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Size composition and indices of relative abundance of the smooth dogfish (*Mustelus canis*) in the near shore Atlantic Ocean

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Executive Summary

The Northeast Area Monitoring and Assessment Program (NEAMAP) has been sampling fish populations within the near coastal Atlantic waters since fall 2007. NEAMAP data for smooth dogfish (*Mustelus canis*) collected during fall cruises from 2007-2012 showed that this species was encountered frequently (5317 animals collected over the time-series), year-specific overall catches were highest in 2007, 2009, 2012, respectively, state-specific overall catches were highest in Delaware, New Jersey, and New York, respectively, and the sex ratio of captured animals was approximately equal (49.7% female, 50.3% male). Trends in nominal and stratified sampling indices of relative abundance were virtually identical showing the highest values in 2007 followed by a slightly decreased and variable pattern thereafter. The generalized linear model (GLM) based index of relative abundance was more variable and showed a dome-shaped pattern across years. Estimated coefficients of variation (CVs) for all indices were fairly low and generally less than 0.4 for all years.

Background

Northeast Area and Monitoring Assessment Program (*NEAMAP*)

The NEAMAP trawl survey is a fisheries-independent sampling program developed by the Atlantic States Marine Fisheries Commission (ASMFC) in response to concerns regarding survey coverage and sampling intensity in the inshore waters (<27 m) of the mid-Atlantic Bight. Specifically, between New York and North Carolina, New Jersey is the only state that regularly monitors fish stocks in near coastal oceanic waters. The National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC) bottom trawl survey historically sampled the near shore waters of the mid-Atlantic Bight until recently, but the sampling intensity (~1 station per 90 nm^2) was appreciably lower than that typically implemented by fisheries-independent surveys operating in estuarine waters in this region and by state coastal ocean surveys in New England (~1 station per 20-50 nm^2). Further, since 2009 the NEFSC survey has been conducted from the *FSV Henry B. Bigelow*, which is much larger than their previous platform, and the draft restrictions of this boat preclude sampling in waters less than approximately 18 m. The NEFSC has therefore been forced to abandon their sampling of the inshore waters of the mid-Atlantic Bight.

The near shore coastal ocean waters of the Mid-Atlantic region serve as an important foraging, spawning, and nursery area for a variety of fishes and invertebrates that support valuable commercial and recreational fisheries. If left unaddressed, the aforementioned gap in sampling coverage by fisheries-independent monitoring programs would at the very least have resulted in major ‘unknowns’ for future stock assessments. As noted, the ASMFC recognized this gap in sampling coverage and its potential consequences, and developed the NEAMAP near shore trawl survey in response; this survey has been structured to provide inputs for both single-species and multispecies stock assessments. The Virginia Institute of Marine Science (VIMS) has been responsible for executing the field, laboratory, and data analysis components of NEAMAP since its inception. VIMS conducted a successful pilot cruise for NEAMAP in the autumn of 2006. As a result, the survey area was expanded in 2007 to include Block Island Sound and Rhode Island Sound (southern New England), two areas where additional sampling was also desired.

This working paper summarizes the available NEAMAP data for smooth dogfish in support of a peer-reviewed stock assessment (SEDAR 39). Specifically, summaries of sampling effort, trawl catches, sex-specific length frequencies, and three differently derived indices of relative abundance are provided based on data collected from fall cruises, 2007-2012.

Material and Methods

Field sampling

Survey characteristics

Timing: The fall NEAMAP typically takes place from mid-September to mid-October in an effort to coincide with the NEFSC fall survey in the mid-Atlantic and southern New England. Since species of management interest are concentrated in the NEAMAP survey area during the early fall, and it is considered particularly important to obtain simultaneous cross-shelf samples during this season.

Sampling area & sites: All sampling occurs between Martha’s Vineyard, MA and Cape Hatteras, NC (Figure 1). West and south of Montauk, NY, sampling is conducted in waters between the 6 m and 18 m depth contours. In Rhode Island Sound and Block Island Sound, sites are sampled between the 18 m and 36.5 m contours. Approximately 150 stations (~1 per 30 nm^2) are sampled during each cruise. Sites are selected according to a stratified random design, with strata defined by latitudinal/longitudinal regions and depth. Regional strata are closely aligned to historical NMFS designations, which generally correspond both to state boundaries and to estuarine outflows. Within each region, depth strata have been established to assure sampling throughout the depth profile and sufficient inshore-to-offshore coverage. The total NEAMAP sampling area is divided into approximately 2,000 sampling cells measuring 1.5nm x 1.5nm each; these cells represent potential sampling units. The number of sites allocated to a given region/depth stratum for each cruise is roughly proportional to the surface area of that stratum. Flexibility is allowed with regard to the starting position and track of each tow, since logistical considerations (known ‘hangs,’ surface traffic, current, etc.) can at times influence the exact tow track. A valid tow is one that remains within the cell and maintains the appropriate depth profile.

Vessel: NEAMAP survey cruises are performed in cooperation with Captain James Ruhle aboard the *F/V Darana R*. This particular partnership has worked extremely well and the captain and crew are at least as responsible for the successful execution of the previous surveys as are the scientific personnel.

Fishing System: To assure comparability with NEFSC surveys conducted from the *FSV Henry B. Bigelow*, NEAMAP selected the bottom trawl developed for the NEFSC by the joint Mid-Atlantic/New England Trawl Survey Advisory Panel. A full description of the net design, along with technical plans, is available in the NEAMAP peer review documents (Bonzek et al. 2008). This fishing system was successfully used during the NEAMAP pilot cruise and all subsequent full-scale surveys to date. The NEAMAP net/door combinationhas performed as intended with respect to geometry and consistency within tows, among tows, and across surveys. It also appears to collect a representative sample of a wide variety of species, both managed and unmanaged. With respect to trawl monitoring, the NEAMAP survey uses a *Netmind* system manufactured by *Northstar Technical, Inc*. During fishing operations, acoustic sensors provide near-real-time measures of gear performance, enabling the Captain and crew to adjust tow speeds and scope to obtain the optimum geometry of the net. Equally important, these data are saved to computer files which, when combined with tow distance information from the GPS, allow subsequent data analyses to be performed on an area-swept basis.

