SERFS Chevron Trap Red Snapper Index of Abundance: An Investigation of the Utility of Historical (1990-2009) Chevron Trap Catch Data

Joseph C. Ballenger

SEDAR41-DW51

Submitted: 17 August 2015

This information is distributed solely for the purpose of pre-dissemination peer review. It does not represent and should not be construed to represent any agency determination or policy.

Please cite this document as:

Ballenger, J. C. 2015. SERFS Chevron Trap Red Snapper Index of Abundance: An Investigation of the Utility of Historical (1990-2009) Chevron Trap Catch Data. SEDAR41-DW51. SEDAR, North Charleston, SC. 39 pp.

SERFS Chevron Trap Red Snapper Index of Abundance: An Investigation of the Utility of Historical (1990-2009) Chevron Trap Catch Data

Joseph C. Ballenger

SEDAR41-DW51

Submitted: August 17, 2015

*Report documents initial explorations made prior to the SEDAR 41 Data Workshop as well as final recommendations made during the Data Workshop

SERFS Chevron Trap Red Snapper Index of Abundance: An Investigation of the Utility of Historical (1990-2009) Chevron Trap Catch Data

Joseph C. Ballenger

Marine Resources Research Institute
South Carolina Department of Natural Resources
P.O. Box 12259
Charleston, SC 29412

(Not to be used or cited without prior written permission from the authors)

SEDAR41-DW51
MARMAP Technical Report # 2015-009

This work represents partial fulfillment of the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program contract (NA11NMF4540174) sponsored by the National Marine Fisheries Service (Southeast Fisheries Science Center) and the South Carolina Department of Natural Resources.

Background

Though widely used for a host of other species, researchers involved in previous assessments of Red Snapper in the South Atlantic region have not used the fishery-independent chevron trap relative abundance index. A primary reason for this is that Red Snapper catches (and number of positive traps) were generally low in the MARMAP (Marine Resources Monitoring, Assessment & Prediction Program) chevron trap reef fish survey prior to 2010. SEDAR 24 panelists cited two primary reasons for the exclusion of the survey from the final assessment model, 1) the large spatial variability in abundance and sampling locations and 2) the low catches and high variability in the data. At the time, panelists did not know why catches of Red Snapper in the chevron trap survey were so low. Three (among others) possible explanations for the low catches were 1) because the chevron trap was a poor gear to index the relative abundance of Red Snapper, 2) the traditional areas sampled by the chevron trap index were not in core Red Snapper habitat, and hence may not track overall regional abundance, and 3) that the low catches in the chevron trap survey were truly indicative of regional Red Snapper abundance, with abundances being extremely low in totality throughout the survey area. The final assessment model derived from SEDAR 24, based on a host of other data sources, concluded that indeed Red Snapper regional abundance was at low levels throughout the history of the traditional MARMAP chevron trap survey (1990-2009; Figure 1).

Since (or in some cases during the terminal year of) SEDAR 24 there have been a host of management changes aimed at increasing Red Snapper abundance throughout the region. Most notable of these was the prohibition of harvest and possession of Red Snapper that began in early 2010 that continues today, with the exception of some very limited harvest in 2012-2014 as part of the Red Snapper “mini-seasons”.

There have also been some significant changes made to the SERFS chevron trap survey since SEDAR 24 due to the availability of additional fishery-independent funds to study reef fish in the region. The first new funding source, the Reef Fish Complement project funded by the Southeast Area Monitoring and Assessment Program, South Atlantic region (SEAMAP-SA), initially allocated funds in 2008, with a first field season in 2009. The second new funding source, the creation of the Southeast Fishery Independent Survey (SEFIS), had a first field season in 2010. This infusion of resources into the traditional MARMAP chevron trap survey has allowed for a large expansion in the geographical coverage of the survey, particularly off Florida (Table 1, Figure 2 and Figure 3) and an increase in the annual sample size of the chevron trap survey. The combined efforts of MARMAP, SEAMAP-SA Reef Fish Complement, and SEFIS to conduct fishery-independent monitoring in the US South Atlantic region are now referred to as the Southeast Reef Fish Survey (SERFS).

Objective

This report presents a summary of an investigation to determine what the net effect of the changes in management regulations pertaining to Red Snapper (and other species in this mixed species fishery) and the changes in the SERFS chevron trap survey has on the utility of the SERFS chevron trap survey in the SEDAR 41 assessment model. Specifically, this report investigates two primary questions:

1) Does the recent increase in capture rate (and relative abundance) of Red Snapper in the survey reflect shifts in spatial sampling distribution of the survey or changes in relative abundance?
2) What does the increase in capture rate since 2010 mean for the utility of the historical (1990-2009) chevron trap data?
    a) Does the historical data accurately represent historical relative abundance in the region?

The investigation focuses on comparing relative abundance trends of Red Snapper derived from valid samples taken from known live-bottom and/or hard-bottom chevron trap stations identified prior to 2010 (MARMAP Universe) to relative abundance trends of Red Snapper derived from valid samples taken from all stations currently identified as part of the SERFS chevron trap universe of known live-bottom and/or hard-bottom habitats (SERFS Universe). Primarily, these two chevron trap universes differ in the number of known live-bottom and/or hard-bottom stations identified (Figure 4) and the geographic distribution of the identified stations (Table 1, Figure 2 and Figure 3; pay particular attention to the distribution in 2009 vs. 2014). As such, the MARMAP Universe dataset can be thought of as a subset of all available data from any given year, representing only data derived from traditional MARMAP chevron trap stations.

