



Northeast Fisheries Science Center Reference Document 10-18

An Updated Spatial Pattern Analysis for the Gulf of Maine-Georges Bank Atlantic Herring Complex During 1963-2009

by Jonathan J. Deroba

August 2010

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US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

August 2010

Northeast Fisheries Science Center Reference Documents

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This document may be cited as:

Deroba JJ. 2010. An updated spatial pattern analysis for the Gulf of Maine-Georges Bank Atlantic herring complex during 1963-2009. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 10-18; 18 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at <http://www.nefsc.noaa.gov/nefsc/publications/>

TABLE OF CONTENTS

Abstract.....	2
1. Introduction.....	3
2. Methods	3
2.1 Survey Data.....	3
2.2 Analyses.....	3
3. Results.....	5
3.1 Kernel Density Plots	5
3.2 Frequency Histograms	5
3.4 Indices of Dispersion	5
4. Conclusions.....	6
5. Acknowledgements.....	6
6. References.....	7

ABSTRACT

Spatial pattern analysis of survey catches have been shown to reflect changes in Gulf of Maine-Georges Bank Atlantic herring abundance, but no such analysis has been conducted using data from the last 11 years (1999-2009). I conducted a spatial pattern analysis by updating previous analyses looking for temporal trends in the spatial distributions of Atlantic herring spring and fall survey catches during 1963-2009. The distribution of herring catch locations expanded to the southwest during spring bottom trawl surveys and generally occurred over a broader area during fall bottom trawl surveys as abundance increased during the mid- to late 1980s. Similarly, herring capture locations during spring and fall bottom trawl surveys became more evenly distributed among latitudes and more closely aggregated as abundance increased. These patterns that are indicative of relatively high abundance have persisted through 2009.

1. INTRODUCTION

Atlantic herring *Clupea harengus* (referred to as herring) on the eastern continental shelf of the United States (US) and Canada have been fished to some extent for centuries, but significant catches did not begin until the 1800s when sardine canneries began operating along the coast of Maine (Anthony and Waring 1980; Tupper et al. 1998). During the 1960s, distant water fleets began fishing on George's Bank and total landings peaked at 479,000 mt in 1968. Over the next decade, the stock complex was fished to near collapse with total landings reaching a low of 44,600 mt in 1983, with most of the landings being taken from the Gulf of Maine and Jeffrey's Ledge. In the 1990s, abundance rebounded and during 1995-2008 landings were stable and averaged 120,000 mt.

Some have hypothesized that fish stocks contract to the most favorable habitats during low abundance, and contractions consistent with this hypothesis have been observed for some pelagic fish stocks (Lluch-Belda et al. 1992; MacCall 1990; Barange et al. 1999). For example, Overholtz (2002) found that the distribution of locations where herring were captured shrank to the north during spring bottom trawl surveys and generally became limited to only the Gulf of Maine during fall bottom trawl surveys as abundance declined. Similarly, herring capture locations during spring and fall bottom trawl surveys were less evenly distributed among latitudes and less aggregated during years of low abundance. So, some spatial patterns in survey capture locations may be indicative of the abundance of a fish stock.

The objective of this study was to make inference about the abundance of Atlantic herring in the Gulf of Maine-George's Bank complex using an update to the spatial analysis of Overholtz (2002). This objective was addressed by conducting a similar analysis to that of Overholtz (2002) using data from spring and fall bottom trawl surveys, but with the addition of 11 years of data.

2. METHODS

2.1 Survey Data

Each analysis described below was done separately for spring and fall bottom trawl surveys conducted by the Northeast Fisheries Science Center. Each survey employs a stratified random sampling design using a standardized bottom trawl towed for 30 minutes at randomly selected stations within a stratum. The survey gear (i.e., nets and doors) has changed through time and in 2009 a new survey vessel was used. The analyses of this paper, however, are focused on capture locations and not relative abundance. Therefore, results and conclusions should be robust to these changes. Additional details of the surveys are provided in Azarovitz (1981), Byrne et al. (1981), and Despres et al. (1988). Data collected during 1968-2009 and in strata 1-30, 36-40, and 61-76 were used in the analyses for the spring survey, and data collected during 1963-2009 and in strata 1-30 and 36-40 were used in the analyses for the fall survey (Figure 1).

2.2 Analyses

The methods used for each of the analyses were similar to those used in Overholtz (2002) and the details of each method can be found in that manuscript. A brief overview was provided here. Some data has been updated or corrected since the analysis of Overholtz (2002) and so some differences may be evident, but they should be few and relatively minor.

2.2.1 Kernel Density Plots

Kernel density plots were used to describe the degree of concentration of herring sample sites in each of the surveys. These bivariate density contours illustrate where herring were most aggregated during each of the surveys. Six year intervals were plotted for spring (1983-2009) and fall (1980-2009) to illustrate the time-series changes in herring sample site locations. These years were chosen so that plots from when stock abundance was low (early 1980s) would be available for comparison to recent years. An arbitrary contour line was plotted with the sampling sites as a visual aid for following the spatial changes in the herring complex, similar to Overholtz (2002). Also as in Overholtz (2002), the analysis was not weighted by herring catch.

2.2.2 Frequency Histograms

Frequency histograms of the latitude and longitude of the herring capture locations were used to examine the degree of uniformity of the capture sites over the survey area. This method is useful for examining the medium scale positioning of the herring sample locations (Overholtz 2002). For this analysis, only selected years were plotted for the spring (1983, 1989, 1995, 2001, 2007, 2009) and fall (1985, 1990, 1995, 2000, 2005, 2009) to provide an overview of the changes in the herring complex without plotting all years and so that some years were the same as those presented in Overholtz (2002).

2.2.3 Nearest Neighbor Distances

Cumulative distributions of nearest neighbor distances were produced as indicators of how closely herring sample sites were spaced. A gradual, smooth curve suggests that the herring sample sites were relatively close and that few sites were “extremely” close or far from each other, while the opposite is true of an abrupt, fragmented curve. Nearest neighbor distances were corrected for regional longitude in the same way as Overholtz (2002). These distributions were plotted for the same range of years in each season as for the frequency histograms of latitude and longitude described above.

2.2.4 Indices of Dispersion

Indices of dispersion for each year and survey were also calculated based on nearest neighbor distances:

$$I = (N + 1) \frac{\sum_1^N (x^2)^2}{(\sum_1^N x^2)^2};$$

where x was the nearest neighbor distance and N was the number of sample sites where herring were caught. A value of $I = 2.0$ suggests a random distribution, <2.0 suggests uniformity, and >2.0 aggregation.

2.2.5 Mean Latitude and Longitude

The mean latitude and longitude of catches for each year and survey was plotted as a measure of the approximate spatial center of abundance. This plot would allow for the examination of temporal trends in the spatial center of the distribution of the stock.

3. RESULTS

3.1 Kernel Density Plots

Kernel density plots for the spring and fall surveys showed a more expansive concentration of herring since abundance was low in the early 1980s. In 1983, the spring survey suggested that the stock complex was concentrated to the north of 40-41° latitude (Figure 2). As the stock recovered during the late 1980s, the herring concentration expanded and displayed an elongate southwest to northeast pattern (Figure 2). This pattern persisted during the 2000s.