Sampling Operations: All fishing operations are conducted during daylight hours. Each tow is 20 minutes in duration, with tow duration measured as the time from which the winch brakes are engaged to the time that the brakes are released. The target vessel speed over ground for each tow is 3.0 kts. Flume tank and field testing have demonstrated that the fishing system performs well at this speed, and that performance is also acceptable above and below that speed. The tow duration and speed used by NEAMAP match those used by the NEFSC Survey on the *FSV Henry B. Bigelow*.

At each station, several parameters are recorded. These include (but are not limited to):

- *Station identification parameters* - date, station number, and stratum.
- *Tow parameters* - beginning and ending tow location, vessel speed and direction, engine RPMs, duration of tow, water depth, and tidal stage.
- *Gear identification are operational parameters* - net type are number, door type are numbers, tow warp length, trawl door spread, wing spread, headline height are bottom contact.
- *Atmospheric are weather data* - air temperature, wind speed are direction, barometric pressure, relative humidity, general weather state, and sea state.
- *Hydrographic data* - water temperature, salinity, dissolved oxygen (each recorded at 2m increments between surface and bottom).

After the completion of each tow, the catch is sorted by species and modal size groups. For species of management interest, a subsample from each size group is selected for 'complete processing'. Previous analyses have shown that a subsample of three to five individuals per species/size group per tow is sufficient for this full processing and in accordance with cluster sampling. The data collected from each of these subsampled specimens include length, weight (whole and/or eviscerated), sex (macroscopic), and maturity stage (macroscopic). Stomachs are removed and those containing prey are preserved onboard for subsequent examination by survey personnel at the VIMS shore-based laboratory. Otoliths or other appropriate ageing structures (e.g., opercles, vertebrae, etc.) are also taken for age determination in the laboratory, although smooth dogfish vertebrae have yet to be processed.

Statistical analysis

To investigate simple patterns in survey catches, summaries were developed for each year and state within the NEAMAP sampling frame. Yearly length frequencies based on expansion factors applied to subsampled animals were generated for males, females, and sexes combined to evaluate size distributions of captured smooth dogfish. Nominal indices of relative abundance by year were calculated as the arithmetic mean number of smooth dogfish captured per-standard-tow-area, which was assumed to be 25,000 m^2. Associated coefficients of variation (CV_y) for the nominal indices were calculated as: $CV_y = se_y/\mu_y$, where se_y and μ_y are the estimated standard error and index values, respectively.

While nominal abundance indices can be useful for inferring general patterns and trends of relative abundance, most contemporary stock assessments utilize indices that are derived from either design-based theory (e.g., random stratified sampling, Cochran (1977)) or have been standardized through model-based procedures for the effects of hypothesized covariates. Accordingly, two additional NEAMAP smooth dogfish indices of abundance were generated, with the first making use of the survey stratification scheme and the second coming from a generalized linear model (GLM; McCullagh and Nelder 1989, Maunder and Punt 2004).

Annual stratified indices (I_y) of relative abundance were calculated as follows:

$$\hat{I}_y = \sum_{h=1}^{L} w_h \bar{d}_h \tag{1}$$

where for stratum h=1,…,L, w_h is the stratum weight (expressed as a proportion) and $\bar{d}_h$ is the mean number of smooth dogfish captured per-standard-tow-area, which was defined to be 25,000 m^2. CVs for the stratified indices were based on the equation:

$$\hat{var}(\hat{I}_y) = \sum_{h=1}^{L} w_h^2 \frac{N_h - n_h}{N_h - 1} s_h^2 \tag{2}$$

where for stratum h=1,…,L, N_h is the total number of potential sampling cells, n_h is the number of cells sampled, and s_h^2 is the sample variance.

The GLM-based indices were based on a negative binomial model applied to the counts of smooth dogfish per-tow, with an offset variable of $\log_e$(area-swept/25,000 m^2) to account for sampling differences among tows. The negative binomial distribution was chosen because it is designed for count data and the variance of catch plotted against the mean catch showed a quadratic pattern and was indistinguishable from the gamma distribution. The specific form of the negative binomial mass function is:

$$\Pr(y_i) = \frac{\Gamma(y_i + k)}{\Gamma(k) + \Gamma(y_i + 1)} \cdot \left(\frac{k}{\mu_i + k}\right)^k \cdot \left(1 - \frac{k}{\mu_i + k}\right)^{y_i} \tag{3}$$

where y_i is the i^{th} count observation and μ is the mean of the distribution which is modeled by a linear combination of covariates. Five fixed effects parameterizations were considered: model M_1 specified year, state, bottom salinity, dissolved oxygen, and temperature covariates, model M_2 specified year, state, salinity, and dissolved oxygen covariates, model M_3 specified year, state, and salinity covariates, model M_4 specified year and state covariates, and model M_5 specified just a year covariate. Interaction terms, particularly year*state, were not included due to instability of preliminary model fits in which they were considered. Year and state covariates were assumed to be categorical and the continuous variables were rescaled by subtracting their mean and dividing by their standard deviation. Variance inflations factors were calculated to assess colinearity among covariates. Akaike's Information Criterion (AIC) was used to discriminate among competing models such that (Akaike 1973, Burnham and Anderson 2002):

$$AIC = -2 \cdot \log_e(\hat{L}) + 2p \tag{4}$$

where $\hat{L}$ is the estimated value of the maximized likelihood for the fitted model and p is the number of estimated parameters. Models were compared using ΔAIC, where ΔAIC is the difference between the AIC values for each model and the smallest AIC within the candidate set. Generally, ΔAIC values between 0 and 2 are indicative of substantial empirical support for the fitted model, values between 4 and 7 are associated with models that have considerably less empirical support, and values > 10 suggest virtually no empirical support (Burnham and Anderson 2002). Predicted yearly indices of relative abundance were generated as marginal means (Searle et al. 1980) from the best fitting parameterization. Yearly CV_y values were estimated as $CV_y = se_y/\mu_y$. All statistical analyses were conducted using the software package R (version 3.1; R Development Core Team 2014). The R library 'MASS' was accessed for fitting the negative binomial GLMs.