A secondary objective is to evaluate the performance of models modeling continuous covariates (e.g. depth or latitude) as polynomials vs. the traditional approach of binning continuous covariates into discrete bins and subsequently modeling them as discrete covariates in index standardization models.

Methods

Survey Design and Gear
(see Smart et al. 2015 for full description)

Sampling area
- Cape Hatteras, NC, to St. Lucie Inlet, Fl (Figure 5)
    - General expansion of geographic coverage through time
- Sampling depths range from 13 to 218 m
    - Generally less than 100 m

Sampling season
- May through September
    - Limited earlier and later sampling in some years

Survey Design
- Simple random sample survey design
    - Annually, randomly select stations from a chevron trap universe of confirmed live-bottom and/or hard-bottom habitat stations
    - No two stations are randomly selected that are closer than 200 m from each other
        - Minimum distance is typically closer to 400 m

- Traps deployed on suspected live-bottom and/or hard-bottom in a given year (reconnaissance) are evaluated based on catch and/or video or photographic evidence of bottom type for inclusion in the universe in subsequent years
  - If added to the known habitat universe, data from the reconnaissance deployment is included in CPUE analysis

<u>Sampling Gear – Chevron Traps</u>
(see Collins 1990 and MARMAP 2009 for descriptions that are more complete)

- Arrowhead shaped, with a total interior volume of 0.91 m^3
- Constructed of 35 x 35 mm square mesh plastic-coated wire with a single entrance funnel ("horse neck")
- Baited with a combination of whole or cut clupeids (*Brevoortia* or *Alosa* spp., family Clupeidae), with *Brevoortia* spp. most often used
  - Four whole clupeids on each of four stringers suspended within the trap
  - Approximately 8 clupeids placed loose in the trap
- Soak time of approximately 90 minutes

Oceanographic Data
- Hydrographic data collected via CTD during soaking of a "set" (typically 6 traps, but may be less) of chevron traps deployed at the same time
  - Bottom temperature (^{o}C) is defined as the temperature of the deepest recording within 5 m of the bottom

Data Filtering/Inclusion
Chevron trap data were limited to:
- Projects conducting monitoring efforts (project IDs: P05, T59, T60; data sources: MARMAP, SEAMAP-SA, SEFIS)
- Reef fish monitoring samples (Data source ≠ "Tag-MARMAP")
  - "Tag-MARMAP" denotes special historic MARMAP cruises that were used to tag various species of fish, with all species captured not being counted and measured
- Traps that fished properly (catch IDs: 0-2, 8, 9, 90-92)
- Traps on live-bottom and/or hard-bottom habitat (station types: Random, NonRandom, ReconConv, Null)
- Traps with soak times that were neither extremely short nor long which often indicates an issue with the deployment not captured elsewhere (included 45-150 minutes)
- For Red Snapper specifically, only the depths at which Red Snapper have ever been captured by any of the monitoring programs (included 15-75 m)
- Excluded any chevron trap samples missing covariate information

Index Model Structure
- Response variable – Catch/Trap
- Offset term – natural log of soak time ($\ln(soak\ time)$)

- Dependent variables
    - Year
    - Covariates
        - Depth, latitude (^{o}N), bottom temperature (^{o}C), and day of year
- Model structure – zero-inflated negative binomial GLM (ZINB)
    - Other model structures considered: Poisson GLM, negative binomial GLM, and zero-inflated Poisson GLM (ZIP)
        - ZINB favored over other model structures in all analyses
- Annual year effect coefficients of variation (CVs) computed using bootstrapping
- Software used
    - R (Version 3.1.0; R Development Core Team 2014)
    - Function zeroinfl in package *pscl* (Jackman 2011; Zeileis et al. 2008)
    - Function gam in package *mgcv* (wood 2011; Wood 2006; Wood 2004; Wood 2003; Wood 2000)

Models and Data

<u>Data</u>

- Time periods (see Figure 5 for annual geographic distribution of SERFS chevron trap sampling)
    - 1990-2014
        - The full SERFS chevron trap survey time-series over which a standardized approach to chevron trap sampling was used
    - 2010-2014
        - Restricted SERFS chevron trap survey time-series during which the annual percent positive rate in each year was greater than 5% and geographic coverage of sampling was increased off the coast of FL
        - Time period during which sampling effort in the region was greatly increased due to the addition of SEAMAP-SA Reef Fish Complement and SEFIS funds
- Data sets (see Table 2 for annual sample size, percent positive rate, and number of Red Snapper captured; see Table 3 for a comparison of several summary metrics comparing the two data sets)
    - Data set derived from stations present in the current SERFS chevron trap station universe of known live-bottom and/or hard-bottom habitats
        - SERFS Universe data set (see Figure 5 for annual geographic distribution of realized sampling from the SERFS Universe)
    - Data set derived from stations sampled annually that were present in the MARMAP chevron trap station universe of known live-bottom and/or hard bottom habitats at the beginning of the 2010 sampling season
        - MARMAP Universe data set (see Figure 6 for annual geographic distribution of realized sampling from the MARMAP Universe during the period 2010-2014)

(Note: there is no difference in annual geographic sampling distribution based on the two data sets during the period 1990-2009)