In 1980, herring were only captured at one site during the fall survey (Figure 3). As the stock recovered during the late 1980s the herring concentration began to occupy a broader area and was found from approximately 41-43° latitude during 1986-1998 and 40-44° latitude during the 2000s (Figure 3).

3.2 Frequency Histograms

Frequency distributions of the latitude and longitude of herring catches in the spring and fall surveys were less fragmented and catches have occurred over a broader range since the stock recovered from low abundance in the early 1980s. In 1983, the frequency distribution of spring survey herring catches was fragmented and centered around 40-45° latitude and 67-71° longitude (Figure 4; Figure 5). As the stock recovered during the late 1980s the herring complex became more broadly distributed and catches between 39-45° latitude and 67-76° longitude became more frequent and remained so during the 2000s (Figure 4; Figure 5).

In 1985, the frequency distribution of fall survey herring catches was fragmented and most sites were north of 42° latitude and between 69-71° longitude (Figure 6; Figure 7). As the stock recovered, catches occurred more frequently towards the tails of the distributions with a greater frequency of sites south of 42° latitude and east of 69° longitude (Figure 6; Figure 7).

3.3 Nearest Neighbor Distances

Cumulative distributions of nearest neighbor distances from spring and fall survey catches have been less fragmented and more gradual since the stock recovered from low abundance in the early 1980s. In 1983, the cumulative nearest neighbor distance distribution for the spring survey was fragmented with about 50% of the distances between 0.1-0.2° and 60% between 0.1-0.4° (Figure 8). As the stock recovered, the cumulative distributions became more gradual. In 1989, the percentage of distances between 0.1-0.2° increased to about 60% with nearly 100% between 0.1-0.6°. Since then, >90% of the distances were between 0.1-0.4° (Figure 8).

The cumulative distributions of nearest neighbor distances from the fall survey have a similar pattern to the spring survey distributions. In 1985, the distribution was fragmented with about 90% of the distances between 0.1-0.6° (Figure 9). In 1990, the distribution was more gradual with about 90% of the distances between 0.1-0.4° (Figure 9). Since then, >90% of the distances were between 0.1-0.4° (Figure 9).

3.4 Indices of Dispersion

Distance indices of dispersion were variable during 1970-1990 for the spring survey and variable for the entire fall survey time series. Aggregation ($I > 2$) was evident in all years of the spring survey except 1995 ($I = 1.94$) and 2009 ($I = 1.94$; Figure 10). Indices of dispersion were

more variable during 1968-1990 (mean = 6.20, range = 2.05-28.27) than 1991-2009 (mean = 2.60, range = 1.94-3.71; Figure 10).

Aggregation was evident in all years of the fall survey except 1974 ($I=1.98$), 1977 ($I=1.79$), 1981 ($I=1.50$), and 1992 ($I=1.96$; Figure 10). Indices of dispersion have become increasingly variable over the fall survey time series (Figure 10).

3.5 Mean Latitude and Longitude

Mean latitude and longitude of herring catches during the spring and fall surveys have remained centered in different locations since the stock recovered from low abundance in the early 1980s. The capture locations from the spring survey were centered in the southwest during the late 1960s, shifted to the northeast during the 1970s, and even farther northeast during the mid-1980s (Figure 11). Since then, the capture locations have shifted back to the southwest near 41° latitude and 70-71° longitude (Figure 11).

The capture locations from the fall survey were generally centered in the southeast during the 1960s, but shifted to the northwest during the mid-1970s and early 1980s (Figure 11). Since then, the capture locations have shifted to the east near 42-43° latitude and 69° longitude (Figure 11).

4. CONCLUSIONS

The spatial patterns of the survey catches can be used to make inference about the general status of the herring complex (Overholtz 2002). The herring complex shrank in range and the spatial center of the survey catches in each season shifted when the stock was near collapse in the early 1980s (Overholtz 2002). As the stock recovered, the range expanded and the spatial center of the survey catches returned to a pattern similar to years prior to the collapse and has remained that way through 2009. These results suggest that the Gulf of Maine-George's Bank herring complex has not returned to a collapsed state since recovery.

The results of this analysis could be used in conjunction with formal stock assessment results to help managers make more informed decisions. The last herring stock assessment concluded that the herring stock was not overfished and that overfishing was not occurring (TRAC 2009). Although the analysis in this manuscript was too coarse to make conclusions about the abundance of herring relative to overfishing reference points, the results were consistent with the conclusions of the previous herring assessment. The previous herring assessment, however, also suffered from multiple sources of uncertainty (TRAC 2009). These uncertainties were considered so severe that the results of the last assessment were not explicitly used to calculate acceptable biological catches (ABC) for 2010-2012, and the New England Fishery Management Council (NEFMC) set the ABCs based on recent catches, which resulted in approximately a 45% decrease in ABCs from the previous three years (NEFMC 2010). By considering whether the results of formal stock assessments are consistent with the results of studies such as this one, managers may be more informed about whether future increases or decreases to ABCs are warranted.

5. ACKNOWLEDGEMENTS

I would like to thank the countless people that helped collect and process the survey data. Bill Overholtz and Gary Shepherd provided comments on an earlier draft of this manuscript. Dan Hennen provided advice on computer coding related to several of the analyses.