Results and Discussion

The number of tows per fall NEAMAP cruise for which there was complete environmental data (bottom temperature, salinity, and dissolved oxygen) ranged from 115 (2012) to 154 (2009), with an average of 142 (Figure 3a). Proportions of those tows for which at least one smooth dogfish was encountered ranged from 0.48 (2008) to 0.77 (2009), with an average of 0.59 (Figure 3b). The total catch of smooth dogfish across the time-series was 5317 individuals, with the highest annual catch occurring in 2007 (Figure 4a), and the highest state-specific catch occurring in Delaware followed by New Jersey and New York (Figure 4b).

The sizes of smooth dogfish captured in the fall survey from 2007-2012 ranged from 36 to 96 cm precaudal length (PCL) for males (Figure 5a), 36 to 98 cm PCL for females (Figure 5b), and 32 to 100 cm for sexes combined (including unsexed animals; Figure 5c). In several years of the time-series, the length frequencies for both the males and females showed bimodal distributions centered approximately at 40 and 55 cm, respectively. Given that pupping occurs in late spring to early summer, the length frequencies within the first mode likely represent recruitment pulses.

AIC statistics strongly supported the model M_1 parameterization of the negative binomial GLM, which was the fully saturated model (Table 1). Relative to M_1, ΔAIC values for all other models were greater than 10 indication no comparably empirical support. Precision of the estimated parameters associated with model M_1 was generally good as most CVs were ranged between 0.2-0.4 (Table 2). Model M_1 was slightly overdispersed such that the ratio of the residual deviance and degrees of freedom was 1.99, however, plots of residuals against the covariates showed no serious undesirable patterns (Figure 6).

Nominal and stratified indices of relative abundance showed very similar patterns with the highest values occurring in 2007, followed by slightly decreased and variable values thereafter. In contrast, the GLM-based index showed more of a dome-shaped pattern over the time-series, with the highest index values occurring in 2009-2010 (Table 3; Figure 7a). The differing pattern of the GLM-index could be due to the influence of environmental covariates, since model M_1 included bottom temperature, salinity, and dissolved oxygen, in addition to a categorical spatial variable. Estimated CVs for the indices were generally less than 0.4 for all years and irrespective of the underlying analytical method supporting estimation (Table 3; Figure 7b).

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Table 1. Akaike's Information Criterion (AIC) and ΔAIC for negative binomial GLM models M_1, M_2, M_3, M_4, and M_5 fitted to fall smooth dogfish (*Mustelus canis*) NEAMAP survey data, 2007-2012. The environmental covariate measurements were taken at the bottom just prior to each trawl tow.

Smooth dogfish		
Model covariates	**Negative binomial**	
	AIC	**ΔAIC**
M_1: Year, State, Salinity, DO, Temp	4002.5	0.0
M_2: Year, State, Salinity, DO	4013.0	10.5
M_3: Year, State, Salinity	4015.9	13.4
M_4: Year, State	4026.0	23.5
M_5: Year	4237.6	235.1

Table 2. Estimates of parameters (β's), standard errors (SE), and coefficients of variation (CV) from the model M_1 parameterization of the negative binomial GLM fitted to smooth dogfish (*Mustelus canis*) NEAMAP survey data, 2007-2012. The year 2007 and the state of Delaware were the temporal and spatial reference levels, respectively.

	Negative binomial model M_1		
Parameter	**Estimate**	**SE**	**CV**
β_0	2.63	0.24	0.09
β_{2008}	-1.25	0.25	-0.20
β_{2009}	0.92	0.24	0.27
β_{2010}	0.78	0.29	0.38
β_{2011}	-0.38	0.22	-0.57
β_{2012}	0.03	0.25	9.45
β_{NC}	-3.59	0.30	-0.08
β_{VA}	-1.75	0.20	-0.12
β_{MD}	-0.93	0.26	-0.28
β_{NJ}	-0.54	0.21	-0.38
β_{NY}	-0.55	0.23	-0.41
β_{RI}	-2.48	0.25	-0.10
$\beta_{Salinity}$	-0.50	0.10	-0.21
β_{DO}	-0.22	0.08	-0.35
$\beta_{Temperature}$	0.32	0.09	0.28

Table 3. Estimated yearly index values and associated coefficients of variation (CV) for smooth dogfish (*Mustelus canis*) collected during fall NEAMAP cruises, 2007-2012. Indices are nominal catch-per-standard-tow-area, stratified catch-per-standard-tow-area, and predictions from the model M_1 parameterization of the negative binomial GLM with an offset variable of $\log_e$(area-swept/25,000 m^2).

	Nominal (catch/standard tow area)		**Stratified (catch/standard tow area)**		**GLM (catch with offset variable)**	
Year	**Index value**	**CV**	**Index value**	**CV**	**Index value**	**CV**
2007	11.4	0.33	12.1	0.61	5.6	0.23
2008	2.7	0.20	2.8	0.36	1.6	0.26
2009	7.6	0.14	7.1	0.22	14.1	0.21
2010	5.3	0.30	5.5	0.59	12.2	0.25
2011	4.4	0.19	4.2	0.33	3.8	0.21
2012	6.4	0.21	5.4	0.37	5.8	0.24

Figure 1. Map of NEAMAP sampling frame from Martha's Vineyard, MA and Cape Hatteras, NC . Red lines delineate regional strata and contour colors indicate depth strata within each regional stratum. Standard cruises are comprised of 150 stations allocated among depth/regional strata in proportion to surface area.