- Covariate treatment

- Polynomial treatment
  - The covariates were each modeled as polynomials in the ZINB standardization model (used function poly in package *stats* (R Core Team 2014); with option raw = TRUE)
    - For each covariate, coefficients were estimated for each raw polynomial from degree 1 to maximum polynomial order
  - Maximum allowed polynomial order for each covariate was based on preliminary generalized additive models (GAMs)
    - Used function gam in package *mgcv* (Wood 2011; Wood 2006; Wood 2004; Wood 2003; Wood 2000)
      - Used Restricted Maximum Likelihood (REML) estimation for smoothing parameter estimation
      - Investigated use of several different spline options (see gam function help in R for available options and descriptions)
        - Chose maximum polynomial order based on the effective degrees of freedom estimate (rounded to the nearest whole number) for the covariate in question using the spline type that provided the lowest REML estimate
    - Modeled Red Snapper abundance versus all covariates
      - Used to inform maximum polynomial order for the count sub-model of the ZIP and ZINB models
      - Used to inform maximum polynomial order for the Poisson GLM and negative binomial GLM models
    - Modeled Red Snapper presence/absence versus all covariates
      - Used to inform maximum polynomial order for the zero-inflation sub-model of the ZIP and ZINB models
  - Model selection based on Bayesian information criterion (BIC; Schwarz 1978) to increase the penalty associated with adding parameters to the model
    - ZIP and ZINB Models (2 step process, optimizing one sub-model during each step; needed because of computational demand)
      - Remove all covariates from the zero-inflation sub-model (i.e., intercept only zero-inflation sub-model) and optimize count sub-model for all covariates
      - Fixing count sub-model to the optimum values found during step 1, optimize the covariate structure of the zero-inflation sub-model
- Discrete treatment
  - Binned each covariate according to decisions made during the SEDAR 41 Data Workshop held in 2014 (Table 4)
  - Model selection based on BIC, optimizing both sub-models of ZIP and ZINB models simultaneously

Models

(see Figure 7 for model hierarchy)

Results

Model Structure, Stability and Performance
(see Table 5 for model structure of each of the best-fit models)

- BIC estimates of model pairs (same data set, different covariate treatment) indicate models using continuous covariates fit with polynomials provide better fit that discrete covariate models (Table 5)
- Despite containing more parameters (Table 5), models using continuous covariates fit with polynomials exhibit higher convergence rates and do a superior job fitting observed catch frequency distribution (Table 6)
- Models based on the SERFS Universe data set produced lower CV estimates than those based on the MARMAP Universe data set (Table 6 and Figure 8)
  - Driven by the larger sample size and higher percent positive rate of Red Snapper in SERFS Universe data set

Covariate Effects
(see Figure 9, Figure 10, and Figure 11)

- Given the same method of modeling covariates (polynomial vs. discrete), predicted covariate effects are similar across models
  - Continuous covariates modeled as polynomials
    - Day of Year – covariate is not retained when using the SERFS Universe data set and short time-series
      - Only very slight negative effect of day of year in the full time series SERFS Universe data set model
      - Models based on the MARMAP Universe data set predict a negative exponential effect of day of year on Red Snapper catch
        - Covariate effect is reduced in the full time-series model compared to the restricted time-series model
    - Depth – effect depends on what data set is used
      - SERFS Universe data set – dome shaped relationship of catch at depth, with maximum catch being at 30-50 m of depth
        - More non-linearity of this depth effect is apparent when using the full time-series
      - MARMAP Universe data set – still see a peak in catch at around 30-50 m of depth, though it also predicts high catch of Red Snapper at deep (> 60 m) depths
        - Peak at 30-50 m of depth is shifted deeper when the full time-series of data is used
        - Increase at deep depth is driven by low sample size at these depths to inform covariate effect
    - Latitude – predicted highest catch of Red Snapper at latitudes <30^{o}N, with smaller increases in catch at approximately 32^{o}N and >34^{o}N
      - Most models are remarkably similar in their predicted effect of latitude over the range 28-34.5^{o}N

        - MARMAP Universe data set models have less data informing covariate effect at extreme latitudes, thus predicted effect differs marginally at extremes when compared to models based on SERFS Universe
    - Temperature – models based on both data sets produce very similar predicted effects of temperature, regardless of survey start data
        - Catch of Red Snapper is predicted to increase exponentially as temperature increases through the range of temperatures observed
  - Discrete covariates
    - Day of Year – covariate is not retained in any of the final models
    - Depth – All models predict higher than average catches at 30-44 m depths
        - Predicted effect of depth on catch is smaller when using the MARMAP Universe data set
        - Similar to above, MARMAP Universe data set predicts above average catch rates of Red Snapper at deep (≥ 60 m) depths
    - Latitude – All models predict higher than average catch at <30°N, with lowest catches between 32.5 and 34°N
        - Predicted effect of latitude on catch is smaller when using the MARMAP Universe data set
    - Bottom temperature – covariate is only retained in the full time-series models
        - When retained, the predicted effect of bottom temperature differs depending on the data set used
            - SERFS Universe data set – generally increases over the range of temperatures observed
            - MARMAP Universe data set – catch peaks at temperatures of 15-26.9°C, decreasing at lower and higher temperatures
- Predicted effect of covariates are generally more coarse when modeling the covariates as discrete covariates than suggested when model covariates as continuous variables using polynomials
- Predicted covariate effects are generally more extreme (see y-axis scale of Figure 9) when covariates are modeled as polynomials instead of as discrete variables

2010 – 2014 Time Series Models

Initially, the goal was to focus on only the four relative abundance index models constructed using the data available from 2010-2014. By excluding the data from 1990-2009, one can focus on the impact that each individual data set (SERFS Universe vs. MARMAP Universe) had on the predicted relative abundance trends. This allows one to investigate whether the recent increase in capture rate (and relative abundance) of Red Snapper in the survey reflect shifts in spatial sampling distribution of the survey or changes in relative abundance? Under the null hypothesis of no change in the predicted relative abundance trend of Red Snapper as a function of data set, one would expect a significant positive correlation among indices, regardless of data set used. This indicates whether the traditional MARMAP chevron trap survey stations, as randomly sampled from 2010 to 2014, can adequately characterize the recent abundance trends of Red Snapper in the region, assuming the abundance trend observed using all the data (SERFS Universe) is the "true" abundance trend.