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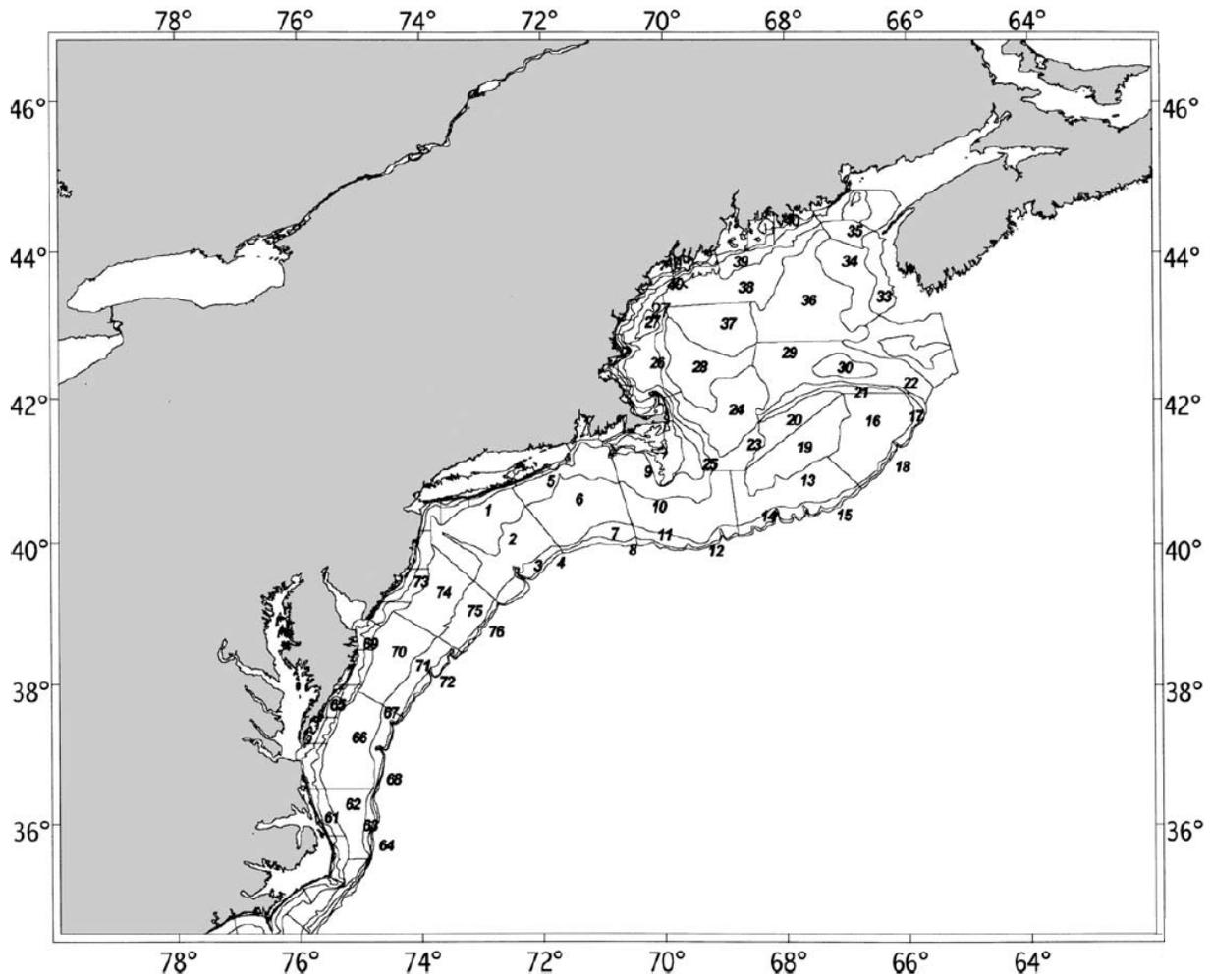


Figure 1. Survey strata used in Northeast Fisheries Science Center bottom trawl surveys.

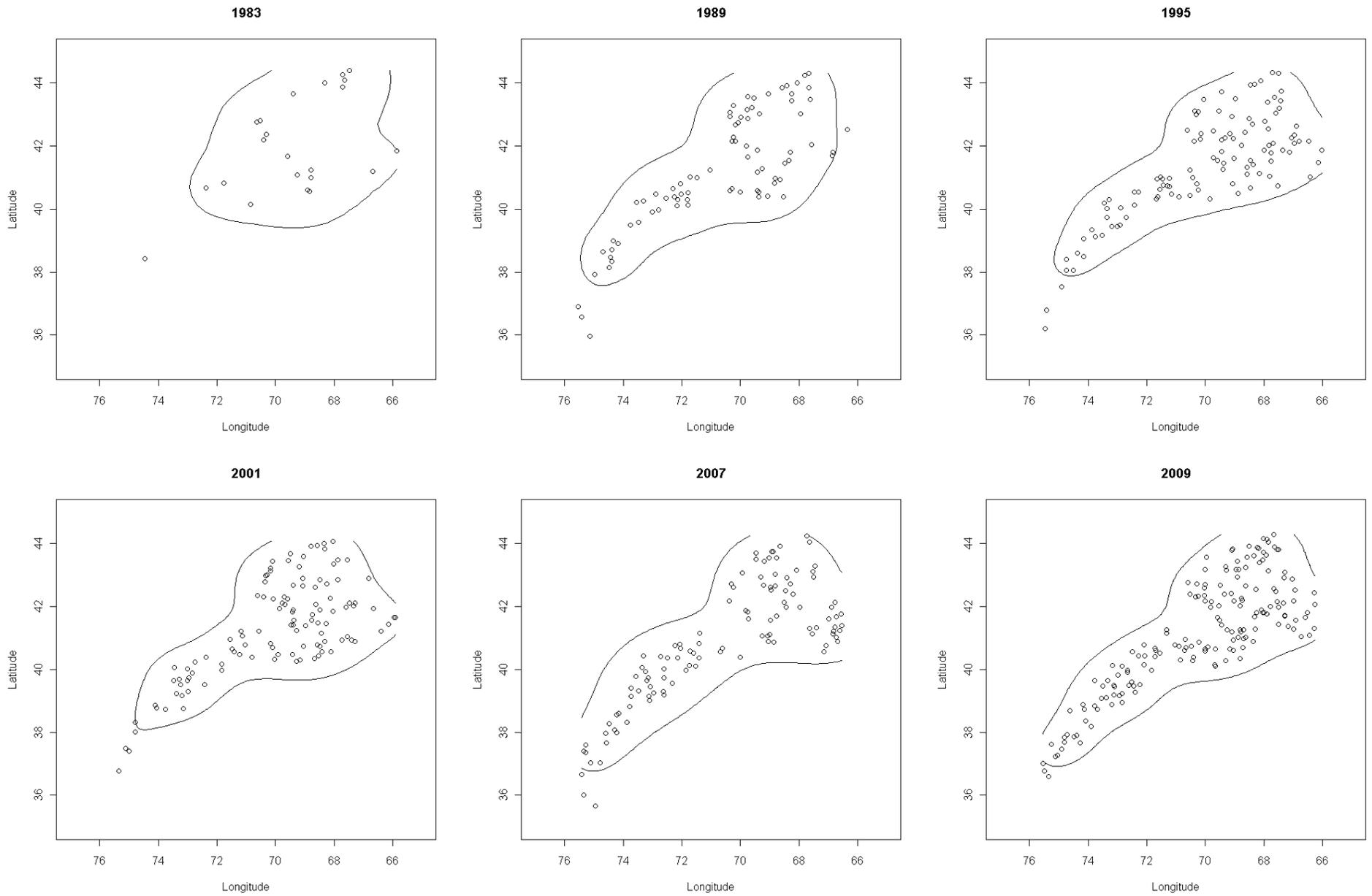


Figure 2. Kernel density plots (with arbitrary contour line) of herring capture locations for selected years from spring bottom trawl surveys.

