Size composition and indices of relative abundance of the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) in coastal Virginia waters

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Executive Summary

The Virginia Shark Monitoring and Assessment Program (VASMAP) has been sampling shark populations in the Chesapeake Bay and coastal Virginia waters using standardized fishery-independent longline gear since 1974. Program data for Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) collected from 1975-2011 show that this species is encountered frequently (1585 animals collected over the time-series), Smith Island Shoals (sampling site L) had the highest overall catch, virtually all sampled animals are older than age-0, and that males (88%) dominated longline catches. Additionally, trends in nominal and two differently derived standardized indices of relative abundance (based on delta-lognormal and zero-inflated negative binomial generalized linear models) were all generally similar and showed a decrease from 1995-2003 and a notable increase from 2004-2011 to the highest index values on record. Estimated coefficients of variation for the standardized indices of relative abundance were moderate (0.6-0.8) with higher values in some years. Based on VASMAP data, it appears that the Atlantic sharpnose shark population has been experiencing a notable increase in abundance over the past decade.

Background

Virginia Shark Monitoring and Assessment Program (*VASMAP*)

Chartered in 1940, the Virginia Institute of Marine Science (VIMS) is one of five graduate schools of the College of William and Mary. Located in Gloucester Point, Virginia, near the shores of Chesapeake Bay, VIMS has a tripartite mission to provide research, education, and advisory service in marine science. The Virginia Shark Monitoring and Assessment Program (VASMAP), which is based out of VIMS, has been sampling shark populations in the Chesapeake Bight using standardized fishery-independent longline gear since 1974. The program provides detailed analyses of abundance, habitat utilization, age, growth, reproduction, trophic interactions, and demographics of dominant species in the Chesapeake Bay and coastal Virginia. Research results from the VASMAP are directly used in National Marine Fisheries Service (NMFS) stock assessments of Atlantic shark species, as well as in the Atlantic States Marine Fisheries Commission (ASMFC) Shark Management Plan. Results are also used by the Virginia Marine Resources Commission (VMRC) in promulgating shark fisheries regulations for the Commonwealth of Virginia.

This working paper summarizes the available VASMAP data for Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) in support of the 2013 peer-reviewed stock assessment (SEDAR 34). Specifically, summaries of longline catches, sex-specific length frequencies, and nominal and two differently derived standardized indices of relative abundance are provided for data collected from 1975-2011. This paper is an extension of the *SEDAR 12-DW-19* document, which summarized the available VASMAP Atlantic sharpnose data from 1975-2005 (Grubbs et al. 2007).

Material and Methods

Field sampling

The VASMAP longline survey is based on a fixed station sampling design with standard and ancillary sampling sites located within the lower Chesapeake Bay and coastal Virginia waters (Figure 1). Cruises are conducted monthly from Jun-Sep, although sampling has occurred in May and Oct in several years. Each longline is comprised of 1.25 nautical miles of 4.8 mm tarred nylon mainline with a deployment time of approximately four hours. One hundred standard gangions are spaced approximately 20 m apart and include a stainless steel tuna clip attached to 2 m of 4.8 mm tarred nylon mainline and 1 m of 1.6 mm stainless steel aircraft cable, terminating in a 9/0 Mustad J hook. The mainline is anchored at each end and delineated every 20 gangions by a Norwegian buoy. Prior to 1995, bait consisted of various coastal teleosts including Atlantic menhaden (*Brevoortia tyrranus*), however, since that time only Atlantic menhaden and Atlantic mackerel (*Scomber scombrus*) have been used.

Data recorded for each longline set include, 1) location, 2) beginning and end set times, 3) minimum and maximum water depth, 4) surface and bottom water temperature (to 30 m), 5) type and number of hooks, and 6) bait species. Since 1996, hydrographic measurements of temperature, dissolved oxygen, and salinity have been recorded at 2 m depth intervals for all longline sets. Captured sharks are sexed and measured to the nearest 0.5 cm for pre-caudal (PCL), fork (FL), and stretched total length (TL). Positively identified animals lost during retrieval are included in catch statistics.

Statistical analysis

All analyses were based on Atlantic sharpnose sharks captured at standard VASMAP sampling locations (six sites: W, C, L, T, V1, and V2, Figure 1) from 1975-2011. Straightforward length frequencies were generated for both males and females and nominal catch-per-unit-effort (CPUE) indices of abundance by year, sampling site, and month were calculated as the mean number of sharks captured per hour per 100 standard hooks. The coefficient of variation (CV) for the nominal indices of abundance was calculated as: $CV_i = se_i/\mu_i$, where se_i and μ_i are the estimated standard error and mean number of sharks captured, respectively.

While a nominal indices can be useful for inferring general patterns and trends of relative abundance, most contemporary stock assessments utilize indices of abundance that have been standardized for the effects of hypothesized covariates. Accordingly, two standardized indices of abundance were generated using generalized linear models (GLMs; McCullagh and Nelder 1989, Maunder and Punt 2004). Inspection of simple frequency plots of the raw Atlantic sharpnose survey data across the time-series showed large spikes at zero, which depending on the definition of sampling effort, provided empirical support for the application of a delta-GLM or zero-inflated GLM.

A delta model specifies that the probability of obtaining a zero CPUE and the nonzero CPUE are modeled separately. The general form of a delta model is:

$$\Pr(Y = y_i) = \begin{cases} w_i & y_i = 0 \\ (1 - w_i) f(y_i) & \text{otherwise} \end{cases} \qquad (1)$$

where y_i is the i^{th} CPUE observation, w_i represents the probability of obtaining a zero catch and $f(y_i)$ is the density function associated with the positive catches (Maunder and Punt 2004). The probability of obtaining zero observation was modeled using a binomial mass function, and the lognormal density function was used to model the nonzero catches. The delta-lognormal GLM has been used historically to develop standardized indices of relative abundance for the Atlantic sharpnose shark (Grubbs et al. 2007), as well as other coastal shark species. In applying the delta-lognormal model, CPUE was defined as the number of sharks captured per hour per 100 standard hooks.

