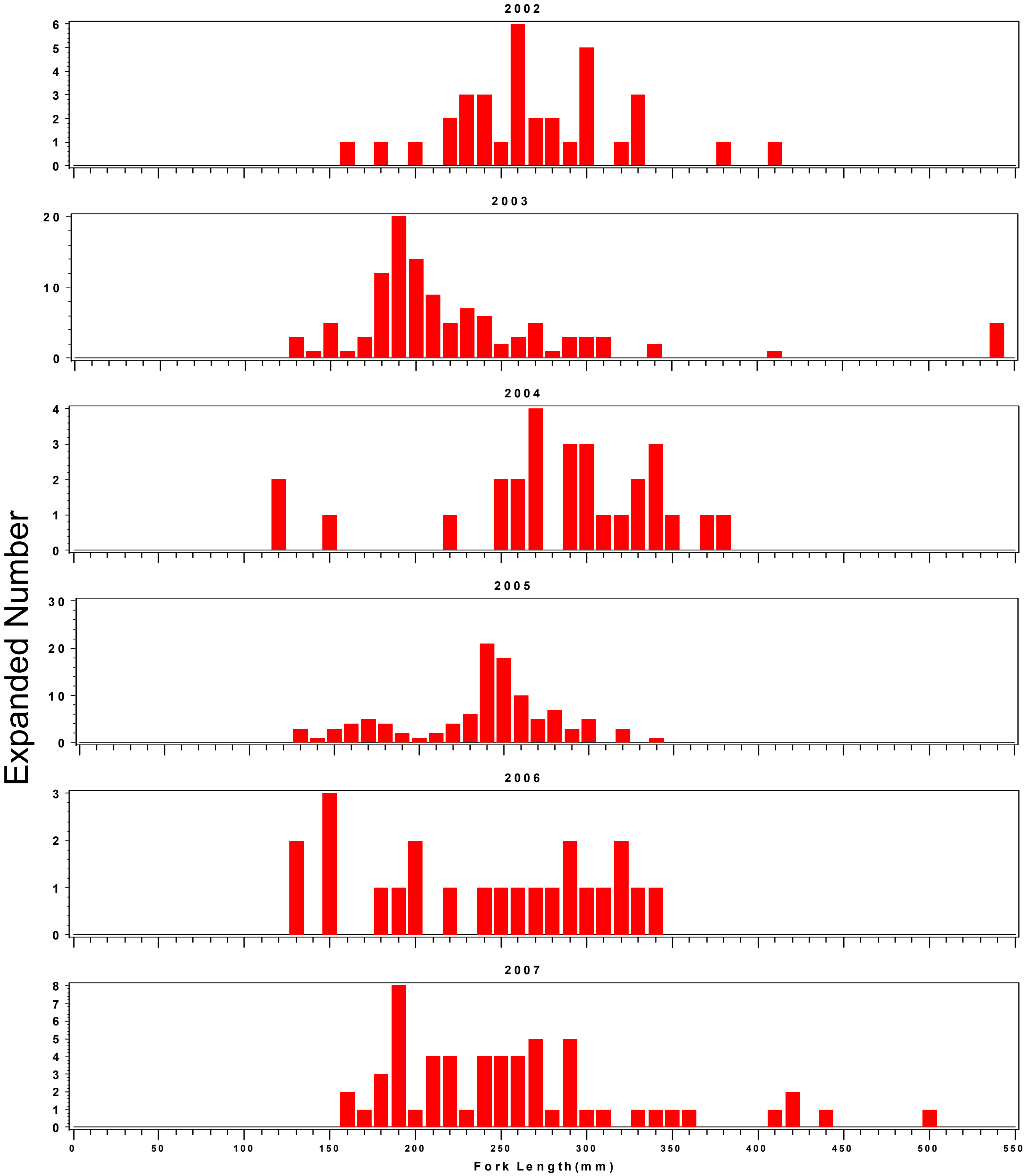


Figure 29. Bluefish age-structure in Chesapeake Bay, 2002-2007.

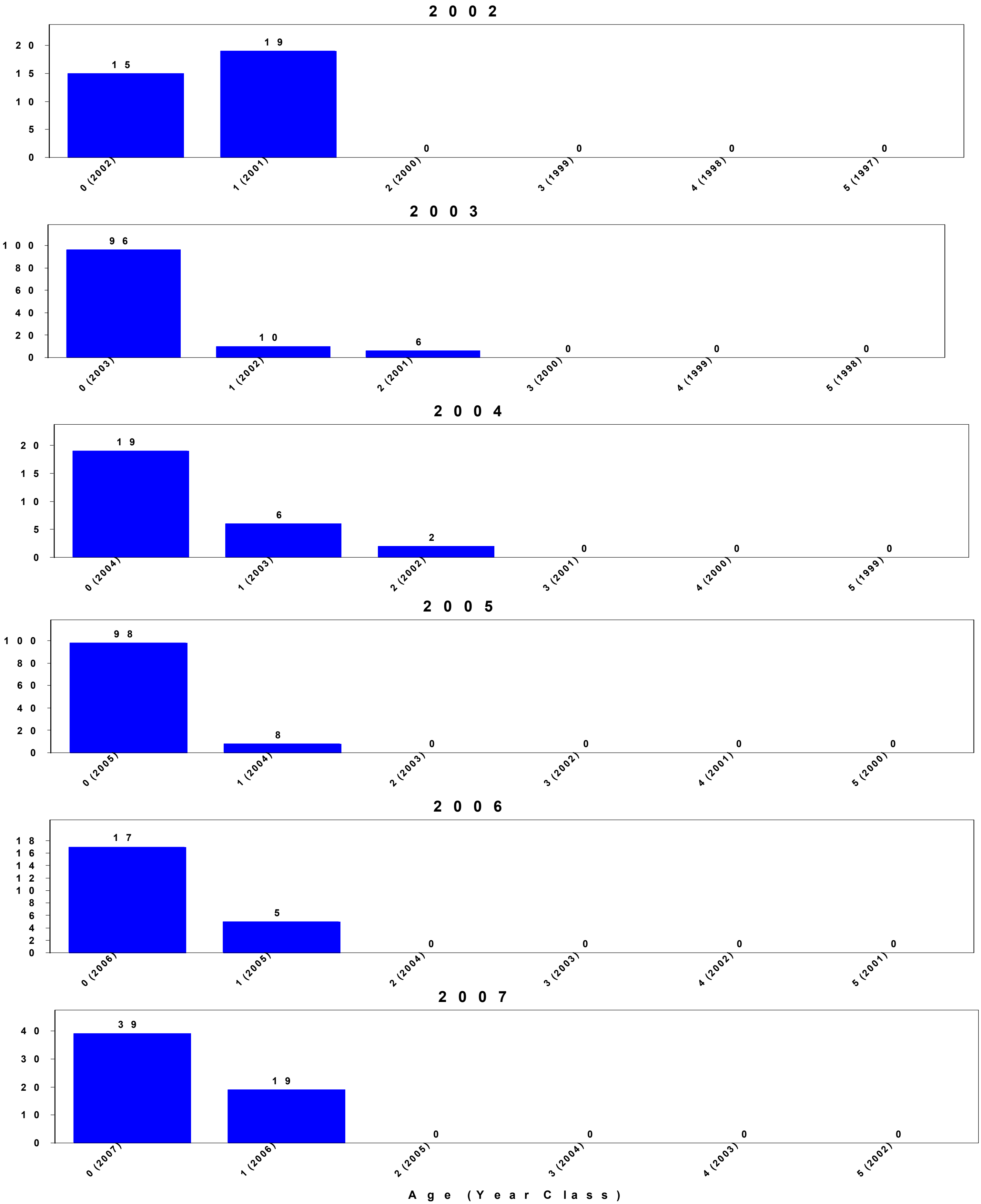


Figure 30. Bluefish sex-ratios in Chesapeake Bay, 2002-2007, by year.

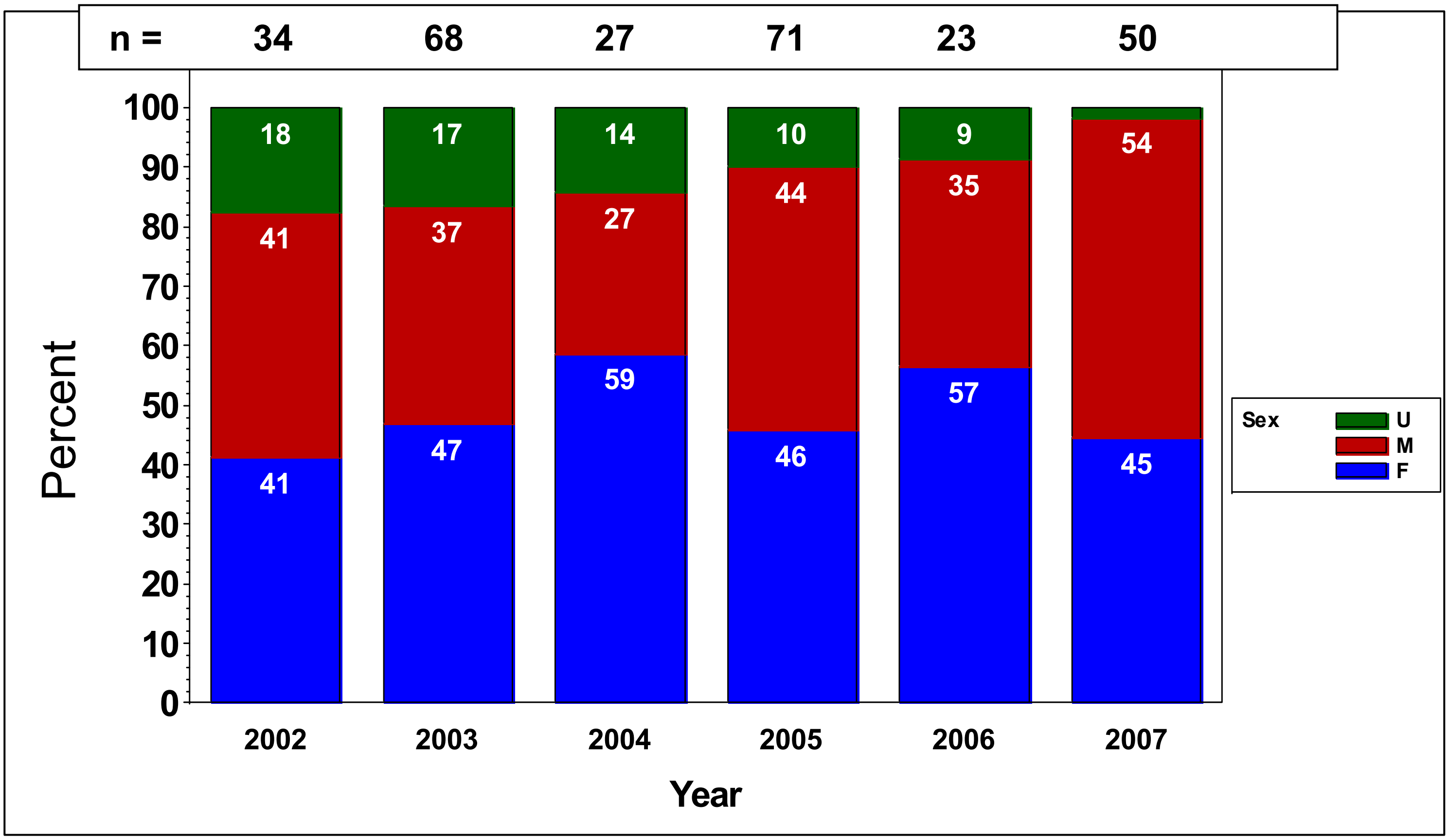
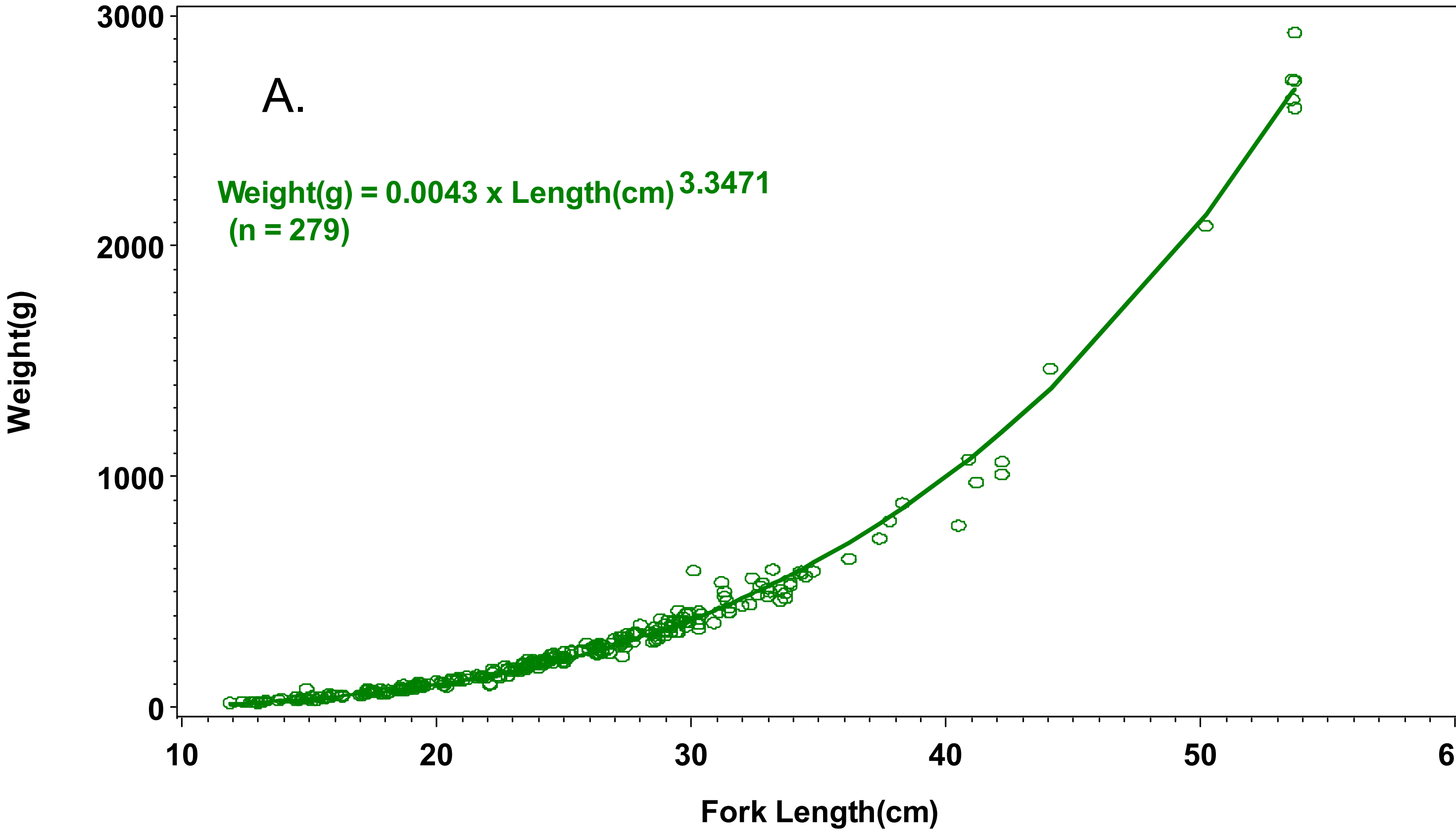


Figure 31. Bluefish length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).



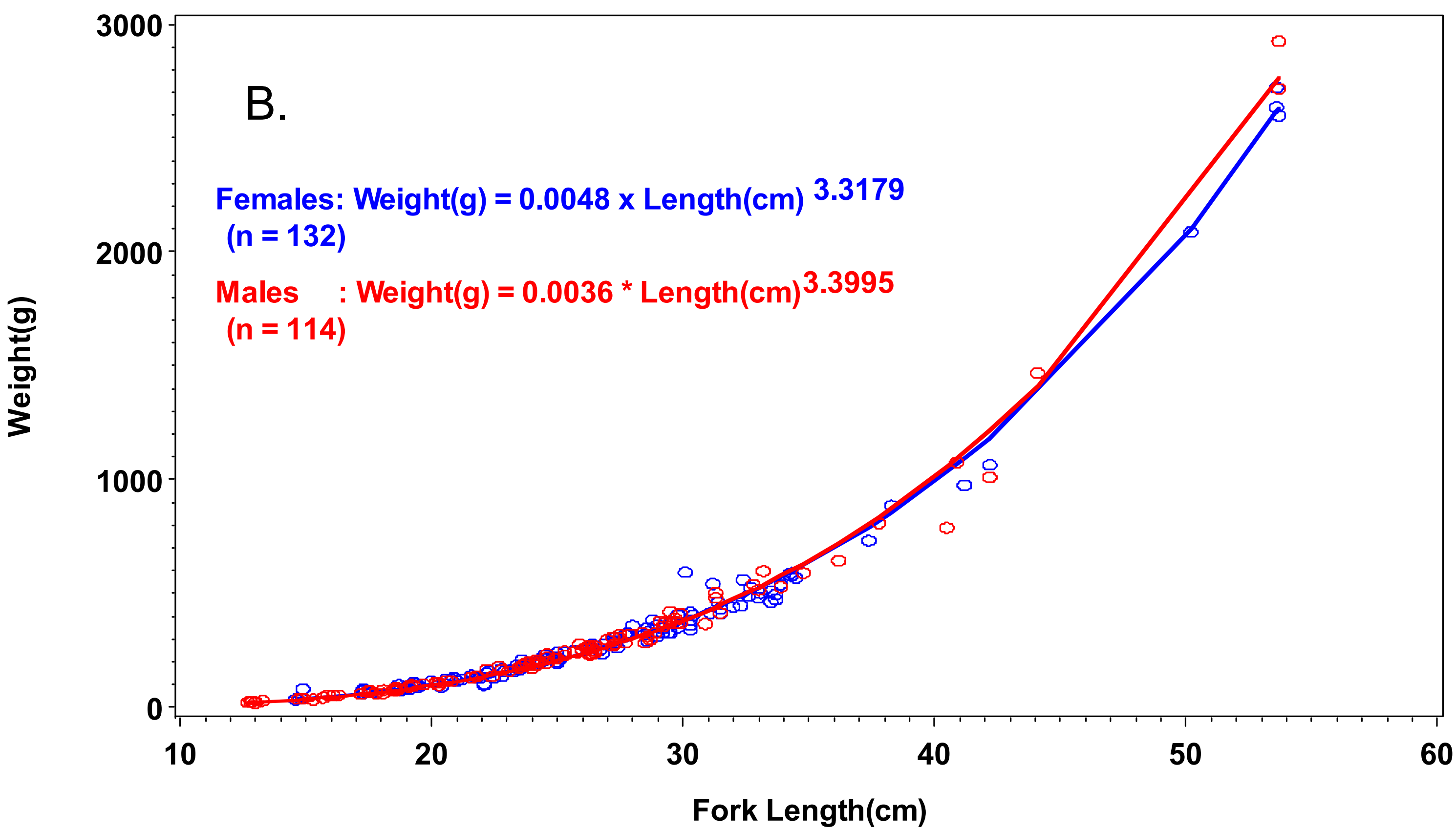


Figure 32. Bluefish maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

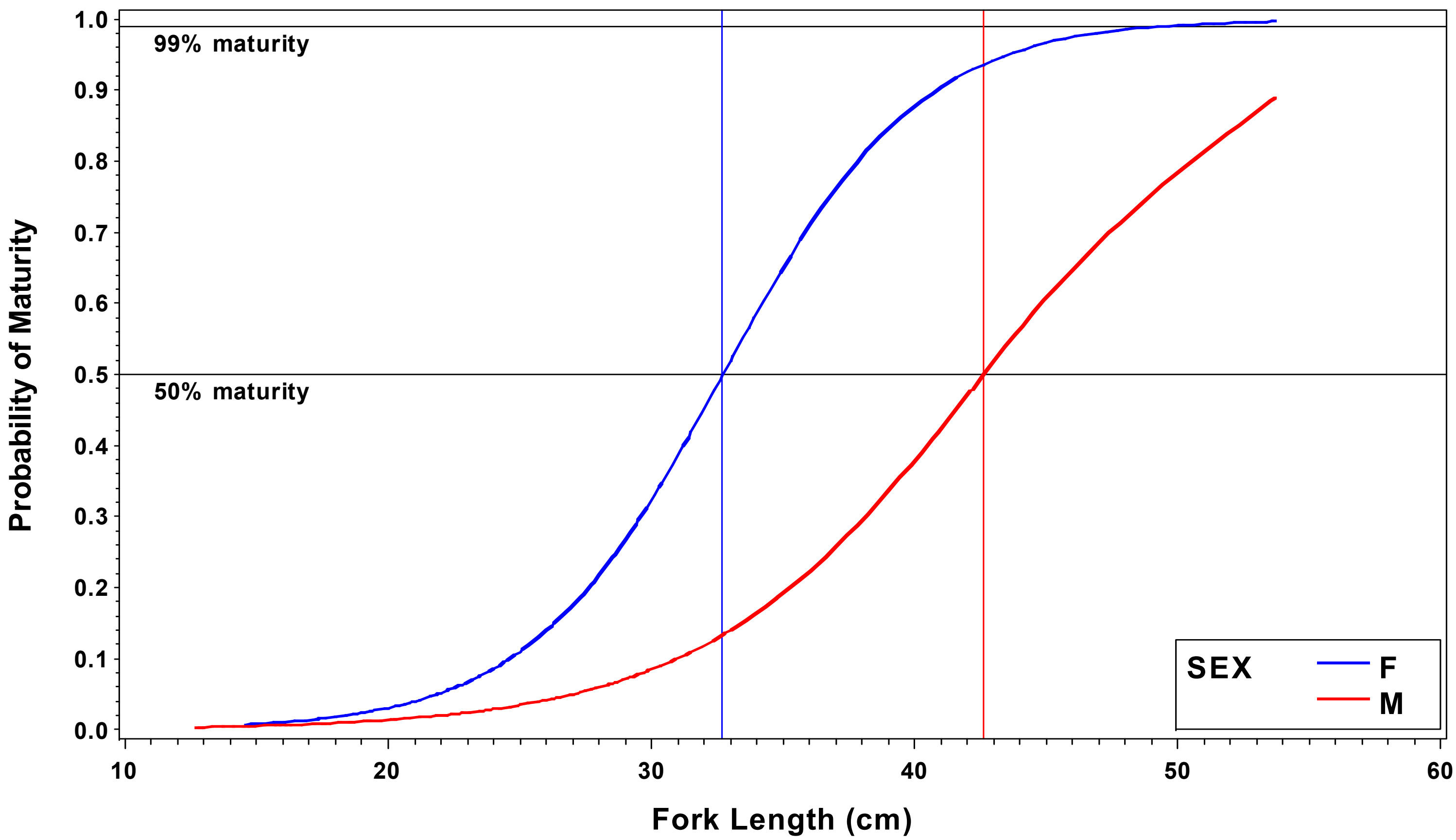


Figure 33. Bluefish diet in Chesapeake Bay, 2002-2007 combined.

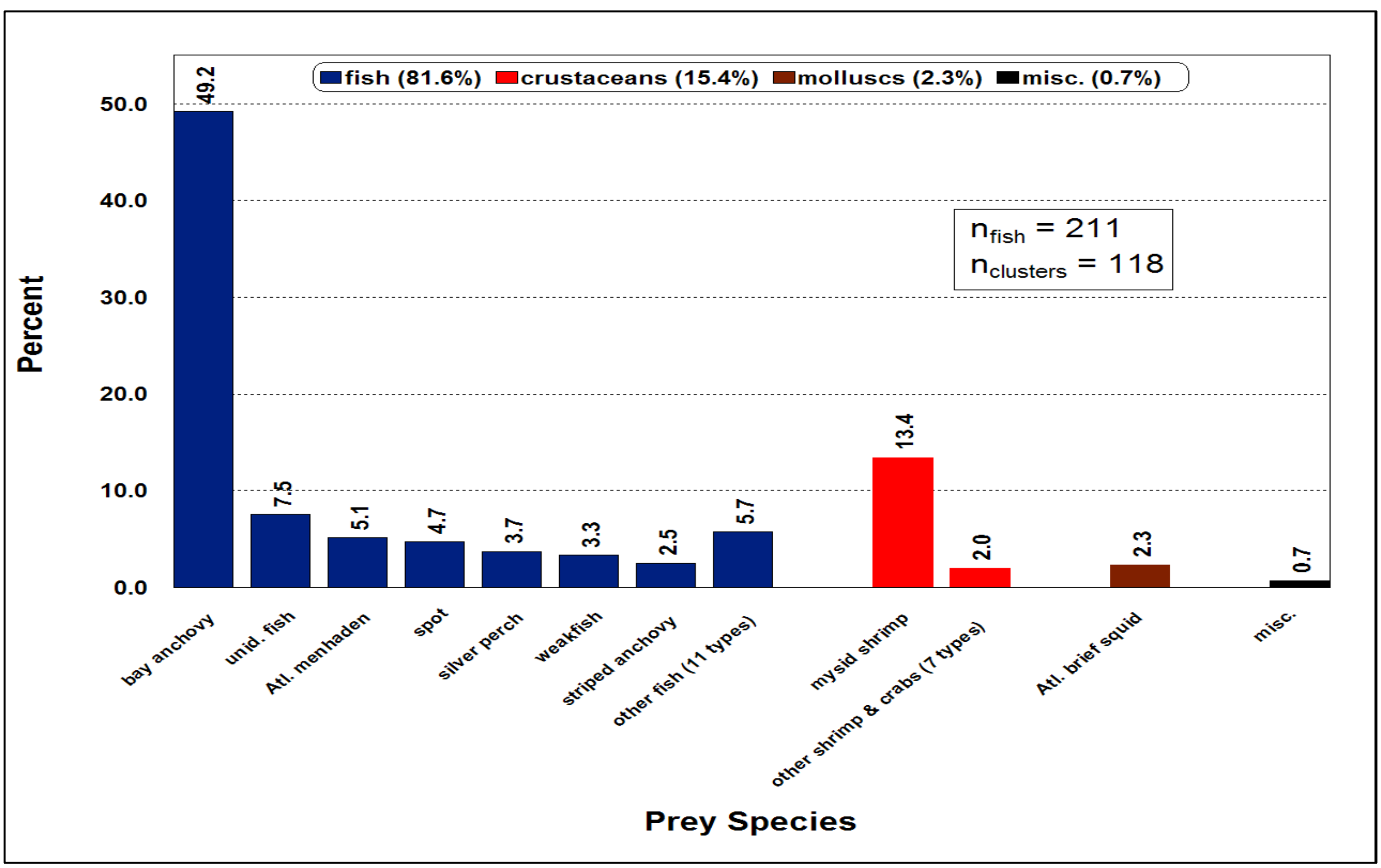
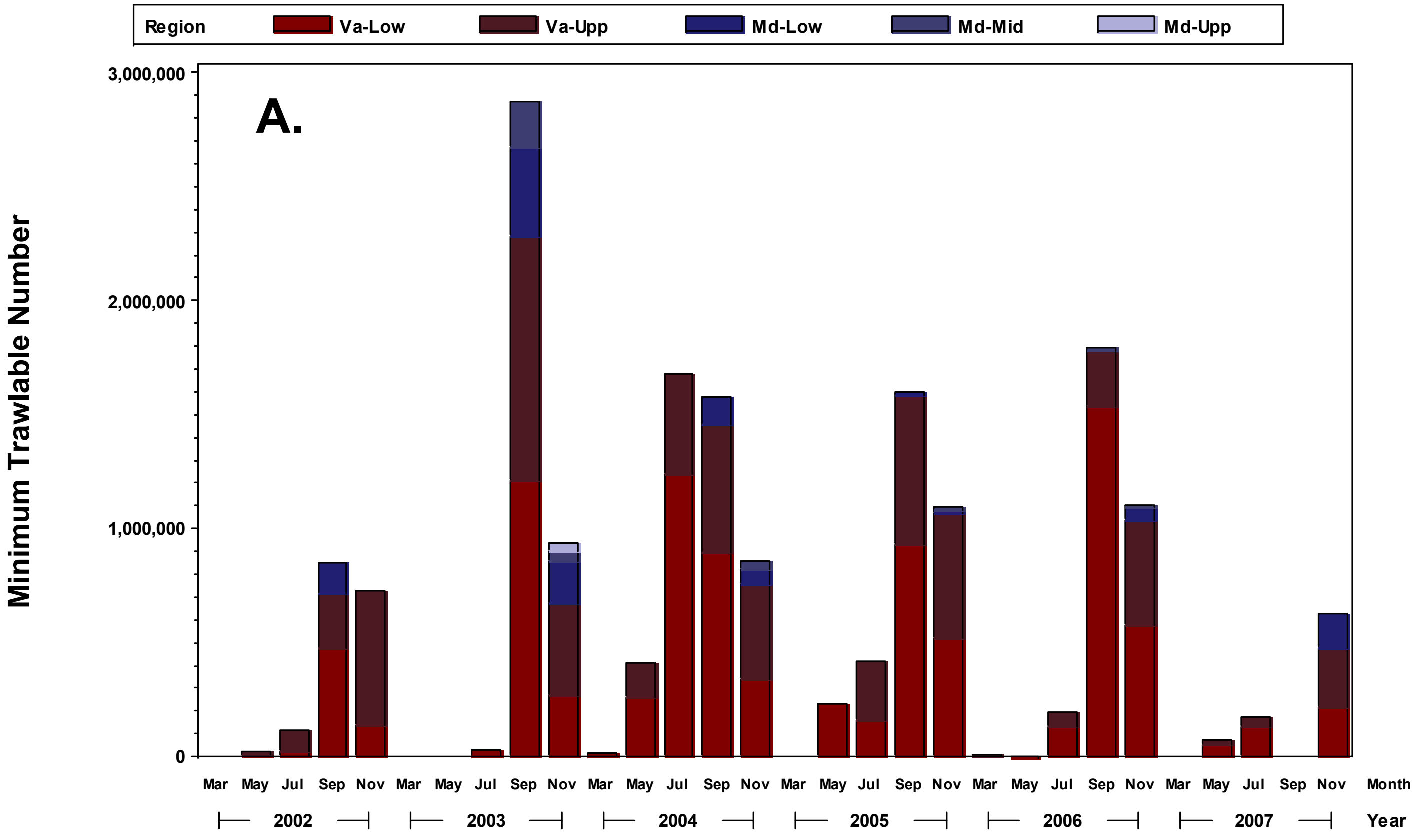


Figure 34. Butterfish minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.



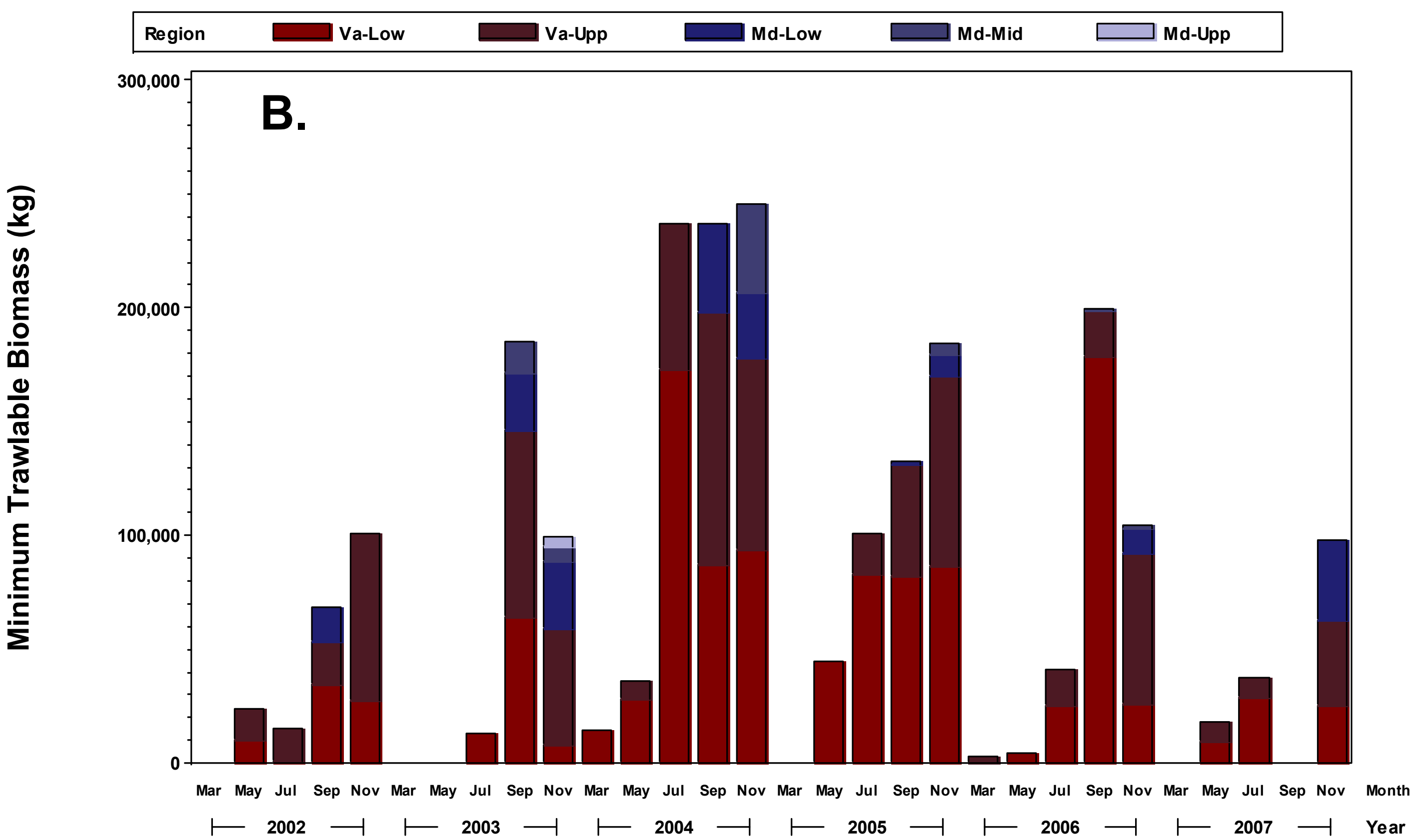


Figure 35. Abundance (number per hectare swept) of butterfish in Chesapeake Bay, 2002.

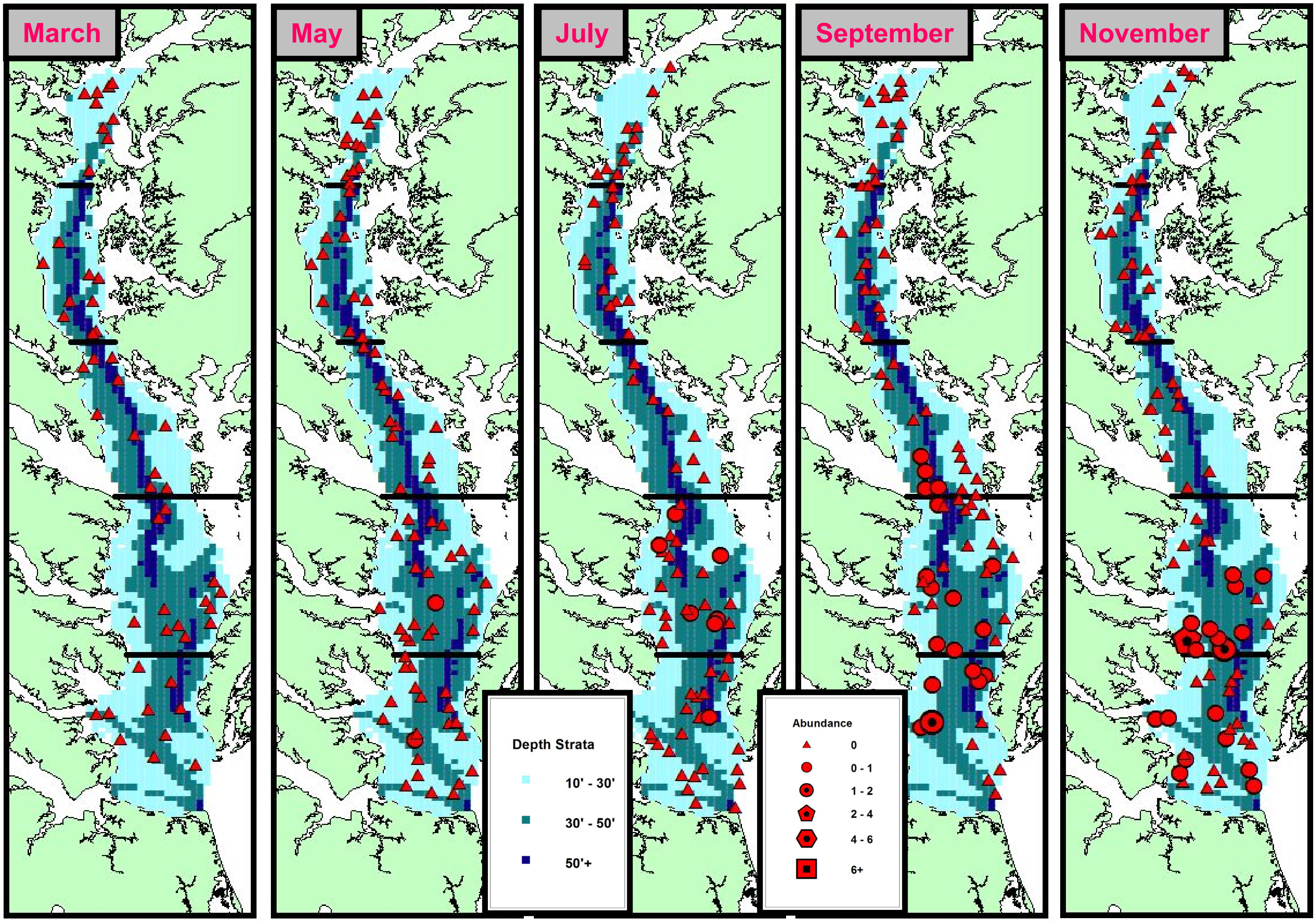


Figure 36. Abundance (number per hectare swept) of butterfish in Chesapeake Bay, 2003.

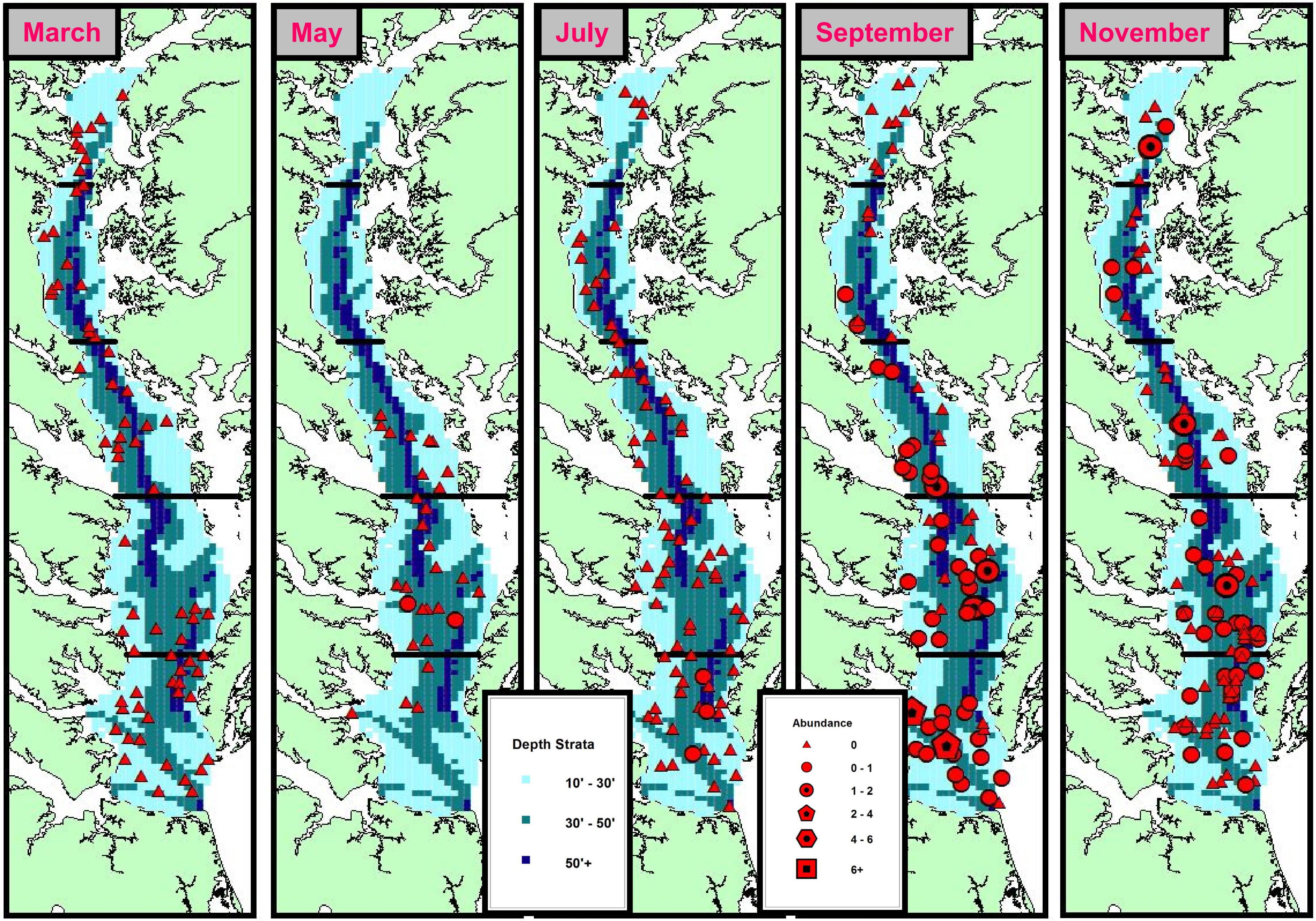


Figure 37. Abundance (number per hectare swept) of butterfish in Chesapeake Bay, 2004.

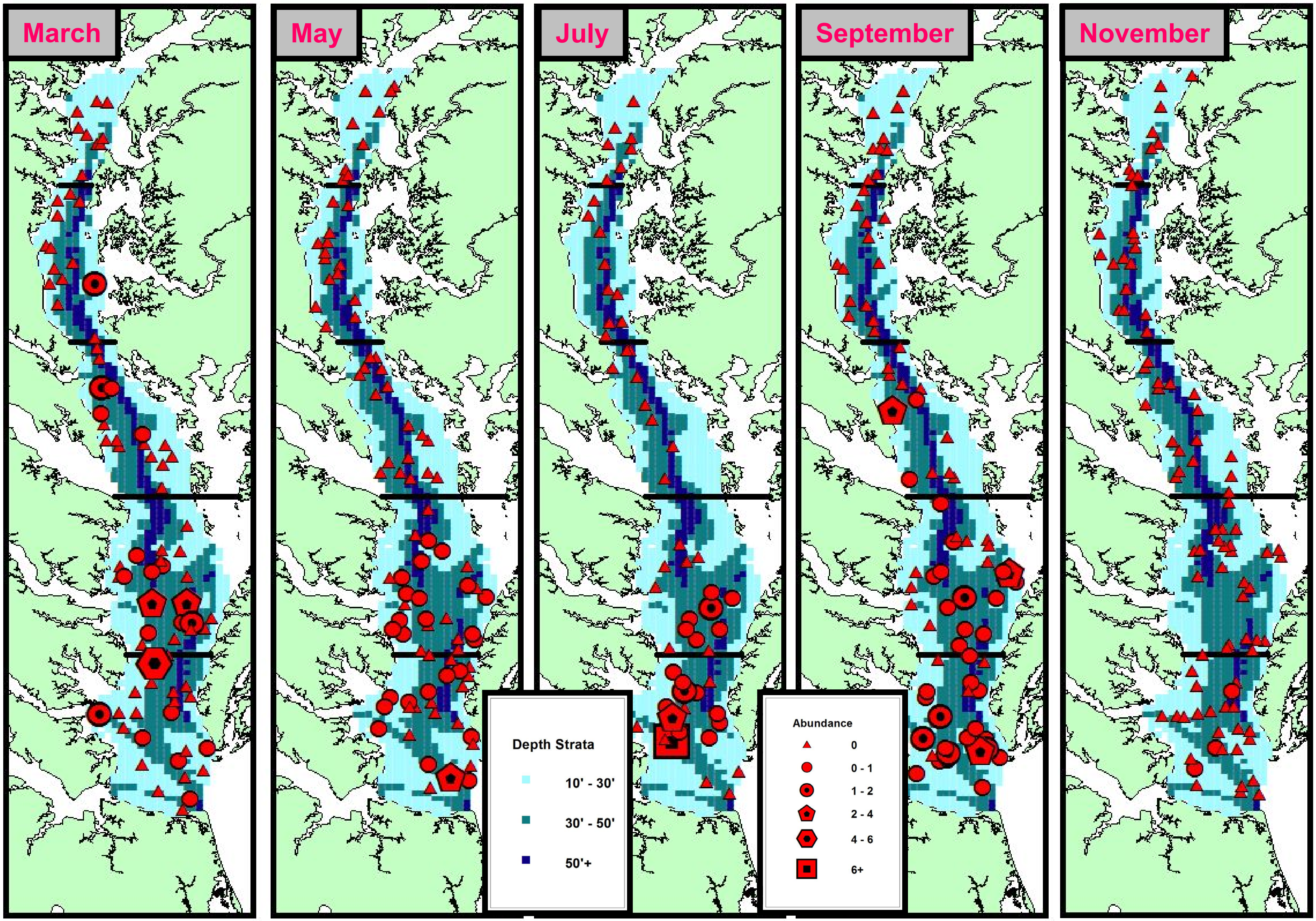


Figure 38. Abundance (number per hectare swept) of butterfish in Chesapeake Bay, 2005.

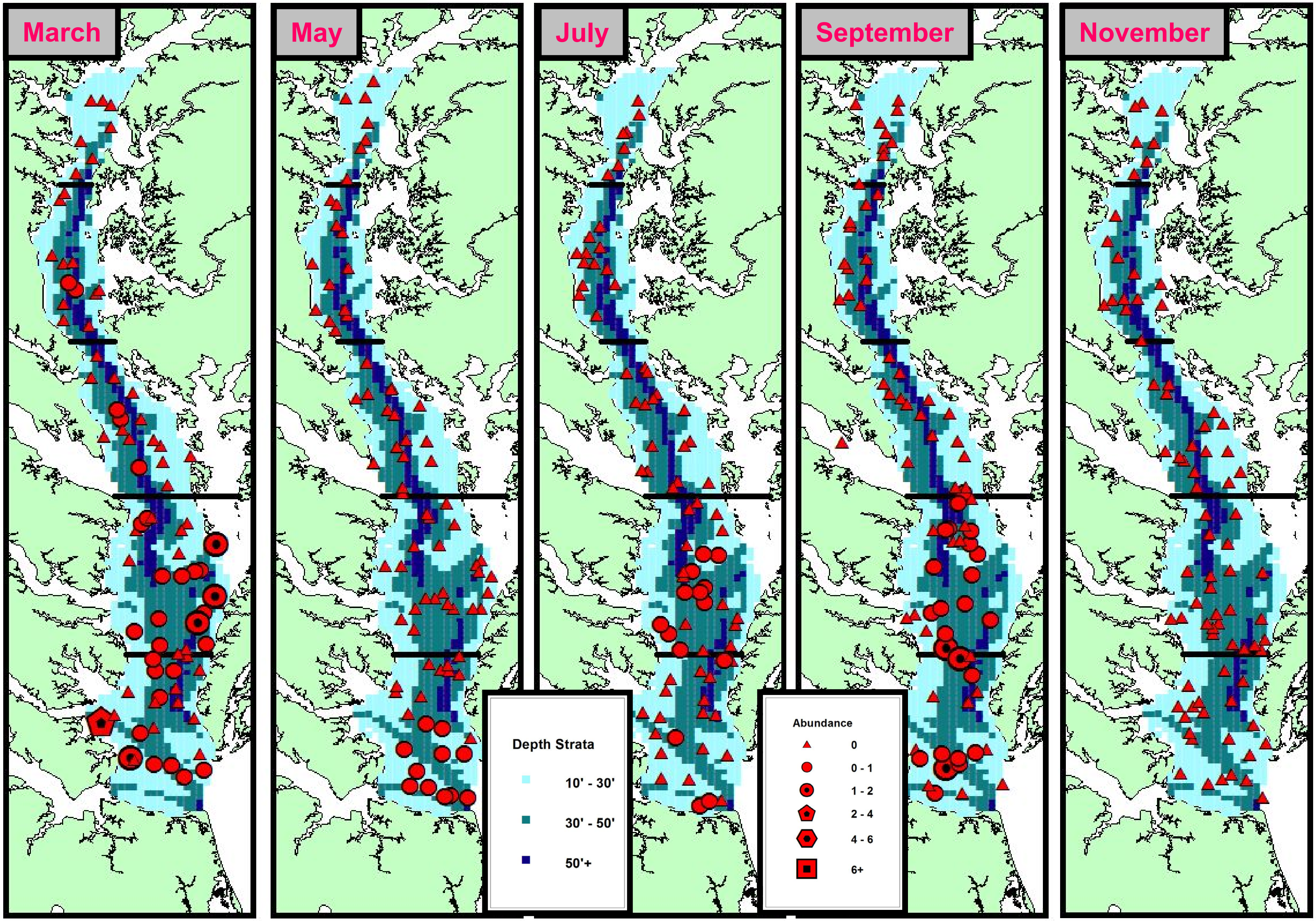


Figure 39. Abundance (number per hectare swept) of butterfish in Chesapeake Bay, 2006.

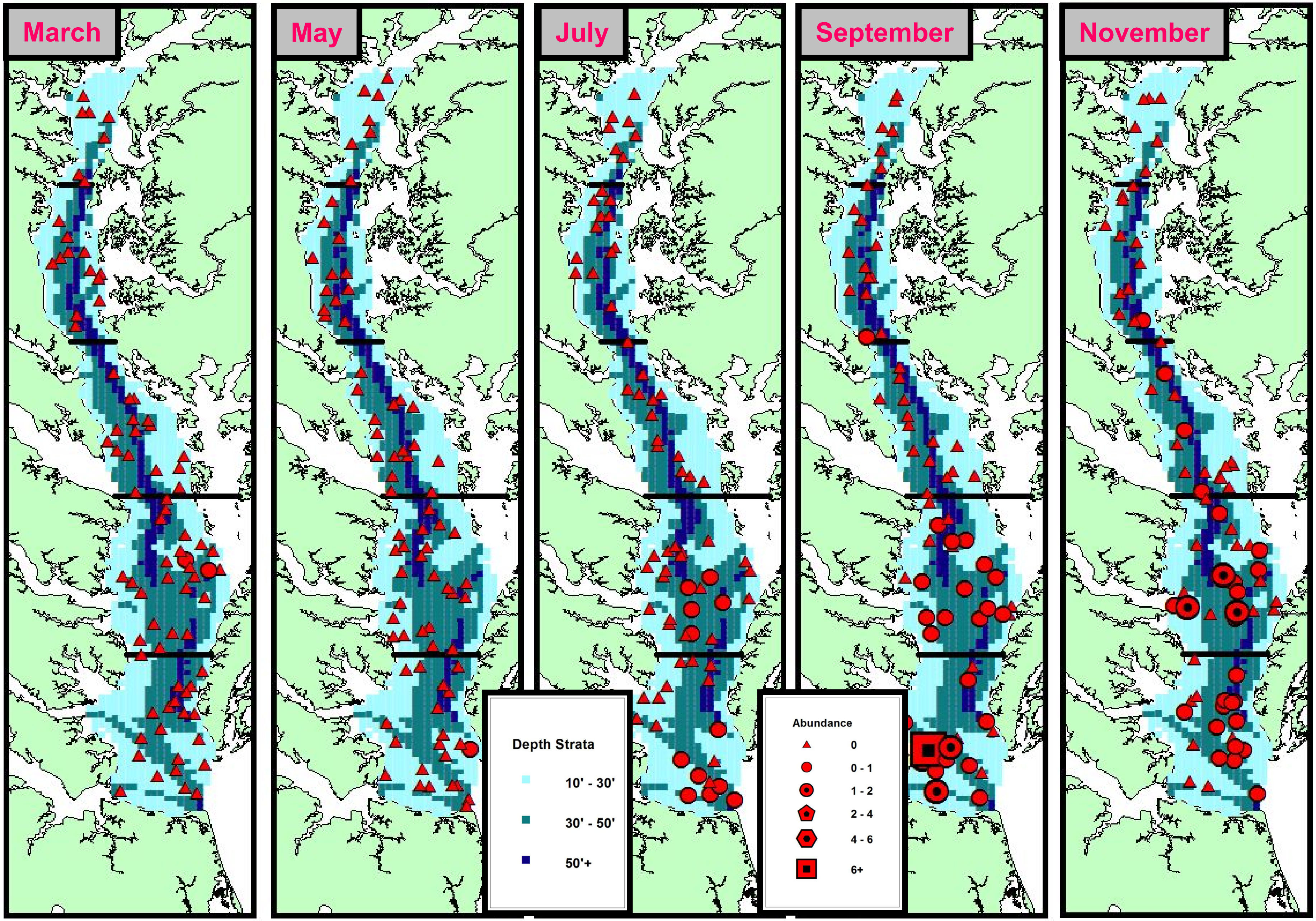


Figure 40. Abundance (number per hectare swept) of butterfish in Chesapeake Bay, 2007.

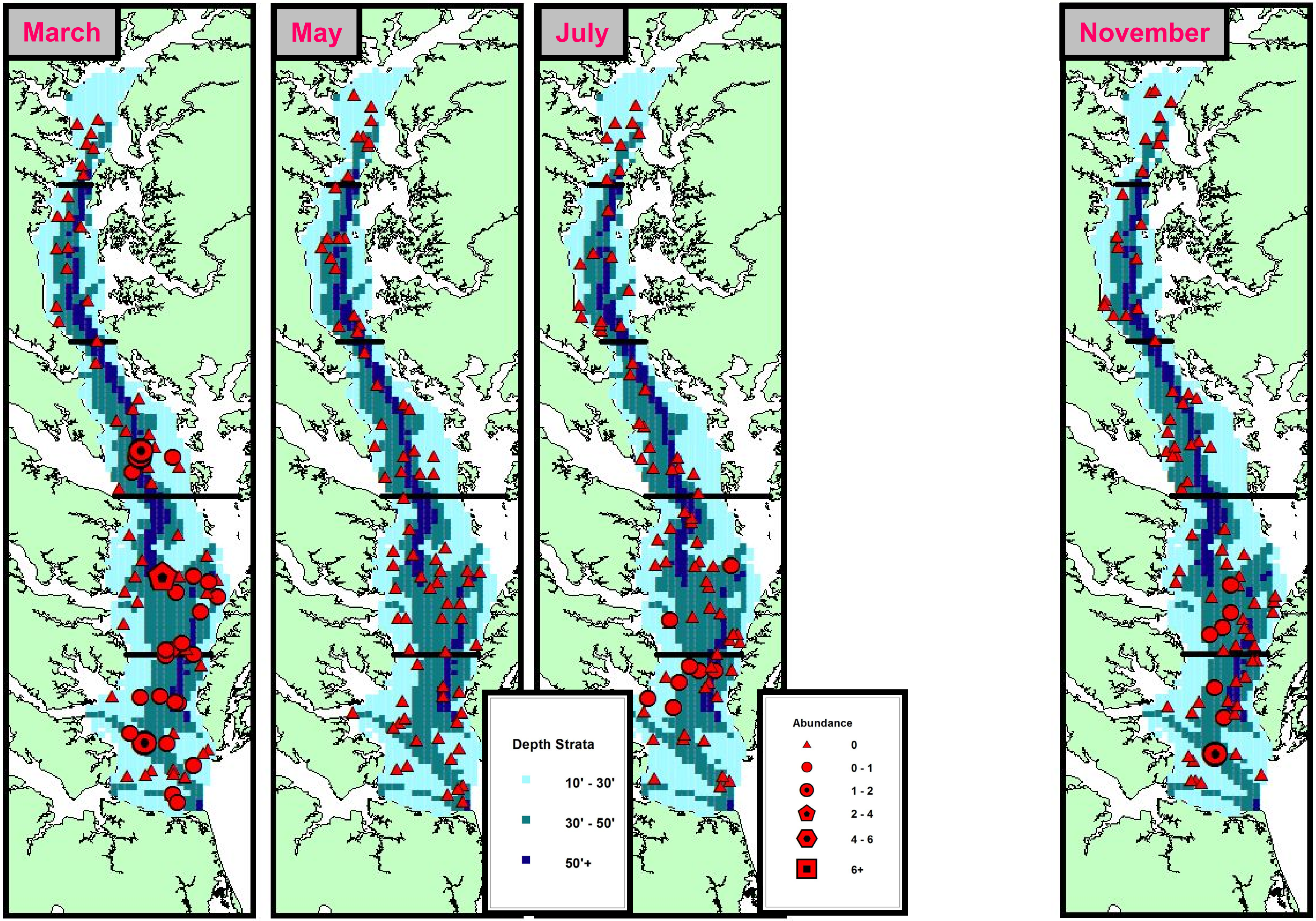


Figure 41. Butterfish length-frequency in Chesapeake Bay, 2002-2007.

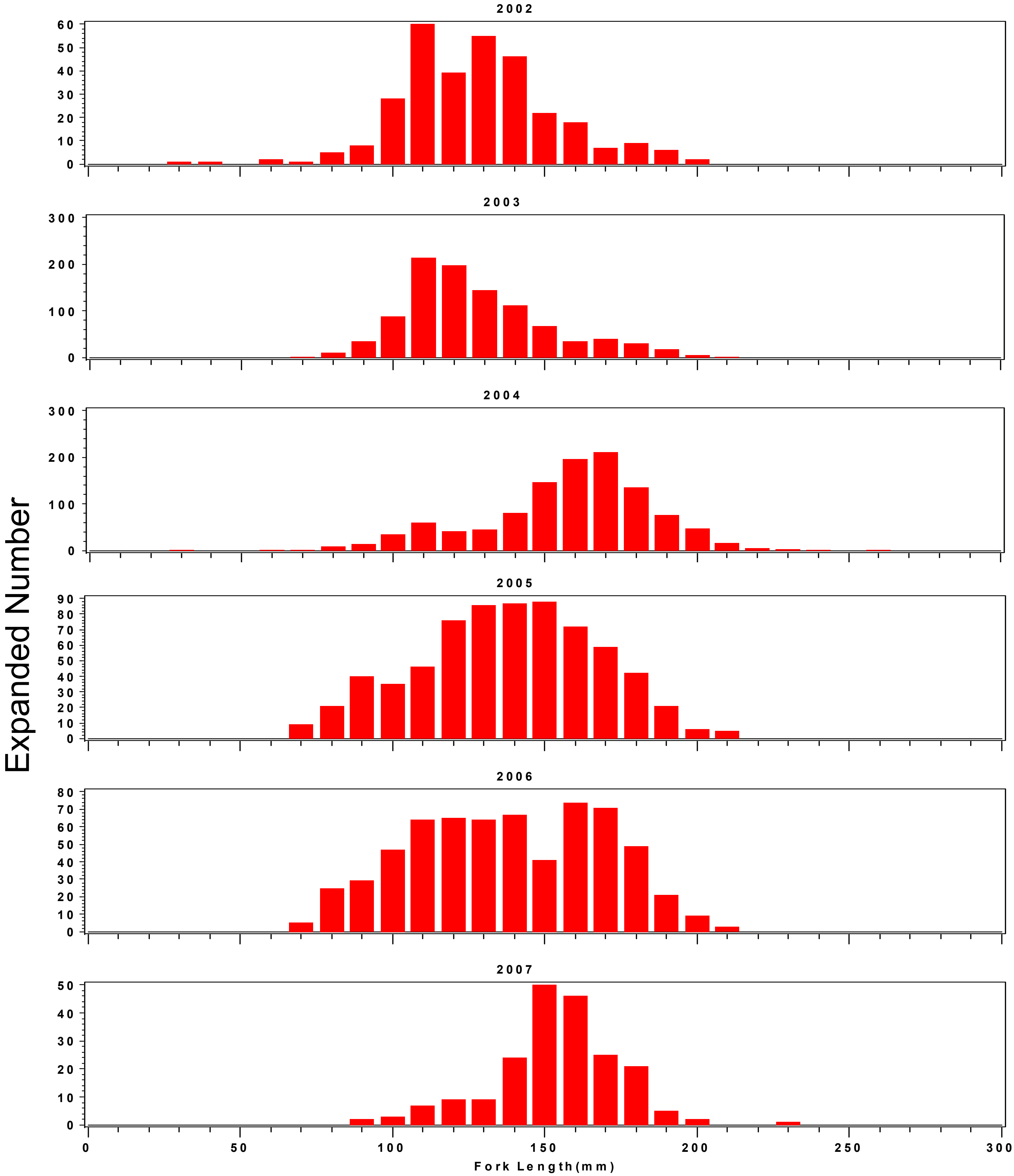


Figure 42. Butterfish length-weight relationship in Chesapeake Bay, 2002-2007, .

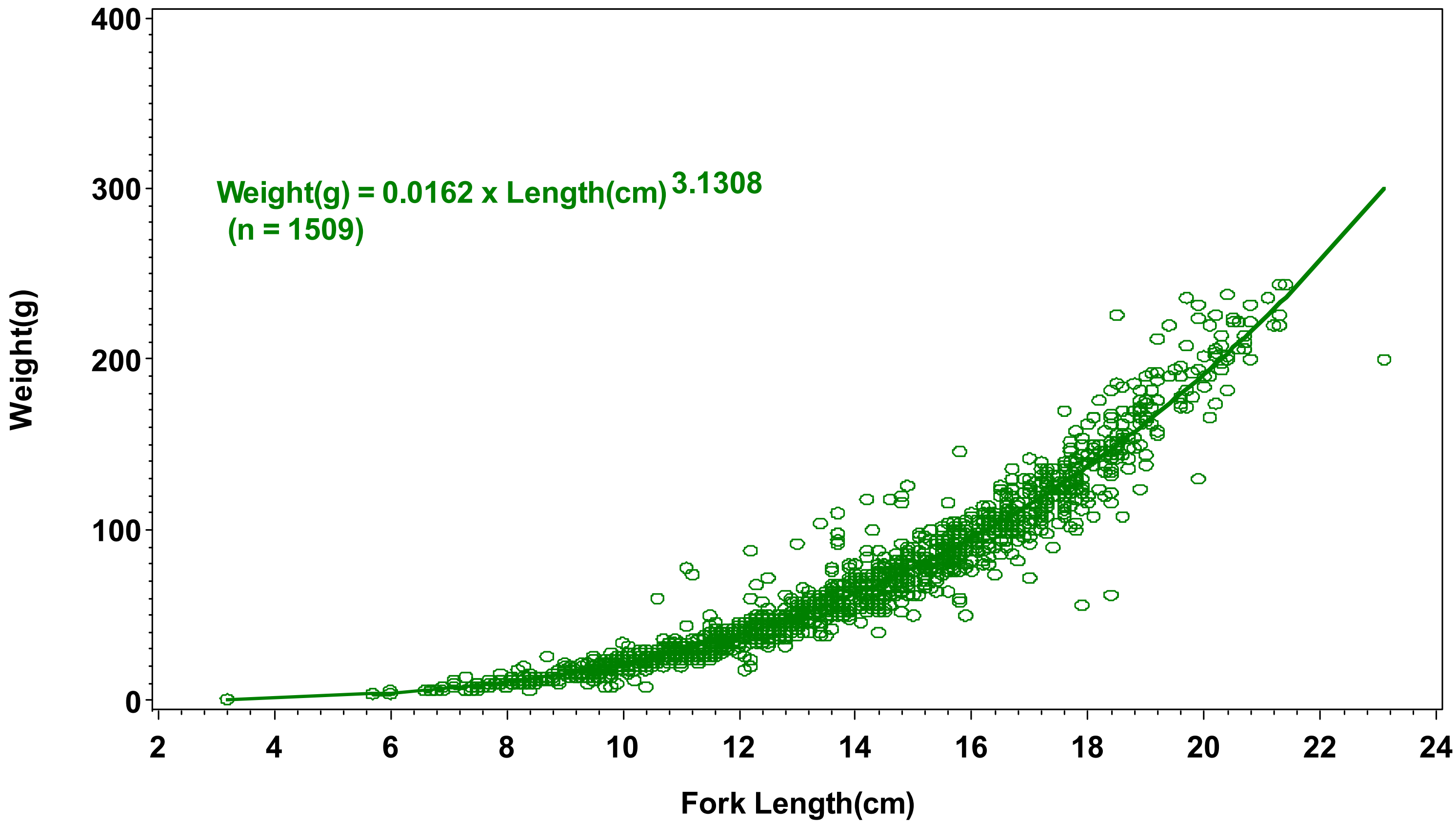


Figure 43. Butterfish diet in Chesapeake Bay, 2002-2003 combined (Note: diets for this species no longer analyzed).

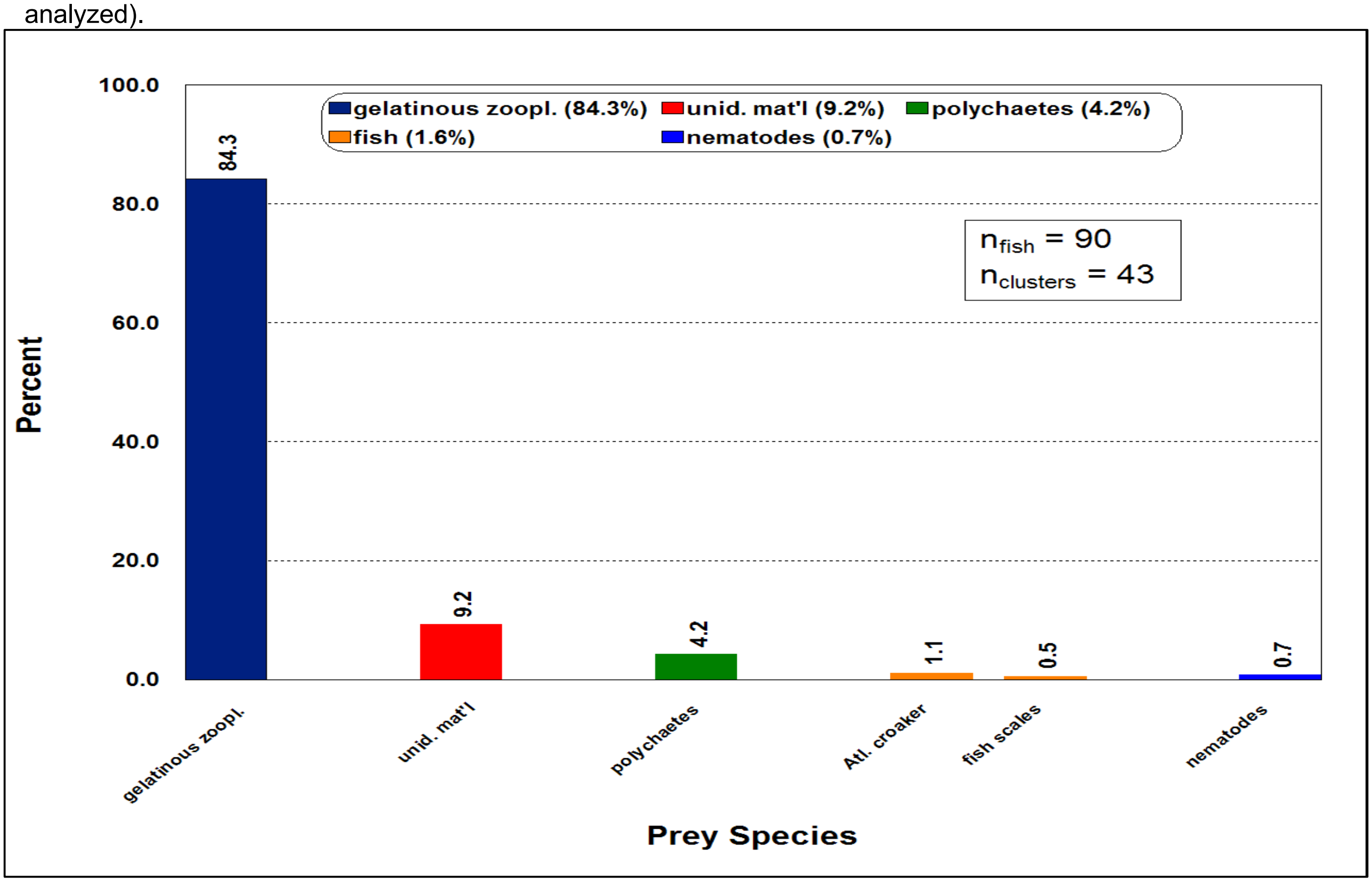
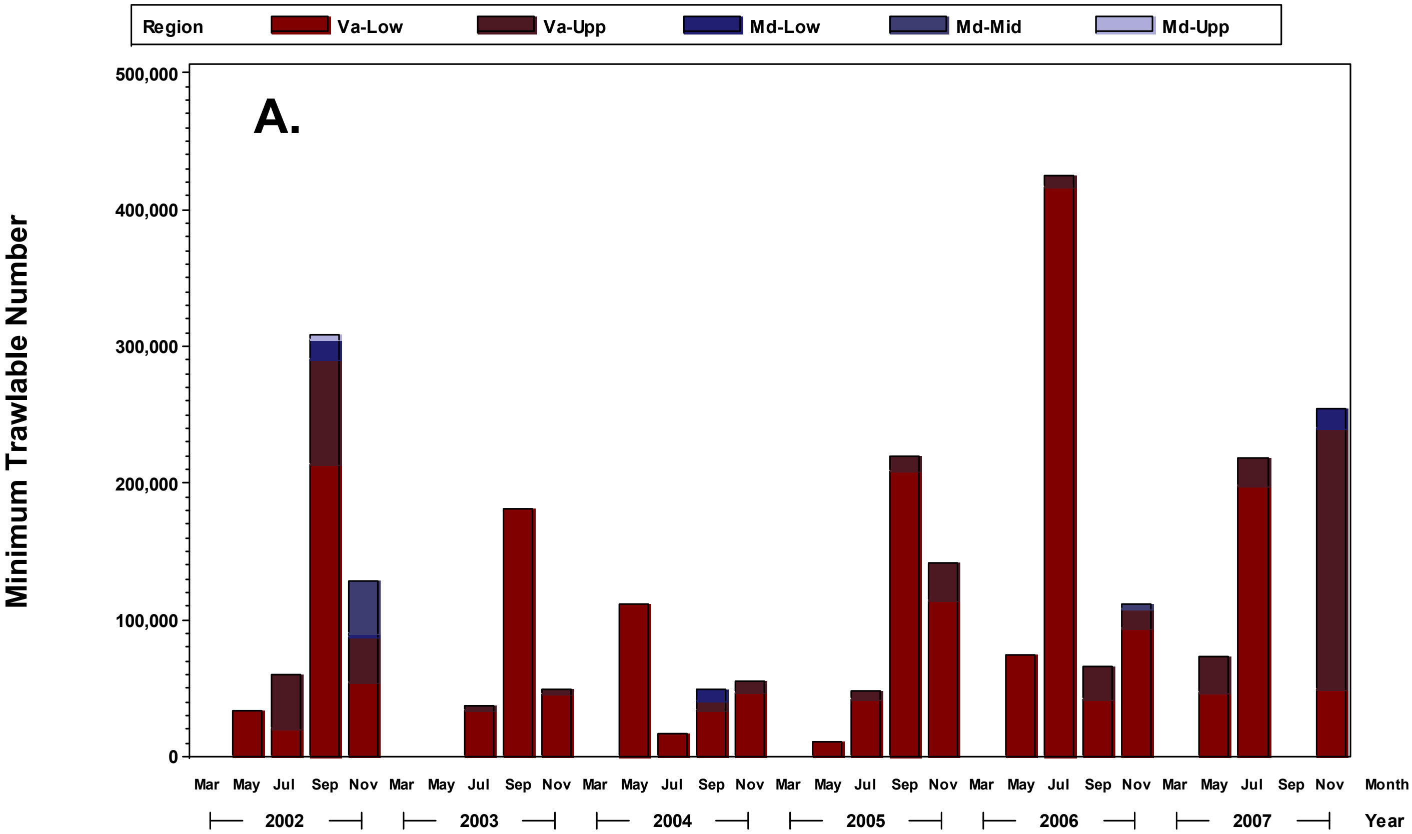


Figure 44. Northern kingfish minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.



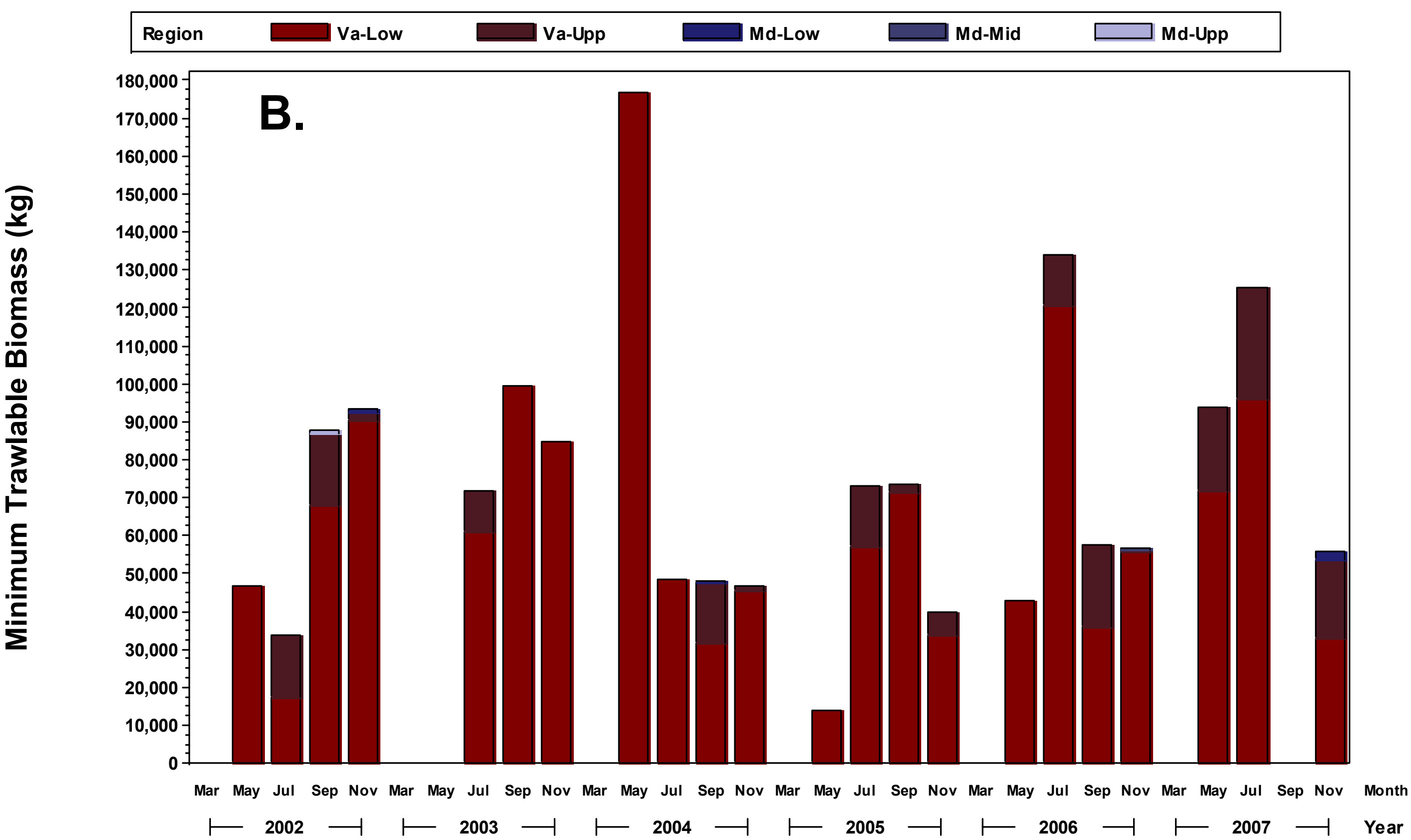


Figure 45. Abundance (number per hectare swept) of northern kingfish in Chesapeake Bay, 2002.

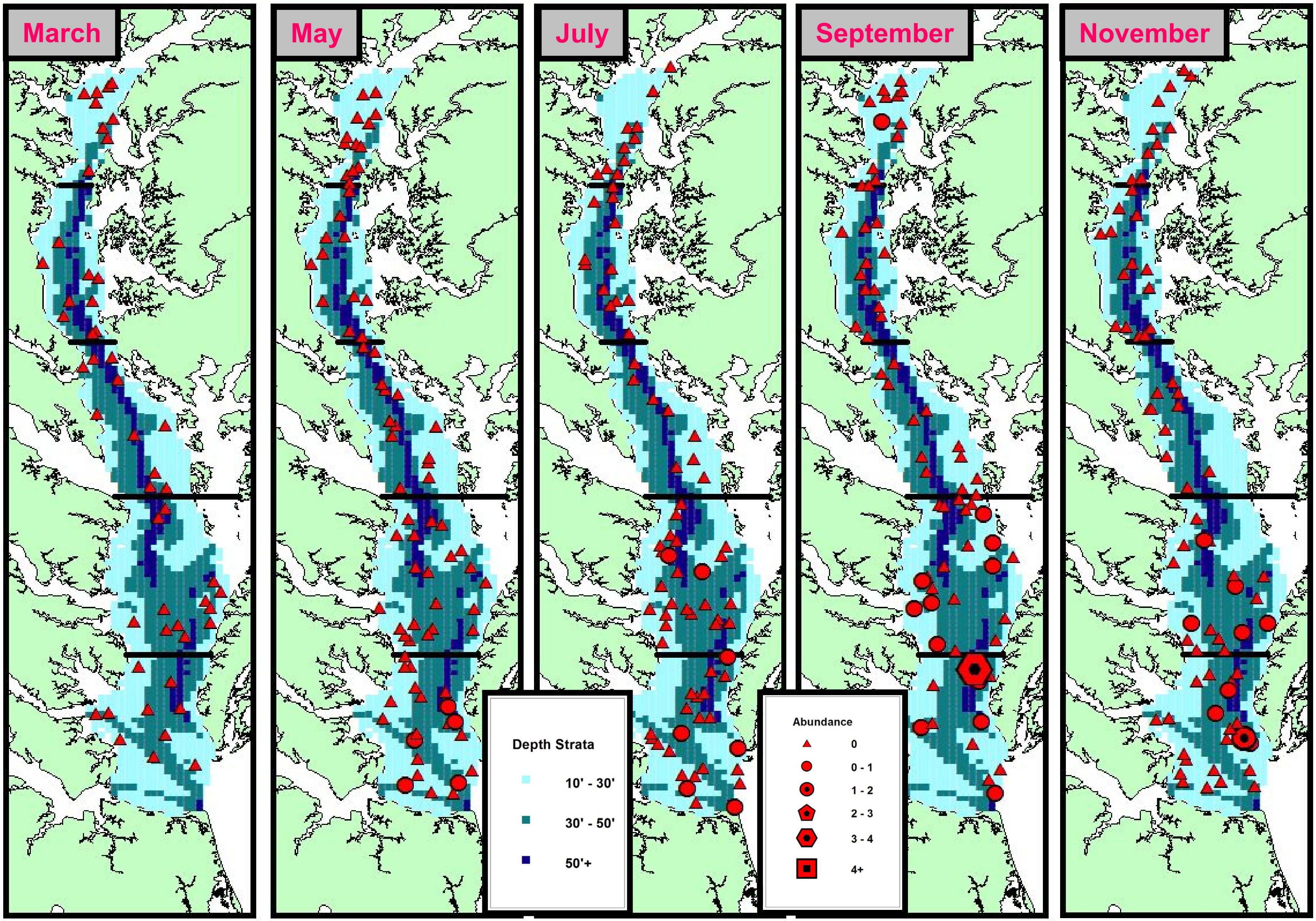


Figure 46. Abundance (number per hectare swept) of northern kingfish in Chesapeake Bay, 2003.