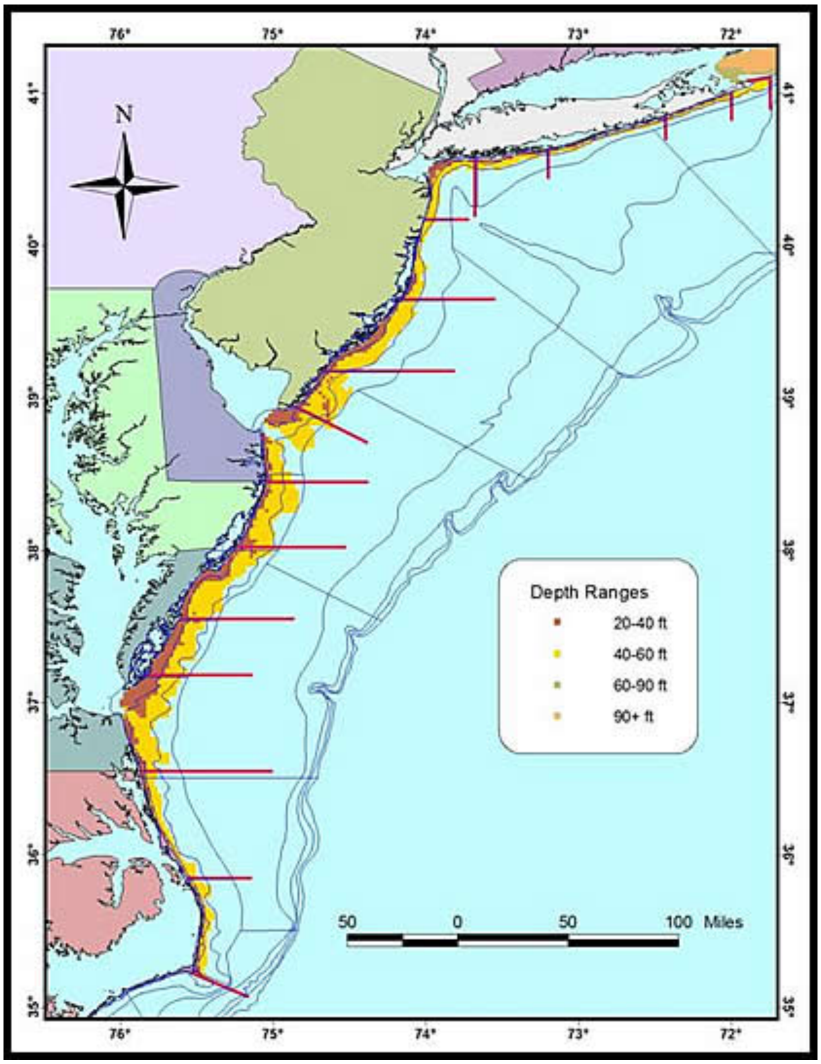


Figure 2. Plots of variance in catch as a function of mean catch (open circles) for smooth dogfish (*Mustelus canis*) data from fall NEAMAP cruises, 2007-2012, with overlaid Poisson (solid line), gamma (long-dashed broken line), and negative binomial (short-dashed line) distribution functions.

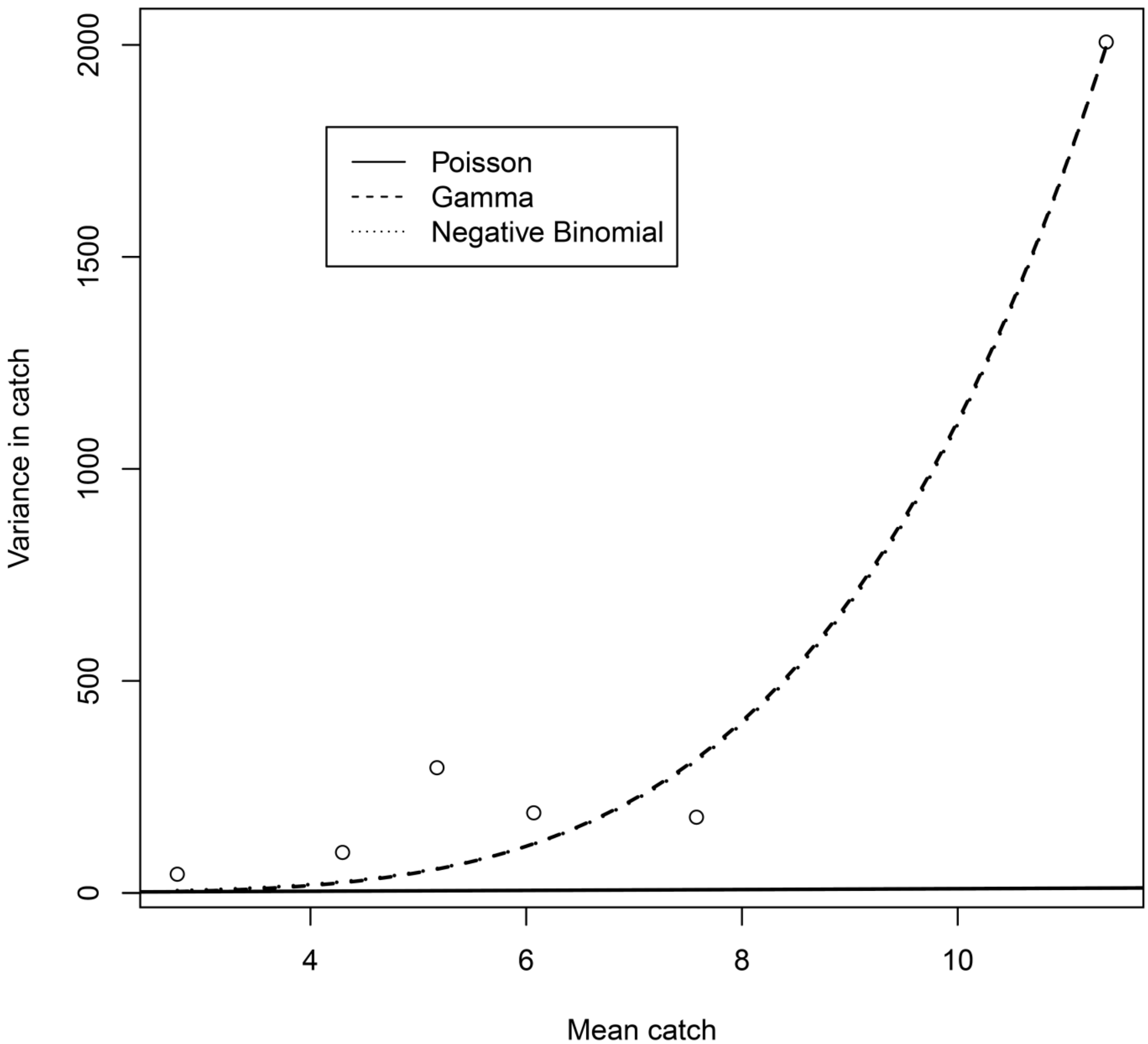


Figure 3. (a) NEAMAP sampling statistics from fall cruises, 2007-2012, expressed as number of tows-per-year, and (b) proportion of tows-per-year for which at least one smooth dogfish (*Mustelus canis*) was encountered. The gray lines represent the respective time-series averages.