Zero-inflated models can also be used to analyze datasets with high frequencies of zero observations. Zero-inflated distributions are a mixture of two distributions, a degenerate component that is zero with certainty and a second component that includes zeros and positive values (Maunder and Punt 2004). In effect, the data are divided into two groups, where the first group contains only zeros (termed false zeros) and the second group contains the count data which may include zeros (true zeros) along with values larger than zero (Zuur et al. 2009). The general form of a zero-inflated model is:

$$\Pr(Y = y_i) = \begin{cases} w_i + (1 - w_i) f(0) & y_i = 0 \\ (1 - w_i) f(y_i) & \text{otherwise} \end{cases} \qquad (2)$$

where y_i is the i^{th} CPUE observation, w_i represents the probability of false zero which was modeled with the binomial mass function, and $f(y_i)$ is the mass function assumed for the true and nonzero catches (Maunder and Punt 2004). Given that zero-inflated models are structured to analyze count data, CPUE was defined to be the number of sharks caught per longline set. To account for variable sampling effort across longline sets, an offset term defined to be the natural logarithm of hours fished per 100 standard hooks was included in all model formulations. Preliminary model fits of zero-inflated Poisson GLMs showed high degrees of overdispersion that was acceptably accounted for through the application of a zero-inflated negative binomial (ZINB) GLM.

For two classes of GLMs considered, three fixed effects parameterizations were fitted to Atlantic sharpnose survey data: model M_1 specified only a year covariate, model M_2 specified year and month covariates, and model M_3 specified year, month, and site covariates. All covariates were treated as categorical variables. Akaike's Information Criterion (AIC) was used discriminate among competing models such that (Akaike 1973, Burnham and Anderson 2002):

$$AIC = -2 \cdot \log_e(L) + 2p$$

where 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. For the delta lognormal GLM, yearly lognormal index values were extracted from the 'best' fitting model to the nonzero CPUE data as back transformed bias corrected means (Lo et al. 1992), while yearly probabilities of encountering Atlantic sharpnose sharks were generated from the 'best' fitting binomial model with the non-year covariates set to the levels that corresponded to the highest nonzero catches. For the ZINB GLM, index values were generated using the same approach as with the binomial component of the delta GLM. Yearly CV_y values for both the delta and ZINB GLMs were estimated as $CV_y = se_y/\mu_y$, where se_y is the estimated year-specific jackknifed standard error of the index value (Efron 1981) and μ_y is the estimated index value in year y. All statistical analyses were conducted using the software package R (version 2.15.1; R Development Core Team 2012). The R library 'pscl' was accessed for fitting the ZINB GLMs.

Results and Discussion

Atlantic sharpnose sharks were the most frequently sampled species by the VASMAP longline survey from 1975-2011. The majority of the animals collected were males (88%), and using 38 and 43 cm fork length (FL) as length cutoffs for males and females, respectively, all but two females were older than age-0 (Figure 2). Smith Island Shoal (site L) accounted for 41.2% of the total Atlantic sharpnose catch and the highest proportion of positive sets (fraction of longline sets with at least one target animal captured, 72.7%). The Chesapeake Light Tower (site C), Triangle Wrecks (site T) and Sandbridge (site V2) each accounted for approximately 17% of the total catch and corresponded to between 42 and 62% positive sets (Figure 3). Total number of Atlantic sharpnose sharks caught and the proportion of positive sets were lowest in June (9.3 and 32.8%, respectively) when compared to the other months (Figure 3).

The nominal CPUE index across years showed a variable pattern with a fairly consistent increase in relative abundance since 2002 (Figure 4). Based on the VASMAP longline survey data and this 'first cut' estimated trend in relative abundance, it appears that the Atlantic sharpnose shark population has been experiencing an increase over the past decade. Estimated CVs for the yearly nominal CPUE index were reasonable with most values less than 0.5. Nominal CPUE indices across sampling sites and months were generally flat and thus without notable trends.

For the three model parameterizations of the delta-lognormal and ZINB GLMs fitted to the Atlantic sharpnose CPUE data, model selection statistics strongly indicated that model M_3 received the most empirical support (Table 1a,b). That is, the ΔAIC values associated with model M_3 were lowest for both the presence/absence (binomial component) and the nonzero CPUE (lognormal component) of the delta-lognormal GLM and for the ZINB GLM. The ΔAIC values for the other competing model parameterizations all exceeded 10, which is the general cutoff value for assessing empirical support (Burnham and Anderson 2002). Diagnostic plots for both GLMs (Q-Q norm plot of the lognormal component of the delta model and Pearson residuals across years for delta-lognormal components and the ZINB model) showed no significant concerns in terms of violation of model assumptions (Figure 5).

Examination of the estimated standard errors and CVs associated with model M_3 of both the delta-lognormal and ZINB GLMs indicated generally poor precision for the estimated parameters. In terms of a simple summary, 35 and 62% of the CVs from the binomial and lognormal components of the delta model, respectively, exceeded 1.0 (arbitrarily chosen reference value), and 88 and 12% exceeded that value for the binomial and negative binomial components of the zero-inflated model (Tables 2,3). Although the diagnostic plots for both GLMs (Q-Q norm plot of the lognormal component of the delta model and Pearson residuals across years for delta-lognormal components and the ZINB model) showed no significant indication of model assumption violation (Figure 5), the lack of precisely estimated parameters is troubling.