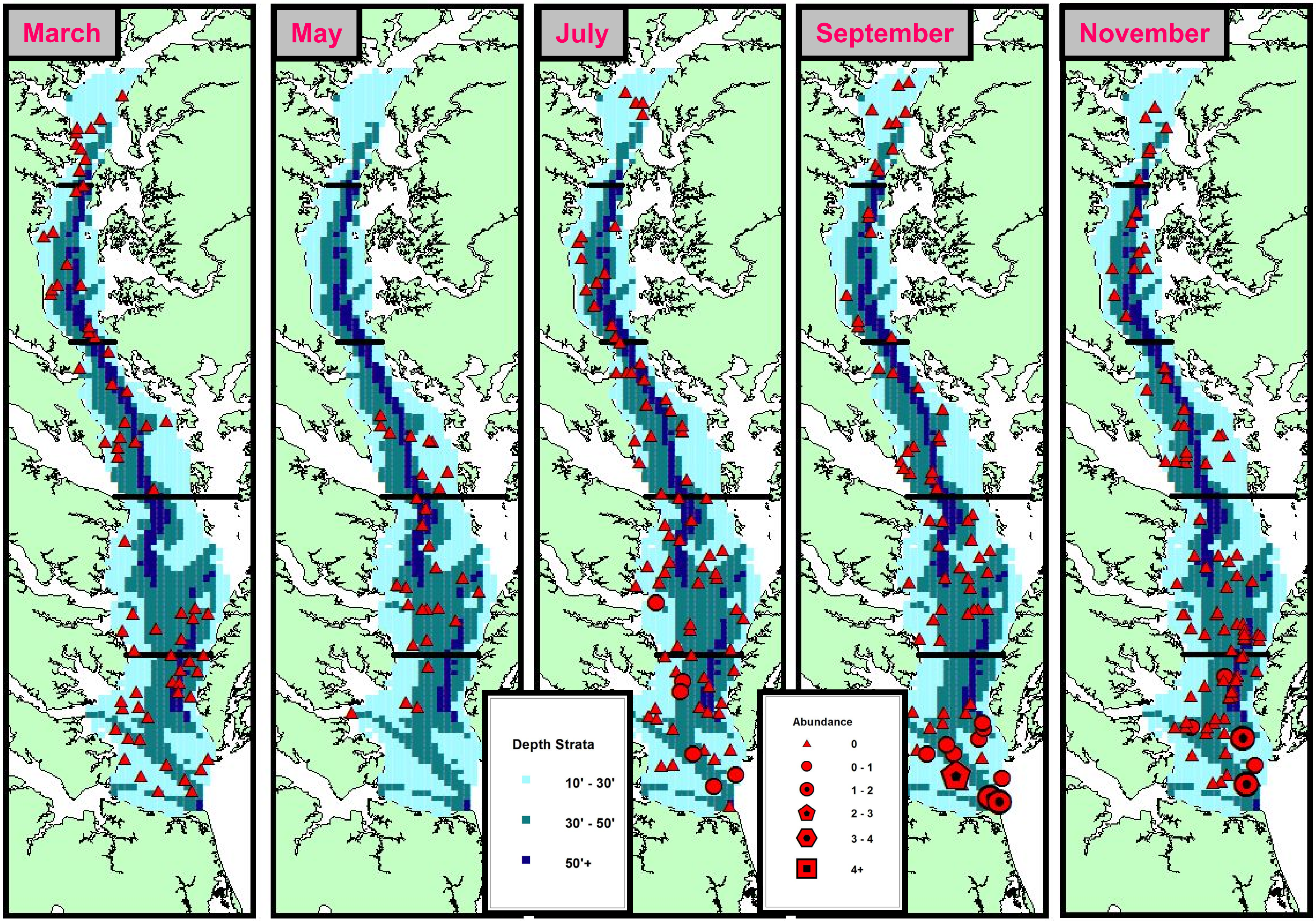


Figure 47. Abundance (number per hectare swept) of northern kingfish in Chesapeake Bay, 2004.

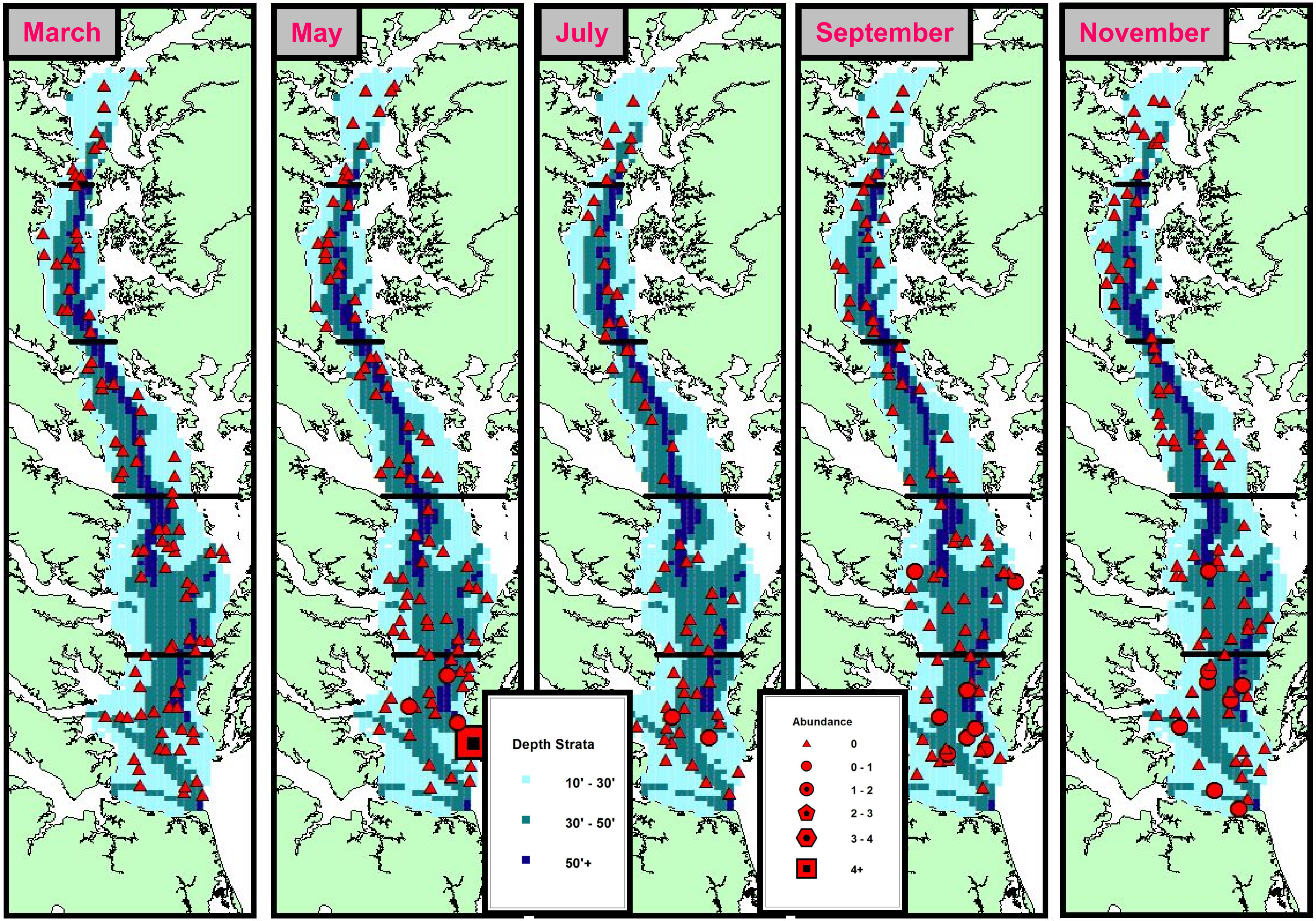


Figure 48. Abundance (number per hectare swept) of northern kingfish in Chesapeake Bay, 2005.

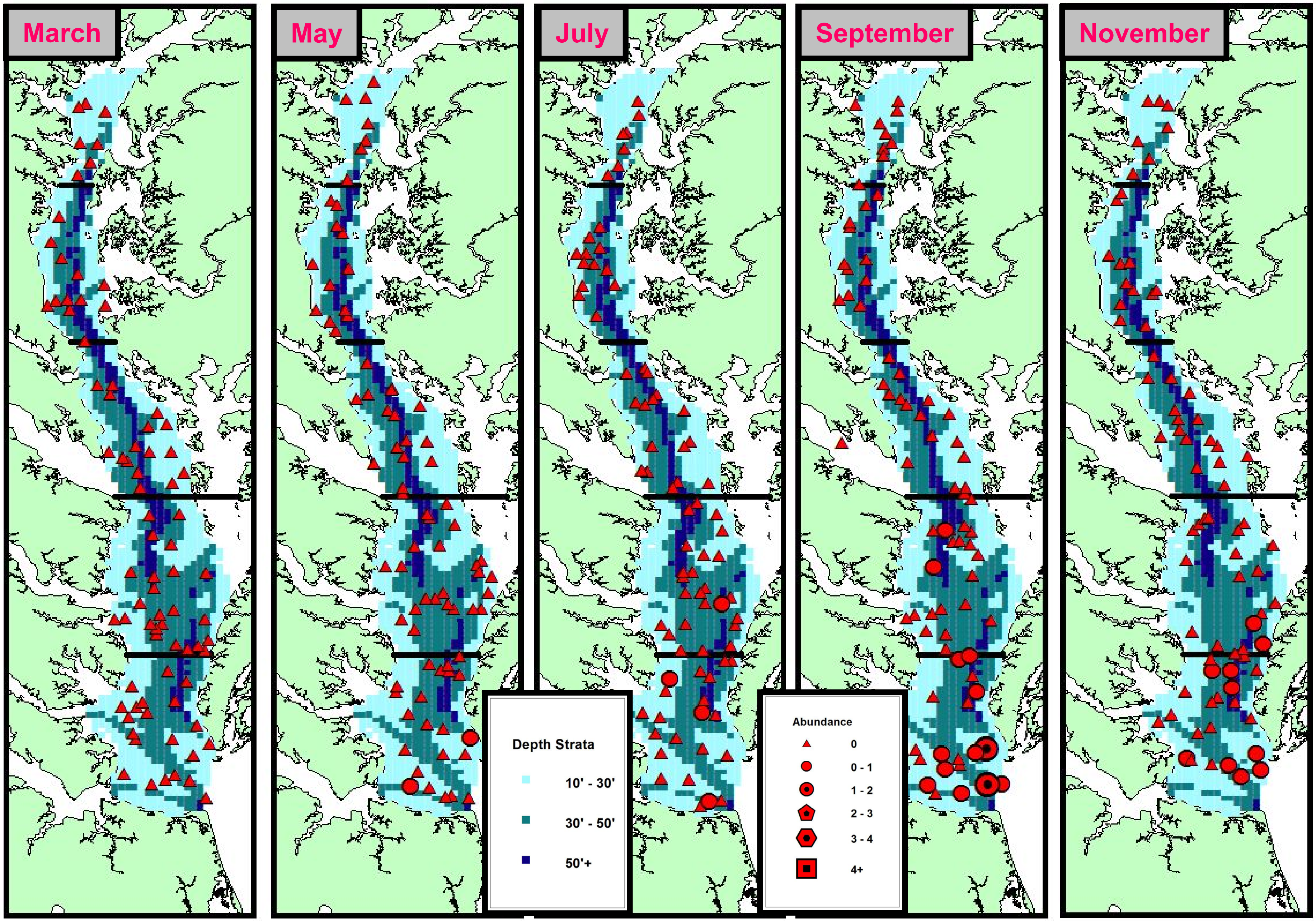


Figure 49. Abundance (number per hectare swept) of northern kingfish in Chesapeake Bay, 2006.

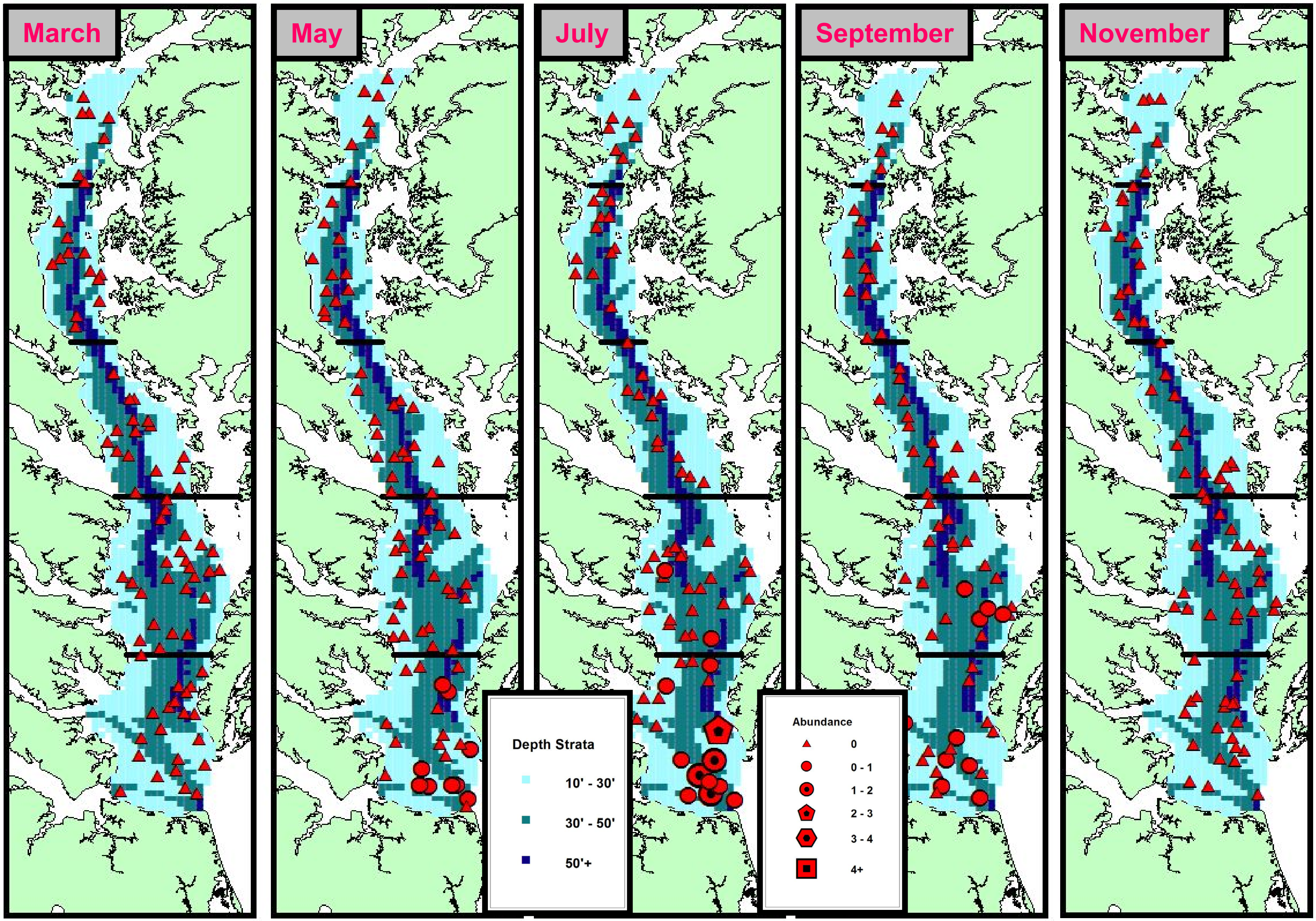


Figure 50. Abundance (number per hectare swept) of northern kingfish in Chesapeake Bay, 2007.

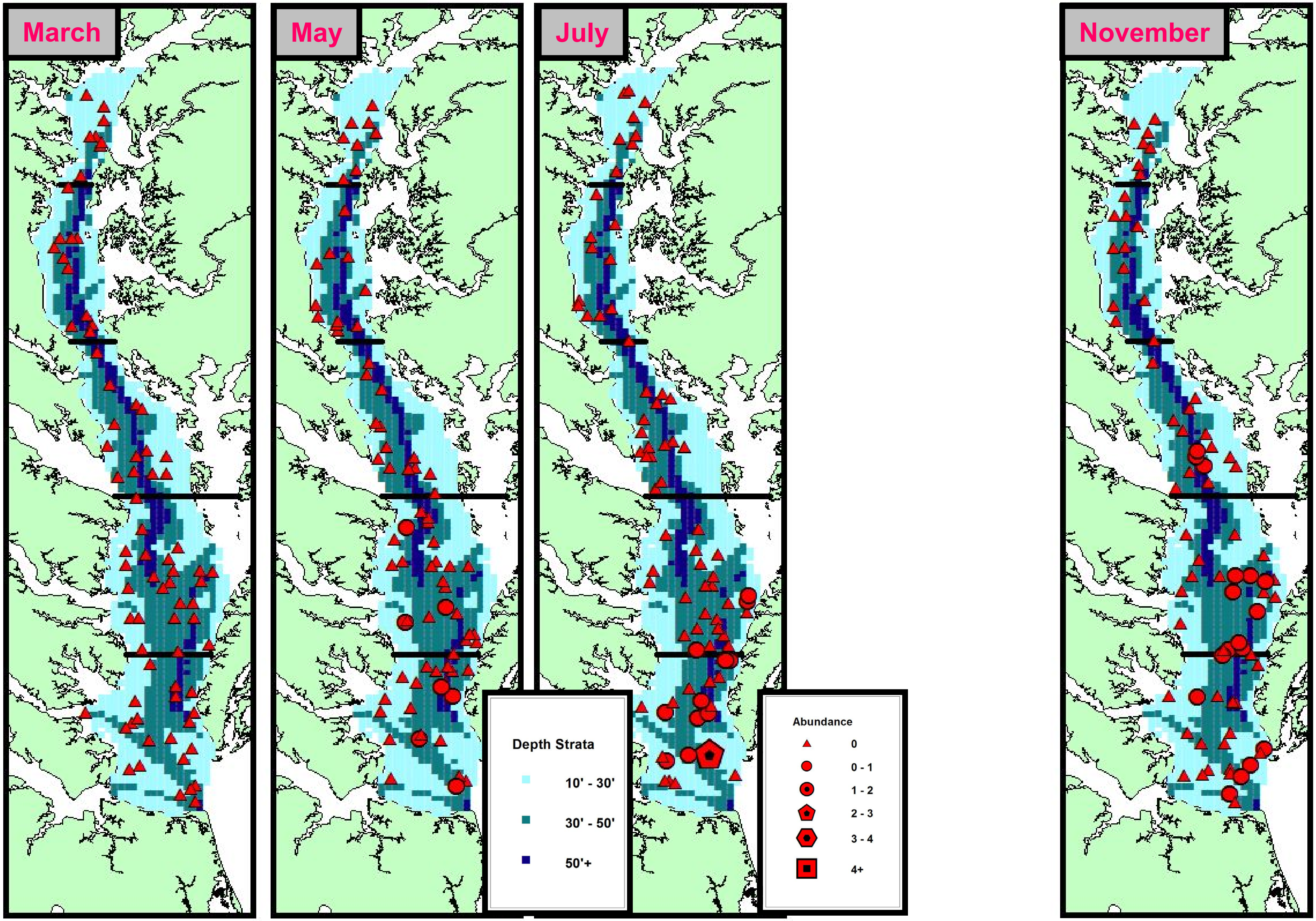


Figure 51. Northern kingfish length-frequency in Chesapeake Bay, 2002-2007.

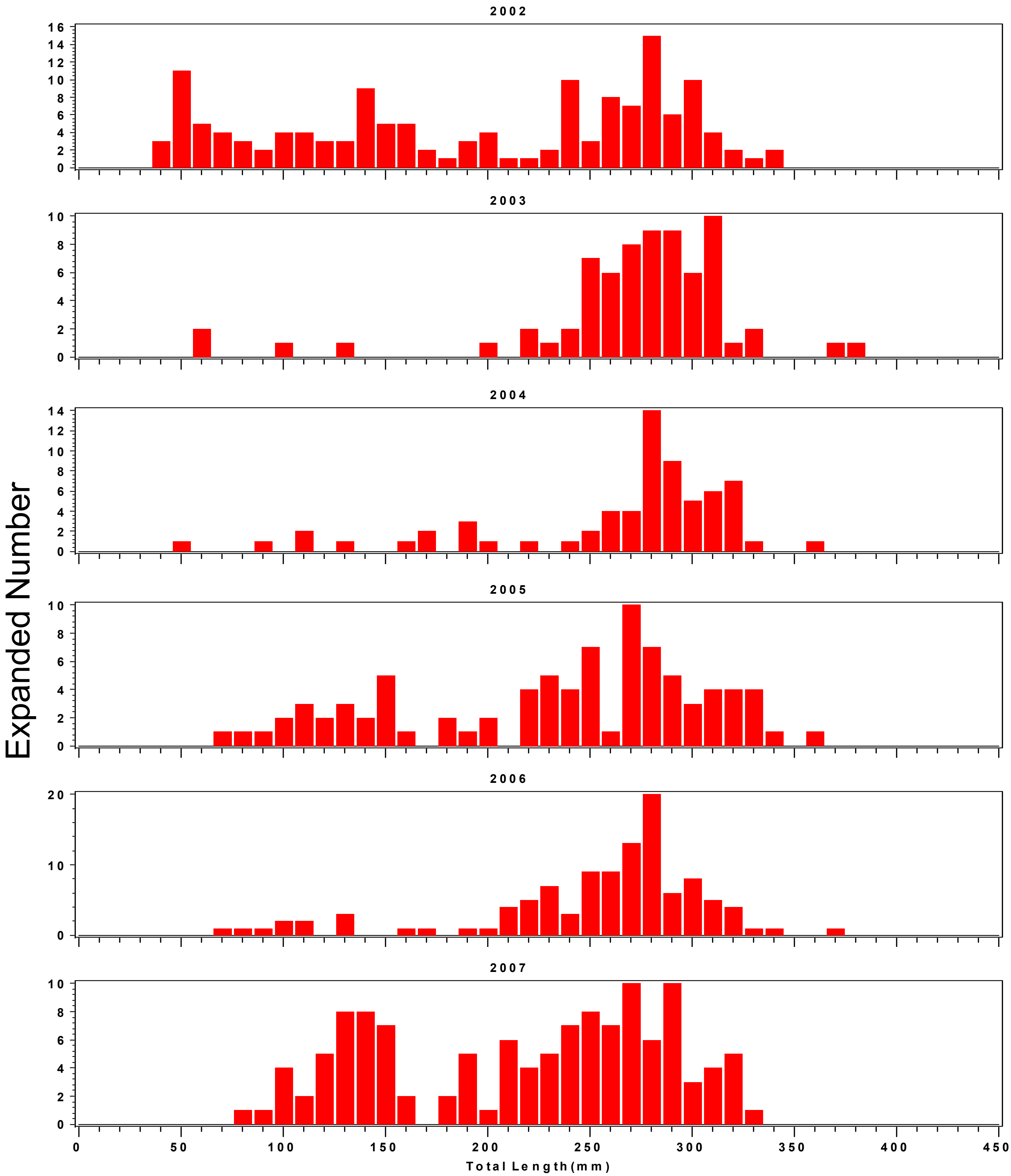


Figure 52. Northern kingfish age-structure in Chesapeake Bay, 2002-2006.

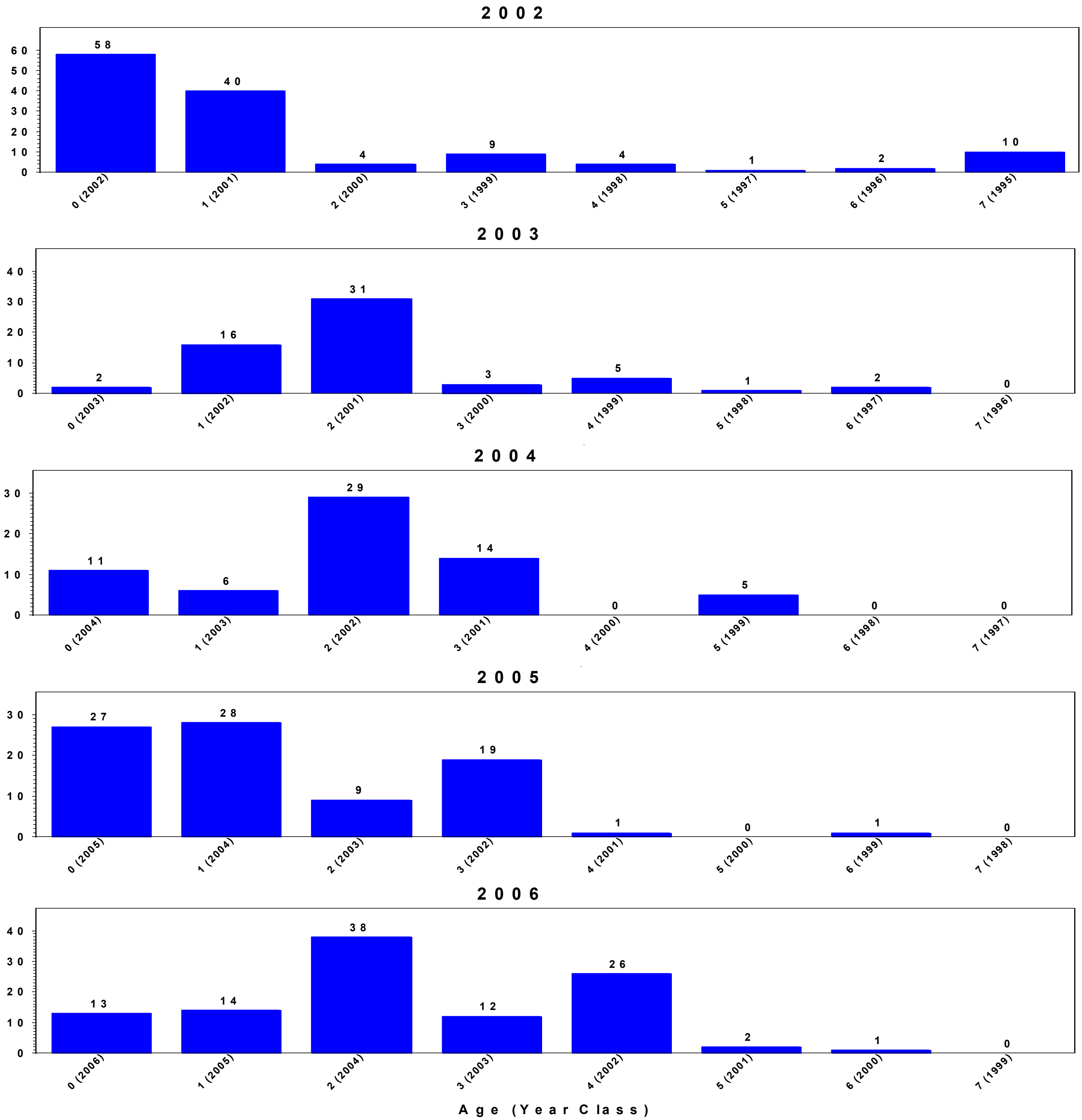
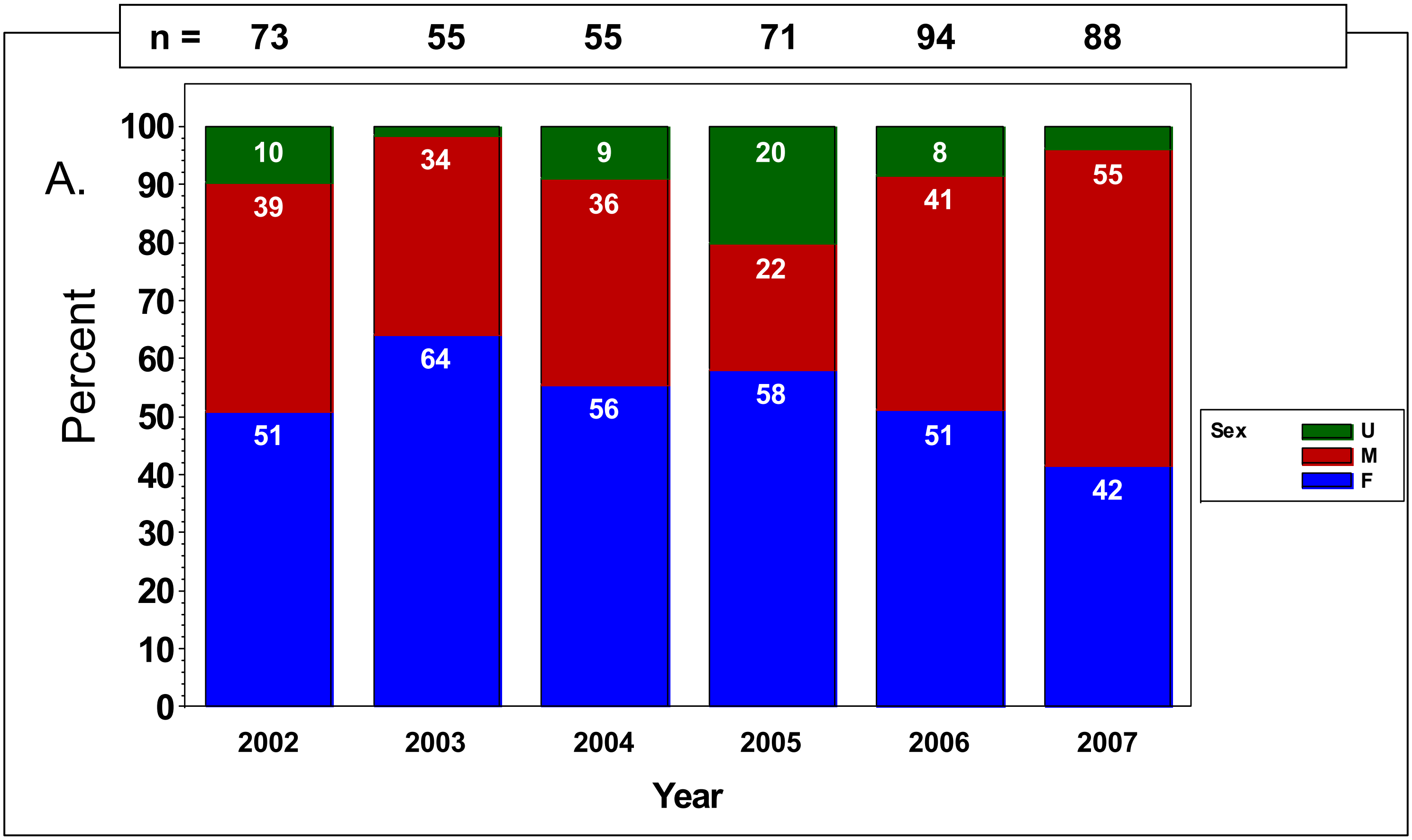


Figure 53. Northern kingfish sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B).



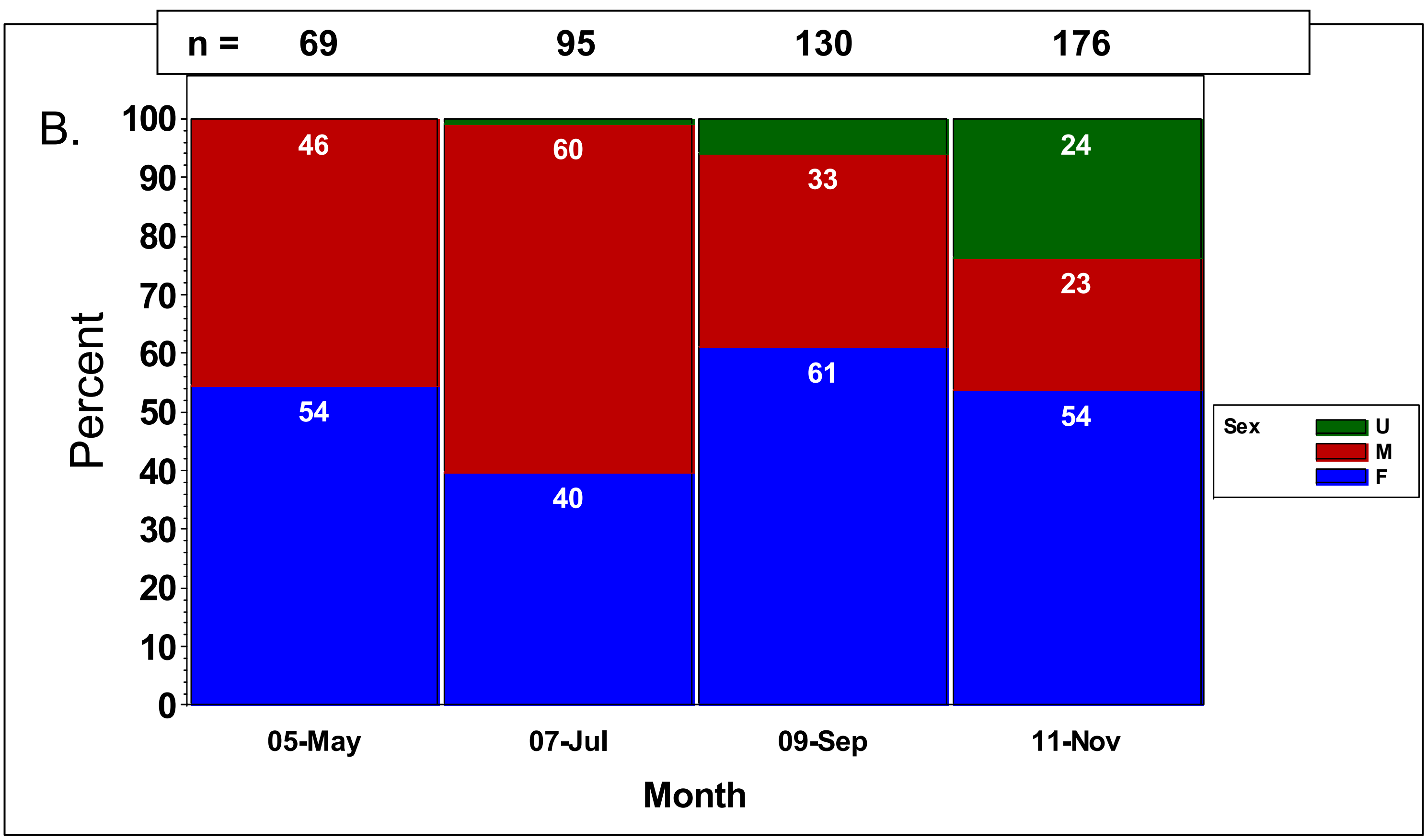
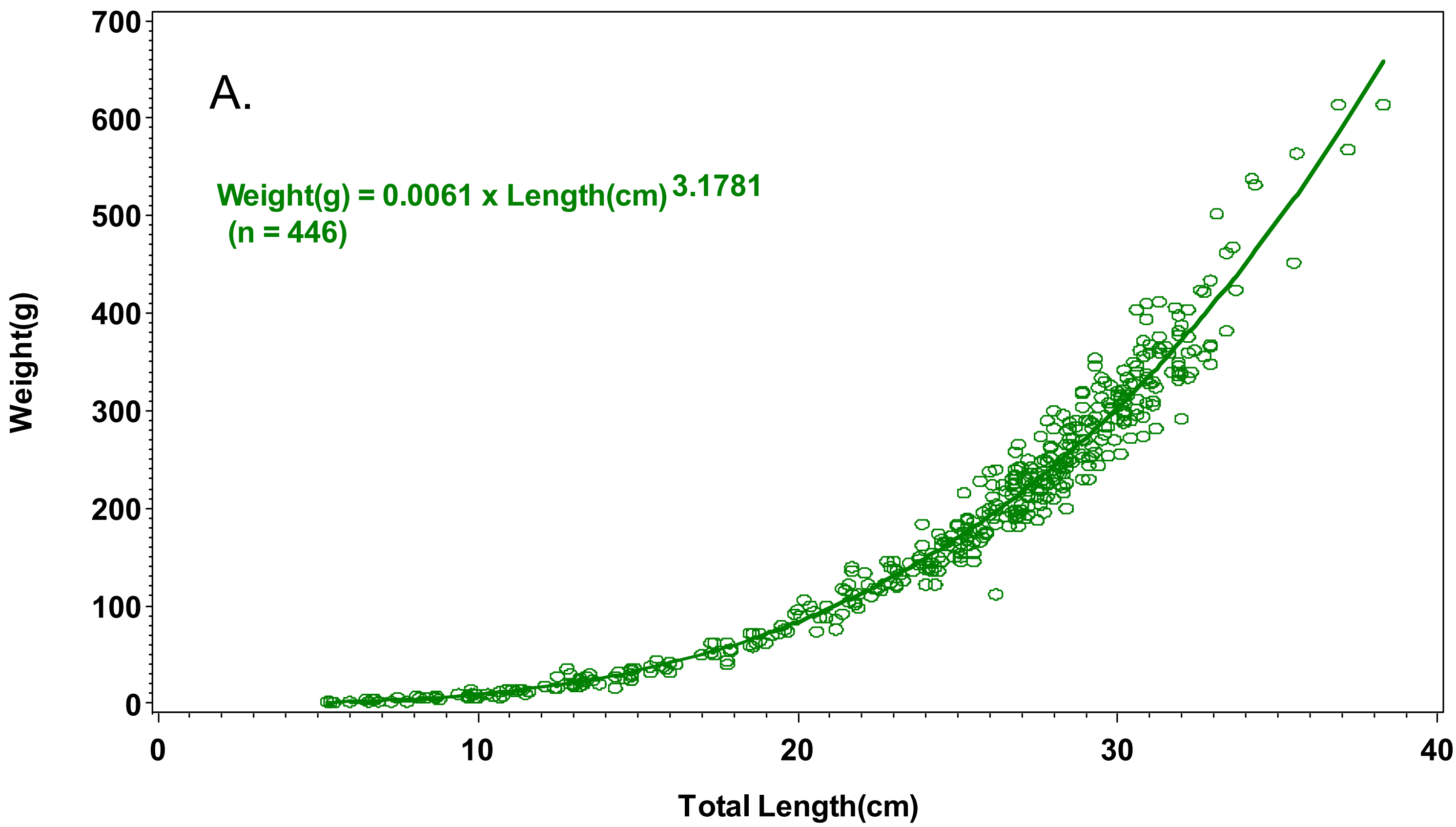


Figure 54. Northern kingfish length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).



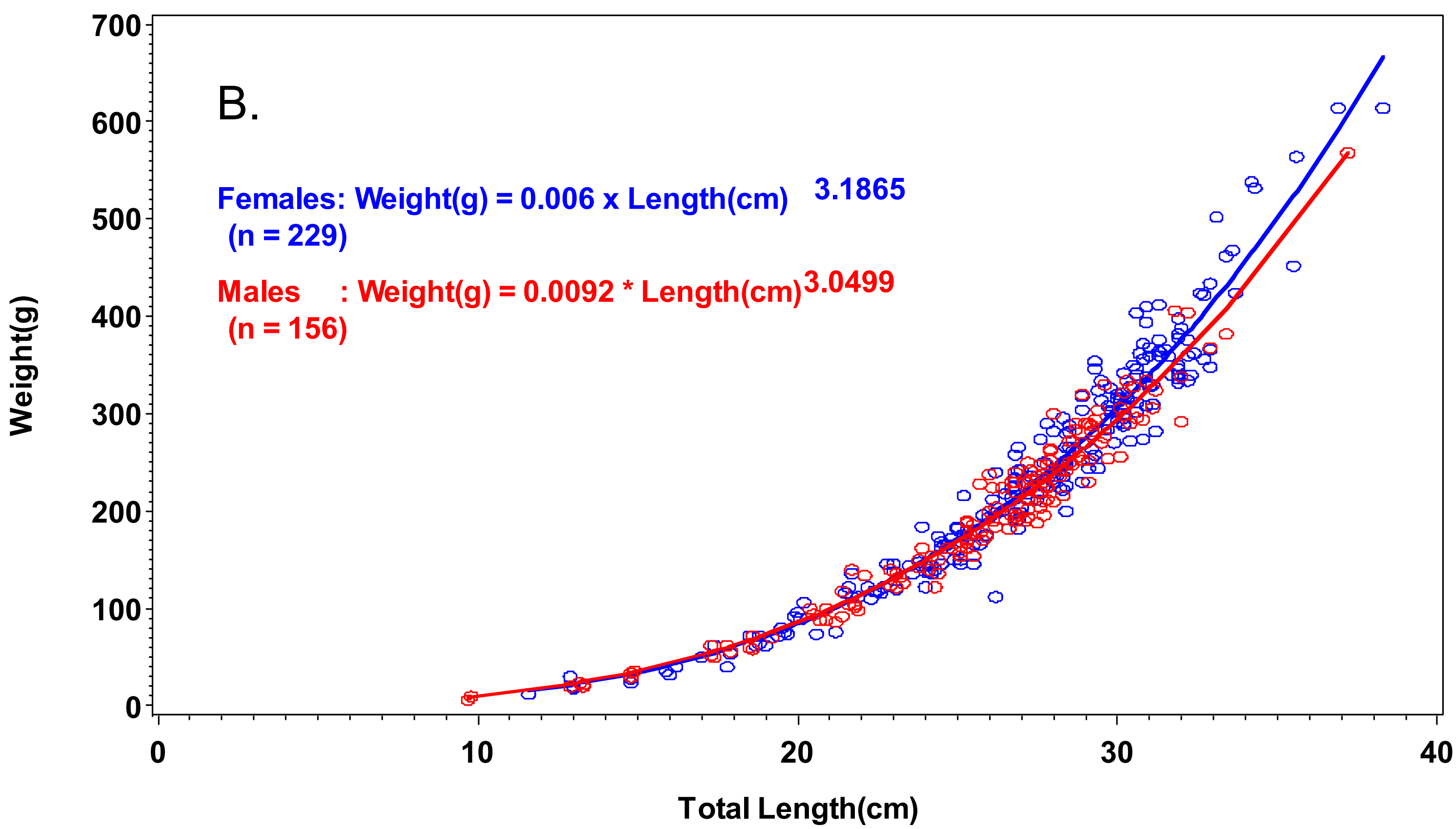


Figure 55. Northern kingfish maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

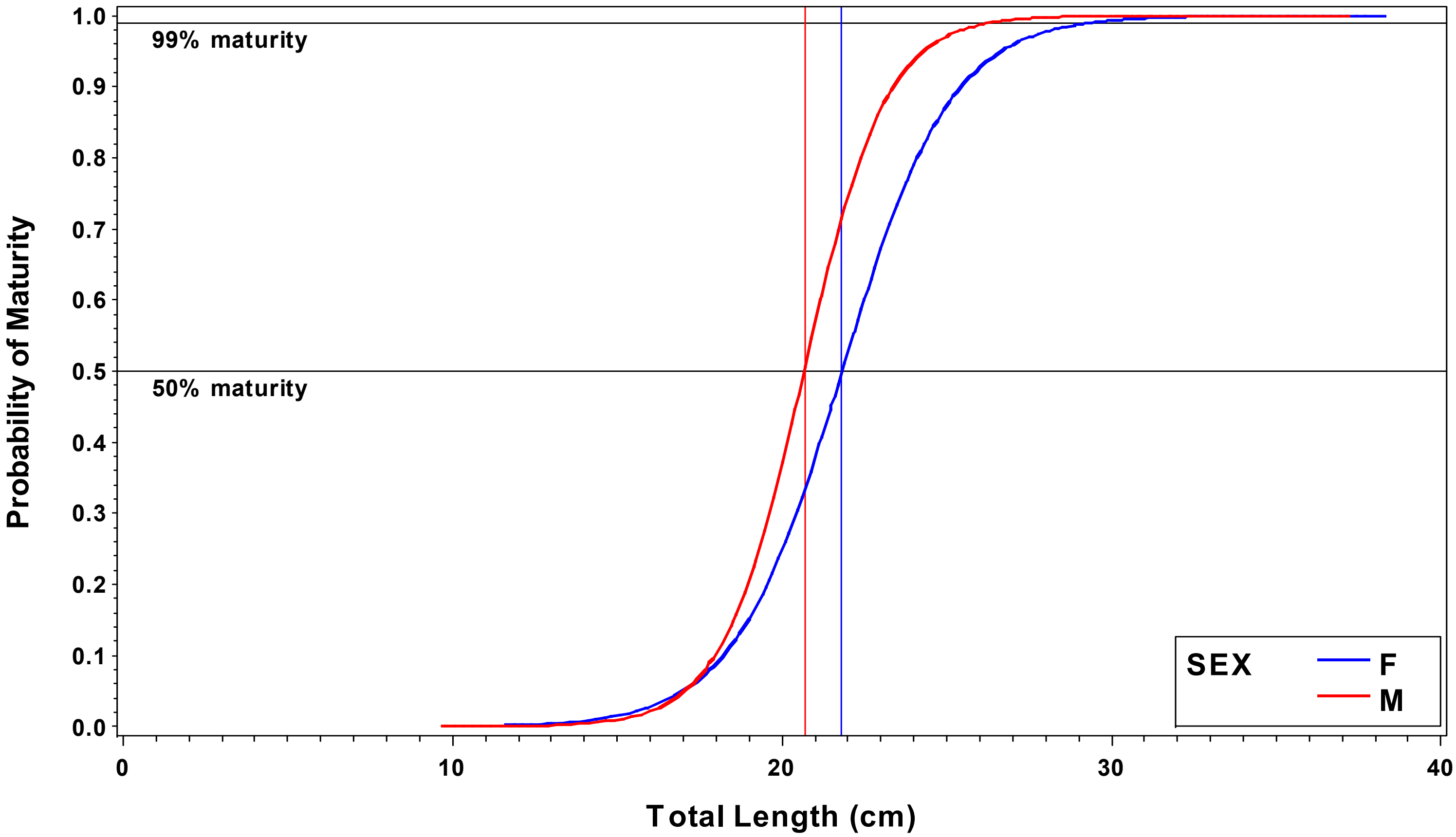


Figure 56. Northern kingfish diet in Chesapeake Bay, 2002-2007 combined.

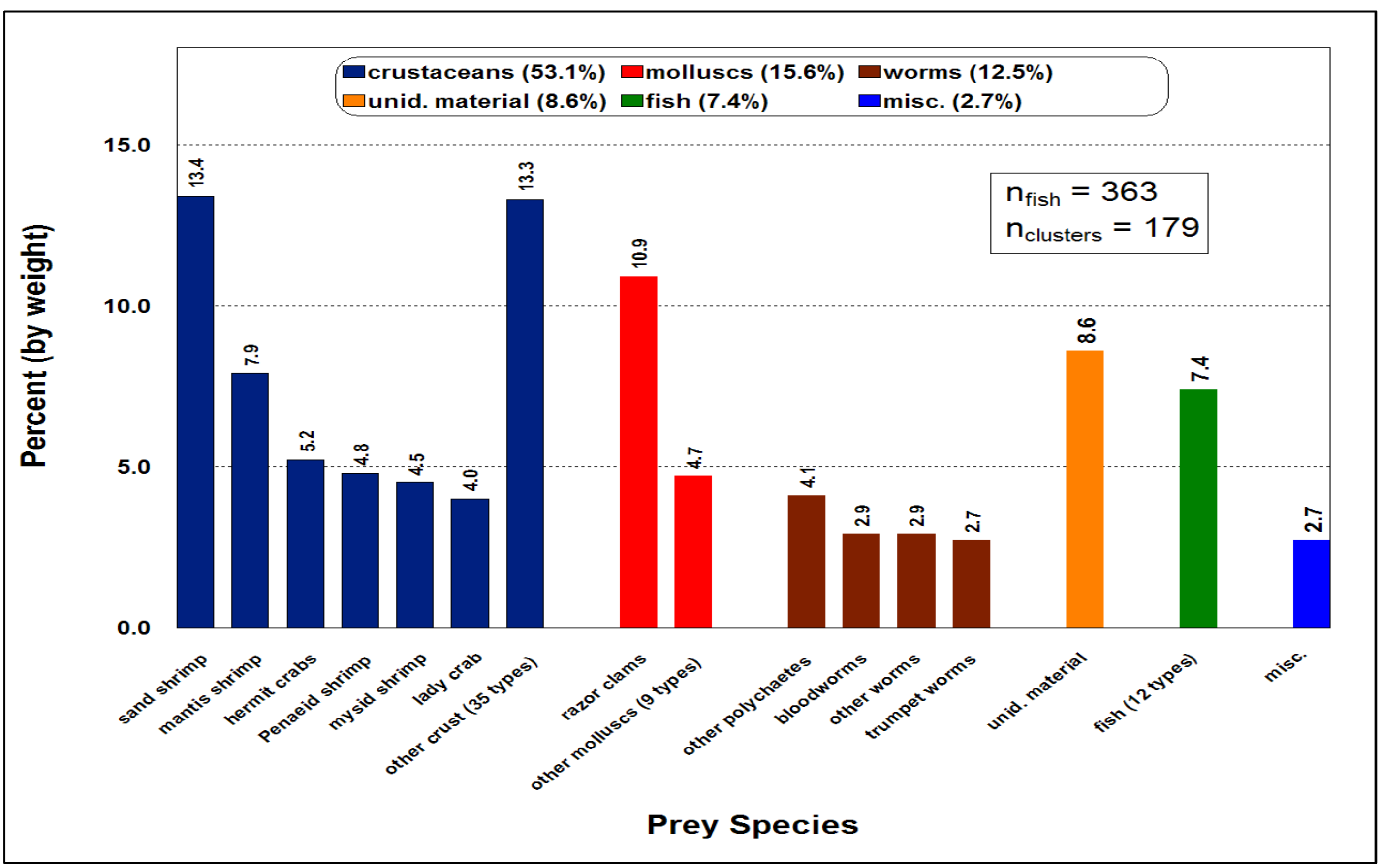
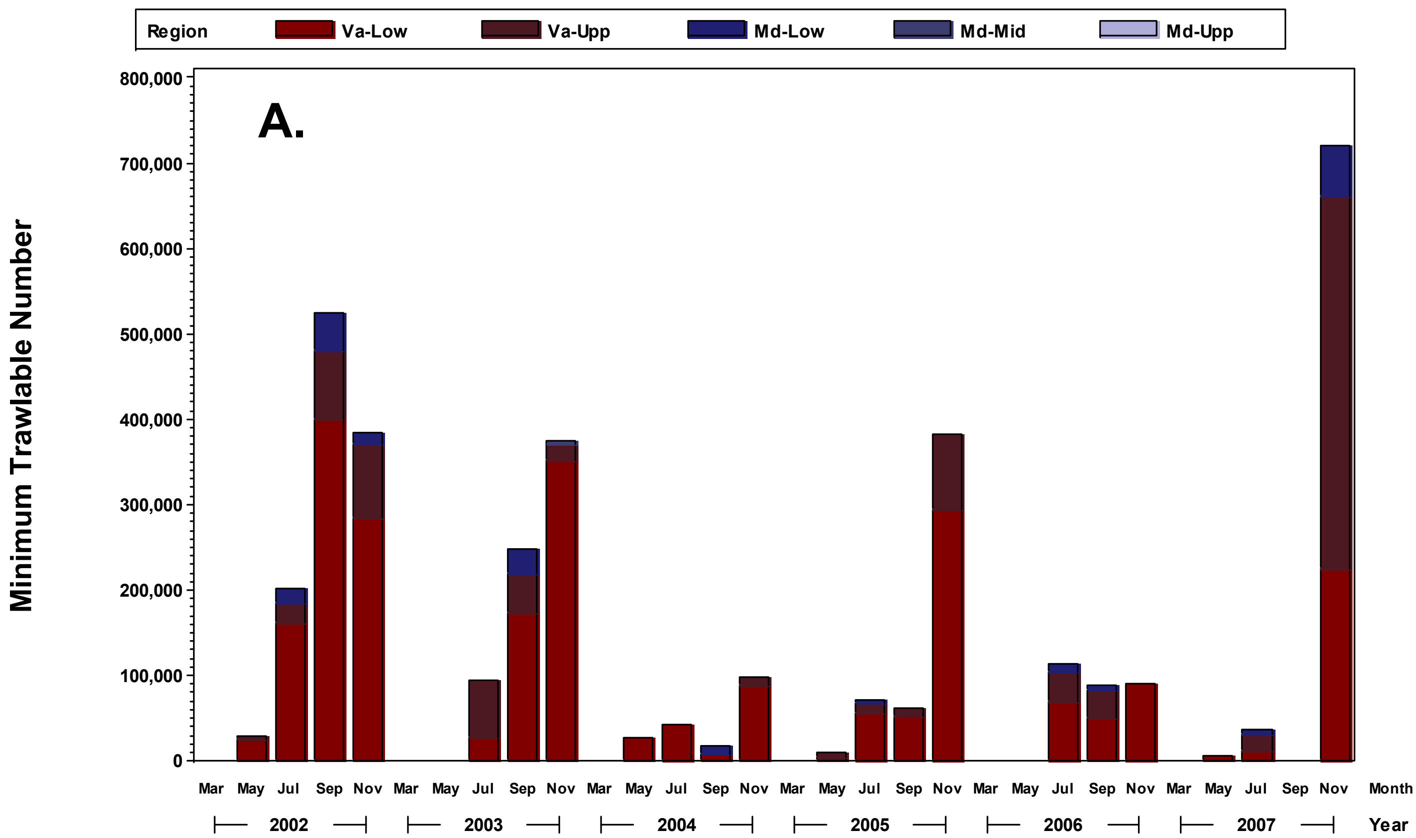


Figure 57. Northern puffer minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.



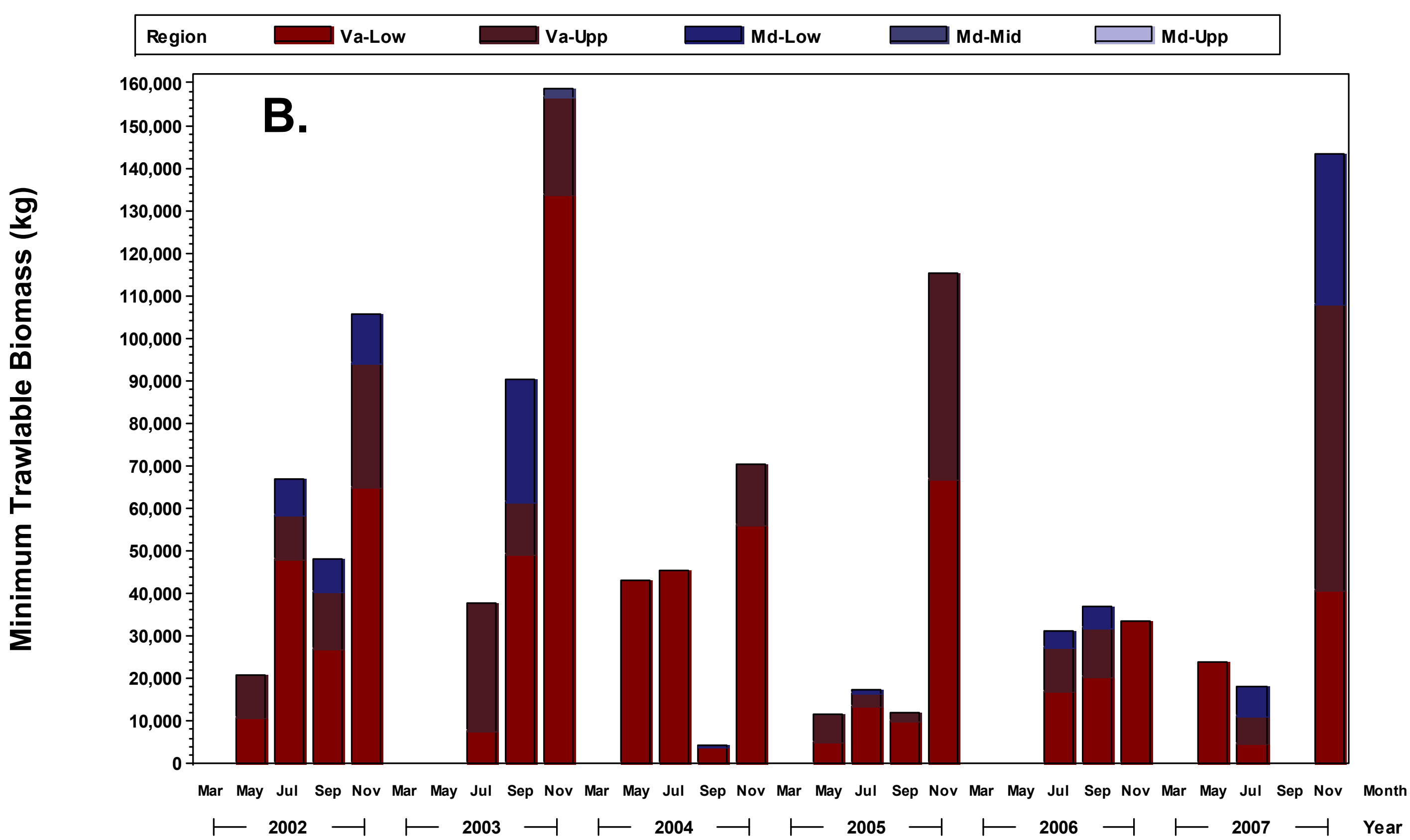


Figure 58. Northern puffer length-frequency in Chesapeake Bay, 2002-2007.

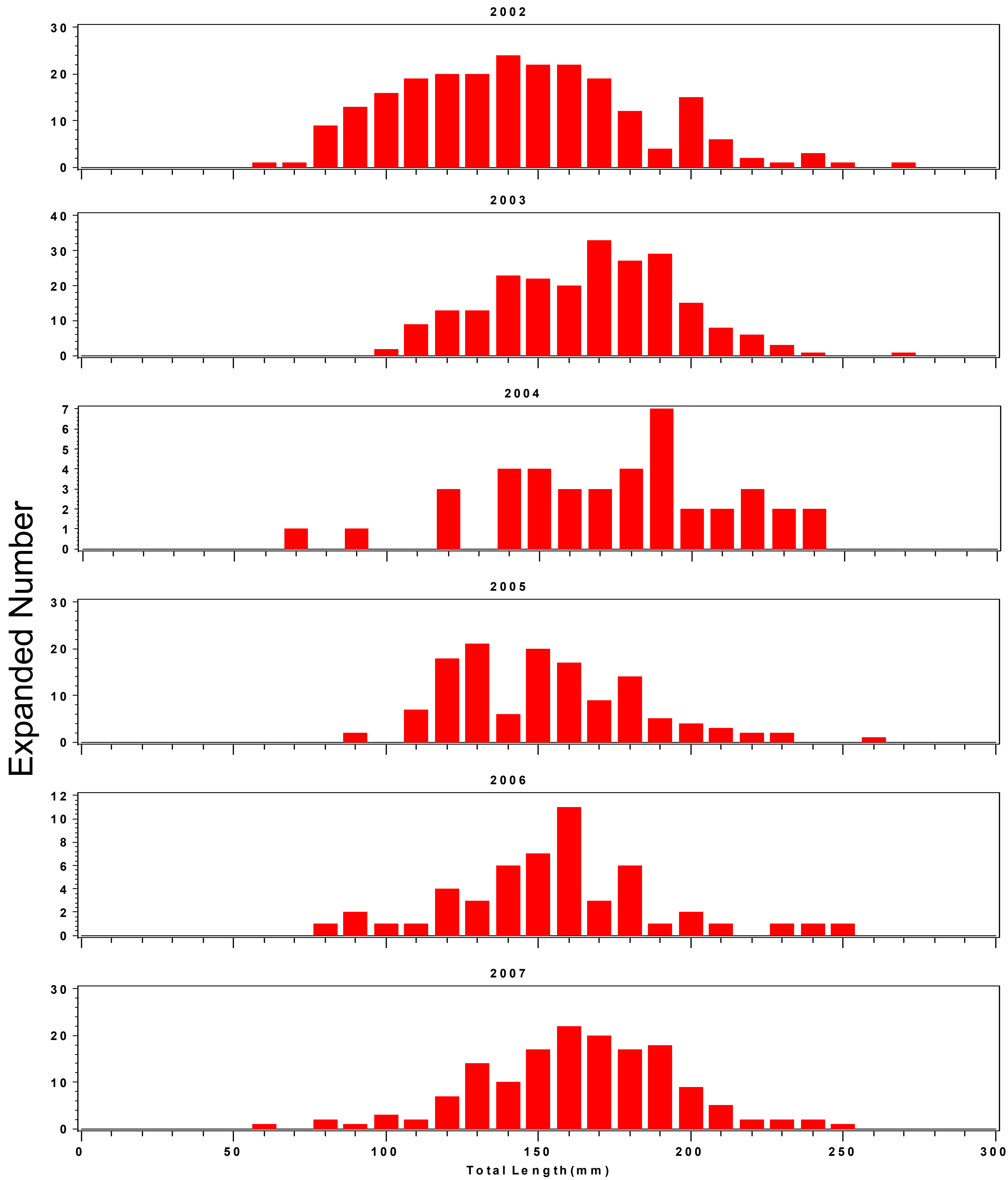
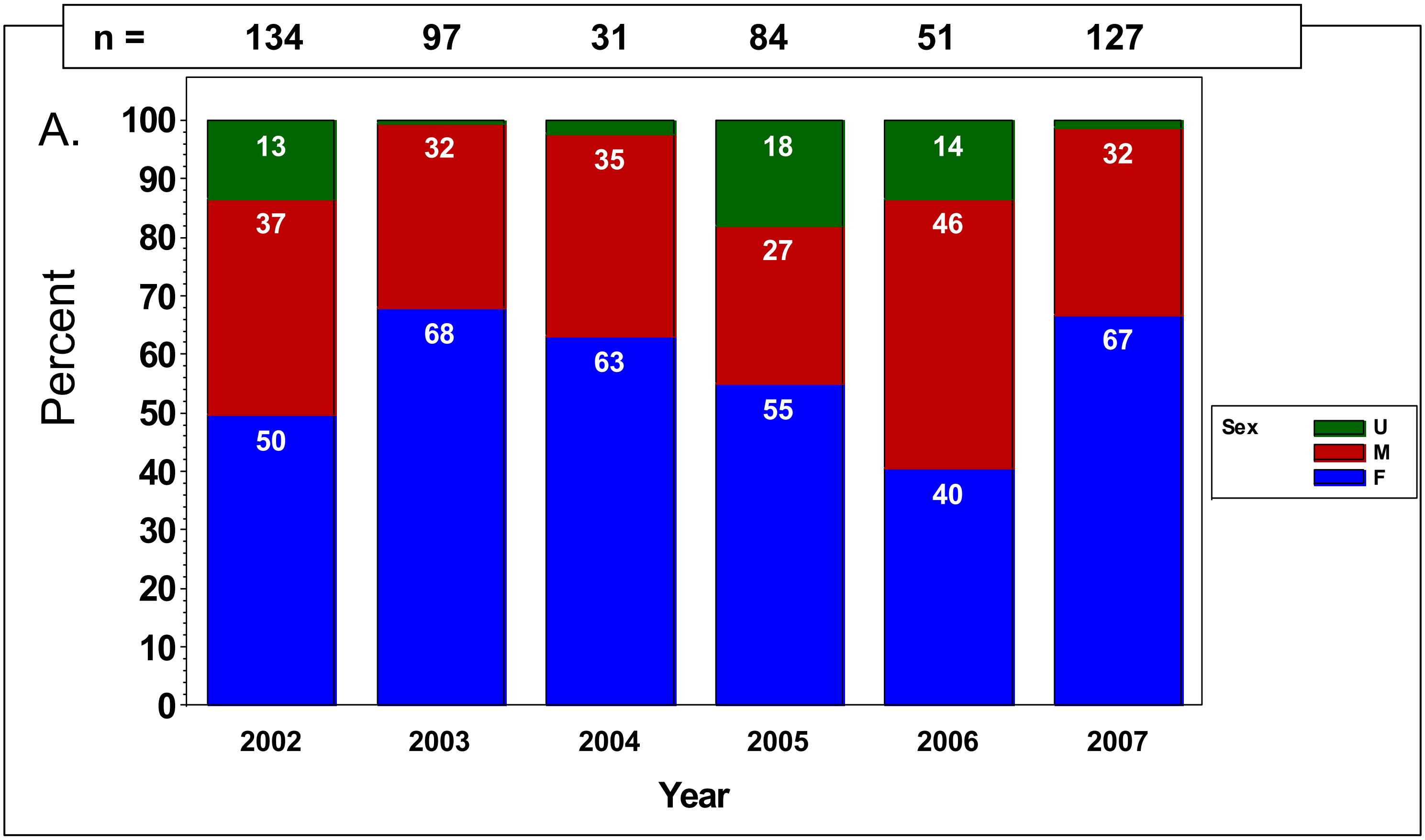


Figure 59. Northern puffer sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B).



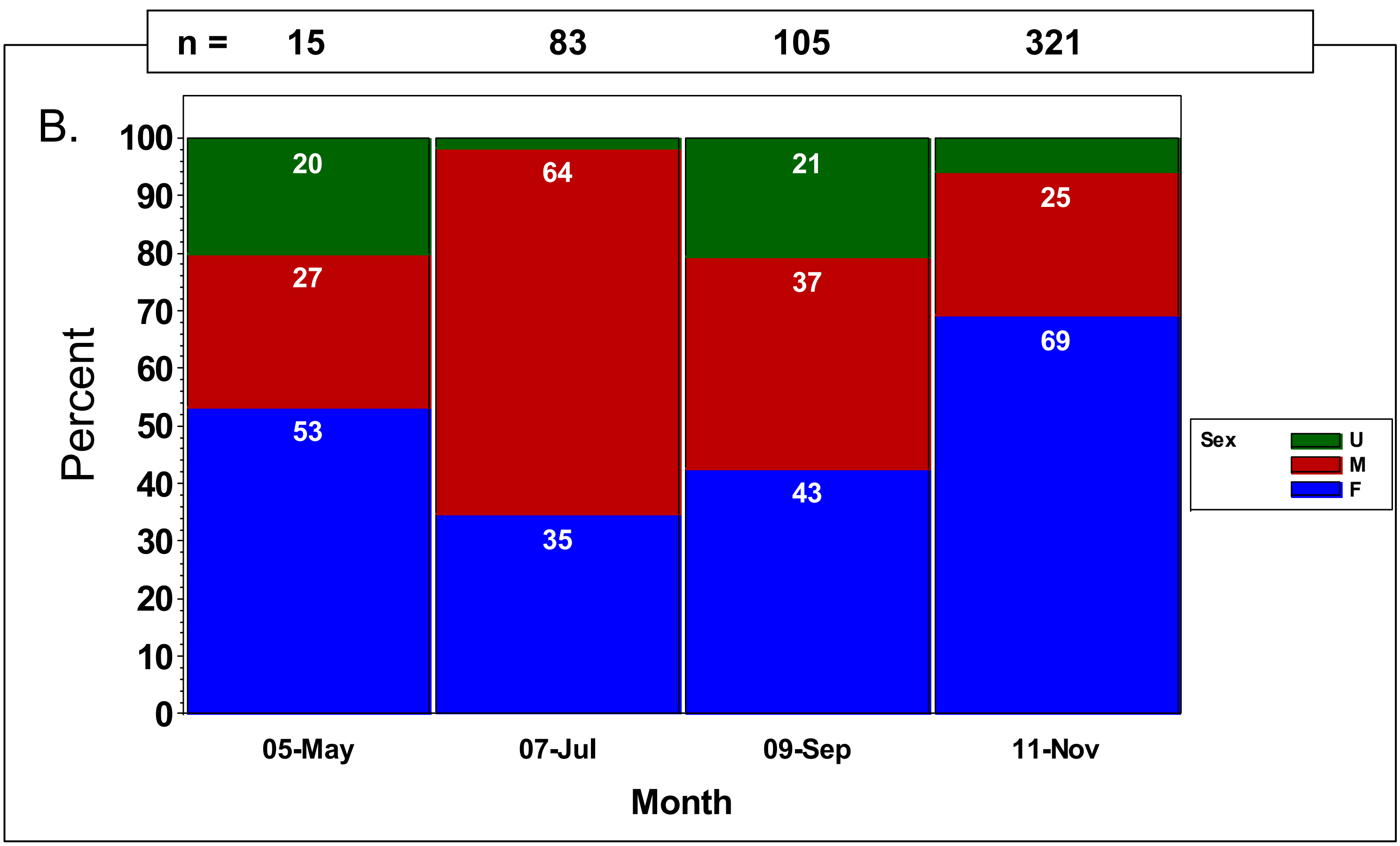
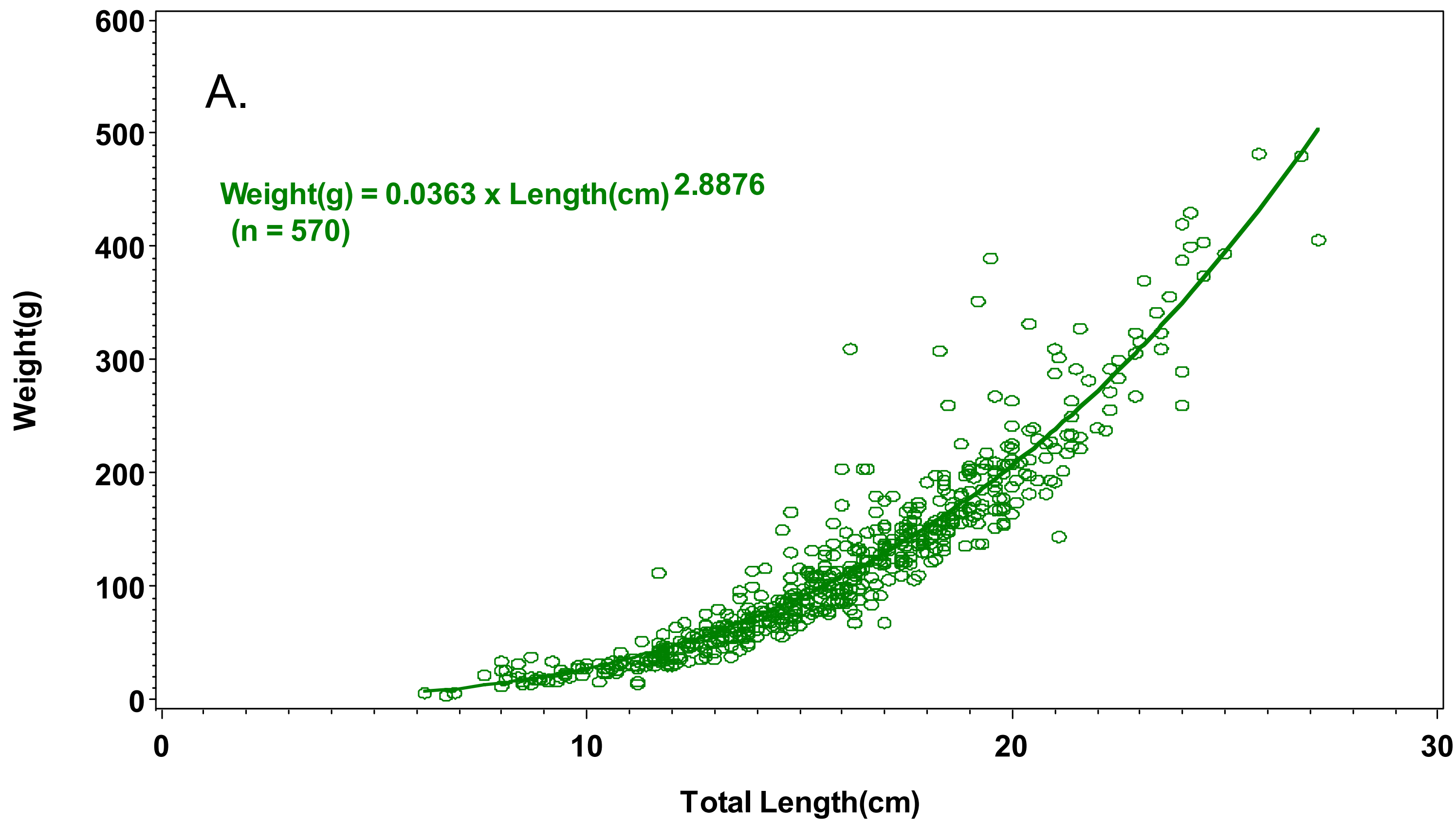


Figure 60. Northern puffer length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).



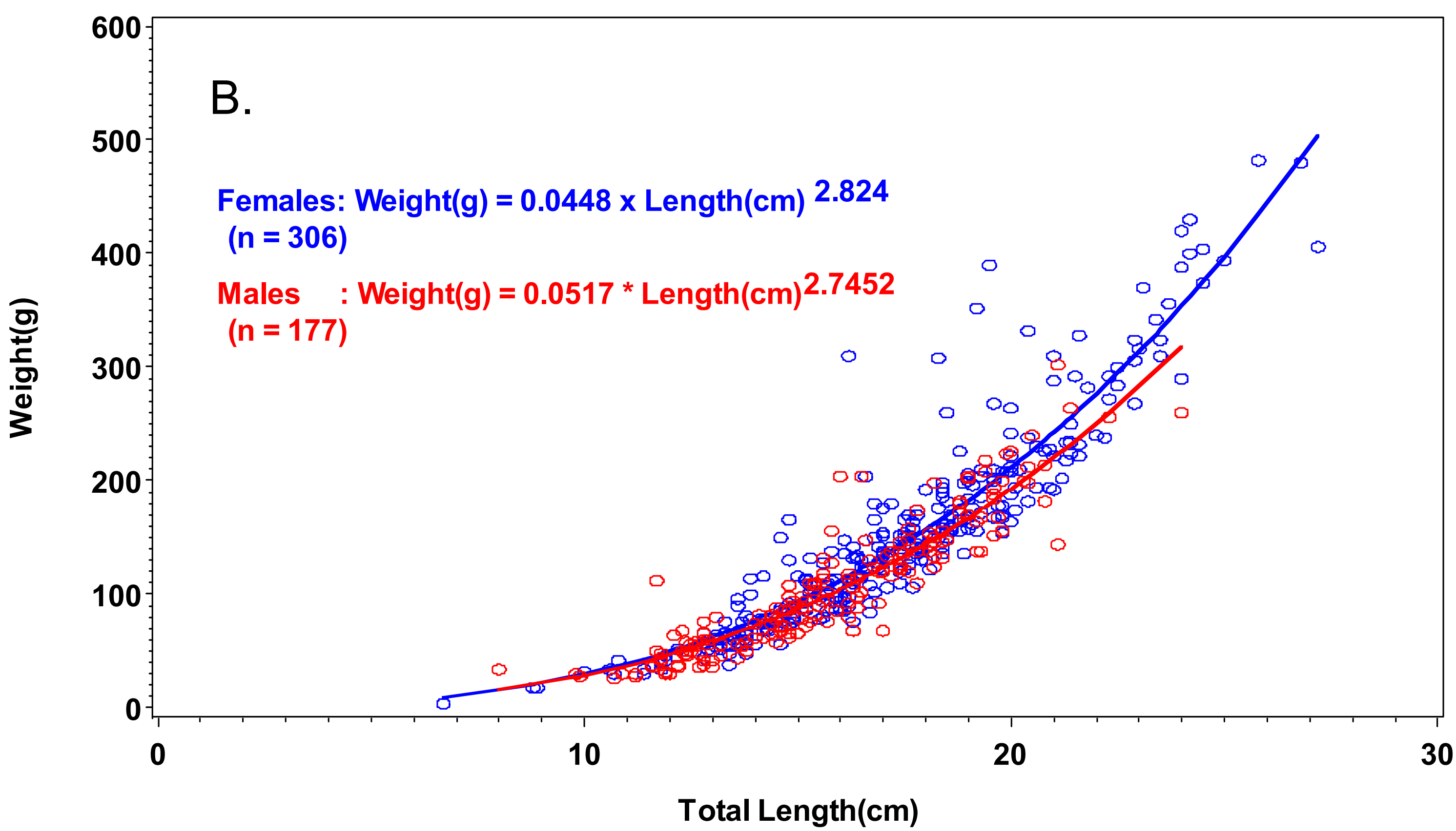


Figure 61. Northern puffer maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

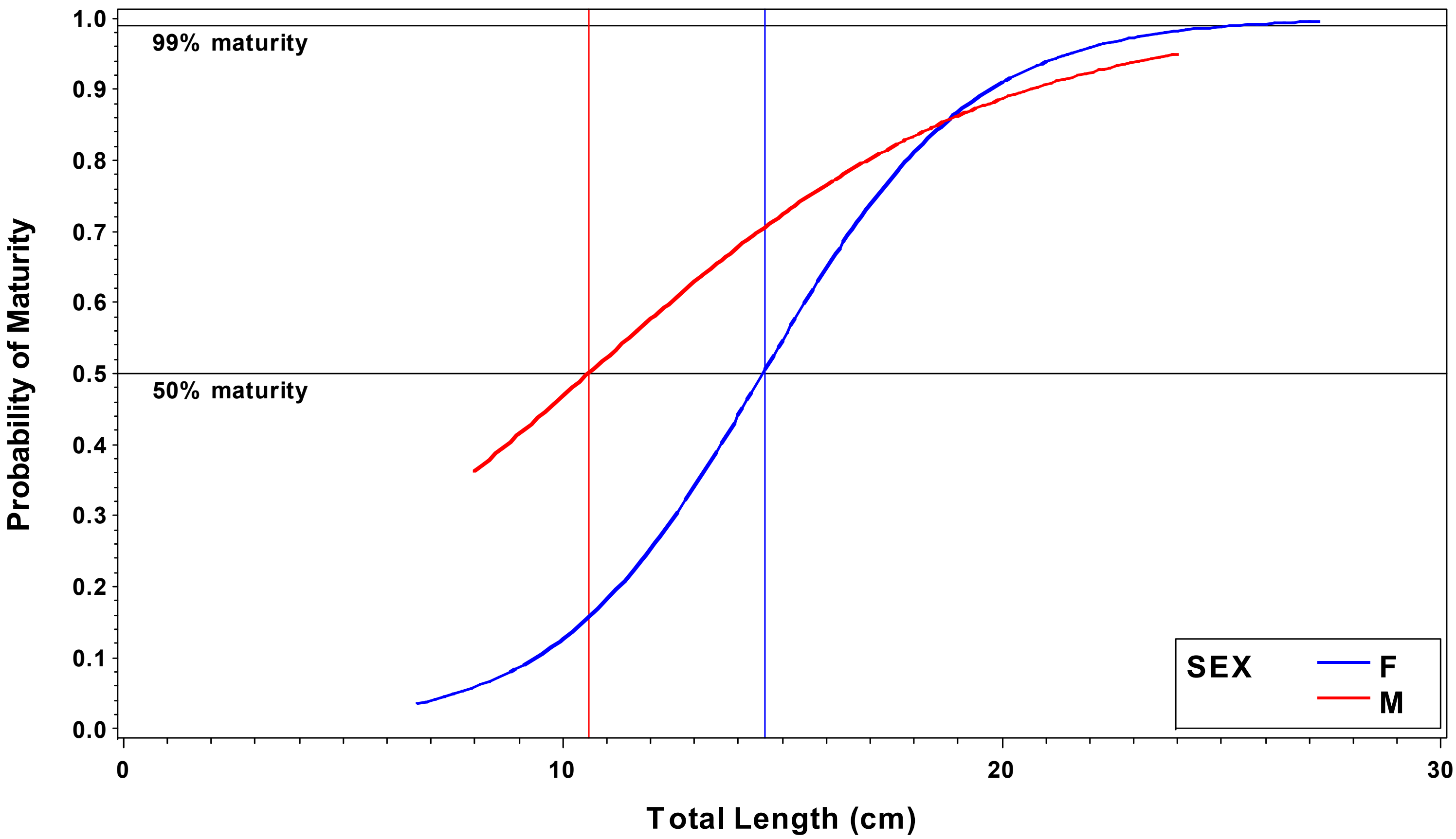


Figure 62. Northern puffer diet in Chesapeake Bay, 2002-2007 combined.