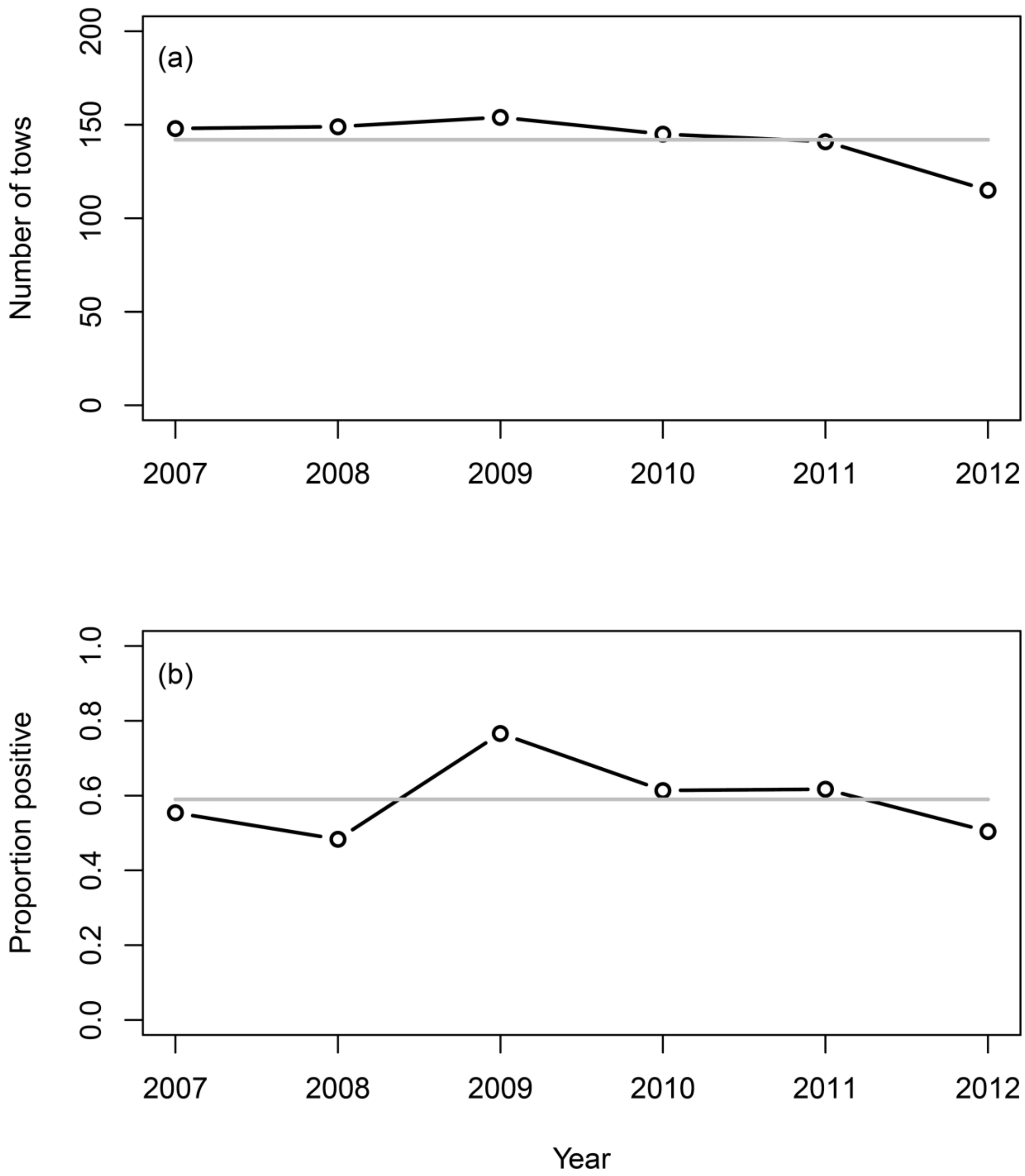


Figure 4. Total catch of smooth dogfish (*Mustelus canis*) from fall NEAMAP cruises, 2007-2012, by (a) survey year and (b) state within sampling frame.