<u>Relative Abundance and Index Correlation</u>

(see Table 7 and Figure 12)

- Relative abundance trend is similar across all four models (generally increasing throughout the time series)
    - Exception is the model using the MARMAP Universe data set and treating covariates as discrete variables (exhibits least correlation with other models)
        - Indicates increasing trend in relative abundance from 2012-2013 while all other models suggest decreasing trend
        - Indicates higher terminal year relative abundance and lower relative abundance in 2012 compared to other models
- All models are correlated at >90% confidence level
    - Models using continuous covariates modeled as polynomials correlated at >95% confidence level
    - Model using SERFS Universe data set and discrete covariates is correlated with the two models modeling the continuous covariates using polynomials at >95% confidence level

<u>Summary</u>

- Indices produce similar relative abundance trends
    - Regardless of data set used
        - Suggest traditional MARMAP stations (representing traditional MARMAP annual spatial distribution of samples) adequately characterize changes in relative abundance of Red Snapper throughout the region
    - Regardless of covariate treatment methodology in standardization model
- Continuous covariate models…
    - More stable despite estimating more parameters
    - Better capture "catch patterns" of Red Snapper in the region
- Models using the SERFS Universe data set produce lower coefficient of variation estimates (Figure 8)

1990 – 2014 Time Series Models

Now the goal is to focus on comparing the short time-series models presented above to relative abundance indices of a similar structure based on the full chevron trap survey time-series (1990-2014; Figure 7) to answer the question does the historical data accurately represent historical relative abundance in the region. If one concludes, based on the above analysis, that the traditional MARMAP chevron trap stations identified prior to 2010 do an adequate job characterizing regional Red Snapper abundance during the period 2010-2014, one can then assume that they would adequately characterize Red Snapper relative abundance in the region over the period 1990-2009. Given this assumption, under the null hypothesis that the historical data does accurately characterize regional Red Snapper abundance, we would expect a high degree of positive correlation in the predicted abundance trends of the full time-series models to the short time-series models. To simplify interpretation, in the correlation analysis I will only compare the four long time-series models presented here to the two "best" short time-series models, those being the two using the SERFS Universe data set (differ in covariate treatment only).

<u>Relative Abundance and Index Correlation</u>

(see Table 8, Figure 13 and Figure 14)

- Relative abundance trend is similar across all models considered
    - All models suggest increasing trend in relative abundance from 2010-2014
        - Excellent agreement in relative abundance trends among models using same data set and covariate treatment approach, but different start years (Figure 14)
    - All full time-series models exhibit good agreement regarding relative abundance over the period 1990-2009
- All models compared are correlated at >90% confidence level (Table 8)
    - All full time-series models are correlated at >99.9% confidence level
    - Most (7 of 8) full time-series models are correlated with the SERFS Universe data restricted time-series models at >95% confidence level
        - Exception is the full time-series model using MARMAP Universe data set and discrete covariates is correlated with the restricted time-series model using the SERFS Universe data set and discrete covariates at only >90% confidence level

<u>Summary</u>

- High degree of positive correlation among all models investigated
    - All models developed using the current station universe (SERFS Universe data set), and hence most data to inform covariate effects, correlated at >95% confidence level
        - Regardless of covariate treatment
        - Suggest they are modeling the same "signal," after accounting for covariate effects, regarding Red Snapper relative abundance
            - Standardization model appears to be working appropriately and as expected by removing the effect of annual variability in sampling distribution with regards to important environmental variables from observed relative abundance
- Indices produce similar relative abundance trends
    - Regardless of data set used
        - Suggest traditional MARMAP chevron trap stations (representing traditional MARMAP annual spatial distribution of samples) adequately characterize changes in relative abundance of Red Snapper throughout the region
    - Regardless of covariate treatment methodology in standardization model
- Continuous covariate models…
    - More stable despite estimating more parameters
    - Better capture "catch patterns" of Red Snapper in the region
- Model stability greater for full time-series models compared to same configuration restricted time-series models
    - Continuous covariate models are more stable despite estimating more parameters
- Continuous covariate models better capture "catch patterns" of Red Snapper in the region
    - Full time-series models do better job than other models
- Time series average CV estimates for full time-series models are larger than restricted time-series counterparts
    - Product of smaller sample sizes in earlier years

  - Produce similar CV estimates as their restricted time-series counterparts during the period 2010-2014
- Within model structure (covariates modeled as polynomials vs. discrete variables), CV estimates are similar when using full vs. restricted time-series

Comparison to SEDAR 24 Indices
(see Figure 15)

- All indices seem to be in general agreement regarding the overall time-series pattern
  - Decreasing relative abundance pattern from late 1970s through early- and mid-1990s
  - Low relative abundance through late 1990s
  - Brief increase in relative abundance in early 2000s prior to another decrease in relative abundance
  - Consistent increase in relative abundance since the late 2000s