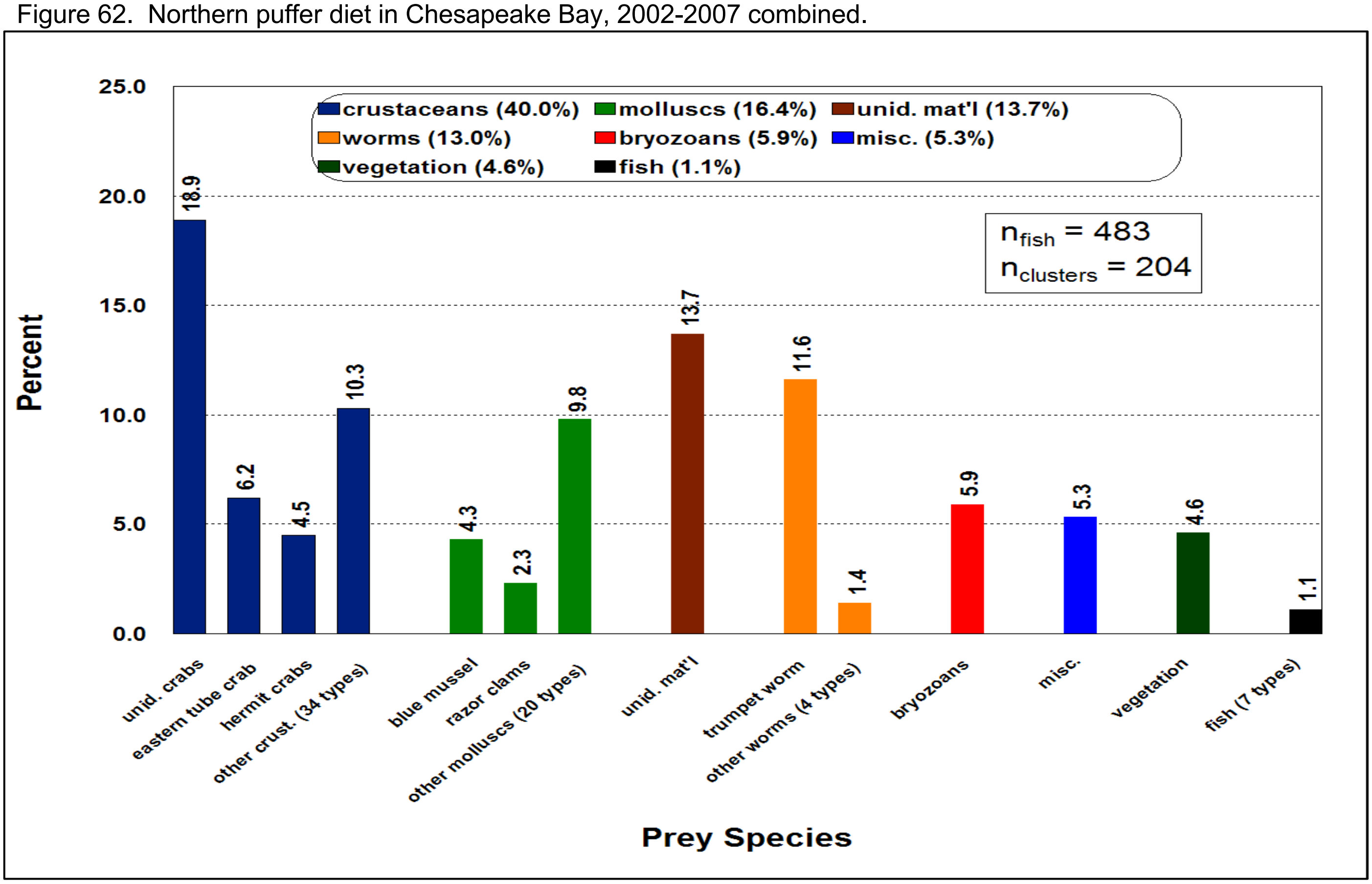
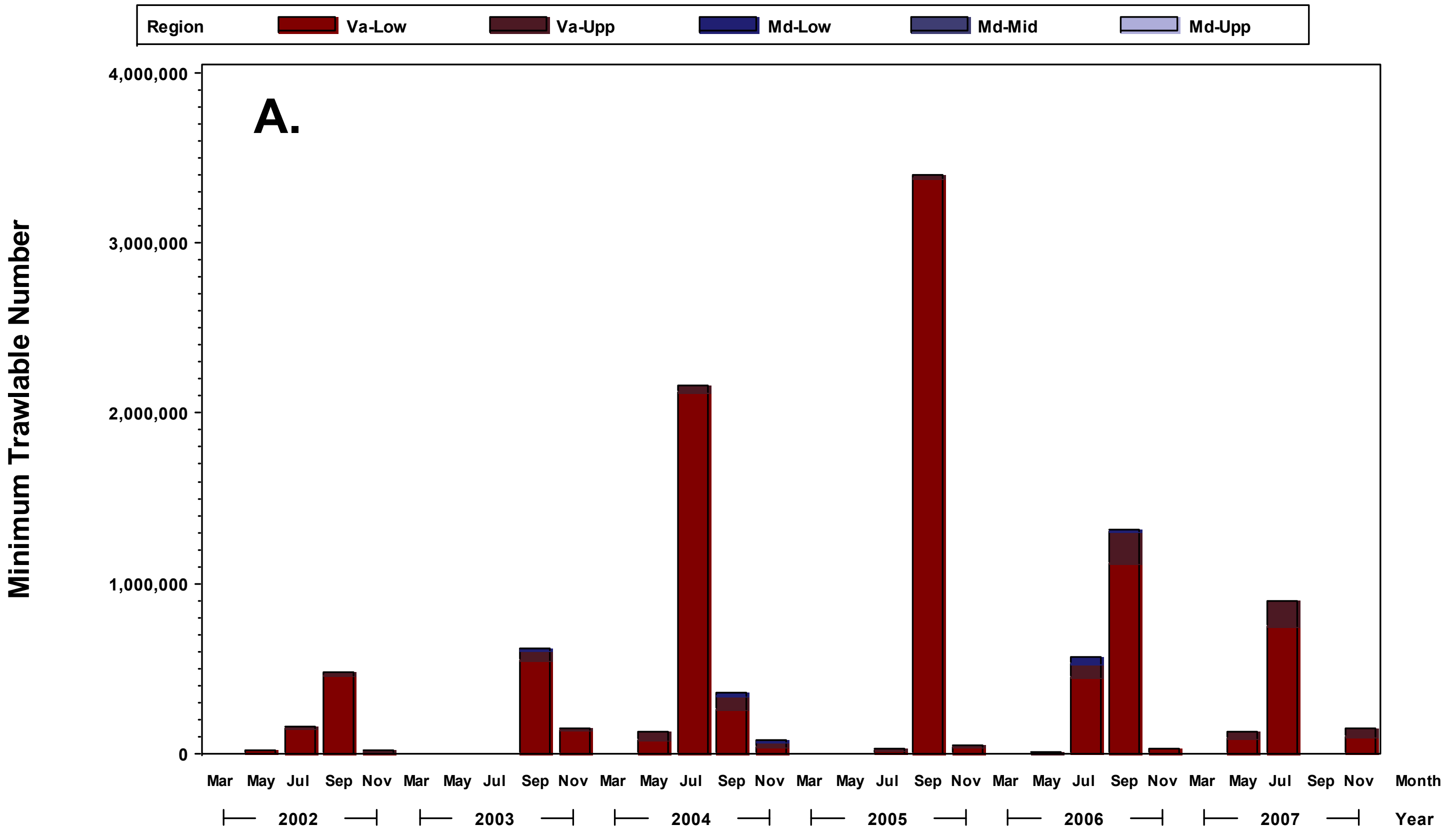


Figure 63. Scup minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.



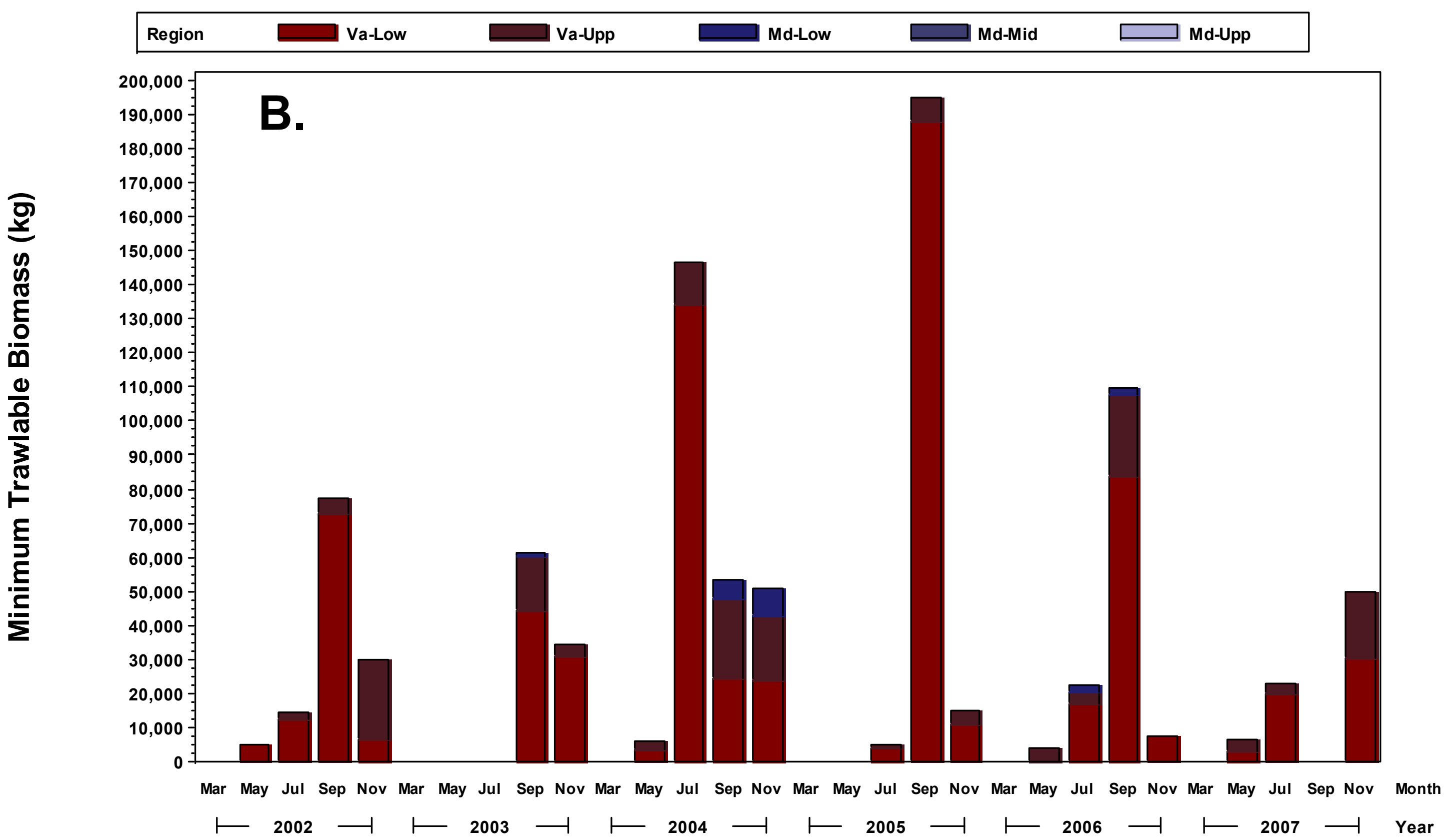


Figure 64. Abundance (number per hectare swept) of scup in Chesapeake Bay, 2002.

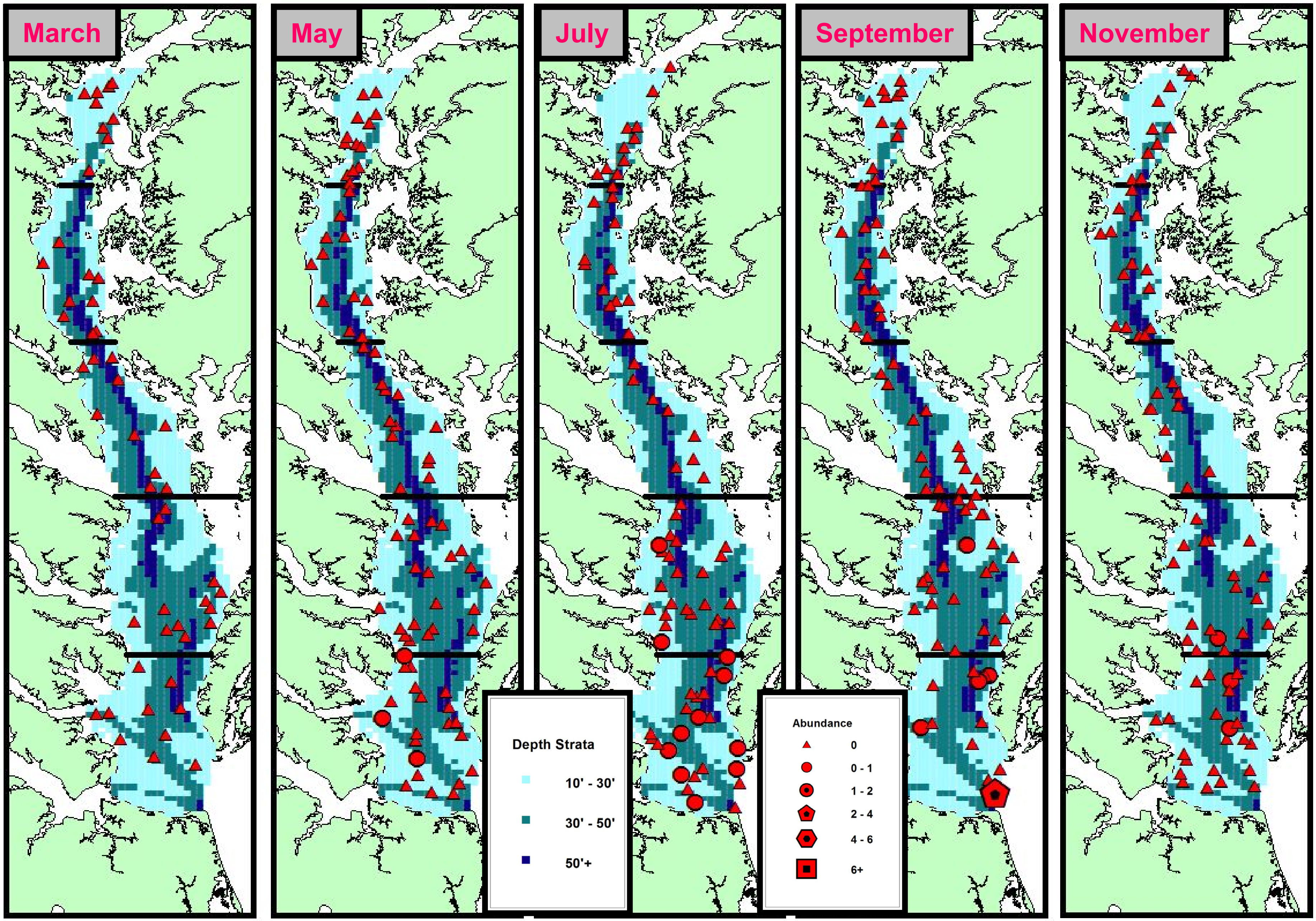


Figure 65. Abundance (number per hectare swept) of scup in Chesapeake Bay, 2003.

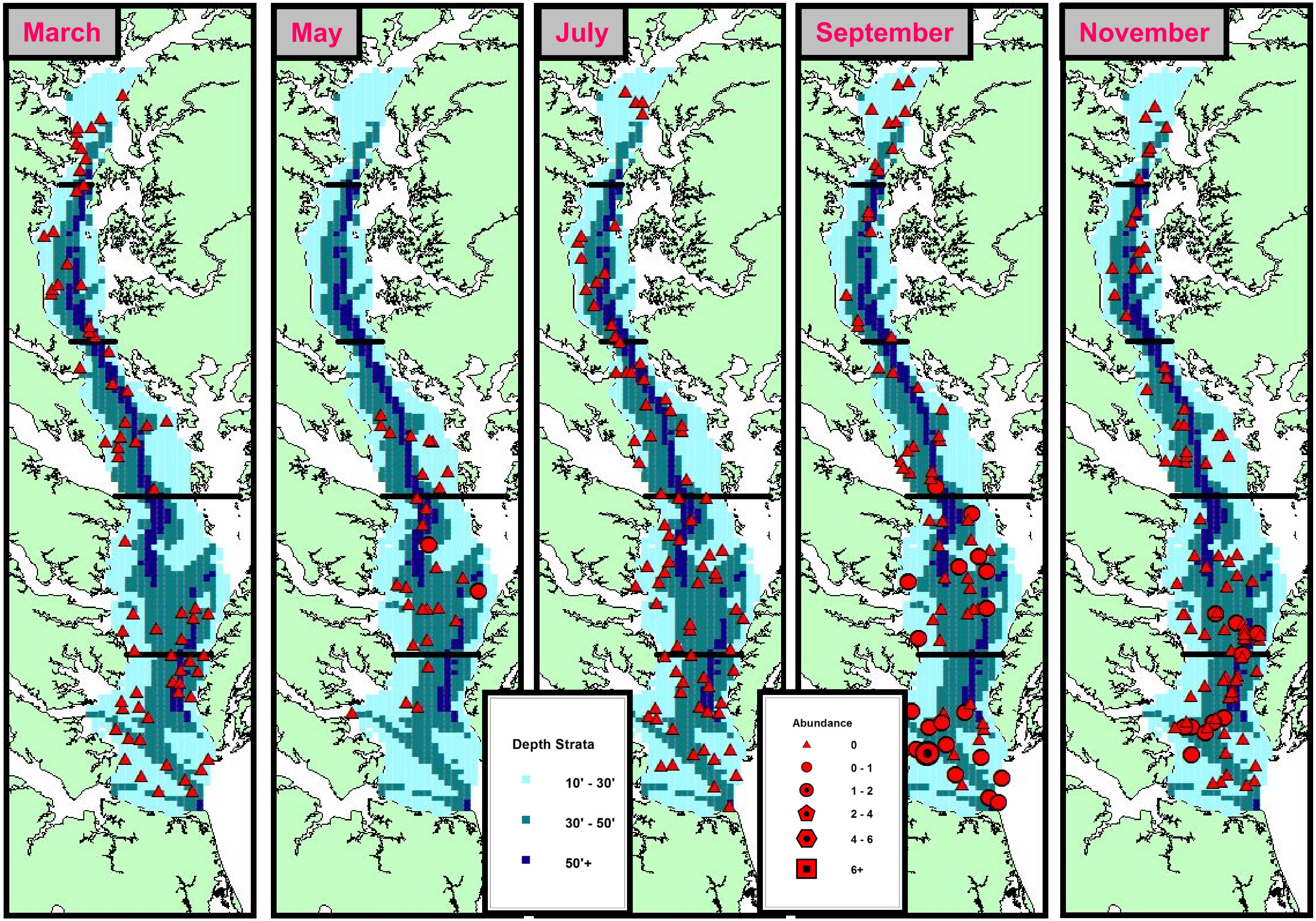


Figure 66. Abundance (number per hectare swept) of scup in Chesapeake Bay, 2004.

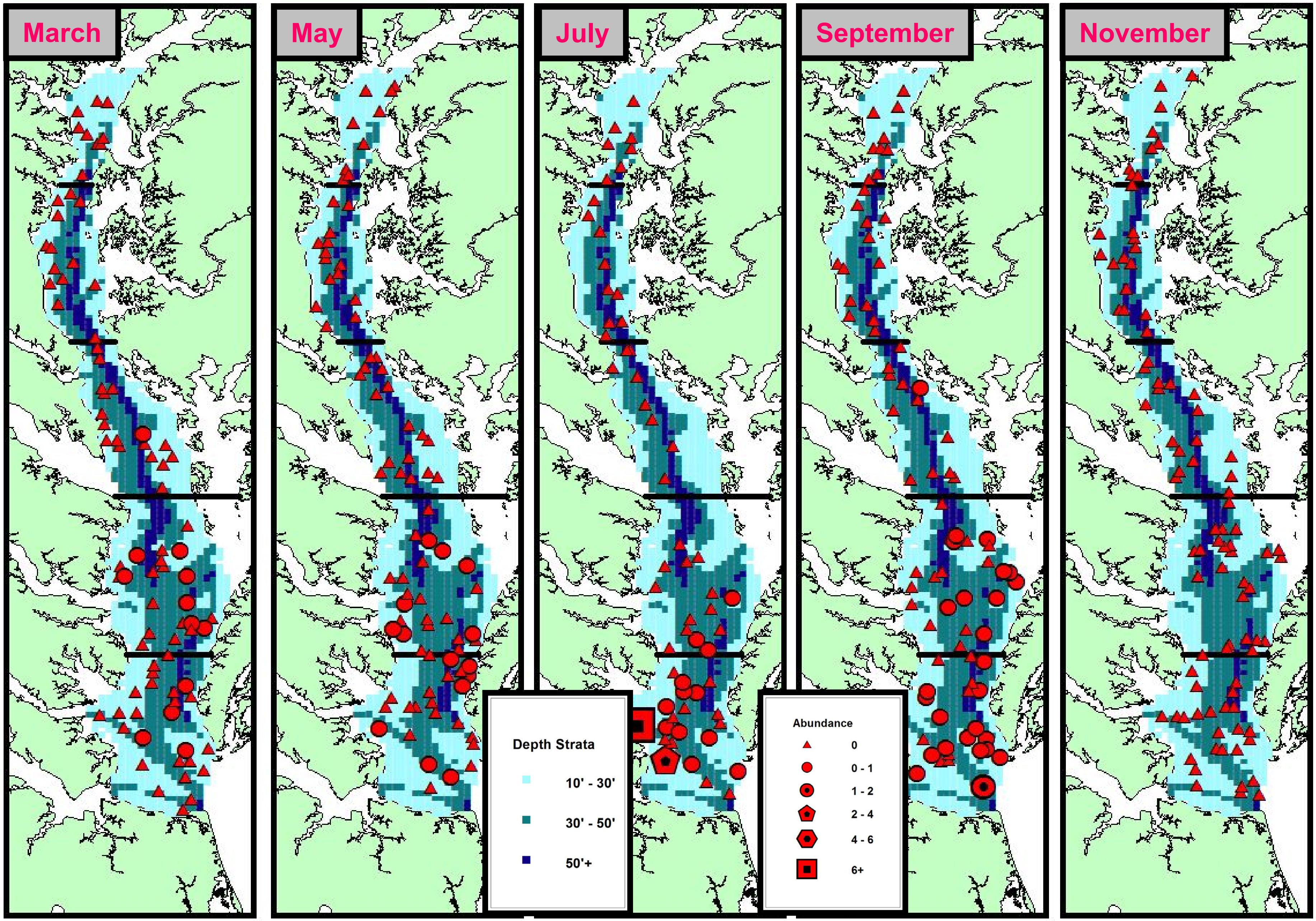


Figure 67. Abundance (number per hectare swept) of scup in Chesapeake Bay, 2005.

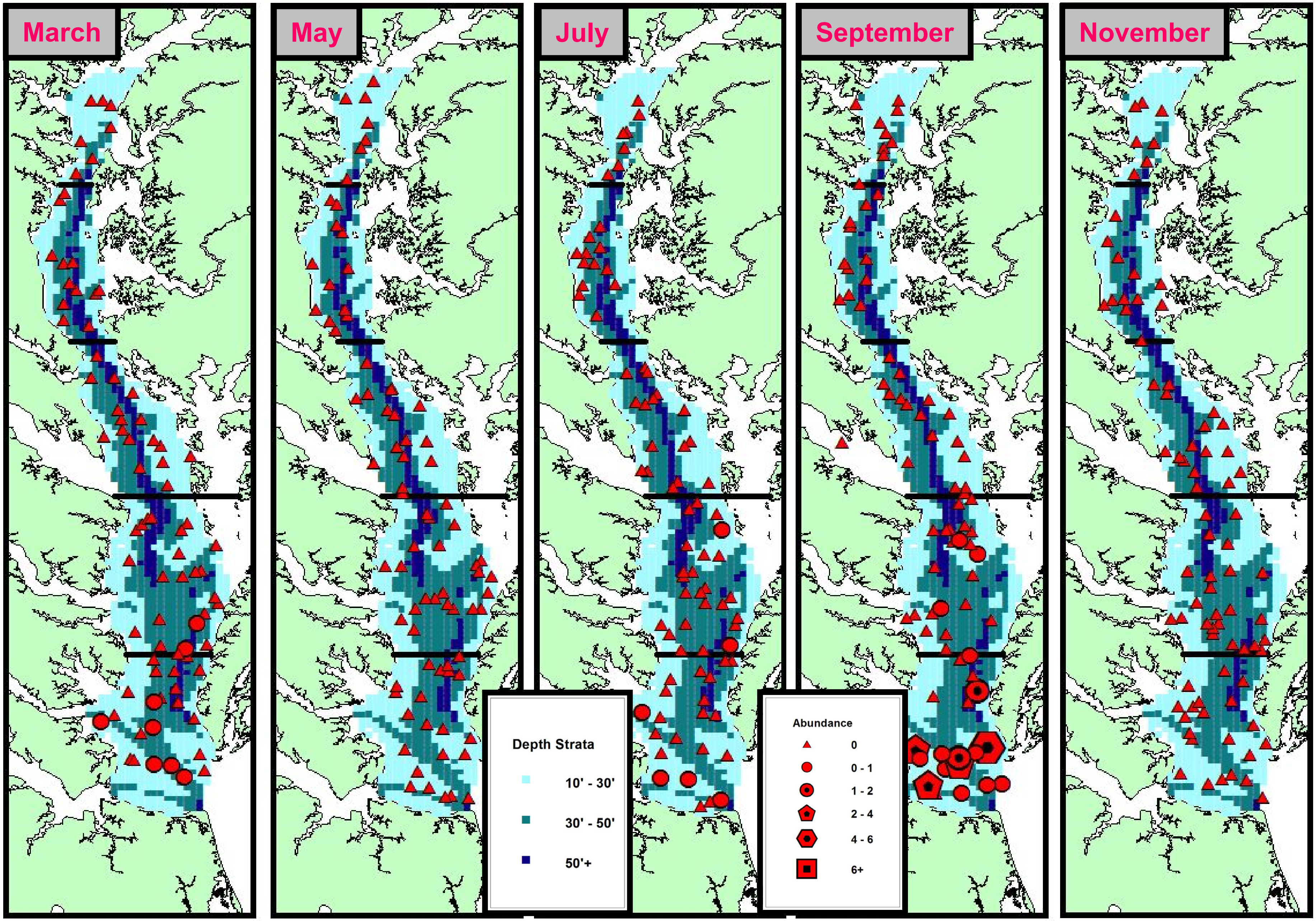


Figure 68. Abundance (number per hectare swept) of scup in Chesapeake Bay, 2006.

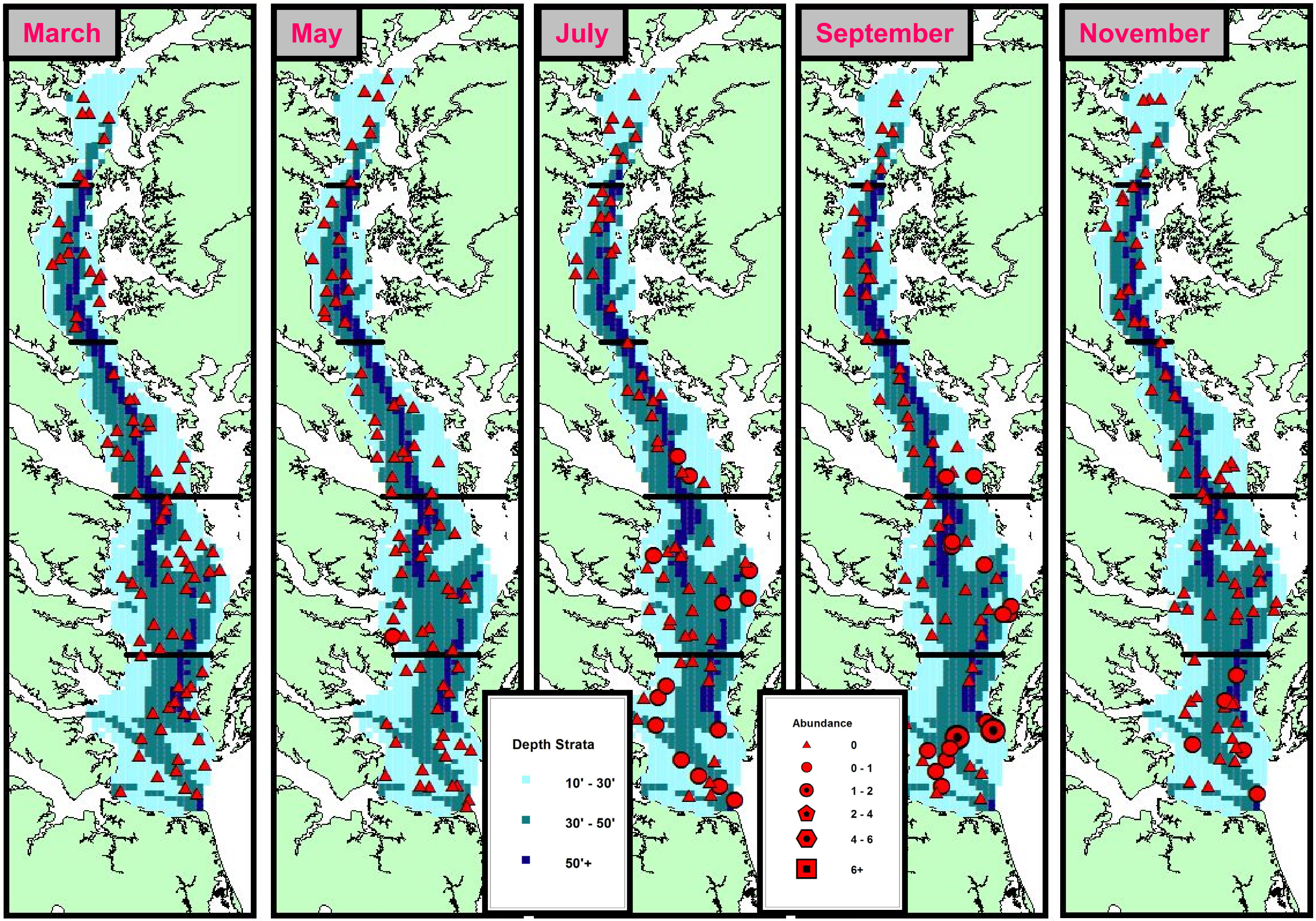


Figure 69. Abundance (number per hectare swept) of scup in Chesapeake Bay, 2007.

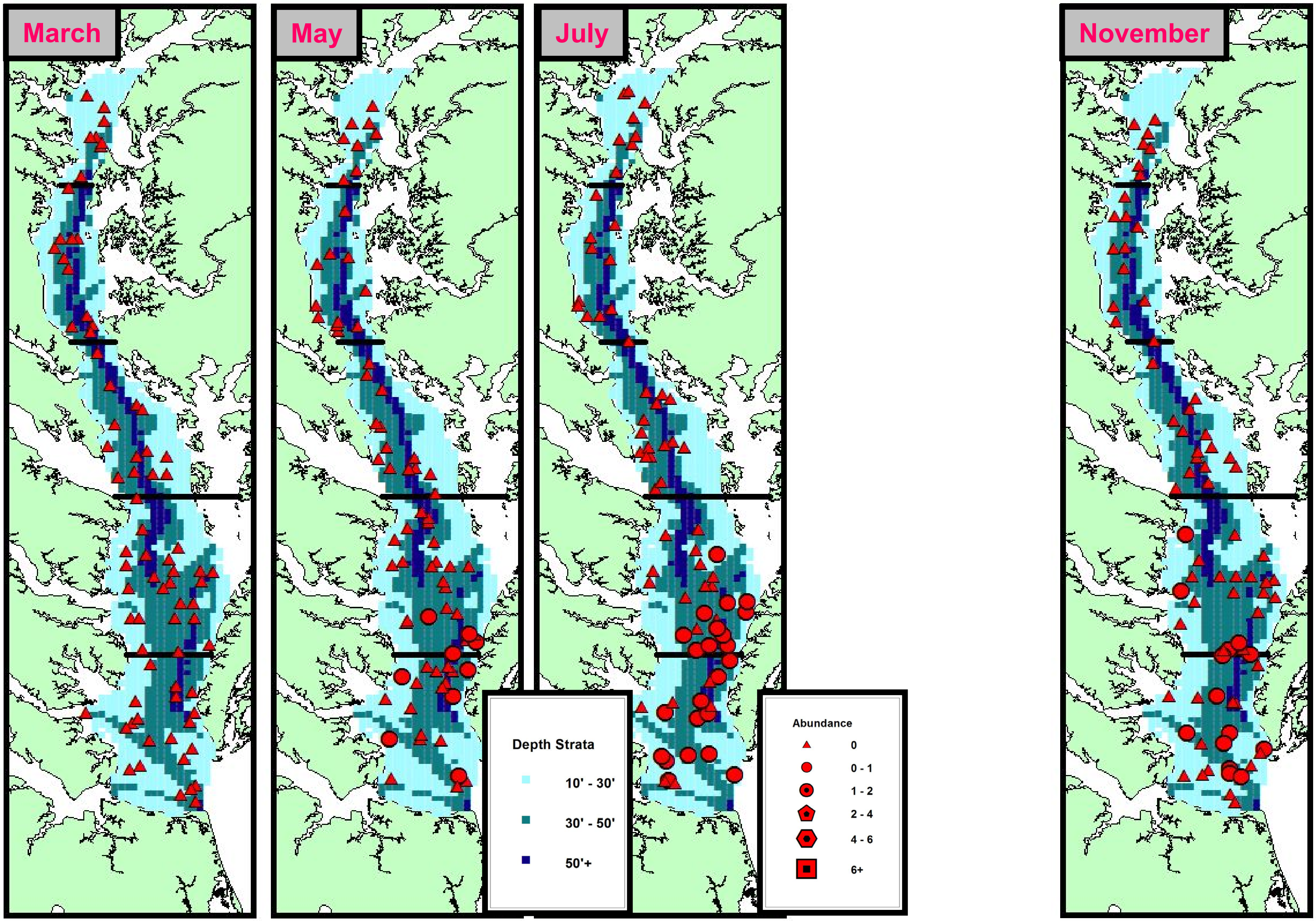


Figure 70. Scup length-frequency in Chesapeake Bay, 2002-2007.

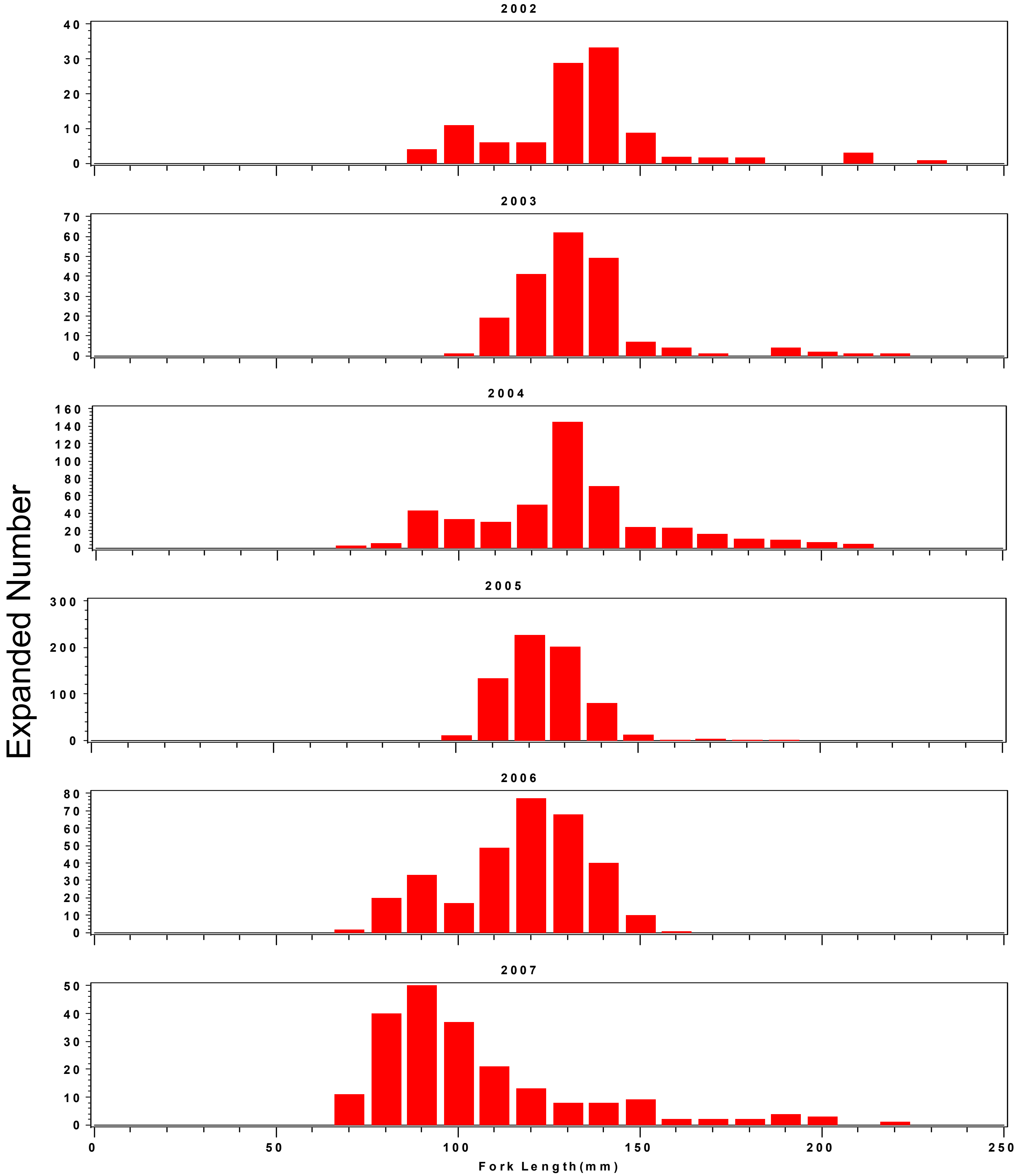


Figure 71. Scup sex-ratios in Chesapeake Bay, 2002-2007, by year (A) and month (B).

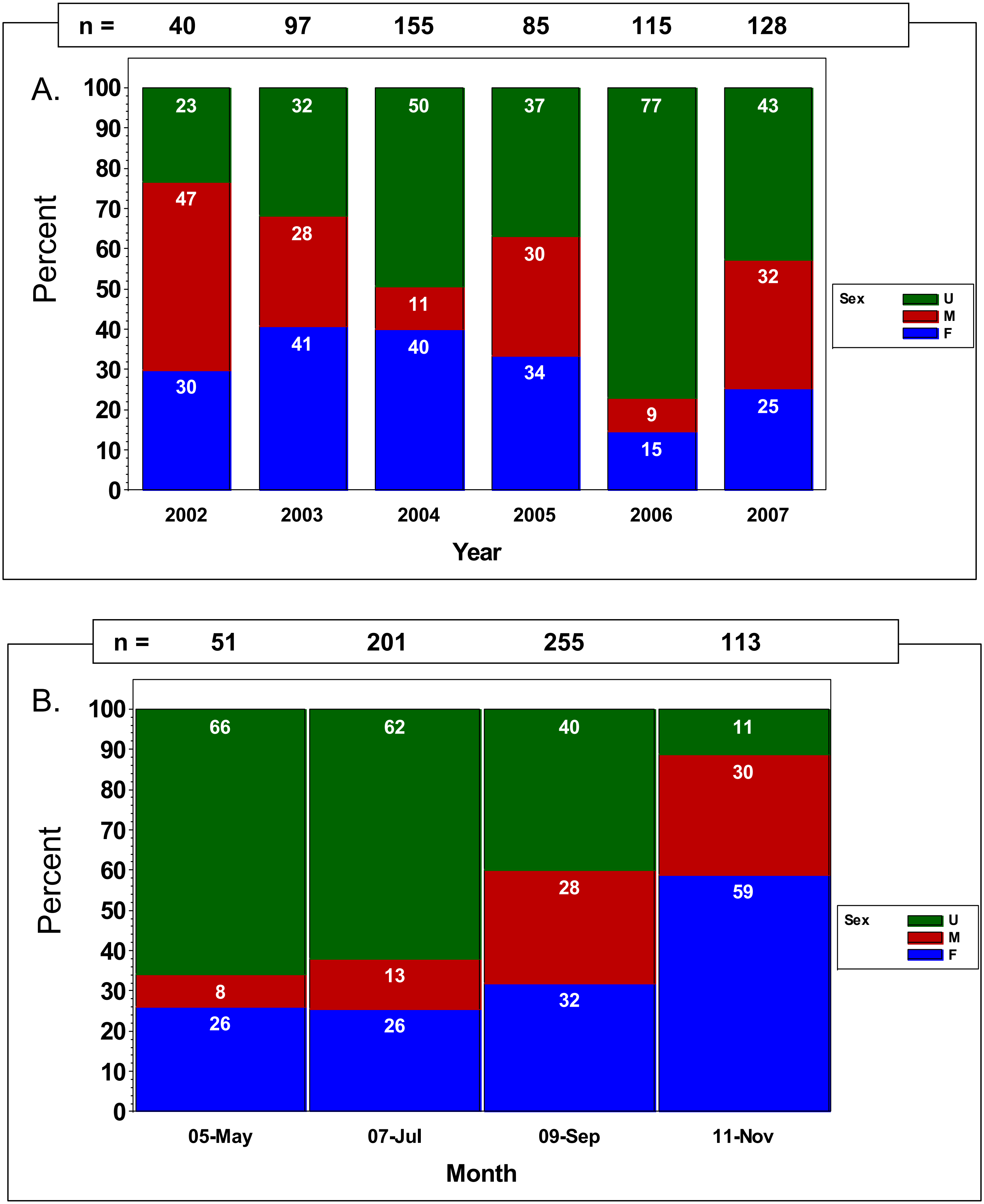


Figure 72. Scup length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).

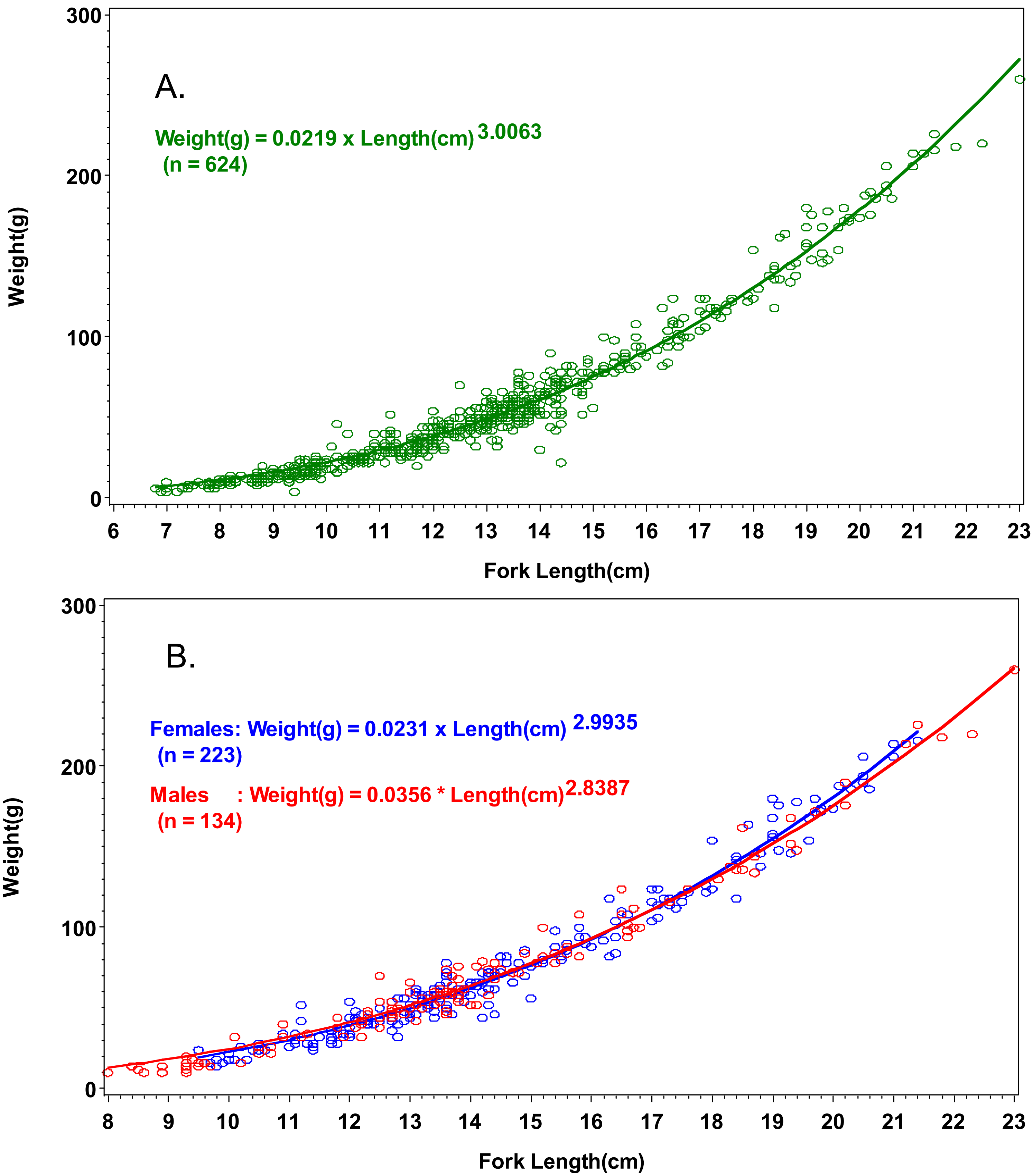


Figure 73. Scup maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

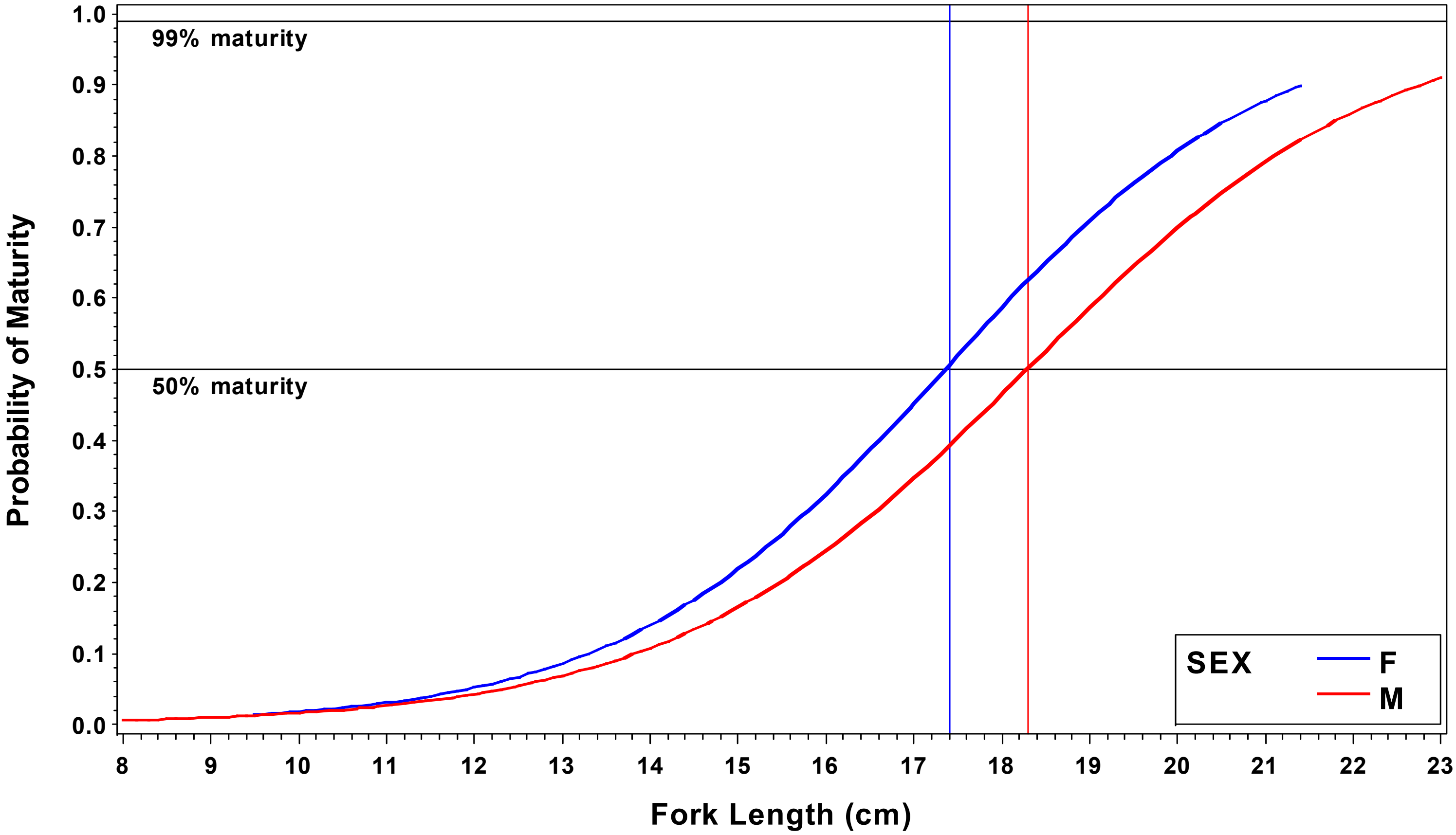


Figure 74. Scup diet in Chesapeake Bay, 2002-2007 combined.

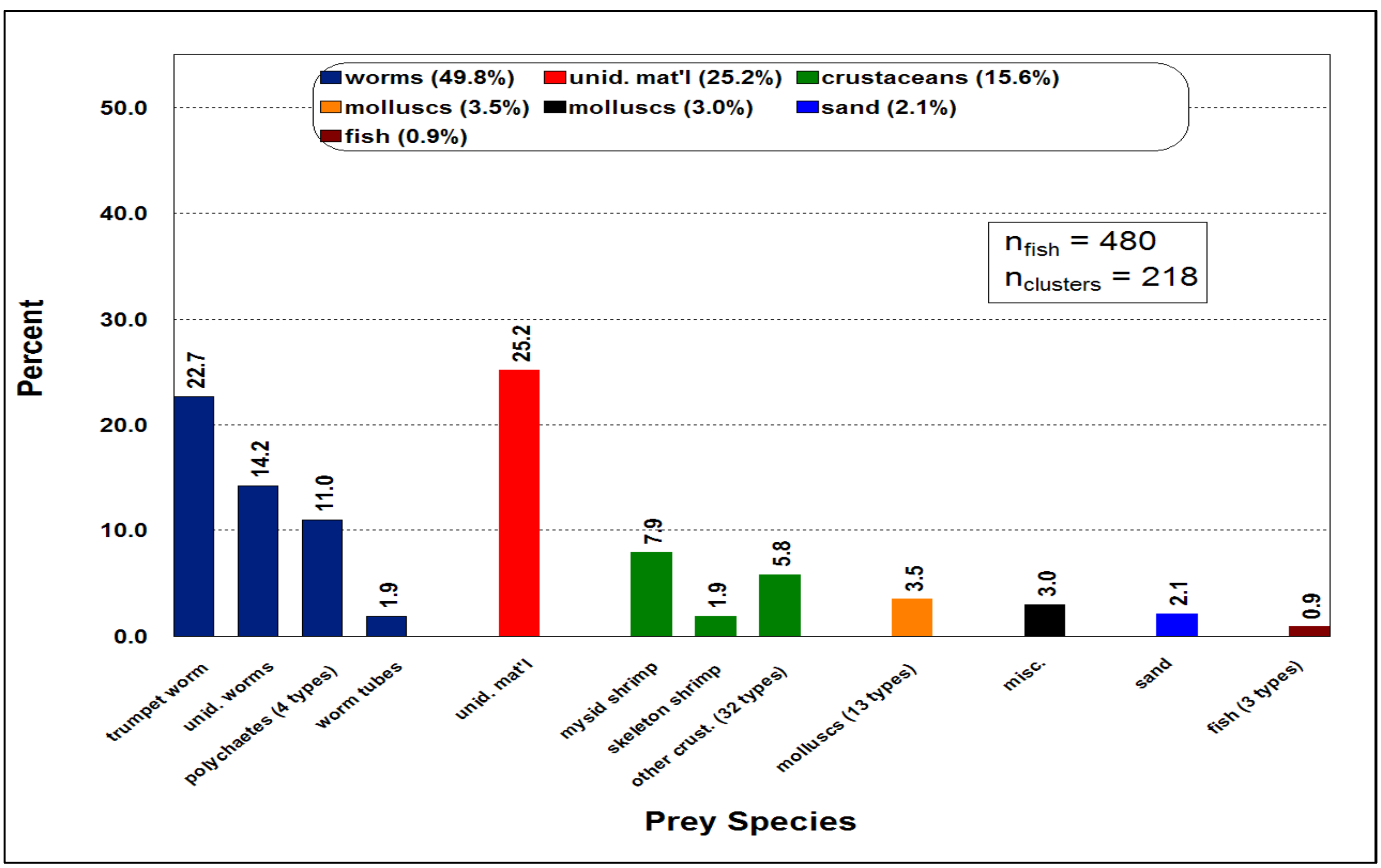
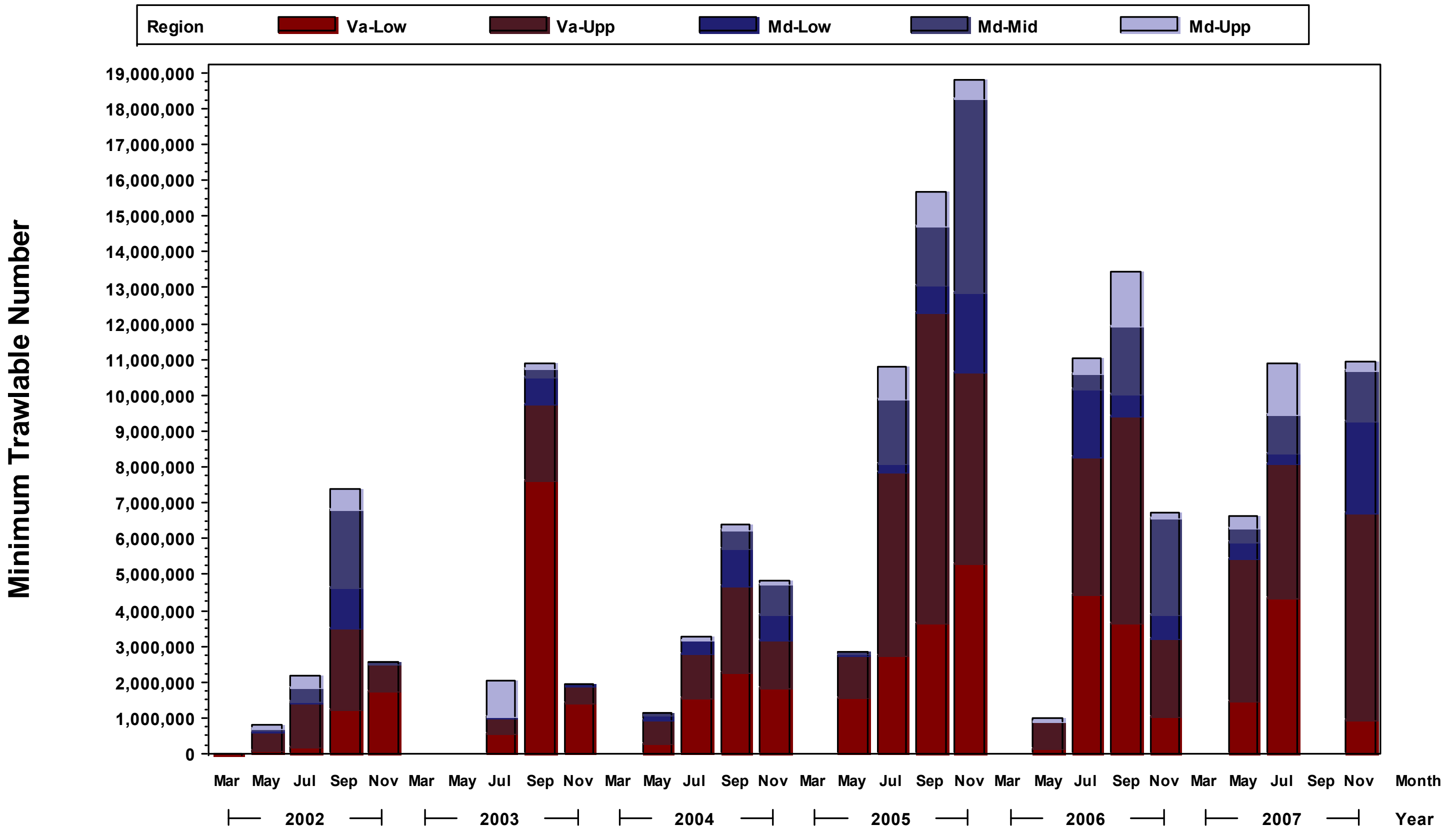


Figure 75. Spot minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.



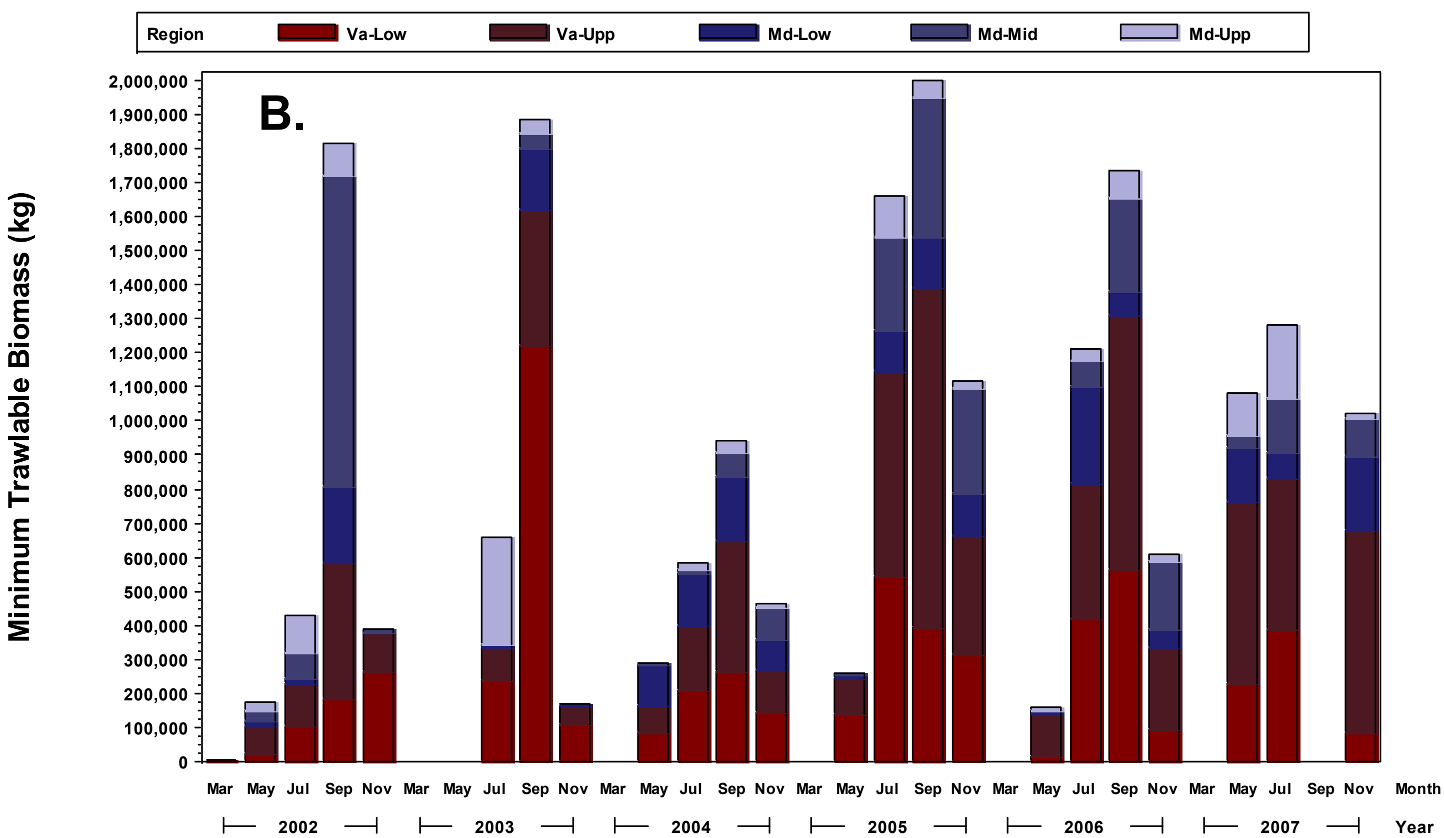


Figure 76. Abundance (number per hectare swept) of spot in Chesapeake Bay, 2002.

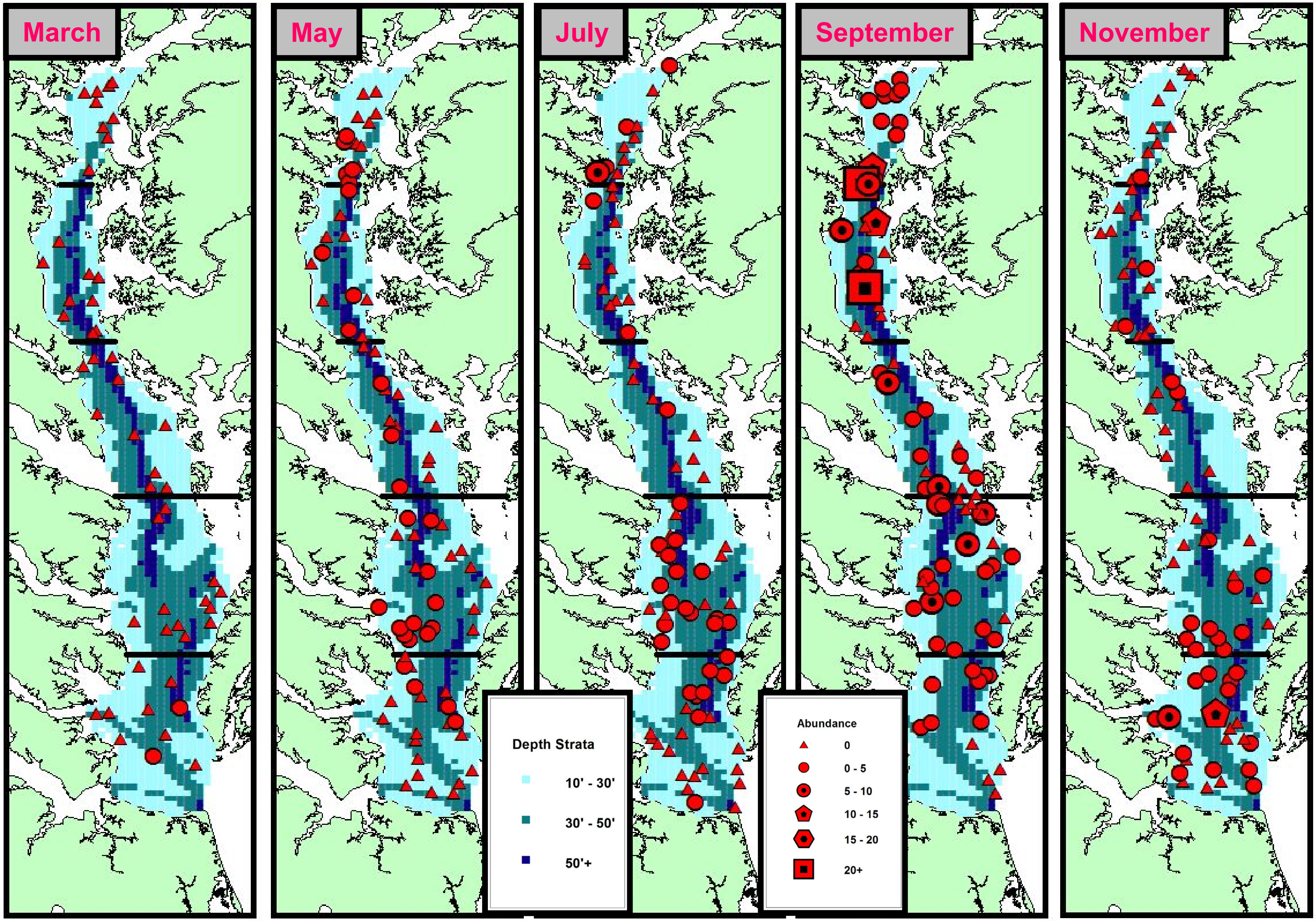


Figure 77. Abundance (number per hectare swept) of spot in Chesapeake Bay, 2003.

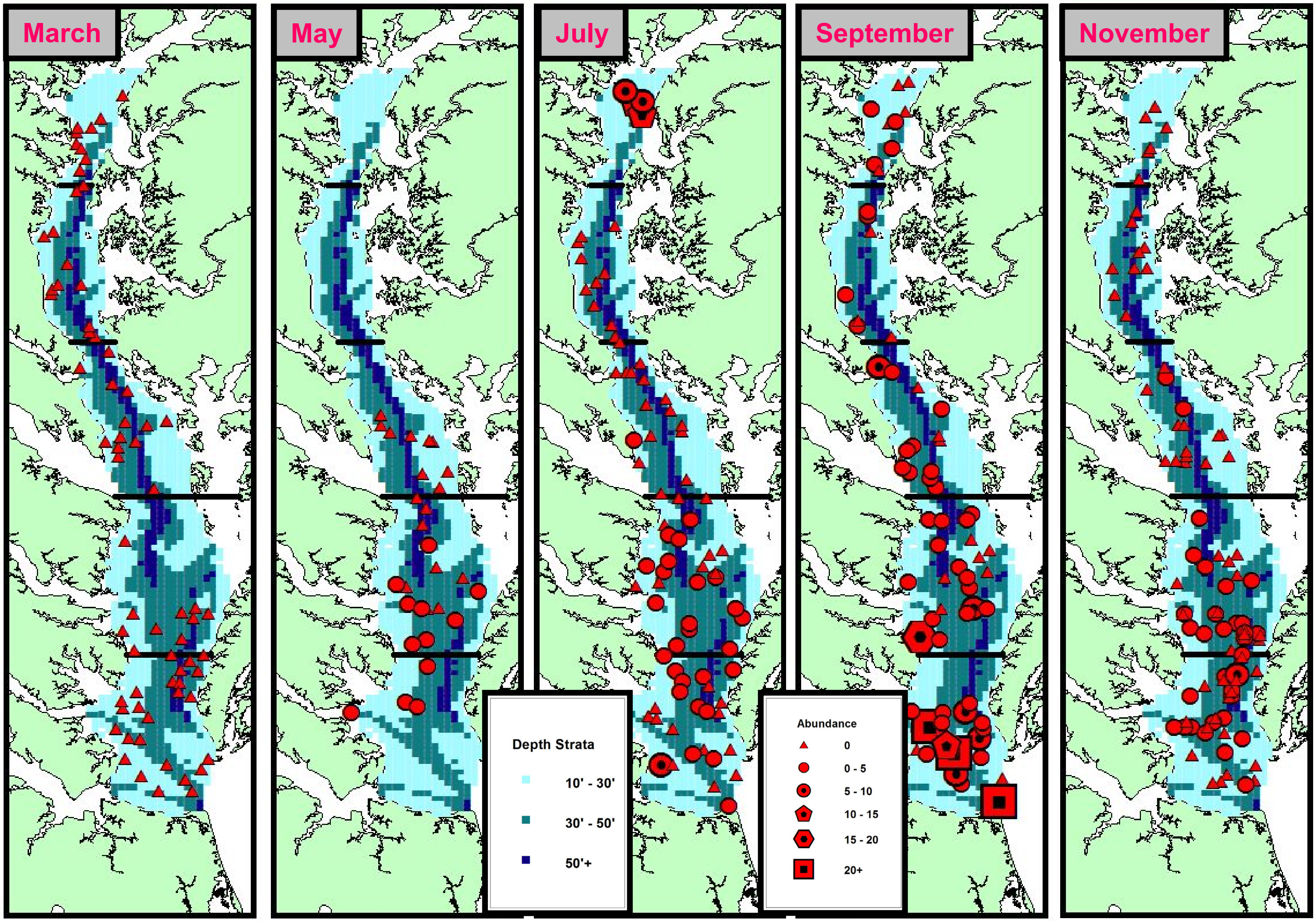


Figure 78. Abundance (number per hectare swept) of spot in Chesapeake Bay, 2004.

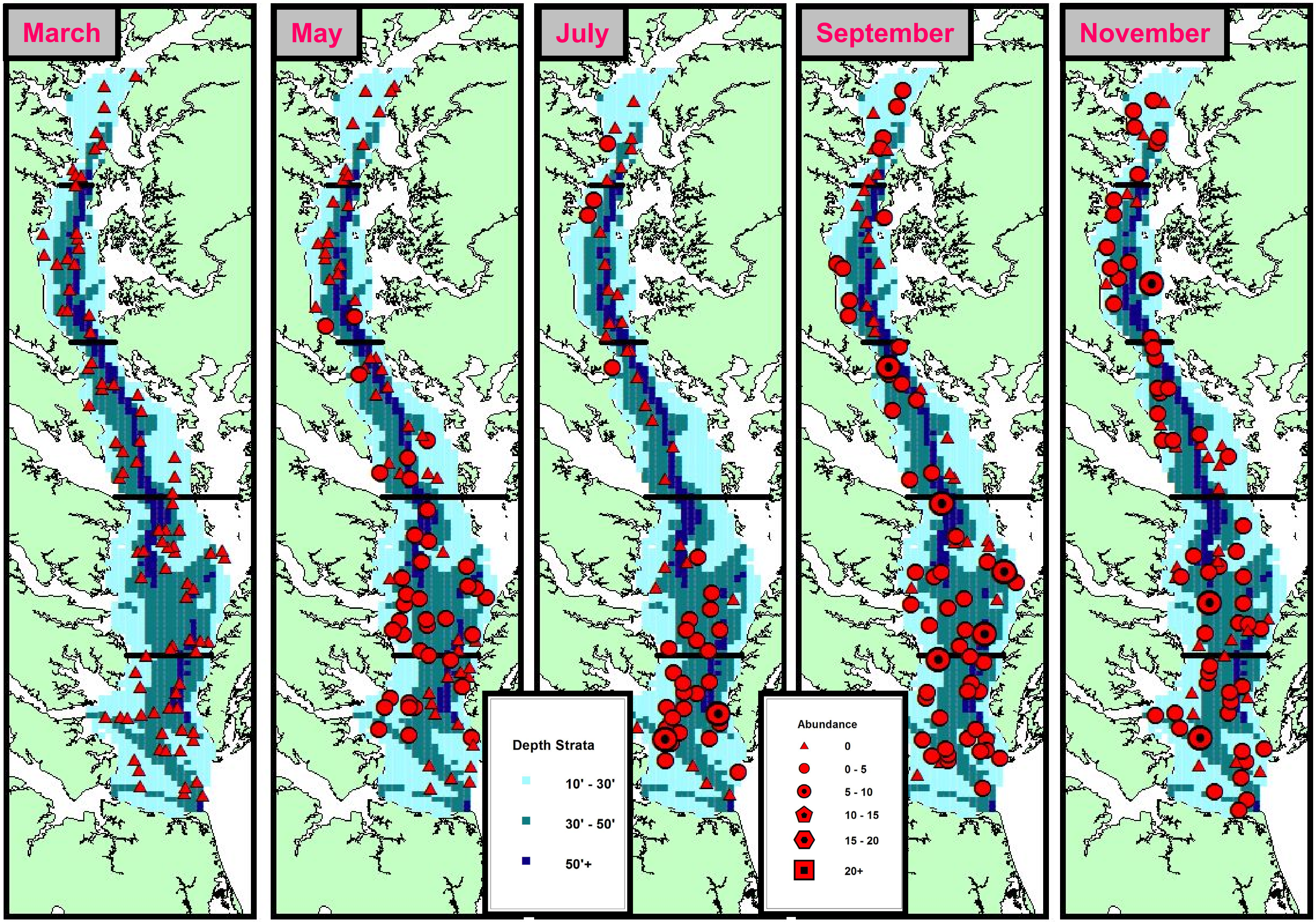


Figure 79. Abundance (number per hectare swept) of spot in Chesapeake Bay, 2005.

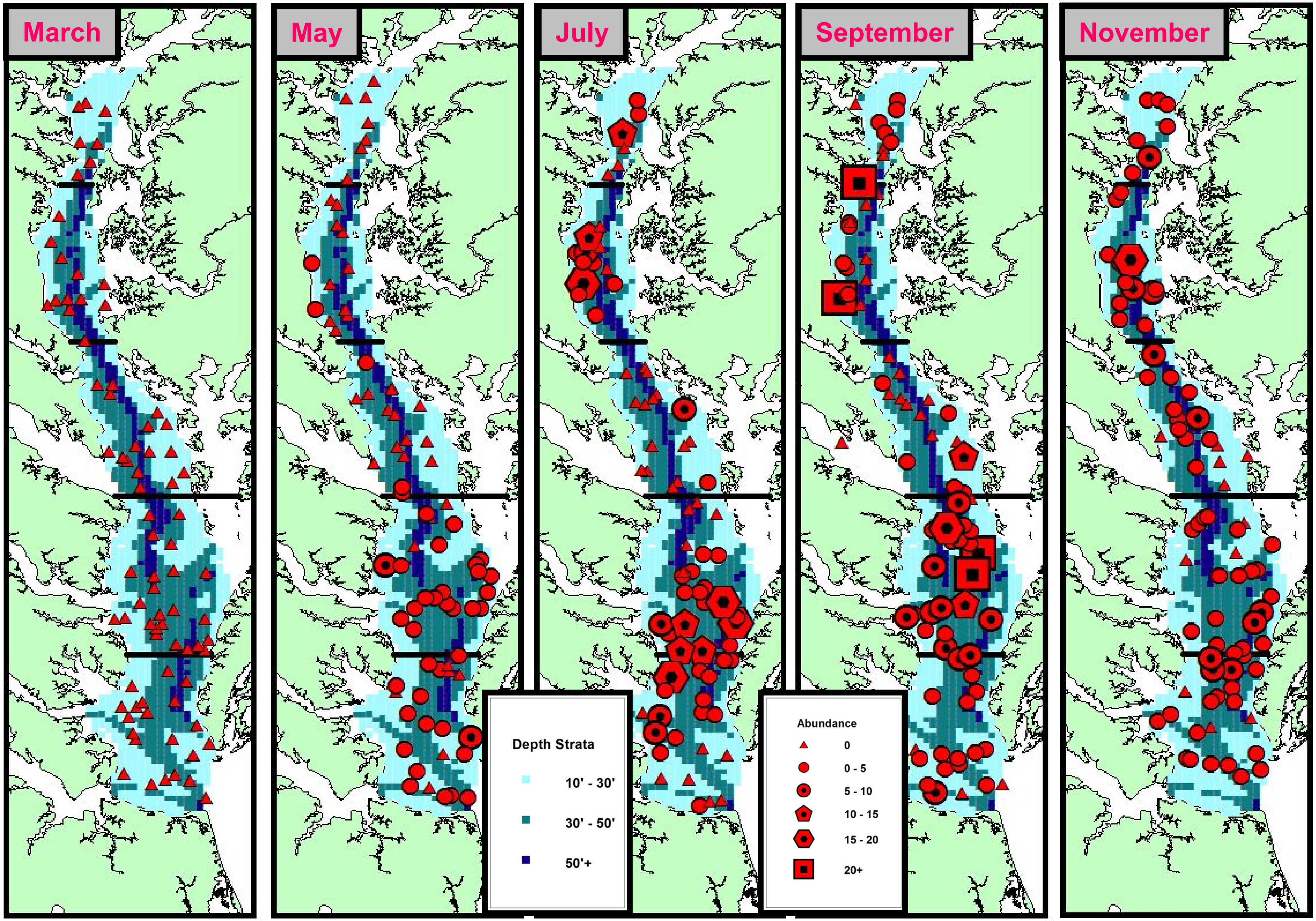


Figure 80. Abundance (number per hectare swept) of spot in Chesapeake Bay, 2006.

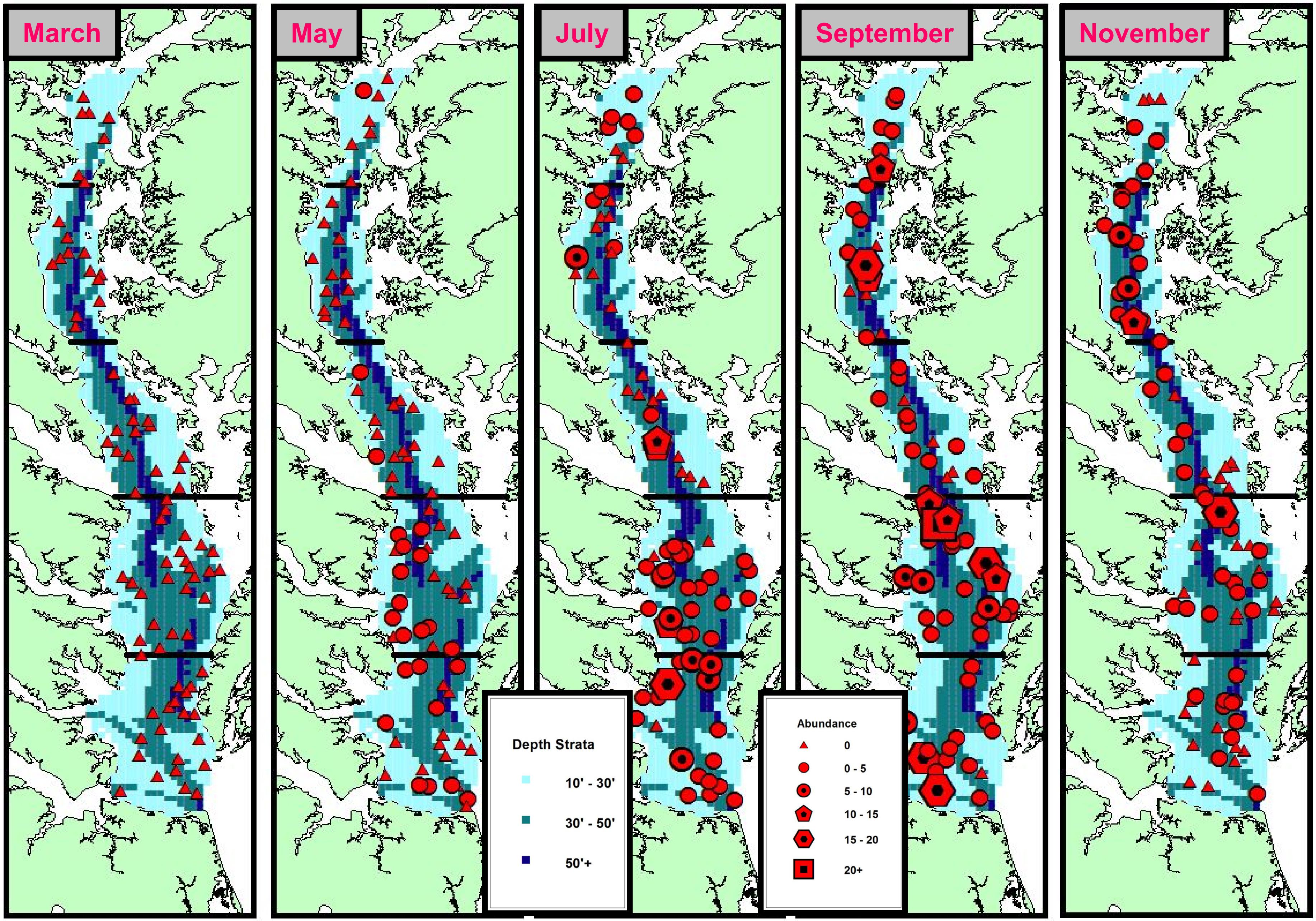


Figure 81. Abundance (number per hectare swept) of spot in Chesapeake Bay, 2007.