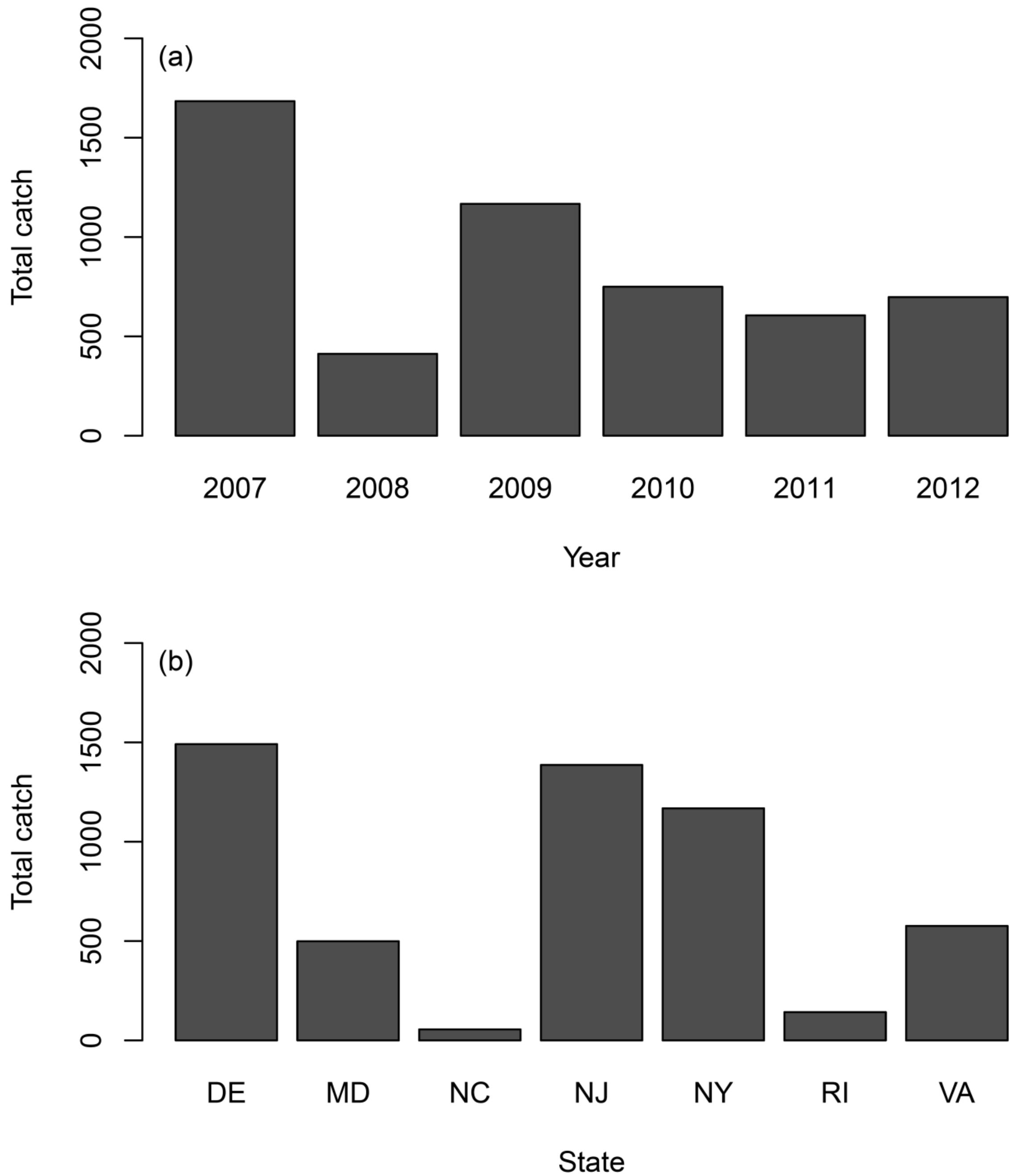
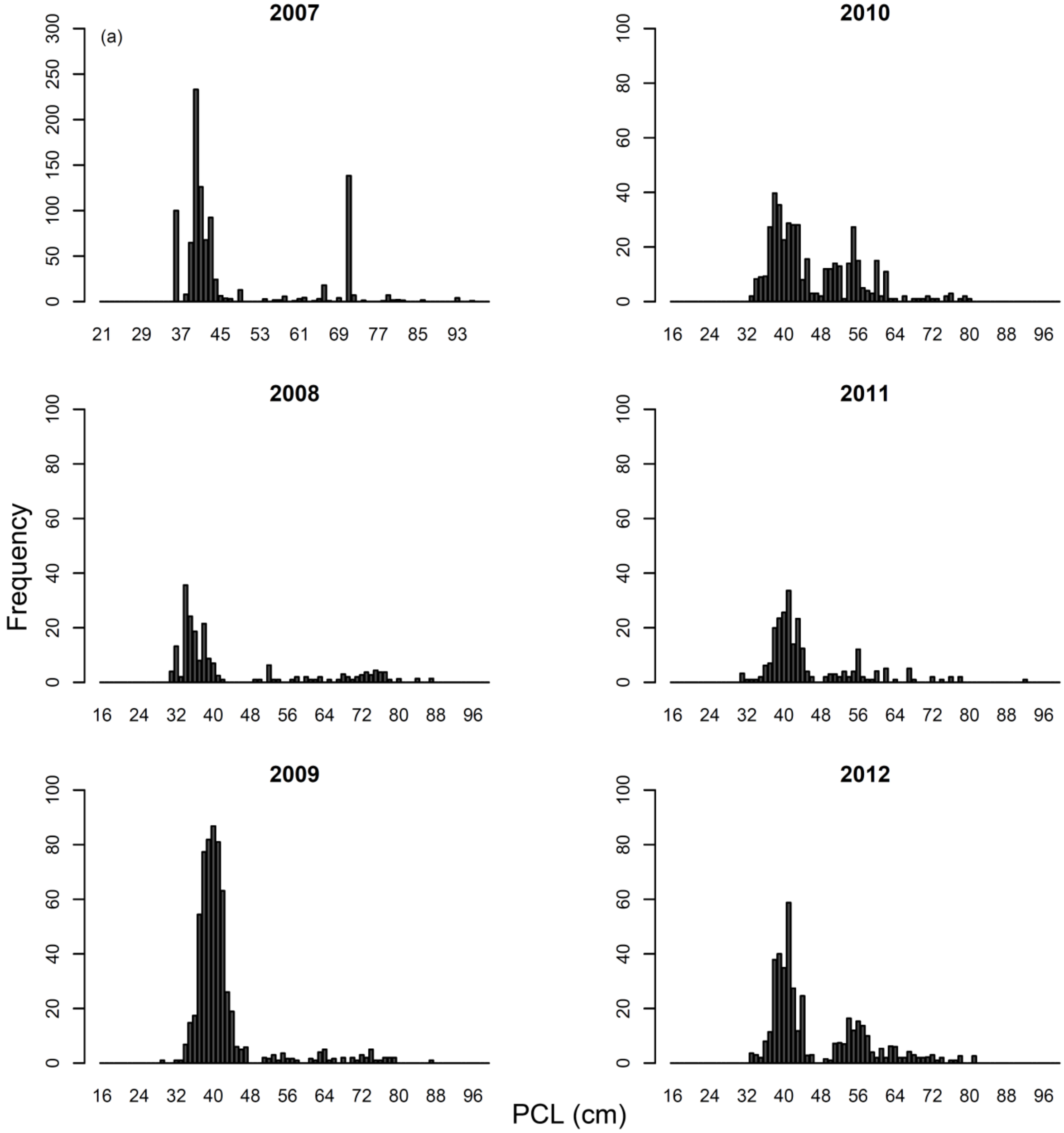