Conclusions
- Strong evidence that, after accounting for annual shifts in sampling distribution with regard to several covariates, that data derived solely from historical MARMAP chevron trap stations can adequately track annual Red Snapper relative abundance
  - If wasn't the case, wouldn't expect the high degree of correlation exhibited between indices developed using data only from historical chevron trap stations (MARMAP Universe data set) and those using the current chevron trap data set (SERFS Universe data set)
  - Further, models developed from different data sets are predicting similar effects of covariates on Red Snapper relative abundance
- As expected, CV estimates for the years 1990-2009 are somewhat larger than those estimated for 2010-2014
  - This is a product of annual sample size of the chevron trap survey, with the net effect of increasing sampling intensity in the recent time period being to decrease uncertainty around relative abundance trends
- Models that allow covariates that are originally measured on a continuous scale to be modeled as continuous variables, with a possibly non-linear effect on the response variable, perform better than analogous models that convert the continuous covariates to discrete variables

Pre-Data Workshop Recommendation
- Use the full time-series relative abundance index using data from all valid stations sampled via chevron traps (SERFS Universe data set) and modeling covariates as continuous variables using polynomials in the assessment model
  - Extends the fishery-independent chevron trap index back an additional 20 years
    - Bridges the gap between the termination of most of the fishery-dependent surveys used in SEDAR 24 and the other fishery-independent index developed using videos that begins in 2010

- Brings the available length comp and age comp data associated with the index into the assessment model for consideration, which can be important for informing year class strength

References

Collins, M.R. 1990. A comparison of three fish trap designs. Fisheries Research 9(4): 325-332.

Jackman, S. 2011. pscl: Classes and Methods for R Developed in the Political Science Computational Laboratory, Stanford University. Department of Political Science, Stanford University. Stanford, California. R package version 1.04.1. URL http://pscl.stanford.edu/.

MARMAP. 2009. Overview of sampling gear and vessels used by MARMAP: Brief descriptions and sampling protocol. Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, SC, 40p.

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Schwarz, G. 1978. Estimating the dimension of a model. Annals of Statistics 6: 461-464.

Smart, T.I. and M.J.M. Reichert. 2015. Southeast Reef Fish Survey (SERFS) Sampling Protocols. SEDAR41-RD55.

Wood, S.N. 2000. Modeling and smoothing parameter estimation with multiple quadratic penalties. Journal of the Royal Statistical Society (B) 62(2): 413-428.

Wood, S.N. 2003. Thin-plate regression splines. Journal of the Royal Statistical Society (B) 65(1): 95-114.

Wood, S.N. 2004. Stable and efficient multiple smoothing parameter estimation for generalized additive models. Journal of the American Statistical Association 99: 673-686.

Wood, S.N. 2006. Generalized Additive Models: An Introduction with R. Chapman and Hall/CRC.

Wood, S.N. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society (B) 73(1): 3-36.

Zeileis, A., C. Kleiber, and S. Jackman. 2008. Regression models for count data in R. Journal of Statistical Software 27(8). URL http://www.jstatsoft.org/v27/i08/.

Tables

Table 1: Annual distribution of stations in the chevron trap universe (known live-bottom/hard-bottom stations available for selection via random sampling annually) according to latitude and depth strata. Strata are defined based on multivariate partitioning based on changes in chevron trap catch species composition. Each column represents the number of stations in the universe found in each stratum in a given year.

	Survey Strata											
	Southern Latitudes (<29.71°N)				Mid Latitudes (29.71-32.60°N)				Northern Latitudes (≥32.61°N)			
Year	Inner Shelf (<30 m)	Mid Shelf (30-42 m)	Outer Shelf (43-63 m)	Slope (≥64 m)	Inner Shelf (<30 m)	Mid Shelf (30-42 m)	Outer Shelf (43-63 m)	Slope (≥64 m)	Inner Shelf (<30 m)	Mid Shelf (30-42 m)	Outer Shelf (43-63 m)	Slope (≥64 m)
1990	0	0	0	0	489	109	393	10	286	276	104	1
1991	0	0	0	0	498	109	396	10	286	276	104	1
1992	0	0	0	0	498	109	396	10	286	276	104	1
1993	0	0	0	0	498	131	396	10	287	276	104	1
1994	0	0	0	0	498	133	427	15	287	276	105	2
1995	0	0	0	0	499	137	450	15	287	276	105	2
1996	0	0	0	0	499	141	462	16	297	276	105	2
1997	6	0	0	0	499	146	487	19	312	279	105	2
1998	72	2	8	0	499	154	501	19	320	295	106	5
1999	72	2	22	0	499	155	507	19	320	297	107	5
2000	72	2	22	0	502	158	531	19	325	317	107	6
2001	72	2	22	0	502	159	546	33	328	323	125	6
2002	72	2	22	0	502	163	572	43	328	326	125	6
2003	75	2	22	0	502	163	574	43	330	330	125	6
2004	75	2	22	0	502	163	575	60	330	330	127	6
2005	75	2	22	0	502	163	575	60	330	330	127	6
2006	75	2	22	0	502	163	578	60	341	330	127	6
2007	77	2	22	0	502	164	579	60	348	333	130	11
2008	77	2	22	0	502	164	579	60	348	333	130	11
2009	77	2	22	0	502	164	579	60	348	333	130	19
2010	101	28	65	3	528	238	670	75	352	339	130	19
2011	139	48	117	3	565	252	713	76	390	347	132	25
2012	168	64	122	3	574	294	729	79	450	427	207	65
2013	272	114	145	3	612	360	785	90	456	453	214	65
2014	279	116	150	3	621	360	793	90	567	623	293	101

Table 2: Number of chevron trap stations sampled, proportion of traps positive for Red Snapper, and the total number of Red Snapper captured annually, by data set.