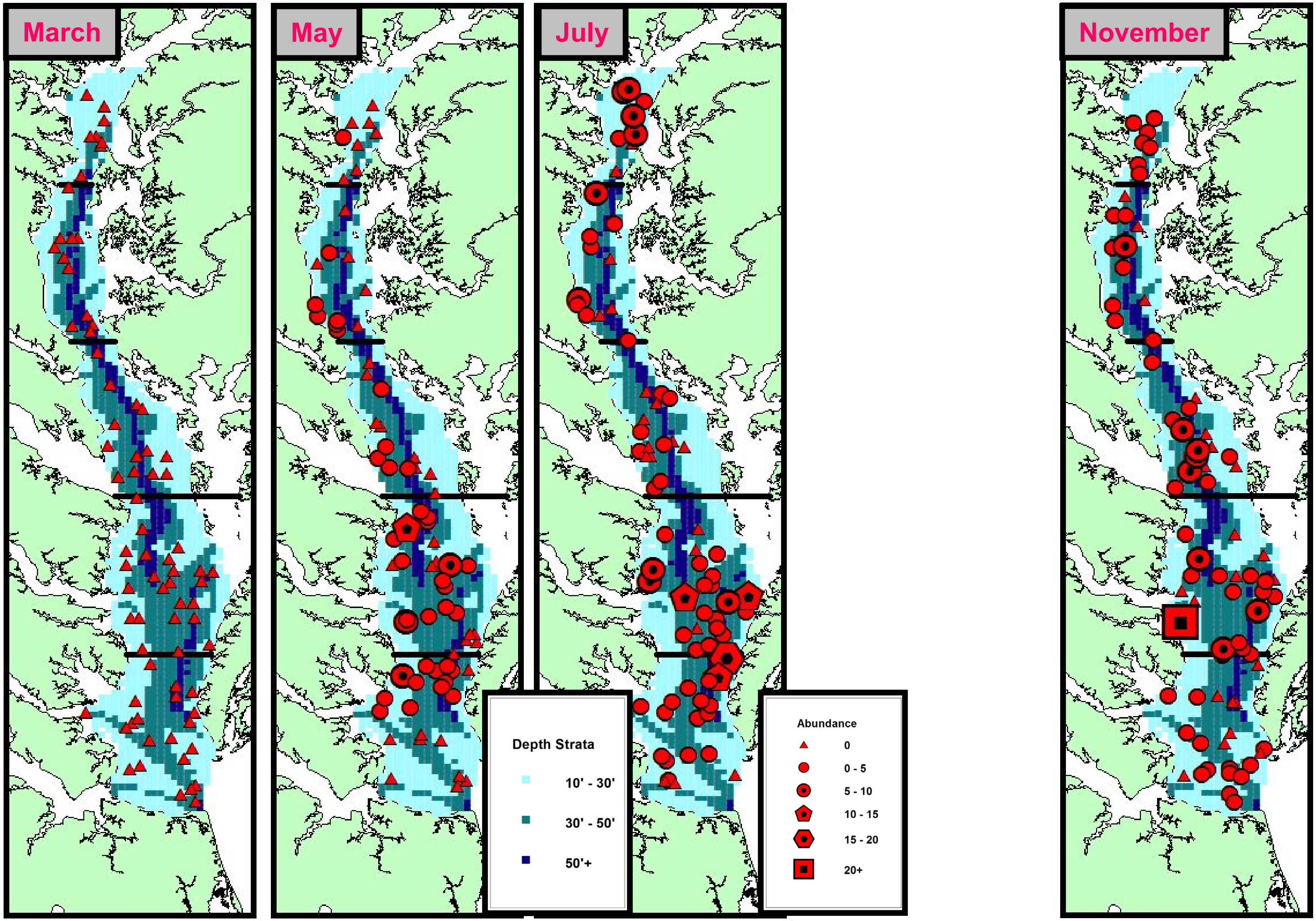


Figure 82. Spot length-frequency in Chesapeake Bay, 2002-2007.

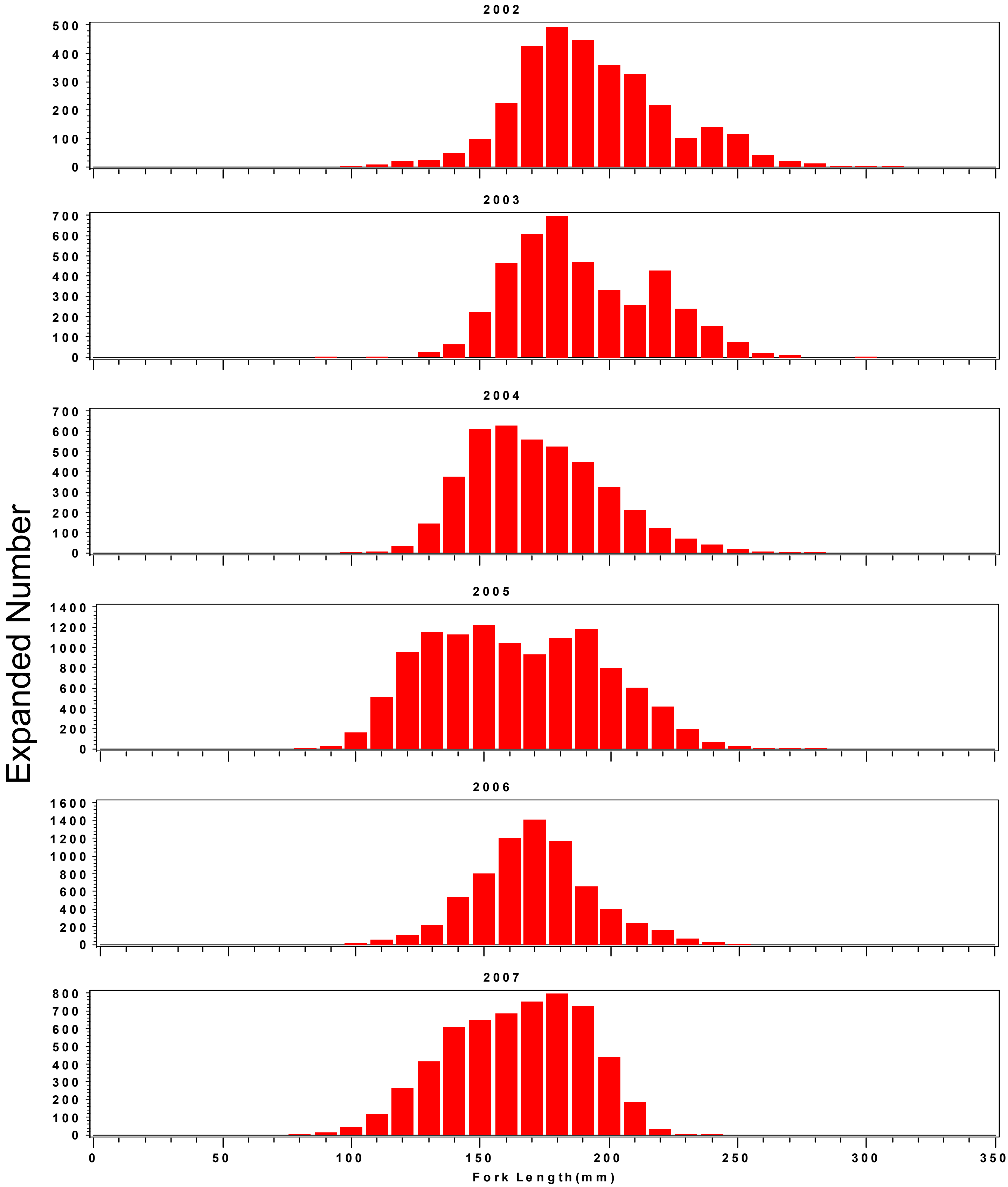


Figure 83. Spot age-structure in Chesapeake Bay, 2002-2007.

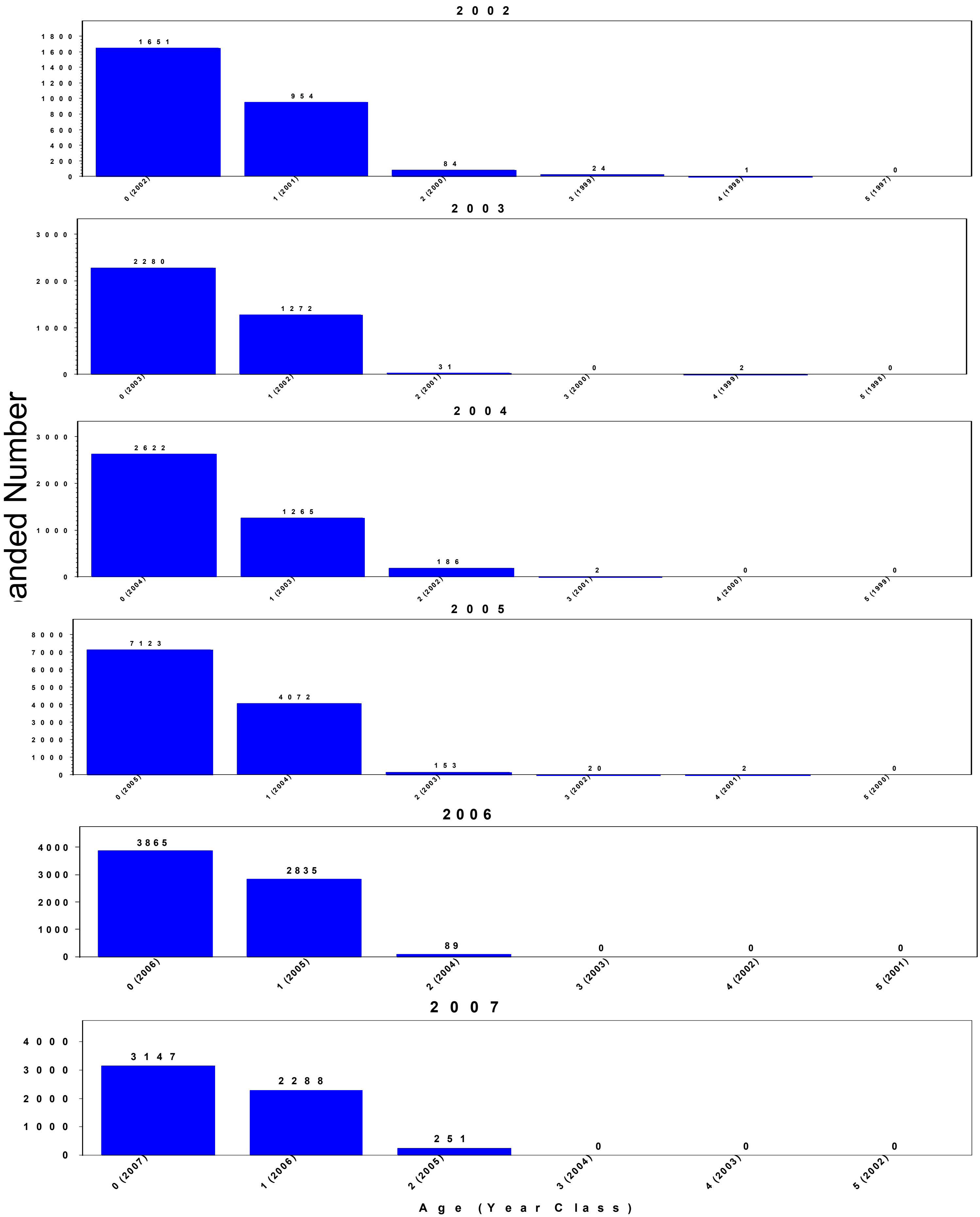
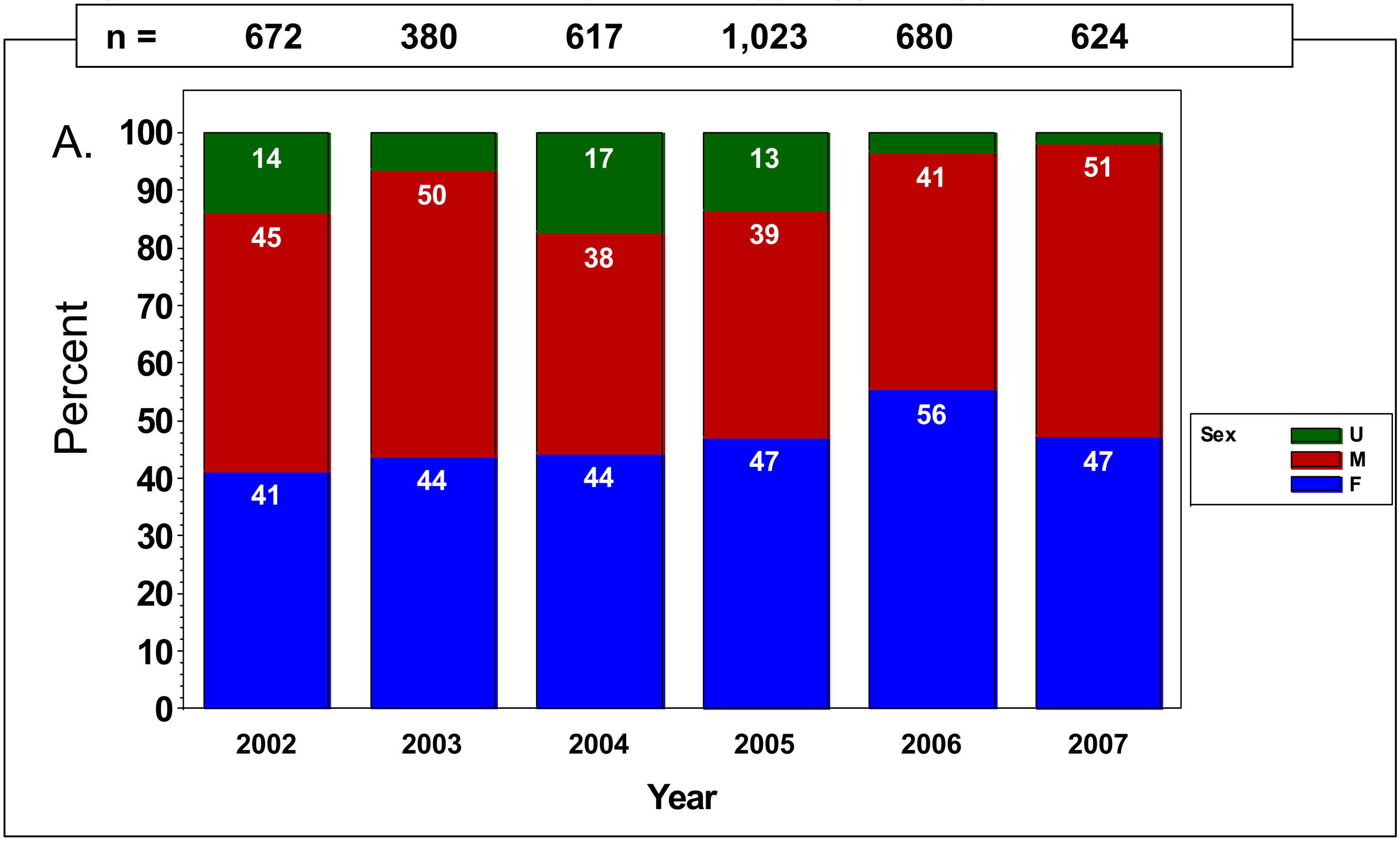


Figure 84. Spot sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B).



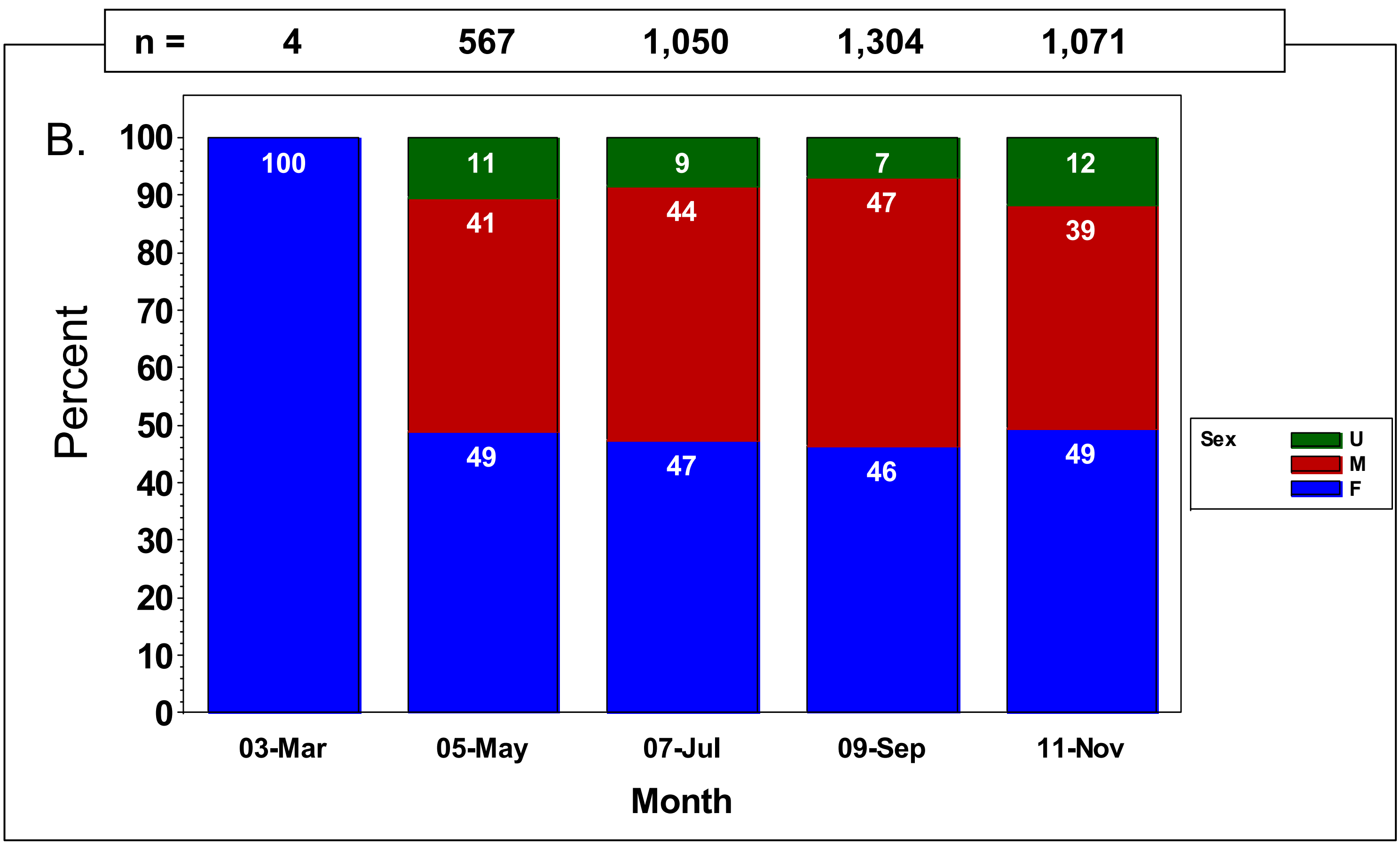
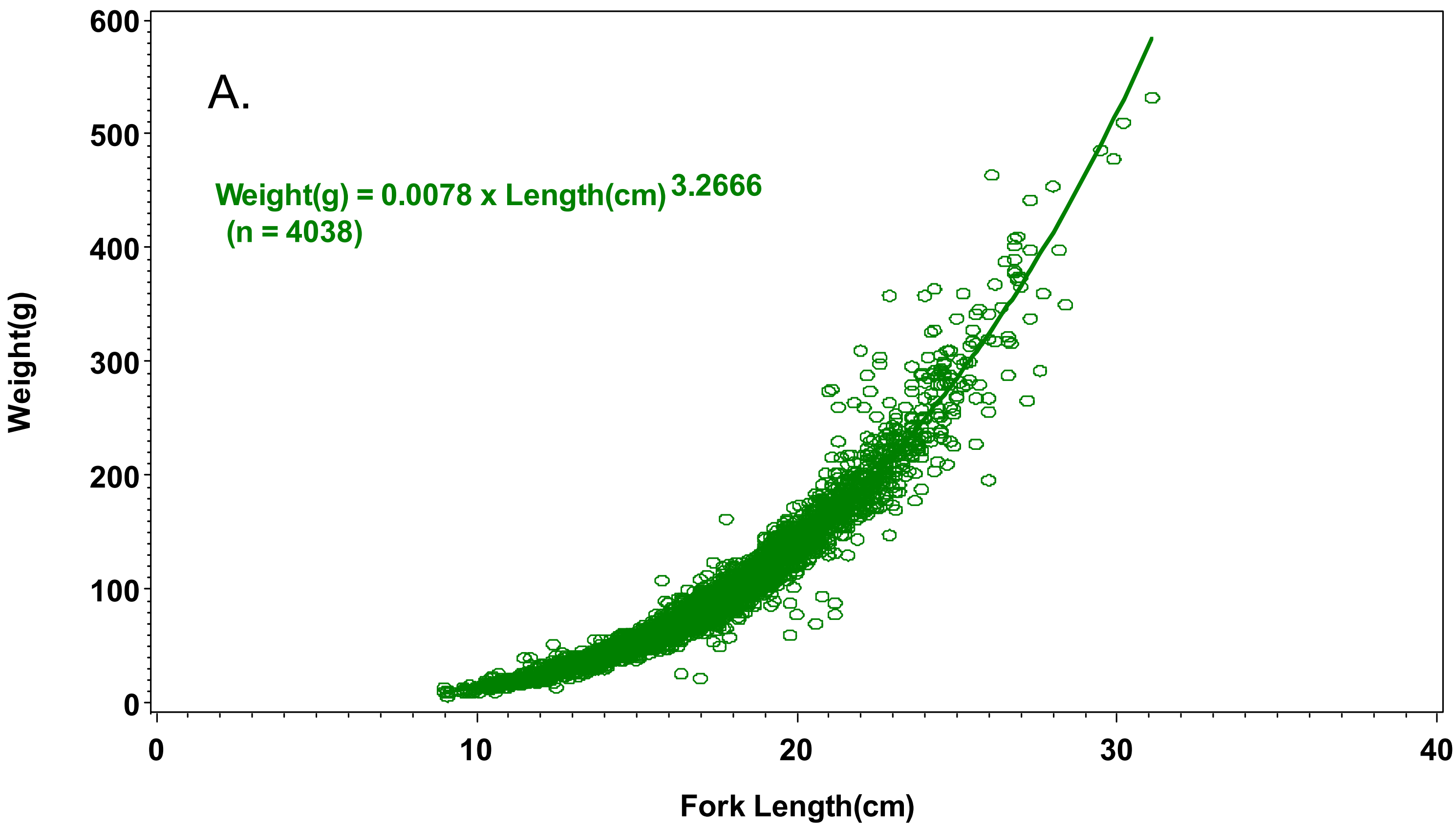


Figure 85. Spot length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).



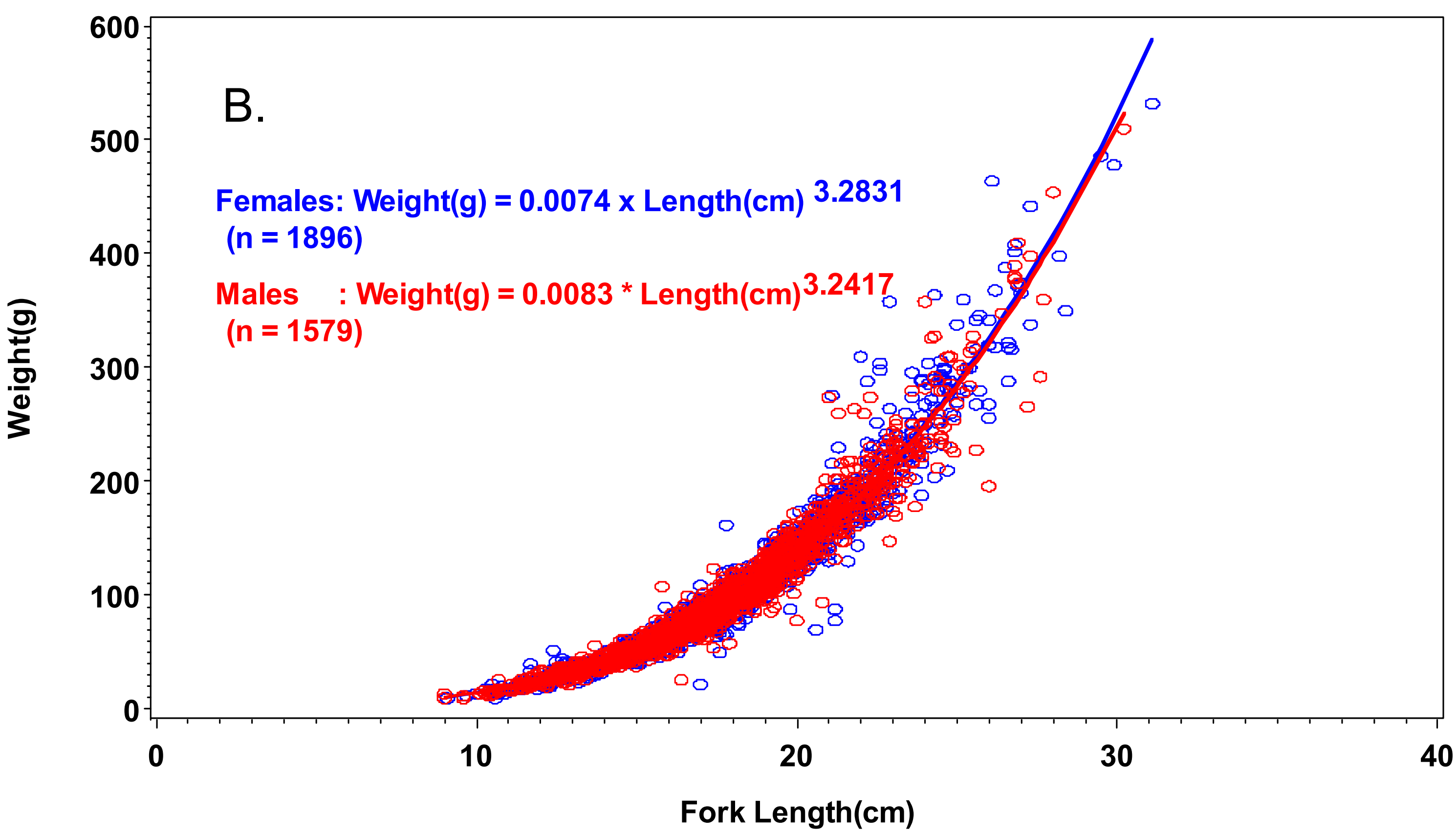


Figure 86. Spot maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

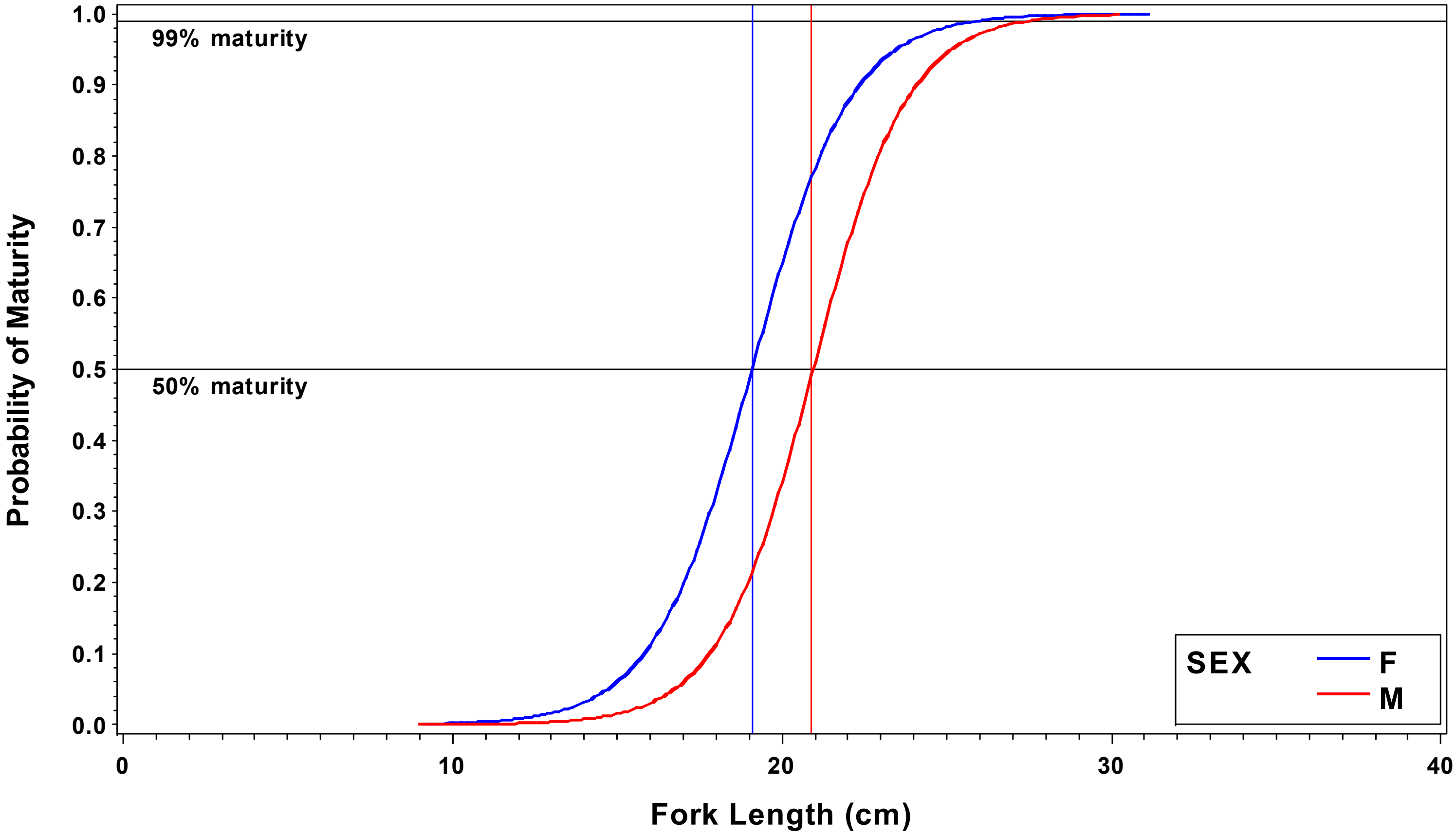
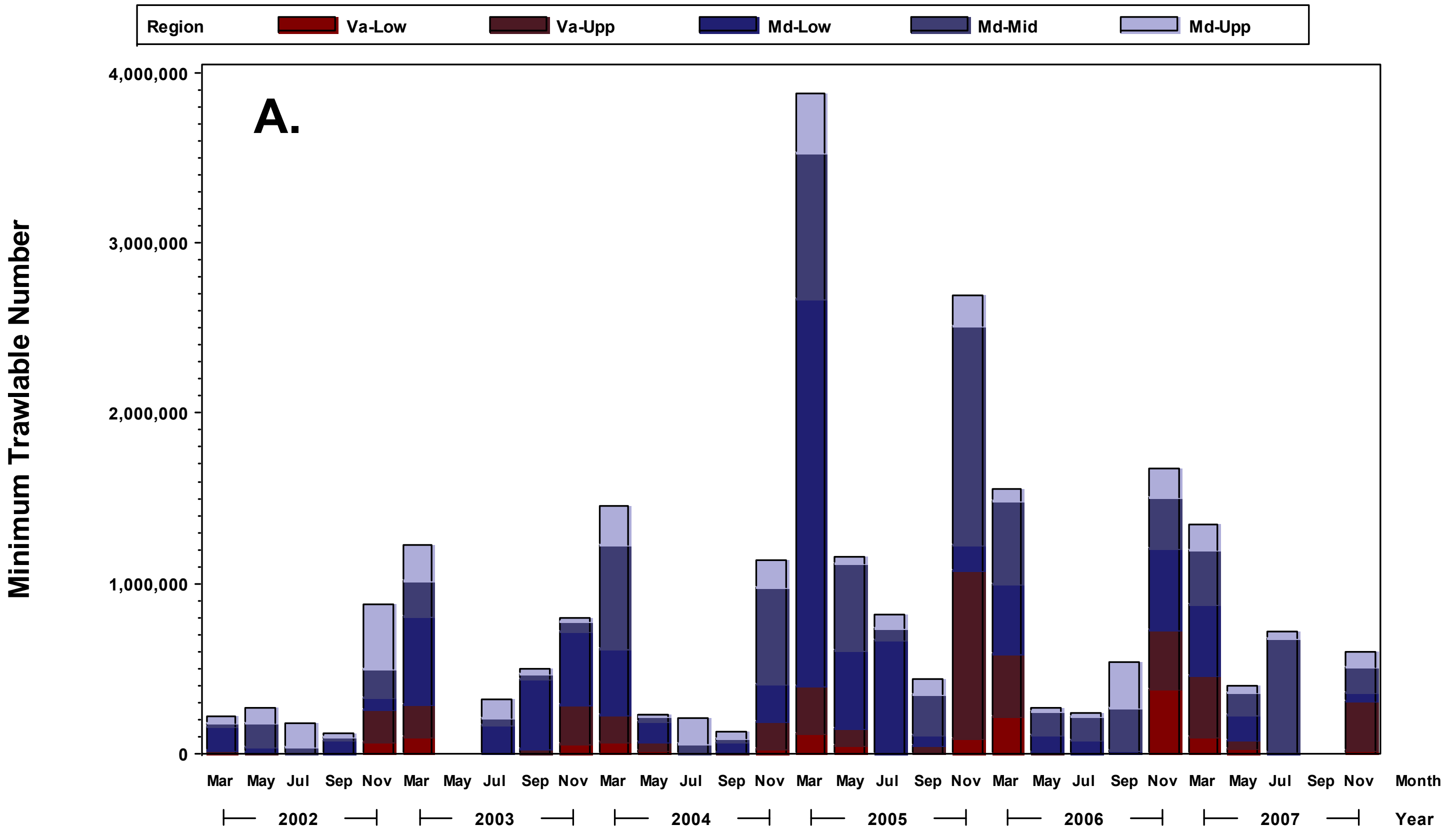


Figure 87. Striped bass minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.



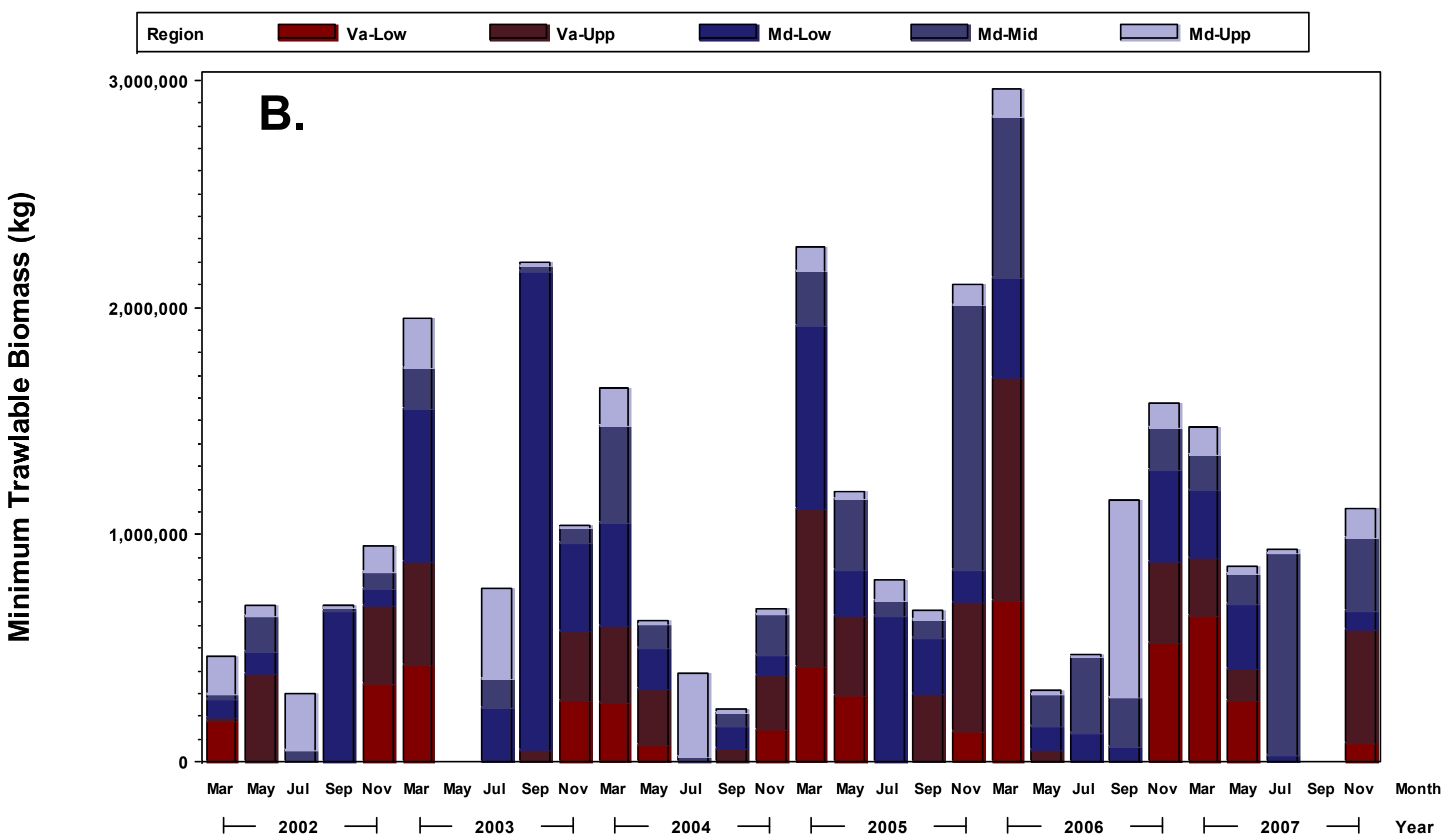


Figure 88. Abundance (number per hectare swept) of striped bass in Chesapeake Bay, 2002.

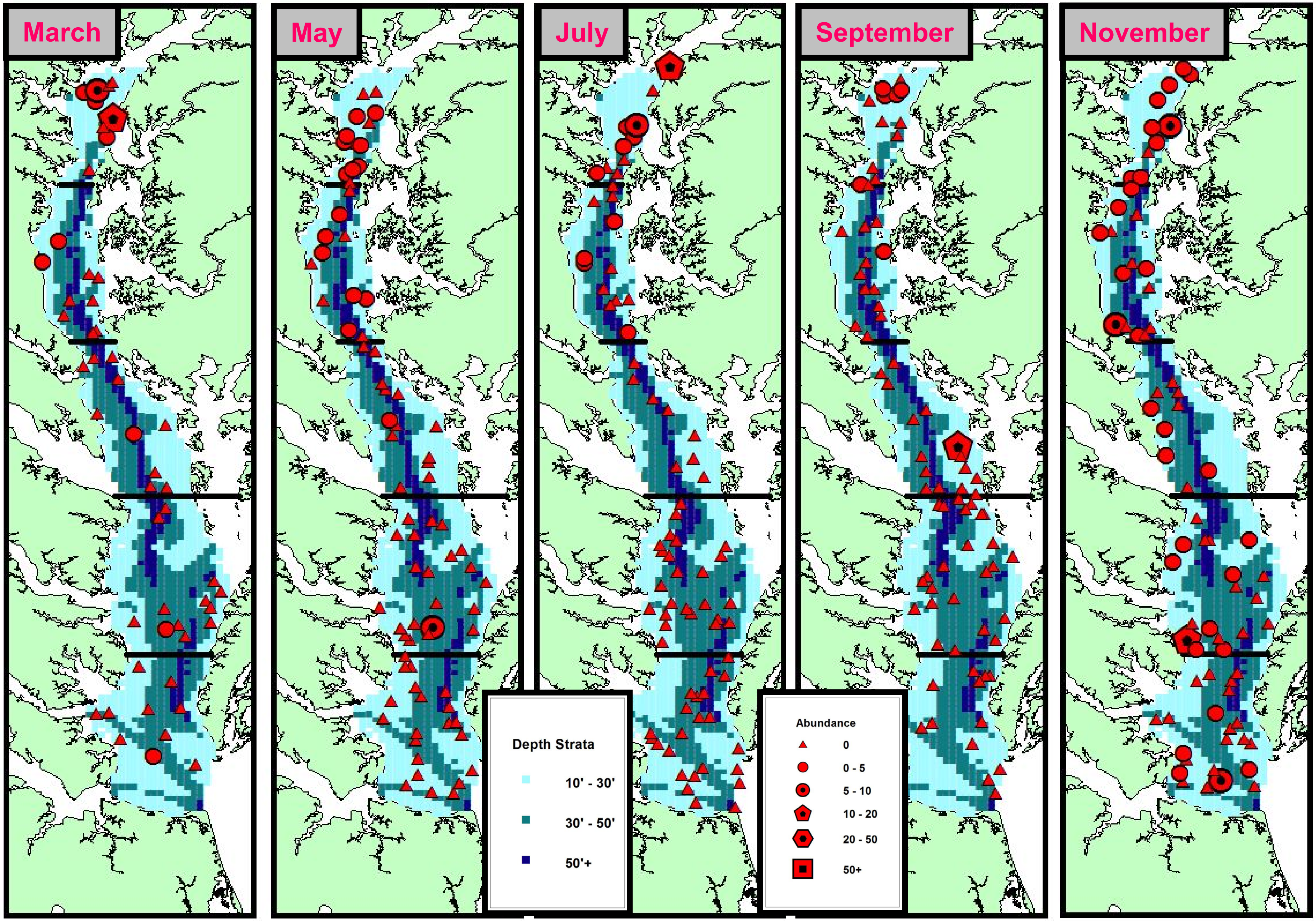


Figure 89. Abundance (number per hectare swept) of striped bass in Chesapeake Bay, 2003.

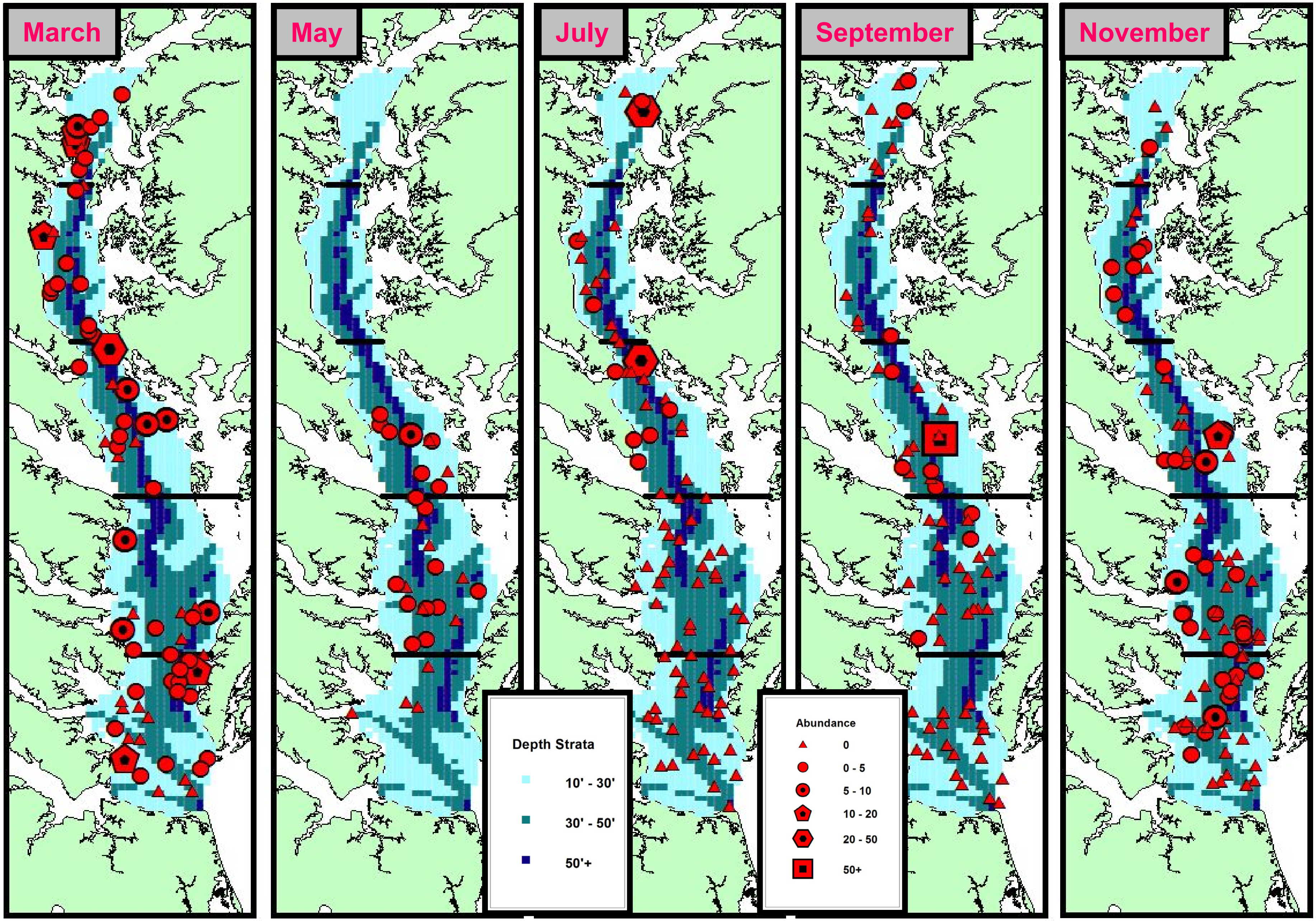


Figure 90. Abundance (number per hectare swept) of striped bass in Chesapeake Bay, 2004.

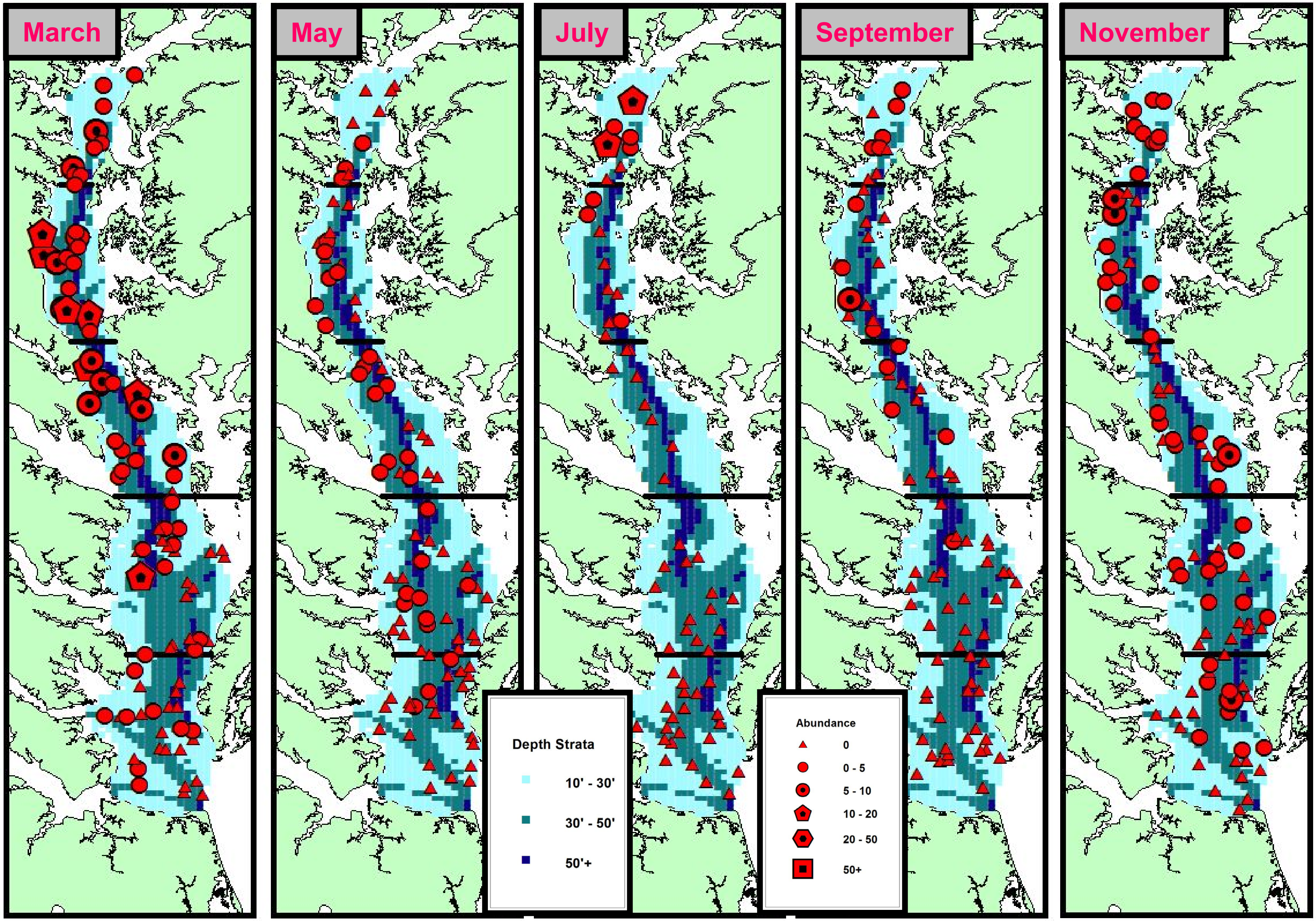


Figure 91. Abundance (number per hectare swept) of striped bass in Chesapeake Bay, 2005.

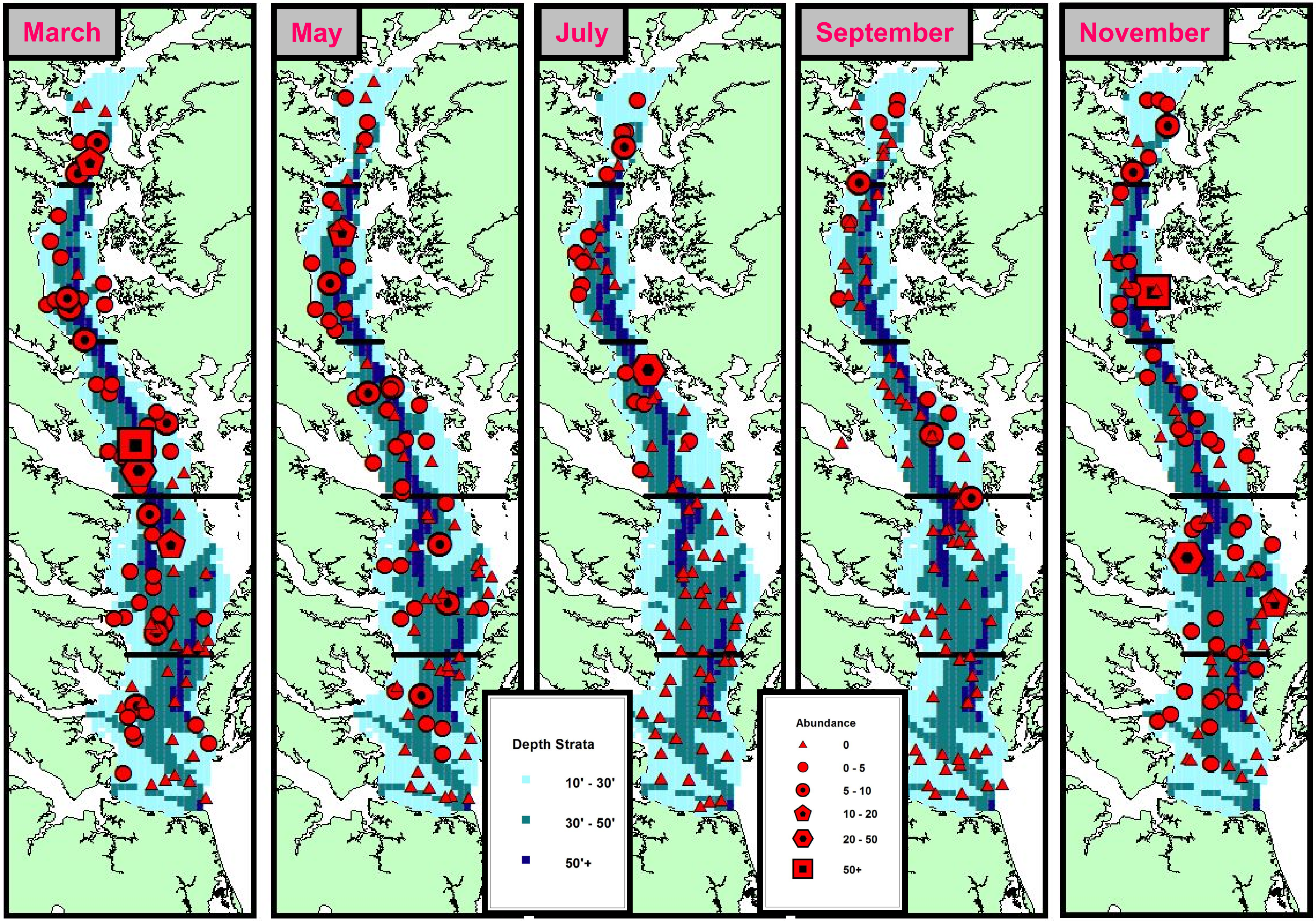


Figure 92. Abundance (number per hectare swept) of striped bass in Chesapeake Bay, 2006.

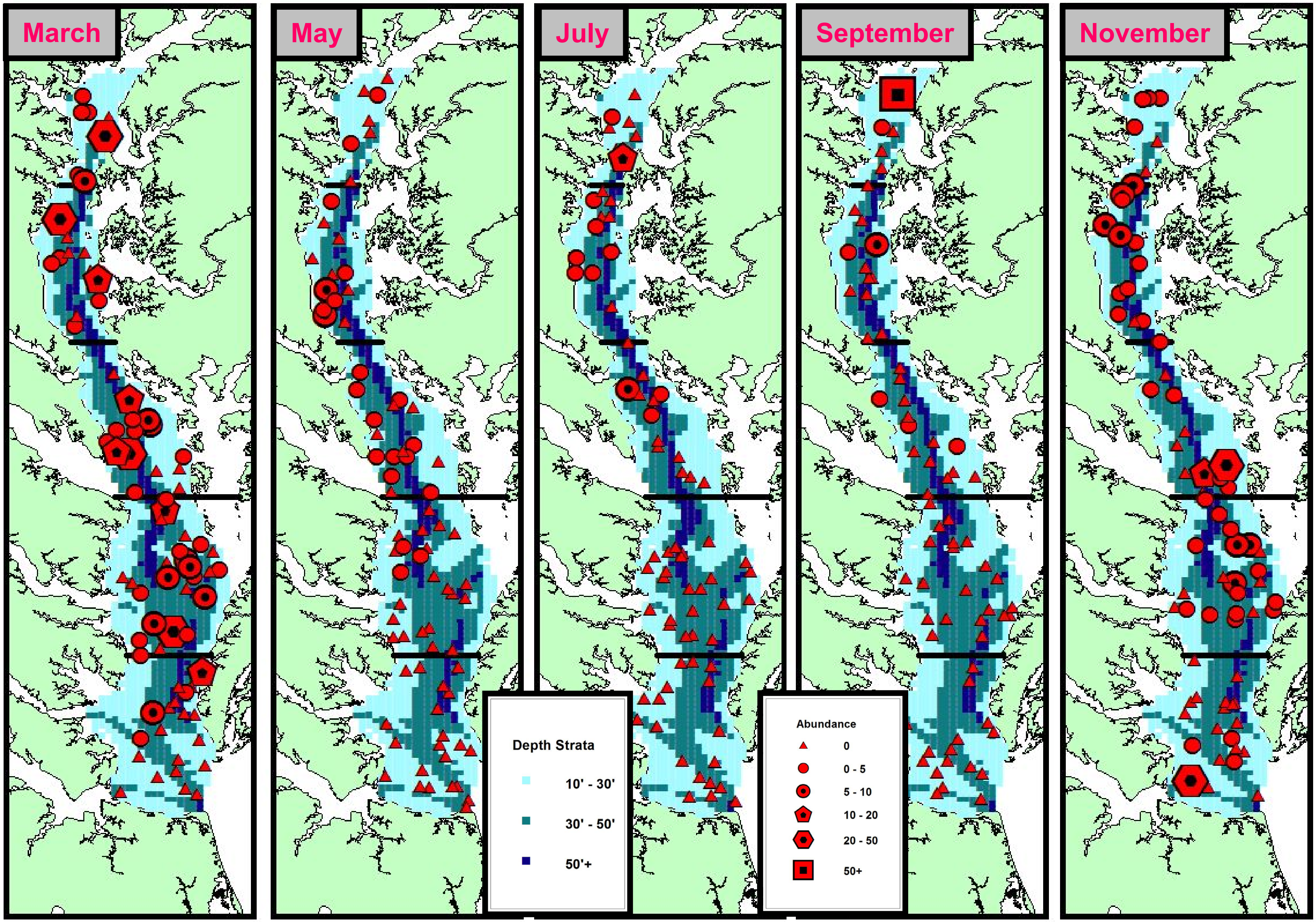


Figure 93. Abundance (number per hectare swept) of striped bass in Chesapeake Bay, 2007.

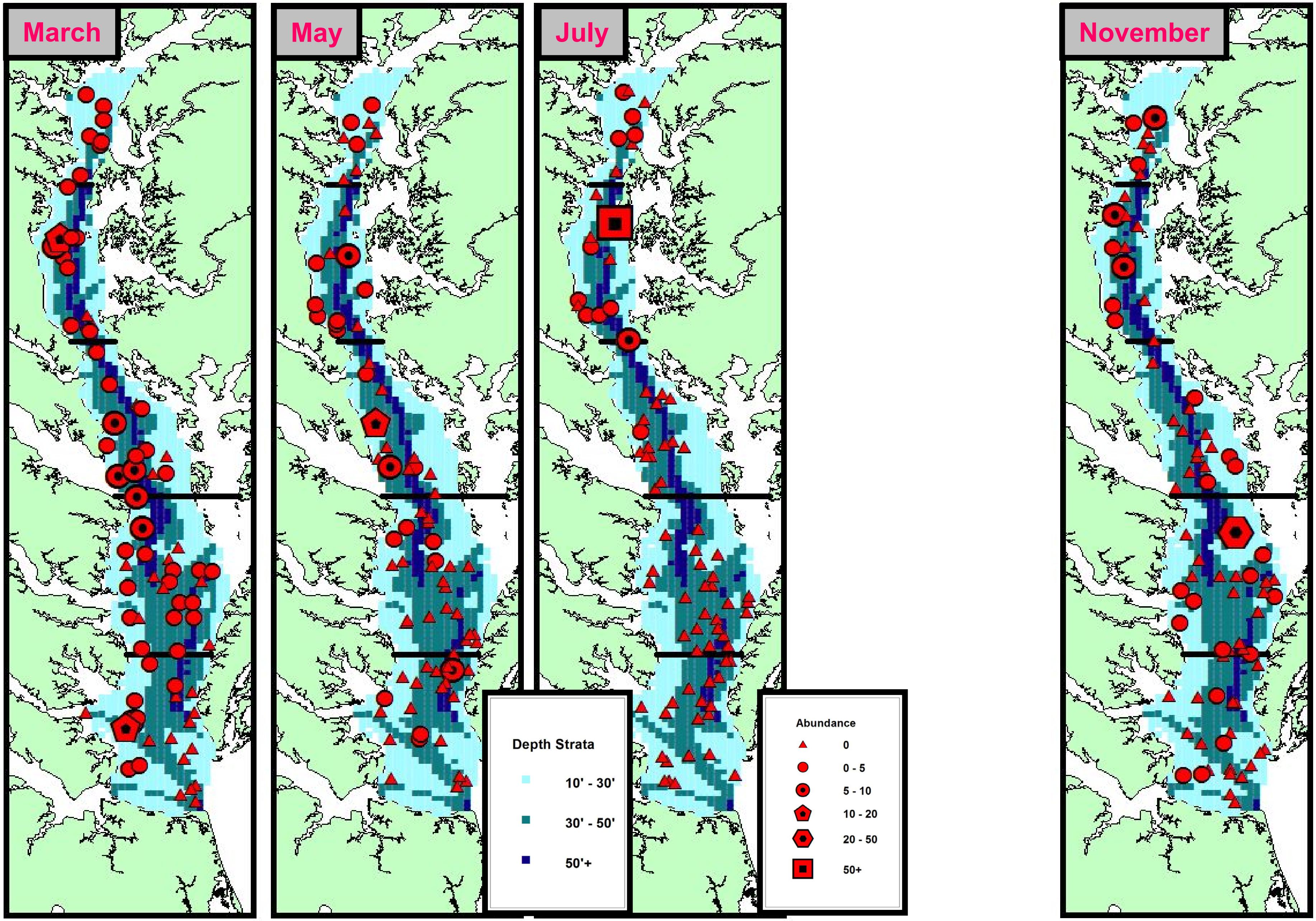


Figure 94. Striped bass length-frequency in Chesapeake Bay, 2002-2007.

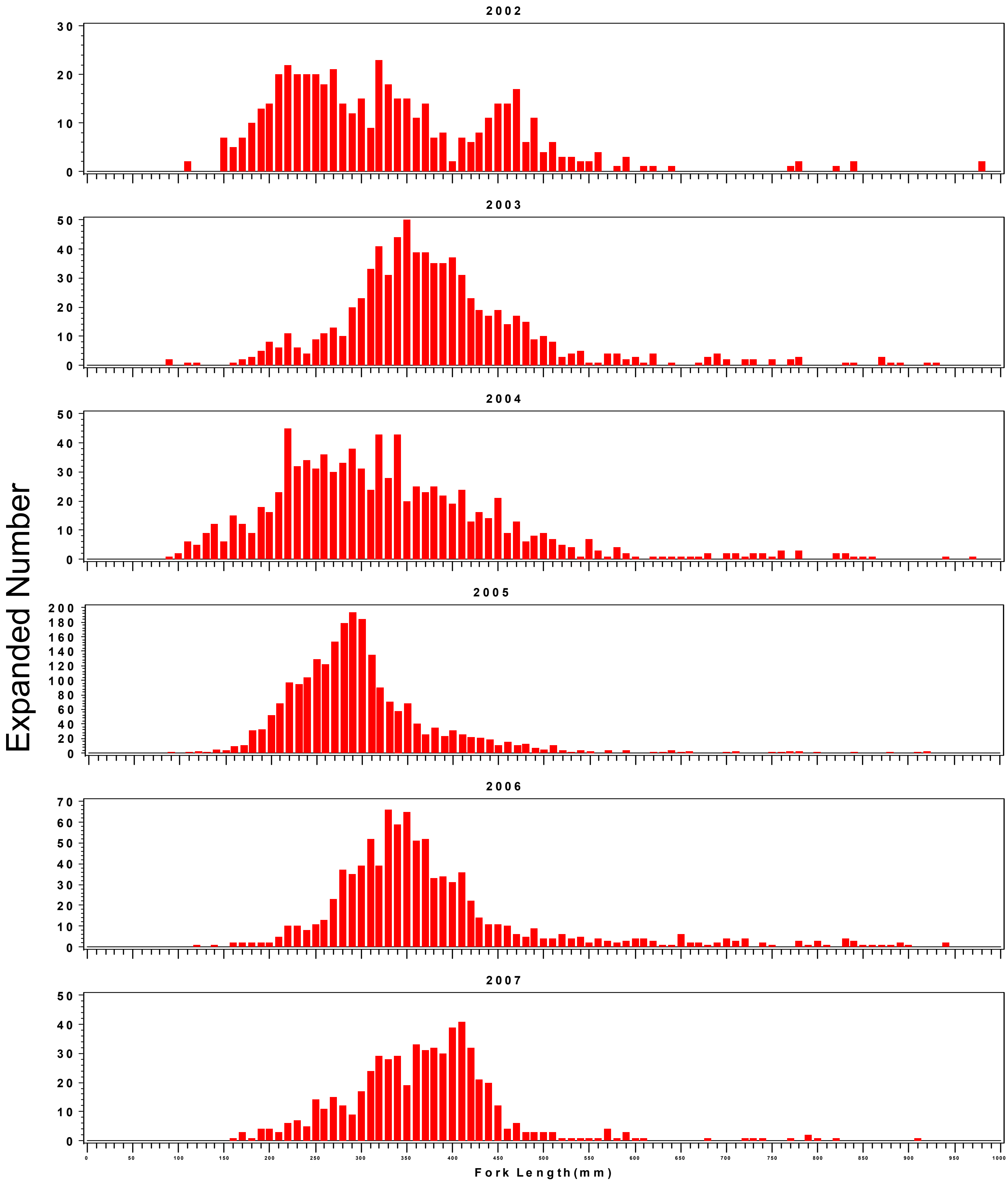


Figure 95. Striped bass age-structure in Chesapeake Bay, 2002-2007.

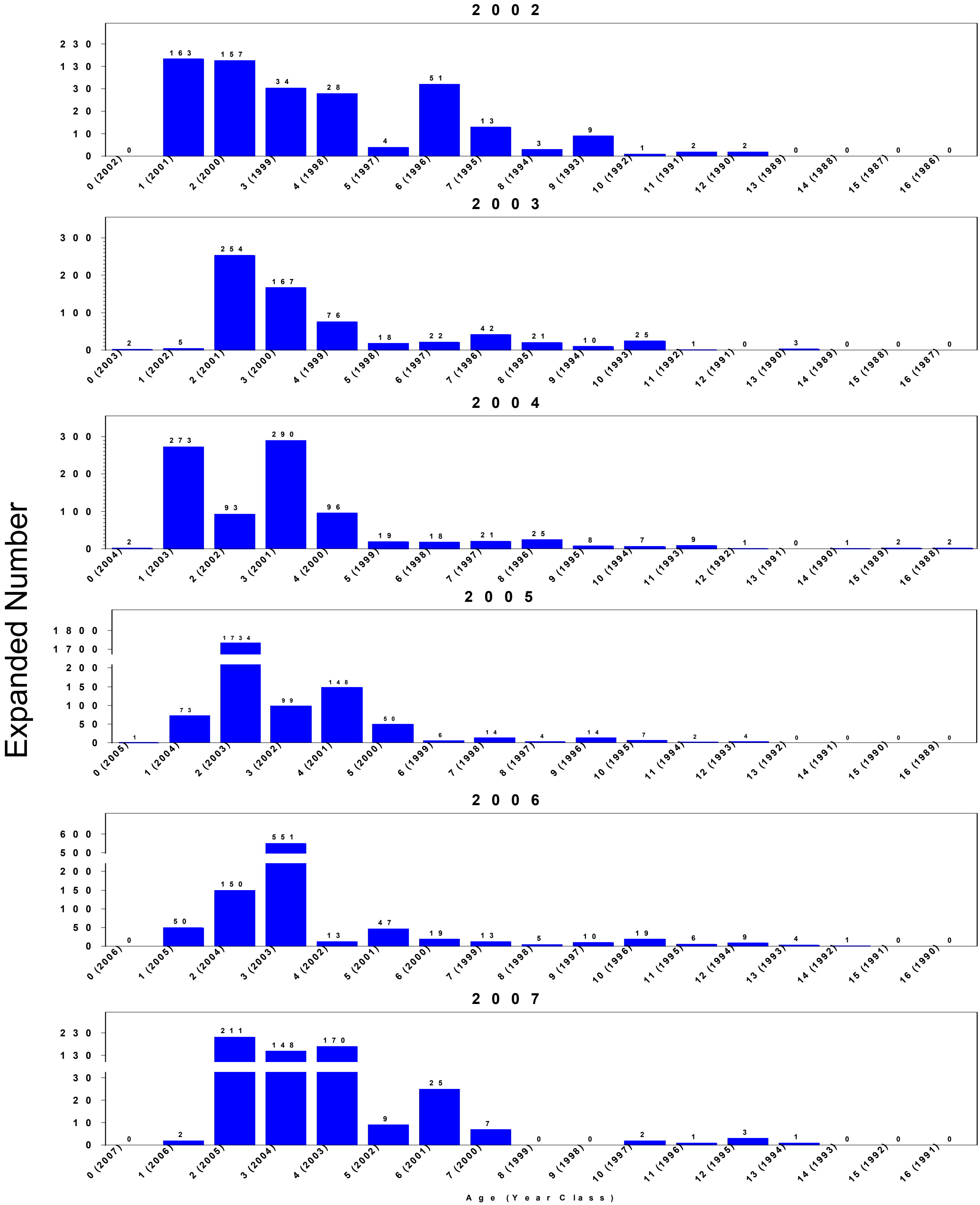


Figure 96. Striped bass sex-ratios in Chesapeake Bay, 2002-2007, by year (A), month (B), age (C).

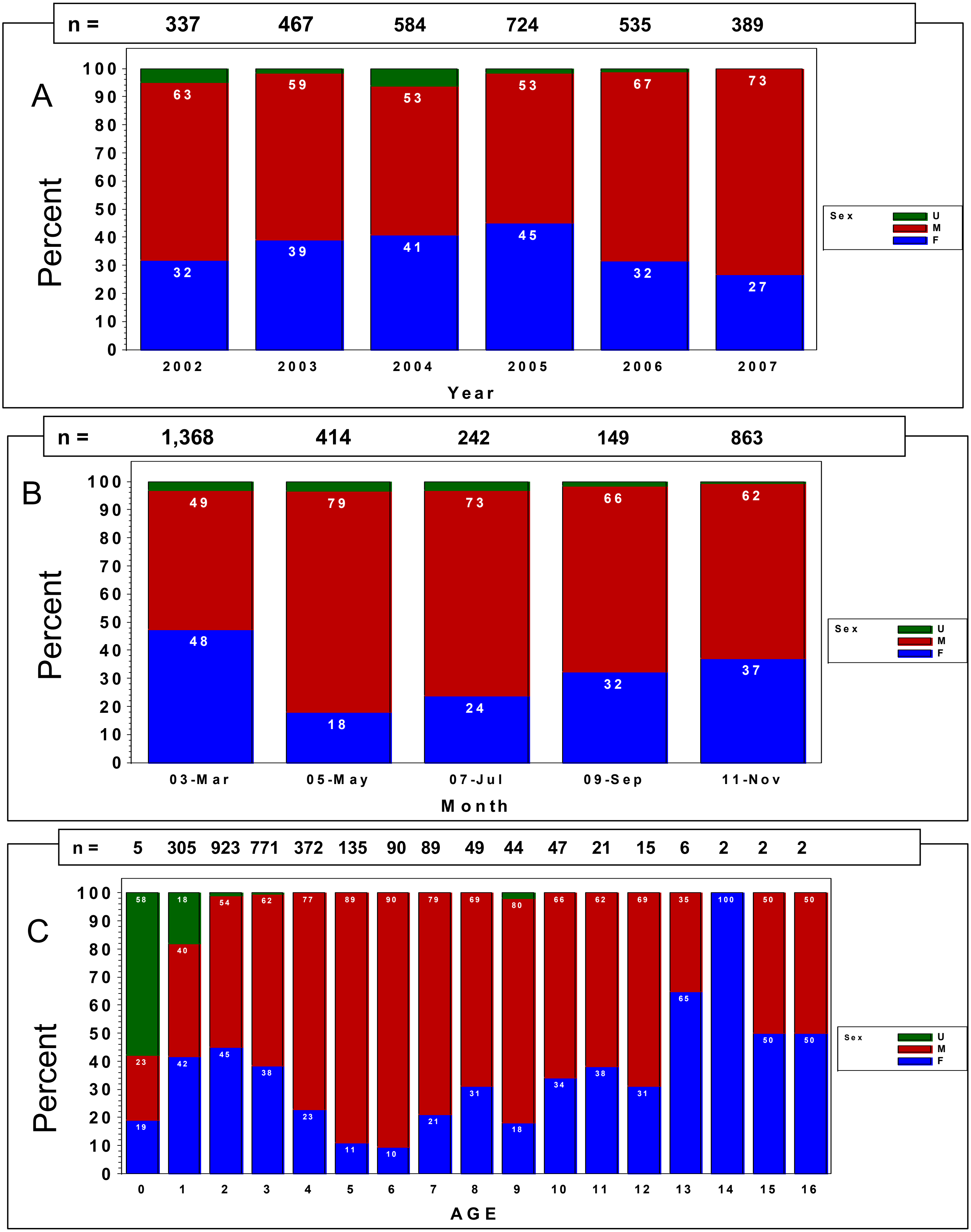
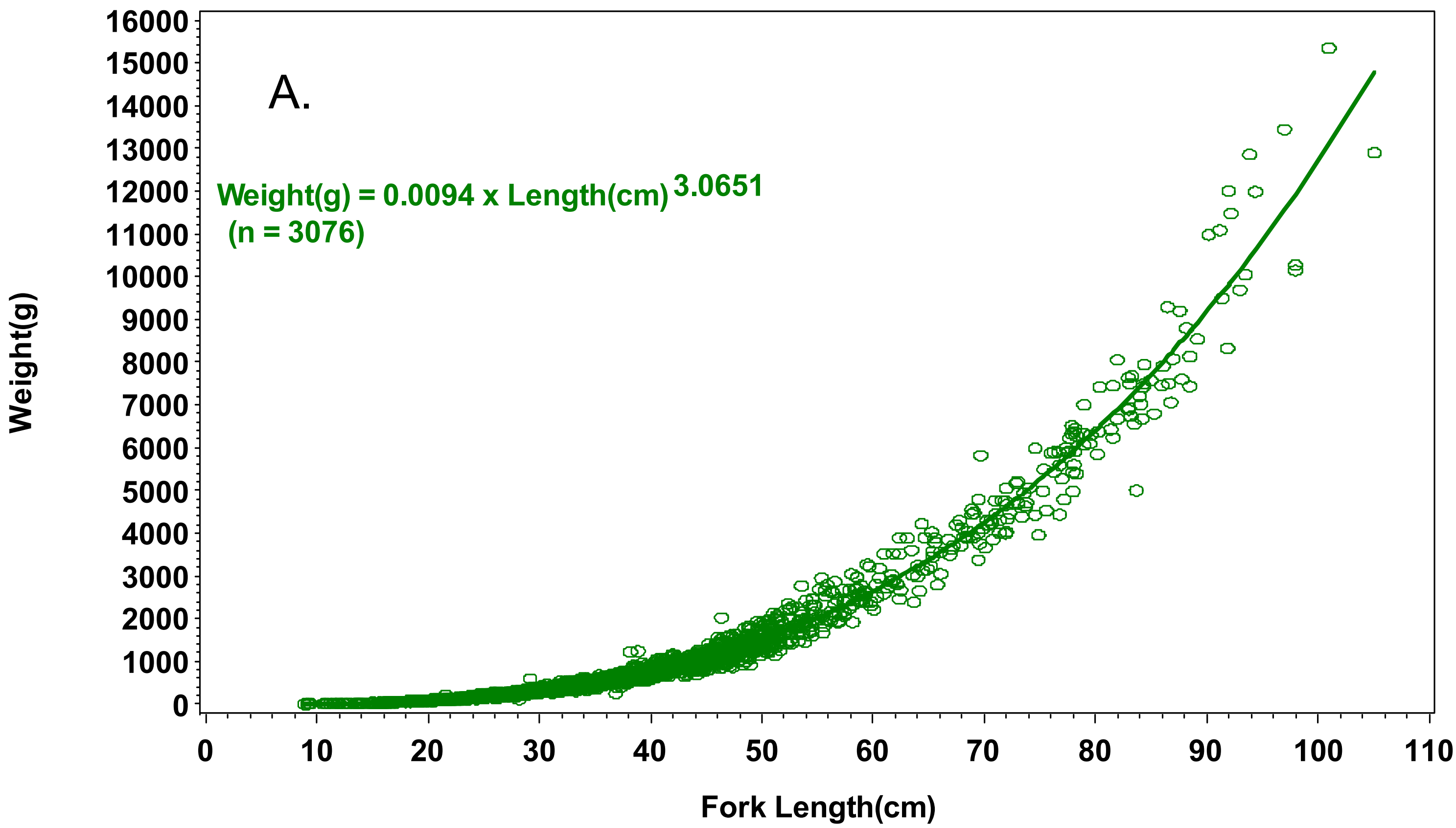


Figure 97. Striped bass length-weight relationships in Chesapeake Bay, 2002-2007 for sexes combined (A) and separately (B).