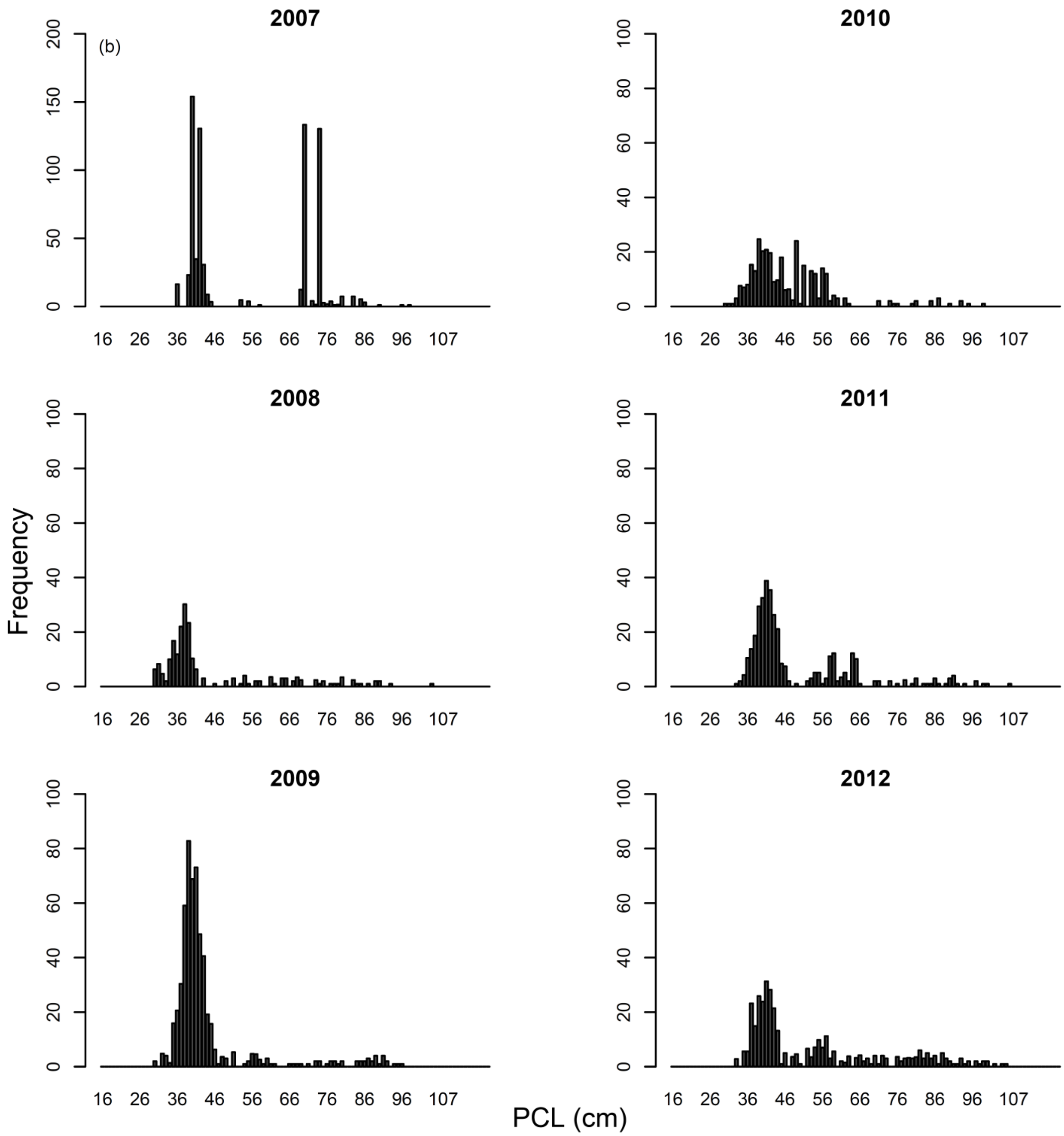