	SERFS Universe			MARMAP Universe		
Year	**# of Traps**	**Prop. Pos.**	**# of Fish**	**# of Traps**	**Prop. Pos.**	**# of Fish**
1990	300	0.023	23	300	0.023	23
1991	265	0.023	17	265	0.023	17
1992	288	0.028	20	288	0.028	20
1993	391	0.031	31	391	0.031	31
1994	388	0.049	45	388	0.049	45
1995	333	0.021	13	333	0.021	13
1996	365	0.016	6	365	0.016	6
1997	382	0.016	24	382	0.016	24
1998	428	0.019	25	428	0.019	25
1999	216	0.005	1	216	0.005	1
2000	286	0.028	17	286	0.028	17
2001	237	0.03	9	237	0.03	9
2002	238	0.055	33	238	0.055	33
2003	219	0.005	7	219	0.005	7
2004	283	0.014	5	283	0.014	5
2005	303	0.023	12	303	0.023	12
2006	286	0.014	5	286	0.014	5
2007	330	0.024	29	330	0.024	29
2008	297	0.024	19	297	0.024	19
2009	391	0.02	10	391	0.02	10
2010	581	0.069	89	402	0.027	14
2011	674	0.096	116	290	0.028	10
2012	1114	0.125	398	413	0.022	15
2013	1331	0.105	367	423	0.035	22
2014	1429	0.105	614	343	0.07	51
Total	**11355**	**0.059**	**1935**	**8097**	**0.026**	**463**

Table 3: Summary metrics for the two data sets considered in the report. Note the similar annual sample size between the two times using the MARMAP Universe data set. "–" represents NA

Metric	Time Period	SERFS Universe	MARMAP Universe
Annual Sample Size	1990-2009	–	311 (216-428)
	2010-2014	1026 (581-1429)	374 (290-402)
# of Years Proportion Positive > 5%	1990-2009	–	1
	2010-2014	5	1
Avg. Proportion Positive	1990-2009	–	0.023
	2010-2014	0.1	0.036
Avg. Fish/Year	1990-2009	–	18
	2010-2014	317	22
Avg. Fish/Positive Trap	1990-2009	–	2.4
	2010-2014	3	1.7
Nominal Catch/Trap	1990-2009	–	0.0564
	2010-2014	0.3088	0.0599

Table 4: Covariate bin structure as defined during the SEDAR 41 Data Workshop held in 2014.

	Covariate			
Bin	**Depth (m)**	**Latitude (oN)**	**Bottom Temperature (oC)**	**Day of Year**
1	< 30	< 28.00	< 15.0	< 150
2	30 – 44	28.00 – 29.99	15.0 – 26.9	150 – 199
3	45 – 59	30.00 – 32.49	≥ 27.0	200 – 249
4	≥ 60	32.50 – 33.99	–	≥ 250
5	–	≥ 34.00	–	–

Table 5: Model structures of each of the best-fit models. Numbers represent the maximum polynomial order for individual covariates. ✓ indicates discrete covariate retained in model. Count = indicates the count sub-model of the ZINB. ZI = zero-inflation sub-model of the ZINB. Lower BIC among pairs of models (1 per column) not separated by line (dashed or solid) indicates most parsimonious model.

		Index Model							
		1990-2014 Time Period				**2010-2014 Time Period**			
		SERFS Universe Data Set		**MARMAP Universe Data Set**		**SERFS Universe Data Set**		**MARMAP Universe Data Set**	
Variable	**Model**	**Polynomial Covariates**	**Discrete Covariates**	**Polynomial Covariates**	**Discrete Covariates**	**Polynomial Covariates**	**Discrete Covariates**	**Polynomial Covariates**	**Discrete Covariates**
Latitude	Count	7	–	5	–	7	✓	1	–
Depth	Count	7	–	3	–	3	✓	4	–
Temperature	Count	1	✓	1	✓	2	–	1	–
Day of Year	Count	–	–	1	–	–	–	1	–
Year	ZI	–	–	–	–	–	–	–	–
Latitude	ZI	4	✓	2	✓	4	✓	4	✓
Depth	ZI	3	✓	1	✓	3	✓	1	✓
Temperature	ZI	–	–	–	–	–	–	–	–
Day of Year	ZI	1	–	–	–	–	–	2	–
	Year Parameters	24	24	24	24	4	4	4	4
	Total Parameters	50	36	40	36	26	21	21	14
	BIC	6760	6936	2656	2674	4757	4950	735	724

Table 6: Model fit diagnostic comparison. Convergence rate is the percentage of 10,000 bootstraps that converged. Obs. Max # in Trap is the maximum number of Red Snapper captured in any trap. Pred. Max # in Trap is the maximum number of Red Snapper predicted to be caught in any given trap according to the model.

Model Structure			Stability and Performance			Coefficient of Variation		
Time Period	**Data Set**	**Covariate Treatment**	**Convergence Rate (%)**	**Obs. Max # in Trap**	**Pred. Max # in Trap**	**Mean**	**Median**	**Range**
2010 – 2014	SERFS	Polynomial	99.94%	54 fish	3.7 fish	0.141	0.119	0.113 – 0.198
2010 – 2014	MARMAP	Polynomial	96.62%	9 fish	3.2 fish	0.342	0.364	0.214 – 0.425
2010 – 2014	SERFS	Discrete	51.87%	54 fish	2.3 fish	0.150	0.137	0.115 – 0.201
2010 – 2014	MARMAP	Discrete	81.91%	9 fish	0.6 fish	0.313	0.335	0.154 – 0.397
1990 – 2014	SERFS	Polynomial	99.91%	54 fish	6.3 fish	0.485	0.448	0.185 – 1.023
1990 – 2014	MARMAP	Polynomial	98.44%	20 fish	4.5 fish	0.539	0.470	0.306 – 1.175
1990 – 2014	SERFS	Discrete	94.78%	54 fish	1.8 fish	0.464	0.432	0.162 – 1.000
1990 – 2014	MARMAP	Discrete	71.05%	20 fish	0.6 fish	0.501	0.423	0.266 – 1.019

Table 7: Pearson's correlation among all pairwise comparisons of the four relative abundance indices using a start year of 2010.