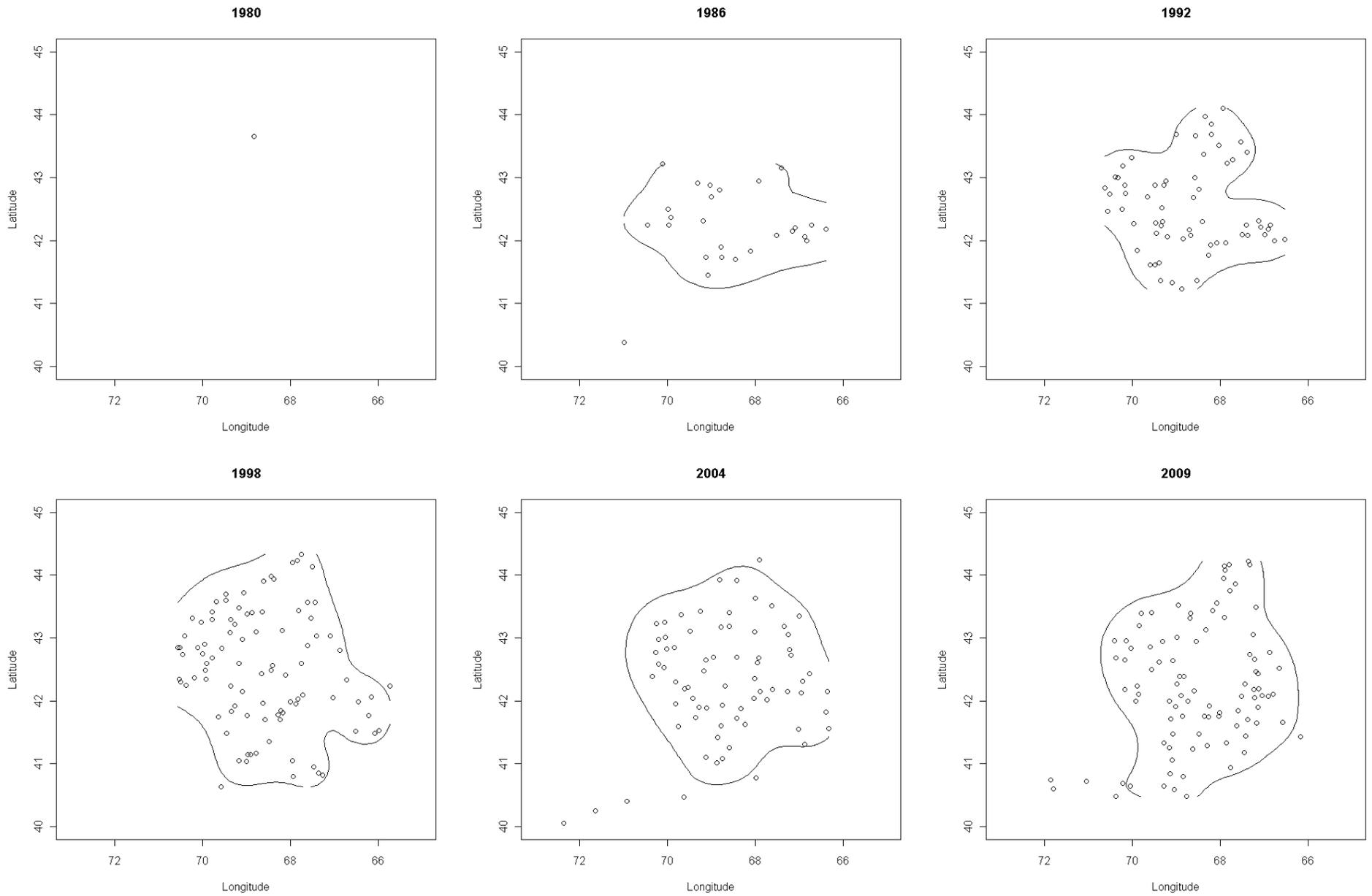


Figure 3. Kernel density plots (with arbitrary contour line) of herring capture locations for selected years from fall bottom trawl surveys.

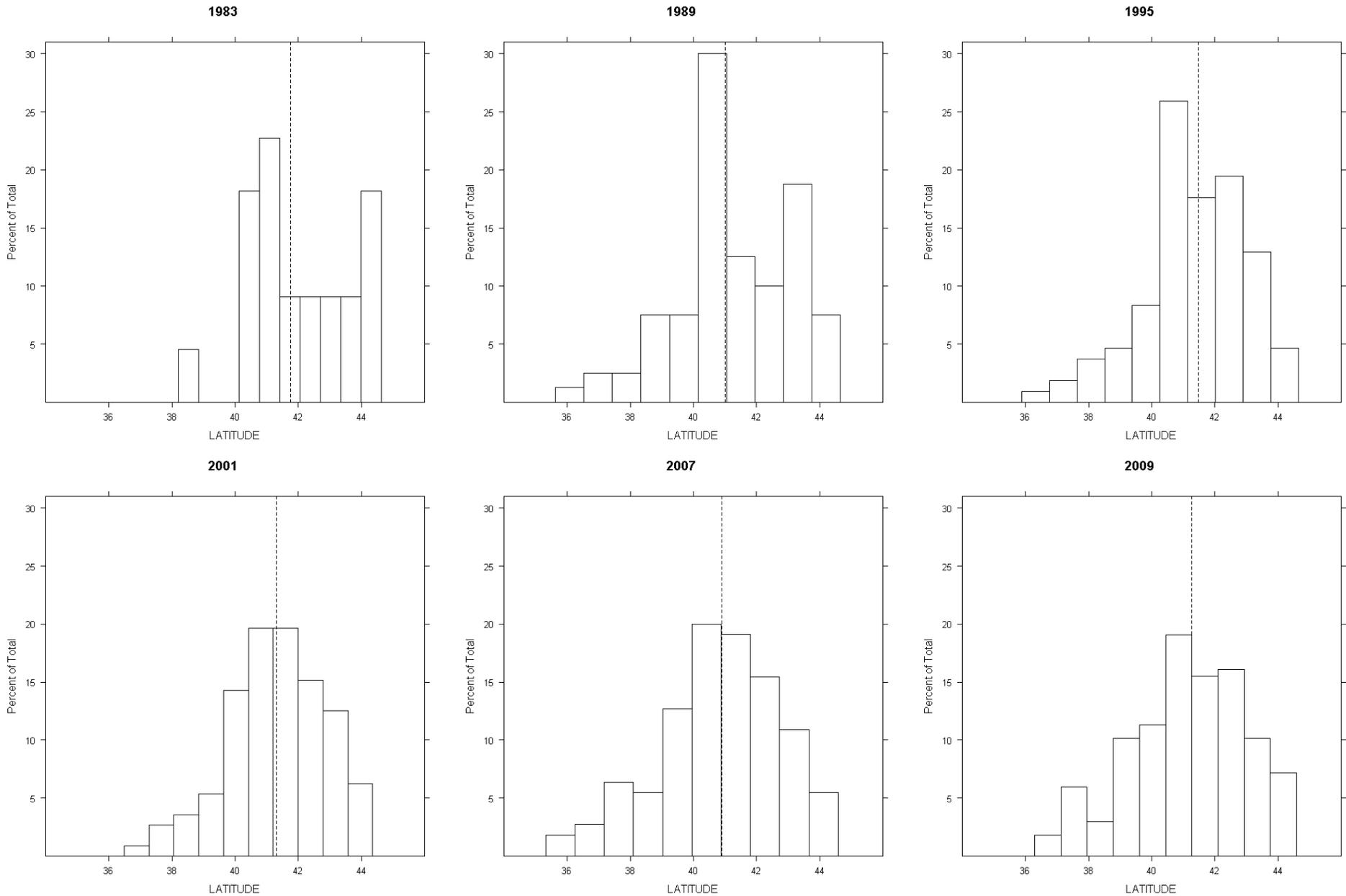


Figure 4. Frequency histograms of the latitude of herring capture locations for selected years from spring bottom trawl surveys. The dashed vertical line represents the median.

