SASI Spatial Analysis

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Introduction

The objectives of the SASI Spatial Analysis were to 1) explore the spatial structure of the asymptotic area swept ($Z\infty$), 2) define clusters of high and low $Z\infty$ for each gear type, 3) determine the levels of $Z\infty$ in present and candidate management areas relative to the model domain, and 4) identify alternative management areas with $Z\infty$ values similar to or higher than the tested areas.

These analyses were developed to answer two types of questions. First, the Local Indicators of Spatial Association (LISA) analysis shows which areas of the continental shelf are most vulnerable to fishing by particular gear types. This will help the Council to select priority areas for implementation of adverse impacts minimization measures such as gear restrictions. Second, the Equal Area Permutation (EAP) analysis will allow the Council to evaluate the extent to which current EFH closures or other management areas encompass habitats that are vulnerable to certain types of fishing gears. In cases where a particular area is relatively less vulnerable compared to other areas of similar size throughout the region, the Council may choose to eliminate that habitat closure. In other instances, maintaining an existing habitat closure area but changing its boundaries may better protect vulnerable habitats.

Note that in the methods description below, $Z\infty$ (Z infinity) refers to the terminal year adverse effect (Z) value from each 100 km^2 grid cell of the SASI uniform fishing effort simulation runs. These values were estimated for otter trawl, scallop dredge, hydraulic clam dredge, demersal longline, sink gillnet, and trap gear types. The spatial domain for each gear type varies, and was truncated to only include depths equal to or shallower than the depth at which 99.9% of the observed trips for that gear type have occurred. These maximum depths limit the analysis for each gear type to an area where fishing could possibly occur.

Determining z_∞ spatial structure and clusters

Local Indicators of Spatial Association (LISA) statistics including Moran Scatterplots and Local Moran's *I* were used to explore the spatial structure of Z_∞ and to delimit clusters of model cells with statistically high and low Z_∞ (Anselin 1995).

Global Moran's *I* is an index of linear association between a set of spatial observations x_i x_j, and a weighted average w_{ij} of their neighbors (Moran 1950):

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j} x_i x_j}{\sum_{i=1}^{n} x_i^2},$$

Where x_i is the asymptotic area swept accumulated in cell i, and X is the overall mean asymptotic area swept accumulated in the entire model domain. The neighborhood weights, $w_{i,j}$, were determined using Queen Contiguity (the 8-neighbor rule) (Fortin and Dale 2005). Moran's $I > 0$ indicates that the Z_∞ values in the model domain are positively autocorrelated, while $I < 0$ indicates negative autocorrelation. When $I = 0$ the values are spatially random.

The spatial association of each survey station with its neighbors was estimated with the Local Moran's I_i (Anselin 1995):

$$I_i = \frac{x_i}{Q_i^2} \sum_{j=1, j\neq i}^{n} w_{i,j} x_i,$$

Where

$$Q_i^2 = \frac{\sum_{j=1, j\neq i}^{n} w_{i,j}}{n-1} - \overline{X}^2.$$

When $I_i > 0$ there is positive local autocorrelation, i.e., the cell is in a neighborhood of cells with similar characteristics, but which deviate (positively or negatively) from the overall mean cell characteristics (mean Z_∞). Negative autocorrelation ($I_i < 0$) occurs when the cell is in a neighborhood with dissimilar Z_∞ characteristics. When $I_i = 0$ the cell is in a neighborhood with random characteristics, or when the cell and its neighbors have characteristics equal to the overall mean (Boots 2002).

Moran scatterplots are bivariate plots of w_i as a function of x_i, and the slope of a line fit to the scatterplot gives global Moran's *I* (Anselin 1996). The four quadrants of the scatterplot indicate each observation's value relative to its neighbors. Cells with higher than average values ($x_i > 0$)

with neighboring high values ($w_i > 0$) are in the High-High quadrant and together with those in the Low-Low ($x_i < 0$, $w_i < 0$) quadrant indicate positive local spatial autocorrelation. The High-Low and Low-High quadrants indicate negative local spatial autocorrelation.

The null hypotheses that $Z\infty$ was globally or locally randomly distributed (I and $I_i = 0$) were tested by estimating p-values for I and I_i. The p-values were calculated using 9,999 permutations of a spatially random reference distribution (GeoDa® software, Anselin et al. 2006). These p-values are one-sided *pseudo*-significance values: $p = (M + 1) / (R + 1)$ where R is the number of permutations and M is the number of instances where I or I_i are greater than or equal to the observed value for positive autocorrelation, or less than or equal to the observed value for negative autocorrelation.

Global autocorrelation in the data increases the likelihood of Type I errors when testing the significance of I_i because cell values may not be independent (Ord and Getis 2001, Boots 2002). However, as not all samples in the data set are correlated to all others multiple comparison corrections (e.g. Sidak or Bonferonni) are too conservative (Boots 2002). Therefore, when the data exhibited global autocorrelation $p \leq 0.01$ was used to define "significant" clusters of $Z\infty$

Calculating z_∞ in present and proposed management areas

Equal Area Permutation (EAP) tests were used to determine the levels of $Z\infty$ in present and proposed management areas relative to the model domain. The area-weighted mean $Z\infty$ for each tested area was compared to a permutation distribution of area-weighted mean $Z\infty$ calculated using 9,999 randomly placed areas equal in size to the test area. The percentile of the tested area's area-weighted mean $Z\infty$ *v*alue and number of areas with area-weighted mean $Z\infty$ greater than or equal to the tested area were identified. These permutation-based areas were mapped along with the 100 highest area-weighted mean $Z\infty$ value areas (99^{th} percentile of the permutations distribution) to indicate alternative management area locations. The shapes and orientations of the tested areas vary depending on their locations and original management objectives. Circles were used to construct consistent permutation distributions for the EAP tests because they are isotropic and their areas can calculated simply using radii (Area = 2π x raduis^2).

Results

LISA - Z∞ Spatial structure and clusters

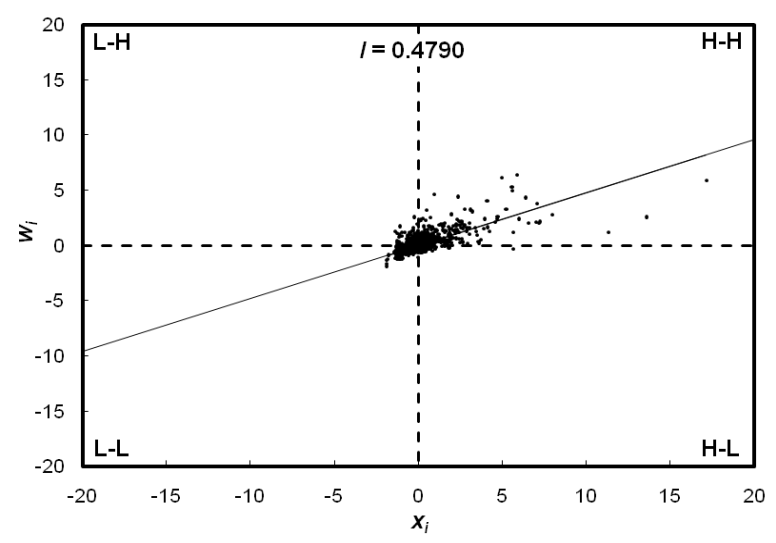
Asymptotic adverse effect (Z∞) for all gear types demonstrated strong global spatial autocorrelation ($I > 0$, $p \leq 0.0001$, Table 1). This result is intuitive, given that adverse effect is related to the underlying substrate, energy, and inferred features, and the distribution of substrates across the domain is highly patchy.

Table 1 – Global Morans *I* statistic and p-value for each gear type.

Gear	Global Morans *I*	p
Trawl	0.4790	≤0.0001
Dredge	0.5075	≤0.0001
H. Dredge	0.8264	≤0.0001
Gillnet	0.4080	≤0.0001
Longline	0.4100	≤0.0001
Trap	0.6775	≤0.0001

The Moran scatterplots show the degree of global spatial autocorrelation for each gear type and identify the quadrant location of every cell and neighborhood in the domain (trawl gear scatterplot is shown in Figure 1).

Figure 1 – Moran scatterplot for trawl gear. The slope of the line indicates the degree of spatial autocorrelation in the data.



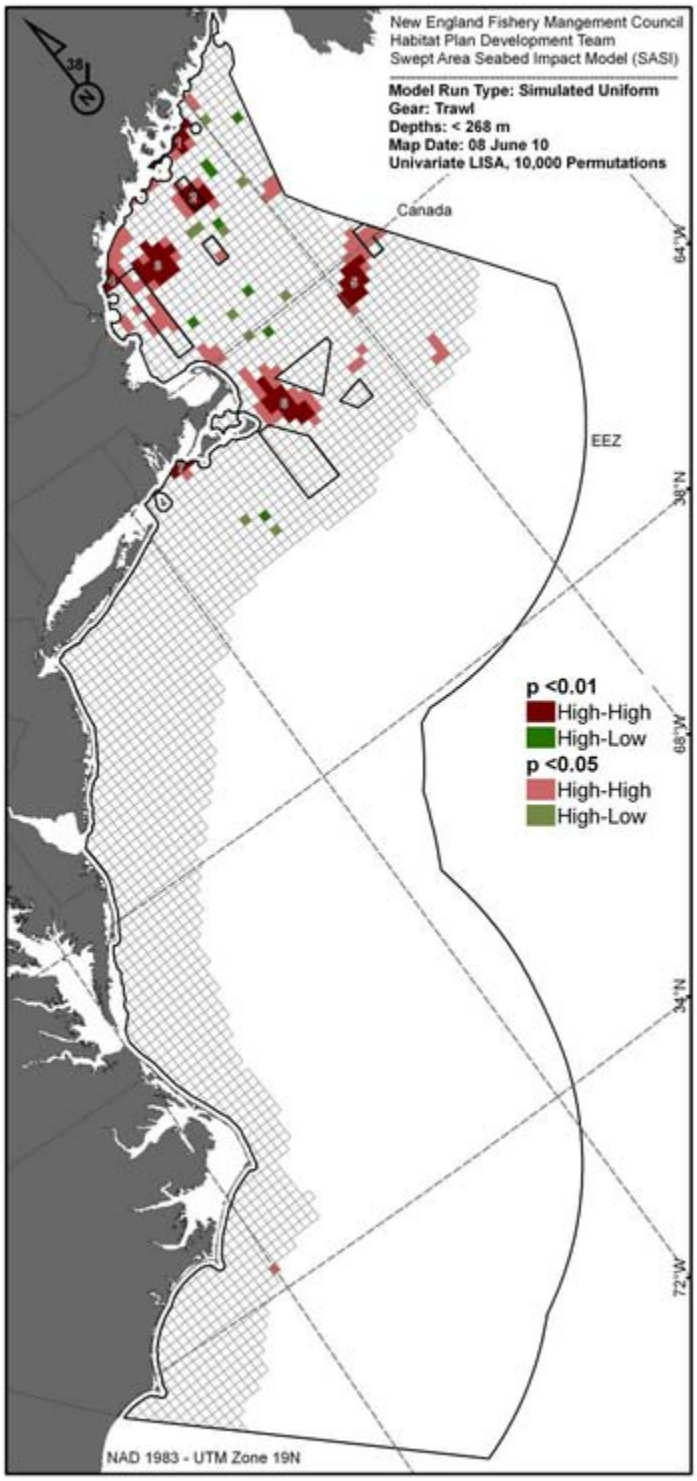
The LISA analysis delimited clusters of high and low Z∞ for all gear types at the $p \leq 0.01$ level and at the $p \leq 0.05$ level. Map 1 - Map 6 show the High-High and High-Low clusters at both probability levels for each of the six gear types. Except for hydraulic dredge and trap gears, the model outputs for most gear types clustered in similar areas. It should be noted that cells identified in clusters are relative to other cells for that gear type only. Thus, the relative magnitude of the potential adverse effects from different gear types cannot be inferred from these figures. Rather, the maps highlight the locations that are relatively more vulnerable to each gear type individually. (The magnitude of the actual adverse effects estimates is shown in the simulated and realized output maps in the SASI Gazetteer document.)