Figure 5. Length frequency of smooth dogfish (*Mustelus canis*) from fall NEAMAP cruises, 2007-2012, for (a) males, (b) females, and (c) sexes combined including unsexed specimens.




2007
(b)
2010
2008
2011
2009
2012
Frequency
PCL (cm)
0
50
100
150
200
0
20
40
60
80
100
16 26 36 46 56 66 76 86 96 107

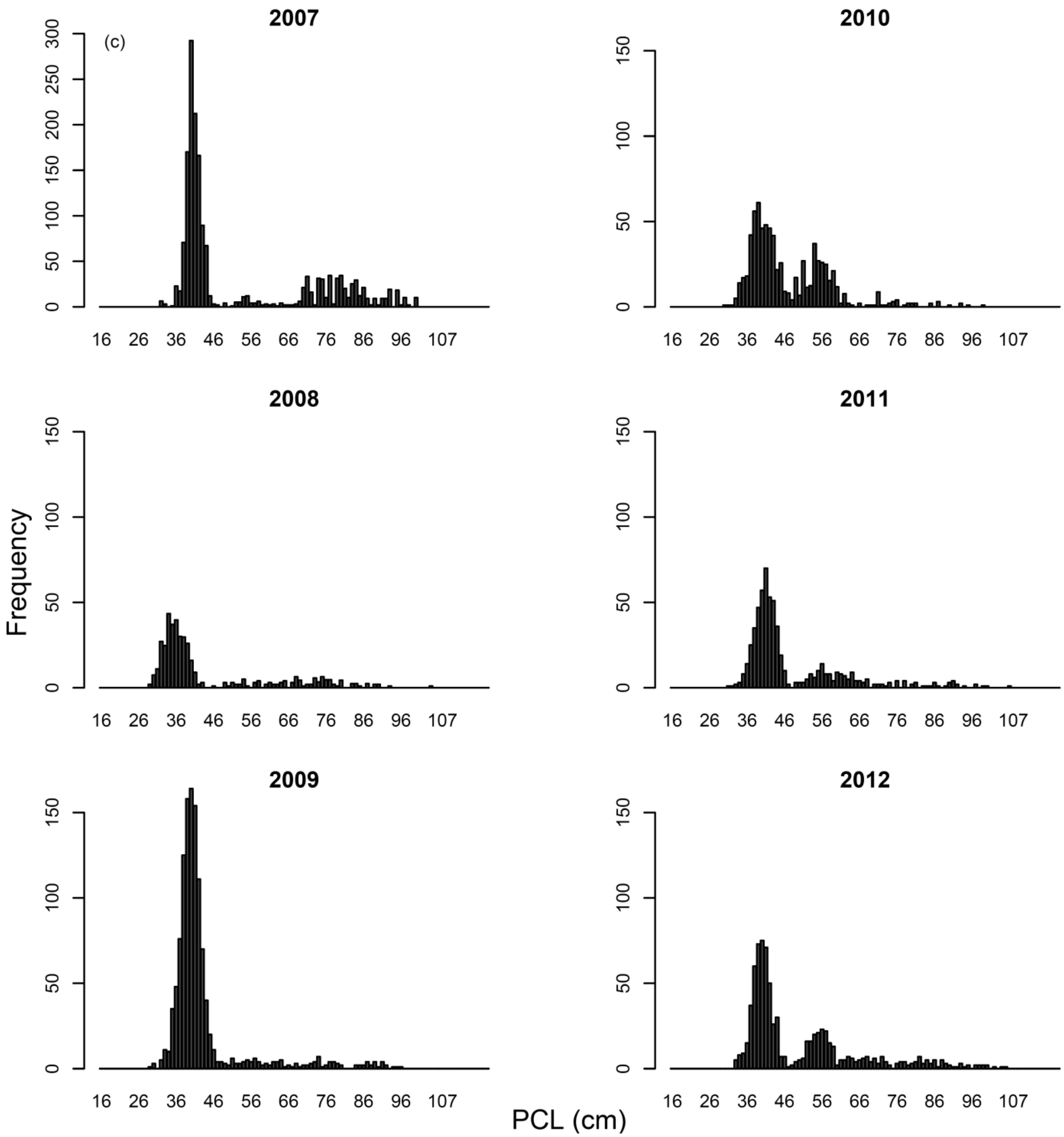

2007
(c)
2010
2008
2011
2009
2012
Frequency
PCL (cm)
16 26 36 46 56 66 76 86 96 107
0 50 100 150 200 250 300
0 50 100 150

Figure 6. Plots of residuals across domain of each covariate included in the model M_1 parameterization of the negative binomial GLM fitted to smooth dogfish (*Mustelus canis*) data from fall NEAMAP cruises, 2007-2012. Note that the environmental covariates were standardized.

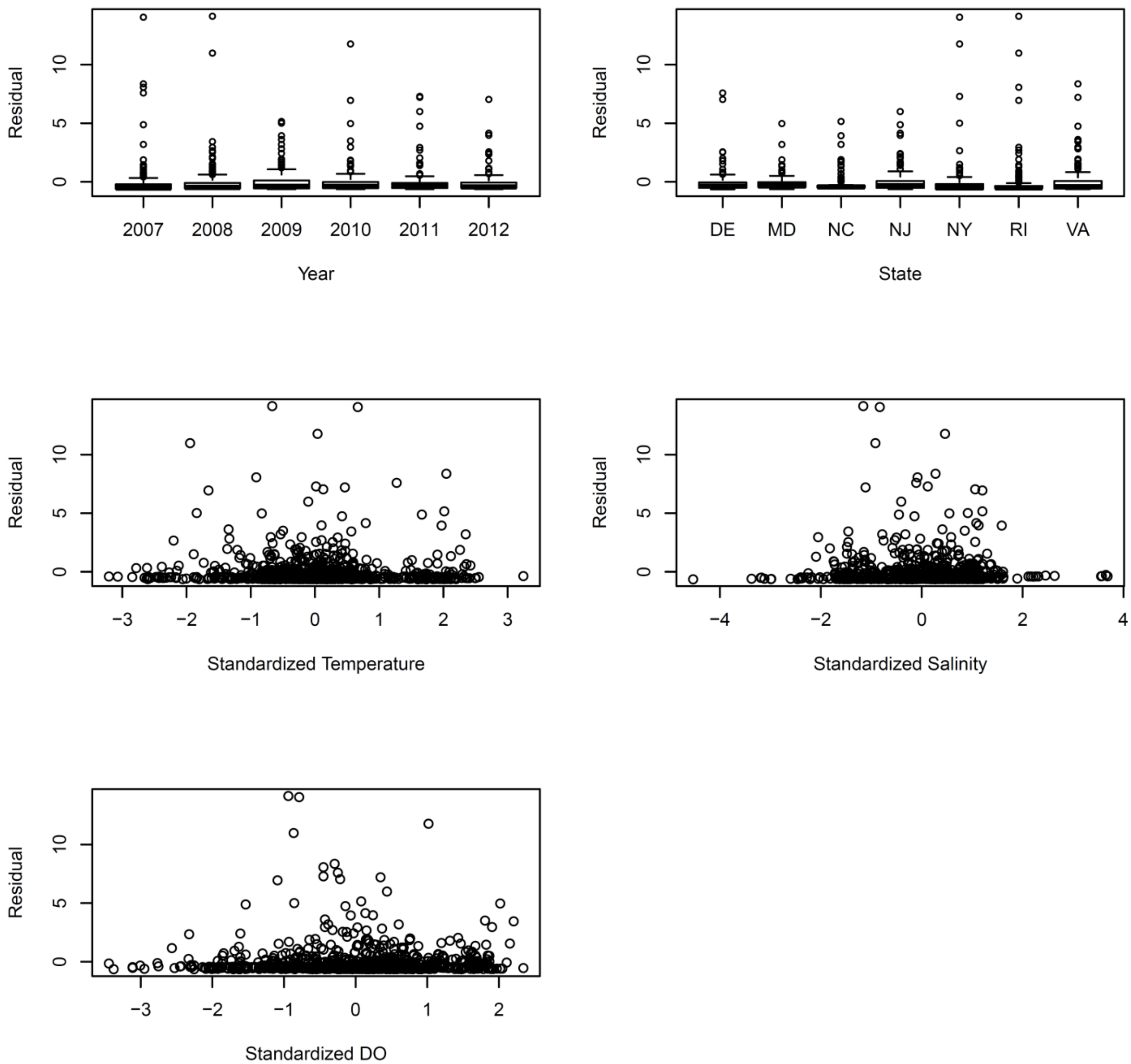


Figure 7. (a) Indices of relative abundance for smooth dogfish (*Mustelus canis*) estimated from fall NEAMAP data, 2007-2012, and (b) associated estimated coefficients of variation. Standard tow are was assumed to be 25,000 m^2.