Model 1		**Model 2**		**Correlation Statistics**		
Data Set	**Covariate Treatment**	**Data Set**	**Covariate Treatment**	**df**	**r**	**p-value**
SERFS	Polynomial	SERFS	Discrete	3	0.9503	0.0066
SERFS	Polynomial	MARMAP	Polynomial	3	0.9301	0.011
SERFS	Polynomial	MARMAP	Discrete	3	0.8959	0.0198
SERFS	Discrete	MARMAP	Polynomial	3	0.9626	0.0043
SERFS	Discrete	MARMAP	Discrete	3	0.7217	0.0843
MARMAP	Polynomial	MARMAP	Discrete	3	0.7125	0.0884

Table 8: Pearson's correlation among all pairwise comparisons of the four full time-series (1990-2014) relative abundance indices and the two restricted time series (2010-2014) relative abundance indices using the SERFS Universe data set.

Model 1			**Model 2**			**Correlation Statistics**		
Data Set	**Time Period**	**Covariate Treatment**	**Data Set**	**Time Period**	**Covariate Treatment**	**df**	**r**	**p-value**
SERFS	1990-2014	Polynomial	SERFS	1990-2014	Discrete	23	0.872	<0.0001
SERFS	1990-2014	Polynomial	MARMAP	1990-2014	Continuous	23	0.8122	<0.0001
SERFS	1990-2014	Polynomial	MARMAP	1990-2014	Discrete	23	0.7092	<0.0001
SERFS	1990-2014	Polynomial	SERFS	2010-2014	Continuous	3	0.9335	0.0102
SERFS	1990-2014	Polynomial	SERFS	2010-2014	Discrete	3	0.8765	0.0256
SERFS	1990-2014	Discrete	MARMAP	1990-2014	Continuous	23	0.7533	<0.0001
SERFS	1990-2014	Discrete	MARMAP	1990-2014	Discrete	23	0.7131	<0.0001
SERFS	1990-2014	Discrete	SERFS	2010-2014	Continuous	3	0.9416	0.0084
SERFS	1990-2014	Discrete	SERFS	2010-2014	Discrete	3	0.978	0.0019
MARMAP	1990-2014	Polynomial	MARMAP	1990-2014	Discrete	23	0.8968	<0.0001
MARMAP	1990-2014	Polynomial	SERFS	2010-2014	Continuous	3	0.9833	0.0013
MARMAP	1990-2014	Polynomial	SERFS	2010-2014	Discrete	3	0.9096	0.0161
MARMAP	1990-2014	Discrete	SERFS	2010-2014	Continuous	3	0.8931	0.0206
MARMAP	1990-2014	Discrete	SERFS	2010-2014	Discrete	3	0.7131	0.0881