Regardless of gear type, most of the cells in the model did not form significant clusters (trawl gear results are shown in Table 2). Where clustering occurred, most of the cells were either classified as Low-Low or High-High, consistent with strong spatial autocorrelation. Outliers (High-Low and Low-High) were rare.

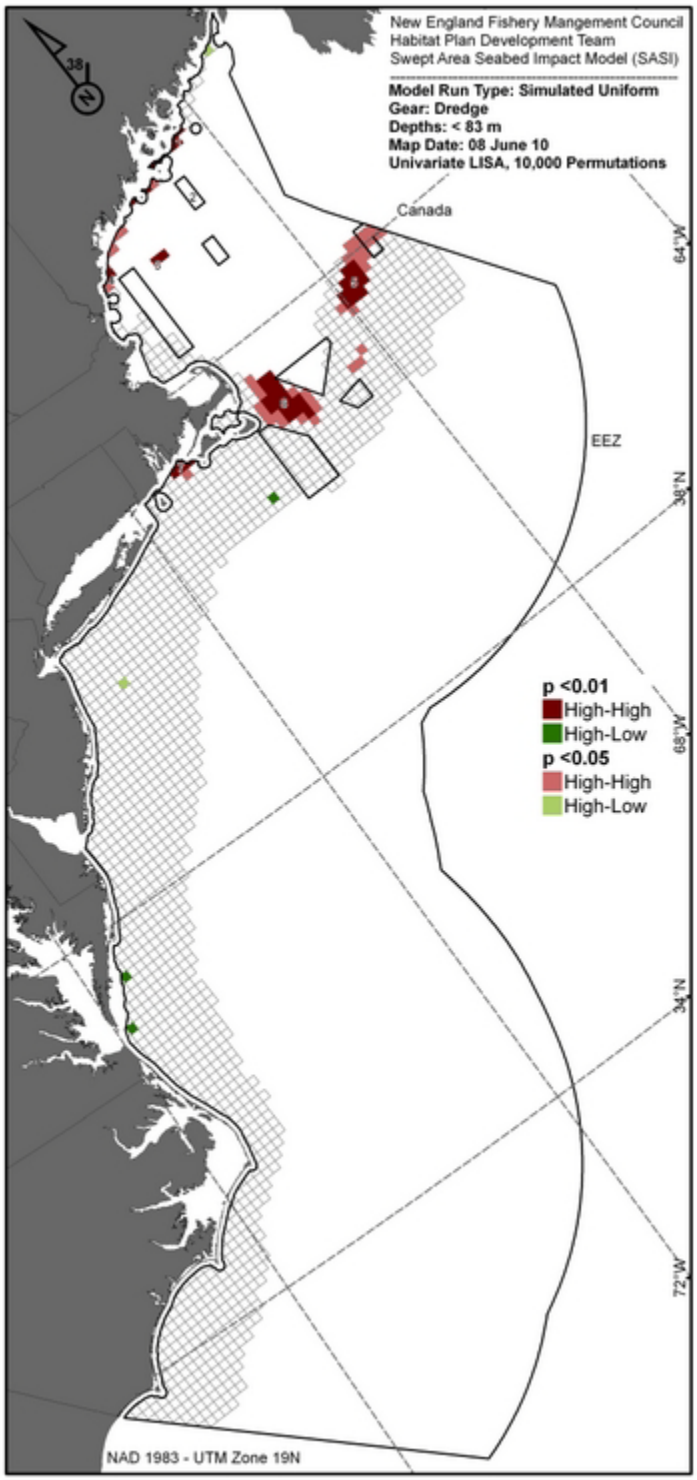
Table 2 – Percentage of cells in each cluster type for trawl gear LISA analysis.

Cluster type	Percentage of cells
Not Significant	76.27%
High cell – High neighborhood	6.79%
Low cell – Low neighborhood	14.98%
Low cell – High neighborhood	1.24%
High cell – Low neighborhood	0.72%
Total	100.00%

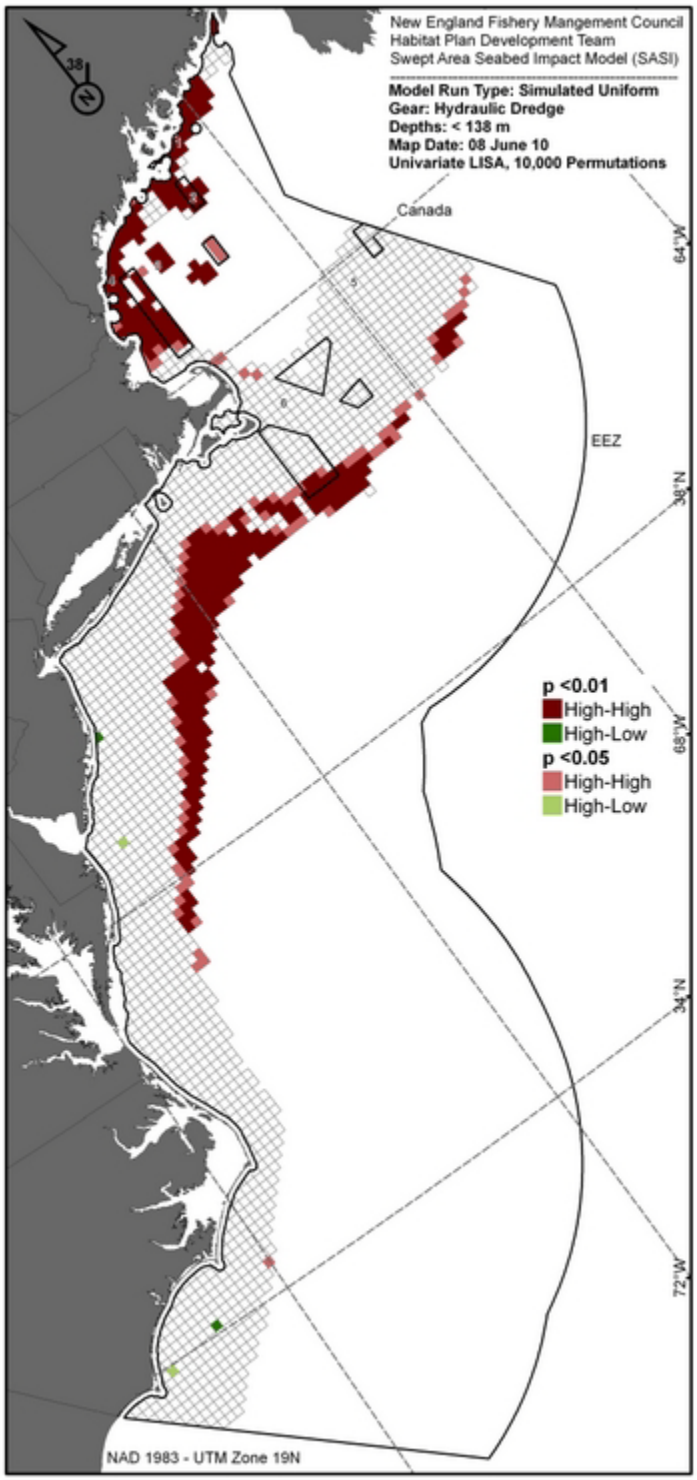
Map 1 – Maps of Z∞ clusters (high-high and high-low only) for trawl gear



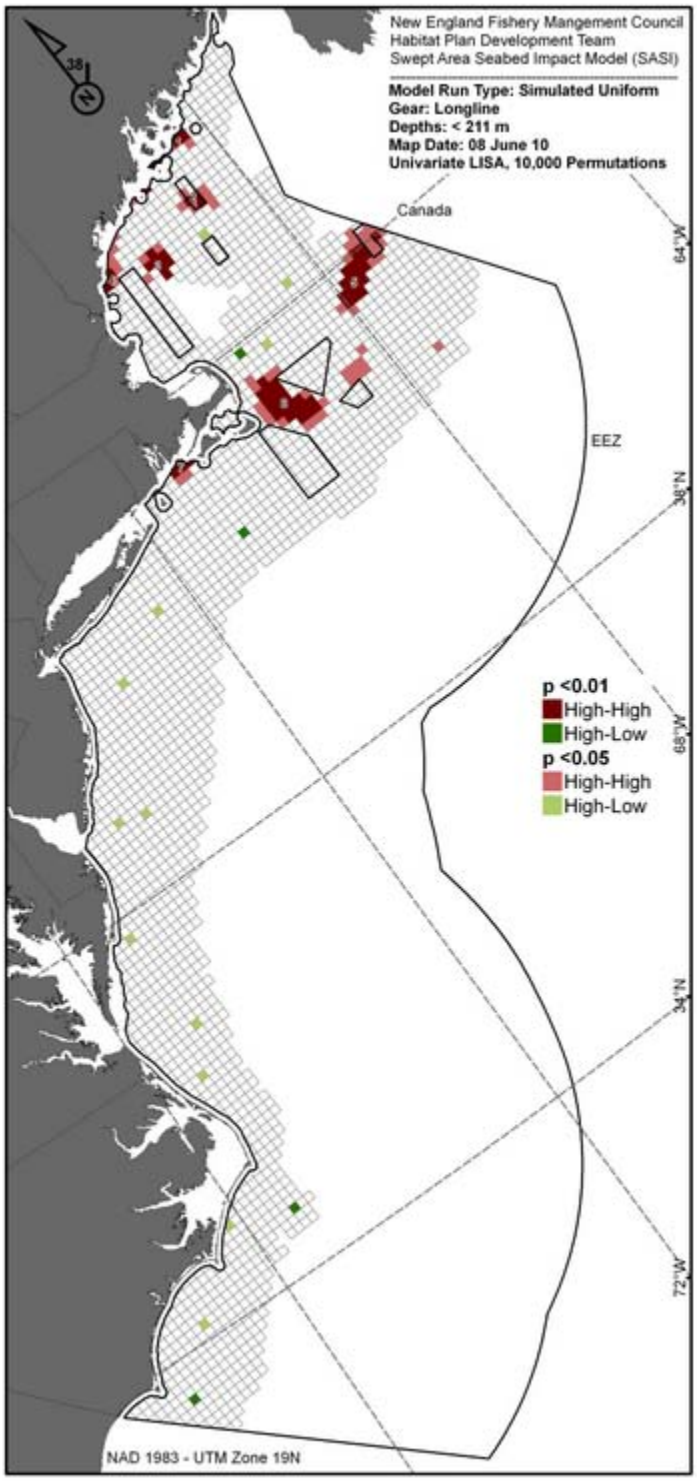
Map 2 – Maps of Z∞ clusters (high-high and high-low only) for scallop dredge gear