Both GLMs yielded generally similar patterns of relative Atlantic sharpnose abundance over the time-series. In particular, from 1995 to 2003, both indices showed a variable but decreasing trend, and from 2004 to 2011, each index sharply and consistently increased to their respective highest values in the time-series (generally occurring from 2007-2009, Figure 6, Table 4). The pattern in the GLM-based indices is largely consistent with that of the yearly nominal trend in CPUE, which strengthens the evidence that the Atlantic sharpnose shark population has been experiencing an increase over the past decade. In terms of uncertainty, the yearly CVs of both GLM indices were moderate (0.6-0.8) with occasional high values. The CVs associated with the delta-lognormal index decreased over the time series to values less than 0.6 (Figure 6, Table 4). The yearly index CVs from the zero-inflated model were fairly consistent across the time-series but slightly higher than those from the delta model.

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Table 1. Akaike's Information Criterion (AIC) and ΔAIC for (a) delta-lognormal and (b) ZINB GLM models M_1, M_2, and M_3 fitted to Atlantic sharpnose shark (*Rhizoprionodon terranenovae*) VASMAP longline survey data, 1975-2011.

(a)

Atlantic sharpnose shark				
Model covariates	**delta-lognormal GLM**			
	Binomial AIC	**Lognormal AIC**	**Binomial ΔAIC**	**Lognormal ΔAIC**
M_1: Year	706.6	719.2	81.6	32.6
M_2: Year, Month	698.3	714.1	73.3	27.6
M_3: Year, Month, Site	625.0	686.5	0.0	0.0

(b)

Atlantic sharpnose shark		
Model covariates	**ZINB GLM**	
	AIC	**ΔAIC**
M_1: Year	2035.0	147.9
M_2: Year, Month	2010.6	123.5
M_3: Year, Month, Site	1887.1	0.0

Table 2. Estimates of parameters (β's), standard errors (SE), and coefficients of variation (CV) from the model M_3 parameterization of the delta-lognormal GLM fitted to Atlantic sharpnose shark (*Rhizoprionodon terranenovae*) VASMAP longline survey data, 1975-2011.

	Binomial component			**Lognormal component**		
Parameter	**Estimate**	**SE**	**CV**	**Estimate**	**SE**	**CV**
β_0	-1.25	0.89	-0.71	-0.28	0.69	-2.46
β_{1977}	0.59	1.14	1.94	-0.58	0.81	-1.39
β_{1980}	0.76	0.97	1.28	-0.24	0.73	-3.10
β_{1981}	1.36	0.97	0.71	-0.37	0.71	-1.94
β_{1983}	0.27	1.37	4.97	0.25	0.94	3.81
β_{1990}	0.57	0.97	1.71	-0.24	0.74	-3.09
β_{1991}	0.44	0.99	2.23	-0.24	0.75	-3.17
β_{1992}	1.06	0.99	0.94	-0.34	0.73	-2.17
β_{1993}	0.67	1.01	1.51	-0.56	0.75	-1.33
β_{1995}	1.51	0.98	0.65	-0.29	0.71	-2.48
β_{1996}	0.82	0.95	1.16	-0.49	0.72	-1.47
β_{1997}	0.46	0.97	2.09	-0.64	0.74	-1.15
β_{1998}	1.27	0.97	0.77	-0.21	0.72	-3.38
β_{1999}	1.76	1.00	0.57	-0.24	0.72	-2.96
β_{2000}	0.45	0.96	2.13	-1.04	0.74	-0.71
β_{2001}	1.13	0.94	0.84	-0.77	0.72	-0.93
β_{2002}	0.69	1.00	1.46	-1.19	0.75	-0.63
β_{2003}	0.03	1.12	39.07	-0.95	0.87	-0.92
β_{2004}	0.75	0.96	1.27	-1.30	0.73	-0.56
β_{2005}	1.47	1.07	0.73	-0.57	0.77	-1.34
β_{2006}	1.83	0.97	0.53	-0.75	0.71	-0.95
β_{2007}	2.30	0.99	0.43	-0.24	0.70	-2.90
β_{2008}	2.05	0.98	0.48	-0.74	0.71	-0.95
β_{2009}	1.74	1.09	0.63	0.09	0.74	7.88
β_{2010}	1.30	0.97	0.75	-0.46	0.72	-1.57
β_{2011}	1.30	0.97	0.75	-0.24	0.71	-3.01
β_{Jul}	1.13	0.30	0.27	0.39	0.19	0.50
β_{Aug}	0.89	0.31	0.35	0.57	0.20	0.35
β_{Sep}	0.94	0.30	0.32	0.59	0.20	0.34
β_L	0.57	0.34	0.60	0.73	0.17	0.24
β_T	-0.80	0.32	-0.40	-0.13	0.20	-1.47
β_{V1}	-0.86	0.42	-0.49	-0.001	0.26	-238.55
β_{V2}	-0.64	0.33	-0.52	0.21	0.20	0.95
β_W	-2.61	0.42	-0.16	-0.42	0.32	-0.77

Table 3. Estimates of parameters (β's), standard errors (SE), and coefficients of variation (CV) from the model M_3 parameterization of the zero-inflated negative binomial GLM fitted to Atlantic sharpnose shark (*Rhizoprionodon terranenovae*) VASMAP longline survey data, 1975-2011.