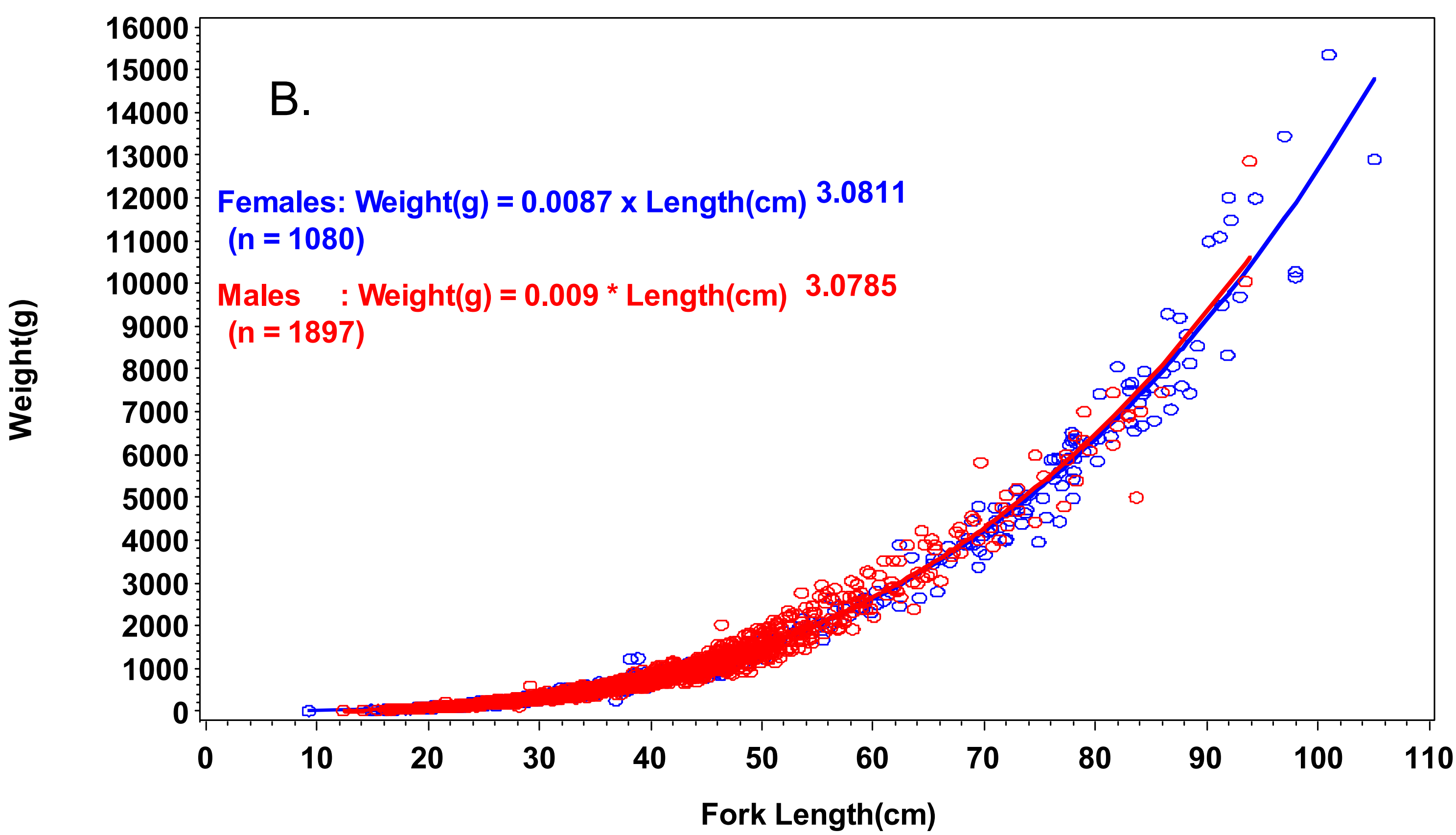


Figure 98. Striped bass maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

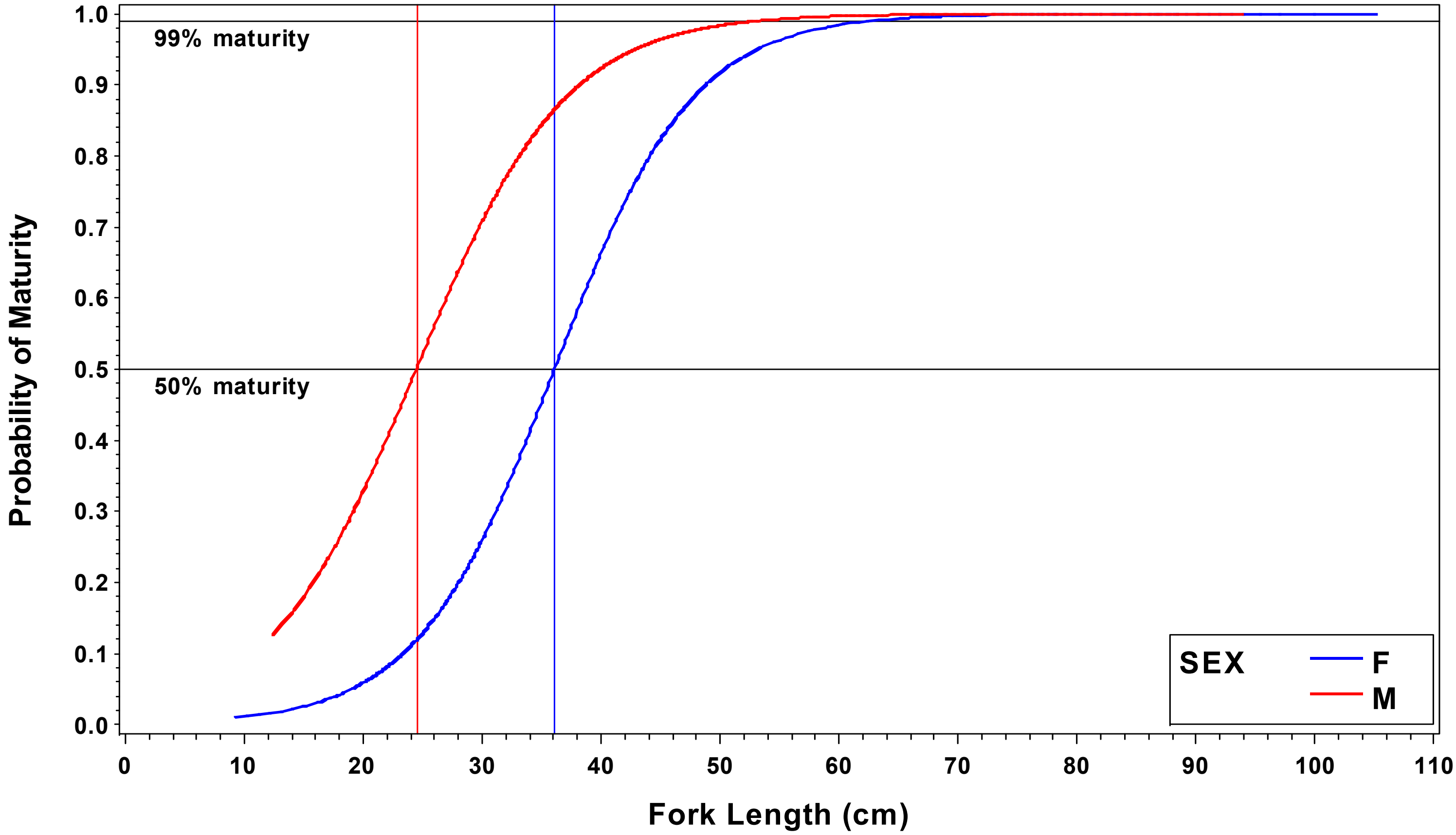


Figure 99. Striped bass diet in Chesapeake Bay, 2002-2007 combined.

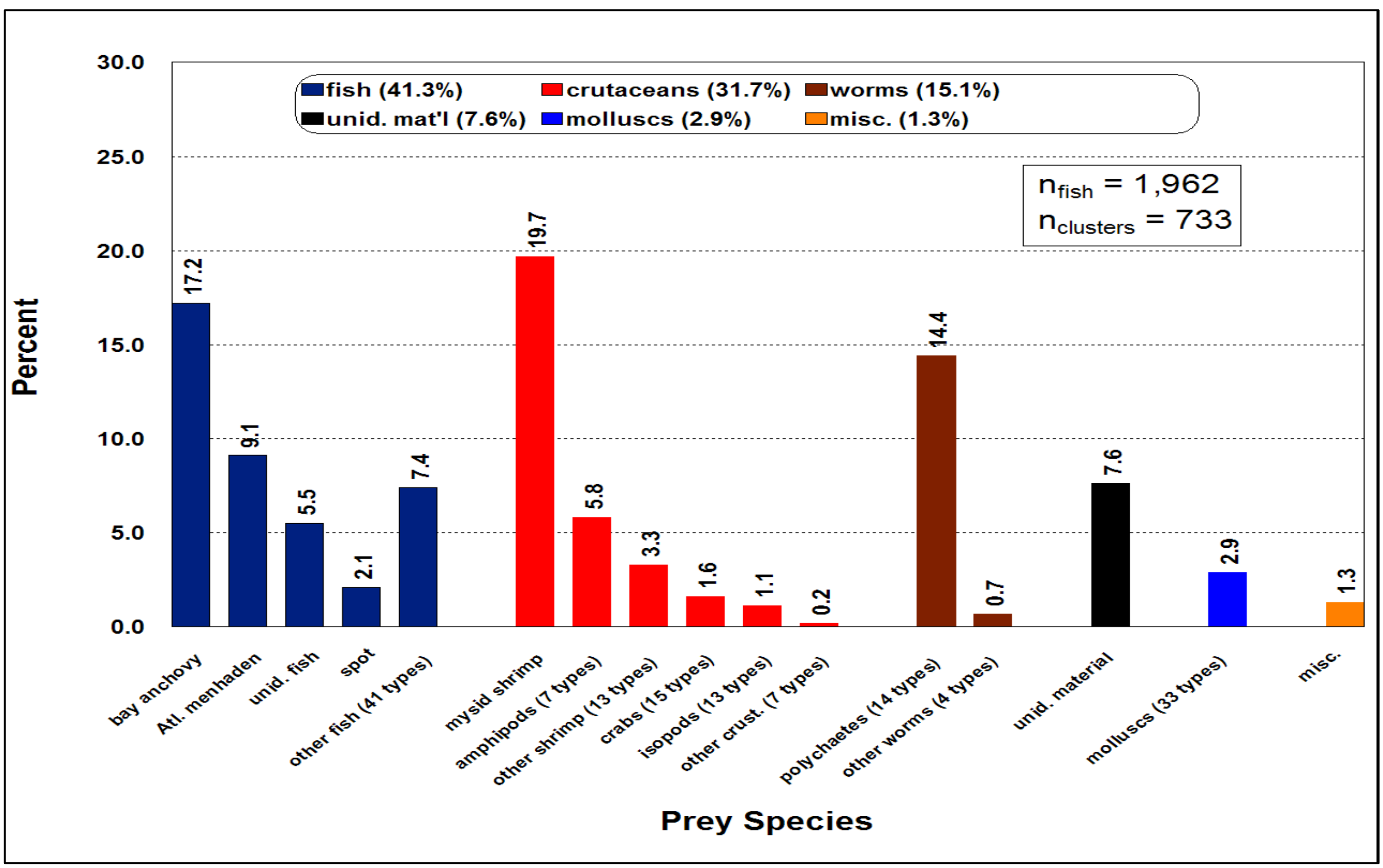
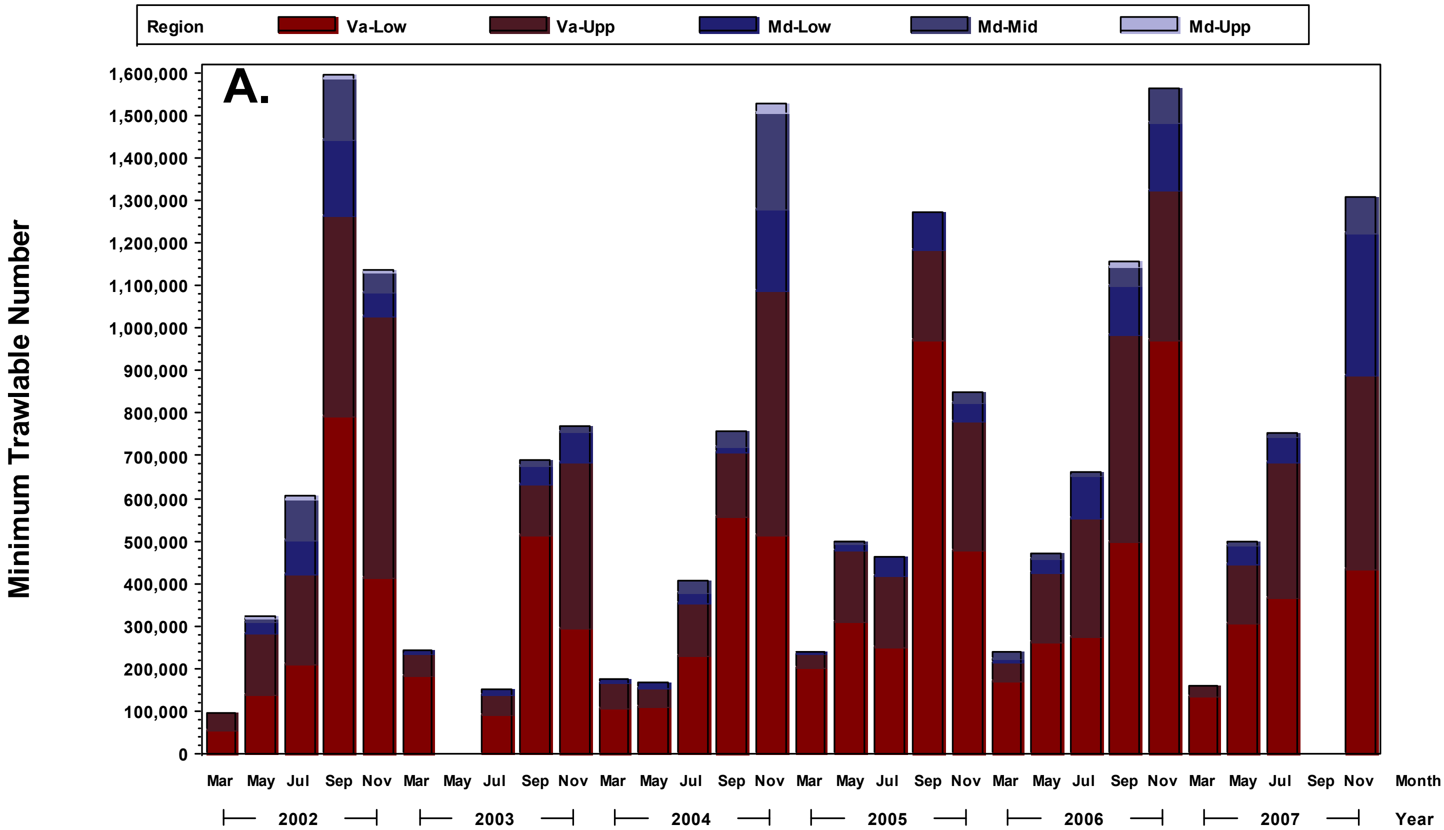


Figure 100. Summer flounder minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.



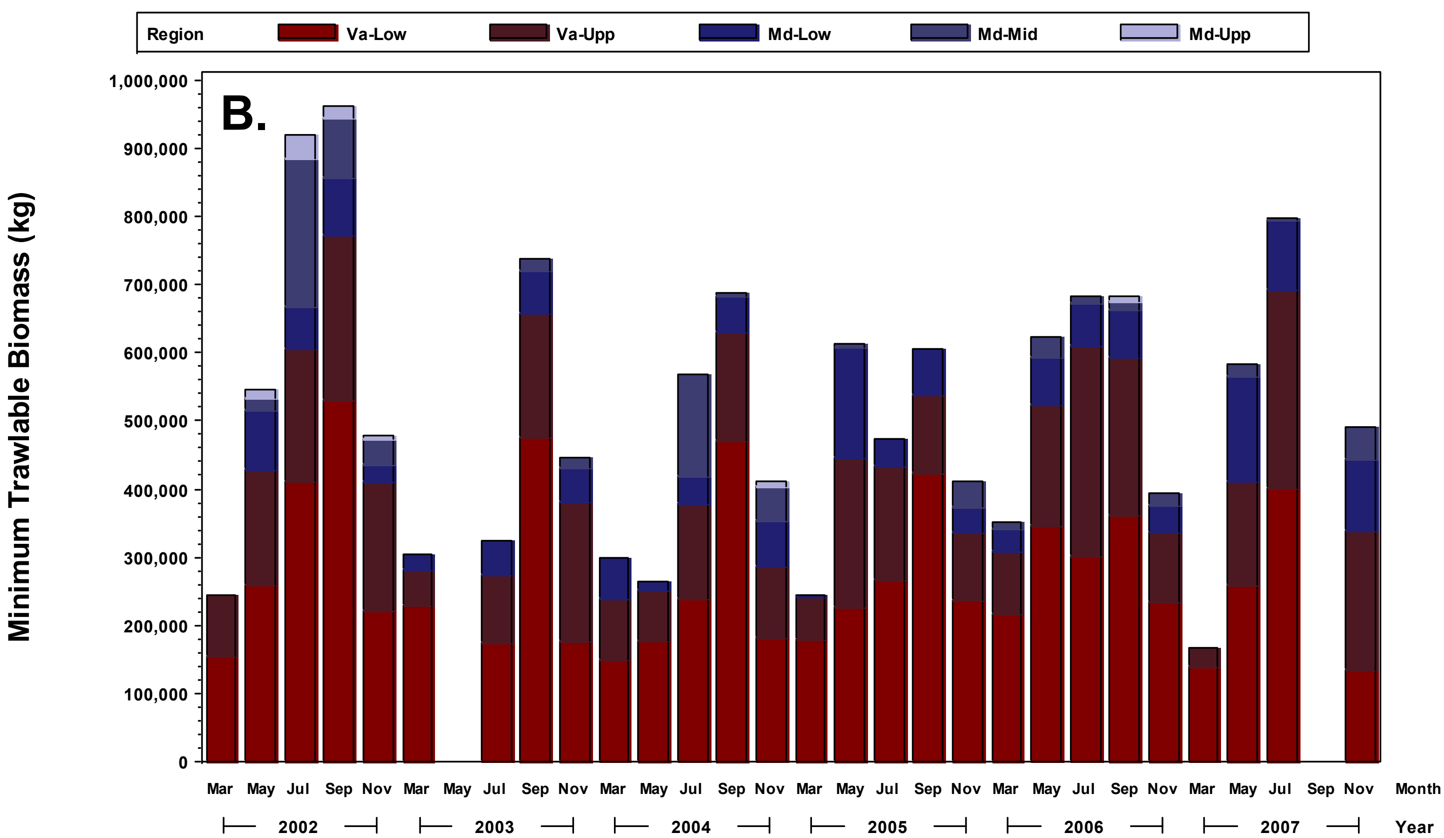


Figure 101. Site-specific summer flounder abundance (number per hectare swept), 2002.

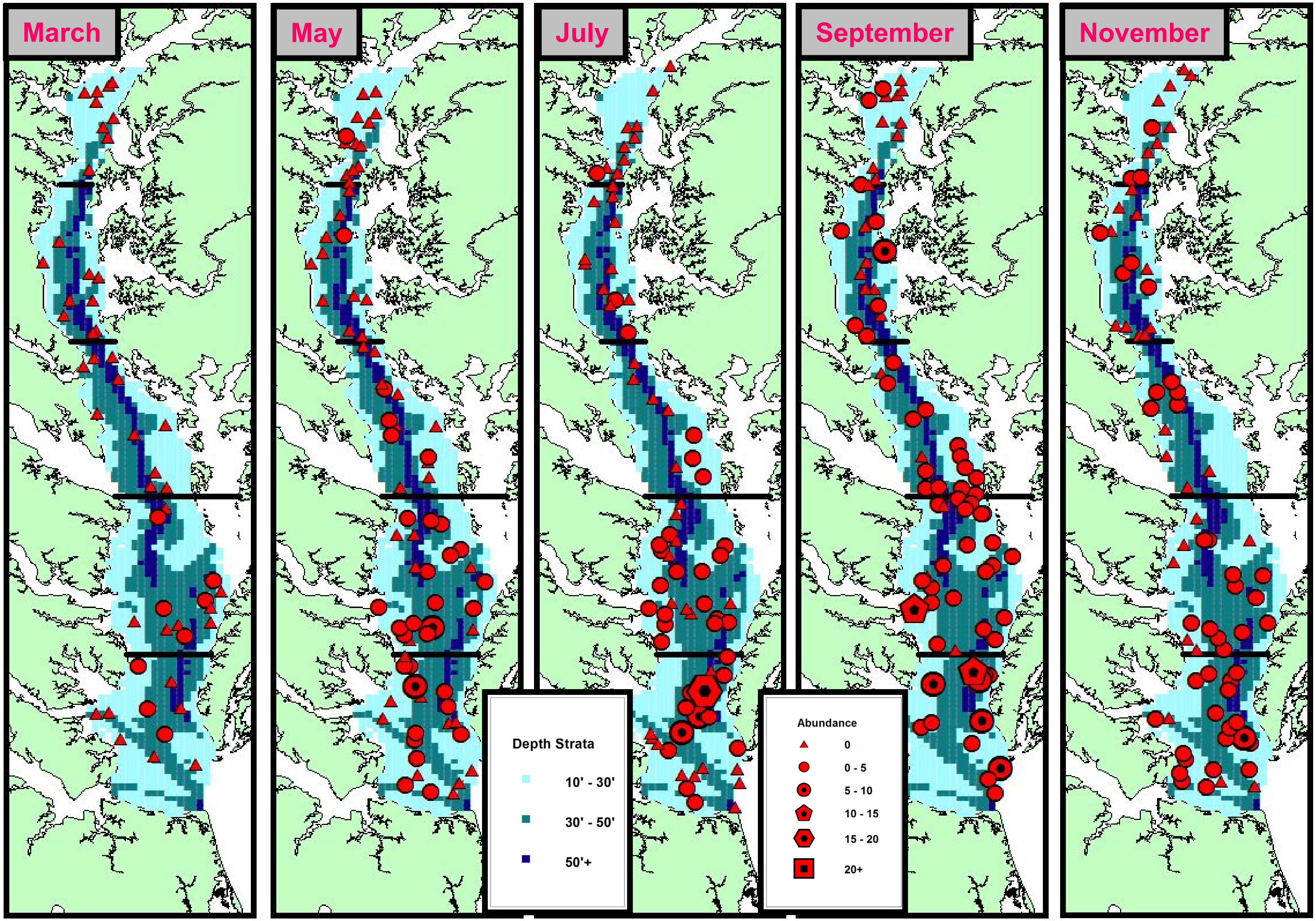


Figure 102. Site-specific summer flounder abundance (number per hectare swept), 2003.

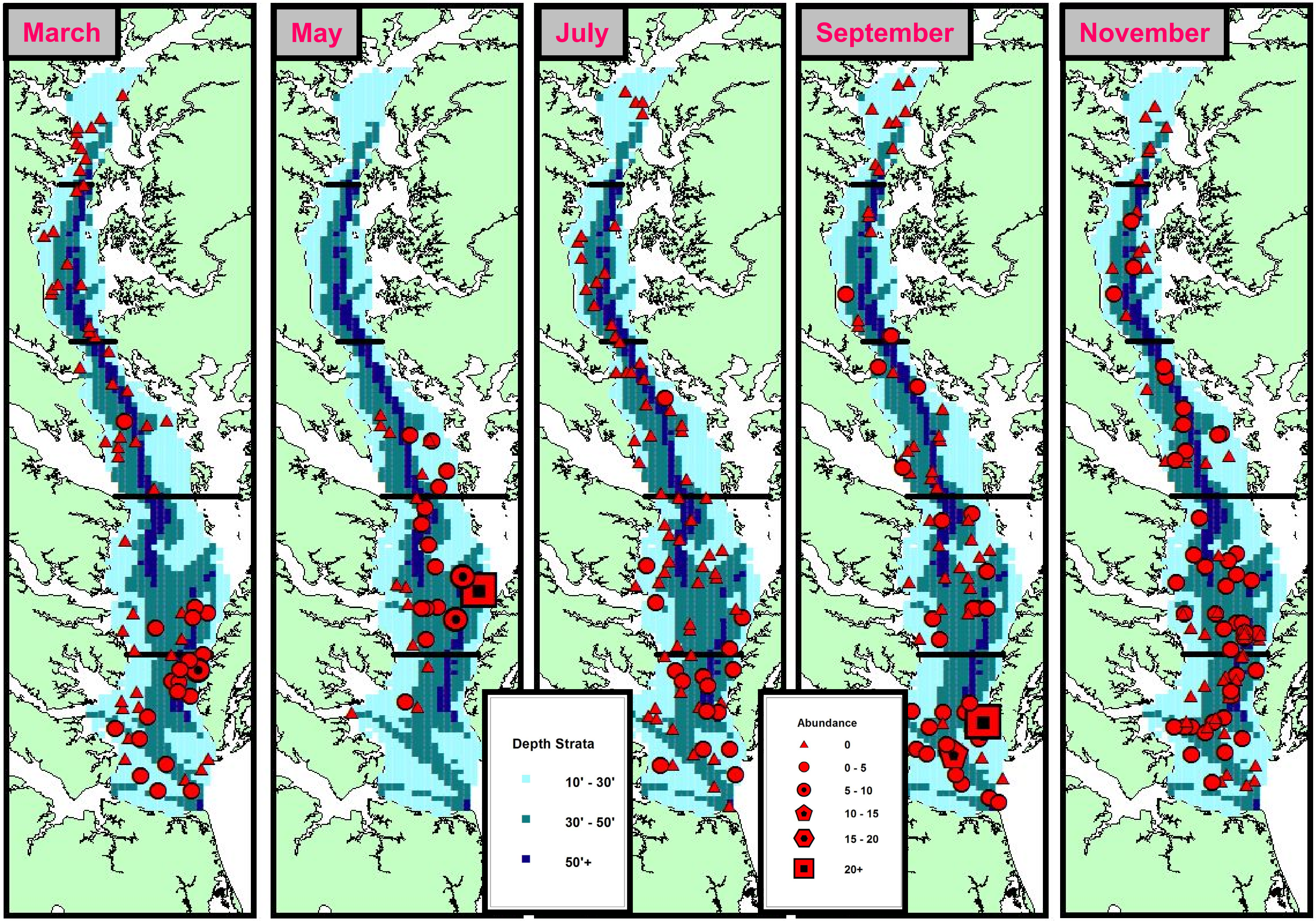


Figure 103. Site-specific summer flounder abundance (number per hectare swept), 2004.

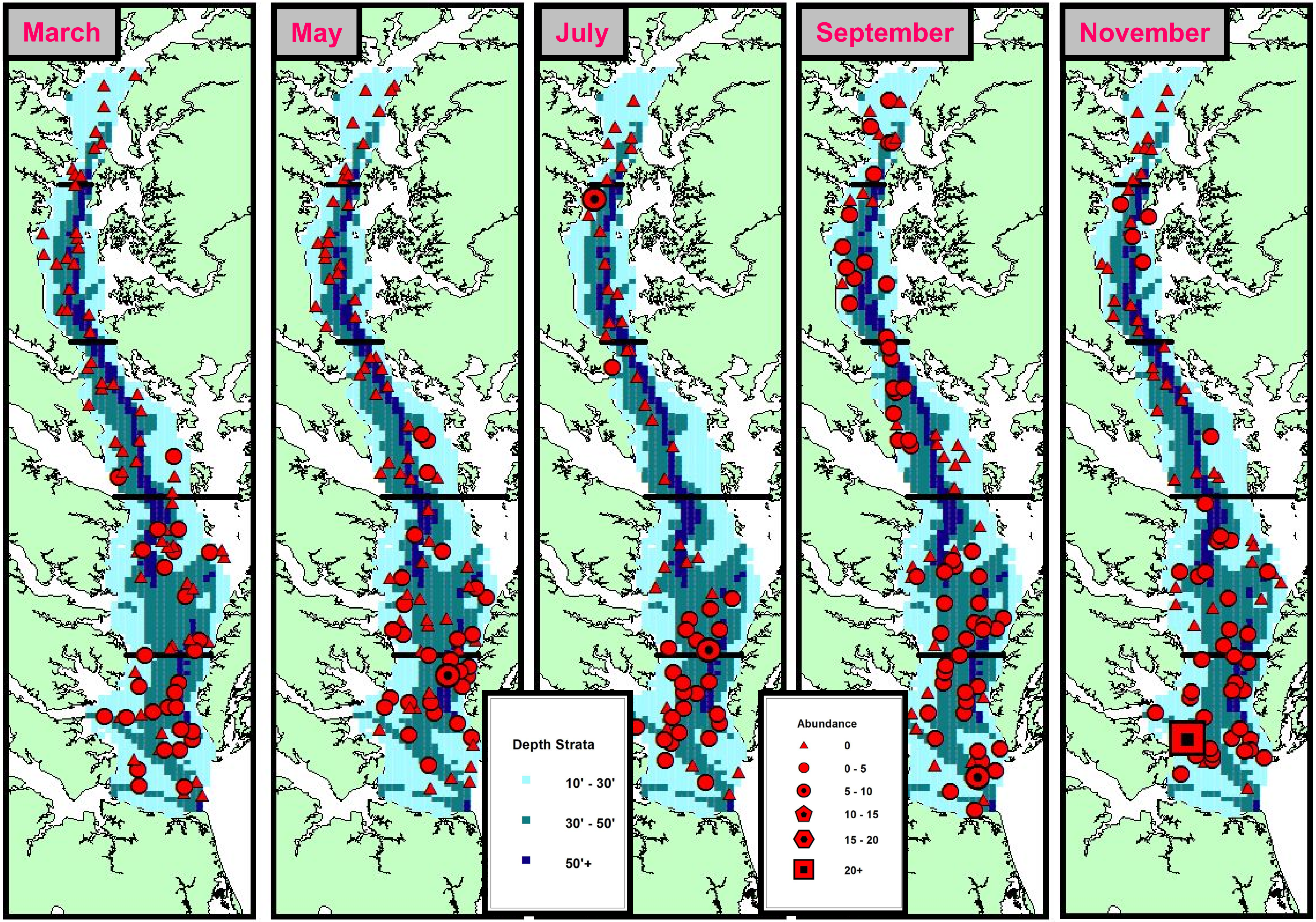


Figure 104. Site-specific summer flounder abundance (number per hectare swept), 2005.

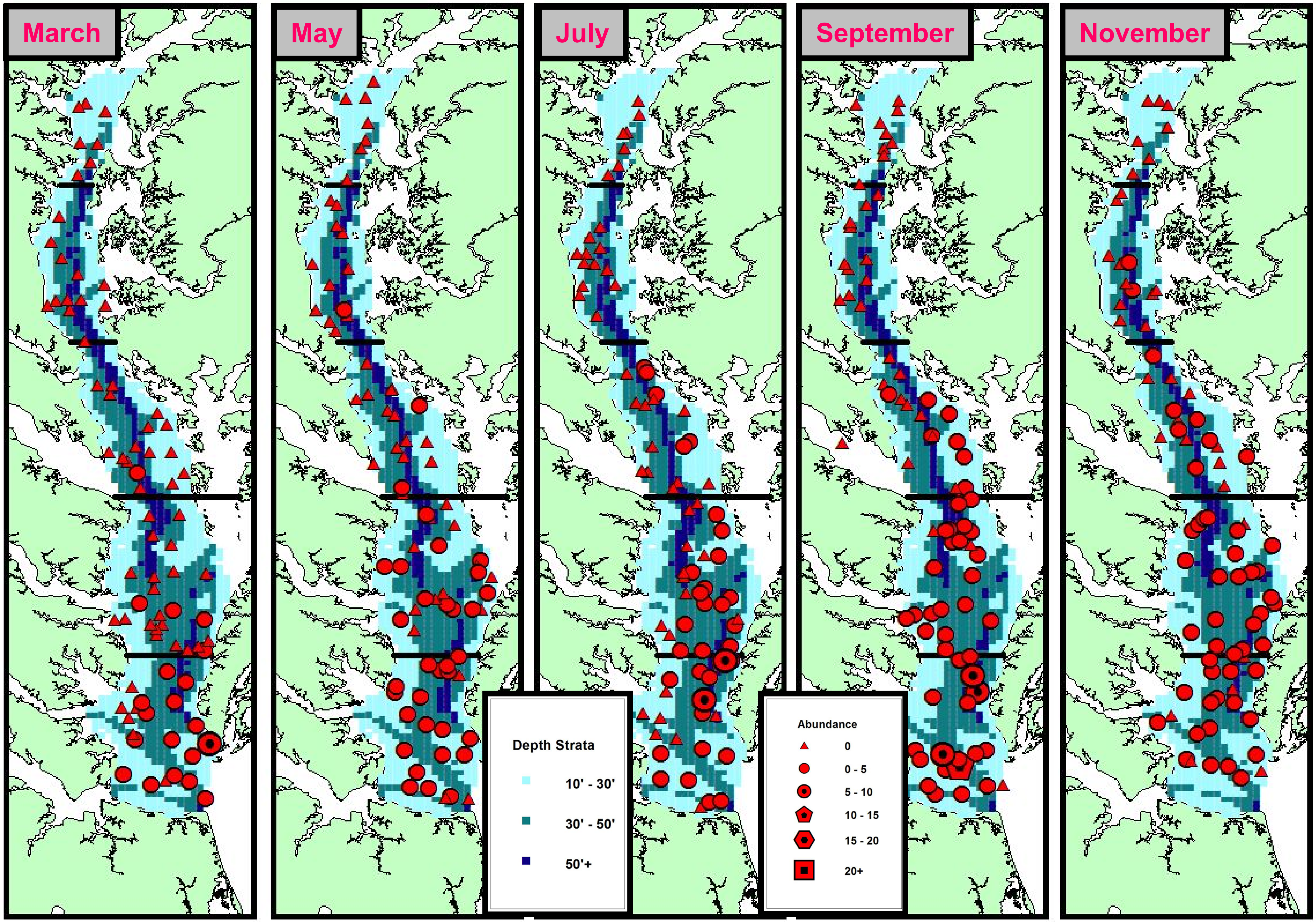


Figure 105. Site-specific summer flounder abundance (number per hectare swept), 2006.

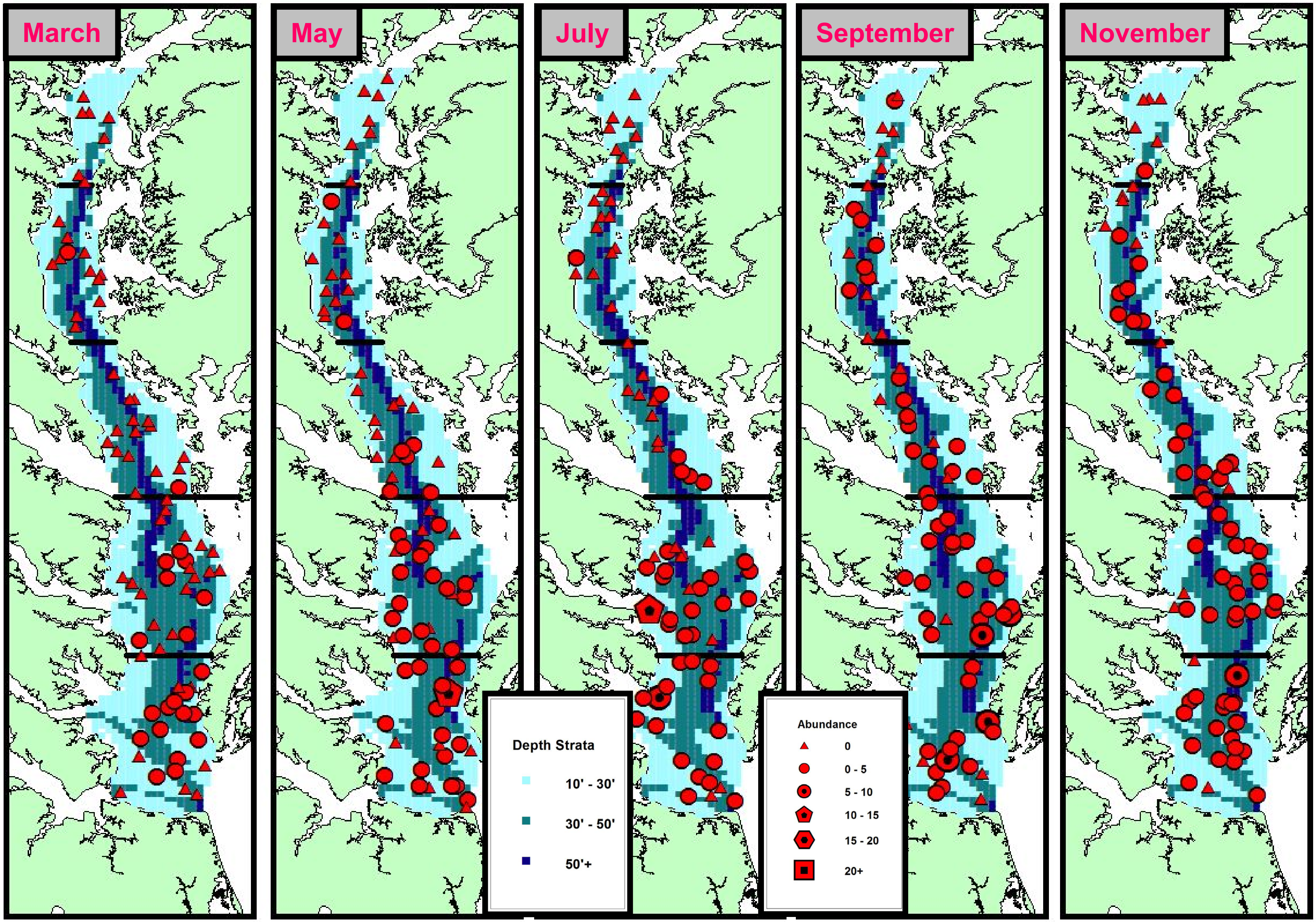


Figure 106. Abundance (number per hectare swept) of summer flounder in Chesapeake Bay, 2007.

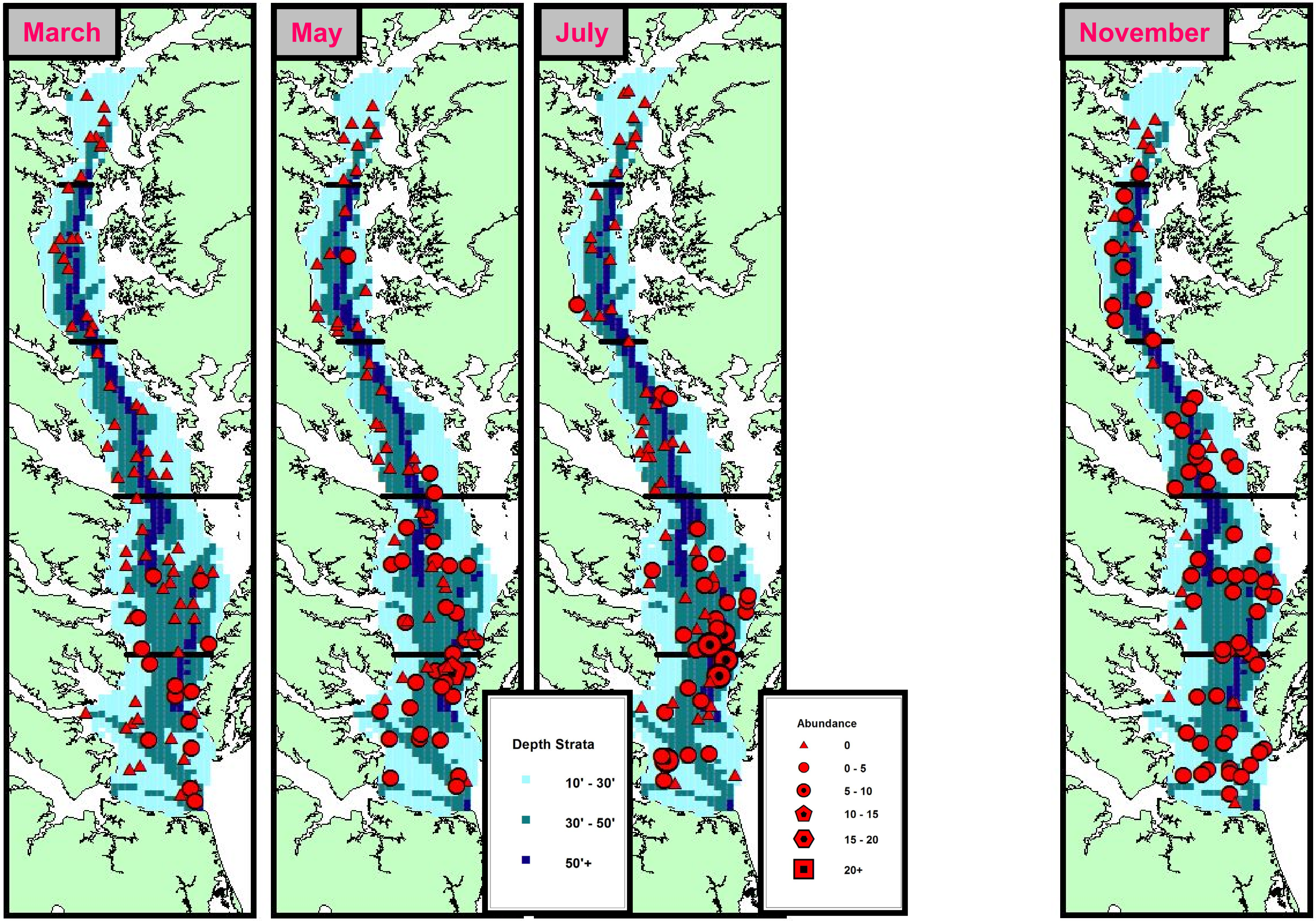


Figure 107. Summer flounder length-frequency in Chesapeake Bay, 2002-2007.

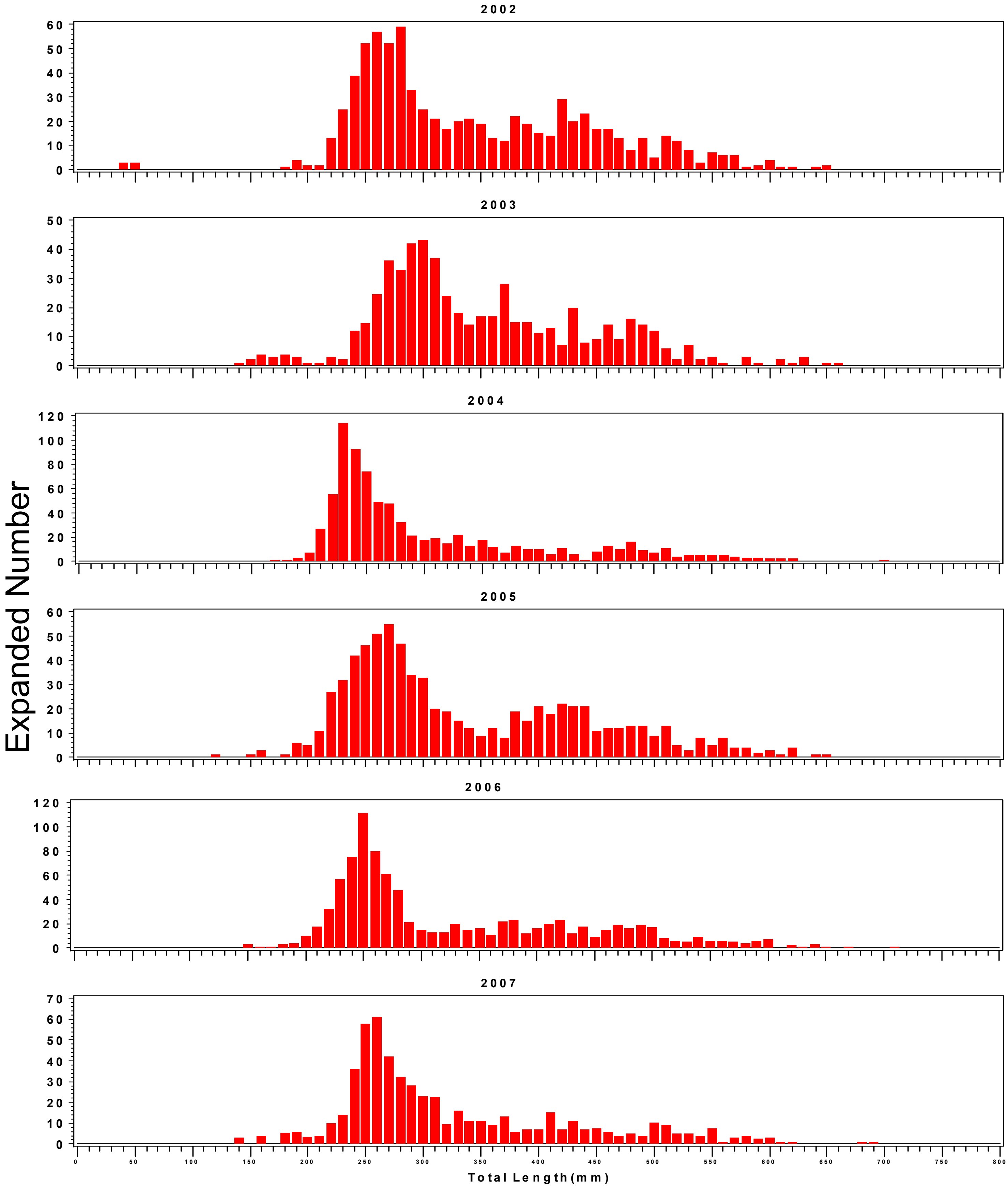


Figure 108. Summer flounder age-structure in Chesapeake Bay, 2002-2007.

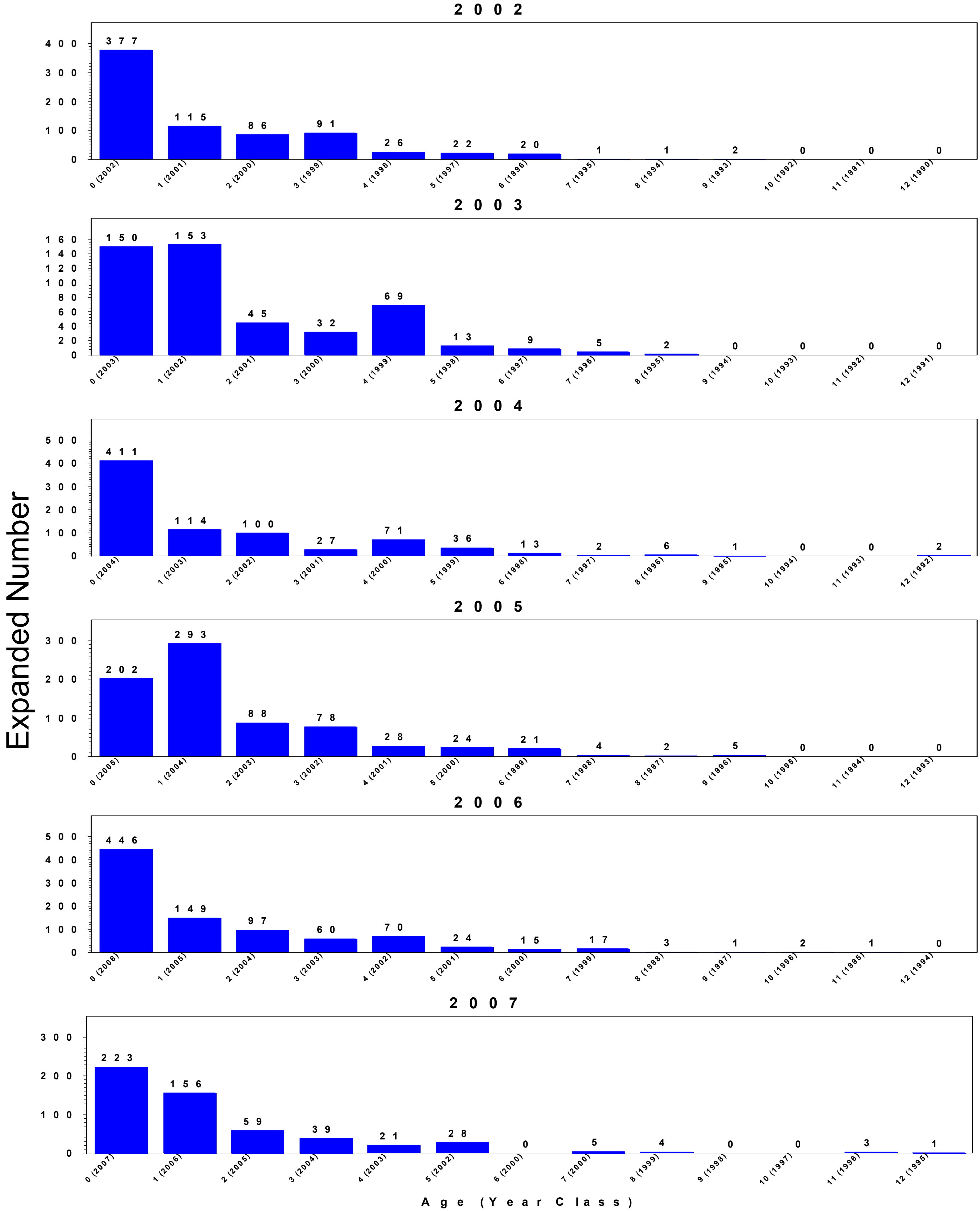


Figure 109. Summer flounder sex-ratios in Chesapeake Bay, 2002-2007, by month (A), region (B), age (C).

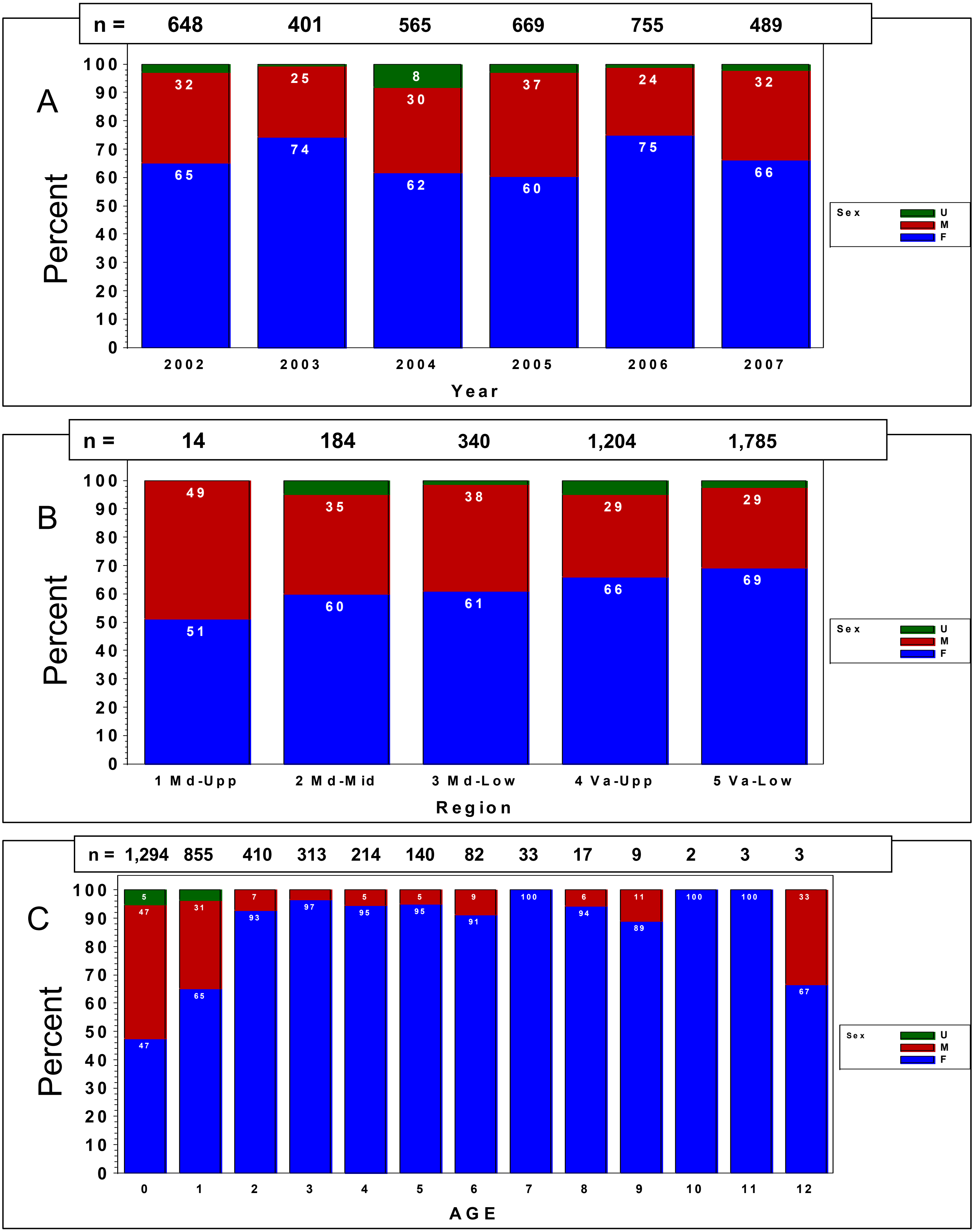
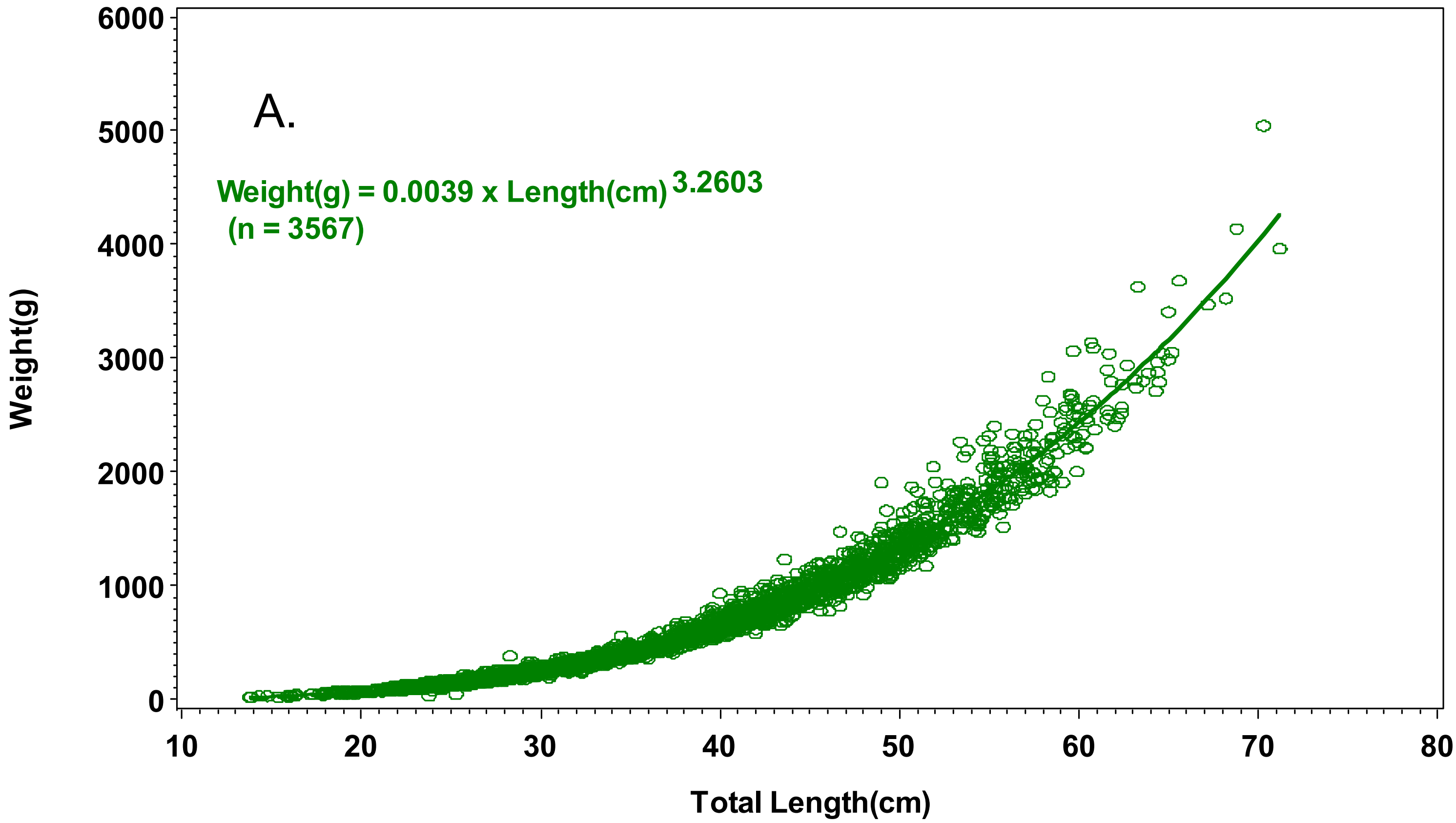


Figure 110. Summer flounder length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).



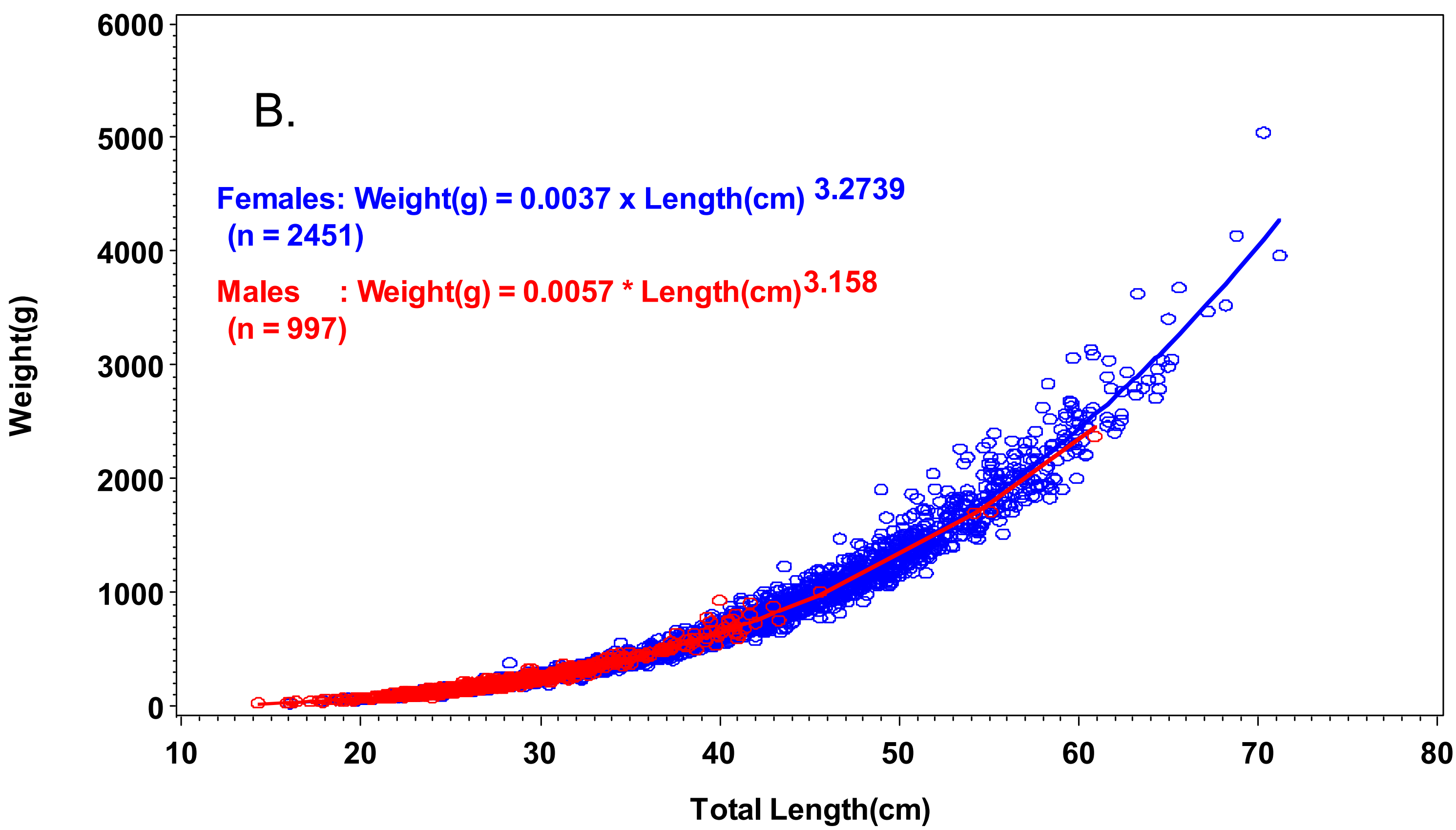


Figure 111. Summer flounder maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

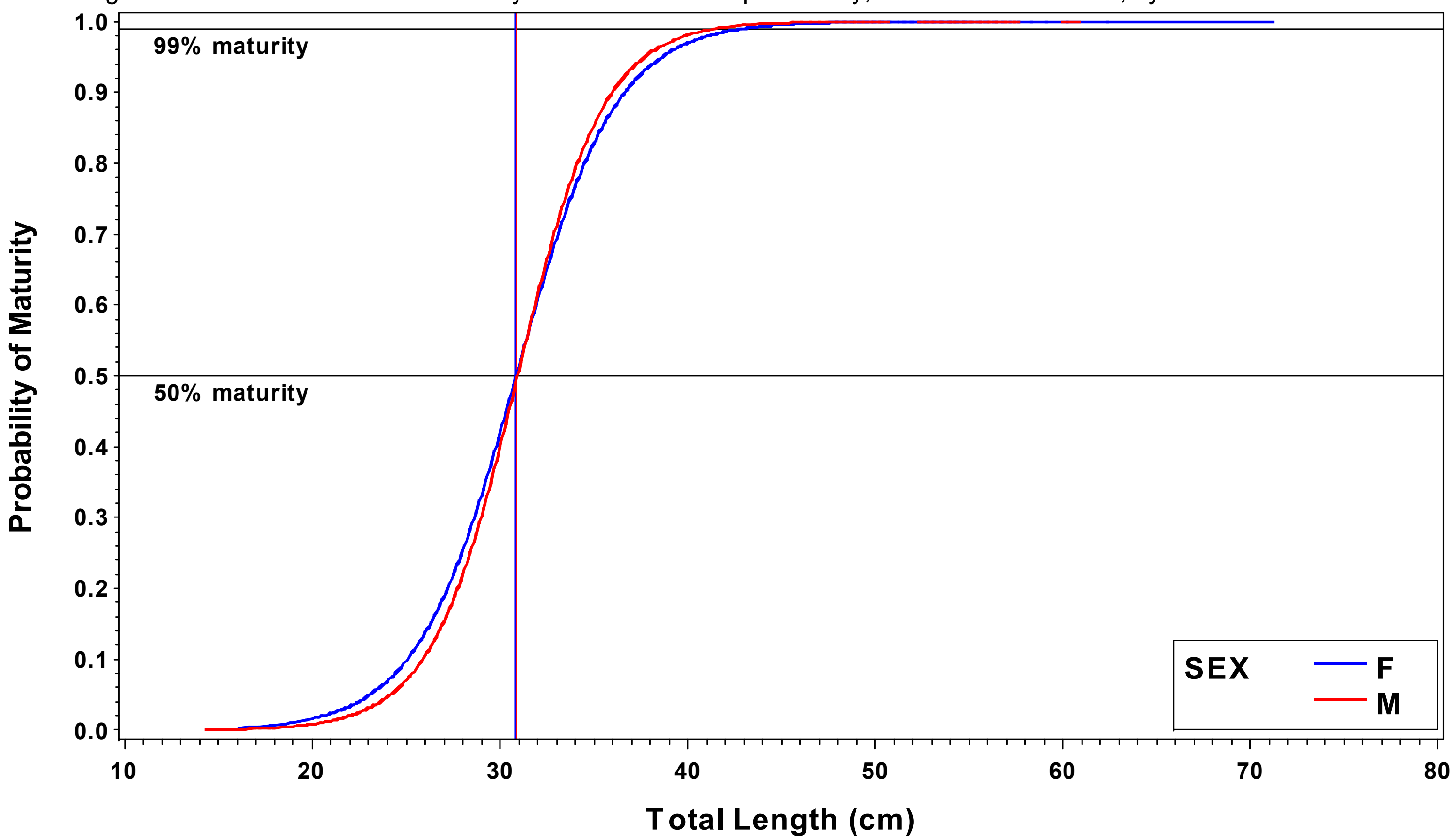


Figure 112. Summer flounder diet in Chesapeake Bay, 2002-2007 combined.

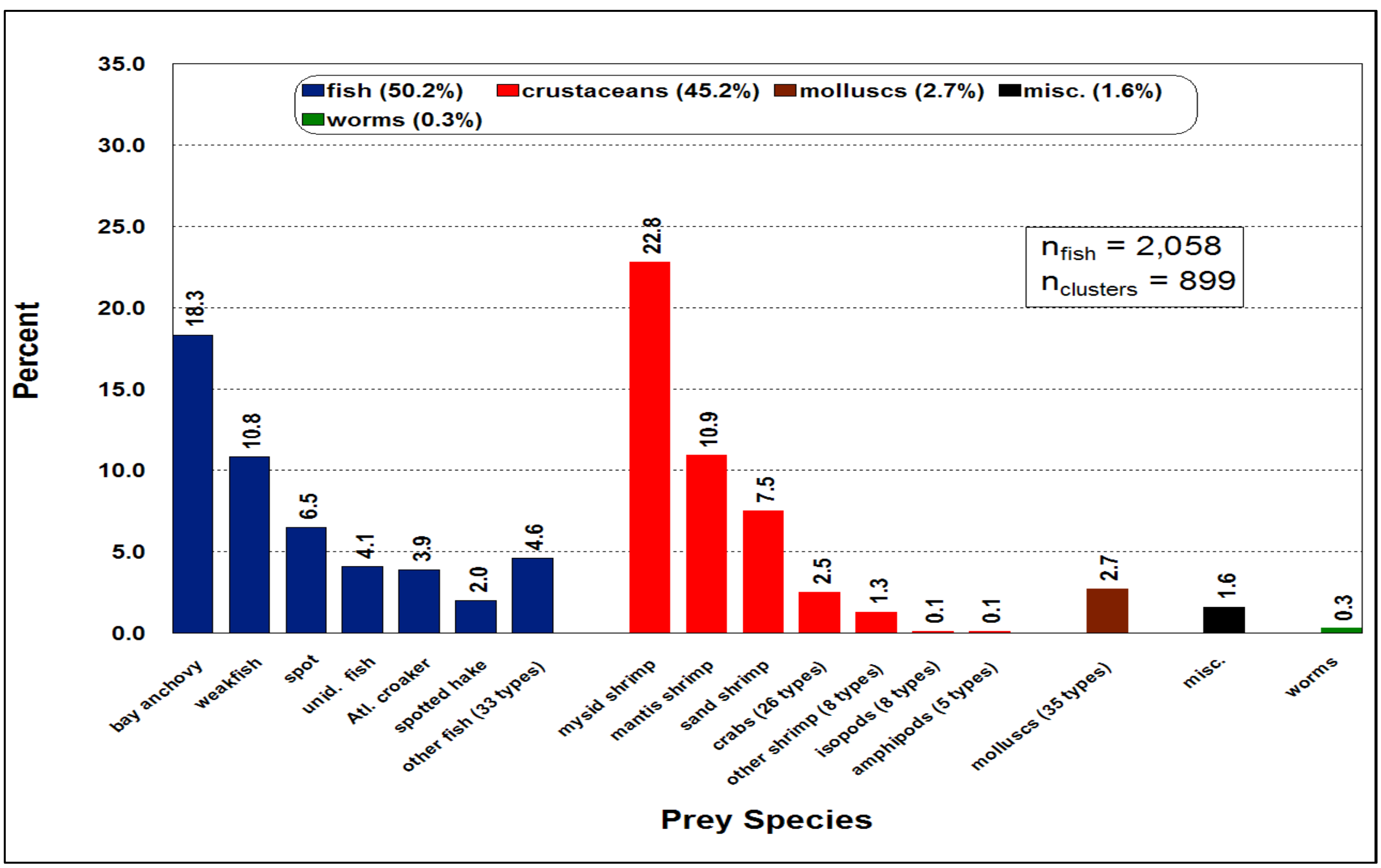
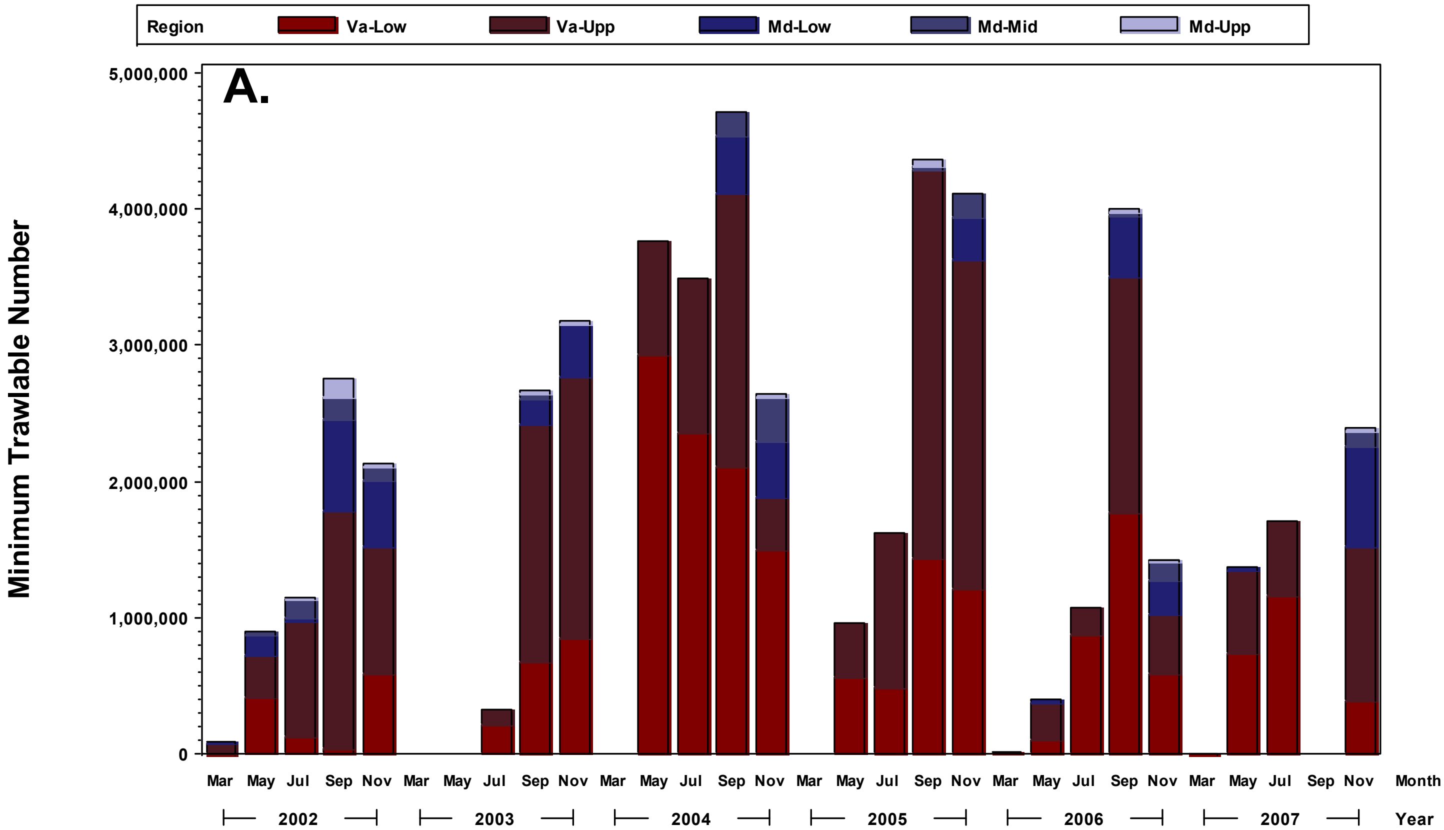


Figure 113. Weakfish minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.



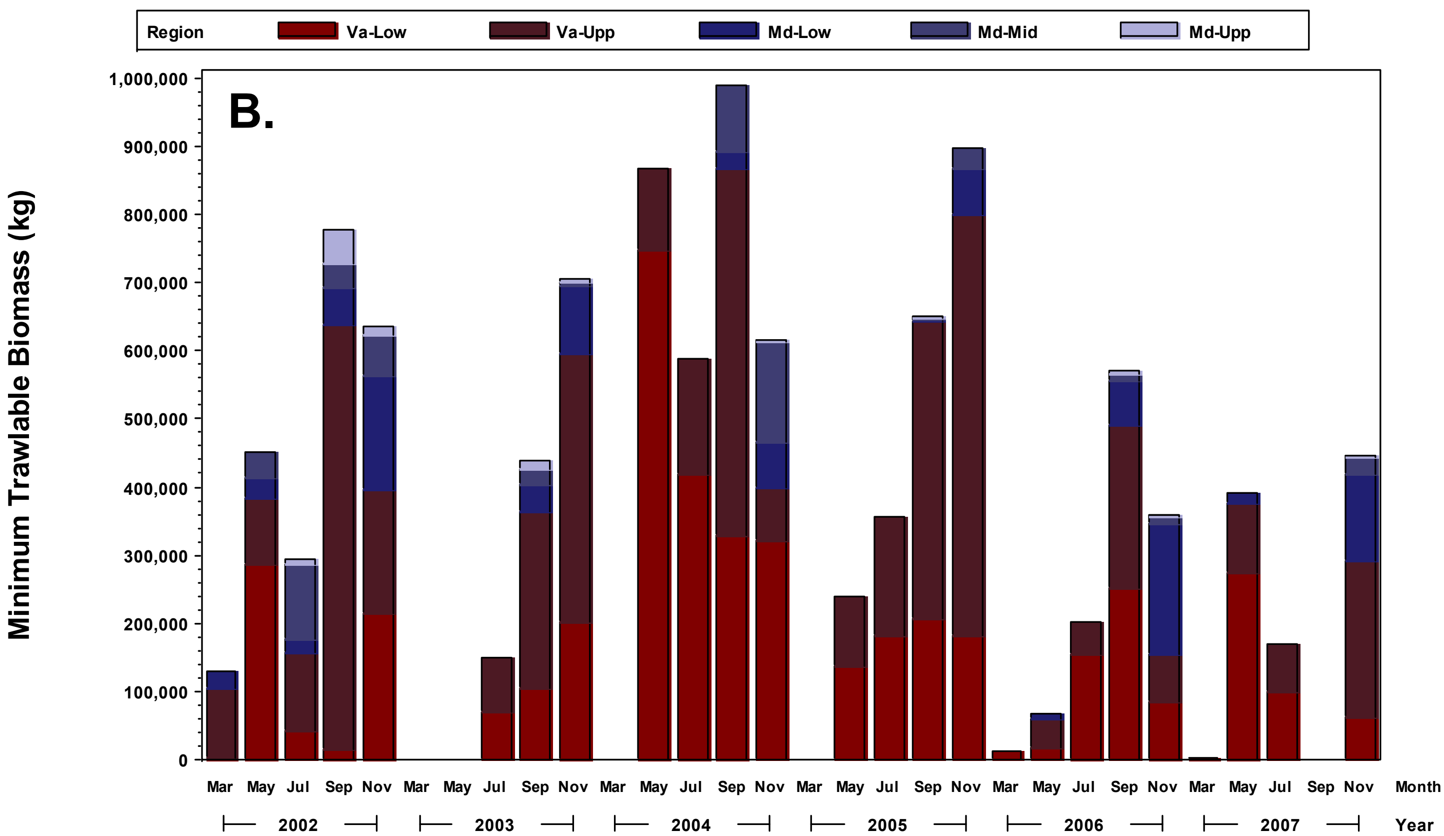


Figure 114. Site-specific weakfish abundance (number per hectare swept), 2002.

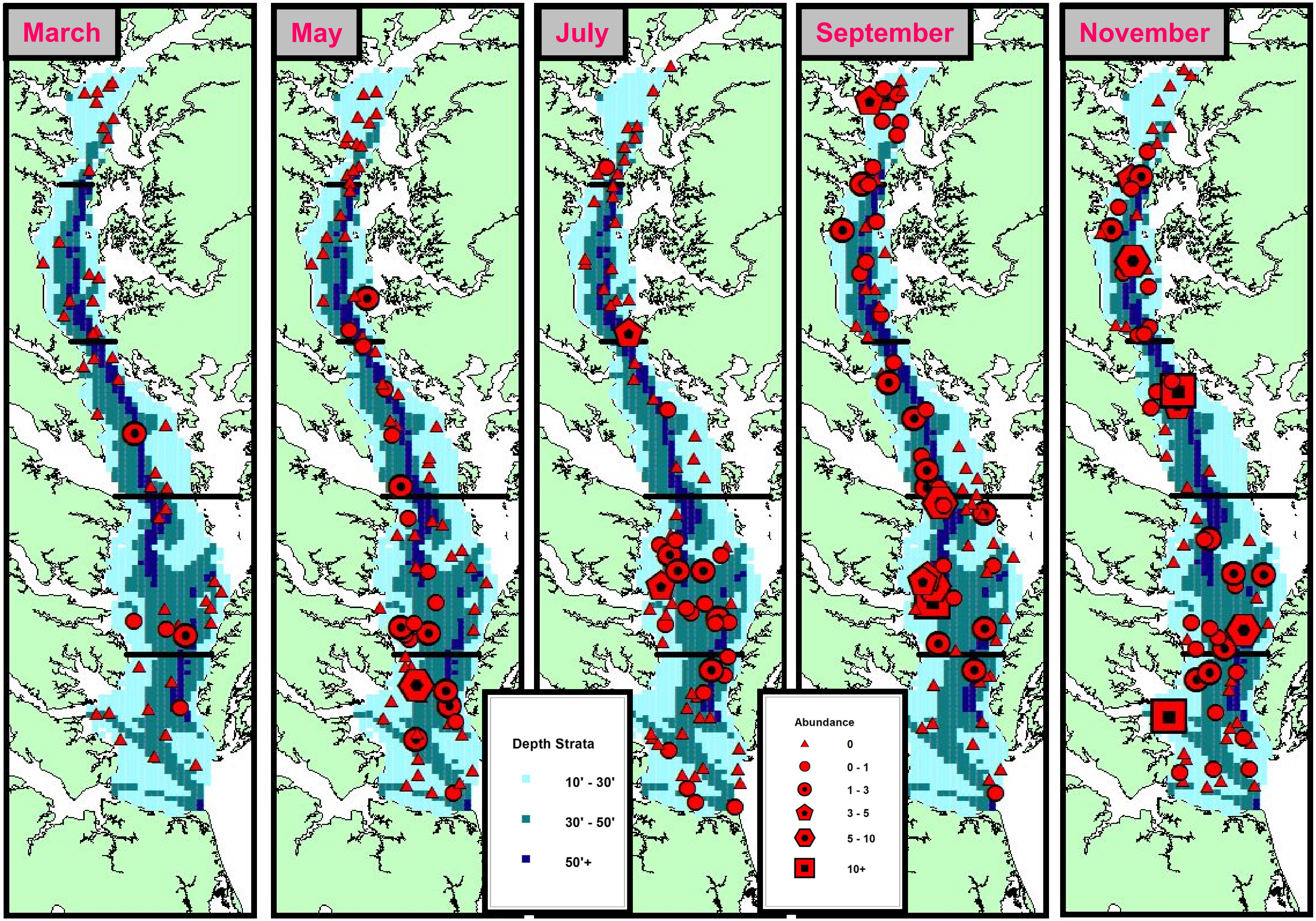


Figure 115. Site-specific weakfish abundance (number per hectare swept), 2003.