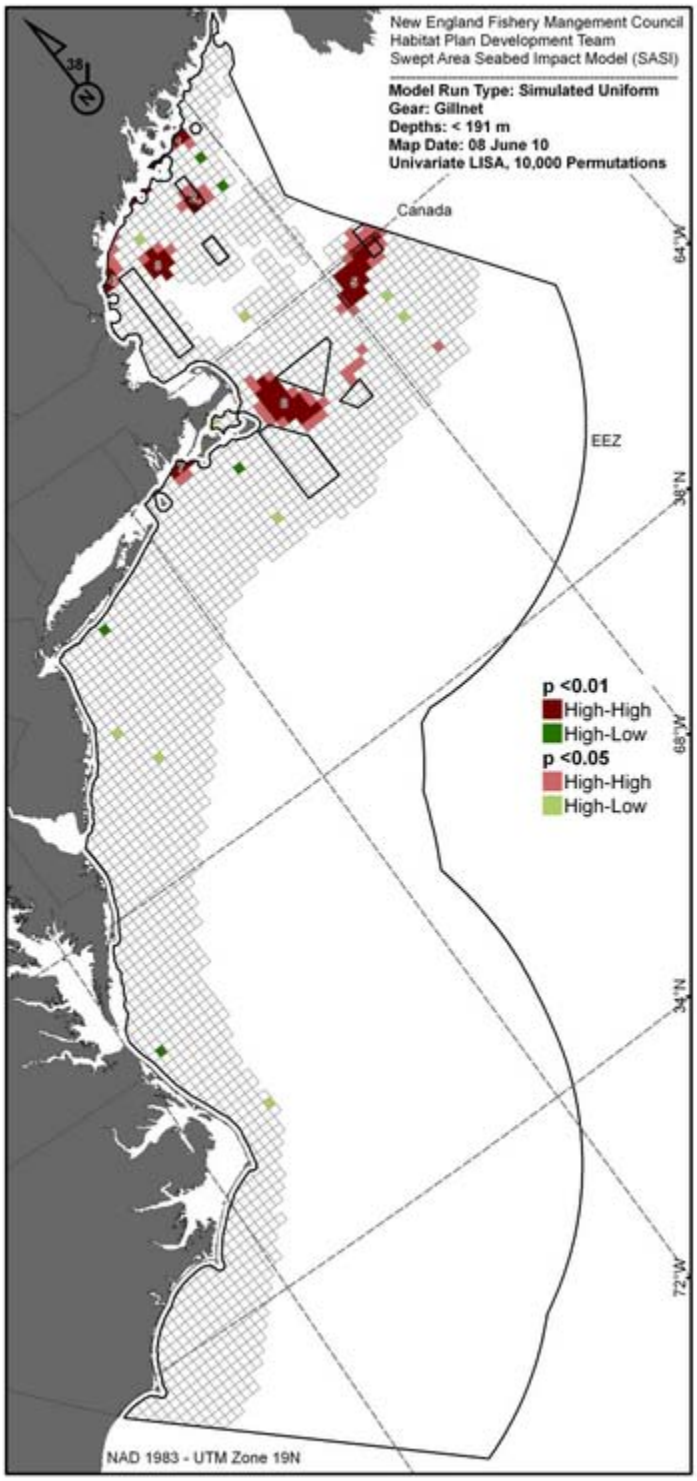
Map 3 – Maps of Z∞ clusters (high-high and high-low only) for hydraulic dredge gear



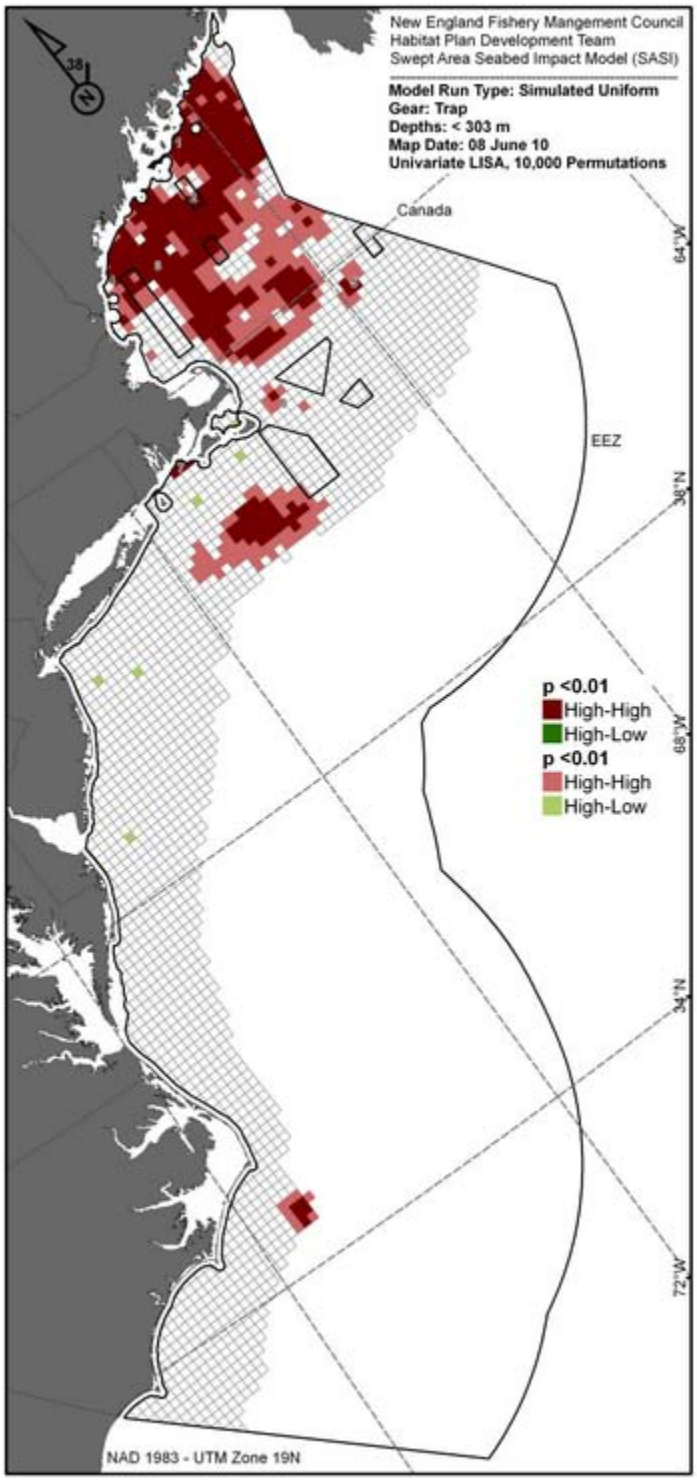
Map 4 – Maps of Z∞ clusters (high-high and high-low only) for longline gear



Map 5 – Maps of Z∞ clusters (high-high and high-low only) for gillnet gear



Map 6 – Maps of Z∞ clusters (high-high and high-low only) for trap gear



Results - Z∞ in present and proposed management areas

The EAP results for otter trawl are presented below in summary tables, histograms, and maps. The summary tables list each tested area, its size, area weighted mean Z∞, the permutation percentile (i.e. where it falls in the distribution of same sized areas), the number of same sized areas with higher area weighted mean Z∞, and the 99th percentile area weighted mean Z∞ value. The histograms (labeled by area) show each area's permutation percentile visually, indicating the position of the tested areas in the respective EAP distribution (dashed line), the area weighted mean Z∞, and permutation percentile (P%). The maps show the locations of permutation areas with area weighted mean Z∞ greater than or equal to the tested areas (open circles), and the 99th percentile of the area weighted mean Z∞ permutation values (gold filled circles). The gold circles which indicate the locations of the highest 100 (top 1%) area weighted mean Z∞ permutation values.

With the exception of the CAII EFH Closed Area, most of the Georges Bank areas have fairly low percentile values, whereas the Gulf of Maine areas have much higher percentile values. Because of the spatial clustering in the underlying data, smaller areas can achieve higher average **Z∞** values. While the EAP analysis is generally intended to be a retrospective evaluation of current EFH management areas, this result may have implications for the design of future EFH management areas.

Table 3 – Trawl EAP results with tested areas, their size, area weighted mean Z∞ permutation percentile (P%) and number of permutation areas with area weighted mean Z∞ ≥ than the tested area.

Closed Area		Tested area result			Permutation results		
		km²	AWM z∞	Sum z∞	P%	Areas with ≥ Mean z∞	99th %
Groundfish (Amendment 13) EFH Closed Areas	Cashes L. EFH GF	443	51.437	588.06	96.00%	400	57.661
	Jeffreys B. EFH GF	499	57.667	510.13	99.10%	90	57.101
	WGOM EFH GF	2272	50.114	1777.55	95.10%	490	52.63
	CAII EFH GF	641	49.425	844.79	92.20%	780	56.567
	CAI N. EFH GF	1937	45.186	1287.93	12.80%	8721	53.15
	CAI S. EFH GF	584	46.085	609.67	50.30%	4970	57.101
	NLCA EFH GF	3387	46.787	2205.24	56.80%	4320	51.884
Multispecies mortality closures	Cashes L. Closed Area	1373	48.505	1186.07	83.00%	1700	54.314
	WGOM Closed Area	3030	49.874	2362.75	94.70%	530	52.037
	Closed Area II	6862	46.338	4354.63	41.10%	5891	50.912
	Closed Area I	3939	45.891	2556.1	34.20%	6581	51.589
	Nantucket Lightship	6248	46.466	4002.39	46.30%	5371	51.015

Figure 2 – Trawl EAP histogram – Cashes Ledge Closed Area.

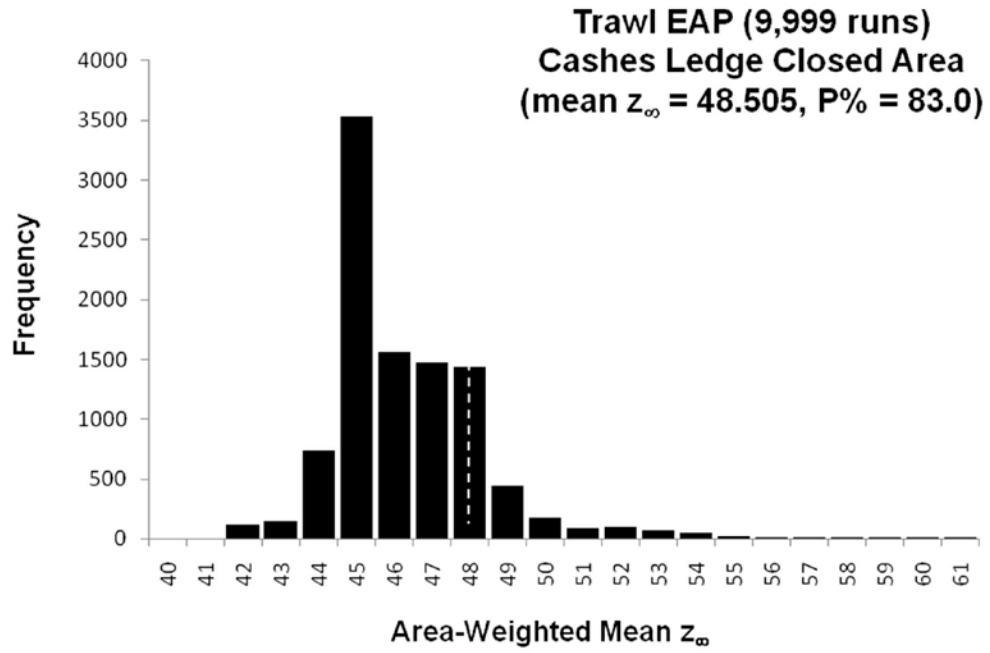


Figure 3 – Trawl EAP histogram – Cashes Ledge EFH Closure.

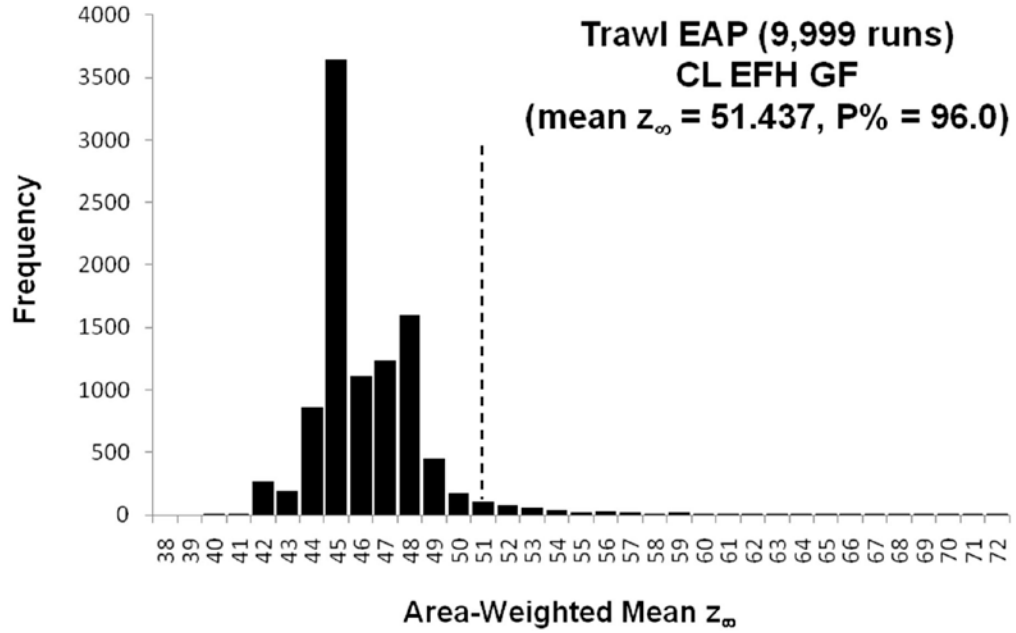


Figure 4 – Trawl EAP histogram – Jeffrey's Bank EFH Closure.