	Binomial component			Negative binomial component		
Parameter	**Estimate**	**SE**	**CV**	**Estimate**	**SE**	**CV**
β_0	-1.44	6.88	-4.77	-2.31	0.78	-0.34
β_{1977}	0.96	6.95	7.28	0.90	0.92	1.02
β_{1980}	1.70	6.81	4.00	2.42	0.84	0.35
β_{1981}	-3.75	6.75	-1.80	1.25	0.79	0.63
β_{1983}	0.78	8.54	10.90	1.33	0.97	0.73
β_{1990}	2.40	6.91	2.88	1.70	0.84	0.49
β_{1991}	2.73	6.86	2.51	2.58	0.87	0.34
β_{1992}	0.58	6.92	11.92	1.74	0.83	0.48
β_{1993}	0.59	6.78	11.50	1.23	0.81	0.66
β_{1995}	-1.32	6.64	-5.04	1.58	0.80	0.51
β_{1996}	-1.72	6.57	-3.83	1.03	0.80	0.77
β_{1997}	0.57	6.76	11.95	1.12	0.82	0.73
β_{1998}	-6.73	8.21	-1.22	1.52	0.81	0.53
β_{1999}	-6.27	7.87	-1.26	1.48	0.81	0.55
β_{2000}	-2.64	6.78	-2.57	0.43	0.81	1.90
β_{2001}	-1.77	6.57	-3.70	1.27	0.81	0.64
β_{2002}	-9.26	16.28	-1.76	0.54	0.85	1.59
β_{2003}	-1.76	6.78	-3.84	0.30	0.92	3.08
β_{2004}	0.07	6.84	99.83	1.15	0.80	0.70
β_{2005}	-2.37	7.17	-3.03	1.86	0.84	0.45
β_{2006}	-3.20	7.30	-2.28	1.67	0.80	0.48
β_{2007}	-10.15	22.62	-2.23	2.27	0.81	0.36
β_{2008}	-9.39	16.00	-1.70	1.60	0.82	0.51
β_{2009}	-5.34	11.96	-2.24	2.38	0.82	0.35
β_{2010}	1.65	7.14	4.32	2.48	0.86	0.35
β_{2011}	3.06	7.03	2.30	2.39	0.82	0.34
β_{Jul}	-3.17	0.98	-0.31	0.62	0.25	0.41
β_{Aug}	-3.29	1.18	-0.36	0.90	0.26	0.29
β_{Sep}	-6.46	1.55	-0.24	0.41	0.25	0.62
β_L	-0.14	0.96	-6.76	0.73	0.22	0.30
β_T	4.60	1.35	0.29	0.76	0.26	0.34
β_{V1}	-8.84	32.22	-3.65	-1.04	0.32	-0.31
β_{V2}	-1.64	1.74	-1.06	-0.50	0.25	-0.51
β_W	0.66	1.78	2.70	-2.37	0.35	-0.15

Table 4. Estimated yearly index values and associated jackknifed coefficients of variation (CV) from the model M_3 parameterization of the delta-lognormal and zero-inflated negative binomial GLMs fitted to Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) VASMAP longline survey data, 1975-2011. Missing years correspond to zero total sharks caught (1978-1979, 1982, 1984, 1986), less than five total annual longline sets (1976, 1987-1989), and no sampling (1985, 1994).

	Delta-lognormal model		Zero-inflated model	
Year	**Index value**	**CV**	**Index value**	**CV**
1975	0.26	2.77	1.52	3.75
1976	NA	NA	NA	NA
1977	0.24	2.15	3.55	0.83
1978	NA	NA	NA	NA
1979	NA	NA	NA	NA
1980	0.39	0.83	14.85	0.85
1981	0.47	0.38	5.51	0.40
1982	NA	NA	NA	NA
1983	0.40	1.35	5.50	1.55
1984	NA	NA	NA	NA
1985	NA	NA	NA	NA
1986	NA	NA	NA	NA
1987	NA	NA	NA	NA
1988	NA	NA	NA	NA
1989	NA	NA	NA	NA
1990	0.35	0.76	6.19	1.21
1991	0.32	0.91	13.39	1.37
1992	0.42	0.56	8.40	0.80
1993	0.27	0.73	5.07	0.85
1994	NA	NA	NA	NA
1995	0.53	0.48	7.57	0.74
1996	0.32	0.54	4.36	0.66
1997	0.22	0.71	4.52	0.65
1998	0.52	0.40	7.21	0.80
1999	0.60	0.46	6.94	0.61
2000	0.15	0.70	2.40	0.79
2001	0.28	0.56	5.54	0.61
2002	0.14	0.74	2.69	0.81
2003	0.11	1.17	2.11	1.25
2004	0.14	0.76	4.80	0.84
2005	0.38	0.77	10.08	1.69
2006	0.37	0.37	8.32	0.85
2007	0.70	0.35	15.26	0.67
2008	0.40	0.35	7.82	0.66
2009	0.82	0.44	16.97	0.79
2010	0.41	0.55	15.85	0.87
2011	0.51	0.50	9.77	1.33