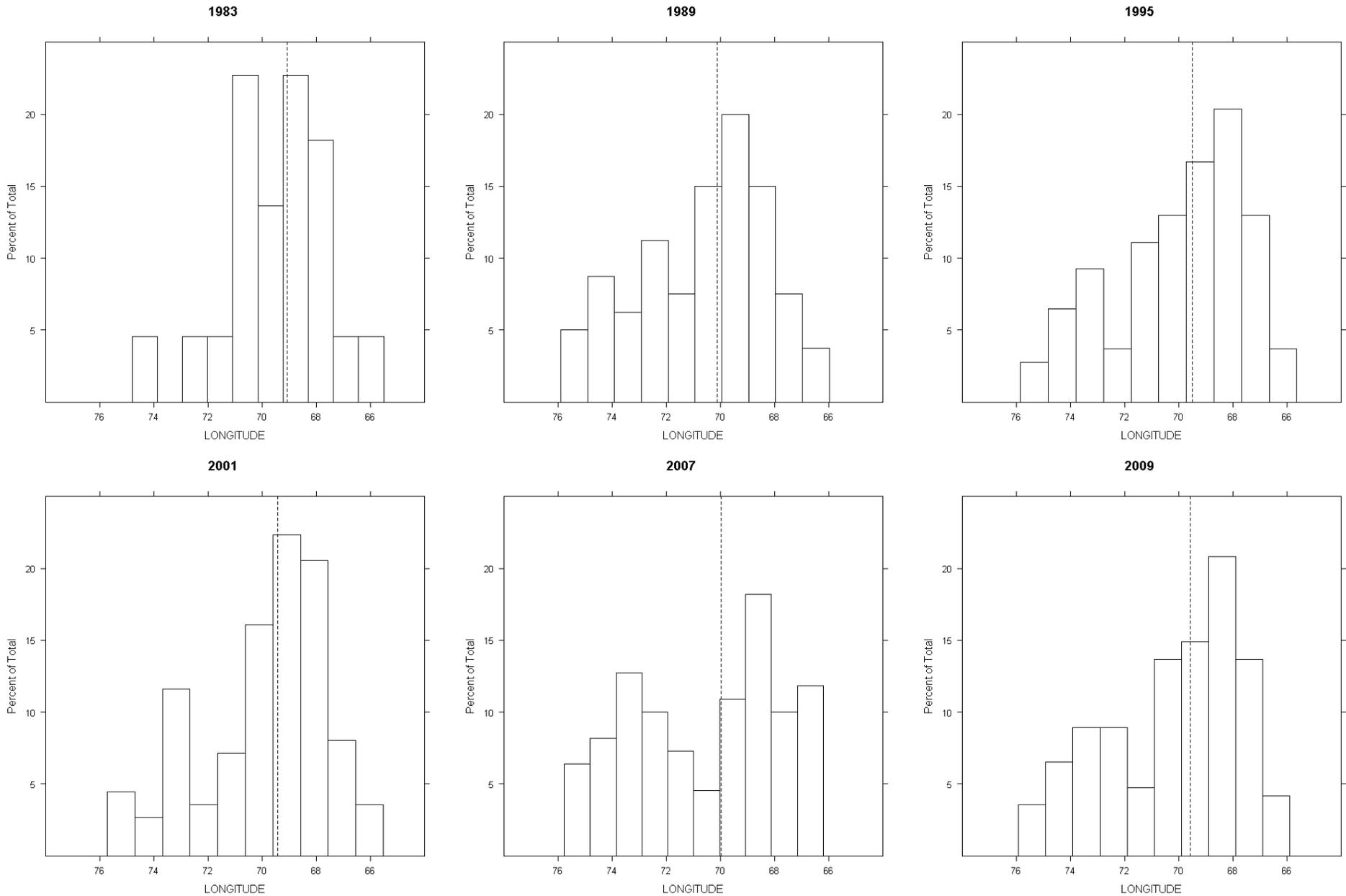


Figure 5. Frequency histograms of the longitude of herring capture locations for selected years from spring bottom trawl surveys. The dashed vertical line represents the median.