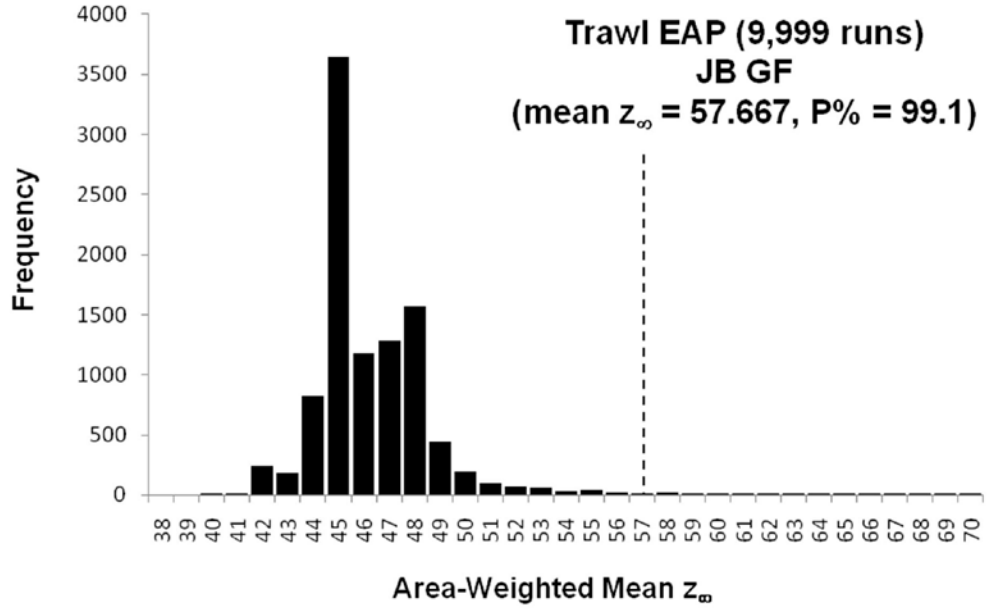


Figure 5 – Trawl EAP histogram – Western Gulf of Maine Closed Area.

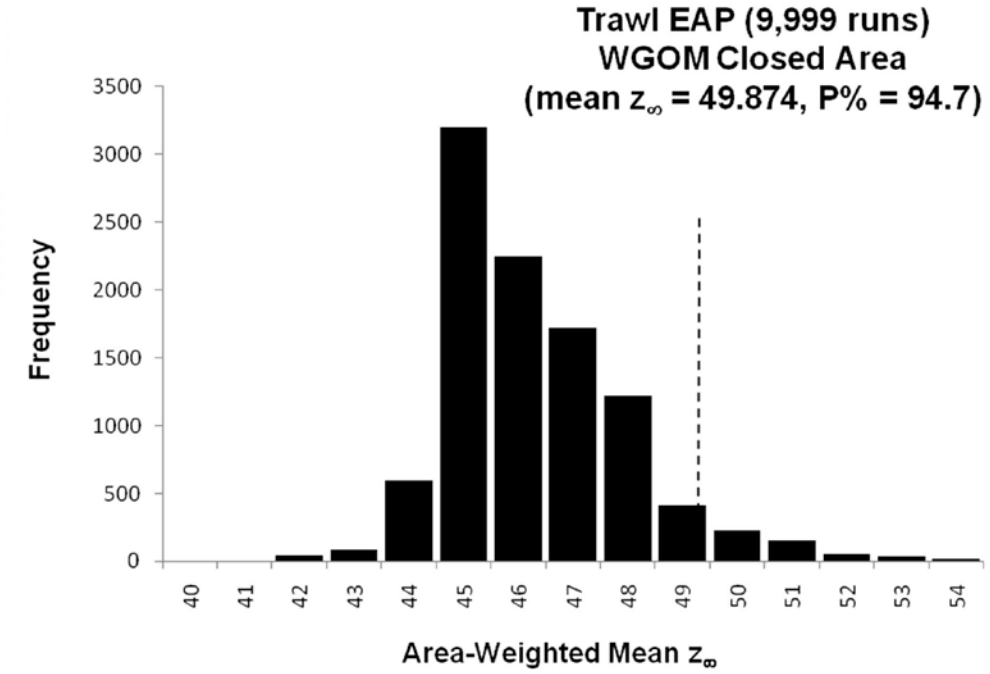


Figure 6 – Trawl EAP histogram – Western Gulf of Maine EFH Closure.

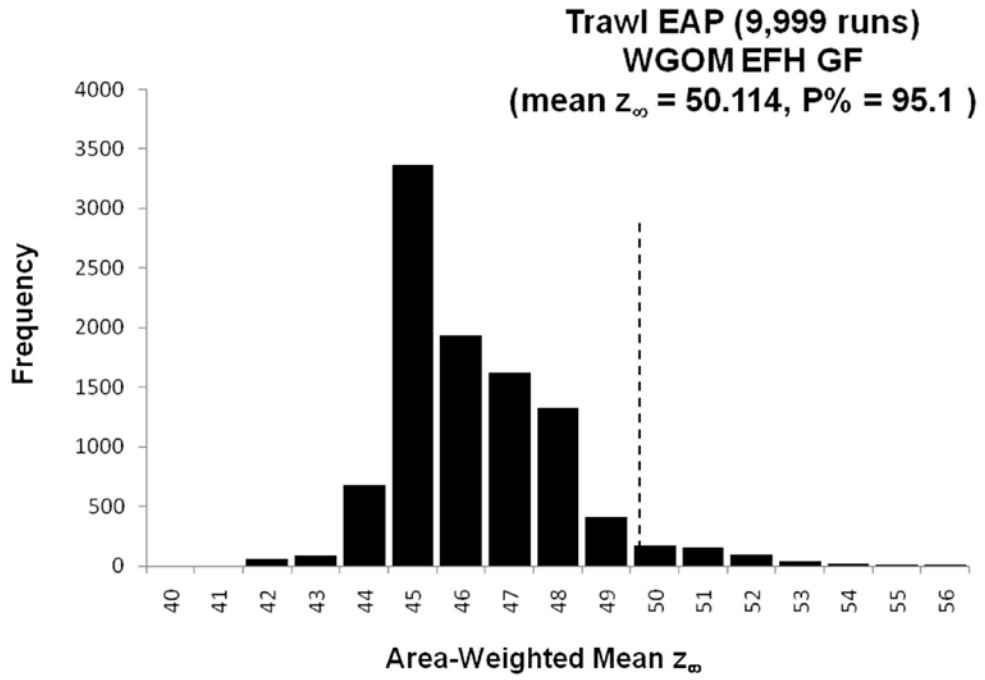


Figure 7 – Trawl EAP histogram – Closed Area II.

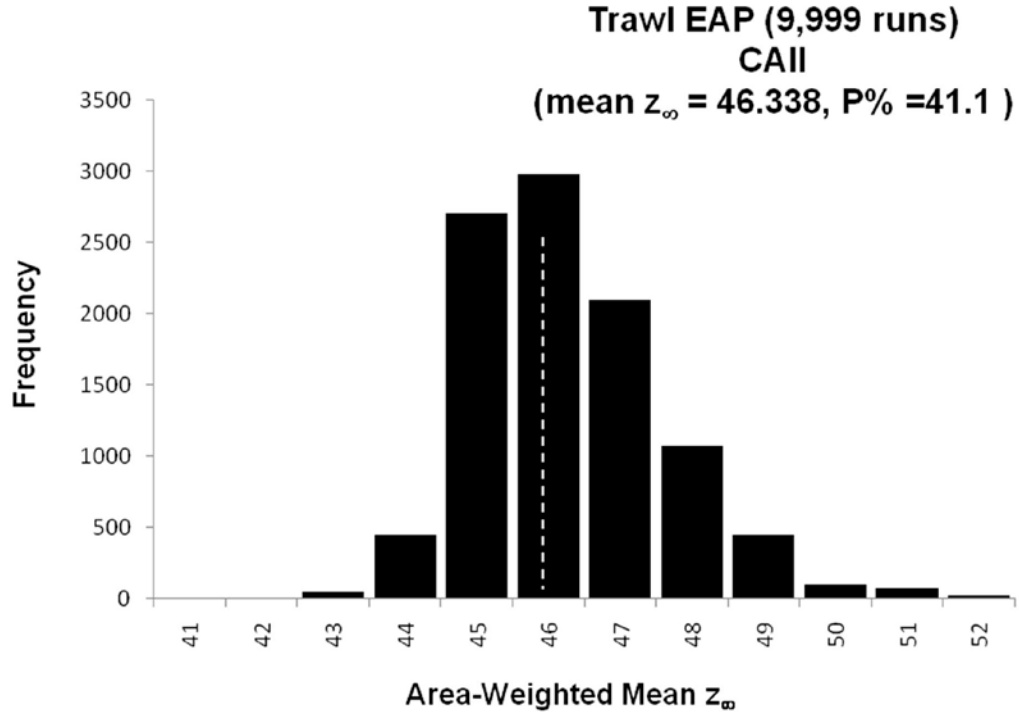


Figure 8 – Trawl EAP histogram – Closed Area II EFH Closure.

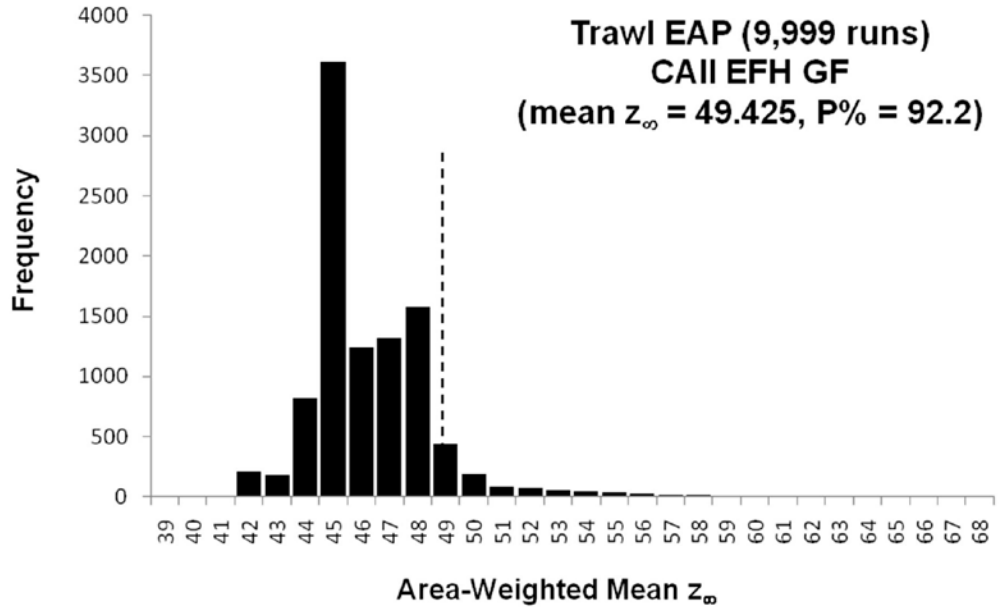


Figure 9 – Trawl EAP histogram – Closed Area I.