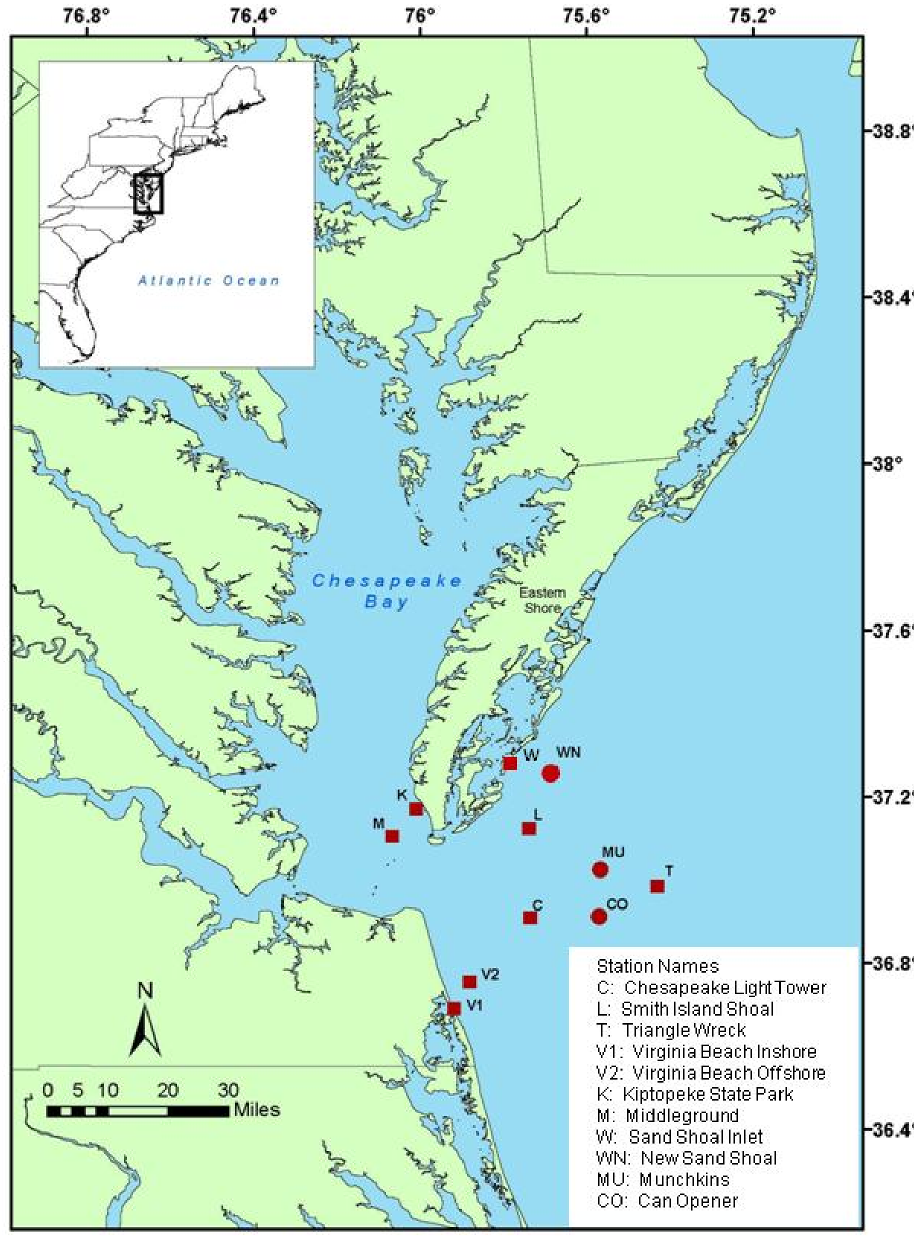

Figure 1. Standard (squares) and ancillary (circles) VASMAP longline sampling sites in the Chesapeake Bay (M, K) and coastal Virginia (C, L, T, V1, V2, W, WN, MU, CO) waters. Only data from standard sites are used in the development of indices of relative abundance for Atlantic sharpnose shark (*Rhizoprionodon terraenovae*).

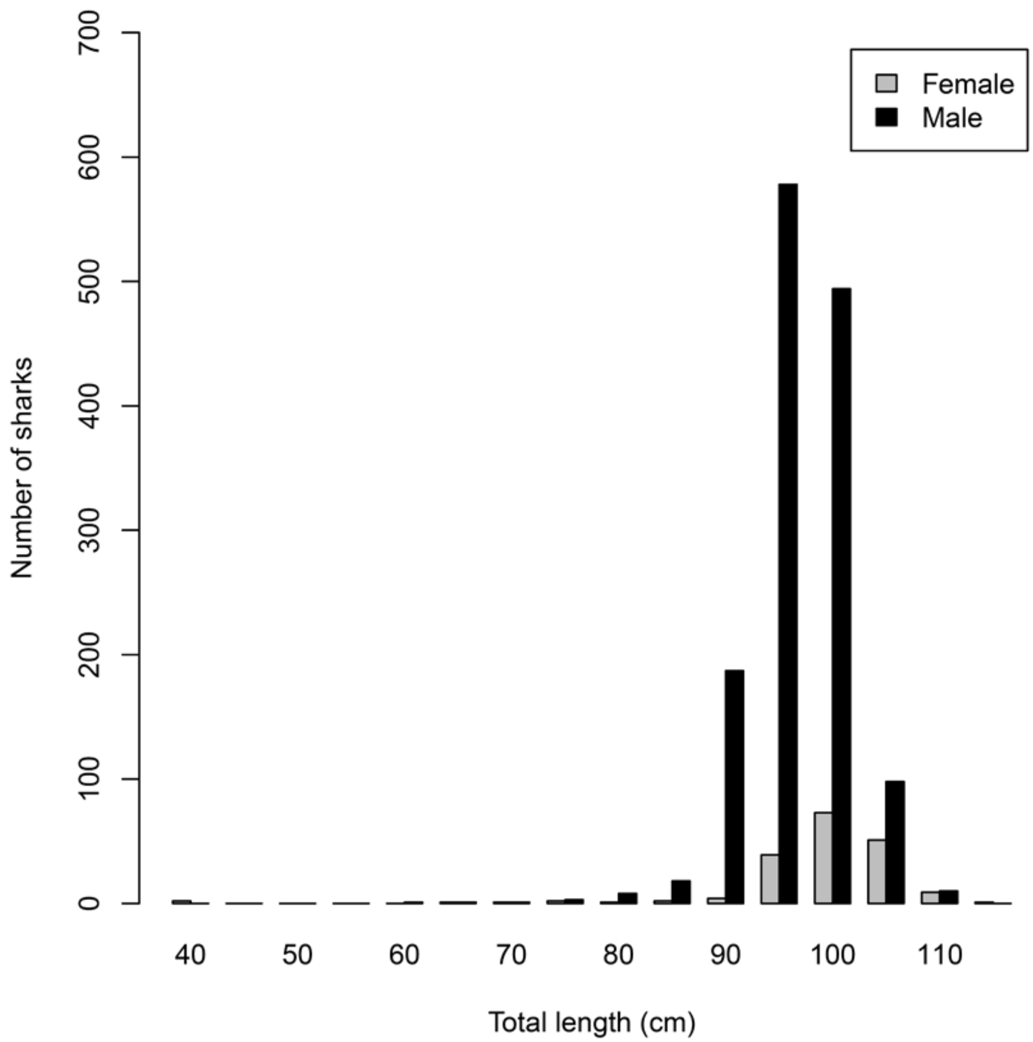

Figure 2. Length frequencies for female (n=186) and male (n=1399) Atlantic sharpnose sharks (*Rhizoprionodon terranenovae*) collected at standard VASMAP sampling sites, 1974-2011.