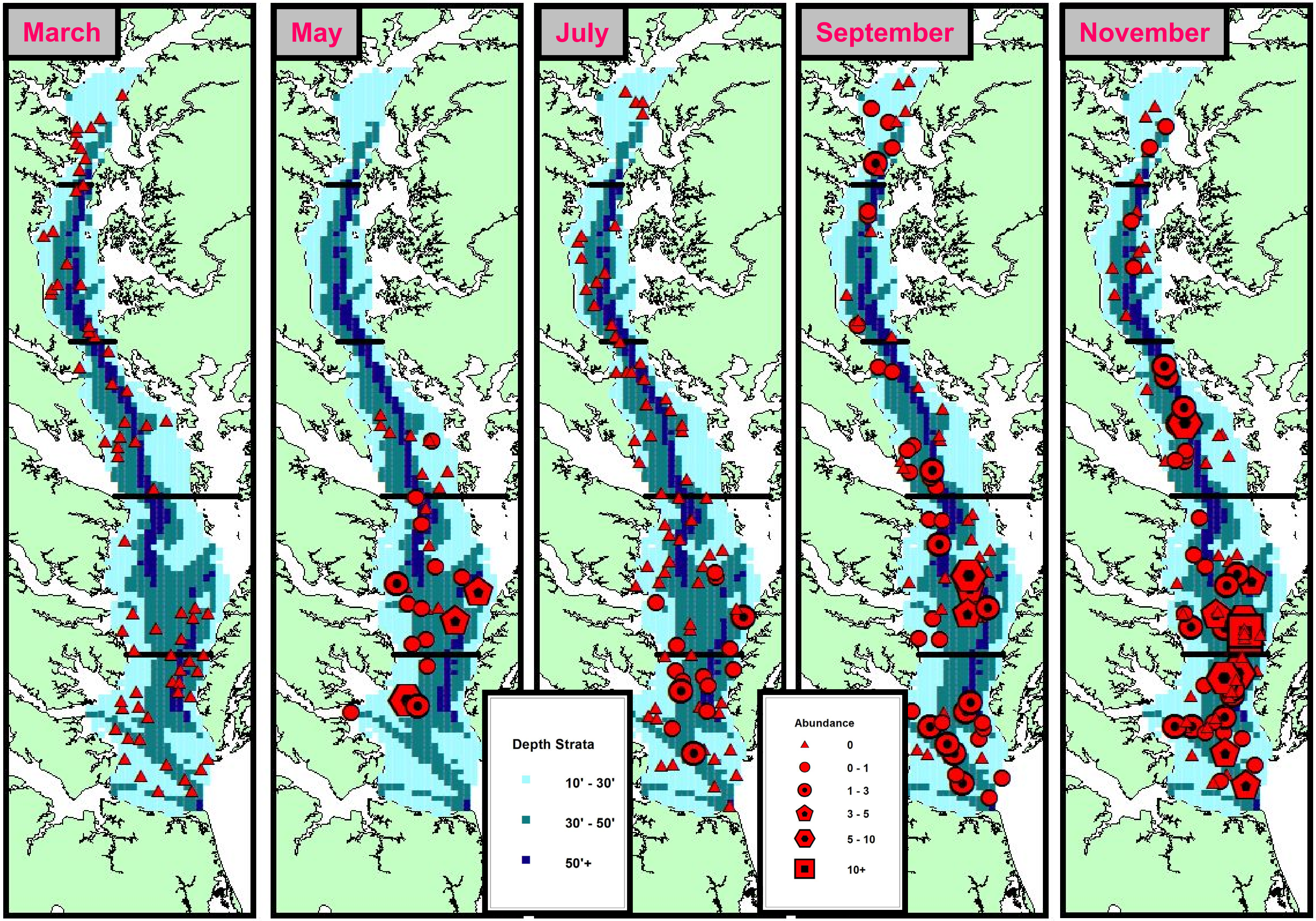


Figure 116. Site-specific weakfish abundance (number per hectare swept), 2004.

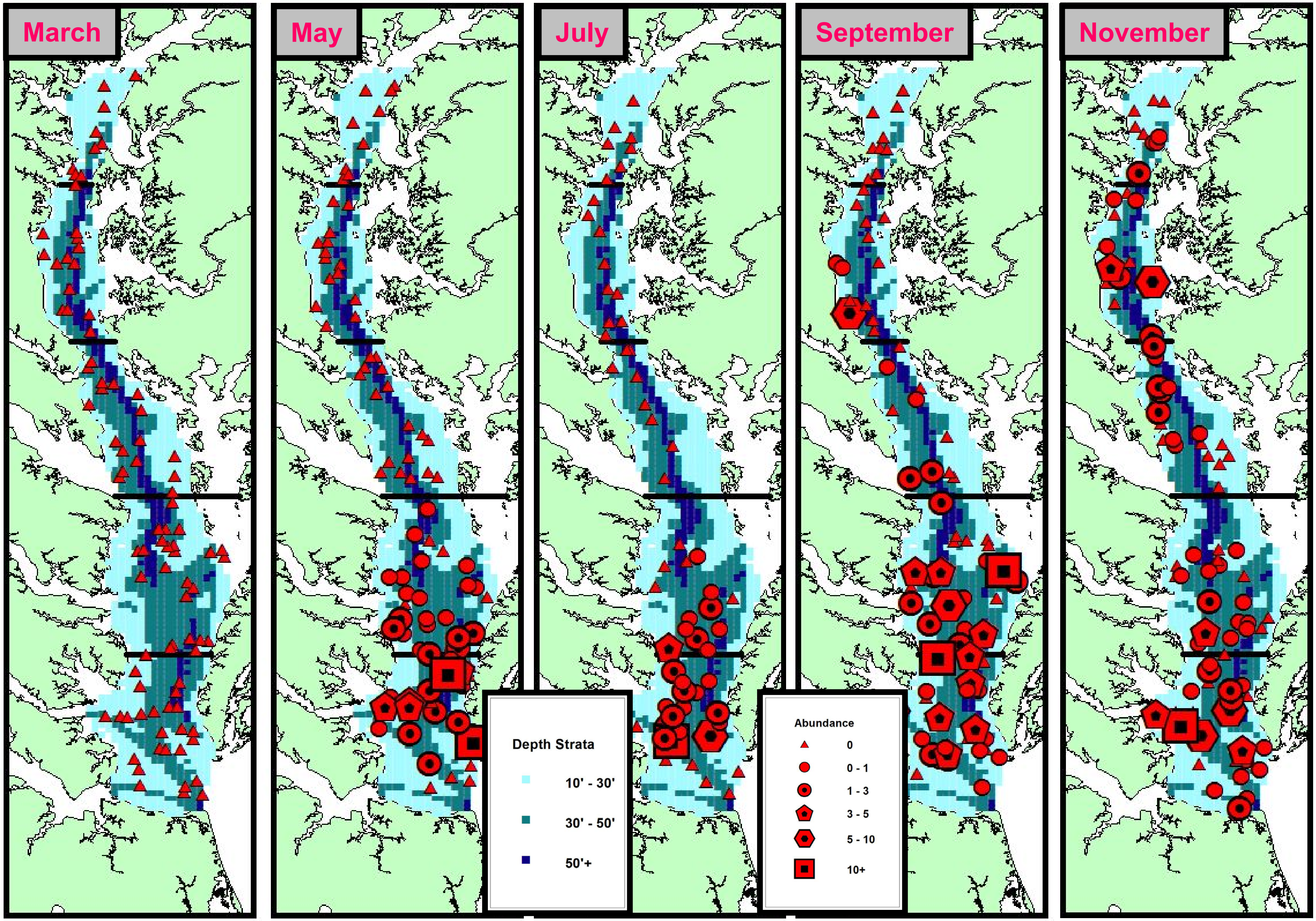


Figure 117. Site-specific weakfish abundance (number per hectare swept), 2005.

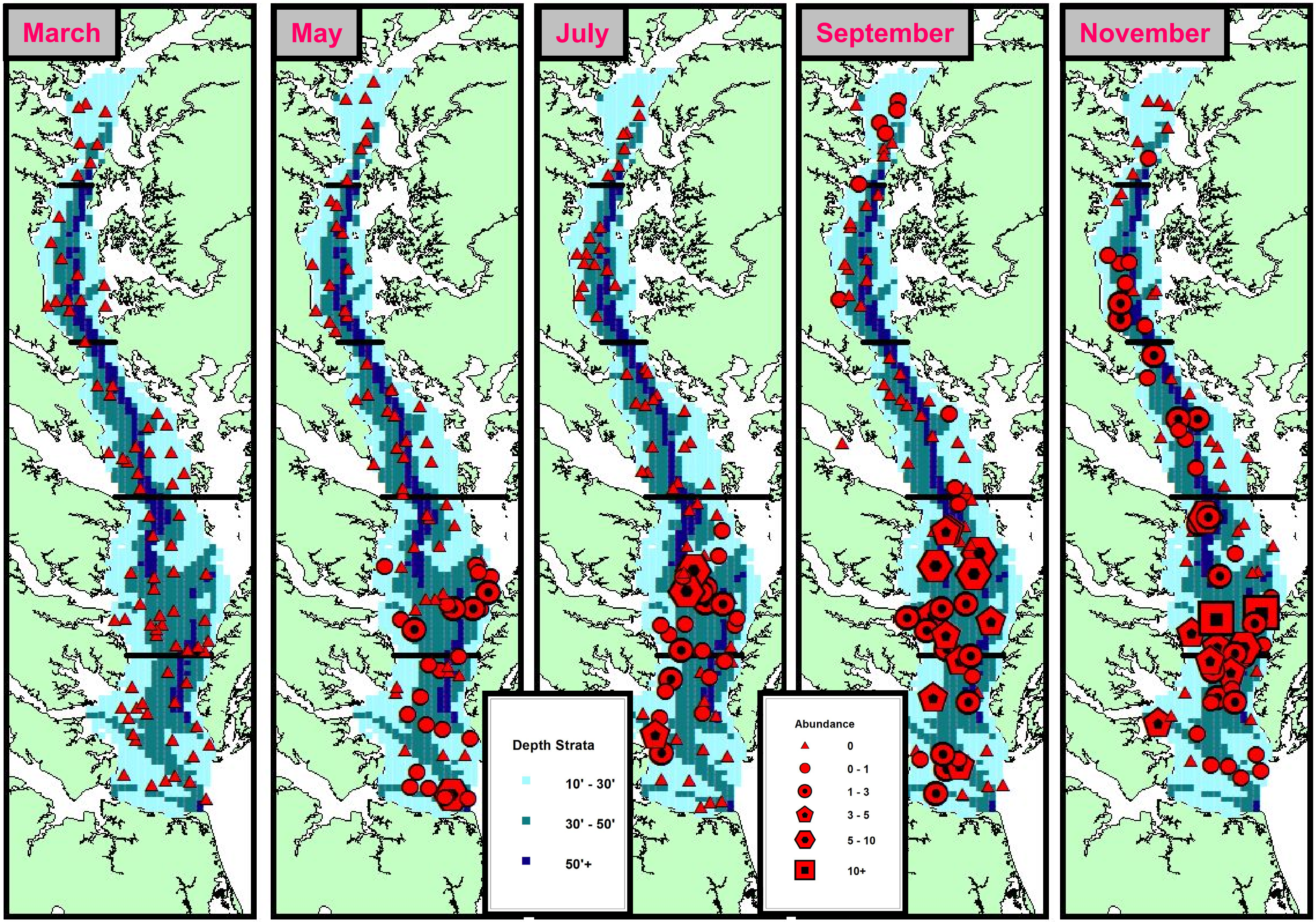


Figure 118. Site-specific weakfish abundance (number per hectare swept), 2006.

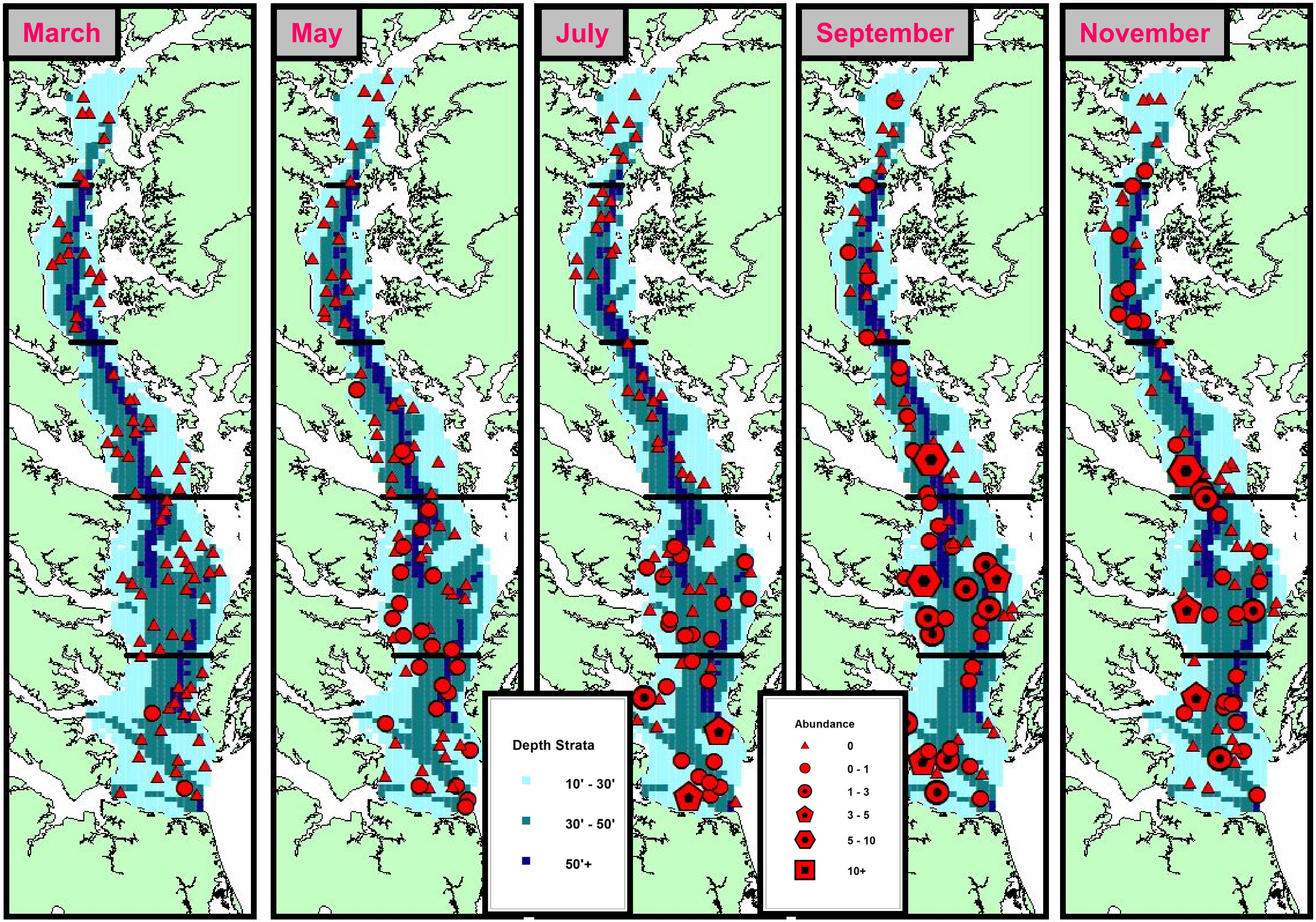


Figure 119. Abundance (number per hectare swept) of weakfish in Chesapeake Bay, 2007.

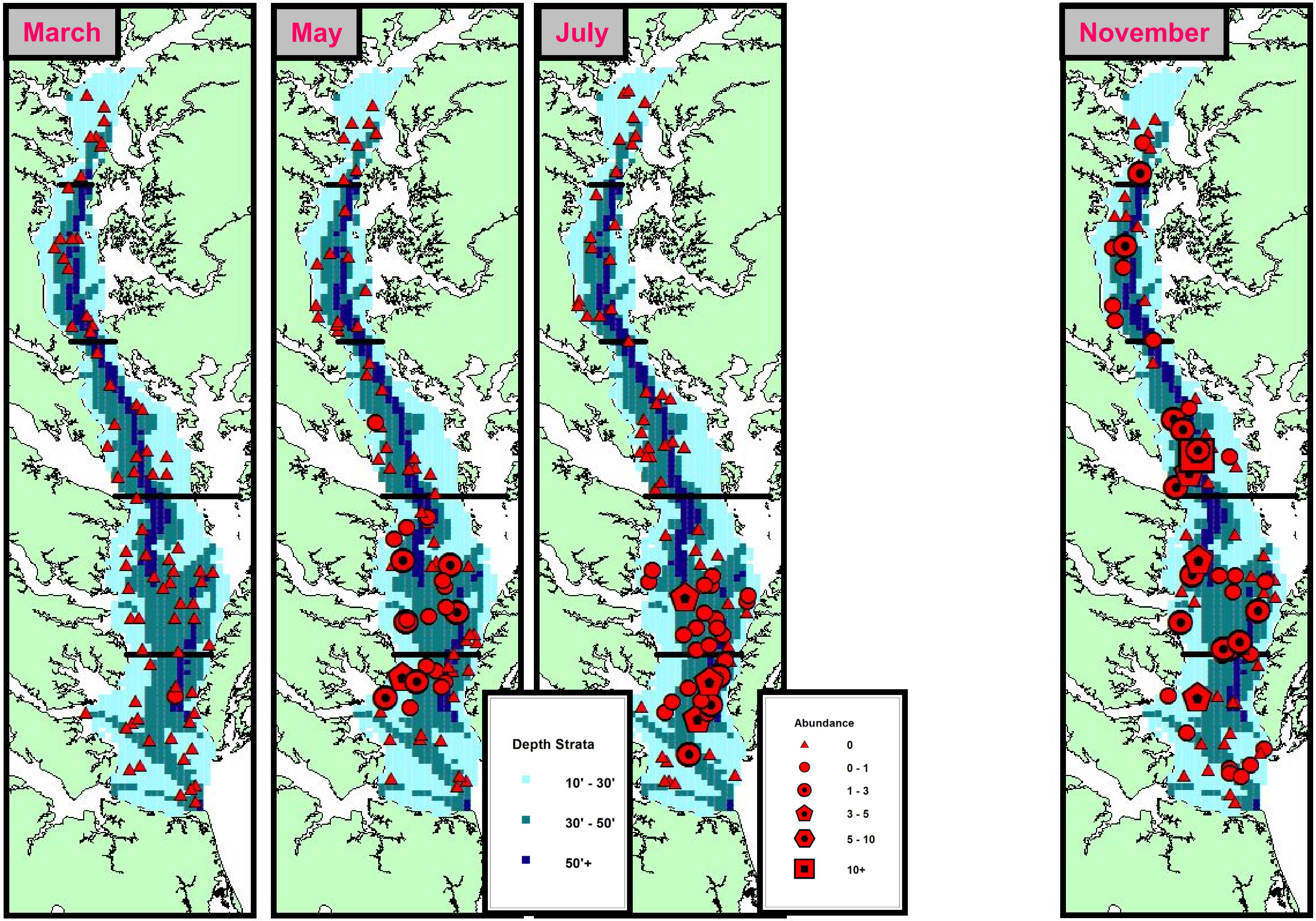


Figure 120. Weakfish length-frequency in Chesapeake Bay, 2002-2007.

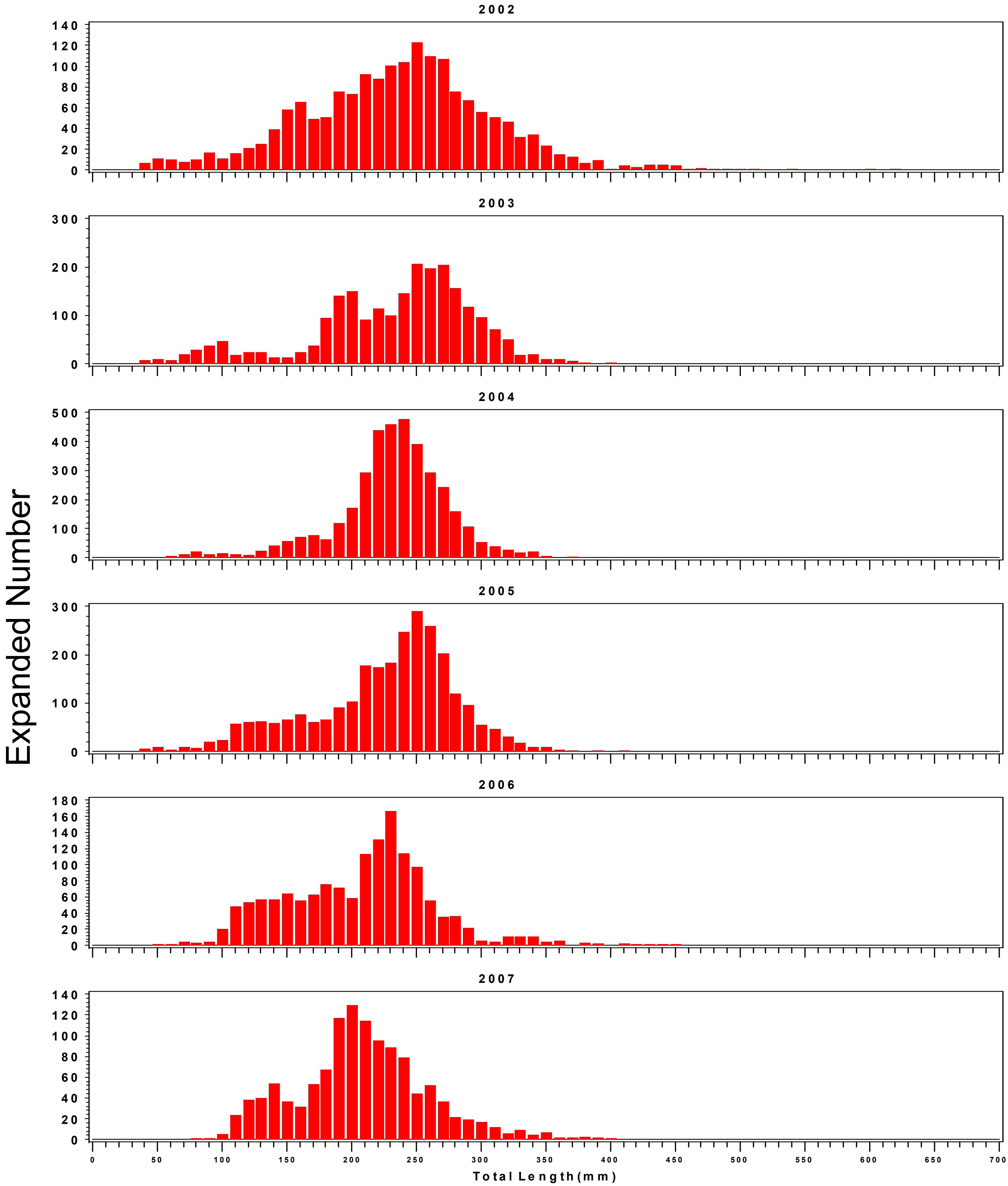


Figure 121. Weakfish age-structure in Chesapeake Bay, 2002-2007.

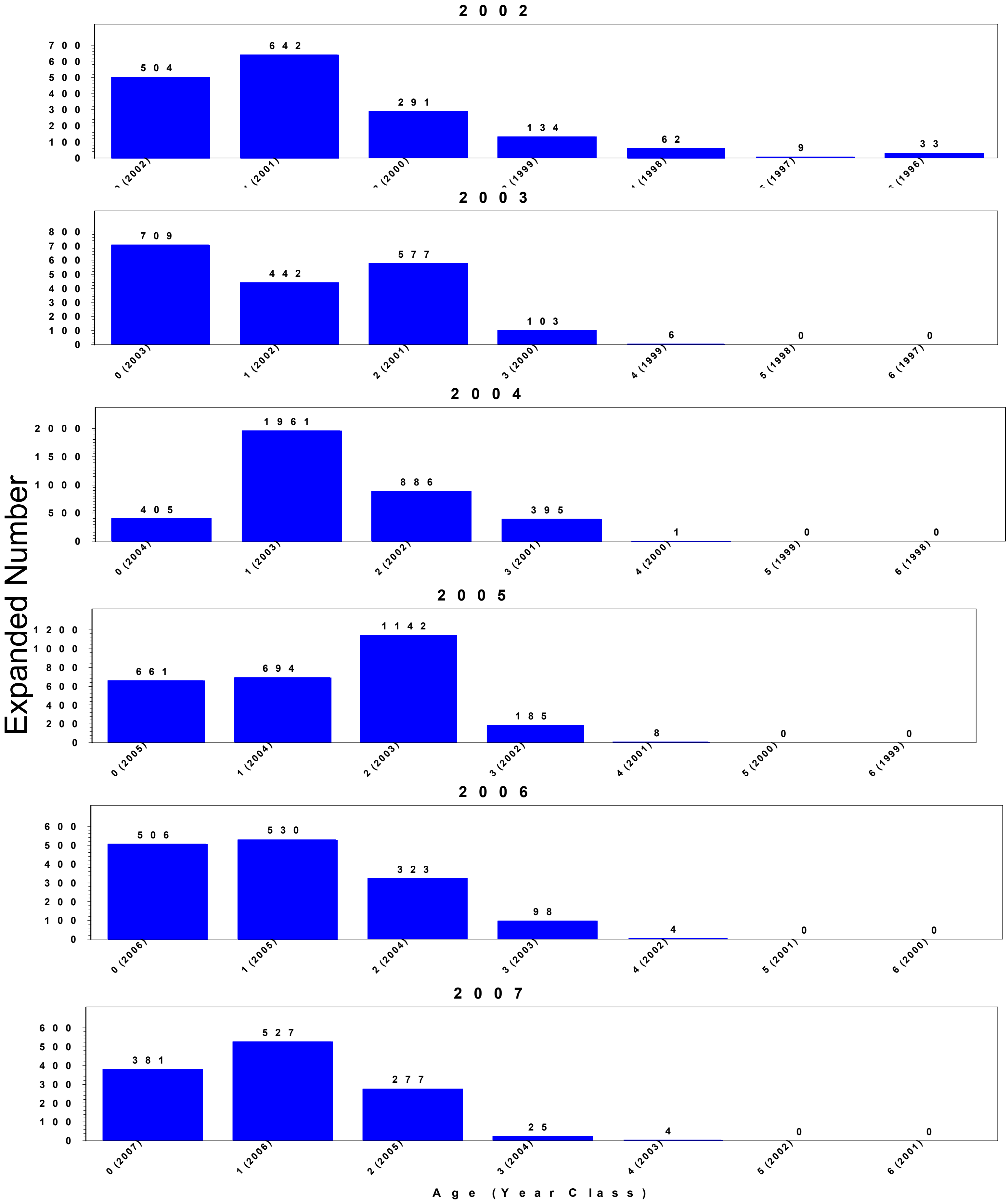


Figure 122. Weakfish sex-ratios in Chesapeake Bay, 2002-2007, by year (A), region (B), age (C).

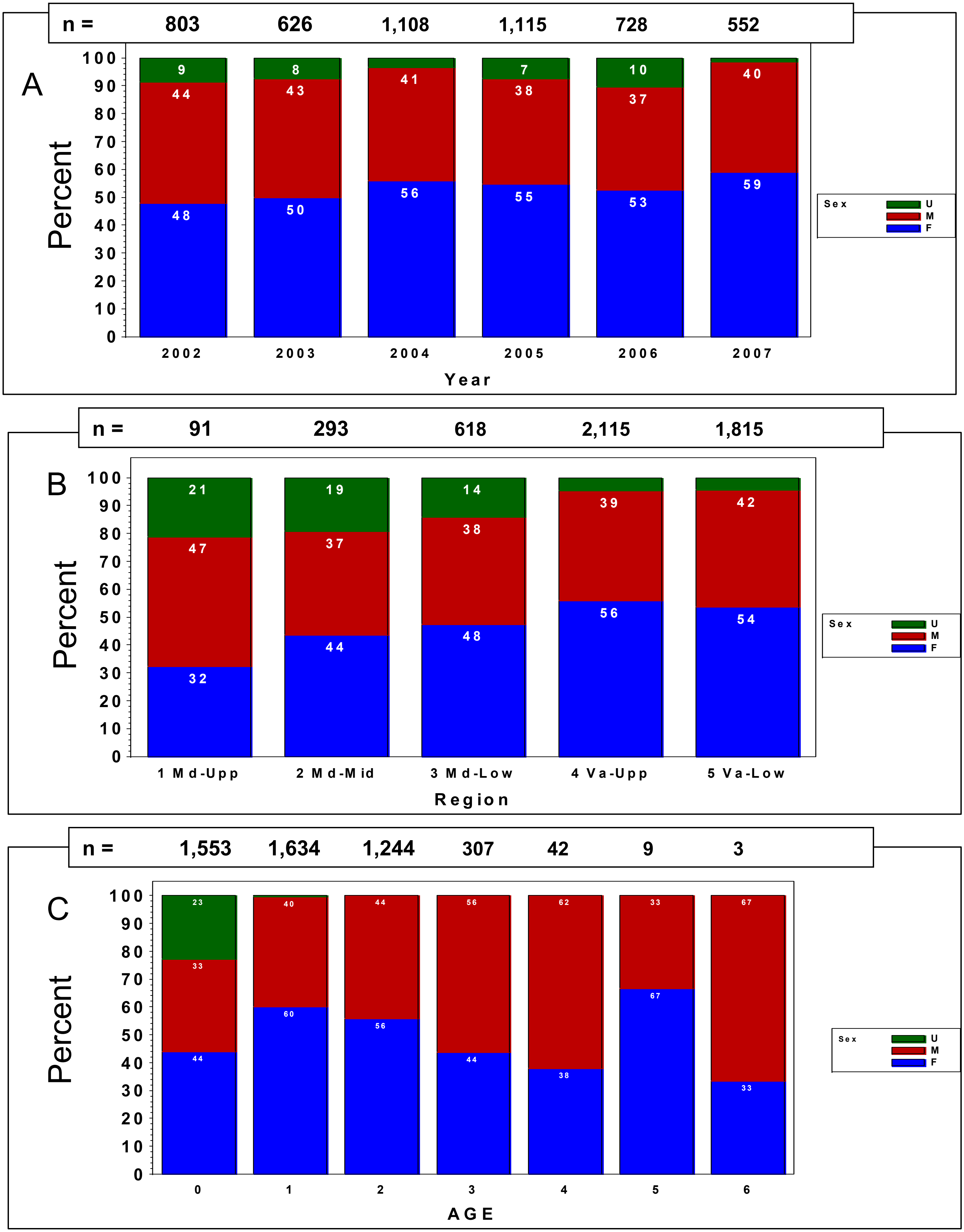
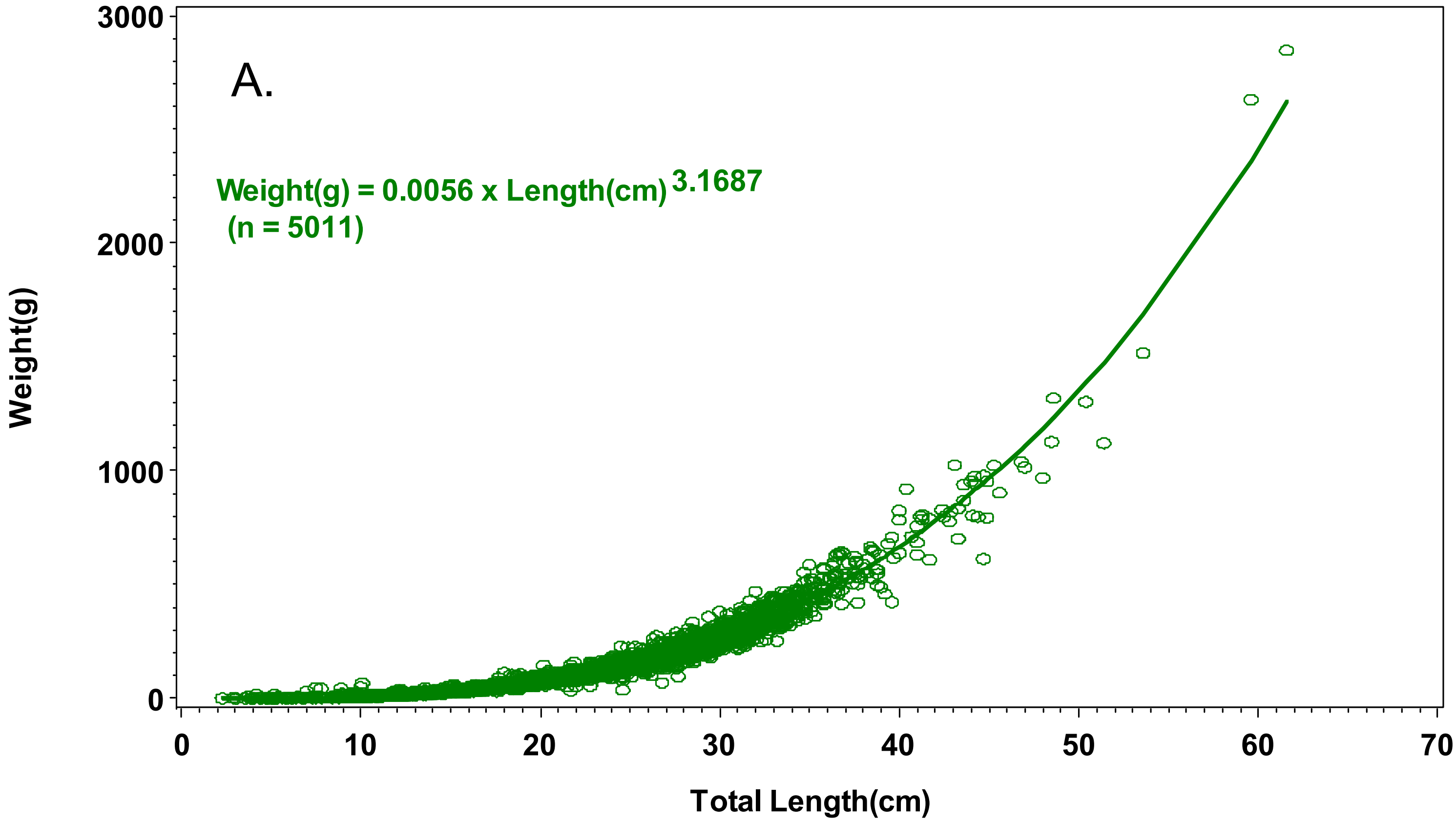


Figure 123. Weakfish length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).



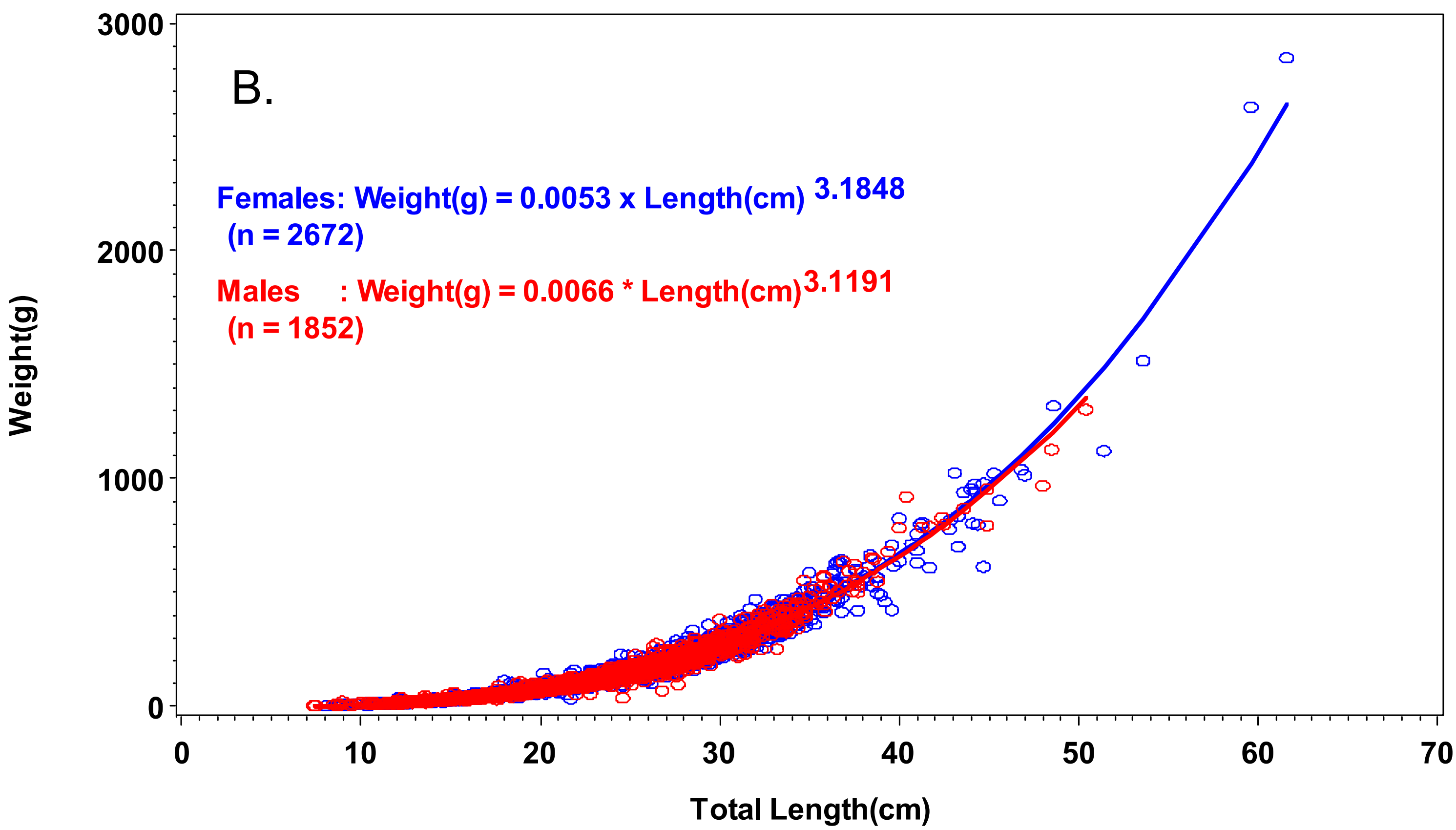


Figure 124. Weakfish maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

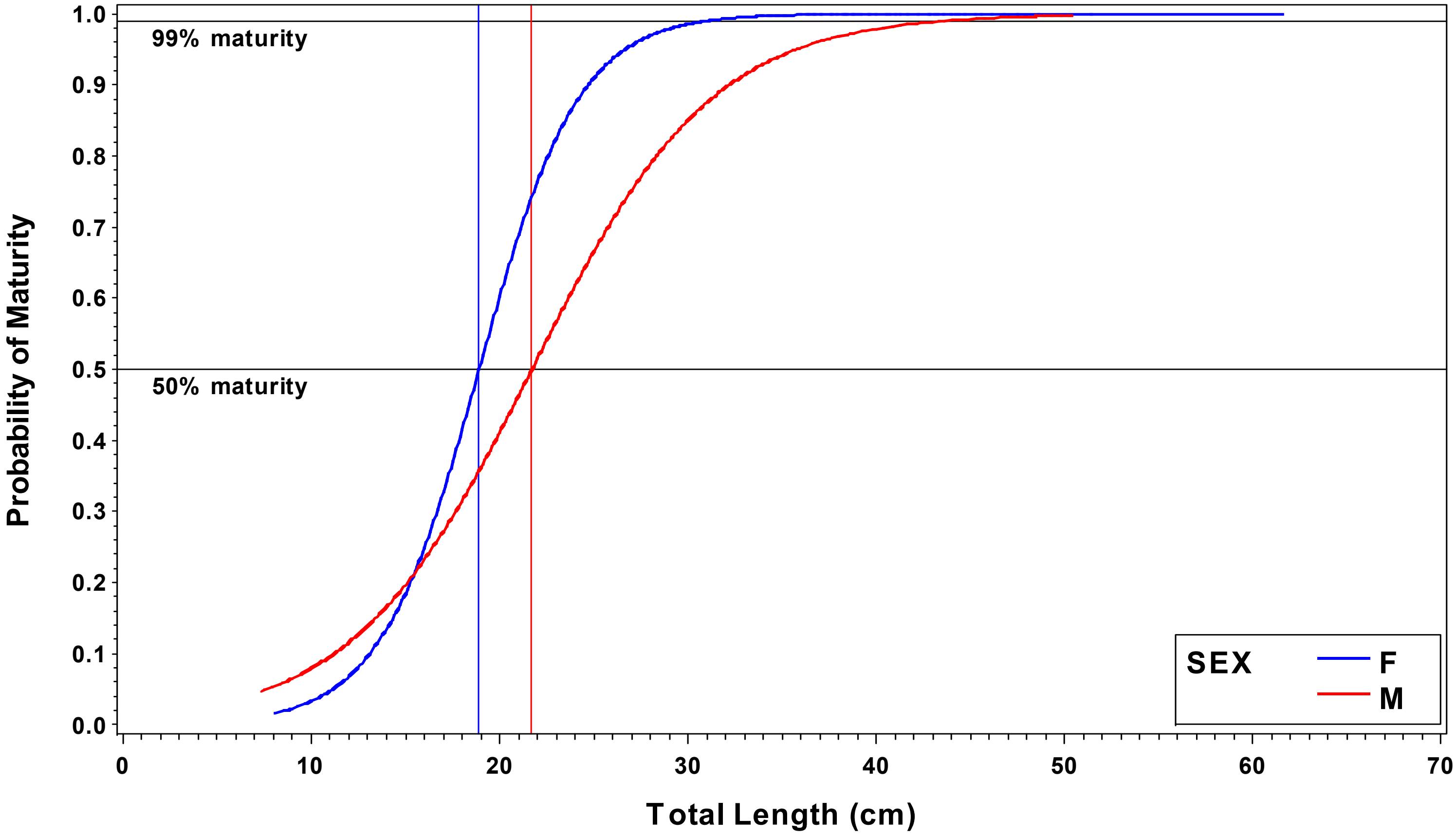


Figure 125. Weakfish diet in Chesapeake Bay, 2002-2007 combined.

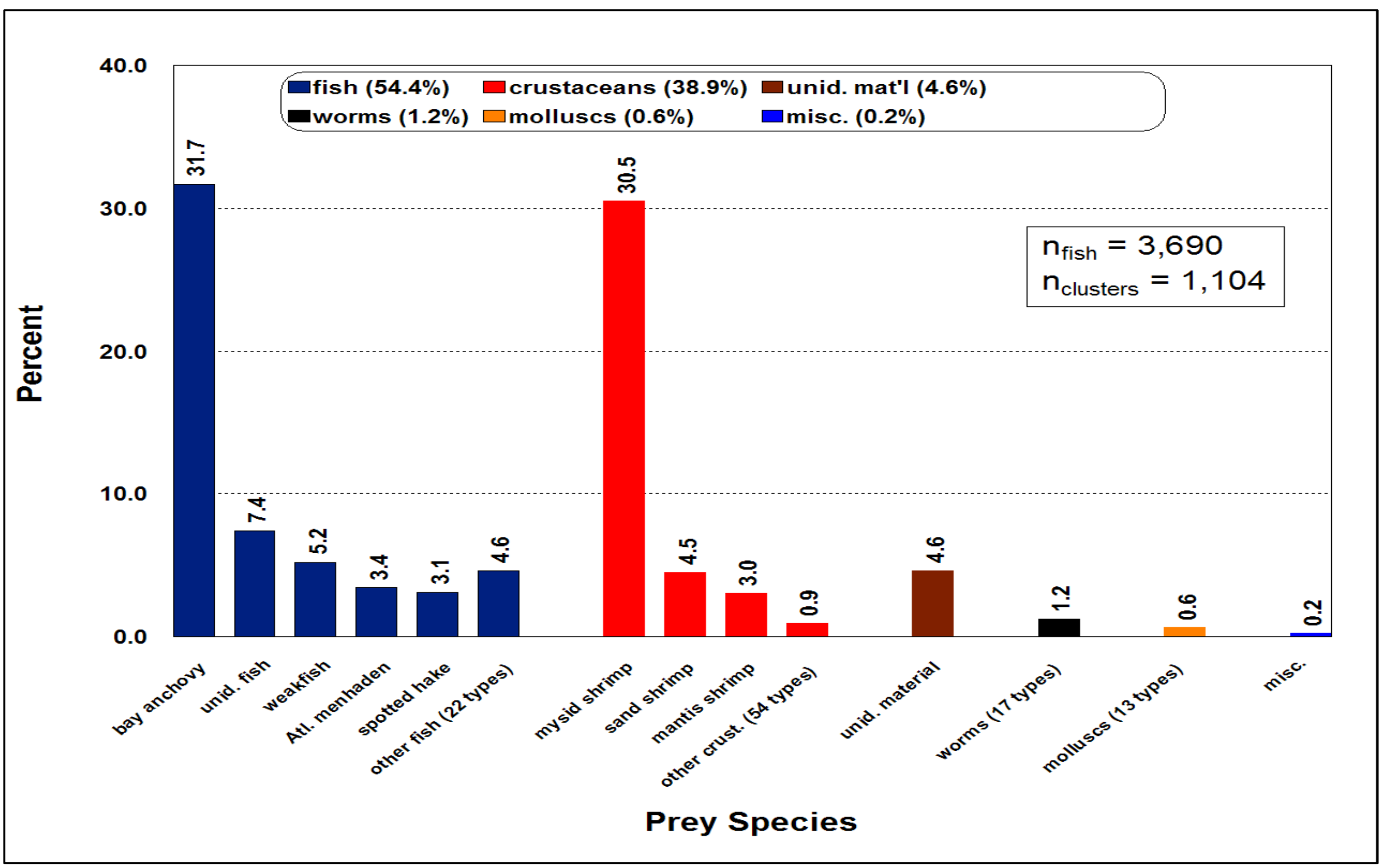
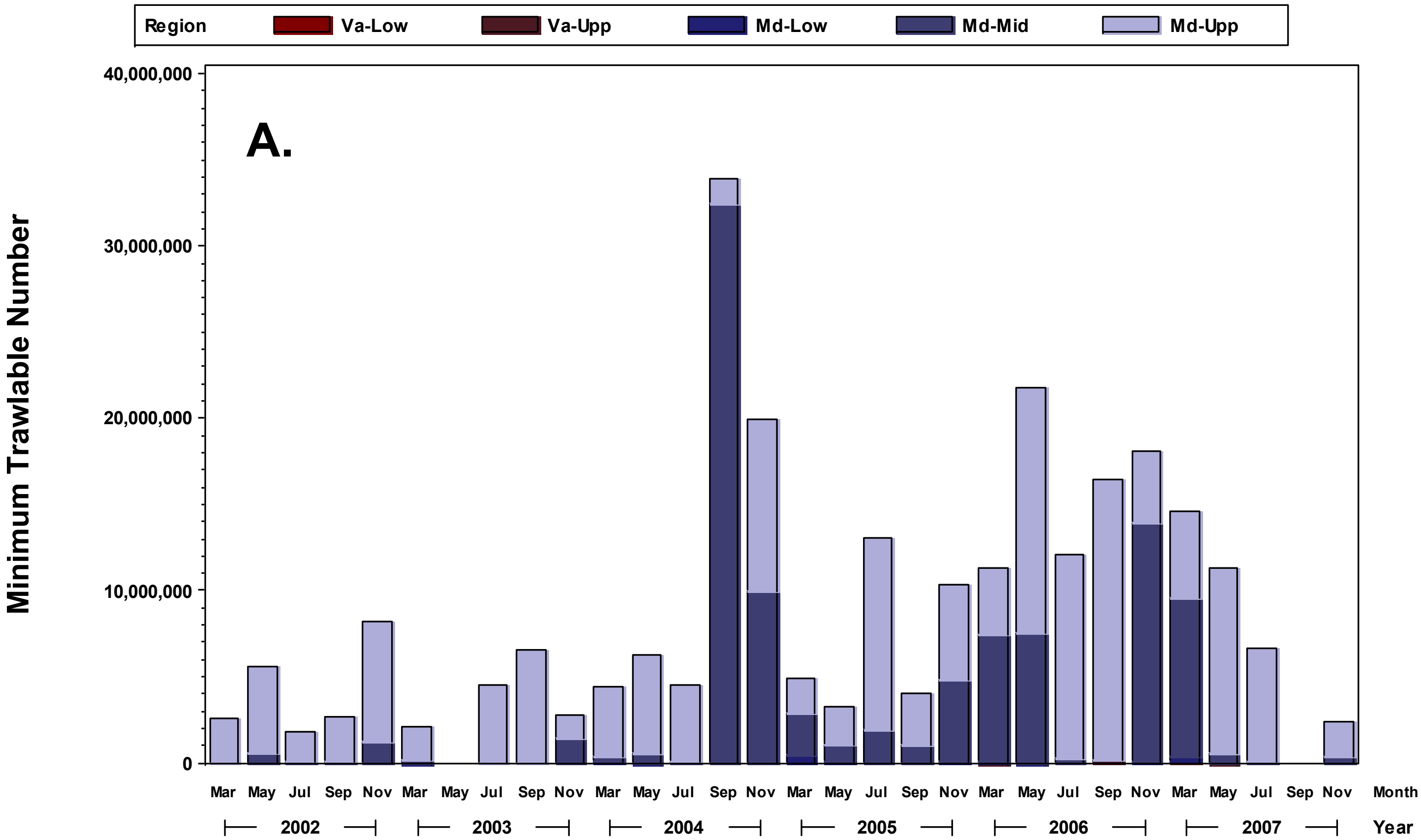


Figure 126. White perch minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay, 2002-2007.



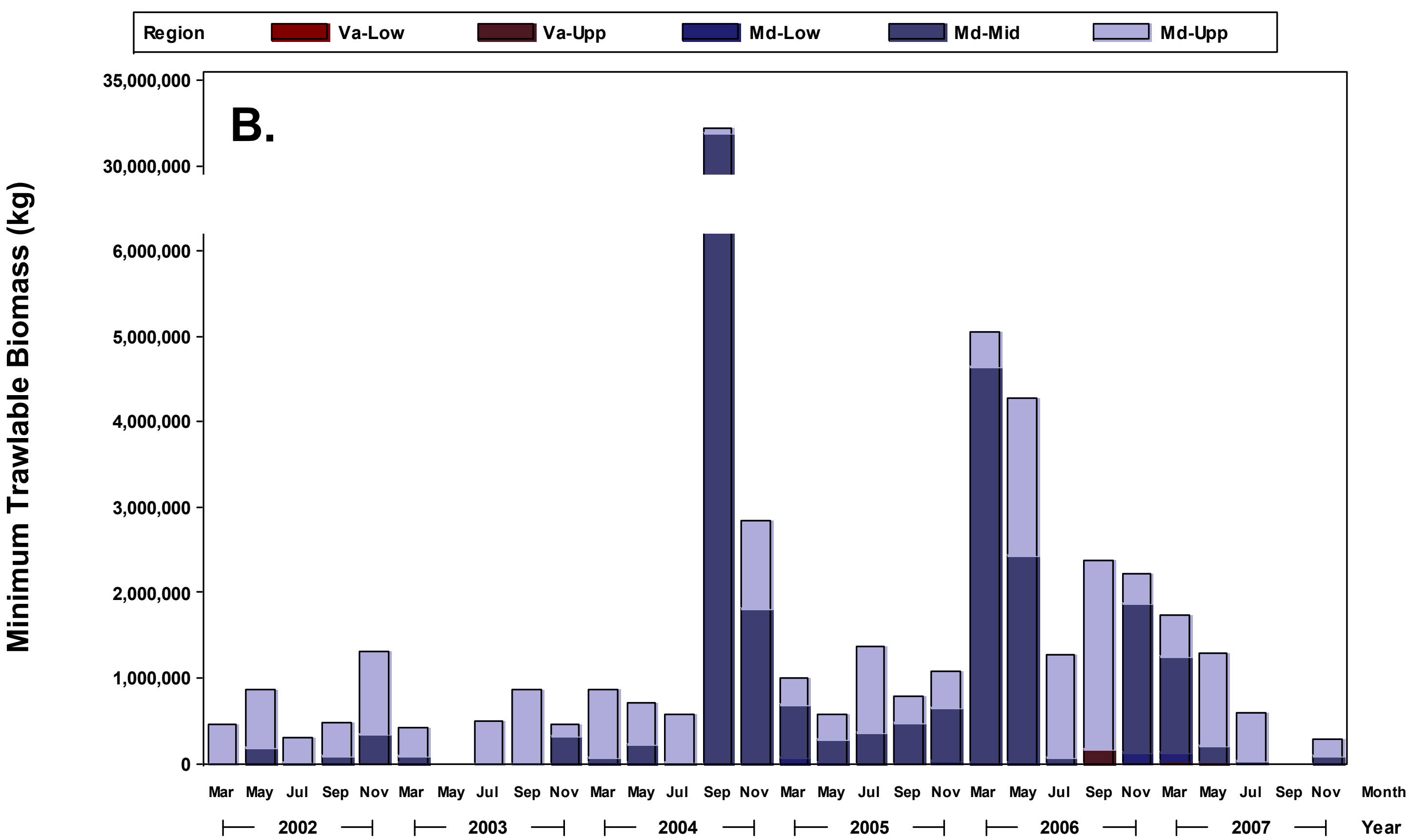


Figure 126. Figures 127. Site-specific white perch abundance (number per hectare swept), 2002.

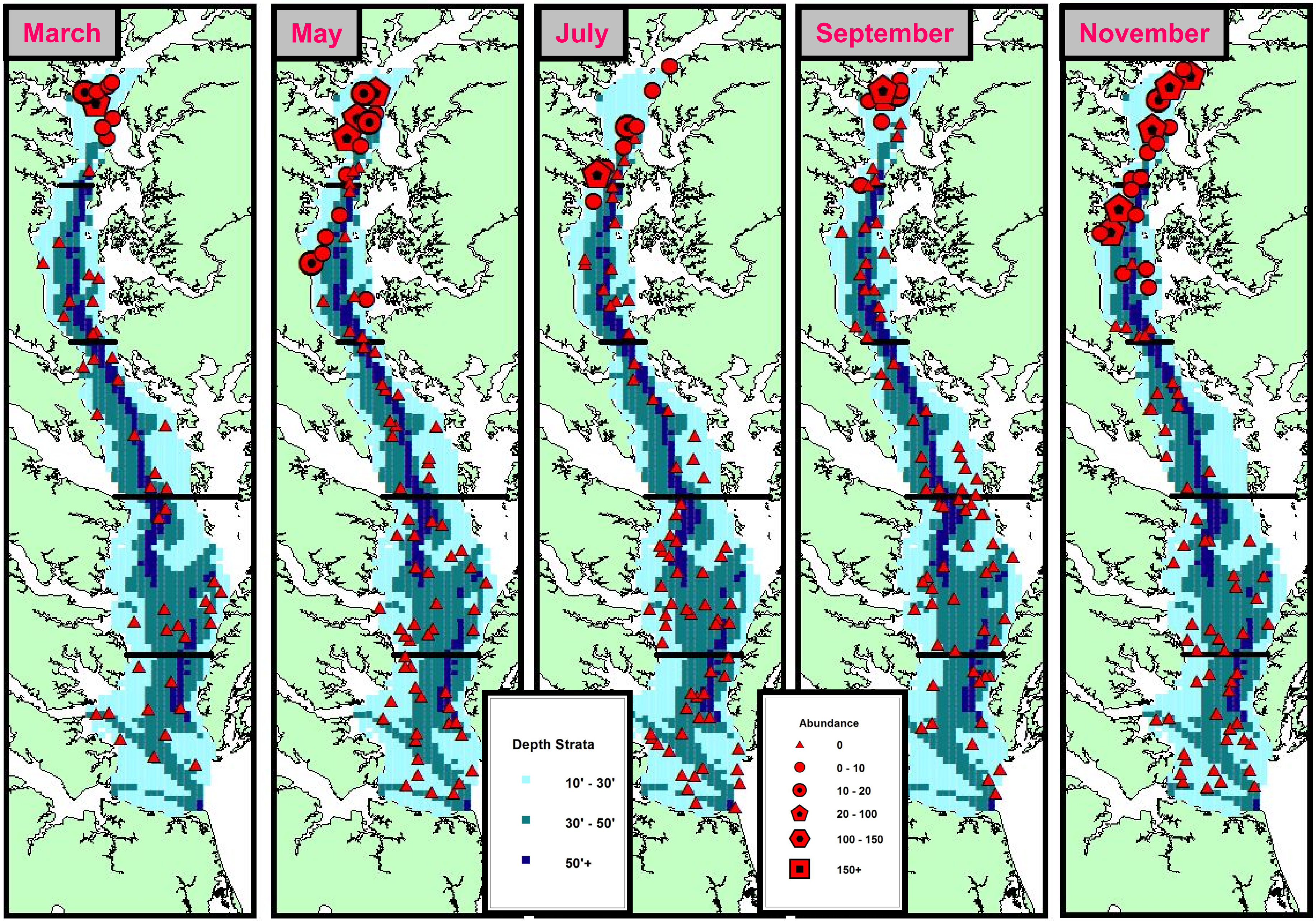


Figure 128. Site-specific white perch abundance (number per hectare swept), 2003.

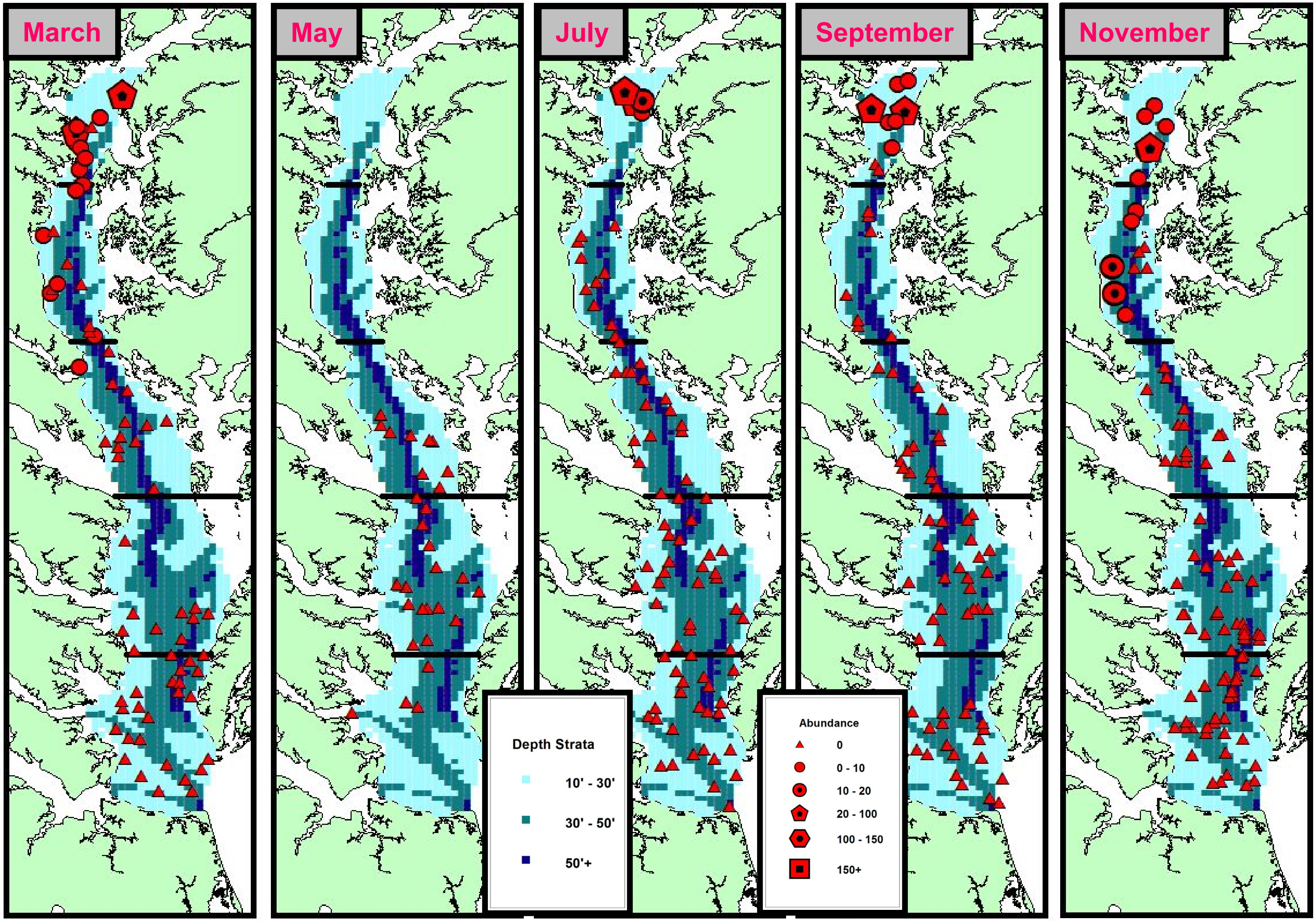


Figure 129. Site-specific white perch abundance (number per hectare swept), 2004.

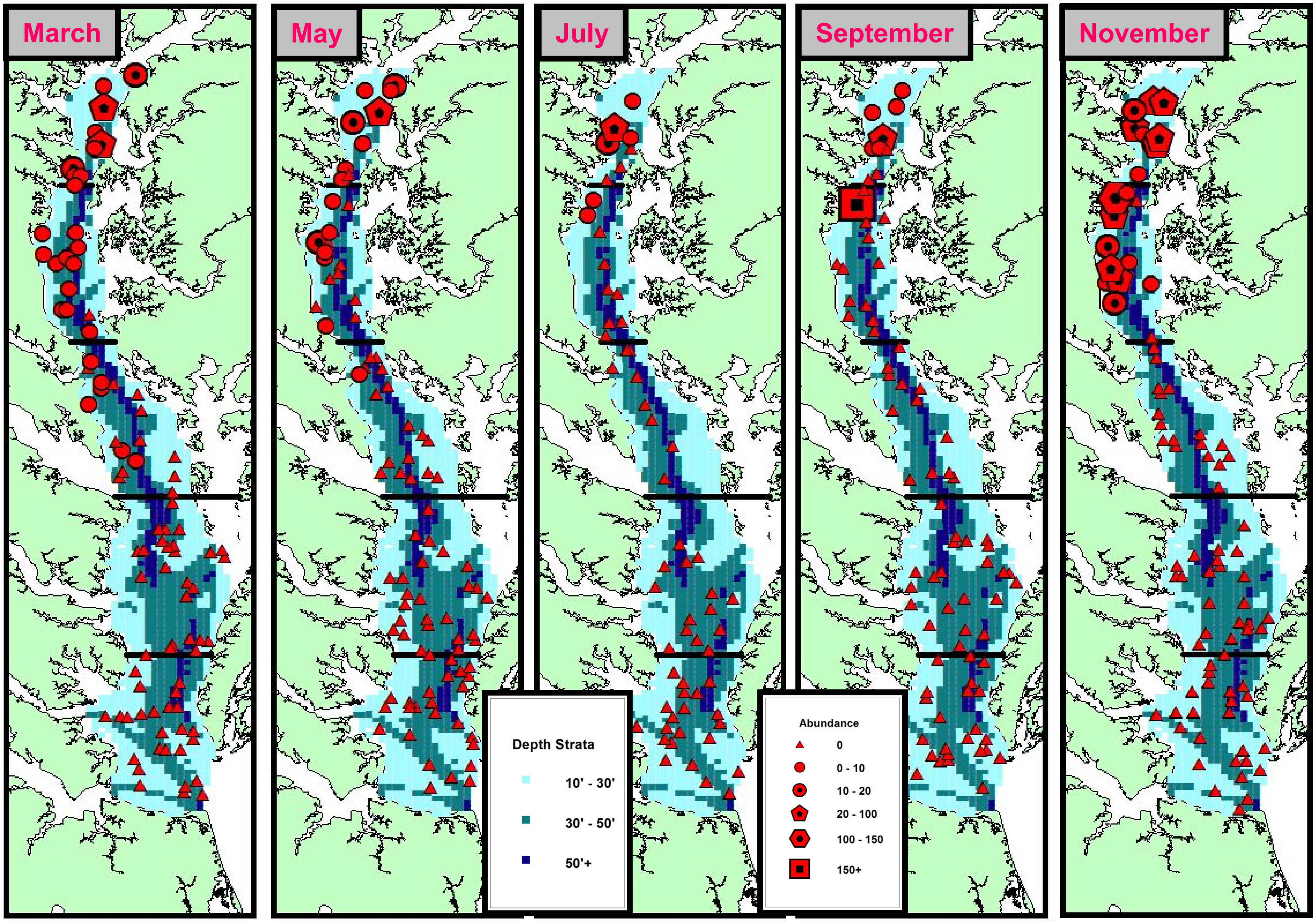


Figure 130. Site-specific white perch abundance (number per hectare swept), 2005.

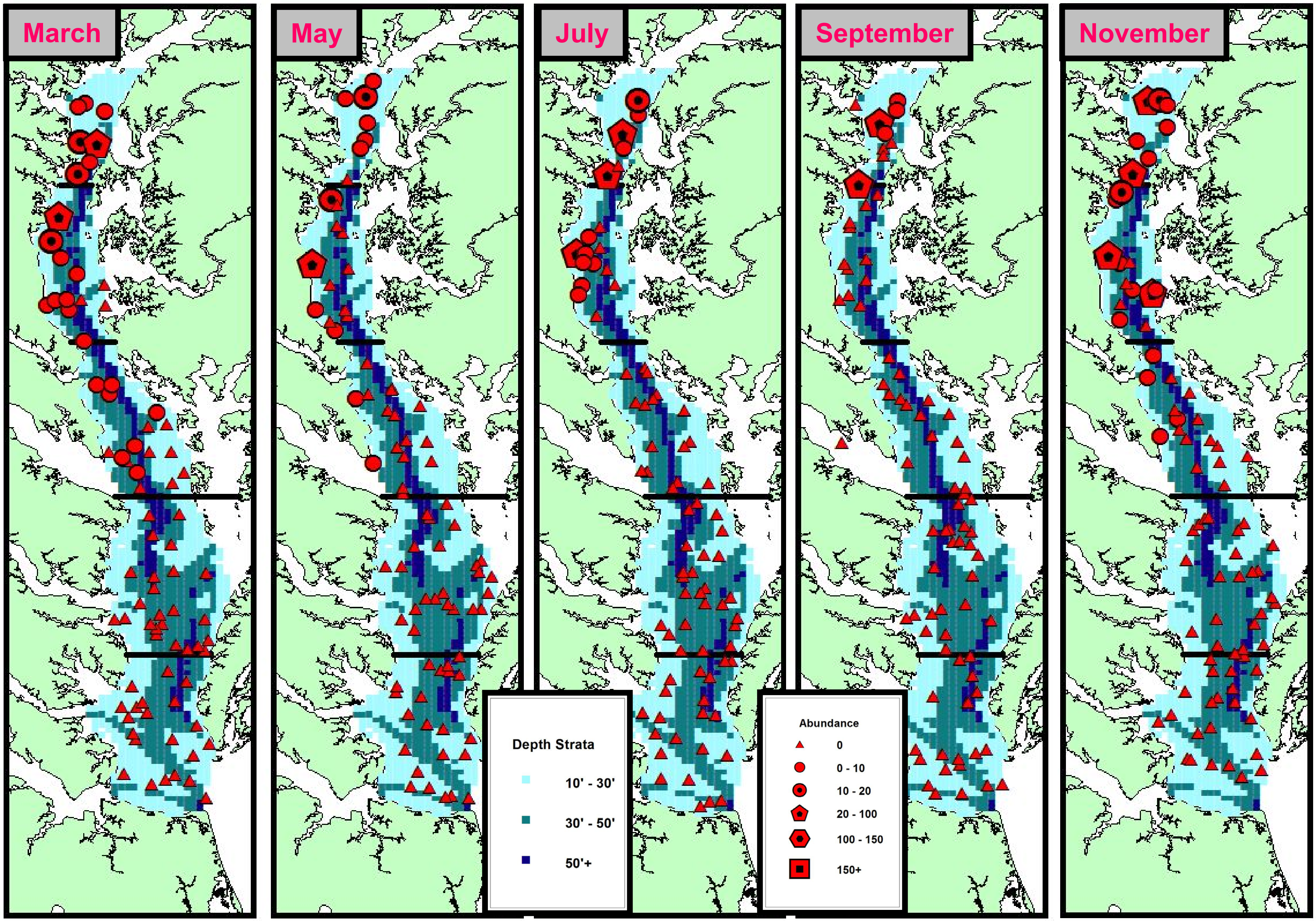


Figure 131. Site-specific white perch abundance (number per hectare swept), 2006.

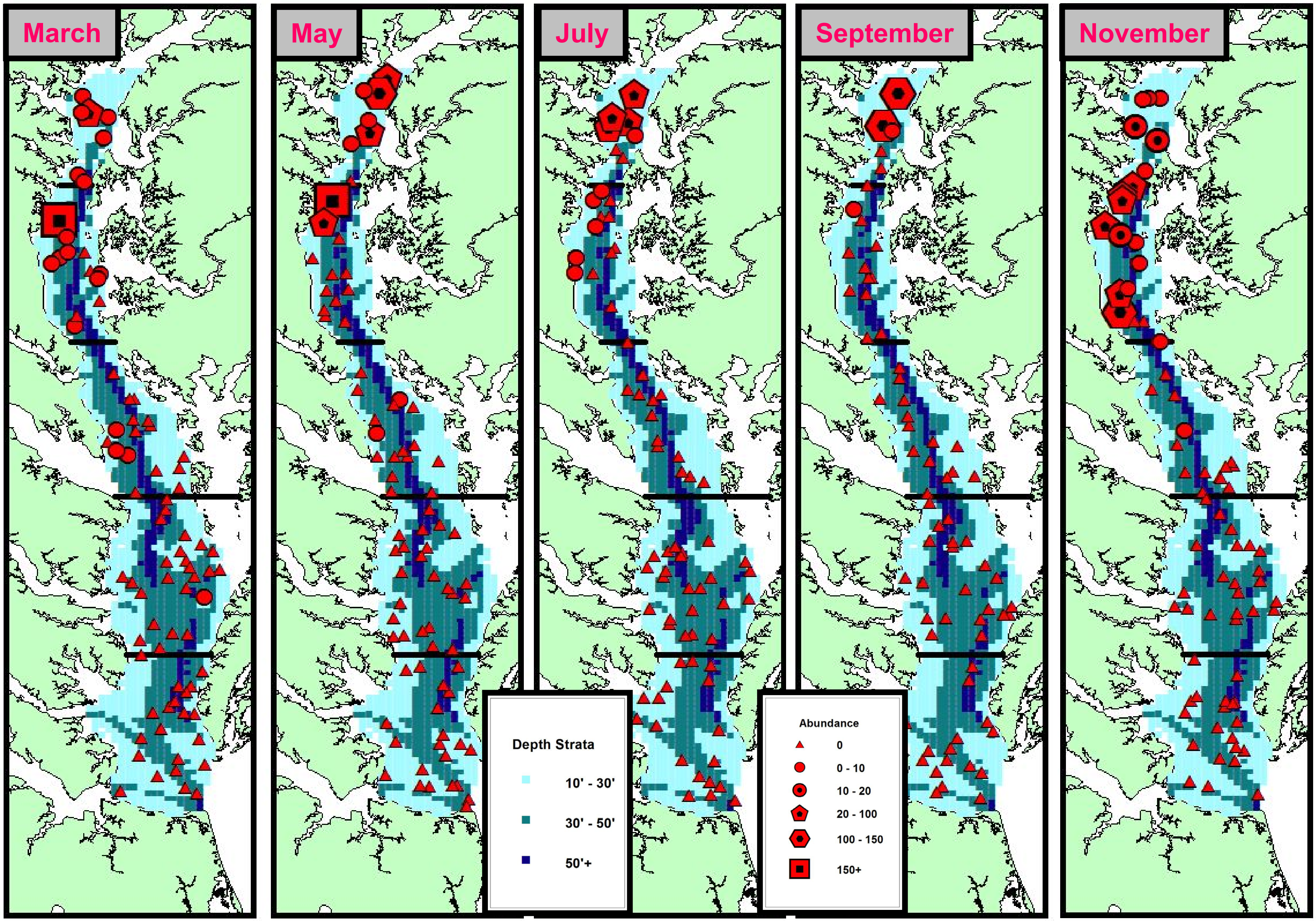


Figure 132. Abundance (number per hectare swept) of white perch in Chesapeake Bay, 2007.

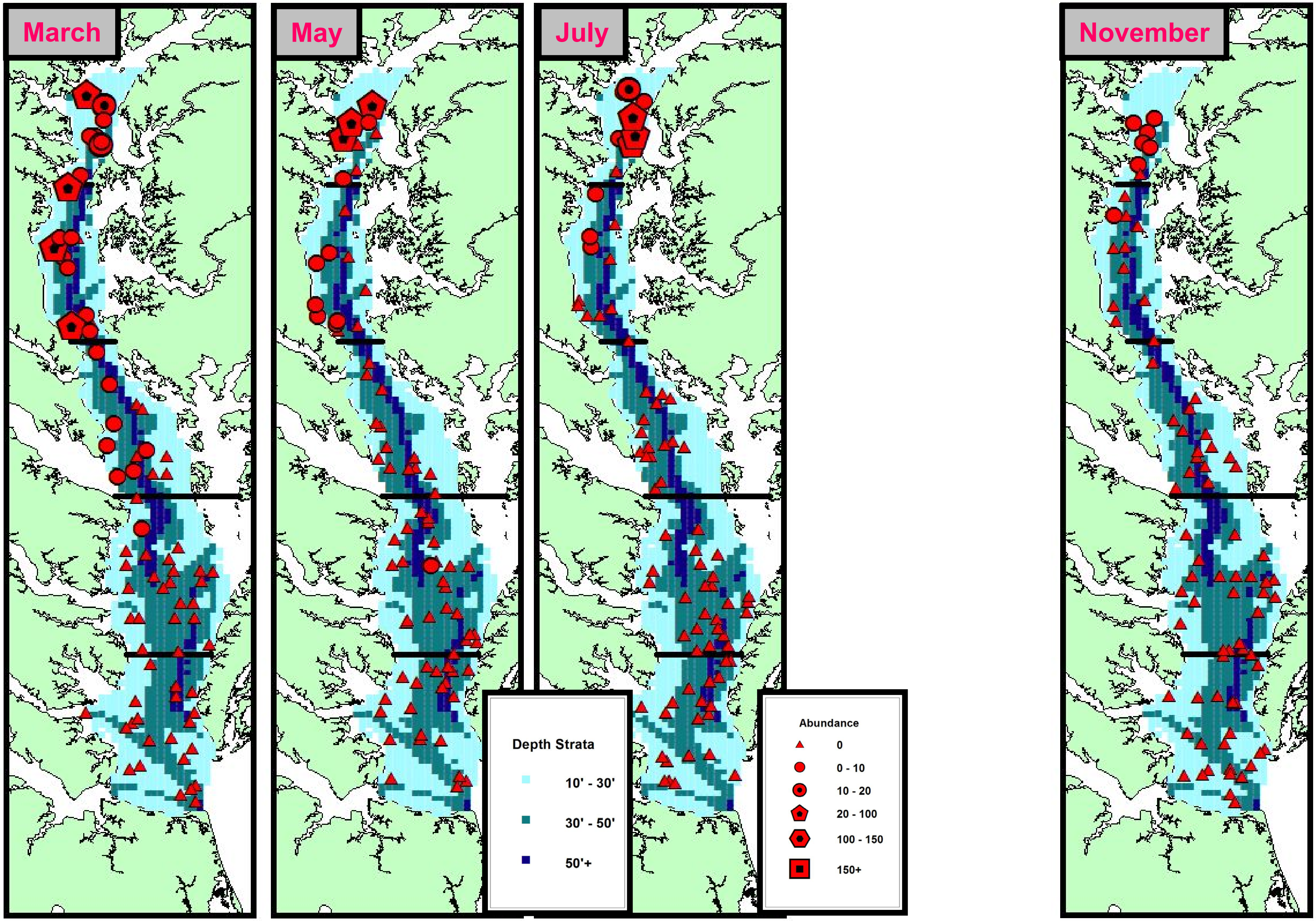


Figure 133. White perch length-frequency in Chesapeake Bay, 2002-2007.

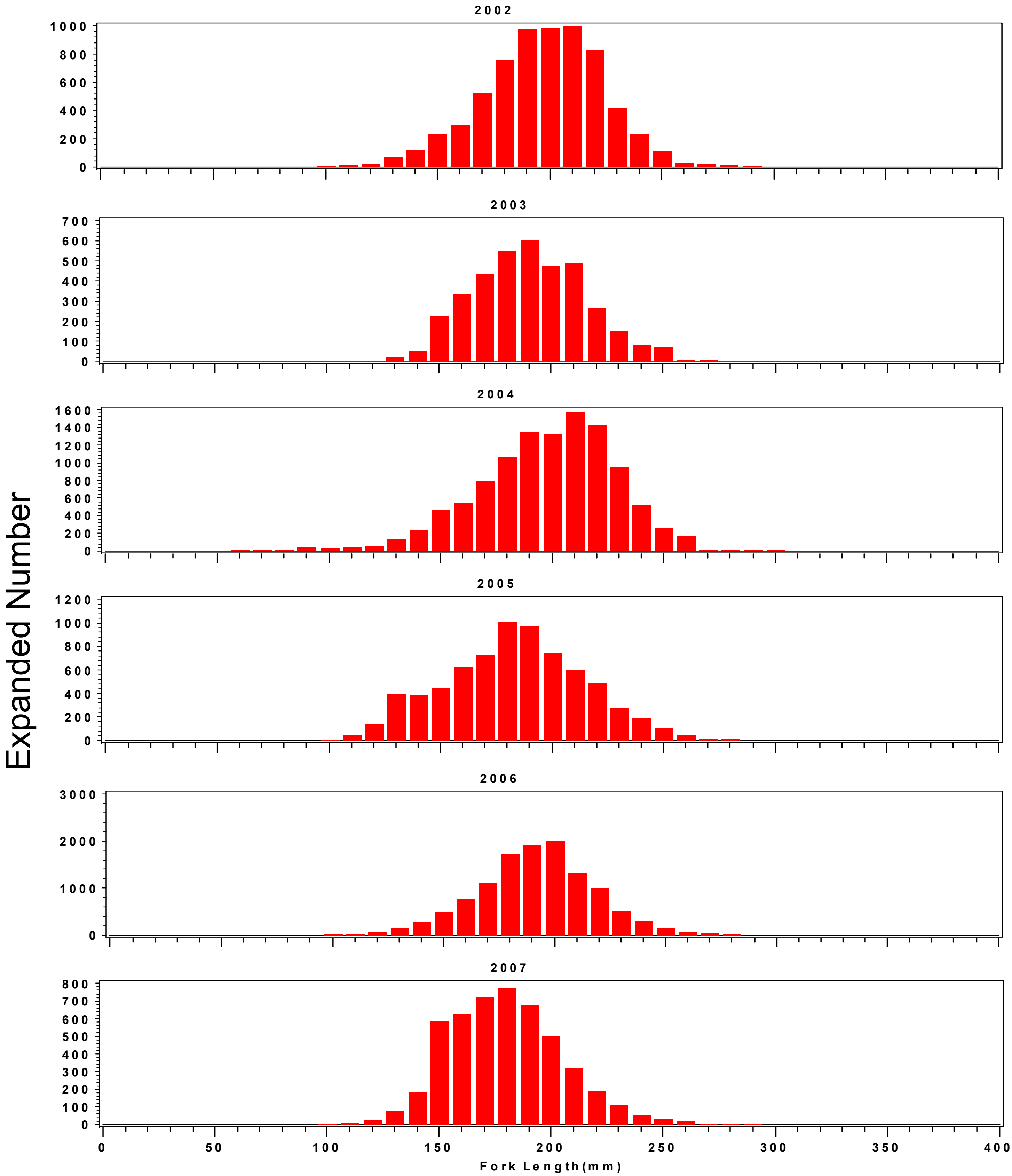


Figure 134. White perch age-structure in Chesapeake Bay, 2002-2007.