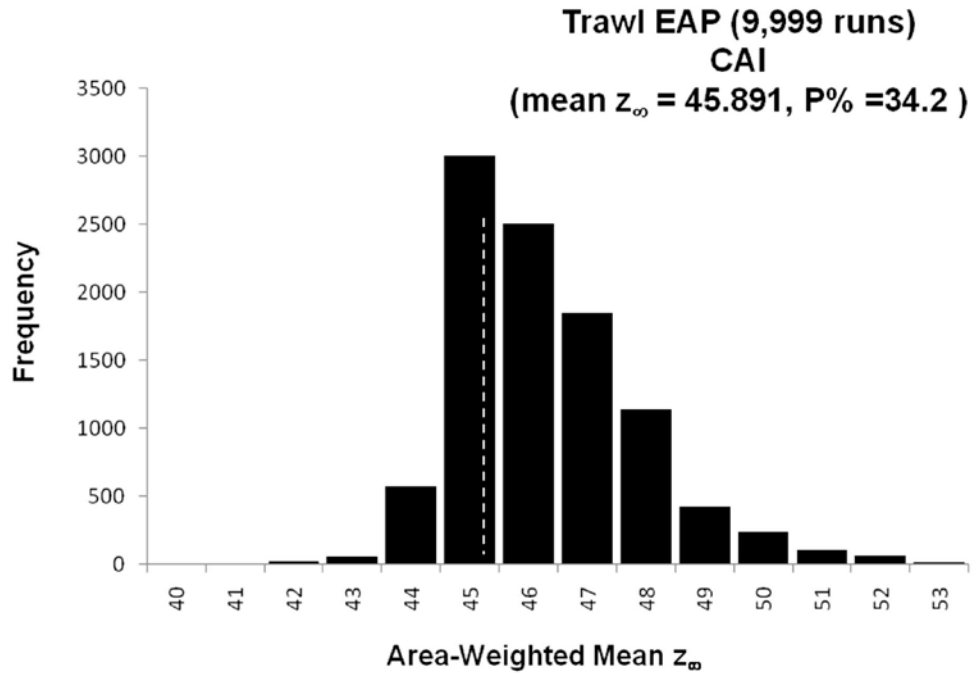


Figure 10 – Trawl EAP histogram – Closed Area I N EFH Closure.

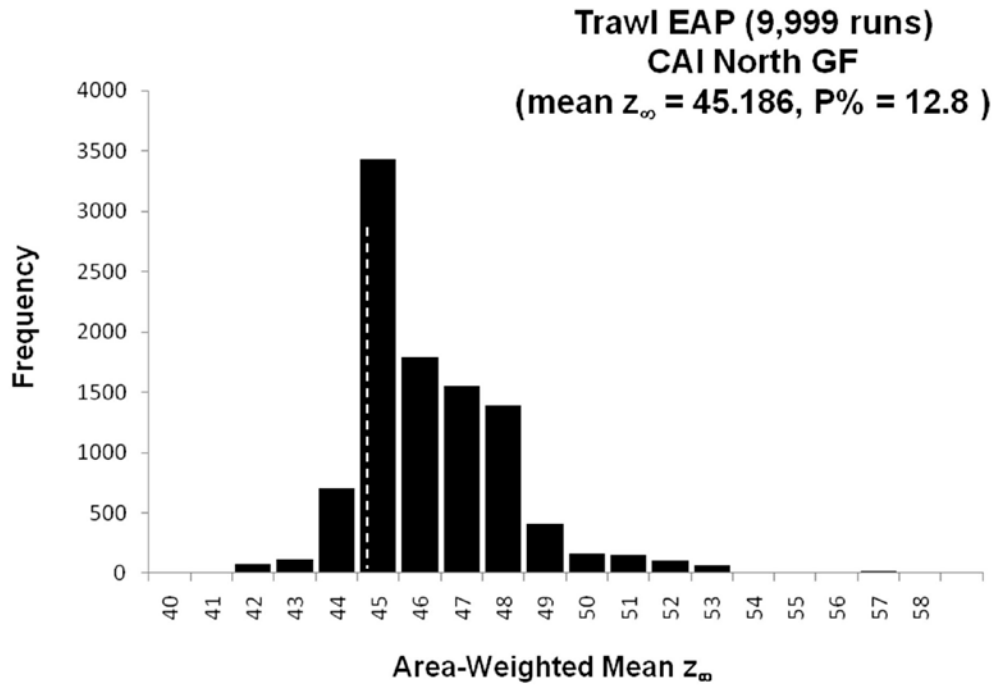


Figure 11 – Trawl EAP histogram – Closed Area I S EFH Closure.

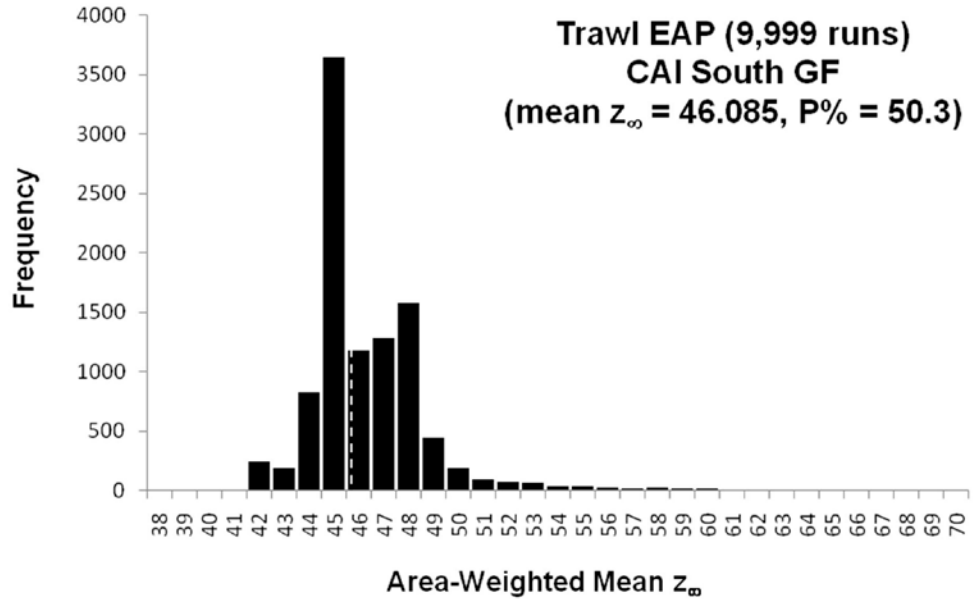


Figure 12 – Trawl EAP histogram – Nantucket Lightship Closed Area.

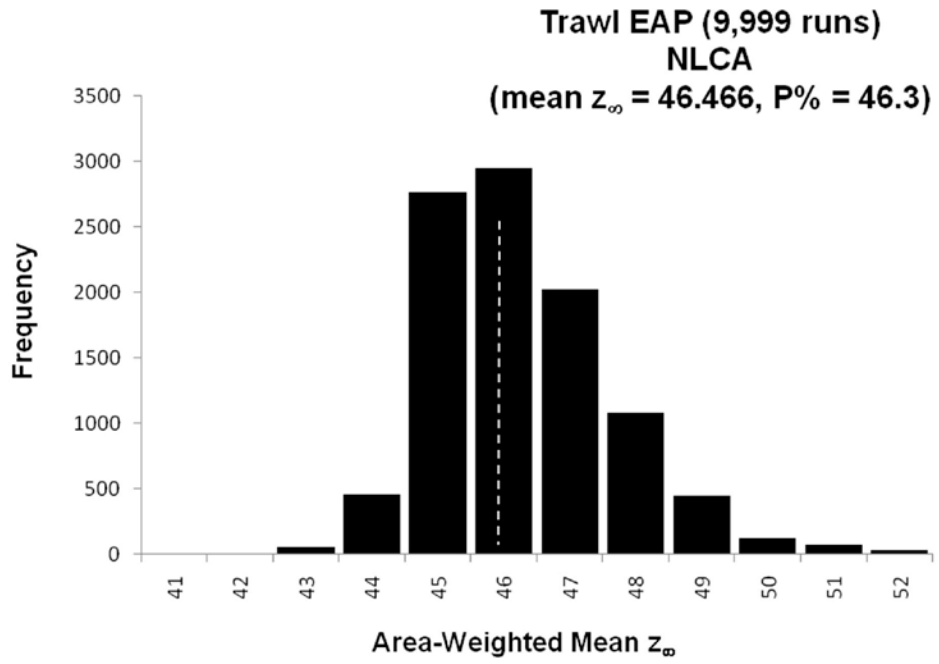
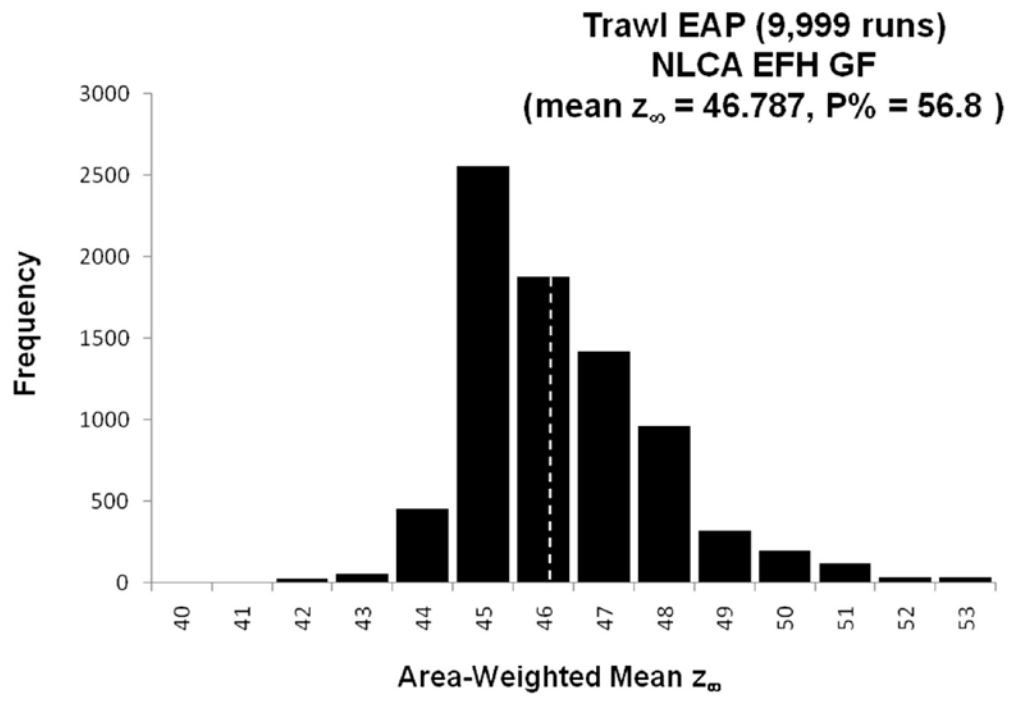
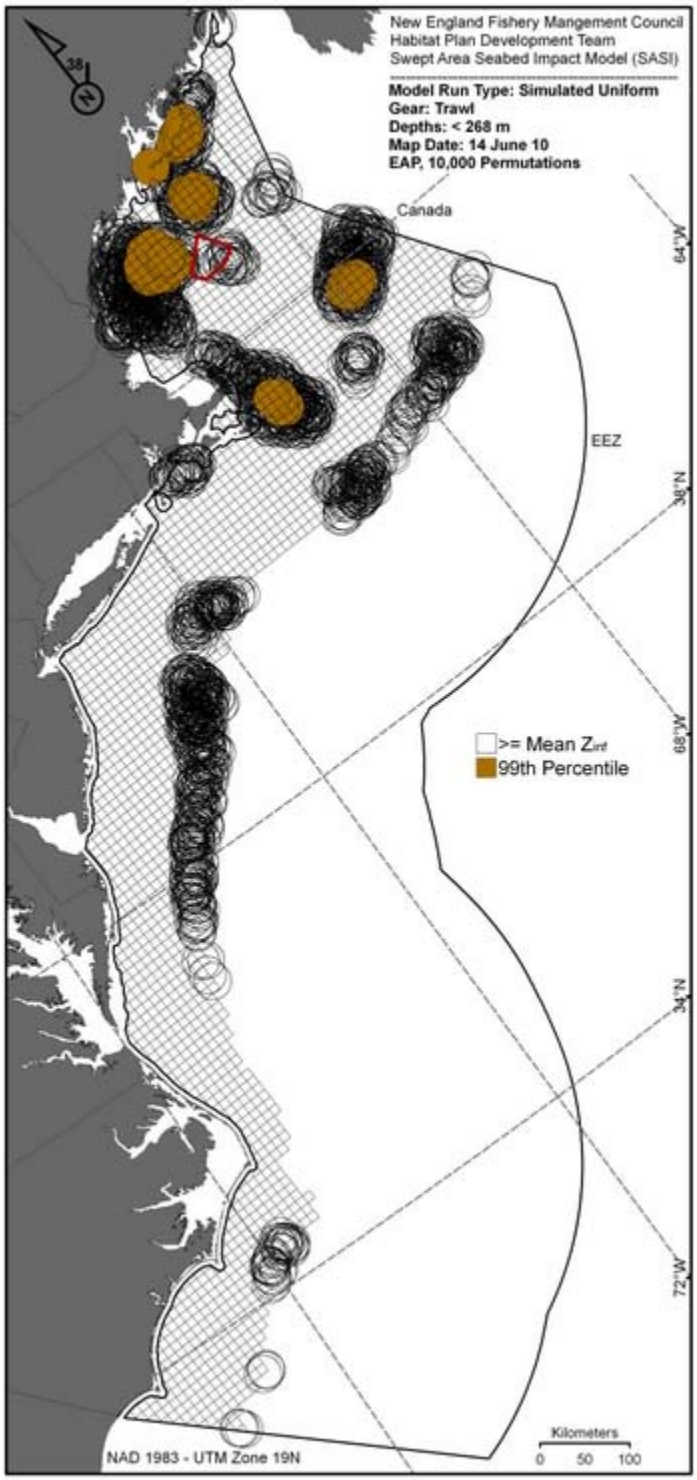