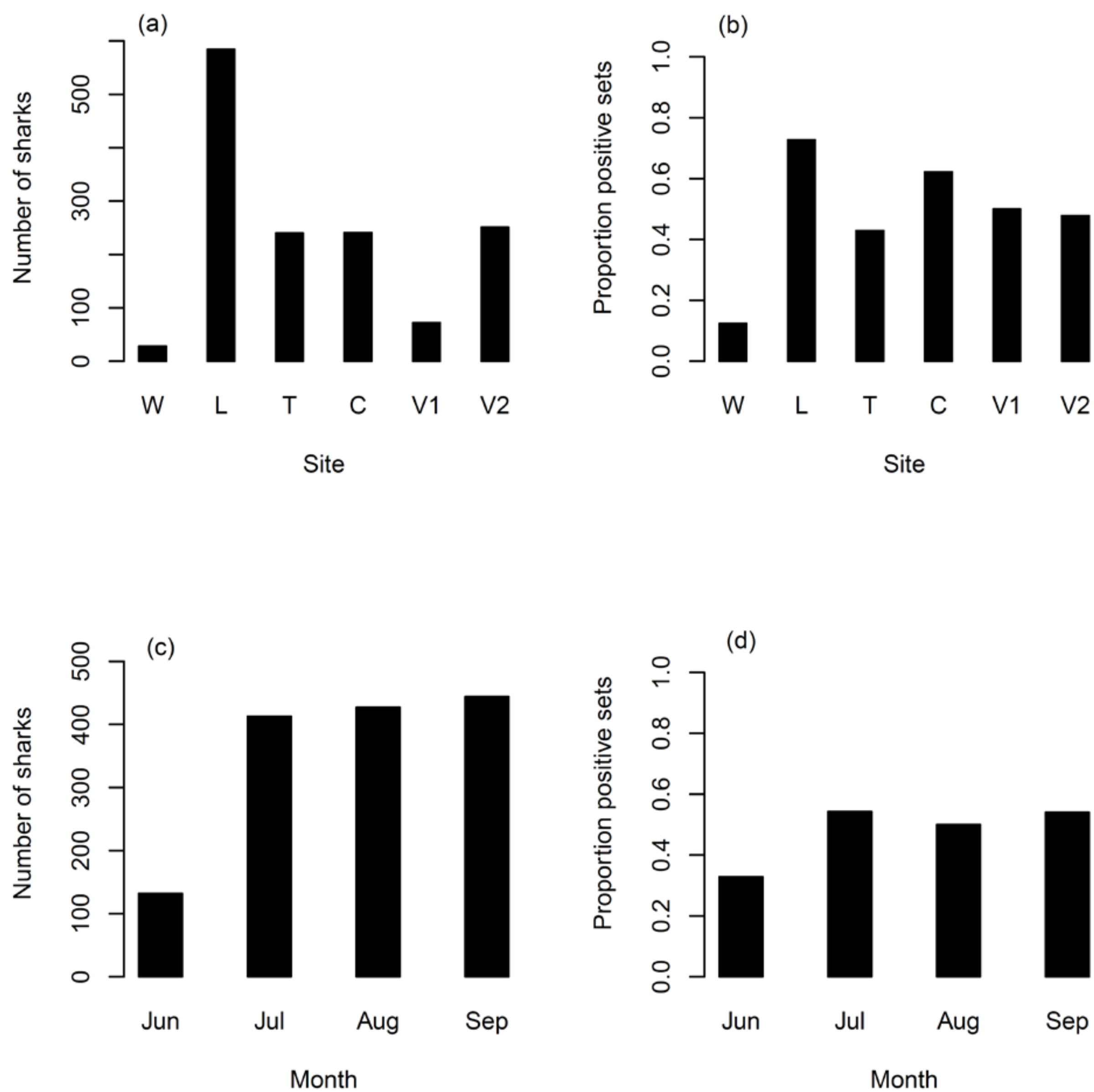

Figure 3. Summary data for Atlantic sharpnose shark (*Rhizoprionodon terranenovae*) collected during 1974-2011 by the VASMAP longline survey; (a) total number of sharks by standard site, (b) proportion of positive sets (at least one animal captured) by standard site, (c) total number of sharks by month, (c) proportion of positive sets (at least one animal captured) by month.