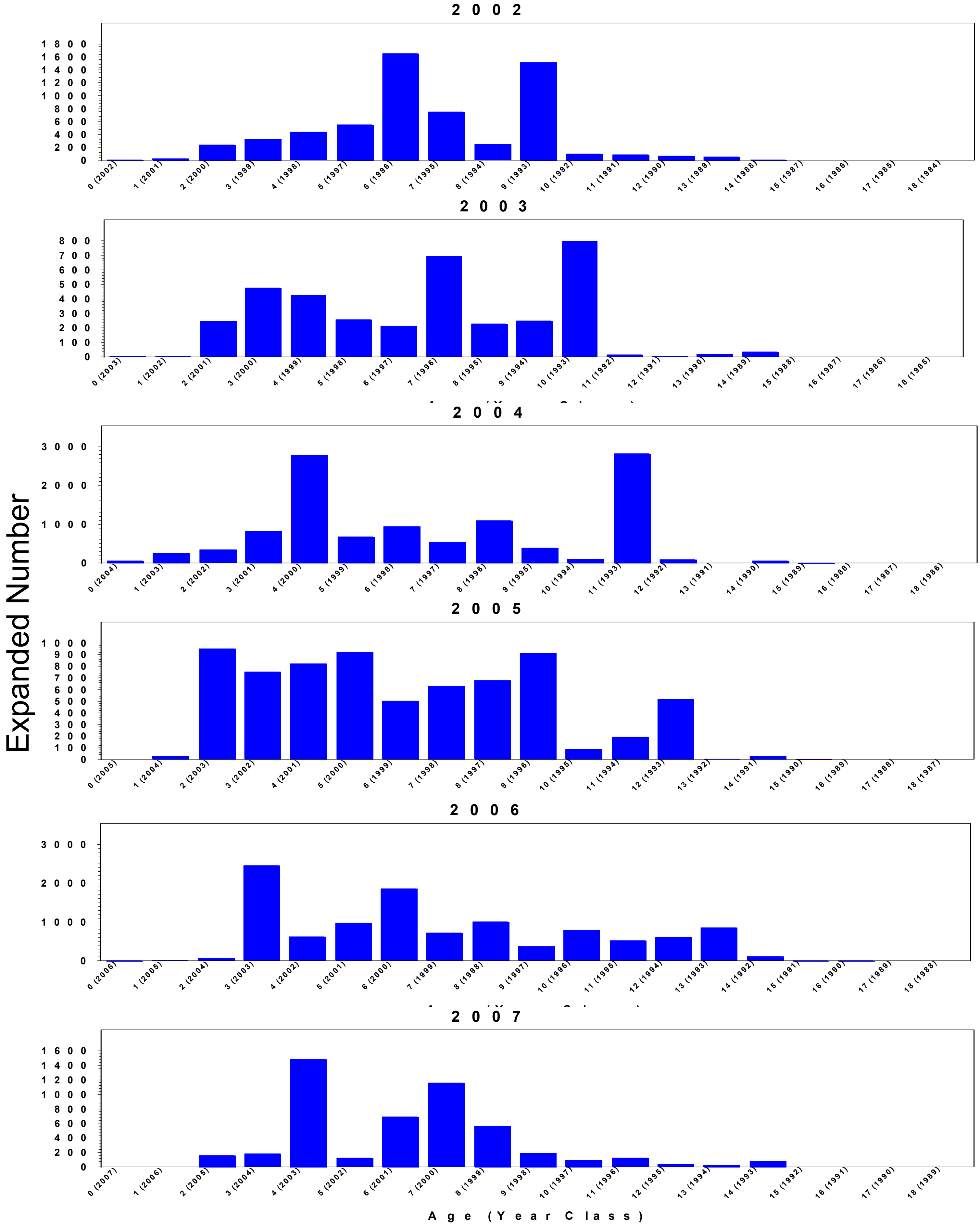
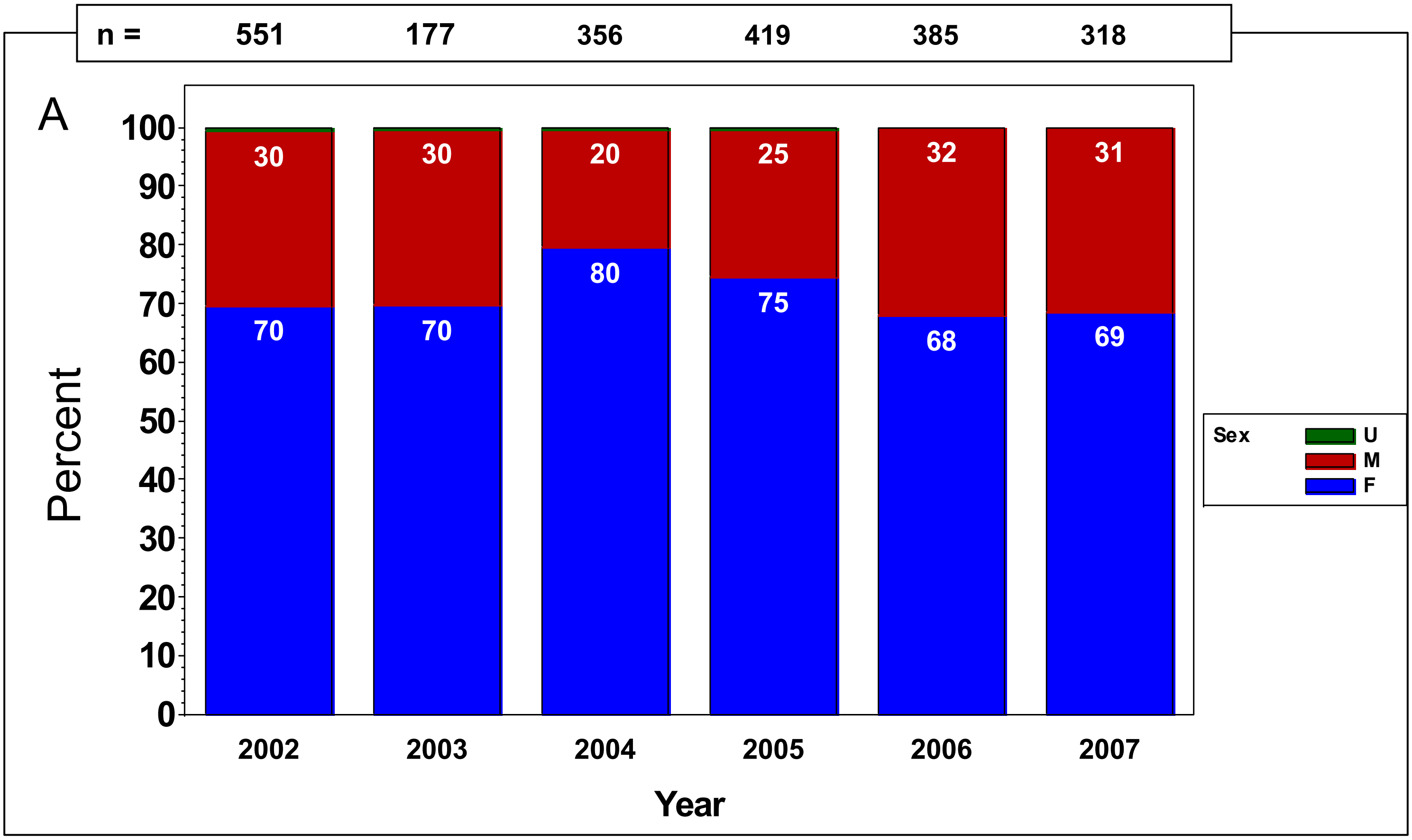


Figure 135. White perch sex-ratios in Chesapeake Bay, 2002-2007, by year (A), age (B).



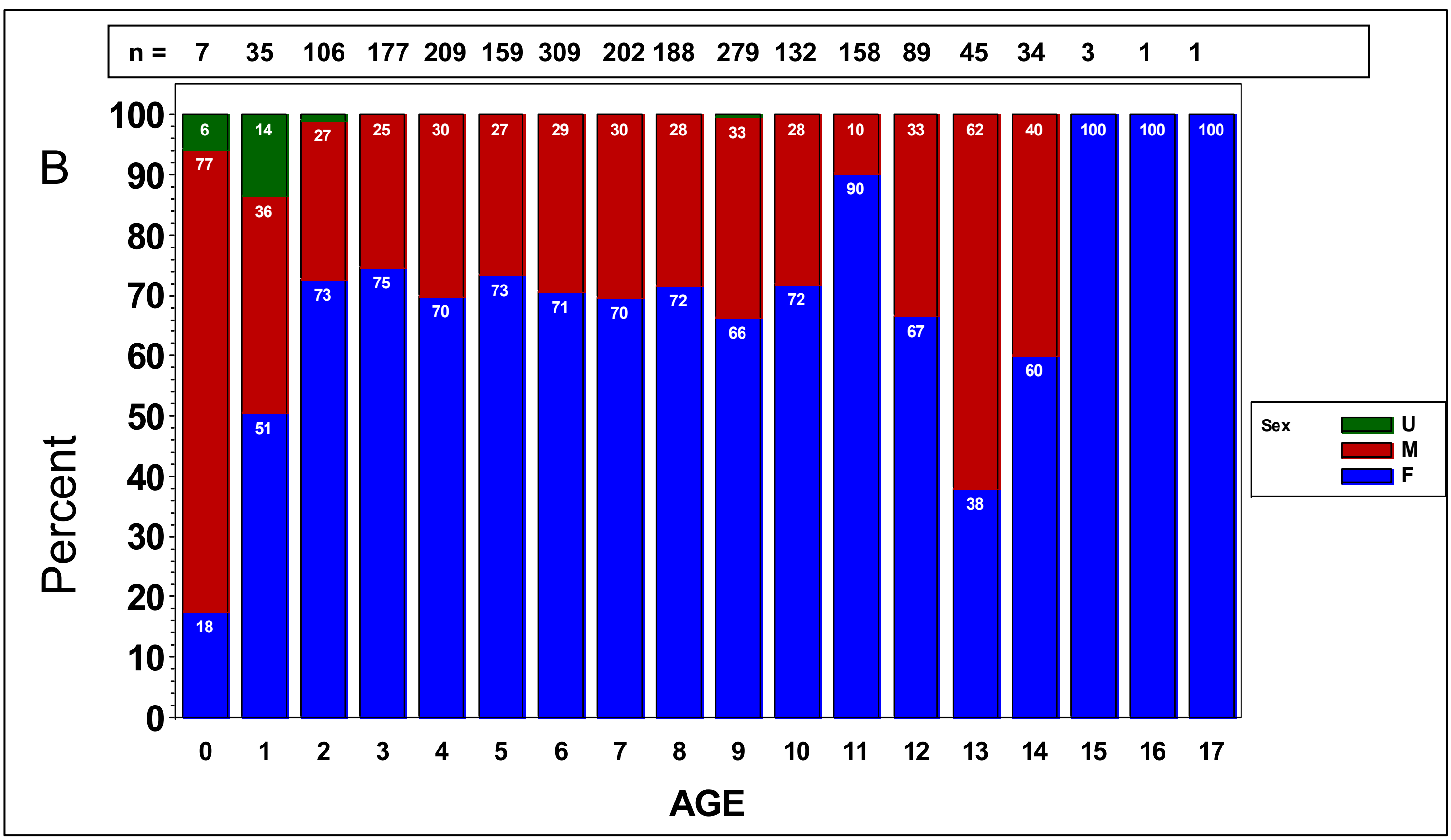
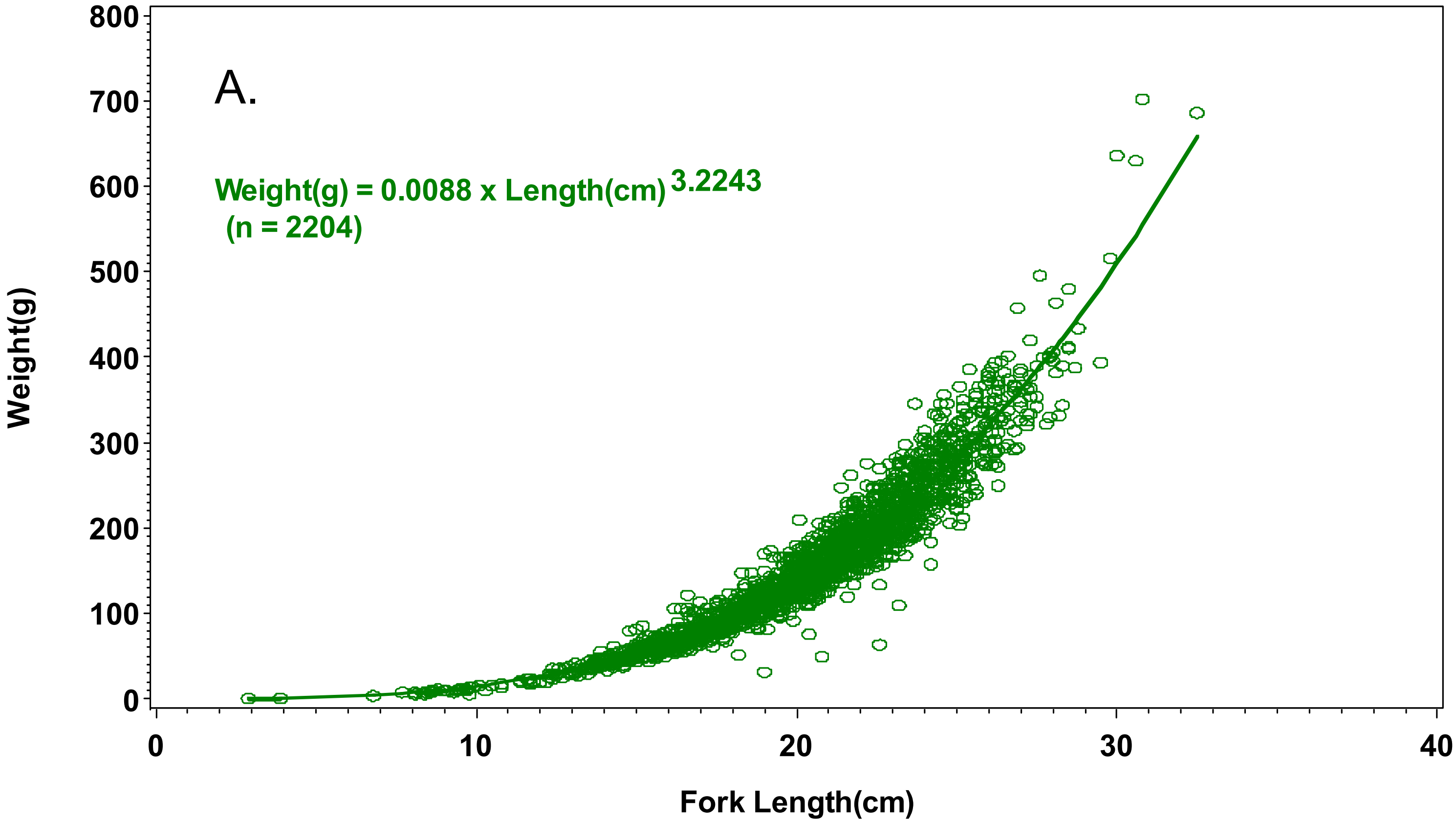


Figure 136. White perch length-weight relationships in Chesapeake Bay, 2002-2007, for sexes combined (A) and separately (B).



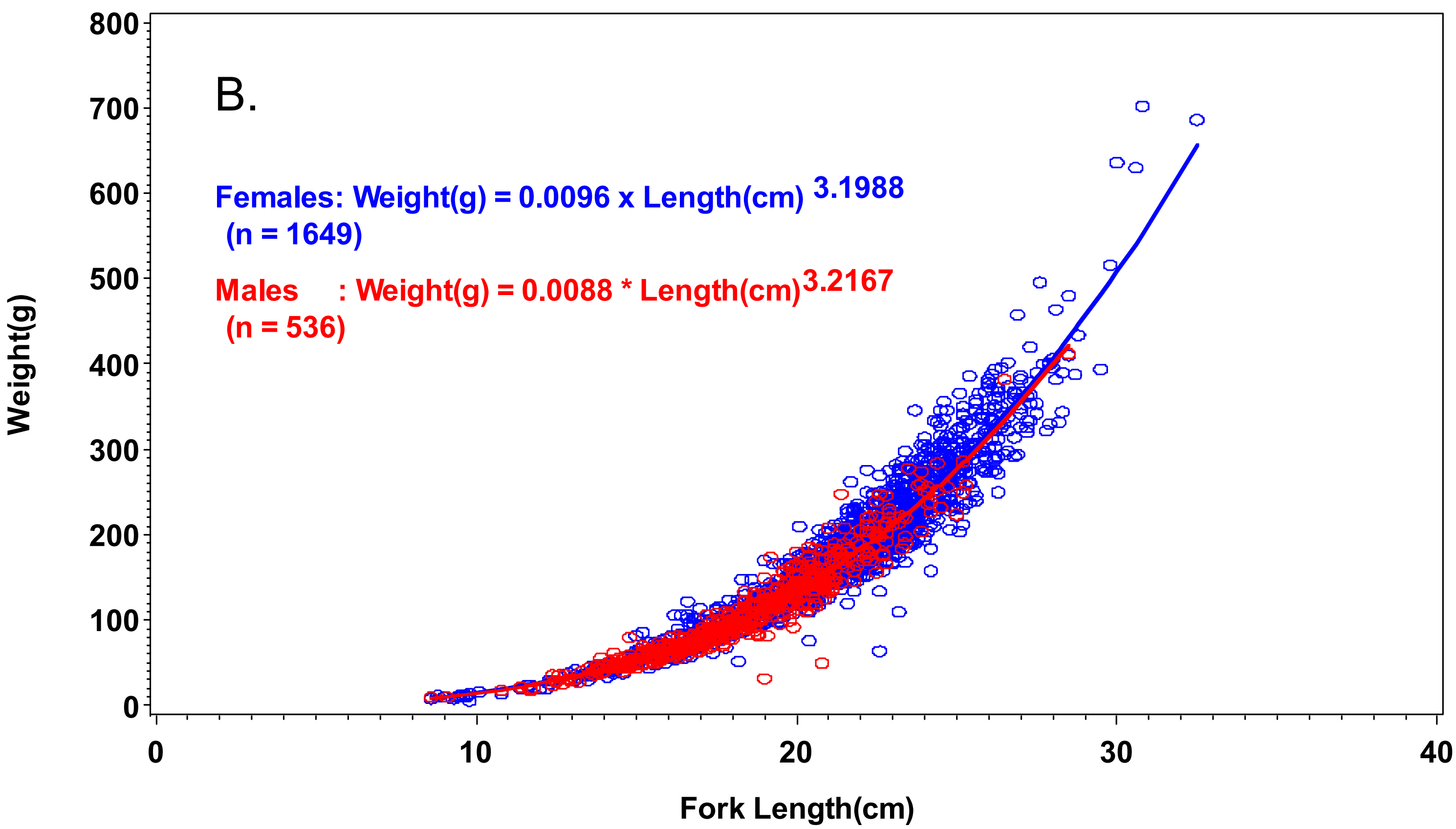


Figure 137. White perch maturity schedule in Chesapeake Bay, 2002-2007 combined, by sex.

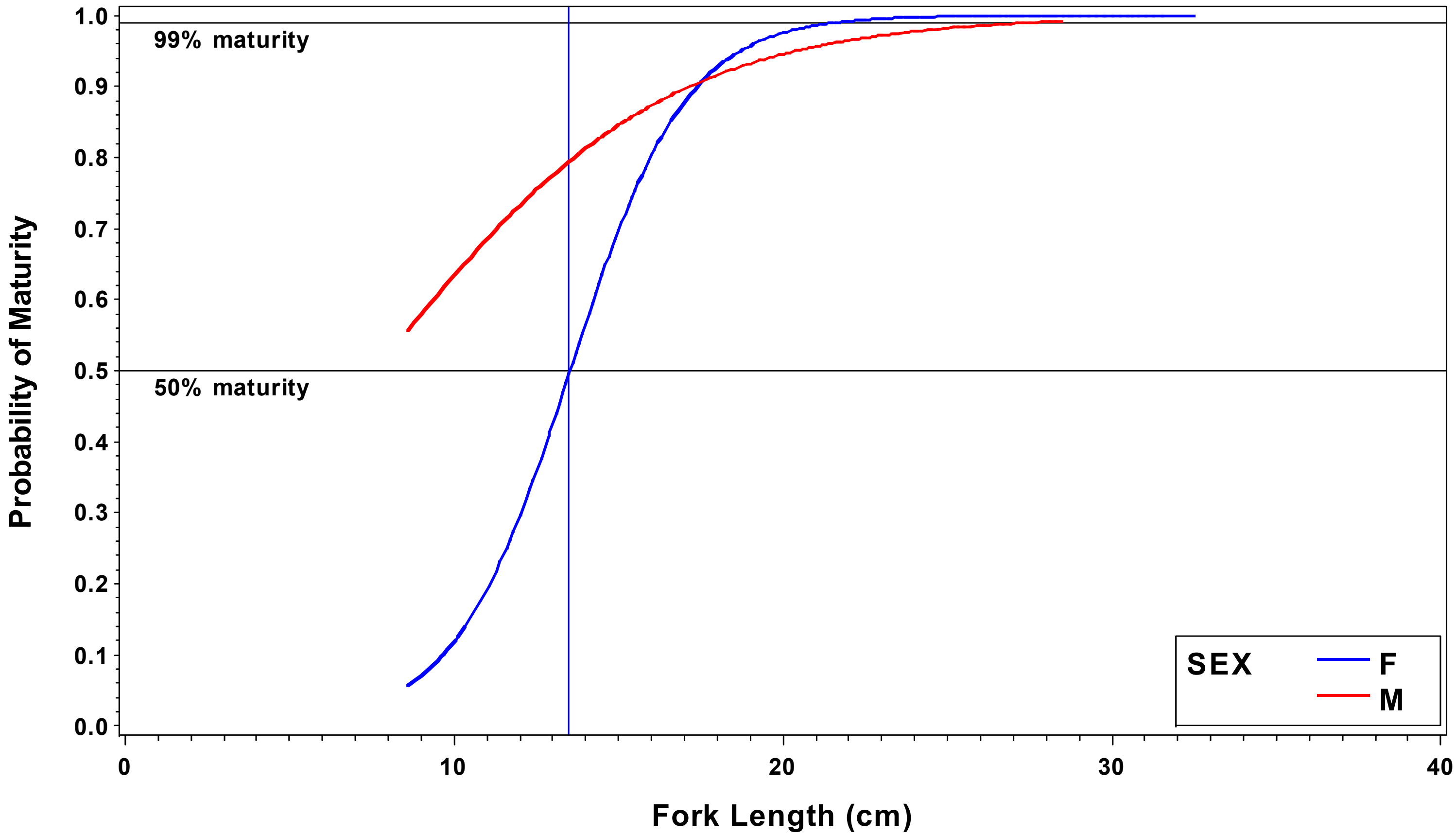


Figure 138. White perch diet in Chesapeake Bay, 2002-2007 combined.

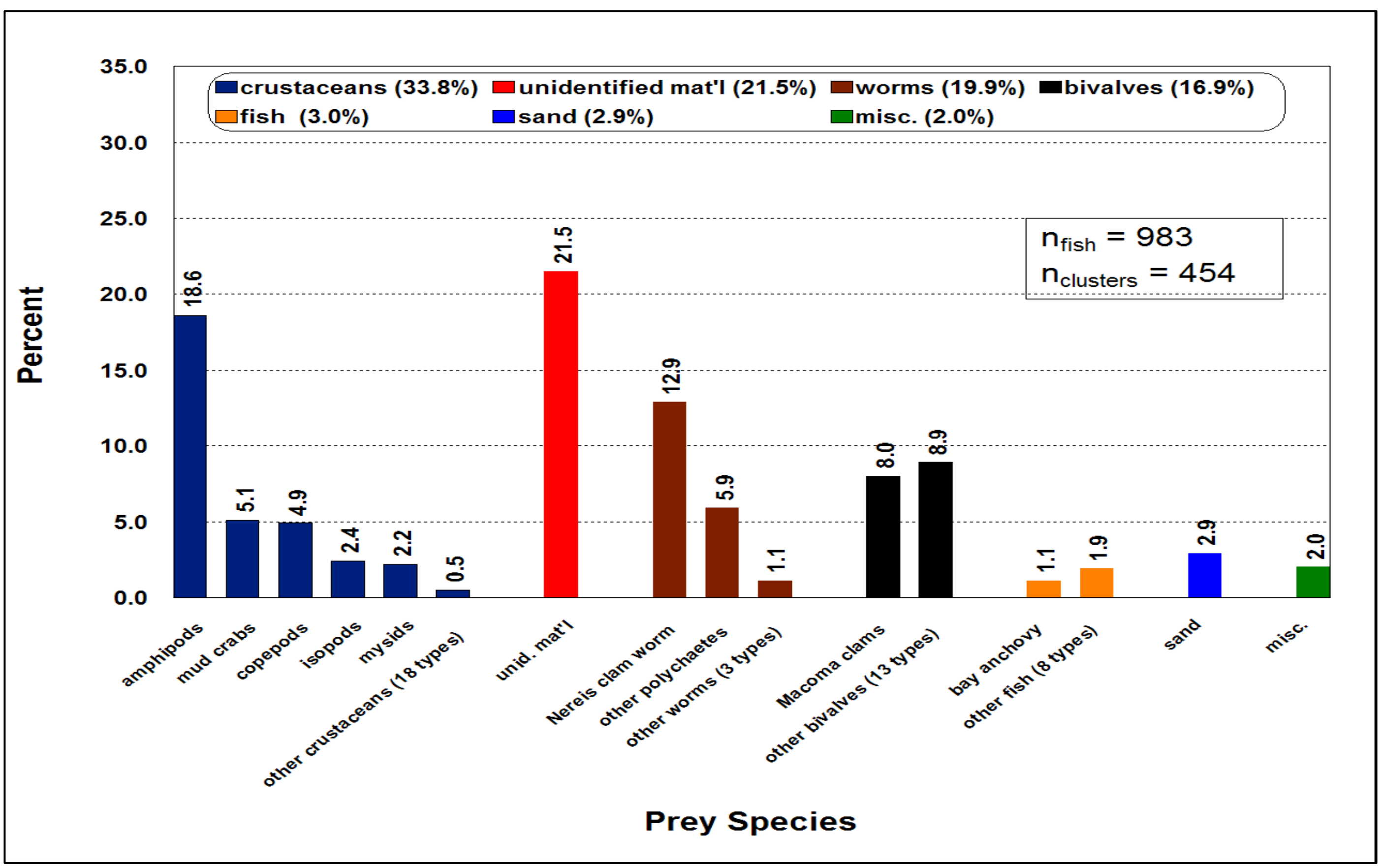


Figure 138. Surface temperature in Chesapeake Bay, 2002.

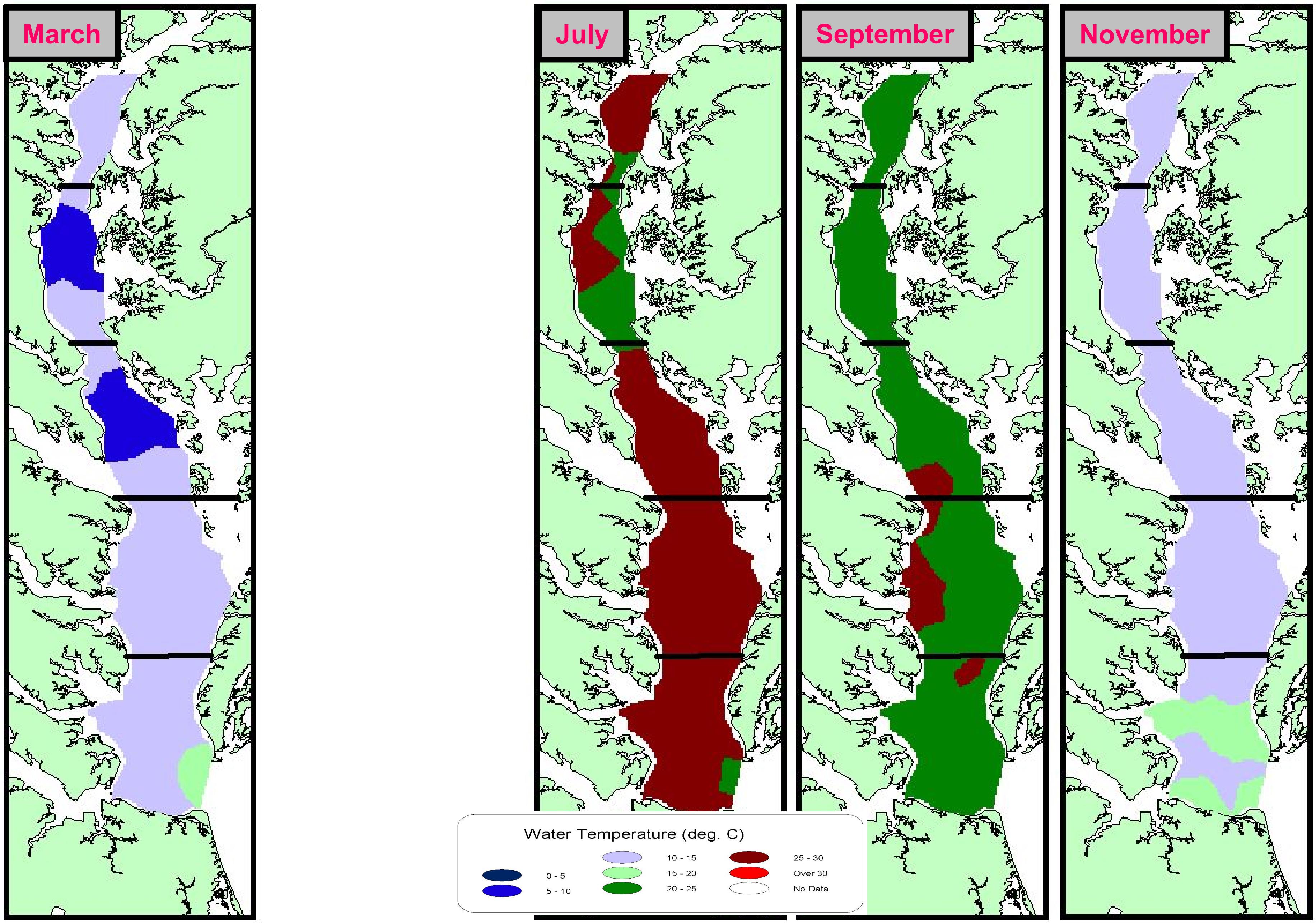


Figure 139. Bottom temperature in Chesapeake Bay, 2002.

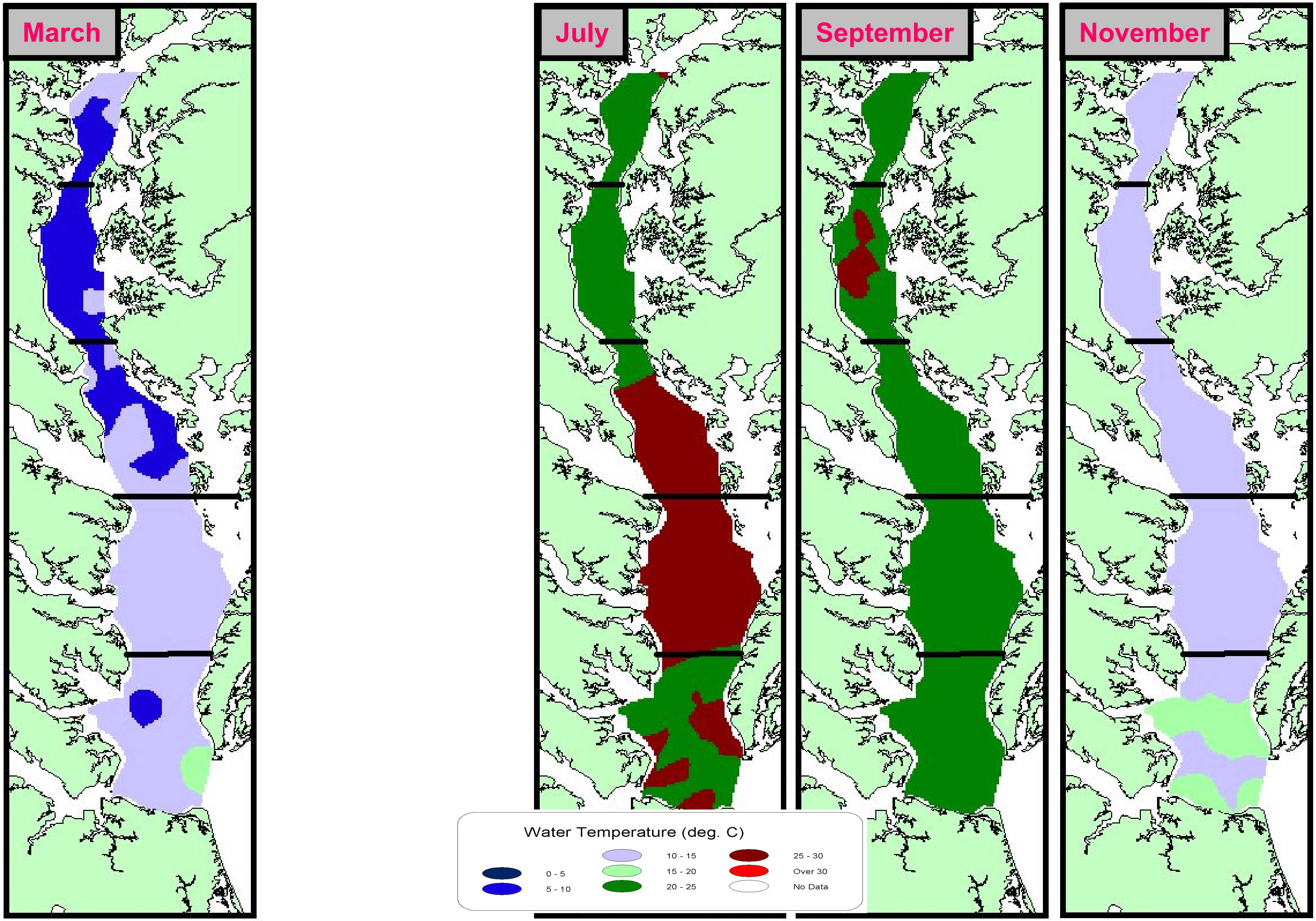


Figure 140. Surface temperature in Chesapeake Bay, 2003.

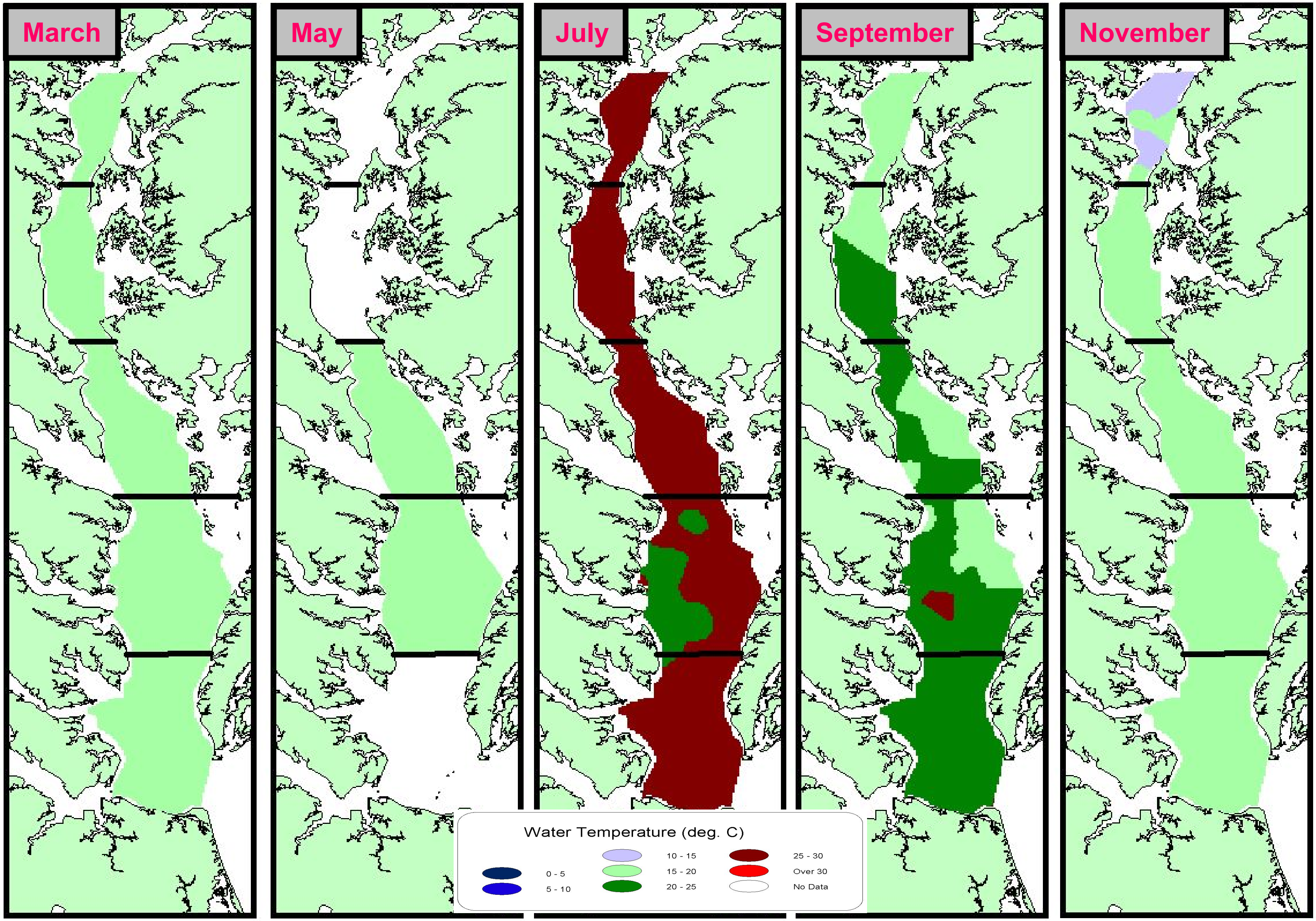


Figure 141. Bottom temperature in Chesapeake Bay, 2003.

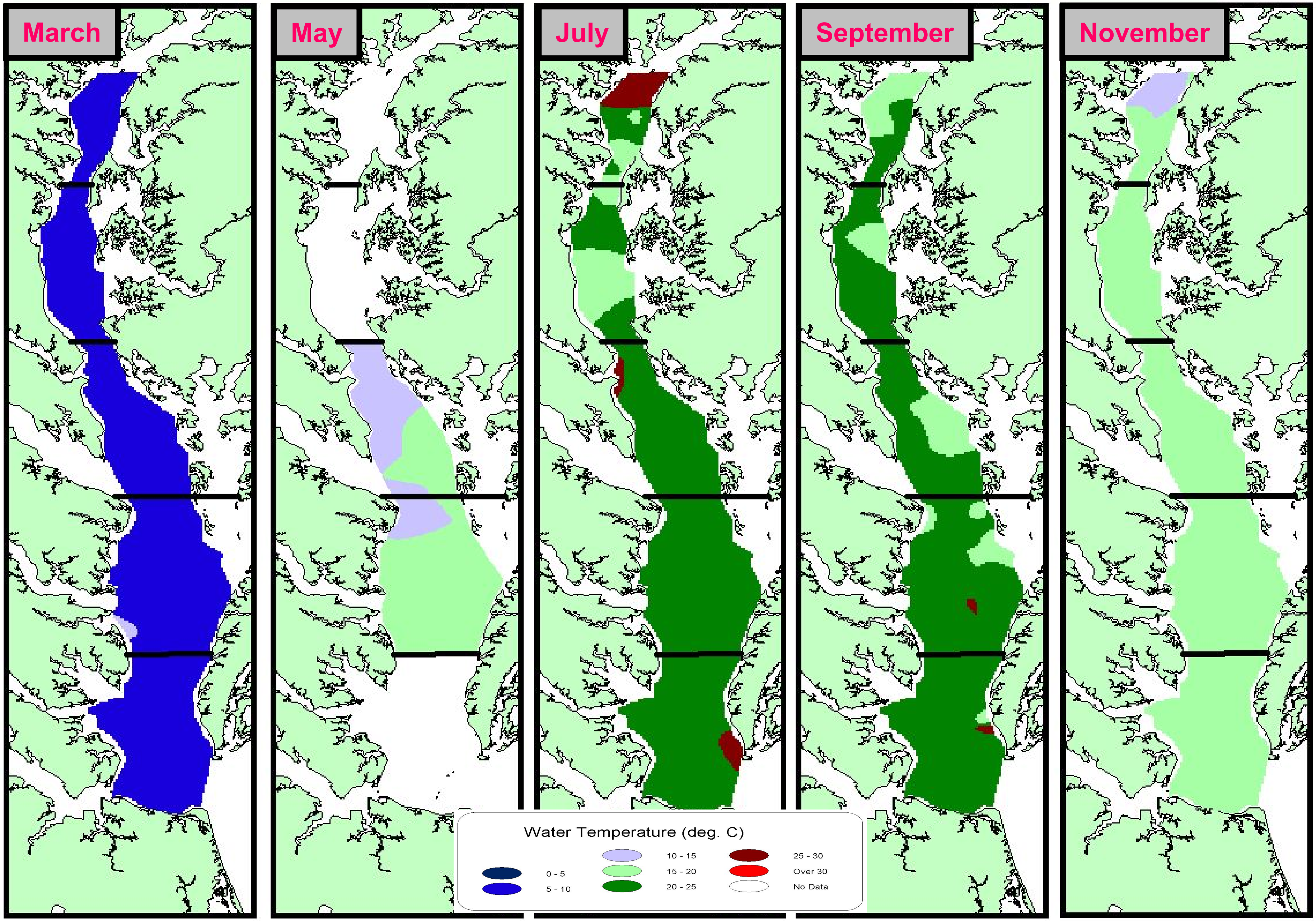


Figure 142. Surface temperature in Chesapeake Bay, 2004.

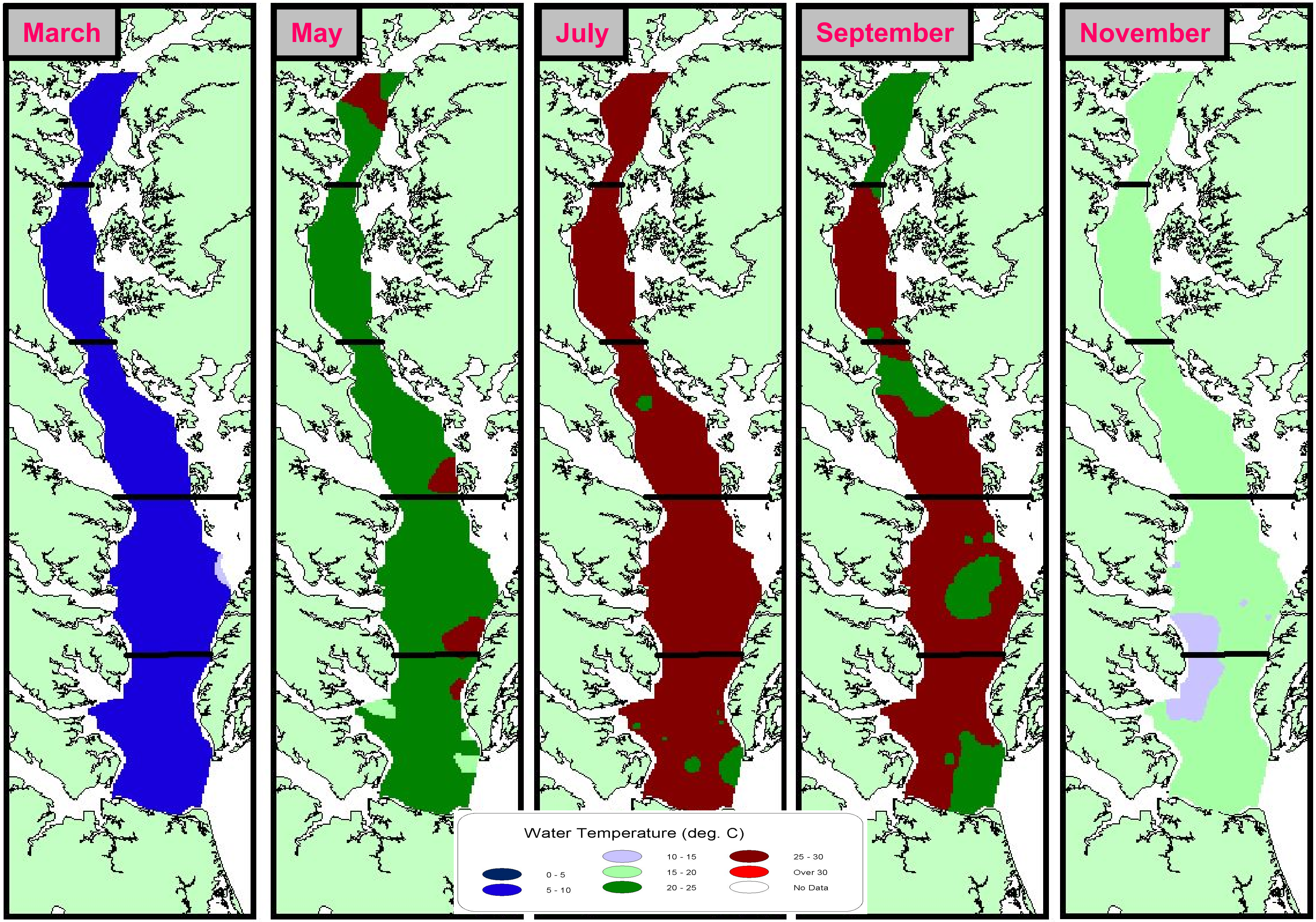


Figure 143. Bottom temperature in Chesapeake Bay, 2004.

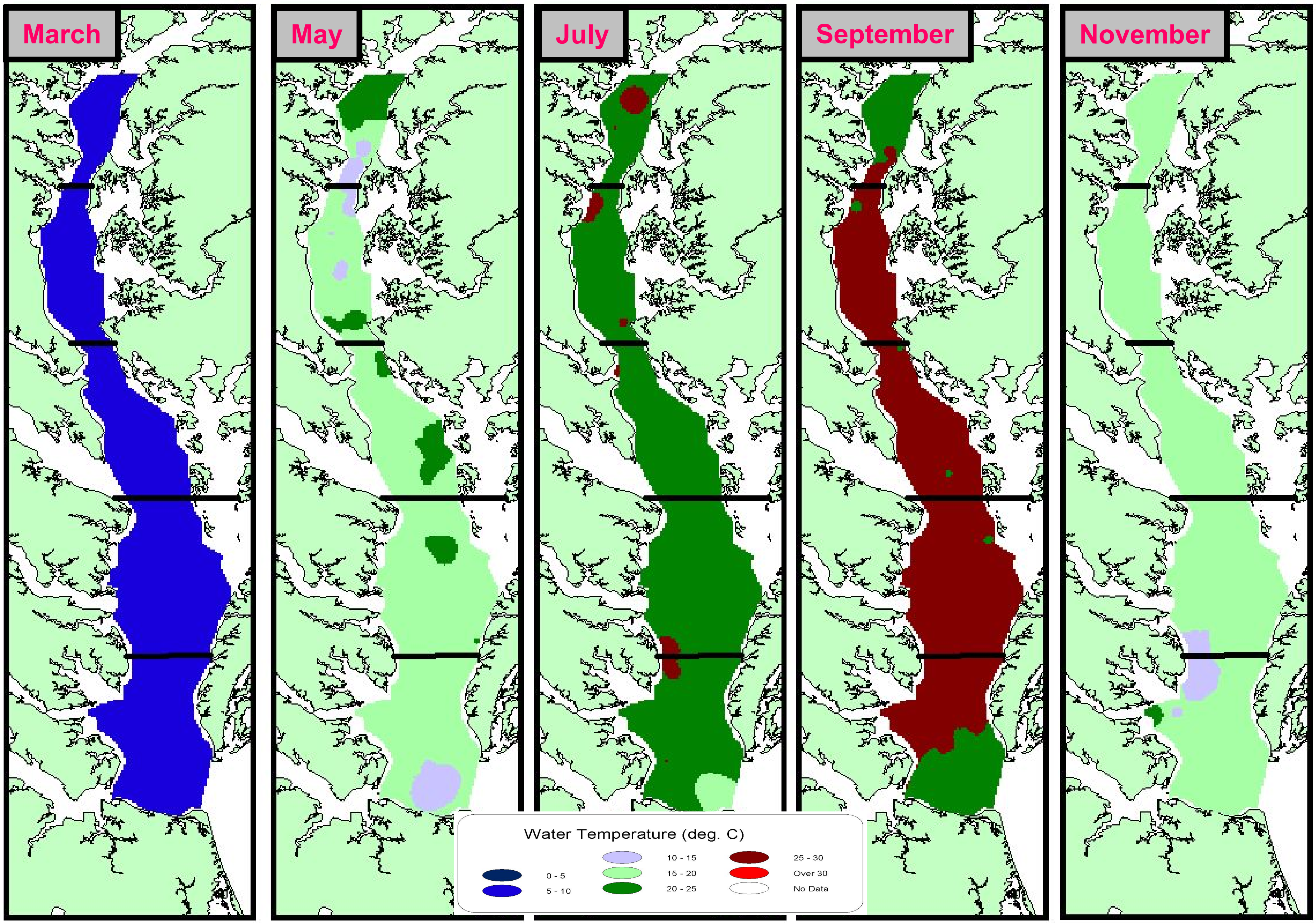


Figure 144. Surface temperature in Chesapeake Bay, 2005.

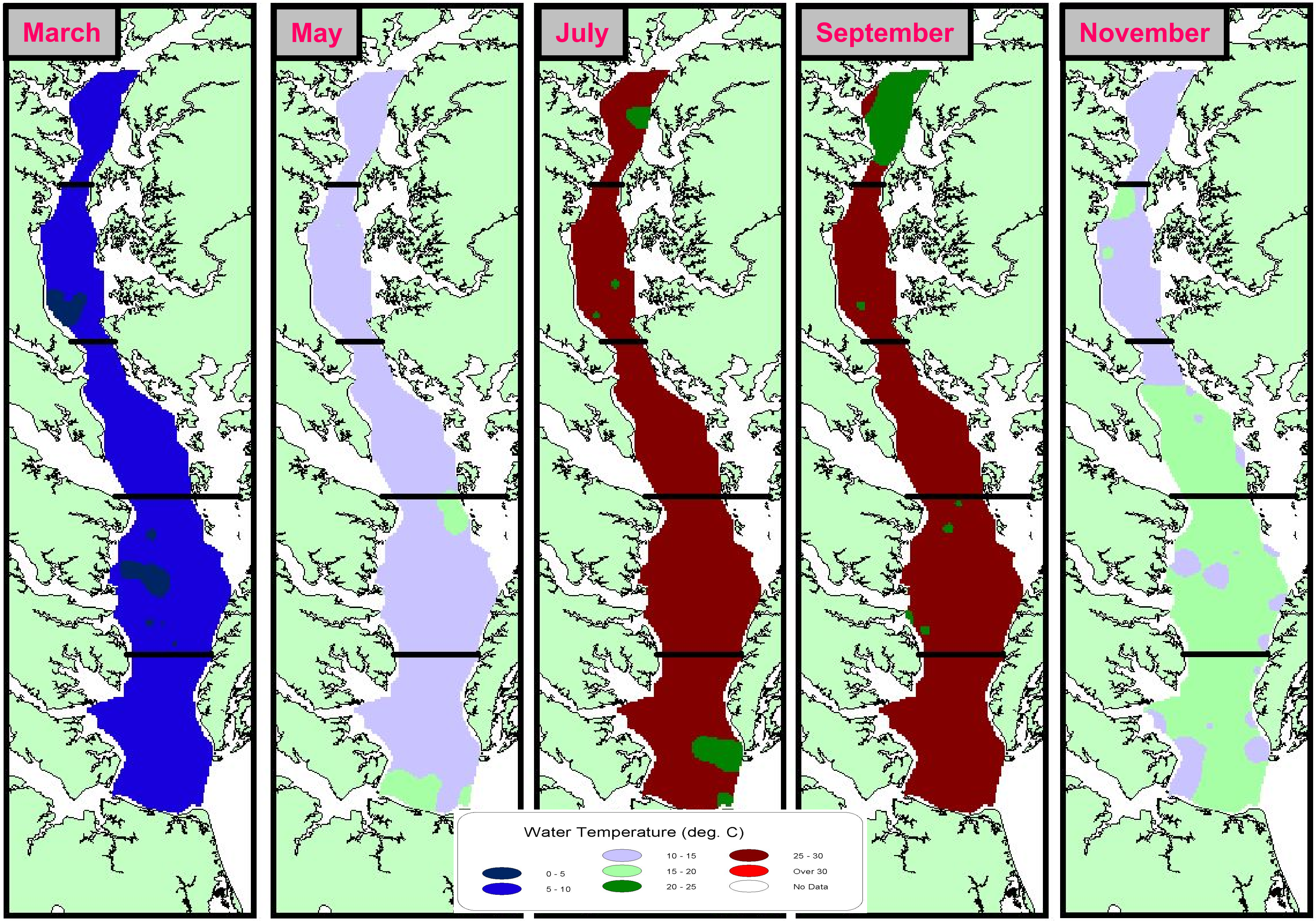


Figure 145. Bottom temperature in Chesapeake Bay, 2005.

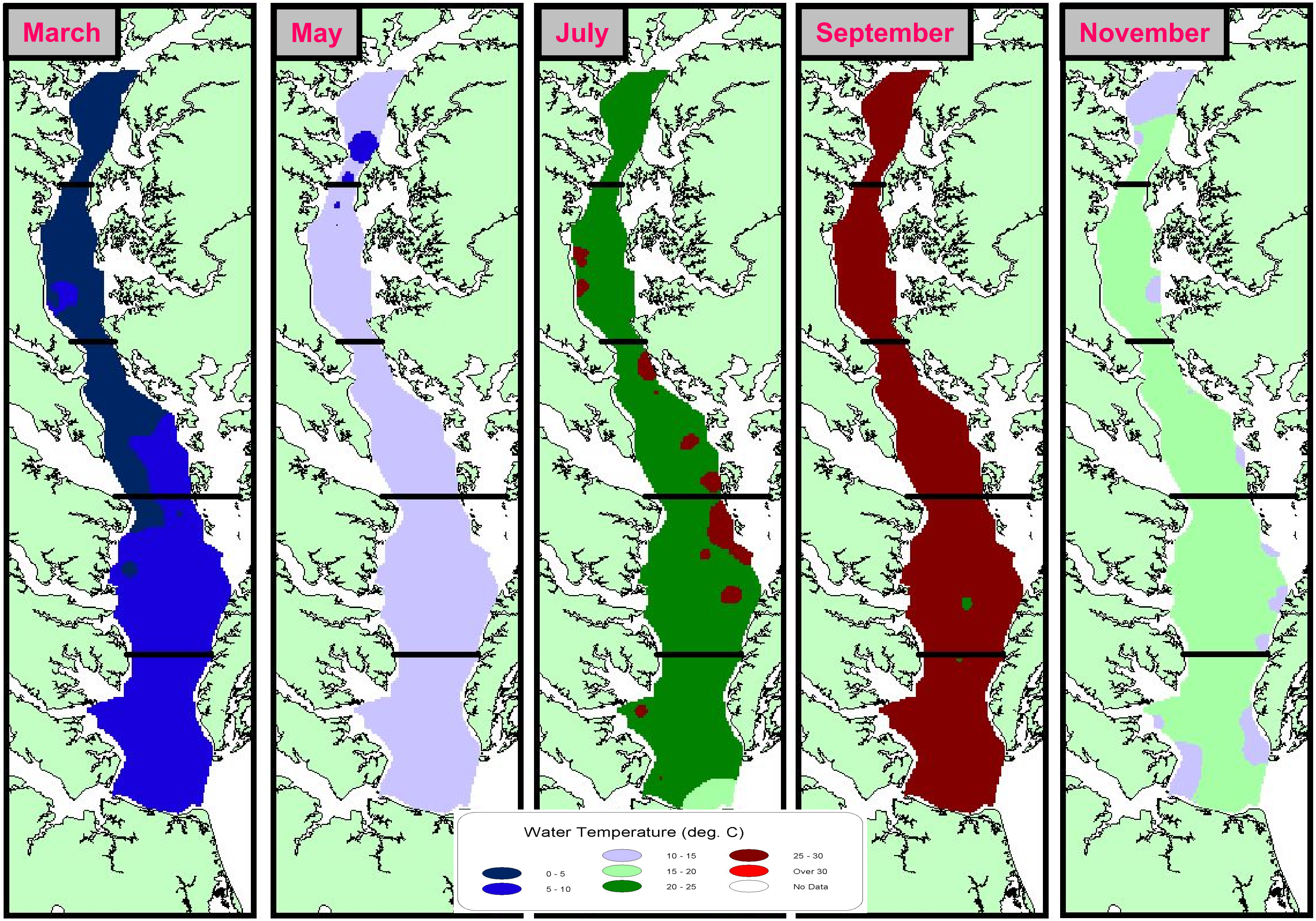


Figure 146. Surface temperature in Chesapeake Bay, 2006.

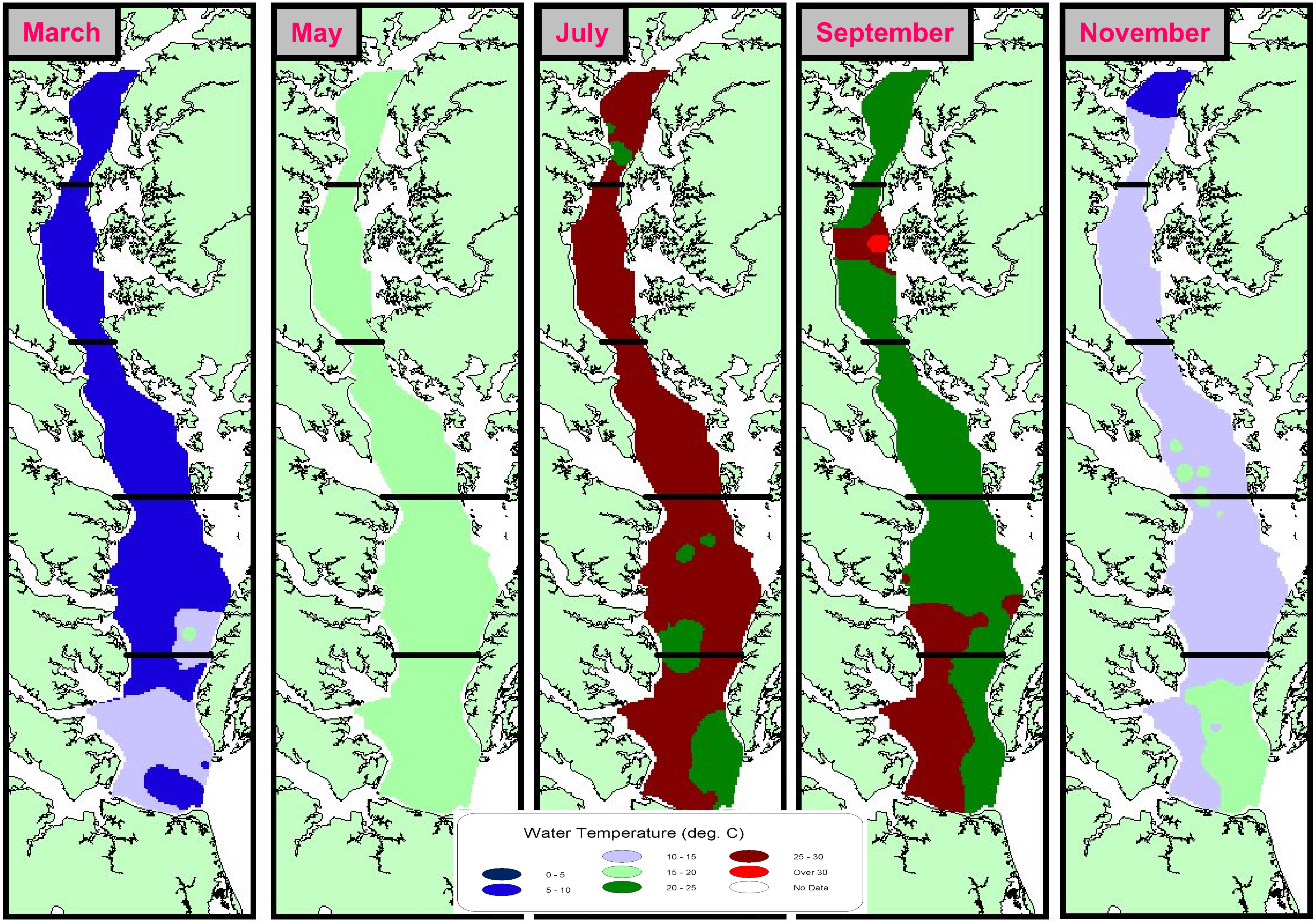


Figure 147. Bottom temperature in Chesapeake Bay, 2006.

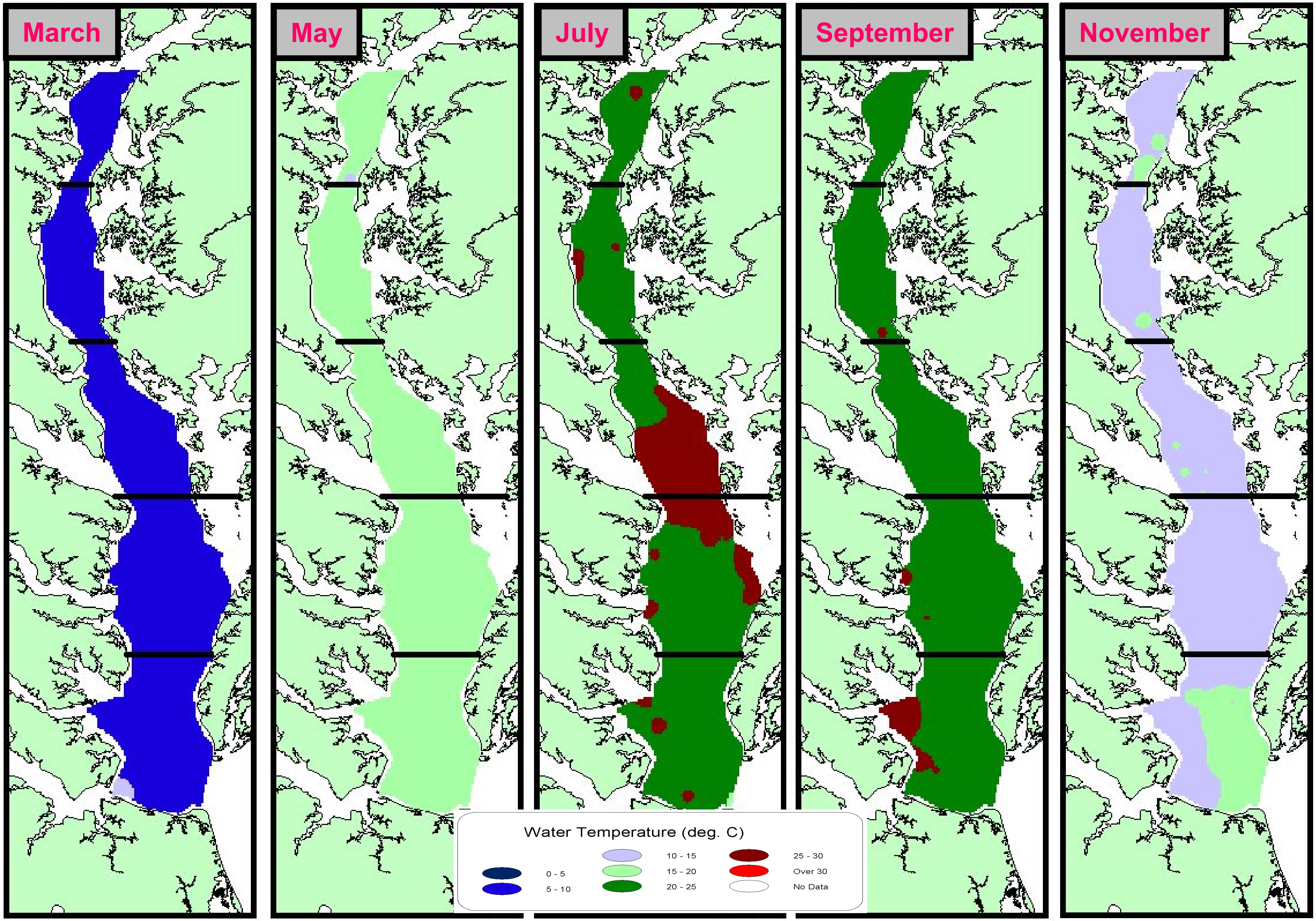


Figure 148. Surface temperature in Chesapeake Bay, 2007.

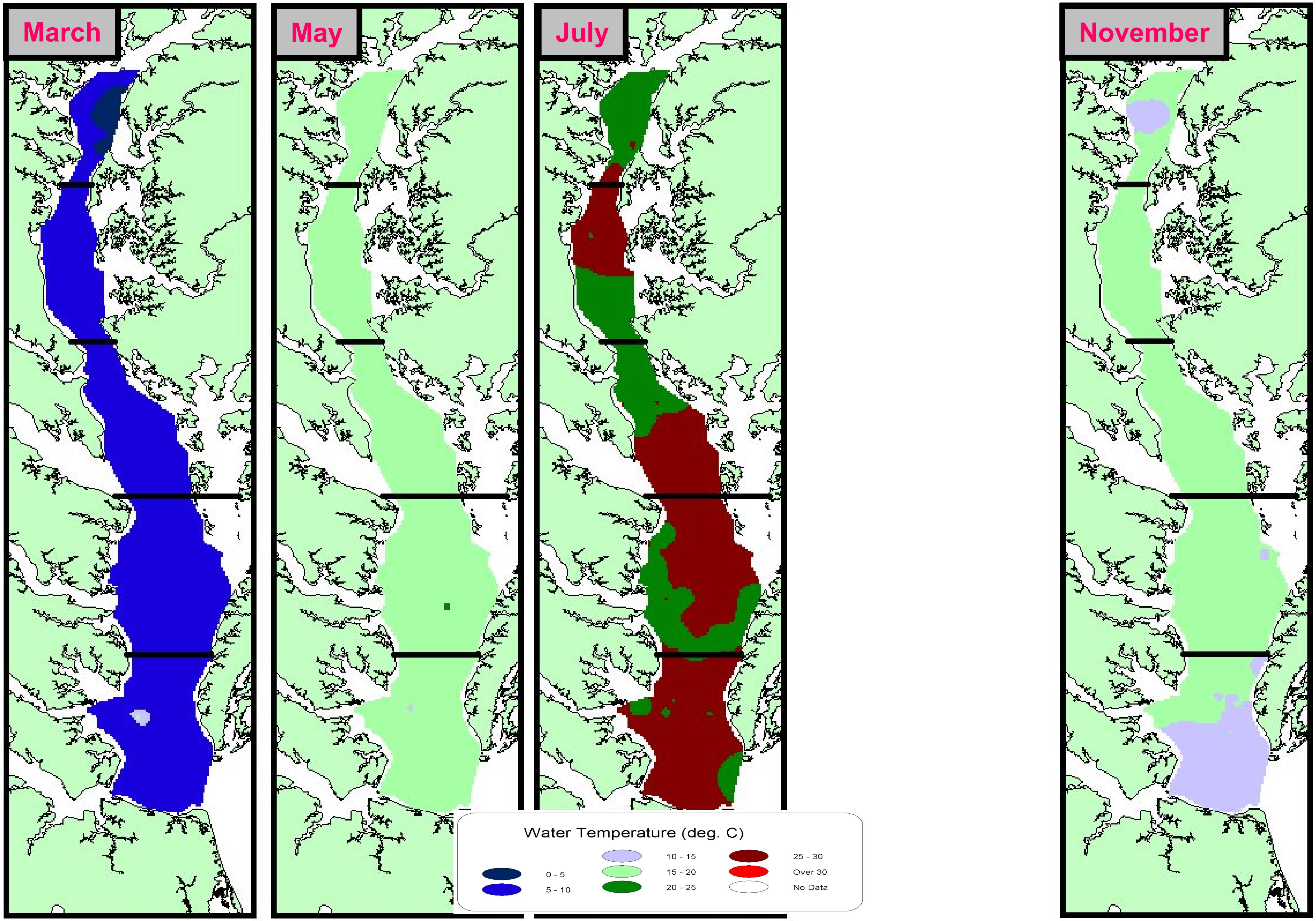


Figure 149. Bottom temperature in Chesapeake Bay, 2007.

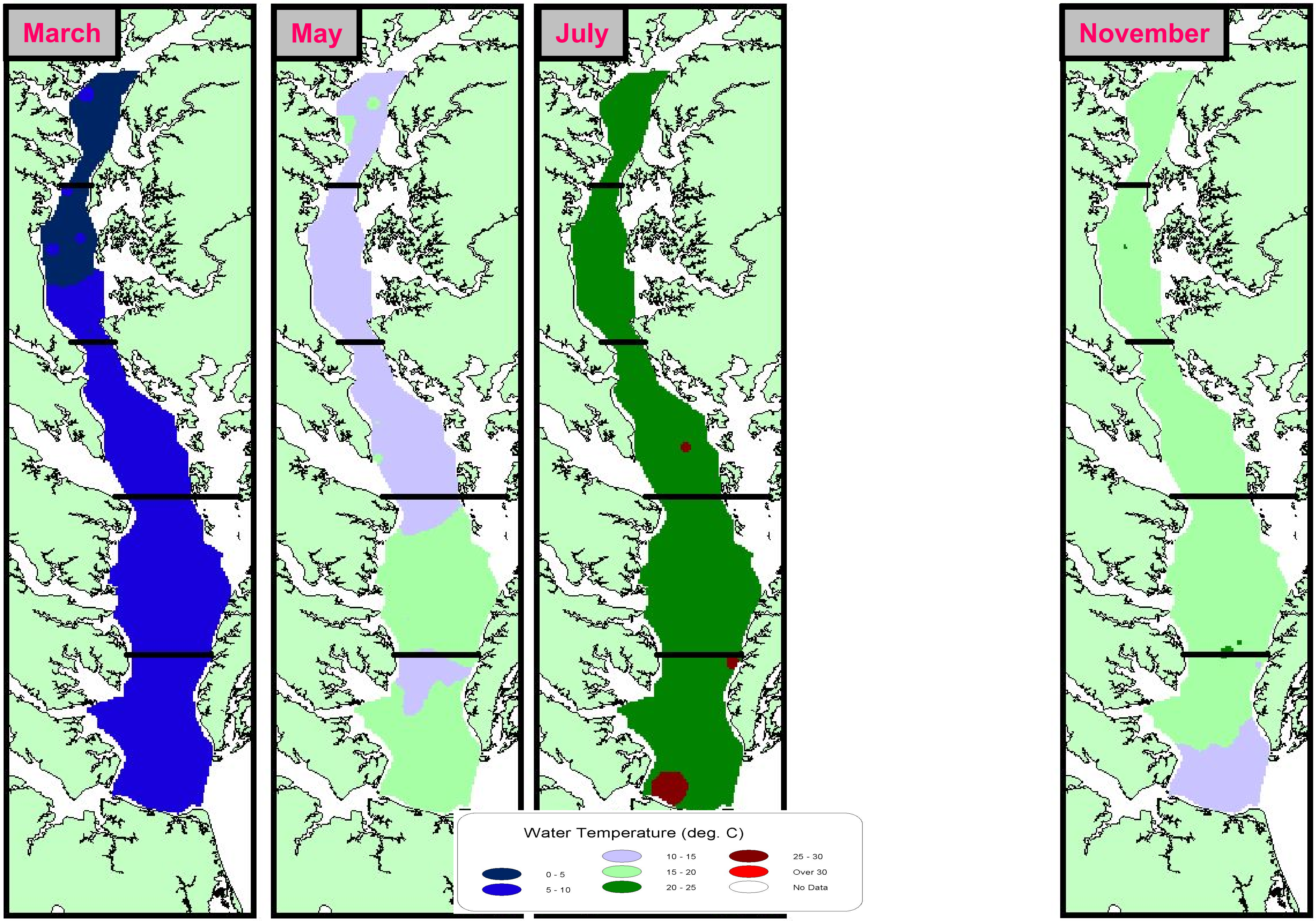


Figure 150. Surface salinity in Chesapeake Bay, 2002.

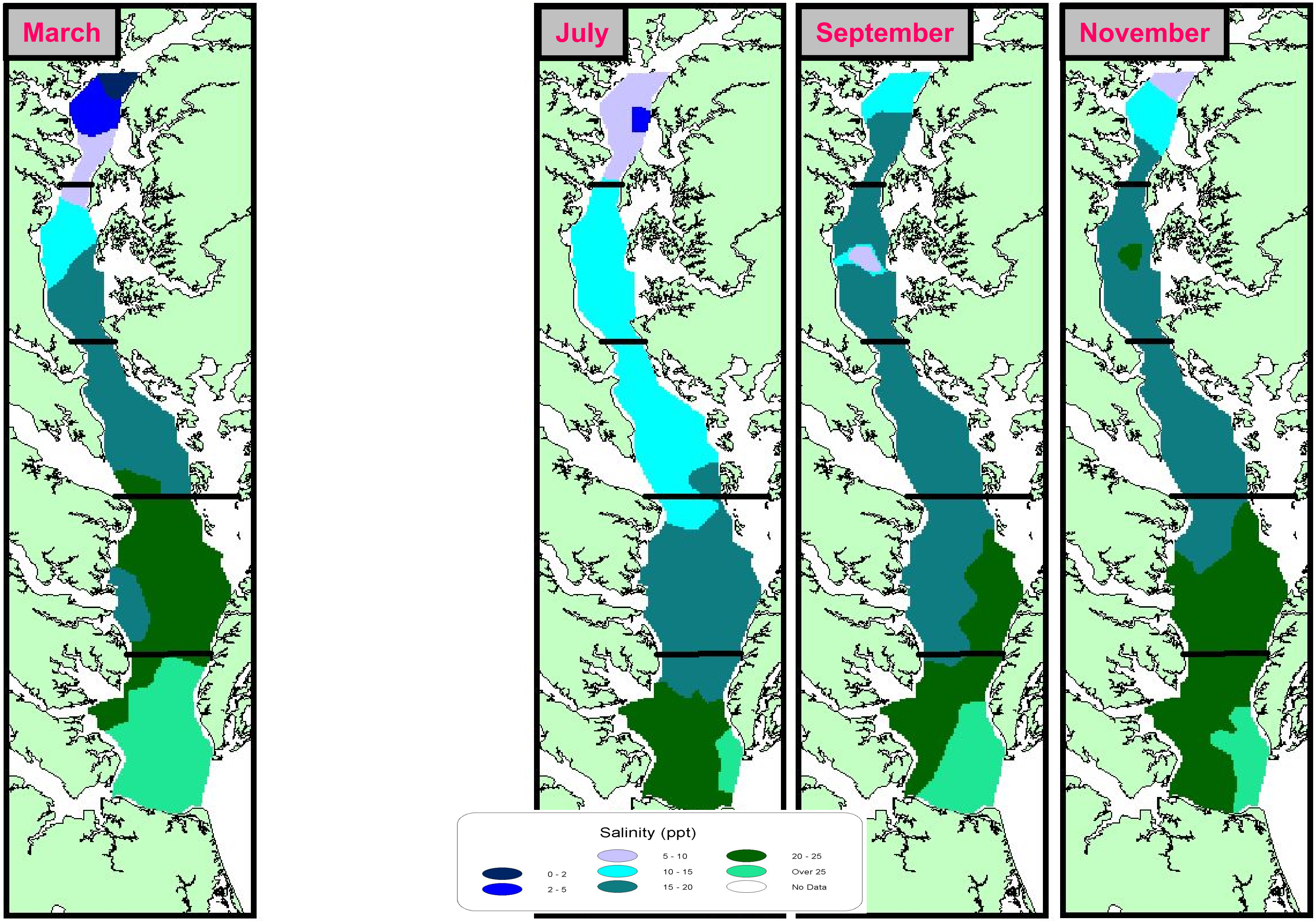


Figure 151. Bottom salinity in Chesapeake Bay, 2002.

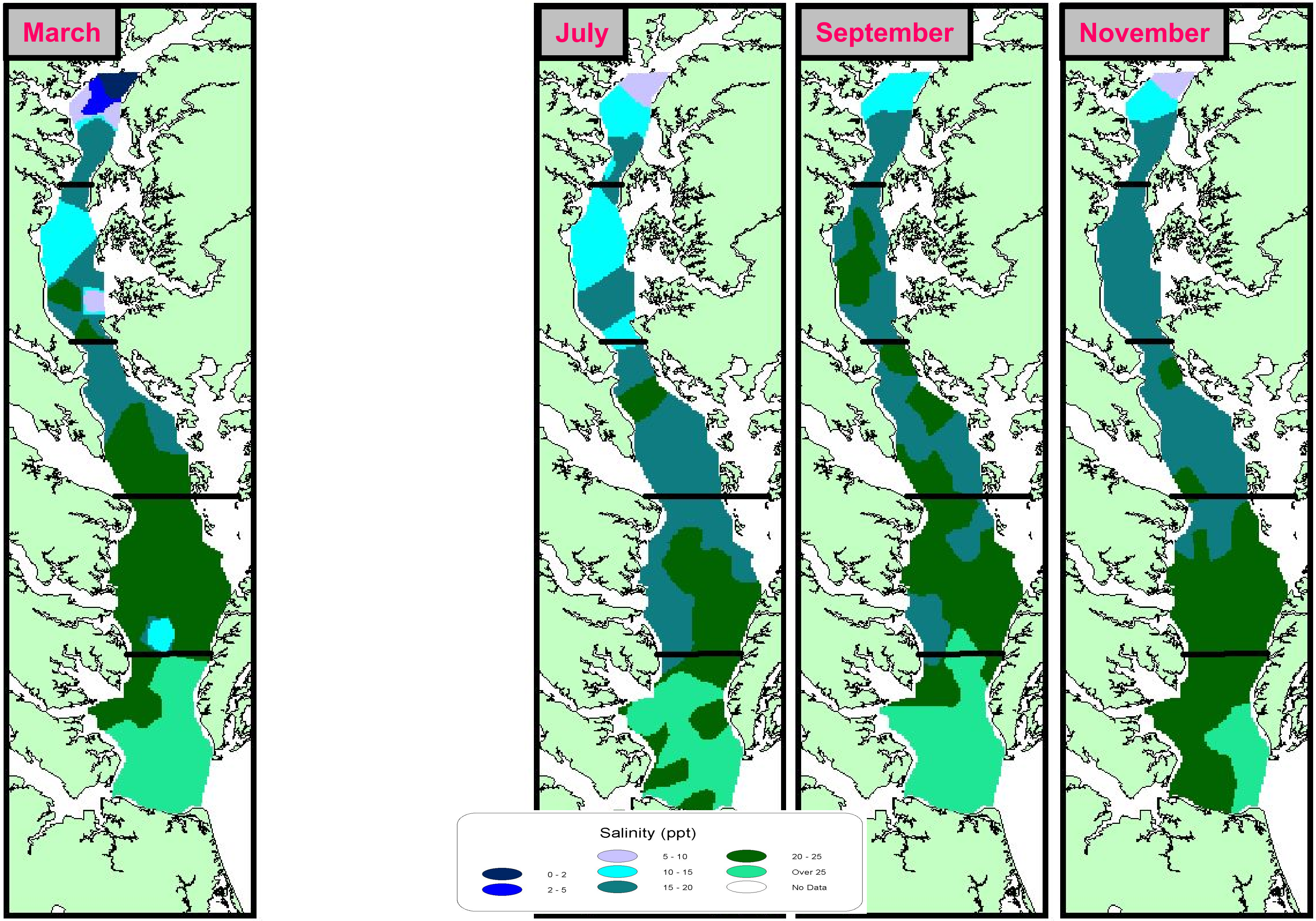


Figure 152. Surface salinity in Chesapeake Bay, 2003.