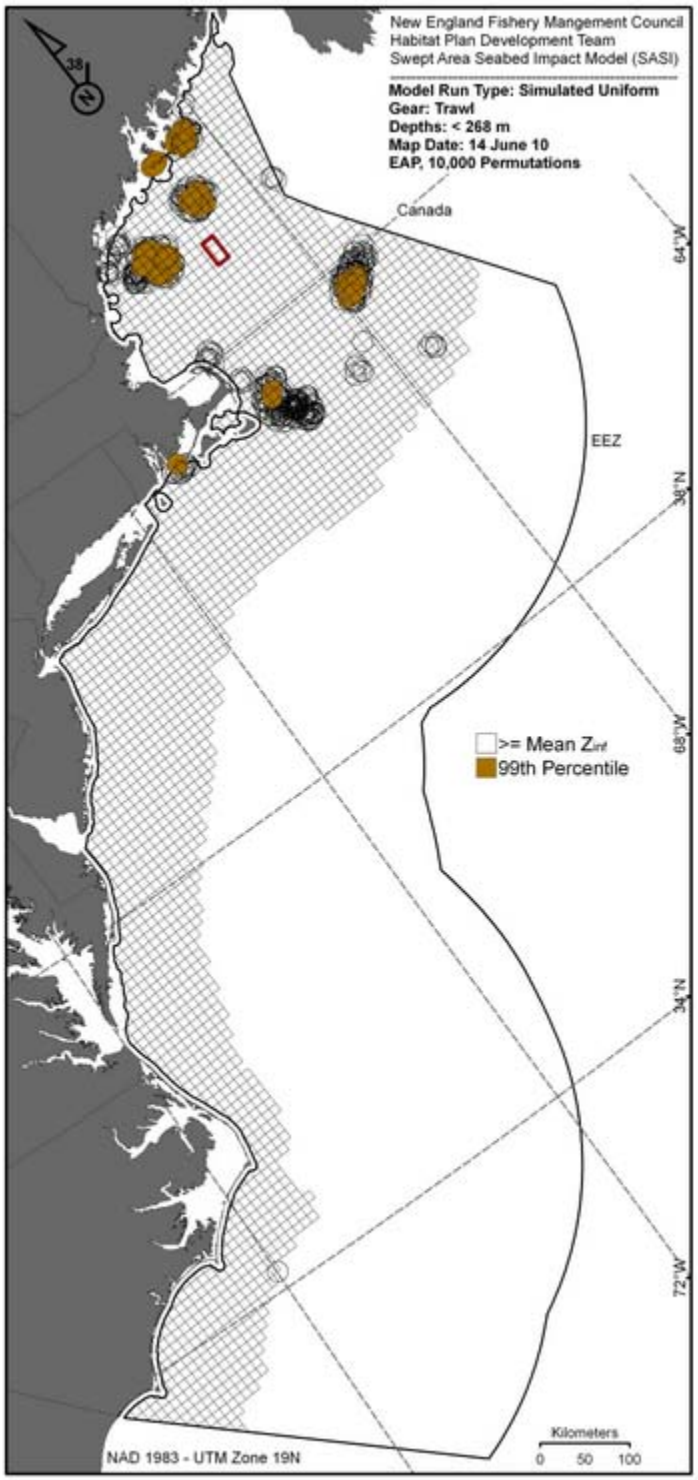
Figure 13 – Trawl EAP histogram – Nantucket Lightship Closed Area EFH Closure.



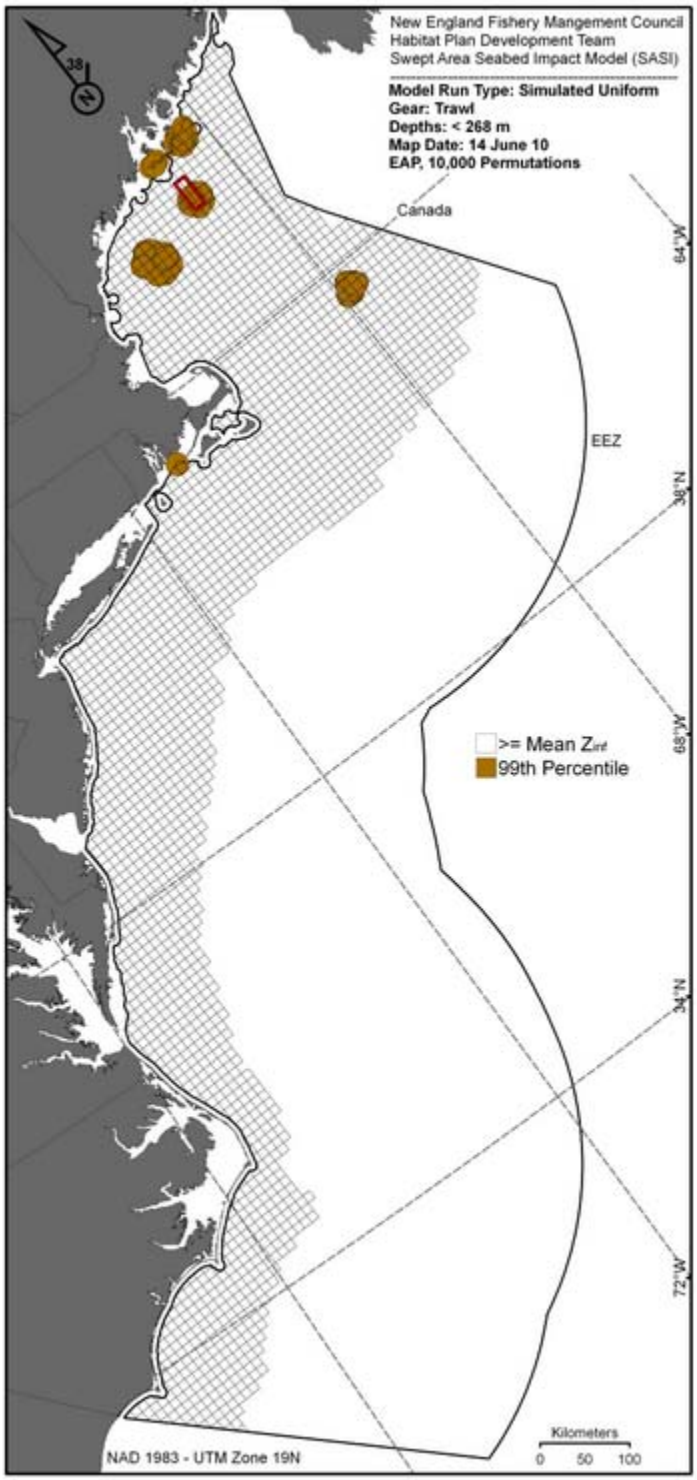
Map 7 Trawl EAP map – Cashes Ledge. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



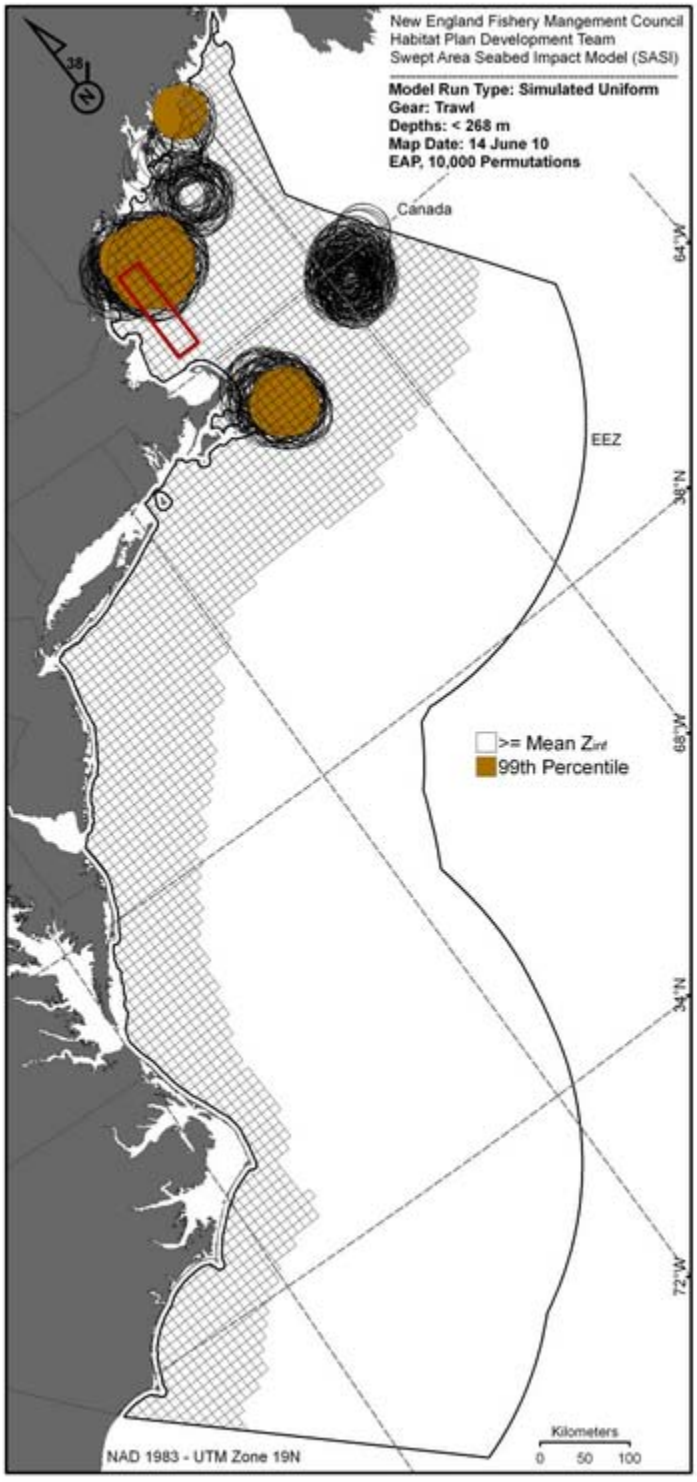
Map 8 Trawl EAP map – Cashes Ledge GF EFH closure. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