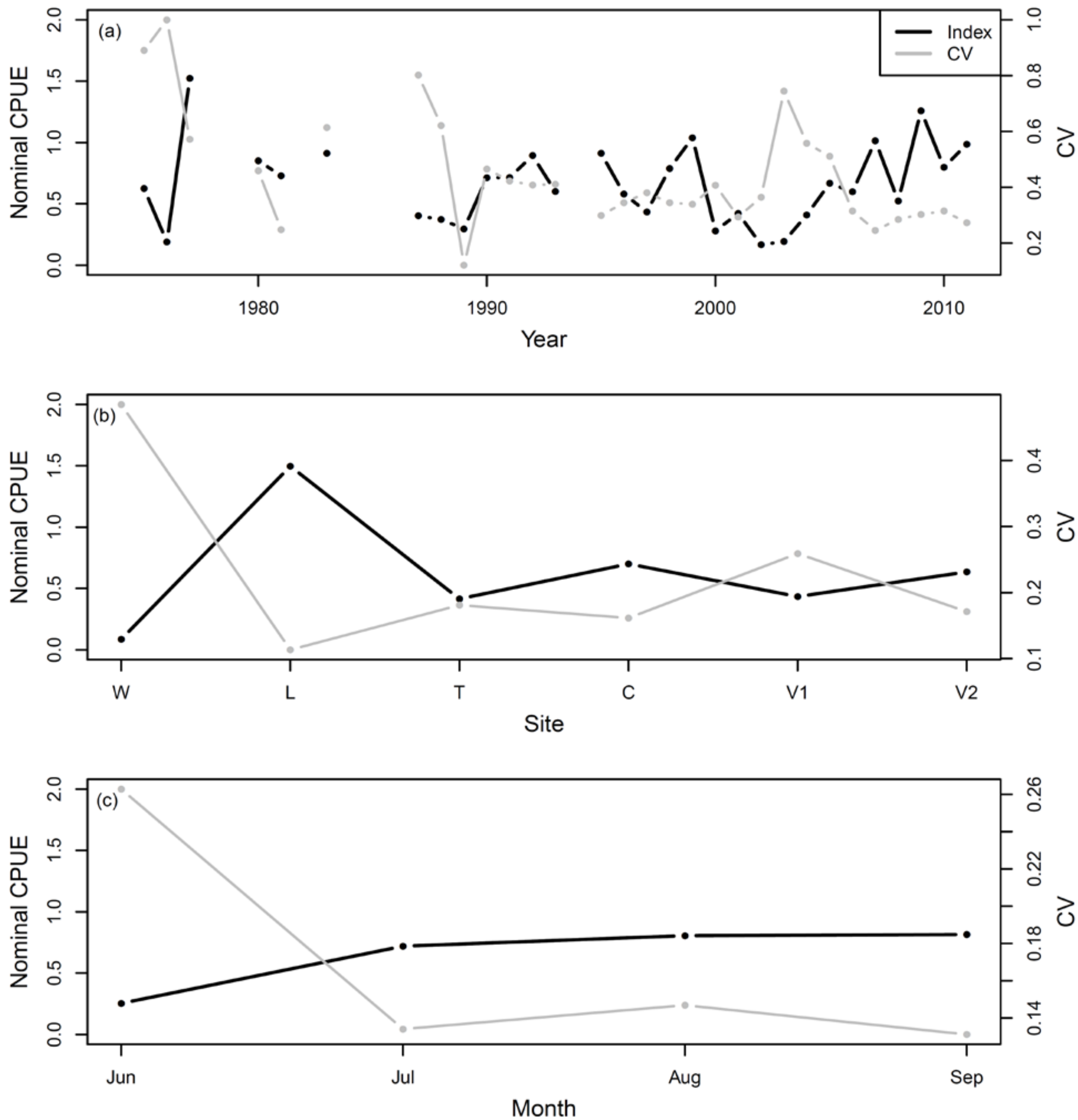

Figure 4. Nominal catch-per-unit-effort (CPUE, left y-axis) and associated coefficients of variation (CV, right y-axis) by (a) year, (b) standard site, (c) month for Atlantic sharpnose shark (*Rhizoprionodon terranenovae*) VASMAP longline survey data, 1975-2011. Missing years correspond to zero total sharks caught (1978-1979, 1982, 1984, 1986), less than five total longline sets were made (1976, 1987-1989), and no sampling (1985, 1994).