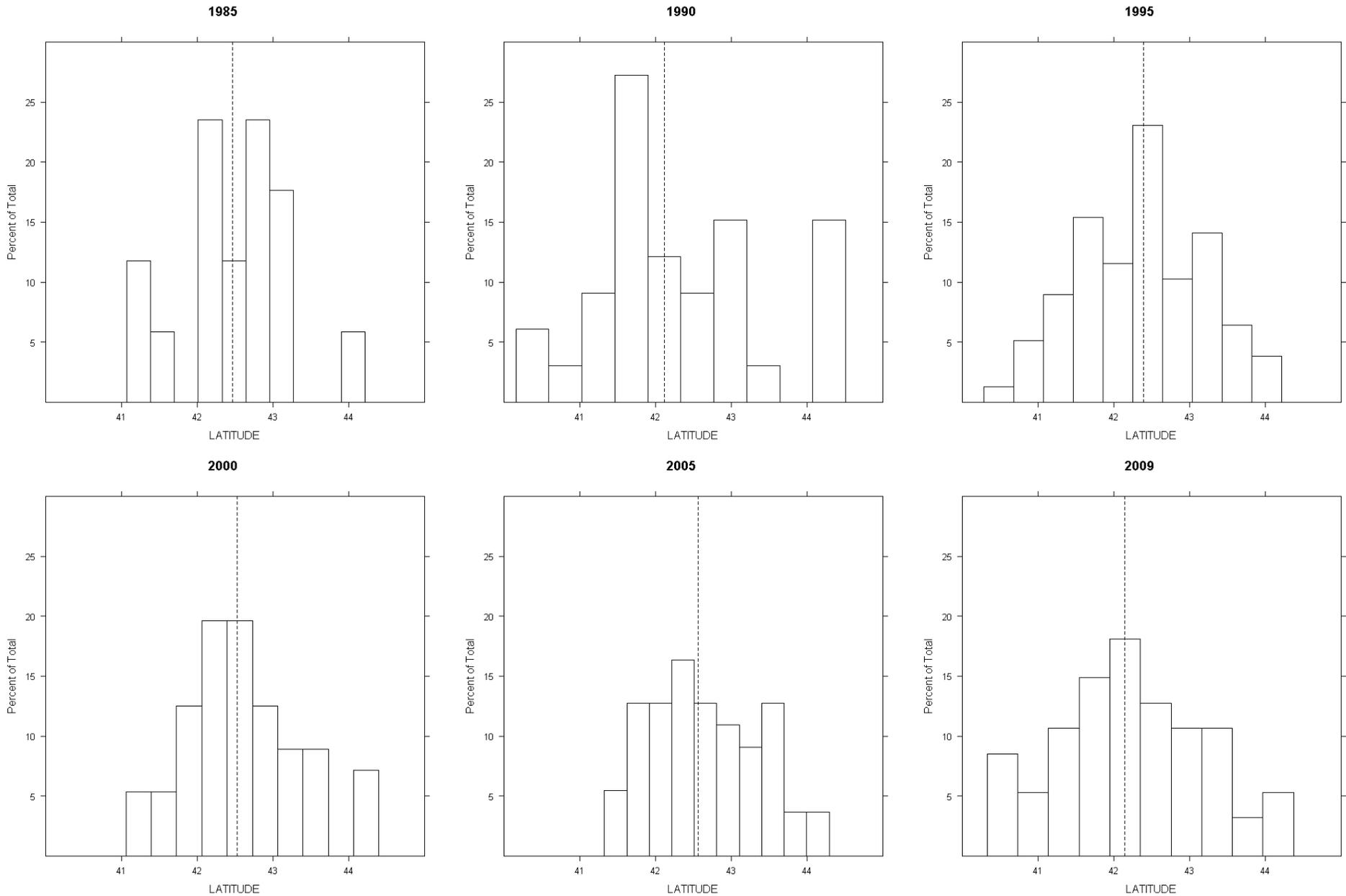


Figure 6. Frequency histograms of the latitude of herring capture locations for selected years from fall bottom trawl surveys. The dashed vertical line represents the median.

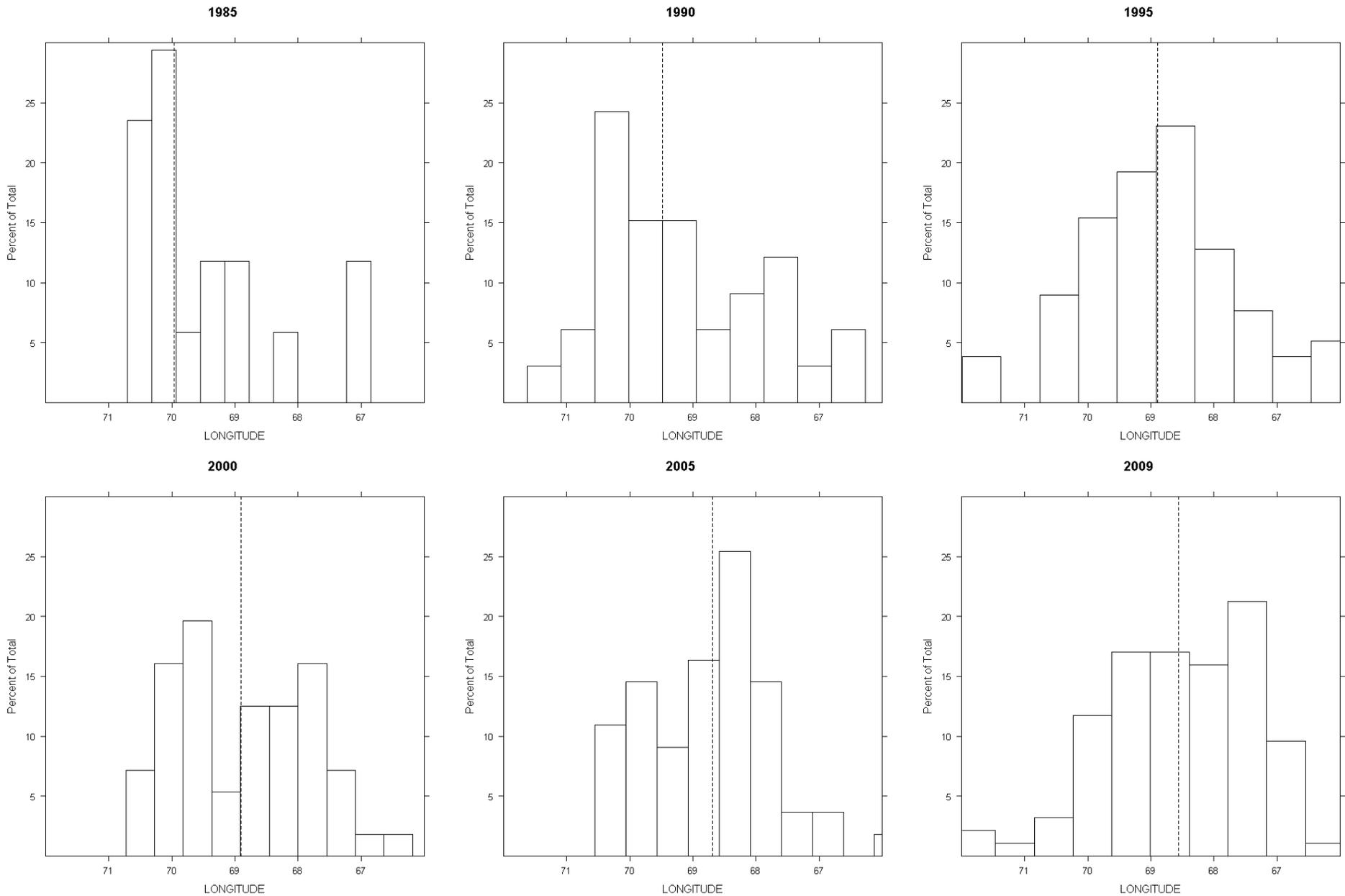


Figure 7. Frequency histograms of the longitude of herring capture locations for selected years from fall bottom trawl surveys. The dashed vertical line represents the median.