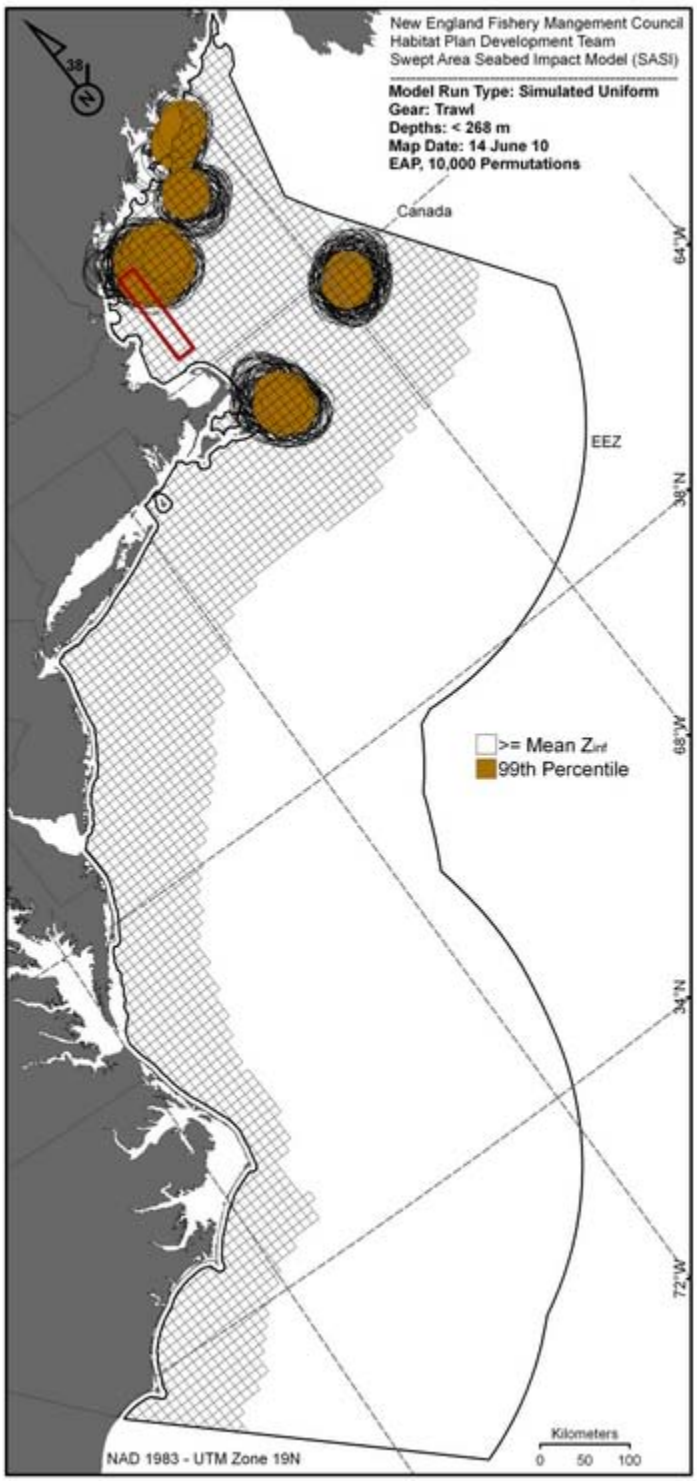
Map 9 Trawl EAP map – Jeffrey's Bank. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



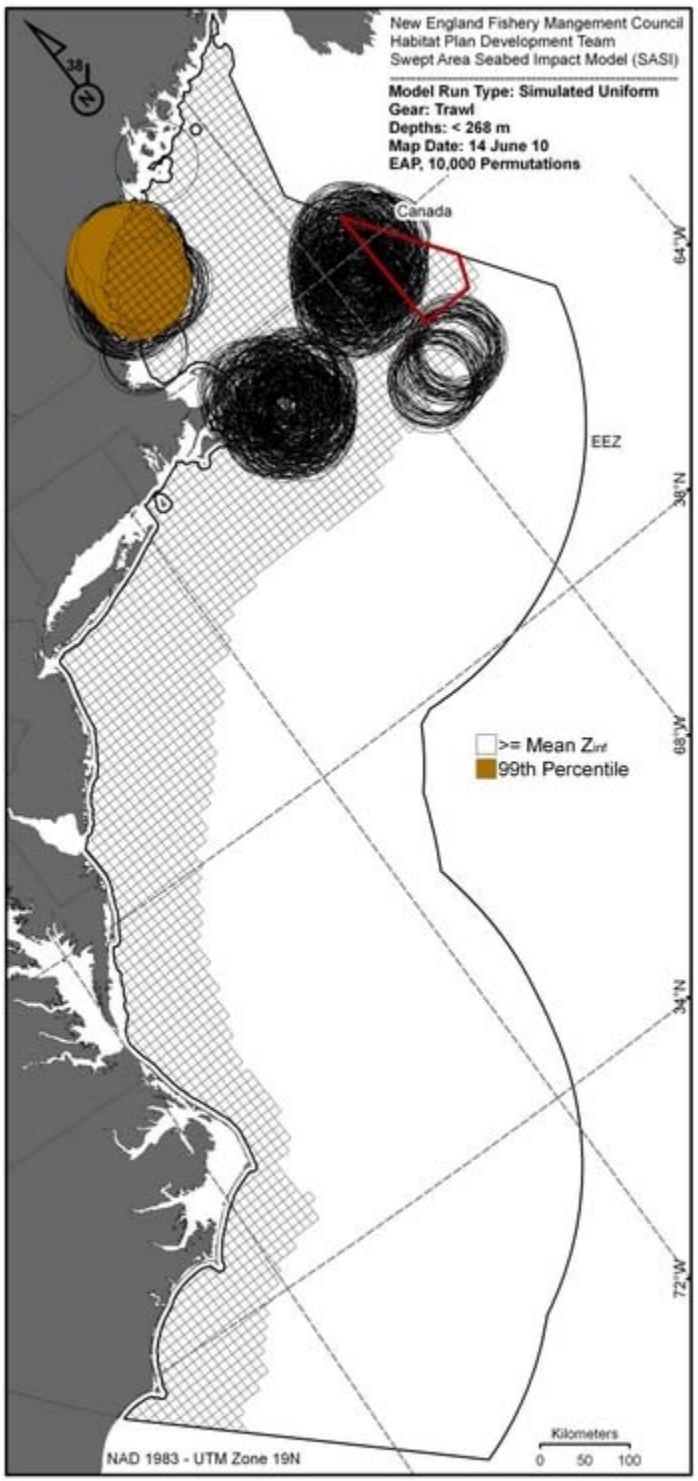
Map 10 Trawl EAP map - WGOM. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



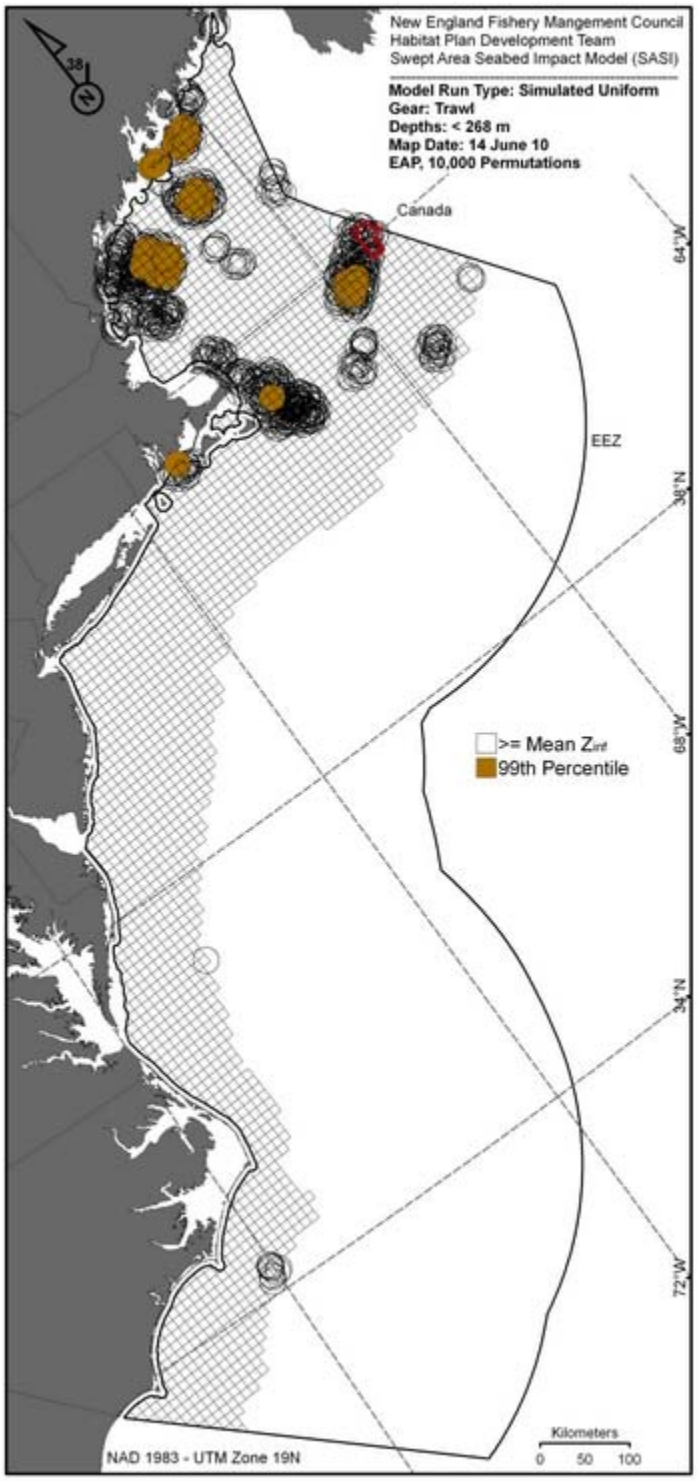
Map 11 Trawl EAP map – WGOM GF EFH. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



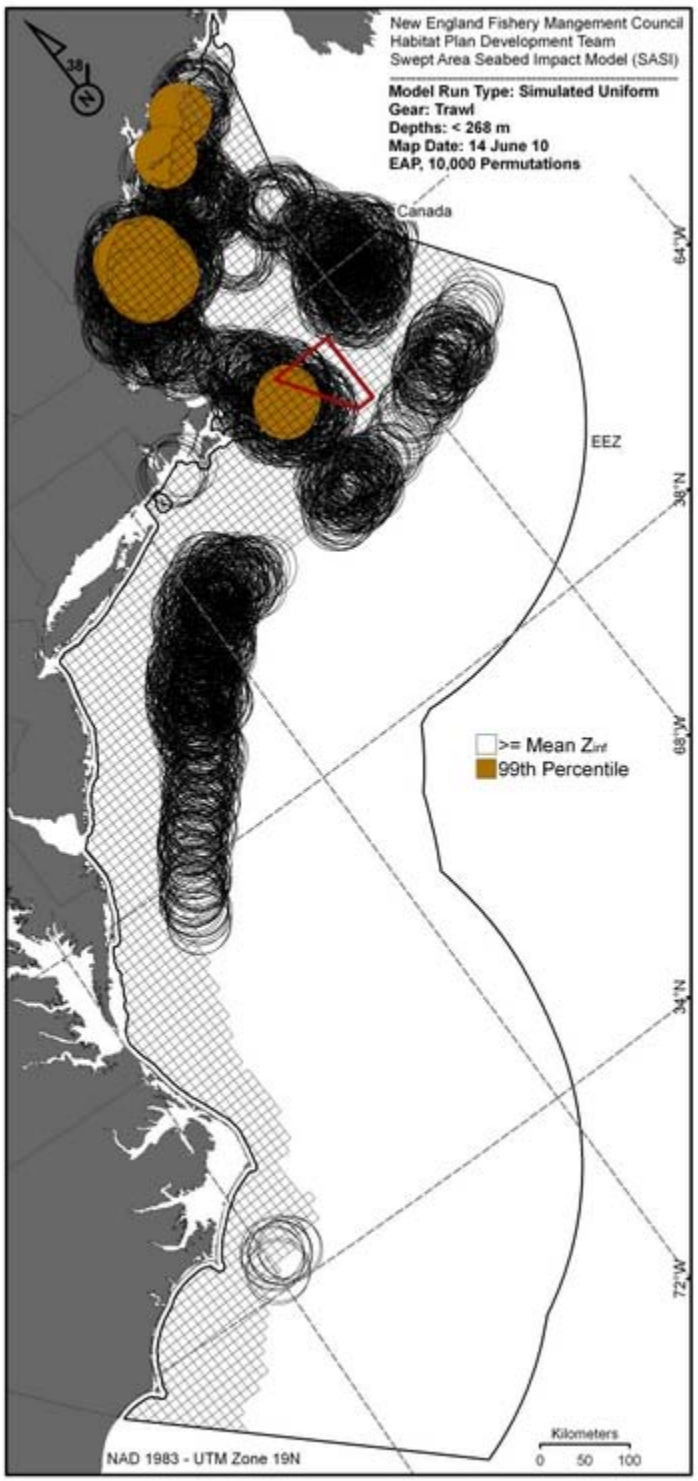
Map 12 Trawl EAP map - CAII. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