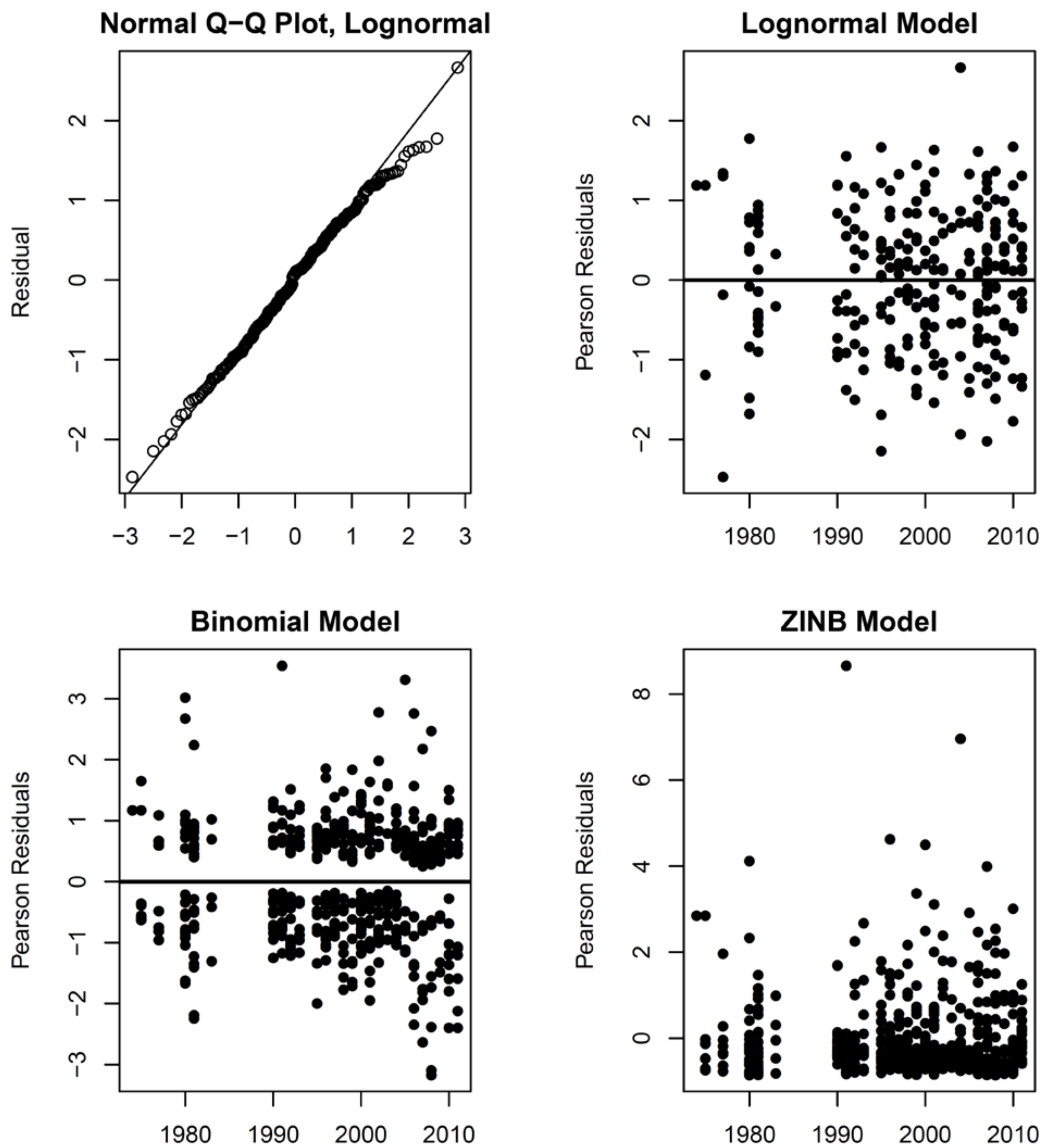

Figure 5. Diagnostic plots associated with model M_3 parameterizations of the delta and zero-inflated GLMs fitted to Atlantic sharpnose shark (*Rhizoprionodon terranenovae*) VASMAP longline survey data, 1975-2011. The Q-Q norm plot is associated with the lognormal component of the of the delta model and the plots of Pearson residuals over years are for both components of the delta model and the zero-inflated model.

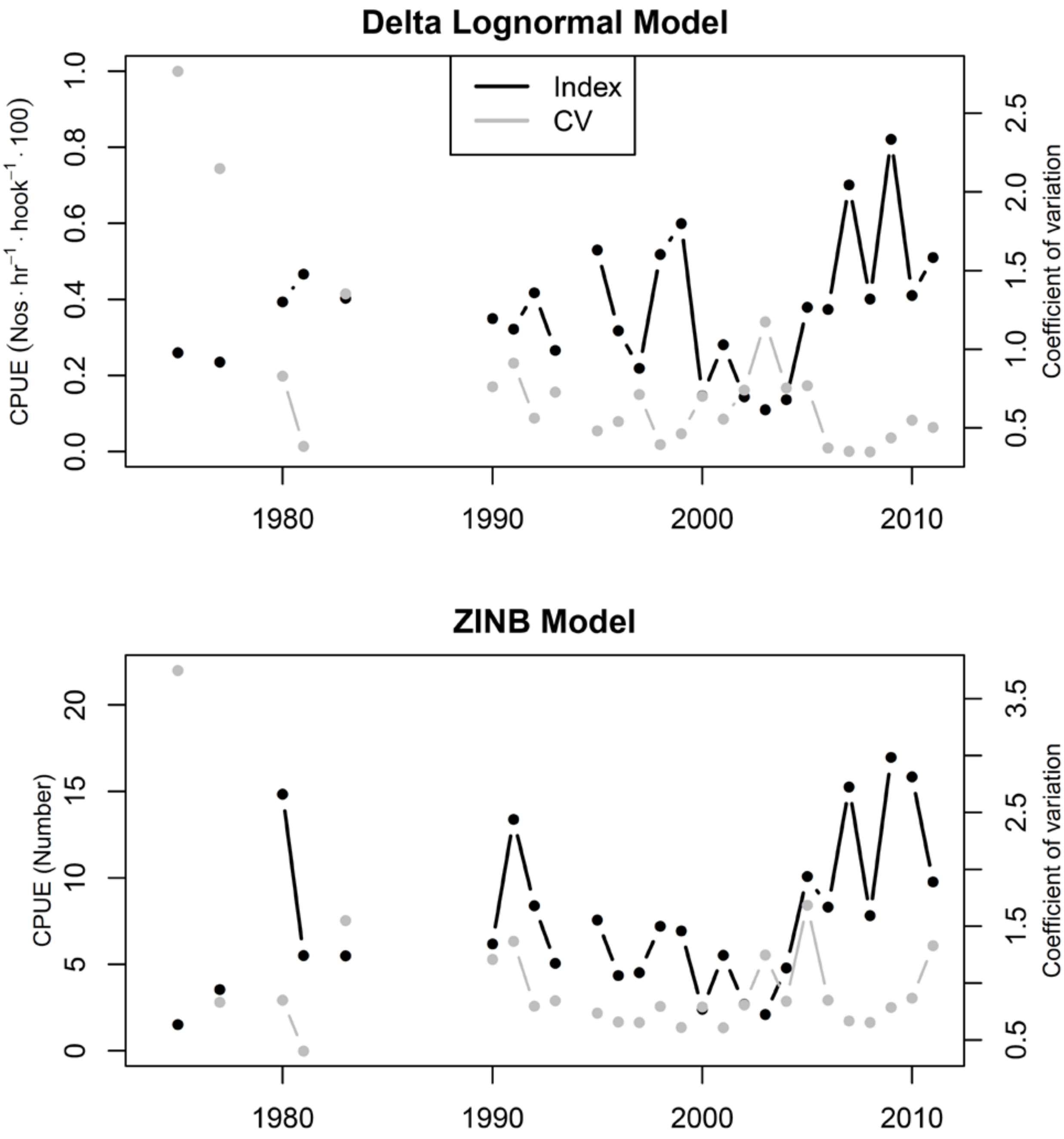

Figure 6. Plots of estimated indices of relative abundance (left y-axis) and jackknife coefficients of variation (right y-axis) from model M_3 parameterizations of the delta and zero-inflated GLMs fitted to Atlantic sharpnose shark (*Rhizoprionodon terranenovae*) VASMAP longline survey data, 1975-2011.