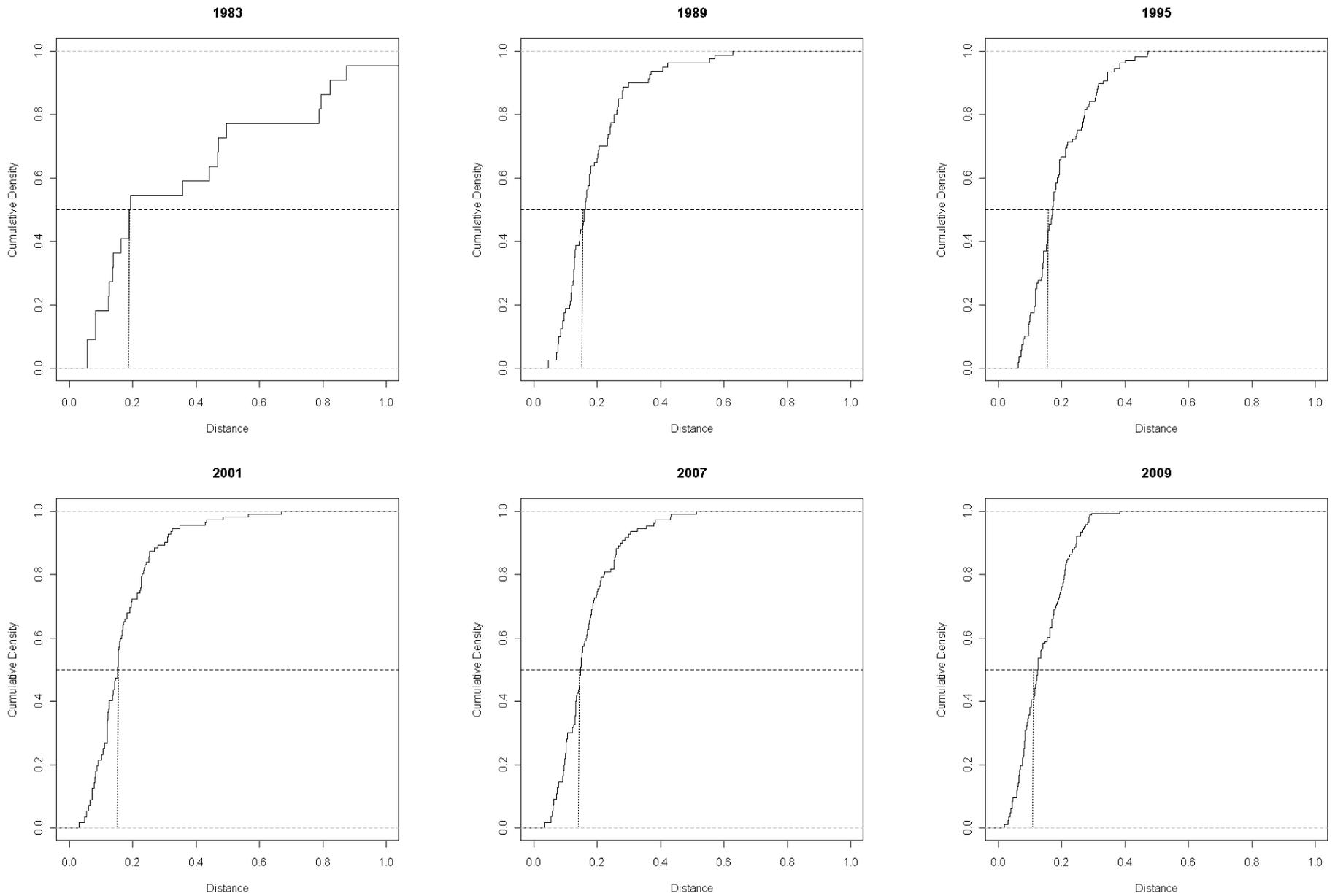


Figure 8. Cumulative distributions of nearest neighbor distances of herring capture locations for selected years from spring bottom trawl surveys. Dashed horizontal lines represent cumulative densities of 0.0, 0.5, and 1.0. The dashed vertical line represents the distance at a cumulative density of 0.5.

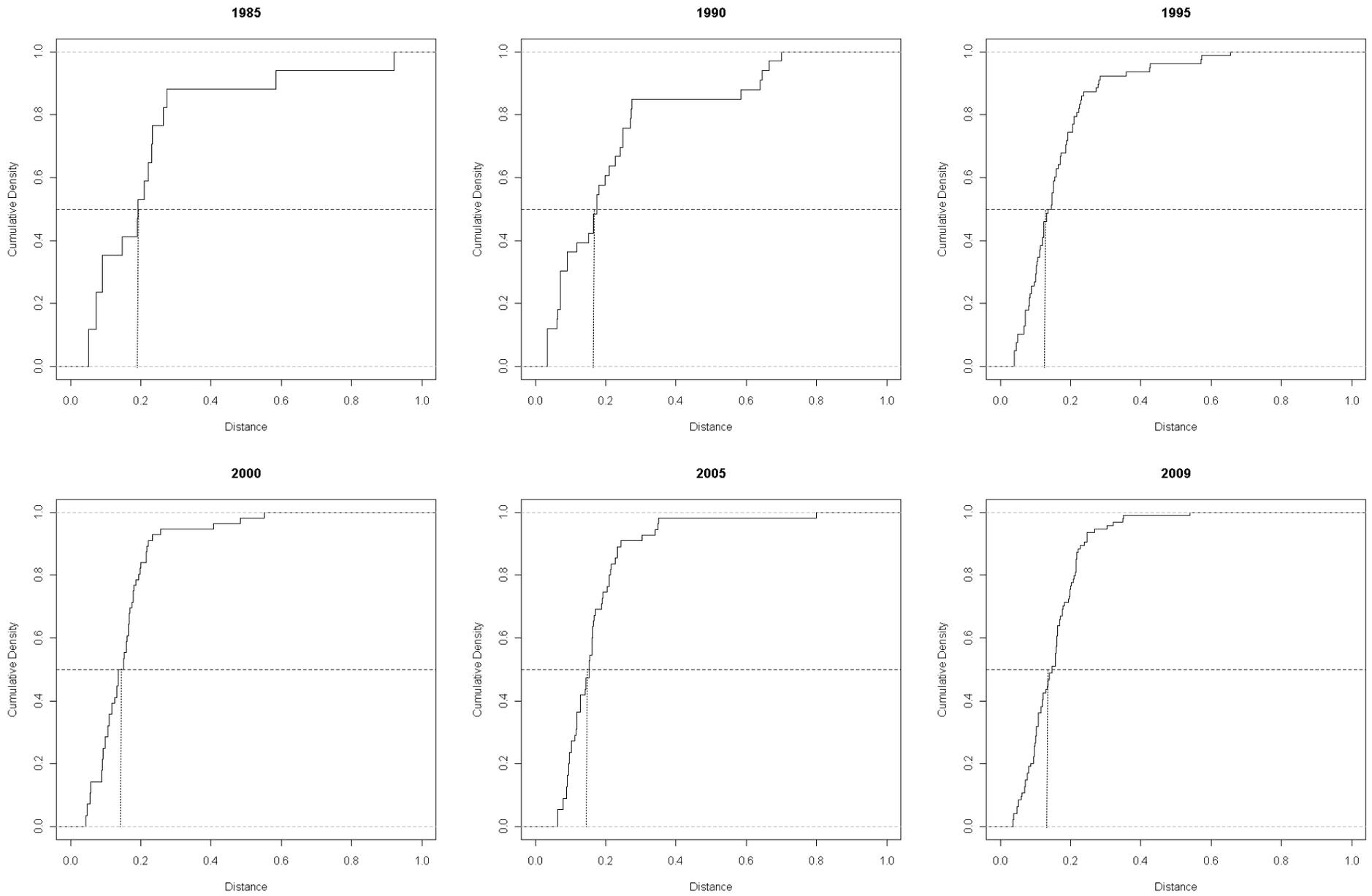


Figure 9. Cumulative distributions of nearest neighbor distances of herring capture locations for selected years from fall bottom trawl surveys. Dashed horizontal lines represent cumulative densities of 0.0, 0.5, and 1.0. The dashed vertical line represents the distance at a cumulative density of 0.5.