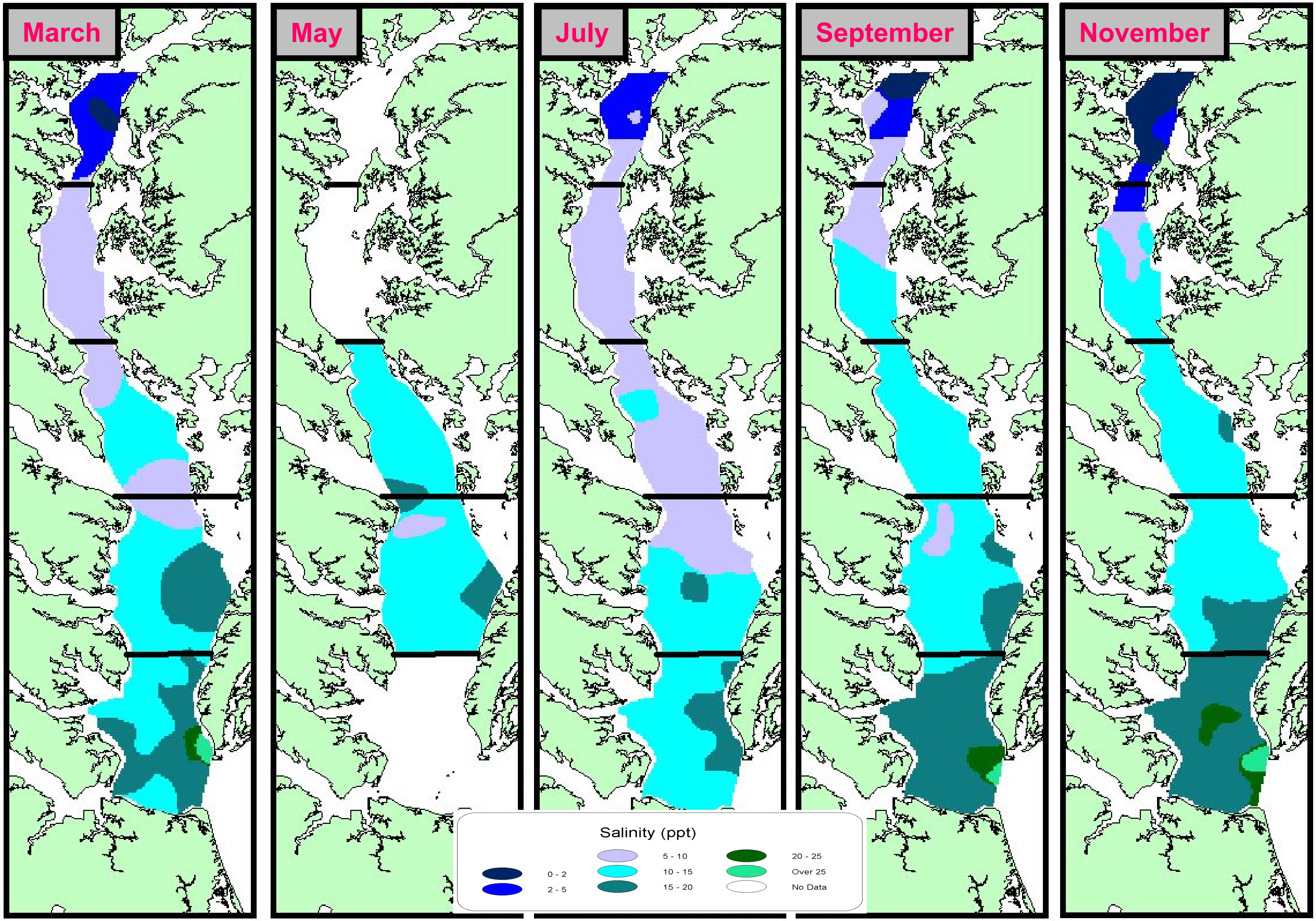


Figure 153. Bottom salinity in Chesapeake Bay, 2003.

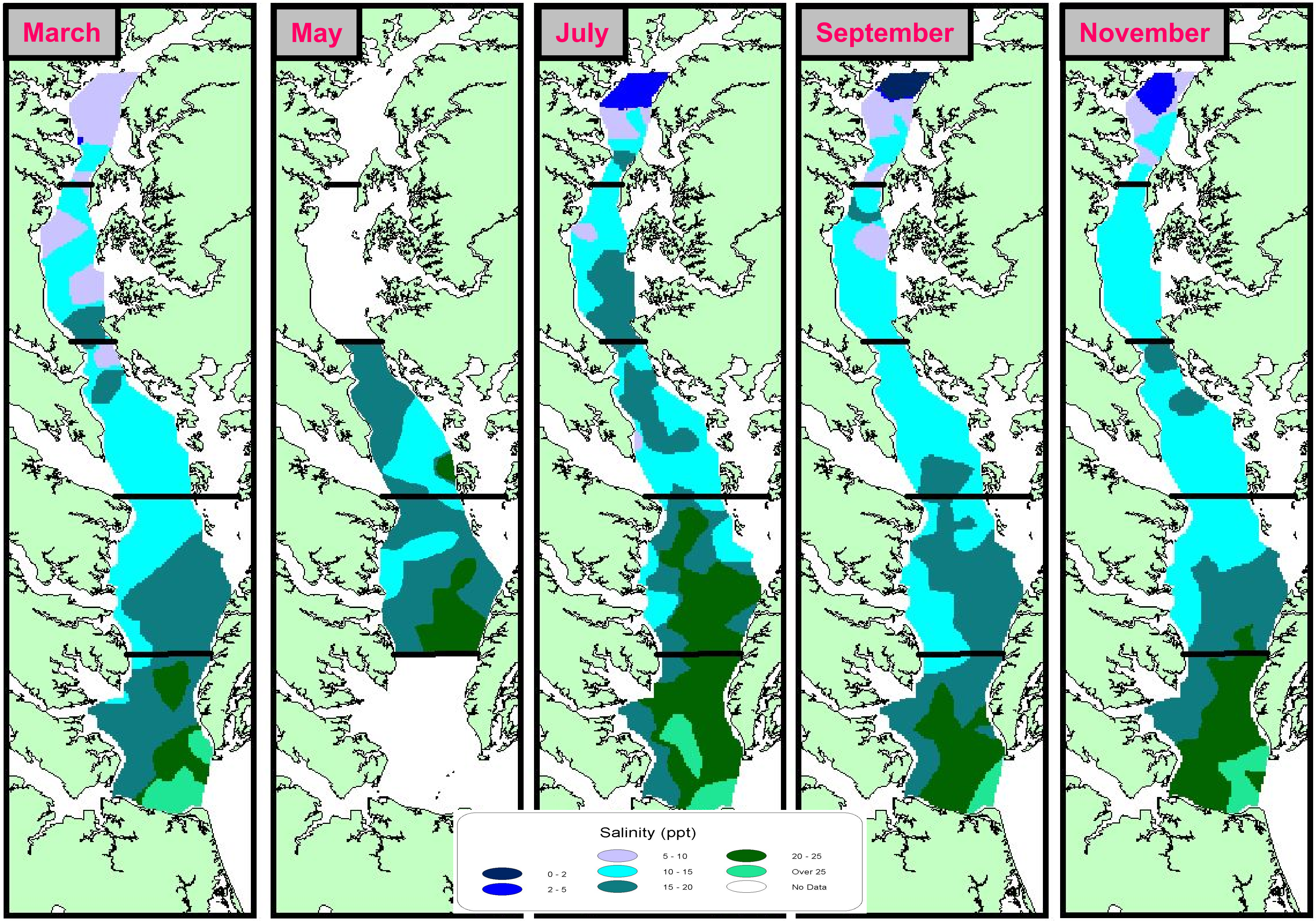


Figure 154. Surface salinity in Chesapeake Bay, 2004.

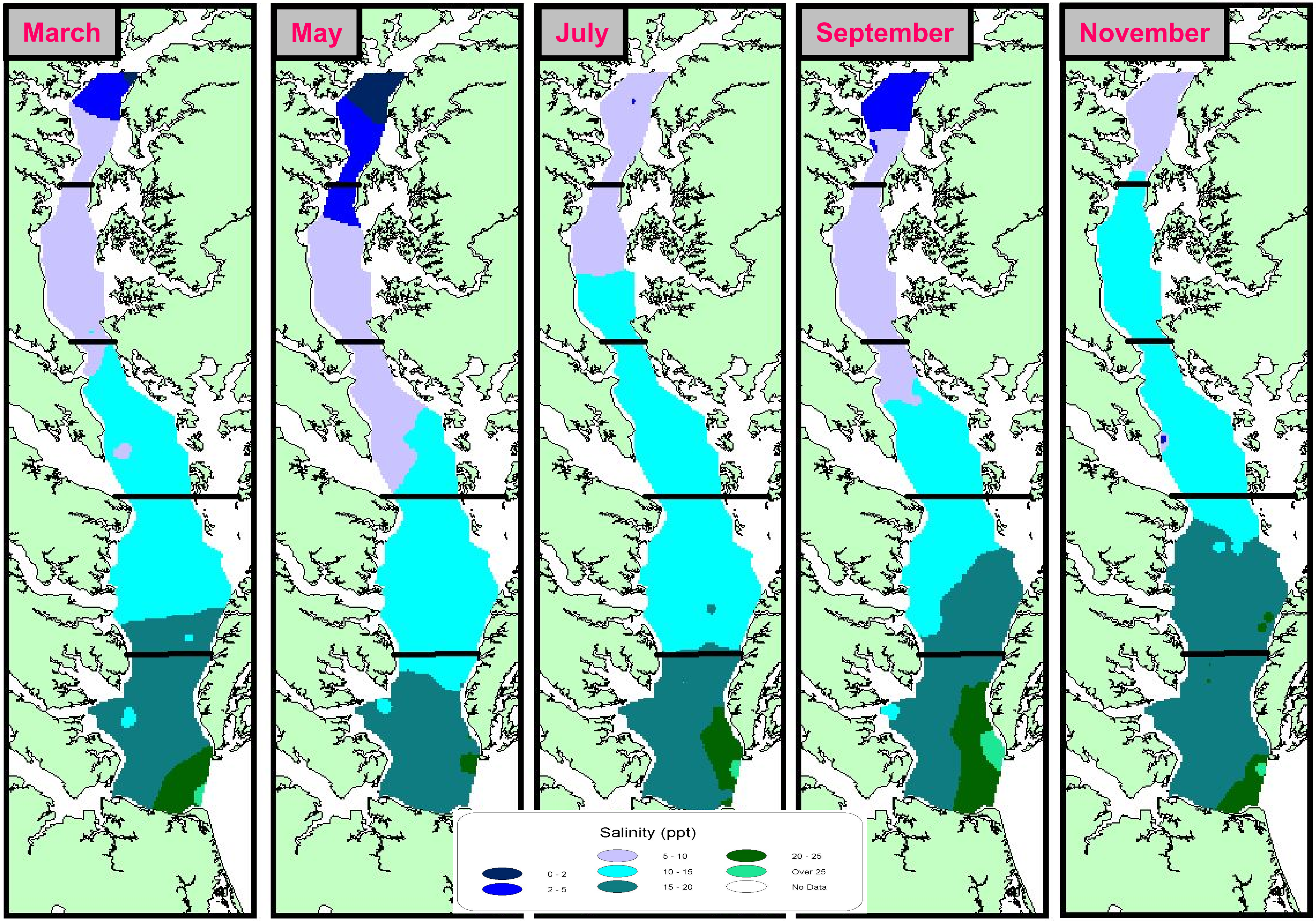


Figure 155. Bottom salinity in Chesapeake Bay, 2004.

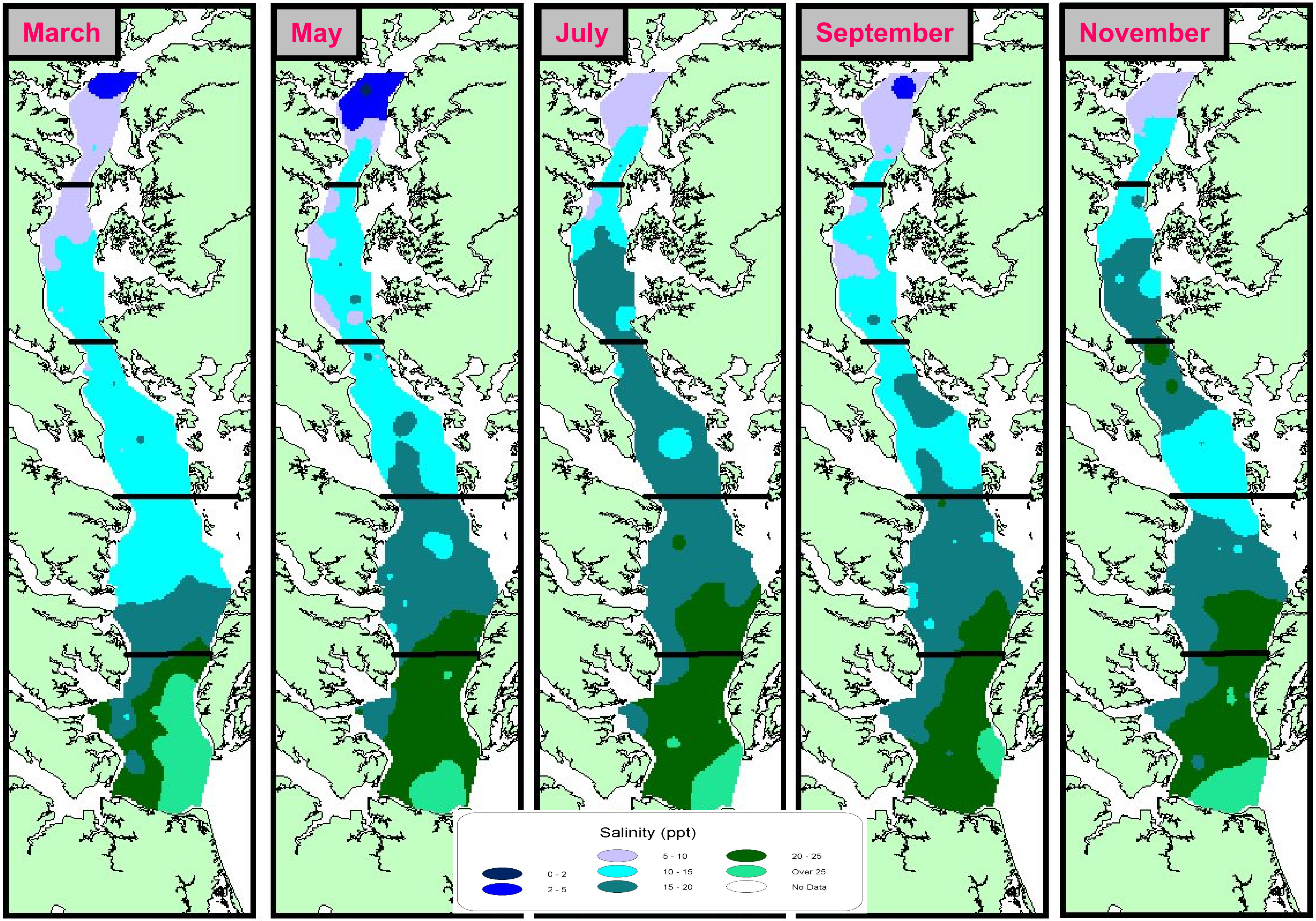


Figure 156. Surface salinity in Chesapeake Bay, 2005.

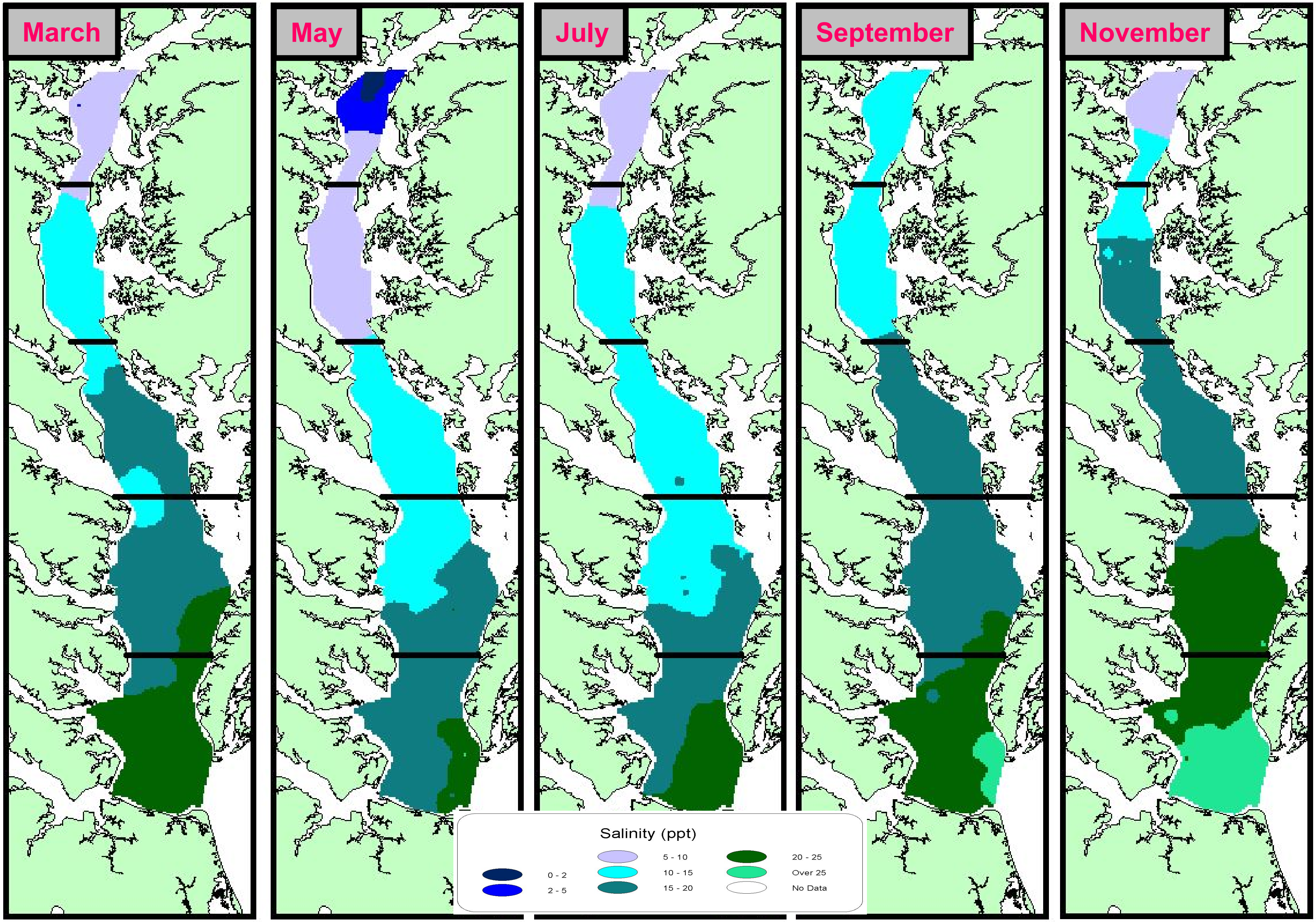


Figure 157. Bottom salinity in Chesapeake Bay, 2005.

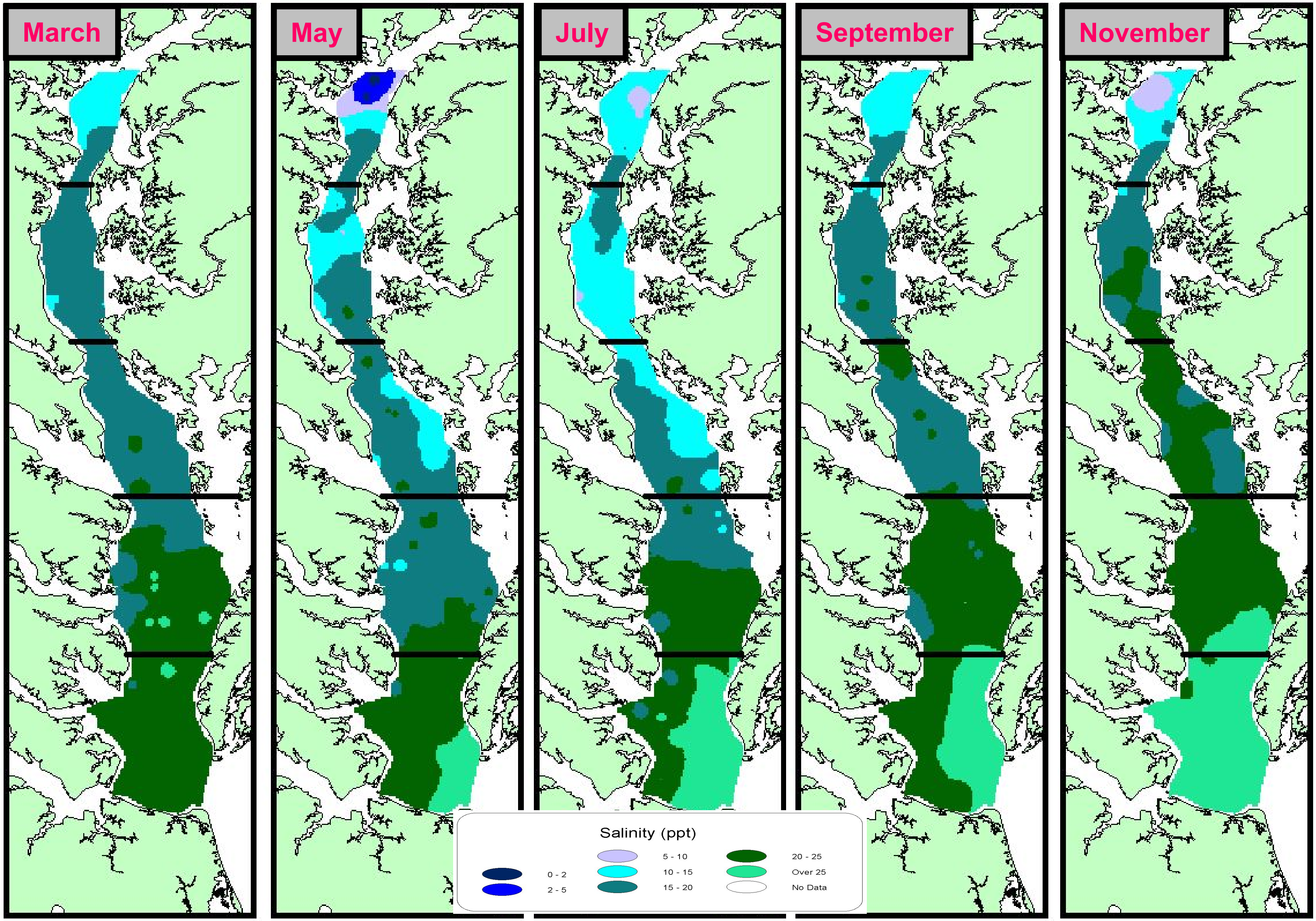


Figure 158. Surface salinity in Chesapeake Bay, 2006.

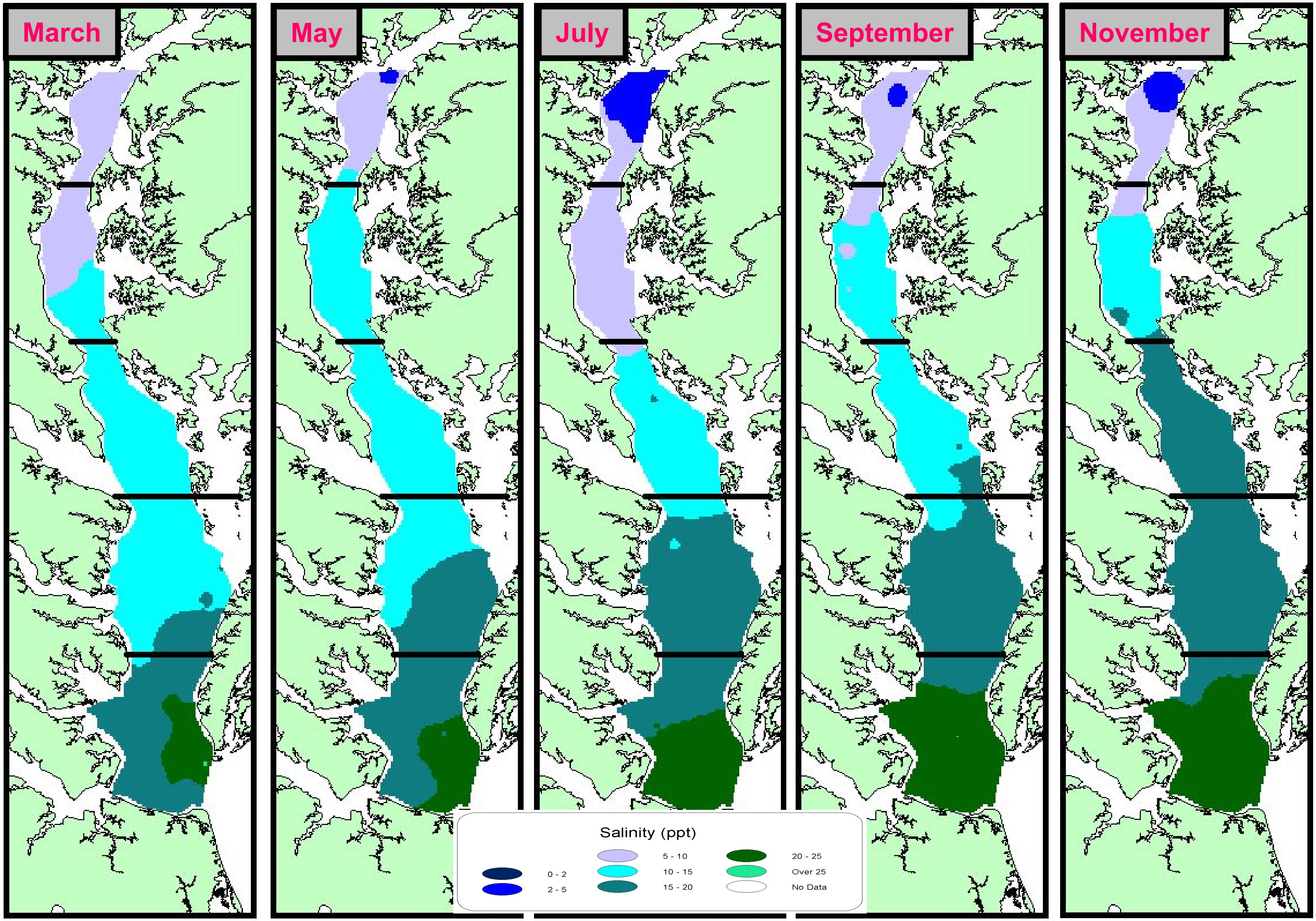


Figure 159. Bottom salinity in Chesapeake Bay, 2006.

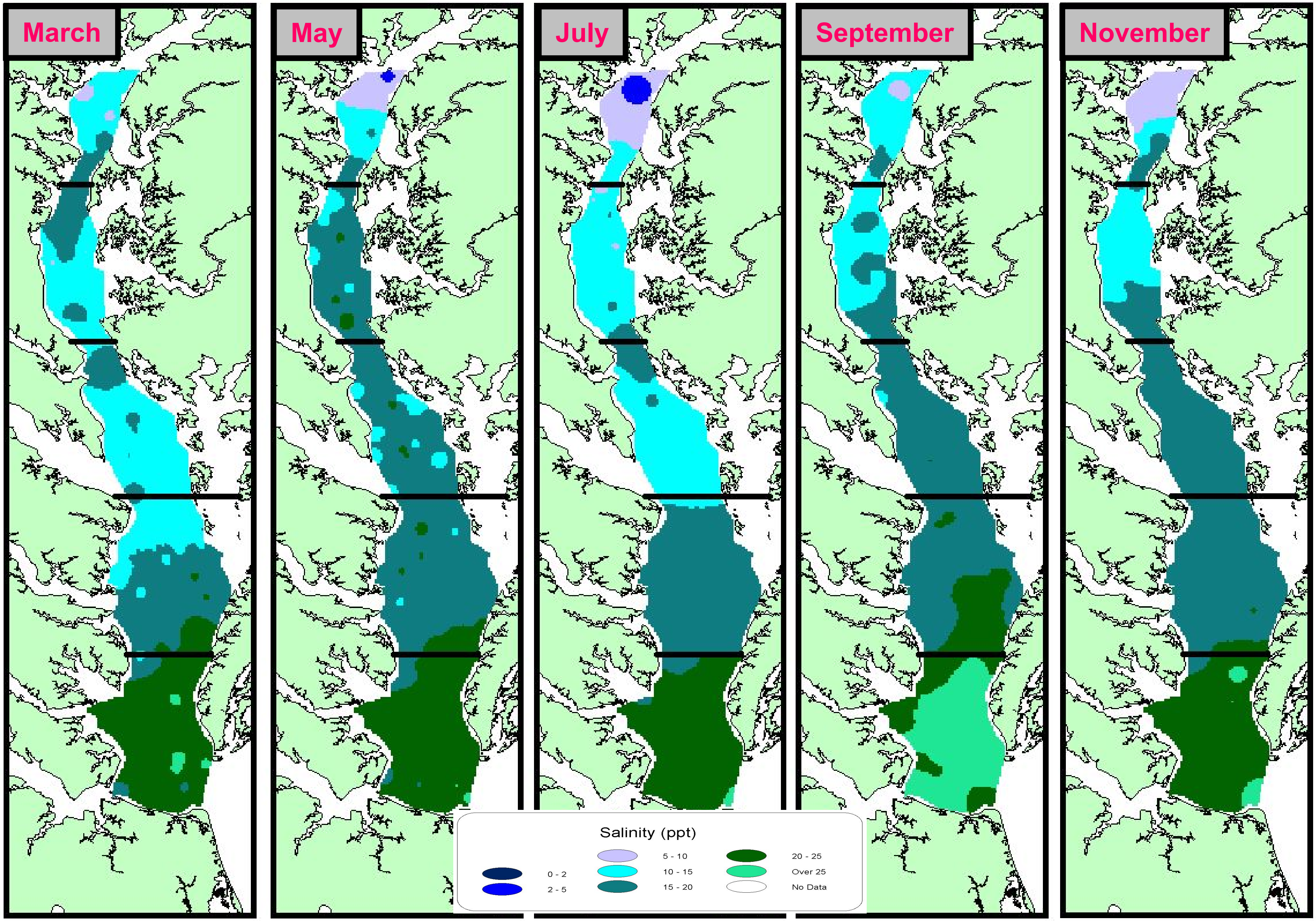


Figure 160. Surface salinity in Chesapeake Bay, 2007.

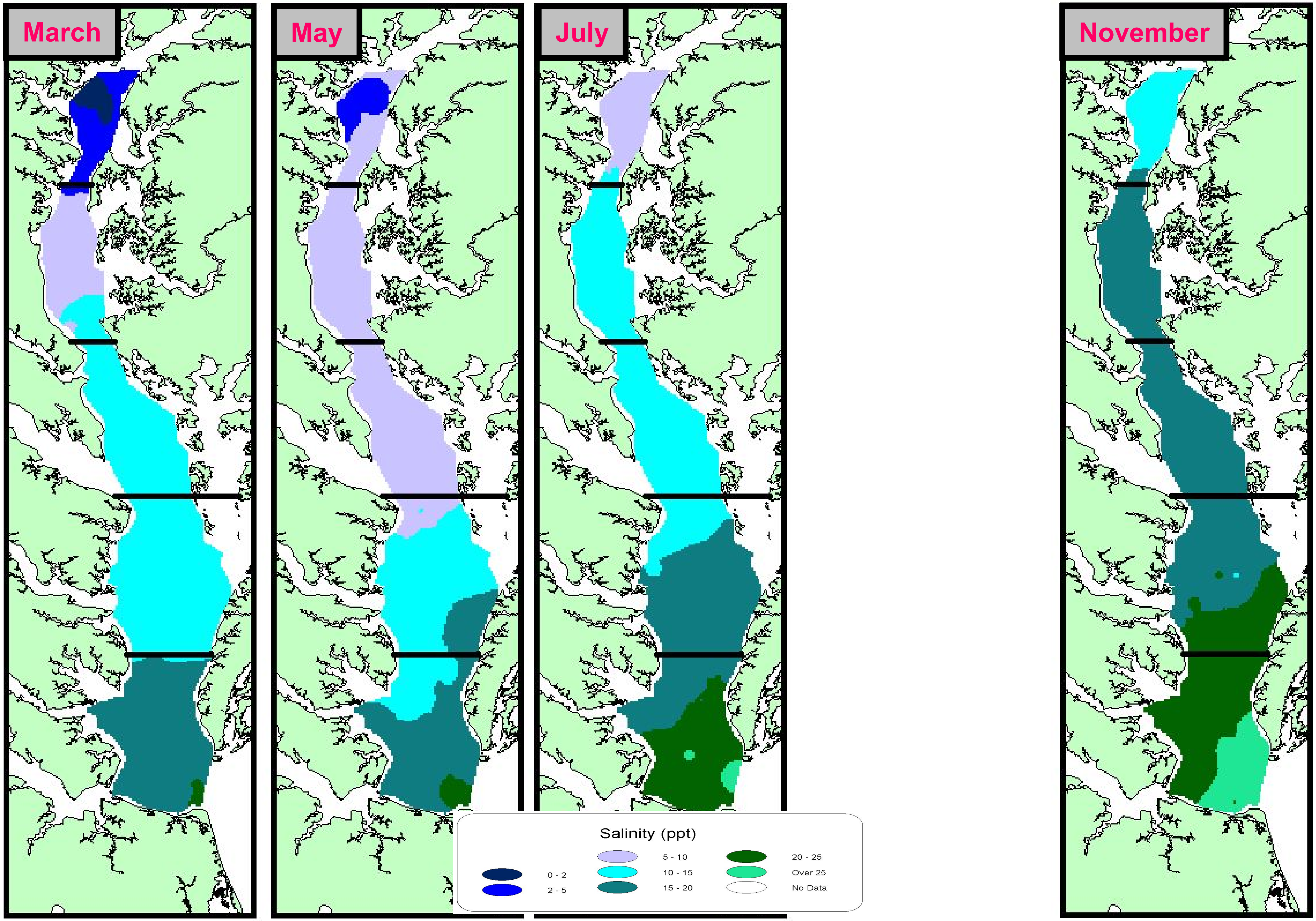


Figure 161. Bottom salinity in Chesapeake Bay, 2007.

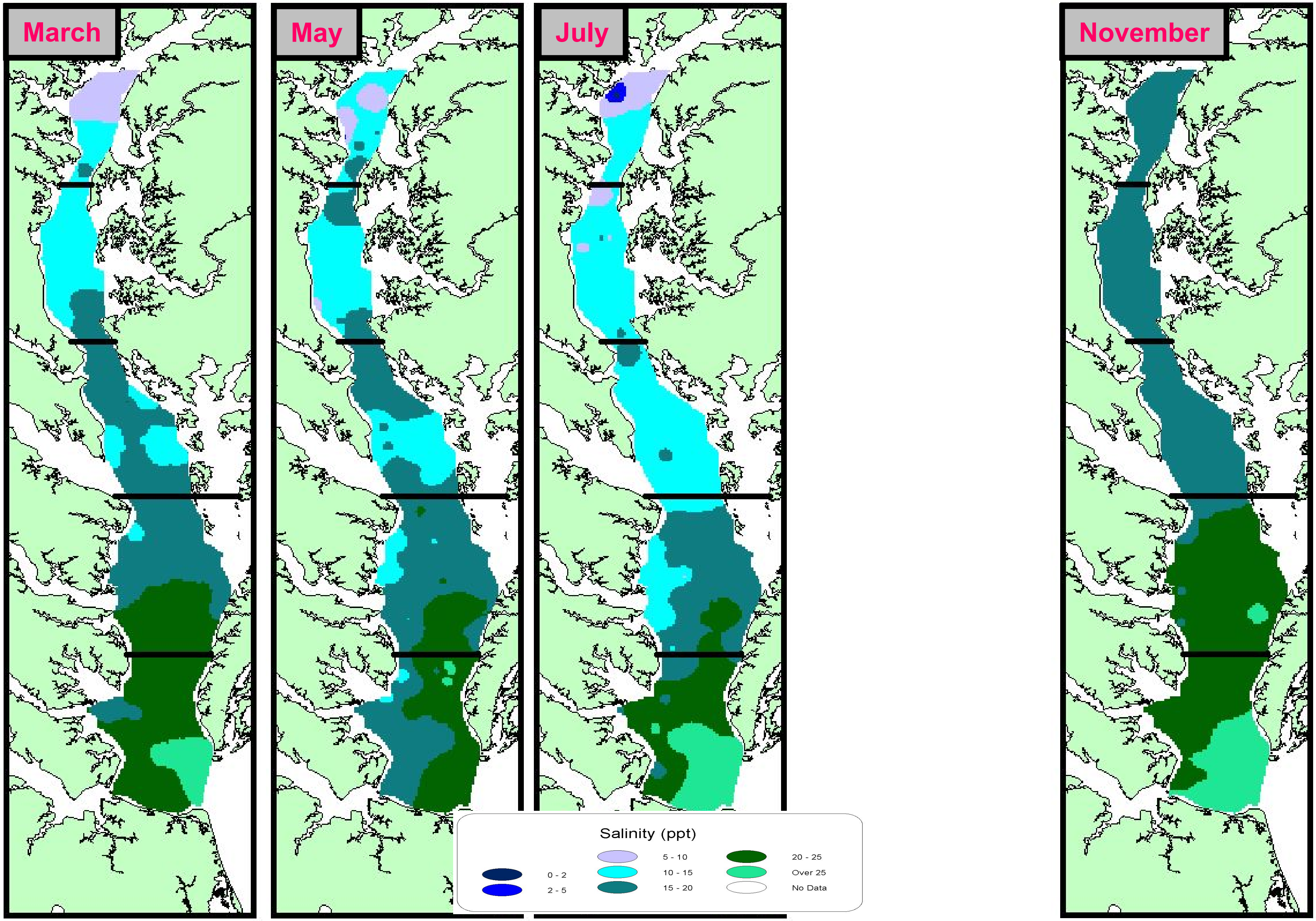


Figure 162. Surface dissolved oxygen in Chesapeake Bay, 2002.

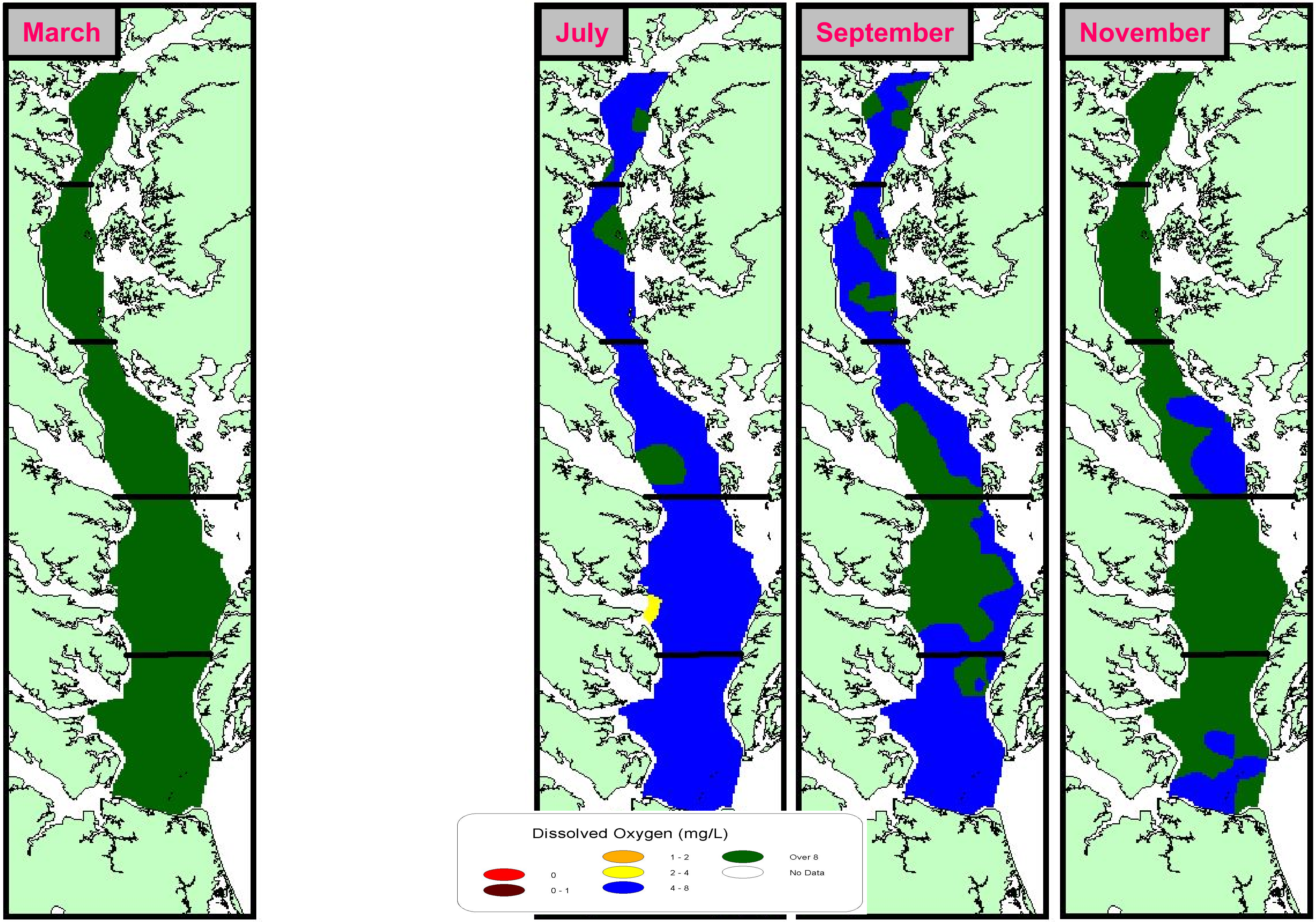


Figure 163. Bottom dissolved oxygen in Chesapeake Bay, 2002.

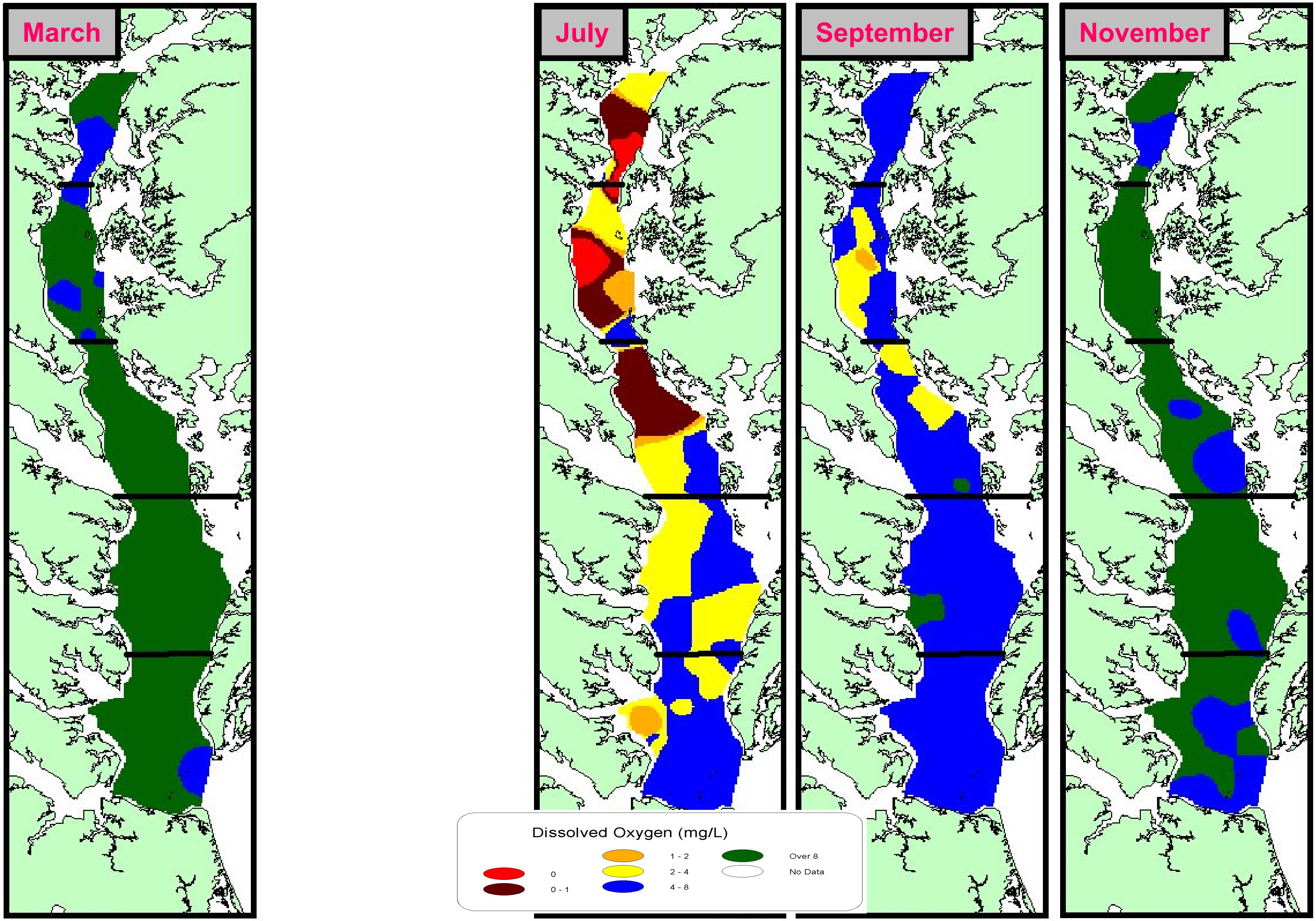


Figure 164. Surface dissolved oxygen in Chesapeake Bay, 2003.

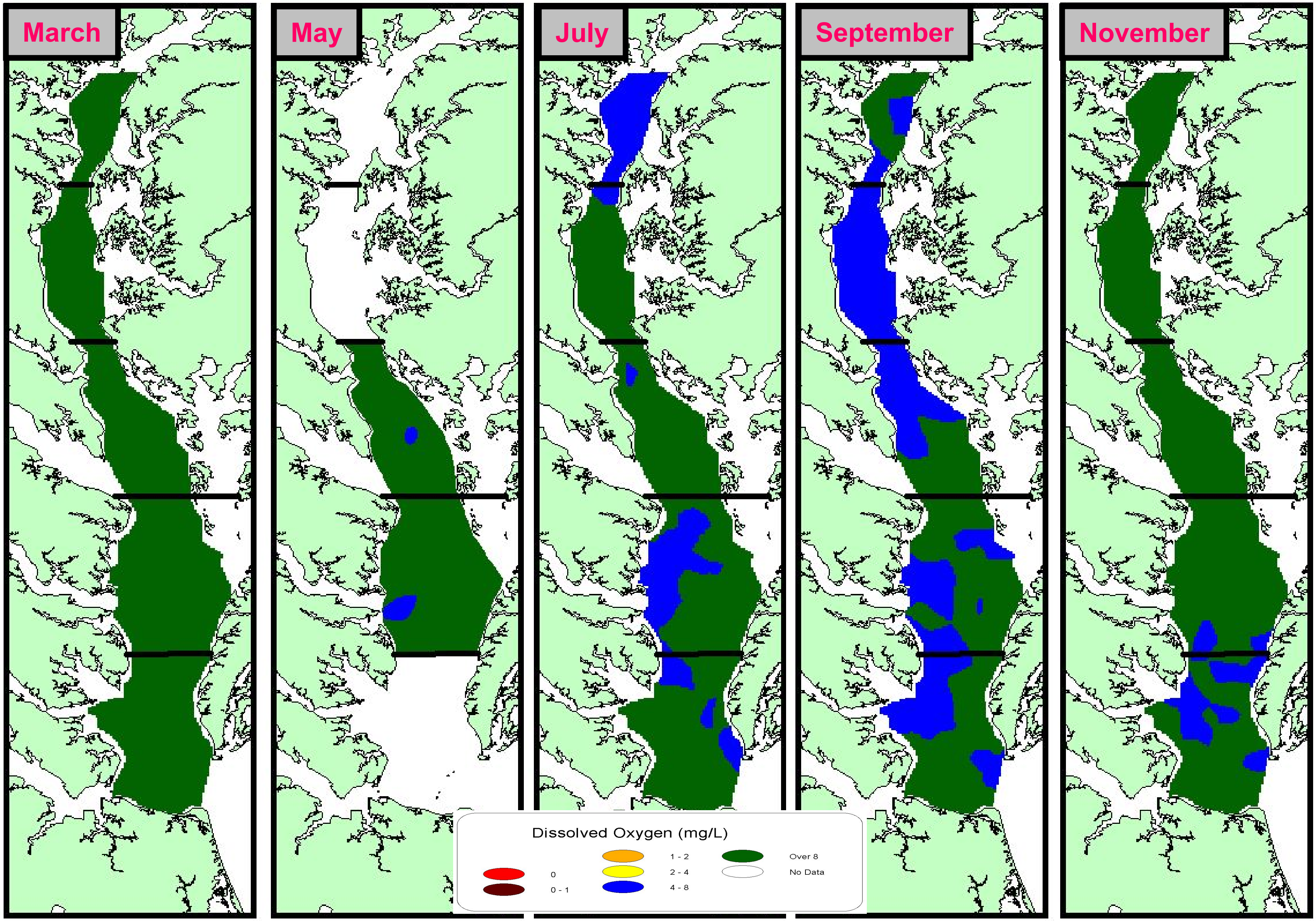


Figure 165. Bottom dissolved oxygen in Chesapeake Bay, 2003.

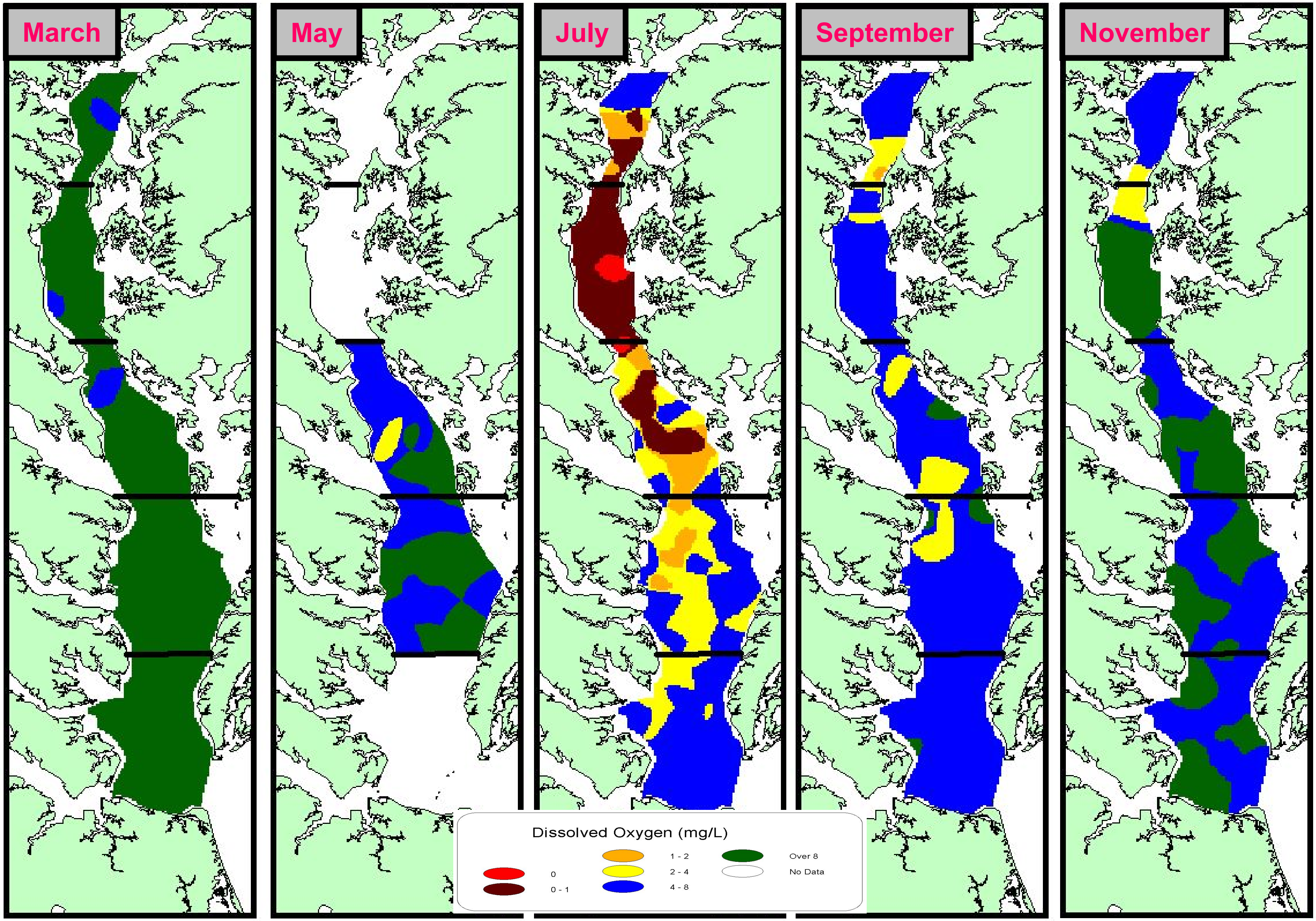


Figure 166. Surface dissolved oxygen in Chesapeake Bay, 2004.

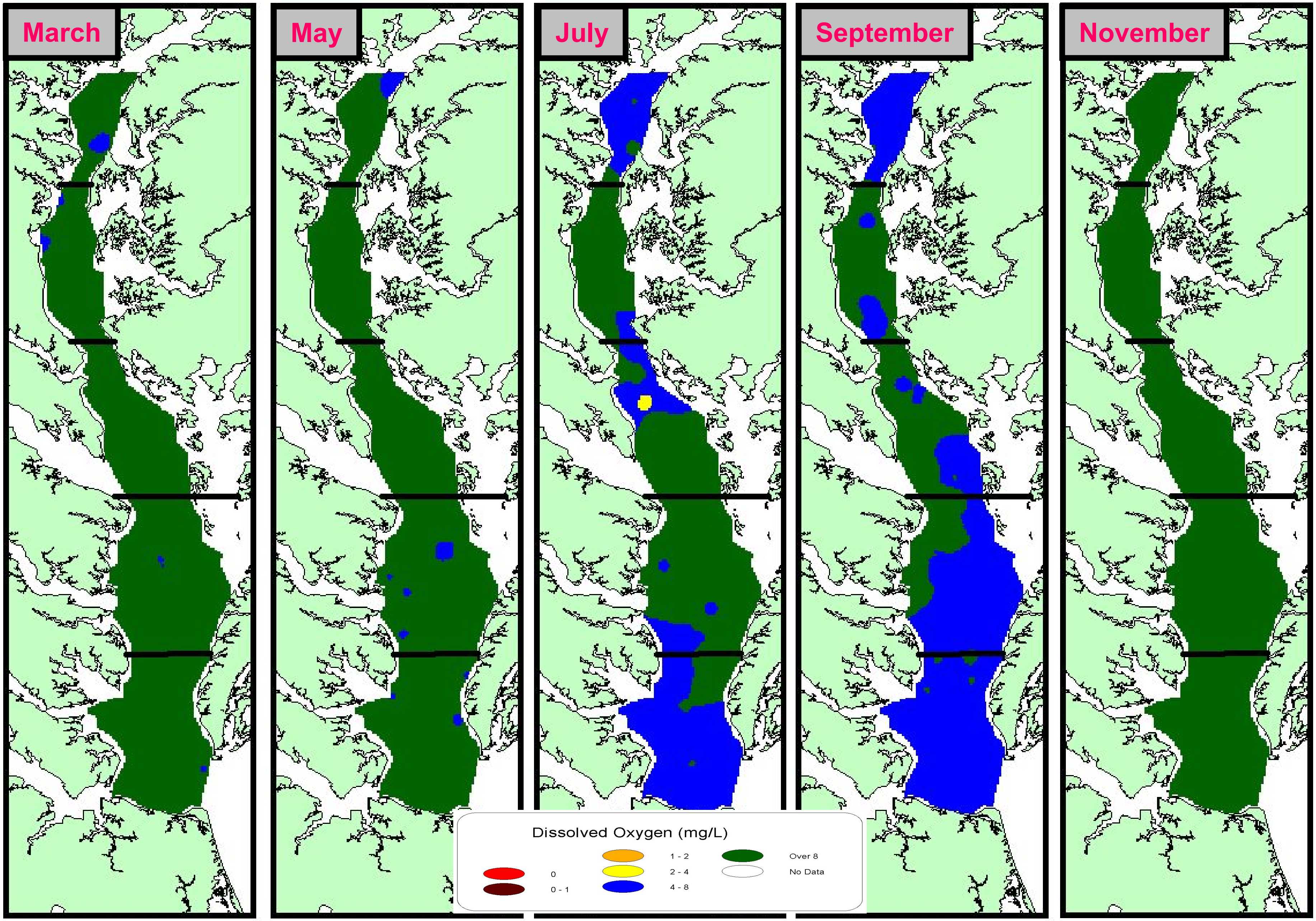


Figure 167. Bottom dissolved oxygen in Chesapeake Bay, 2004.

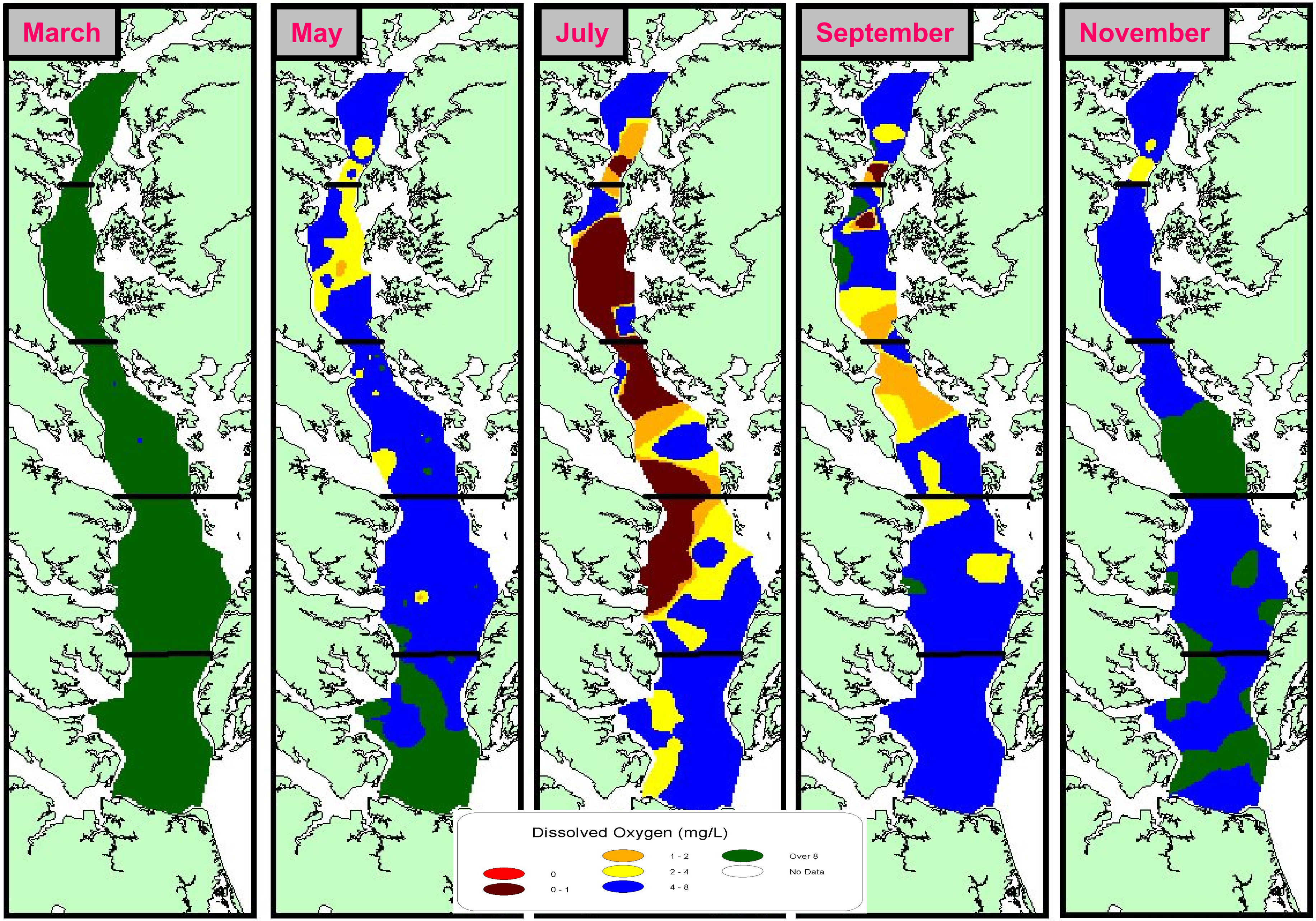


Figure 168. Surface dissolved oxygen in Chesapeake Bay, 2005.

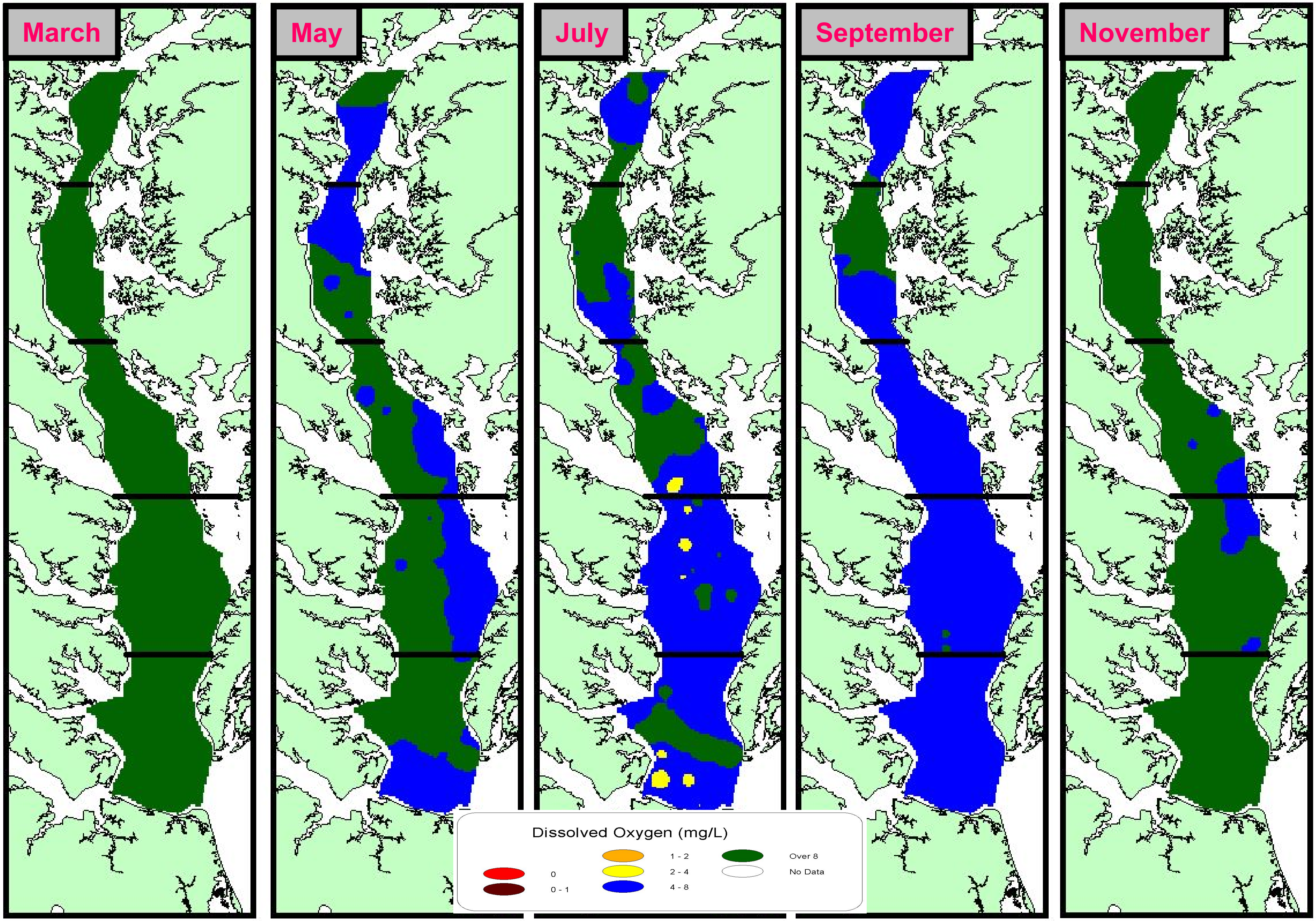


Figure 169. Bottom dissolved oxygen in Chesapeake Bay, 2005.

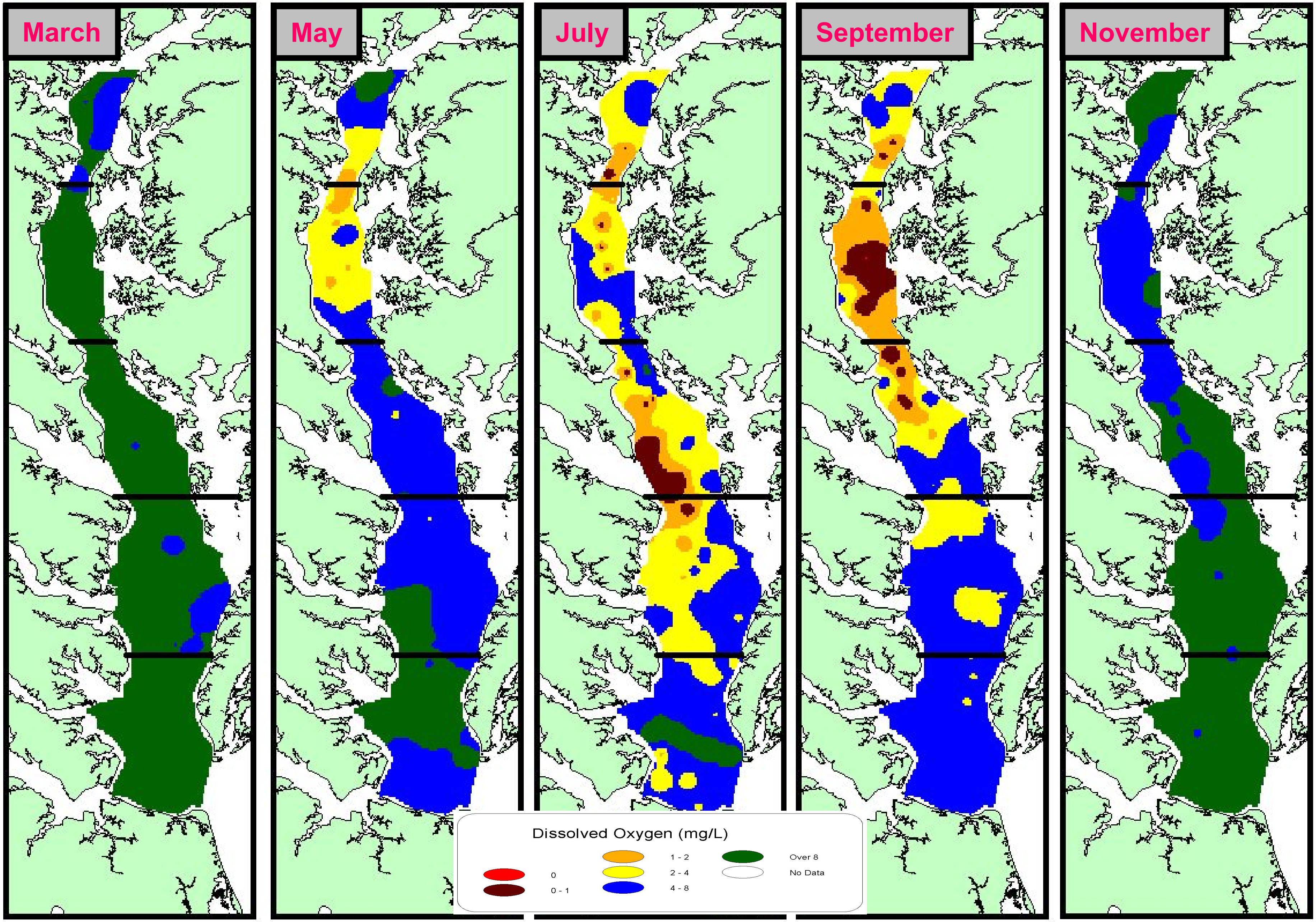


Figure 170. Surface dissolved oxygen in Chesapeake Bay, 2006.

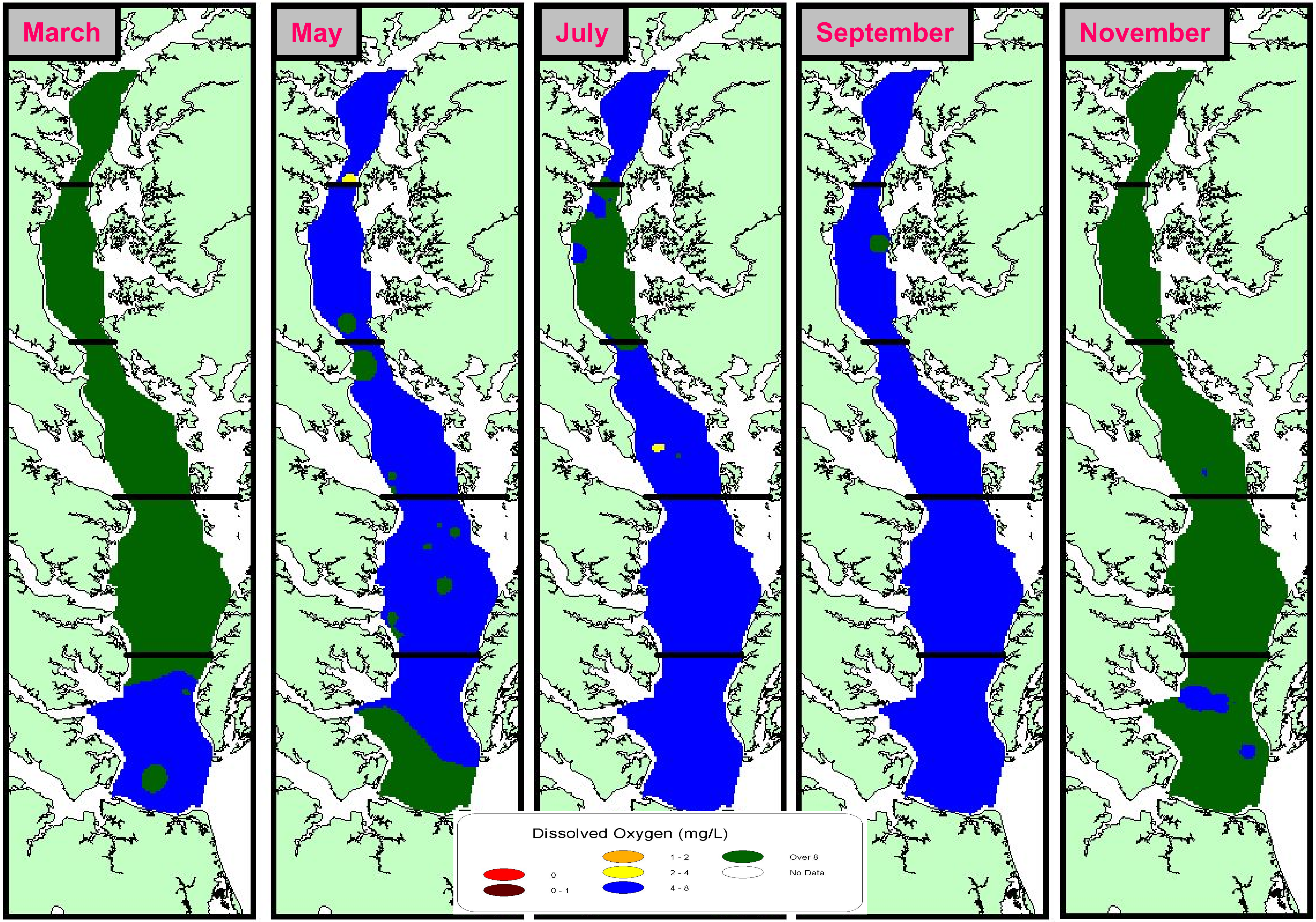


Figure 171. Bottom dissolved oxygen in Chesapeake Bay, 2006.

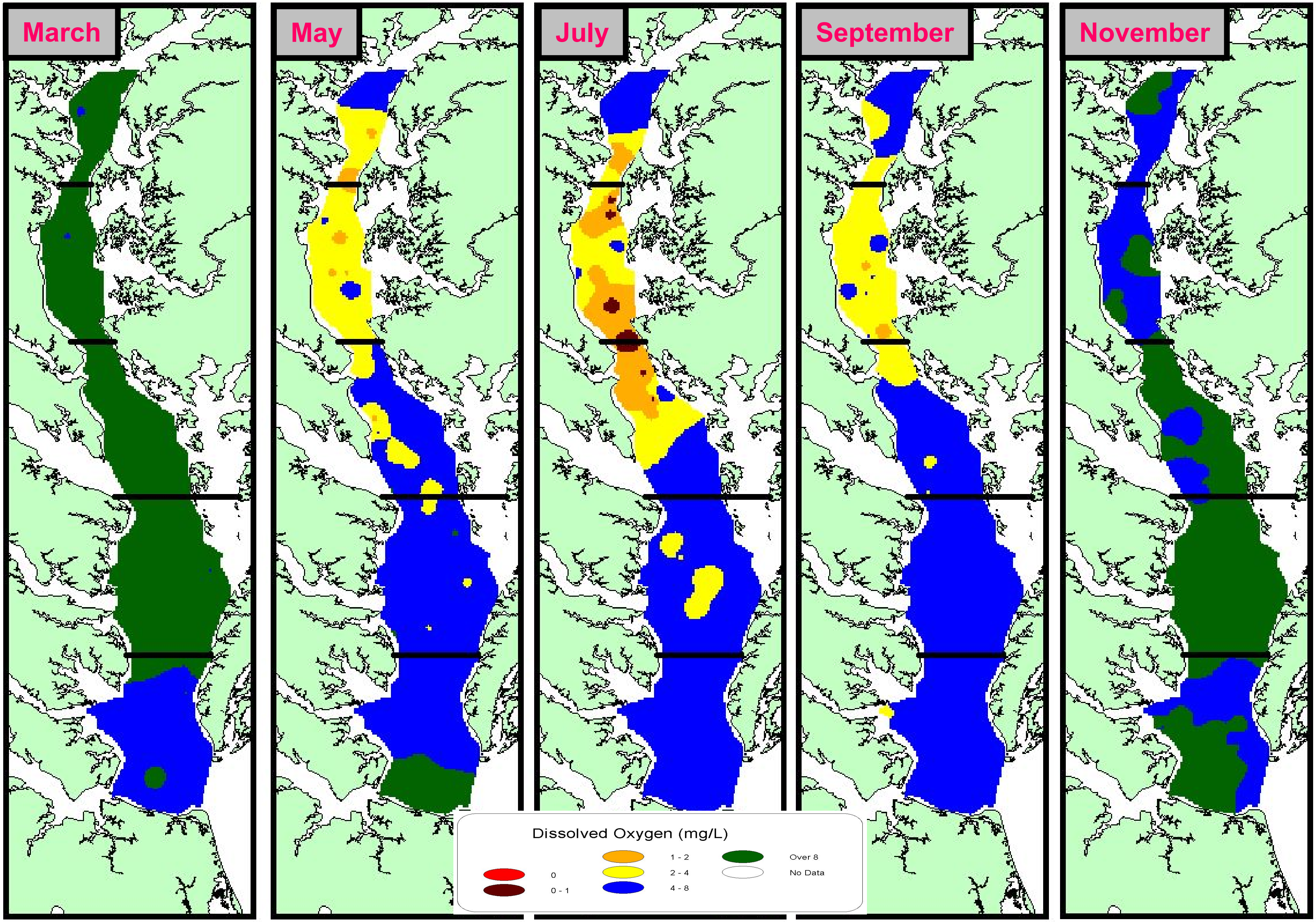


Figure 172. Surface dissolved oxygen in Chesapeake Bay, 2007.

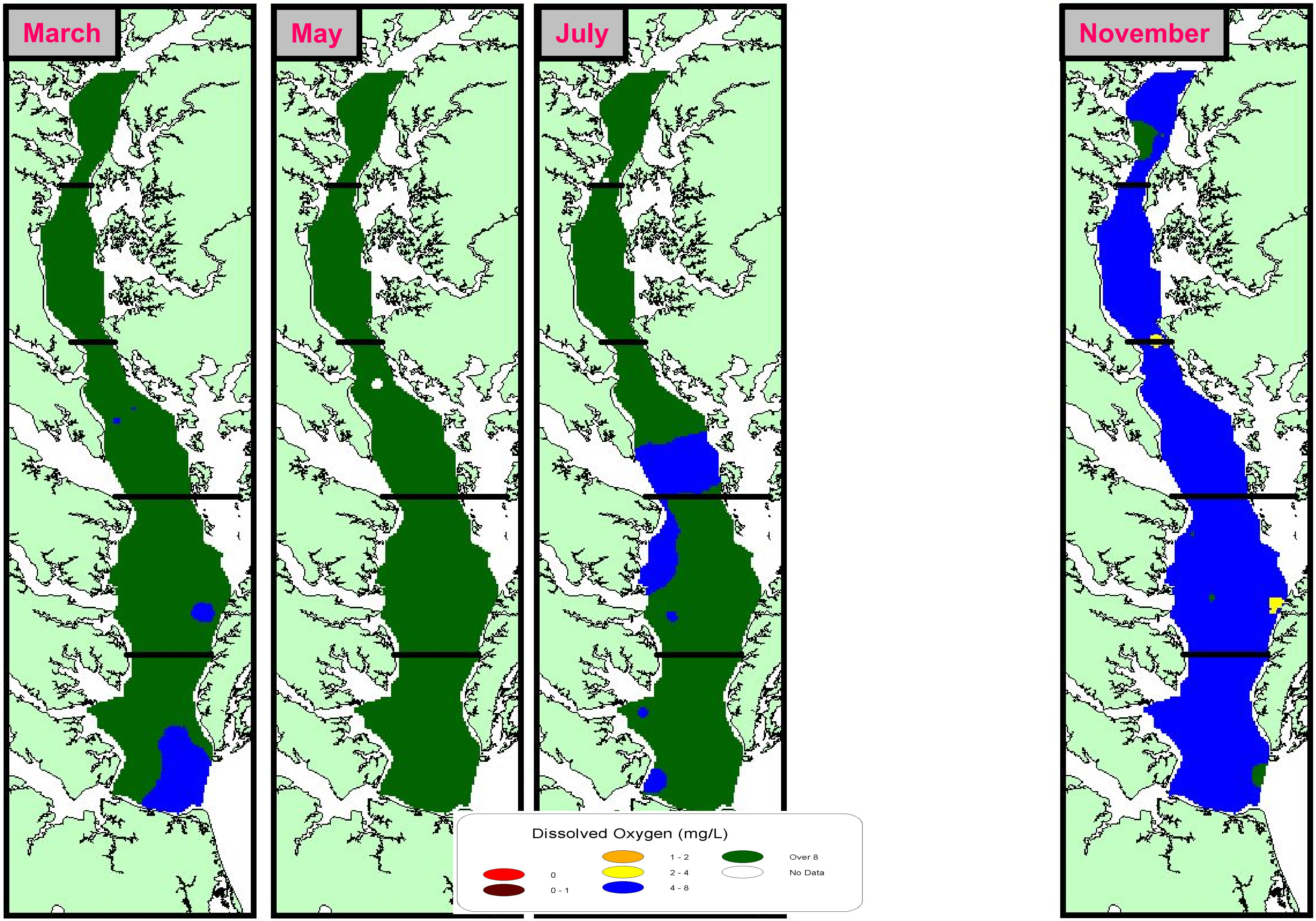


Figure 173. Bottom dissolved oxygen in Chesapeake Bay, 2007.