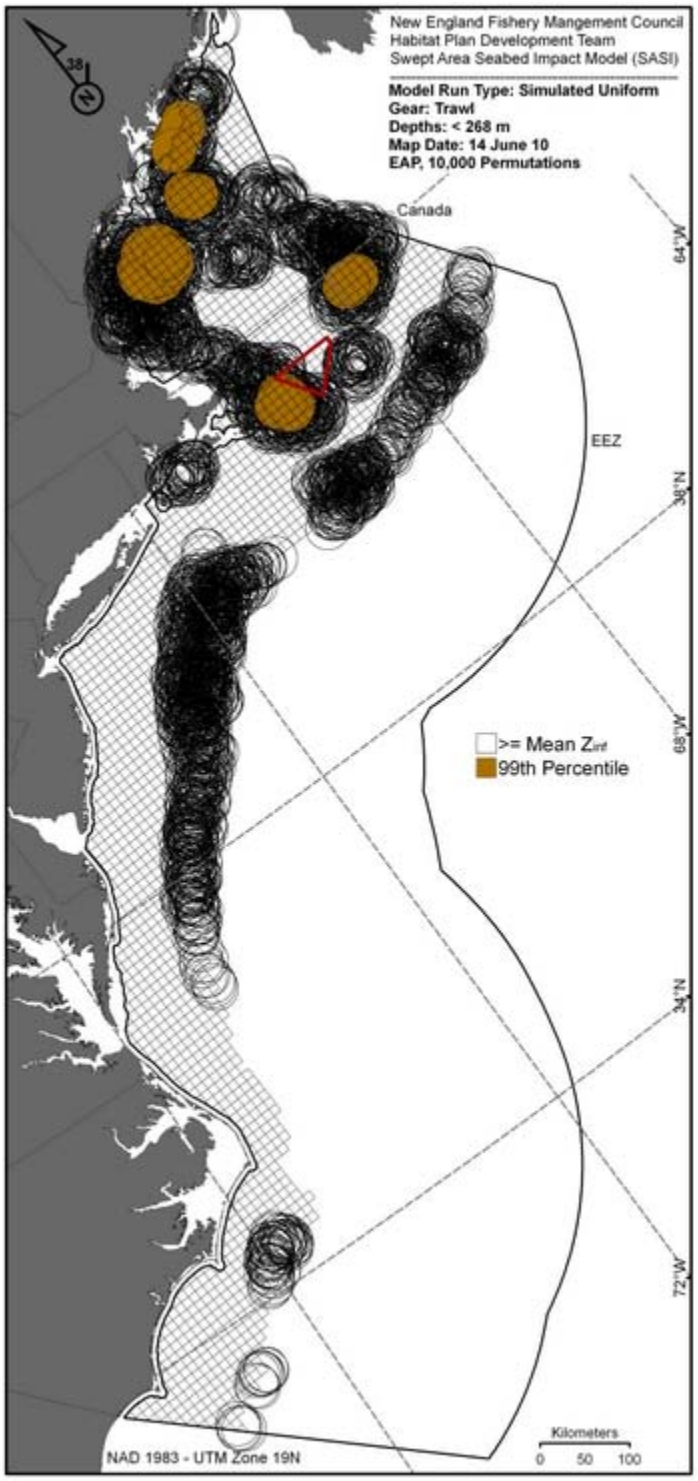
Map 13 Trawl EAP map – CAII GF EFH. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



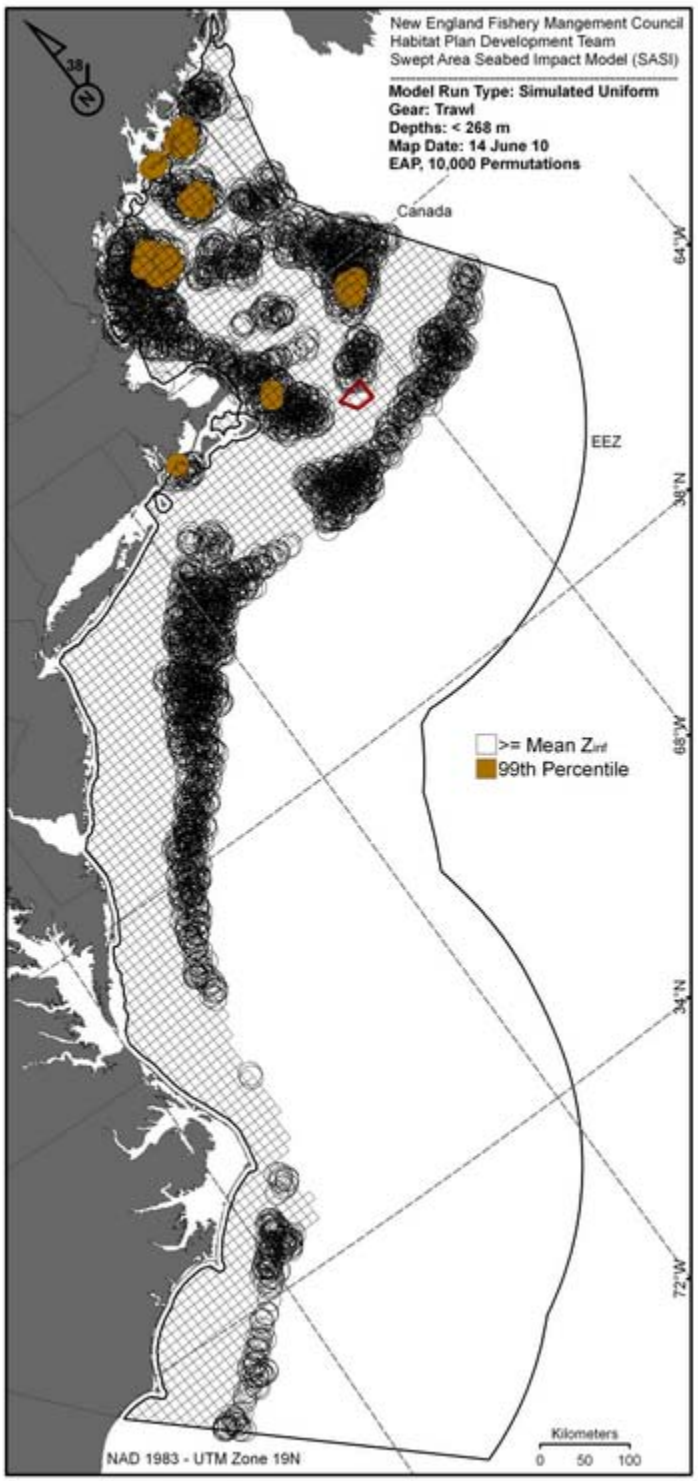
Map 14 Trawl EAP map – CAI. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



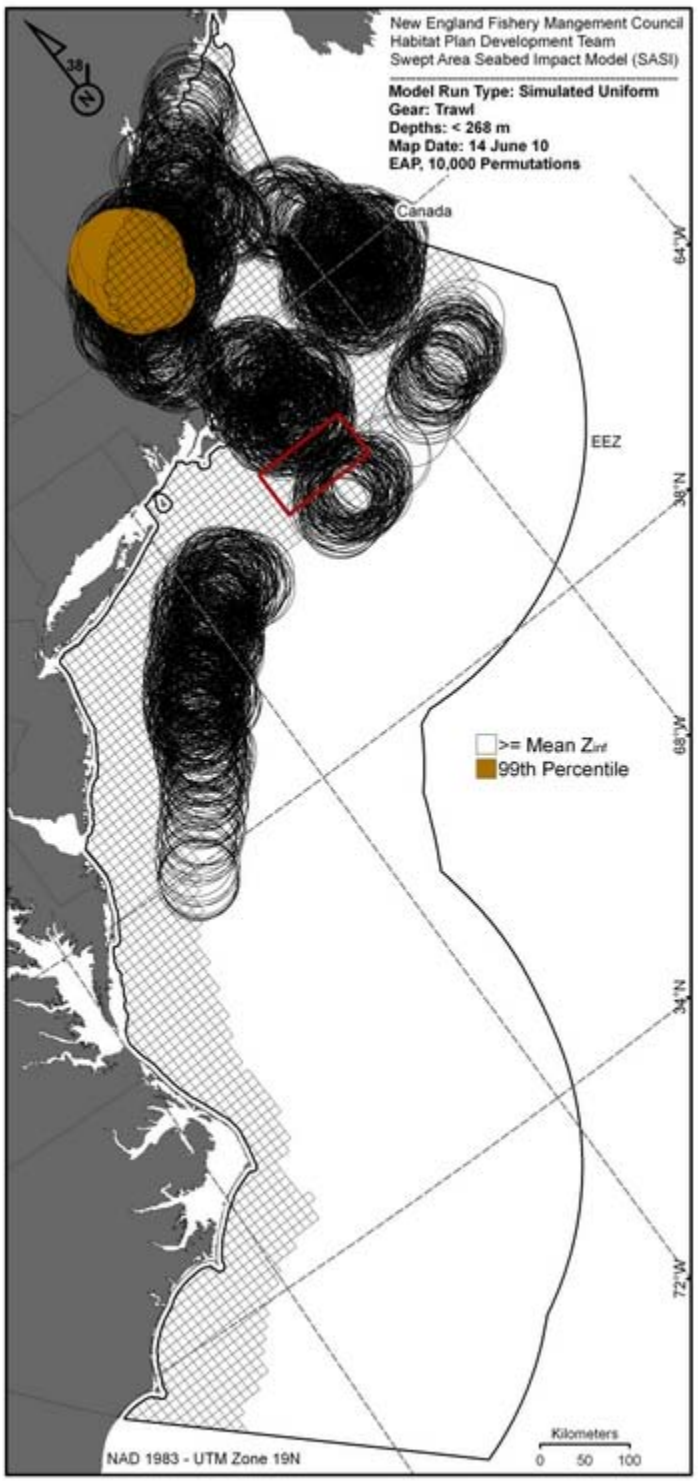
Map 15 Trawl EAP map – CAI N GF EFH. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



Map 16 Trawl EAP map – CAI S GF EFH. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



Map 17 Trawl EAP map – NLCA. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.



Map 18 Trawl EAP map – NLCA GF EFH. Open circles are permutation areas with area weighted mean Z∞ ≥ than the tested area, and orange circles show the locations of the highest 100 area weighted mean Z∞ permutation values.