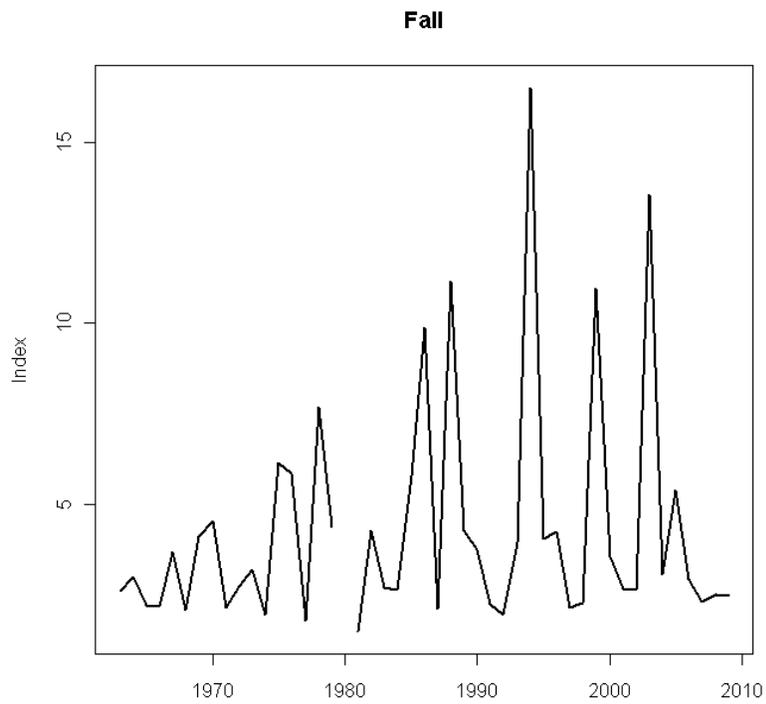
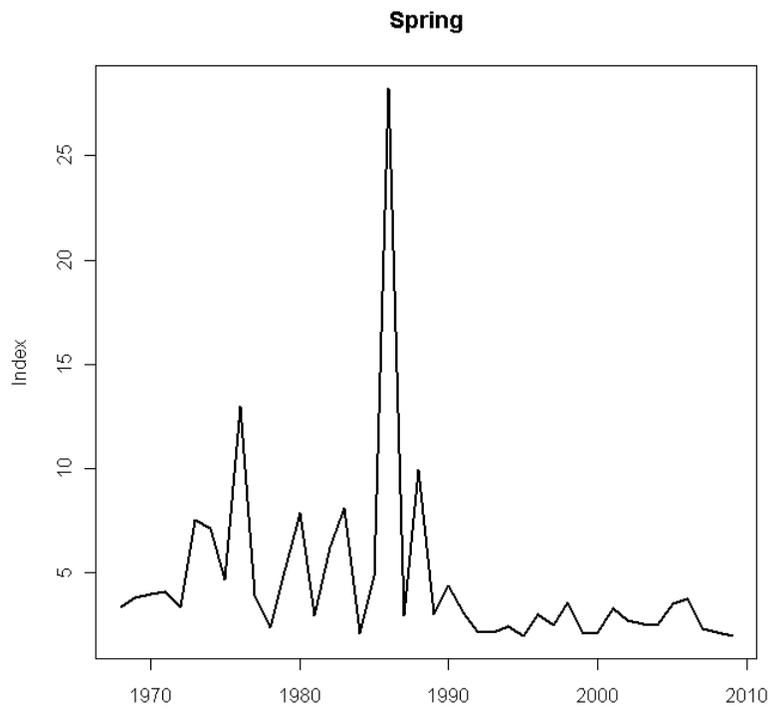


Figure 10. Indices of dispersion distance between herring capture locations during spring (top panel; 1968-2009) and fall (bottom panel; 1963-2009) bottom trawl surveys.

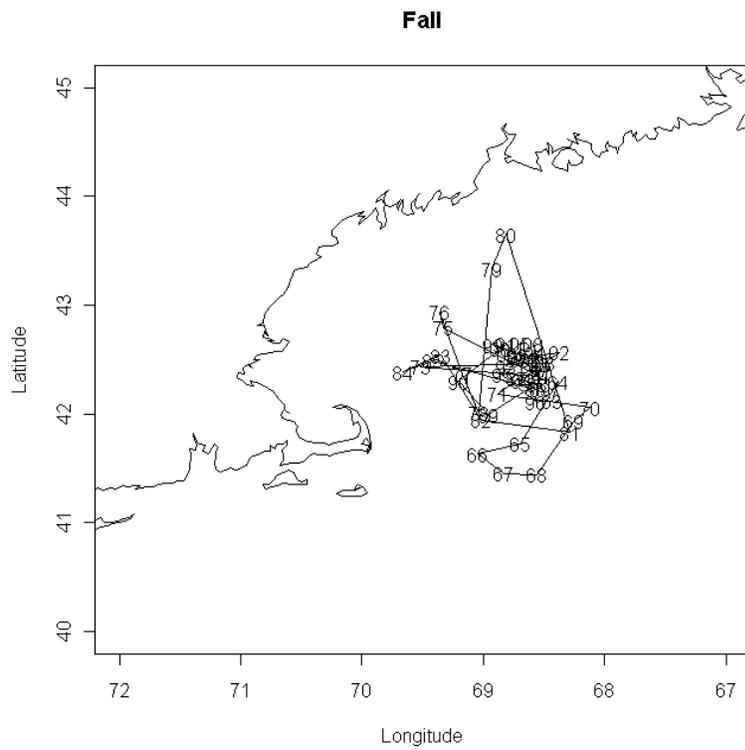
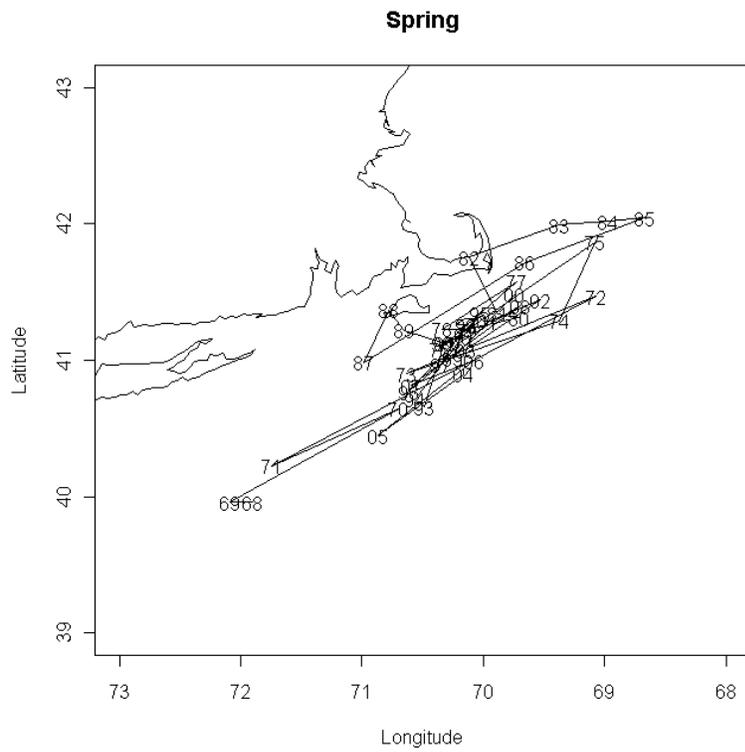


Figure 11. Relative center of herring abundance based on mean latitude and longitude of herring catches during spring (top panel; 1968-2009) and fall (bottom panel; 1963-2009) bottom trawl surveys.

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