Figures

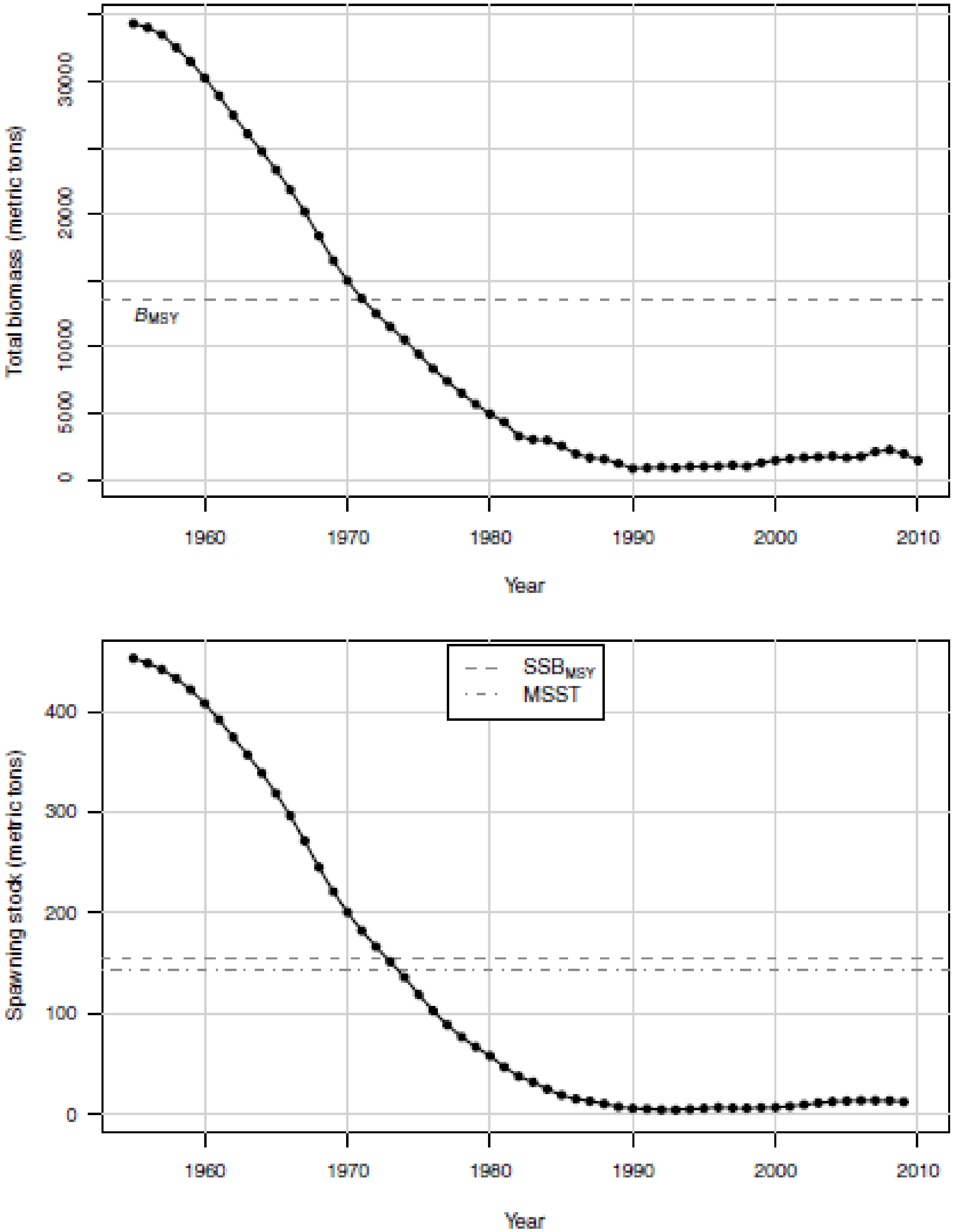

Figure 1: Predicted total biomass (top panel) and spawning stock biomass (bottom panel) of Red Snapper derived from final SEDAR 24 stock assessment (SEDAR 24).

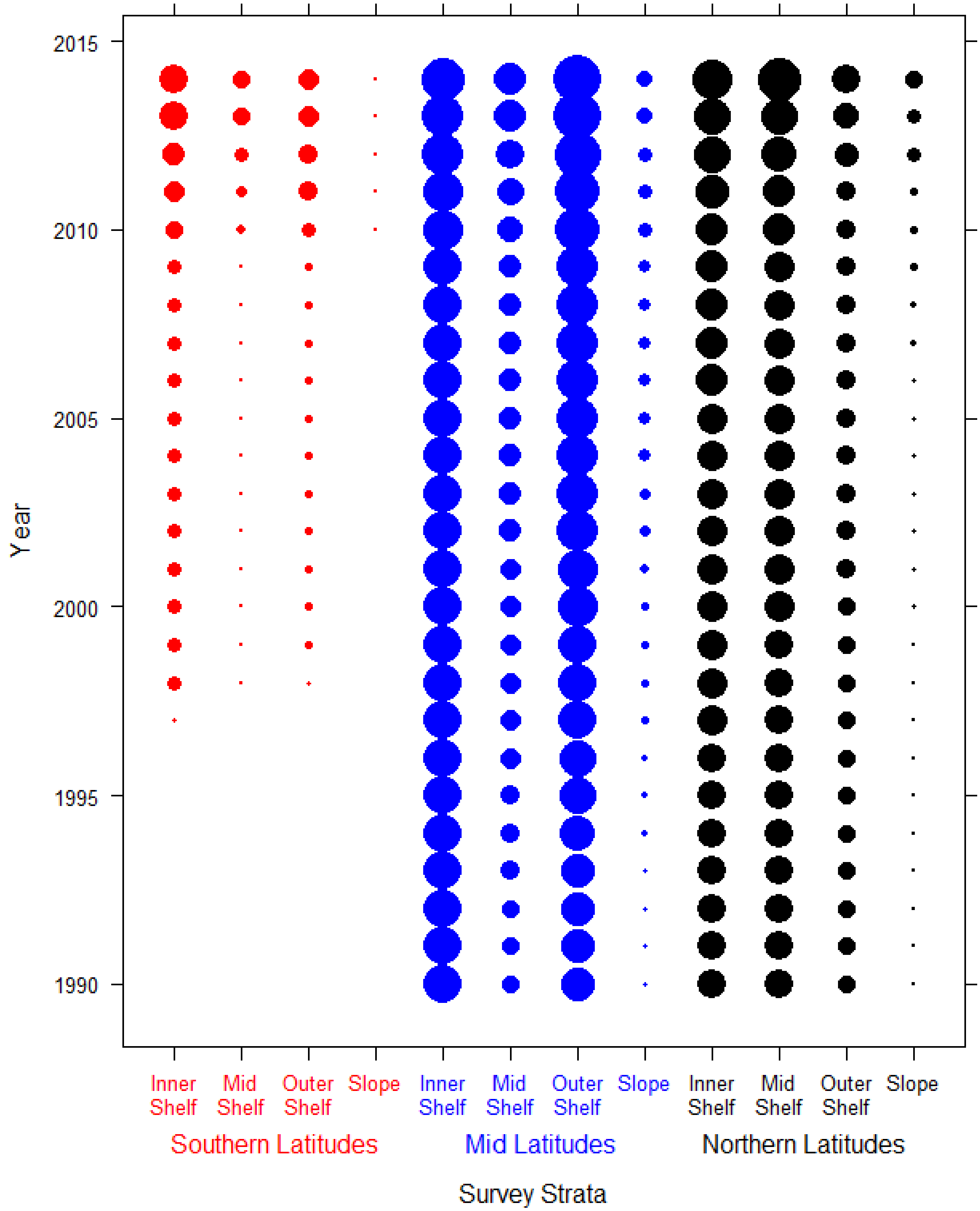

Figure 2: Distribution of SERFS chevron trap stations according to latitude and depth strata. Area of each circle is proportion to the total number of stations found in the strata.

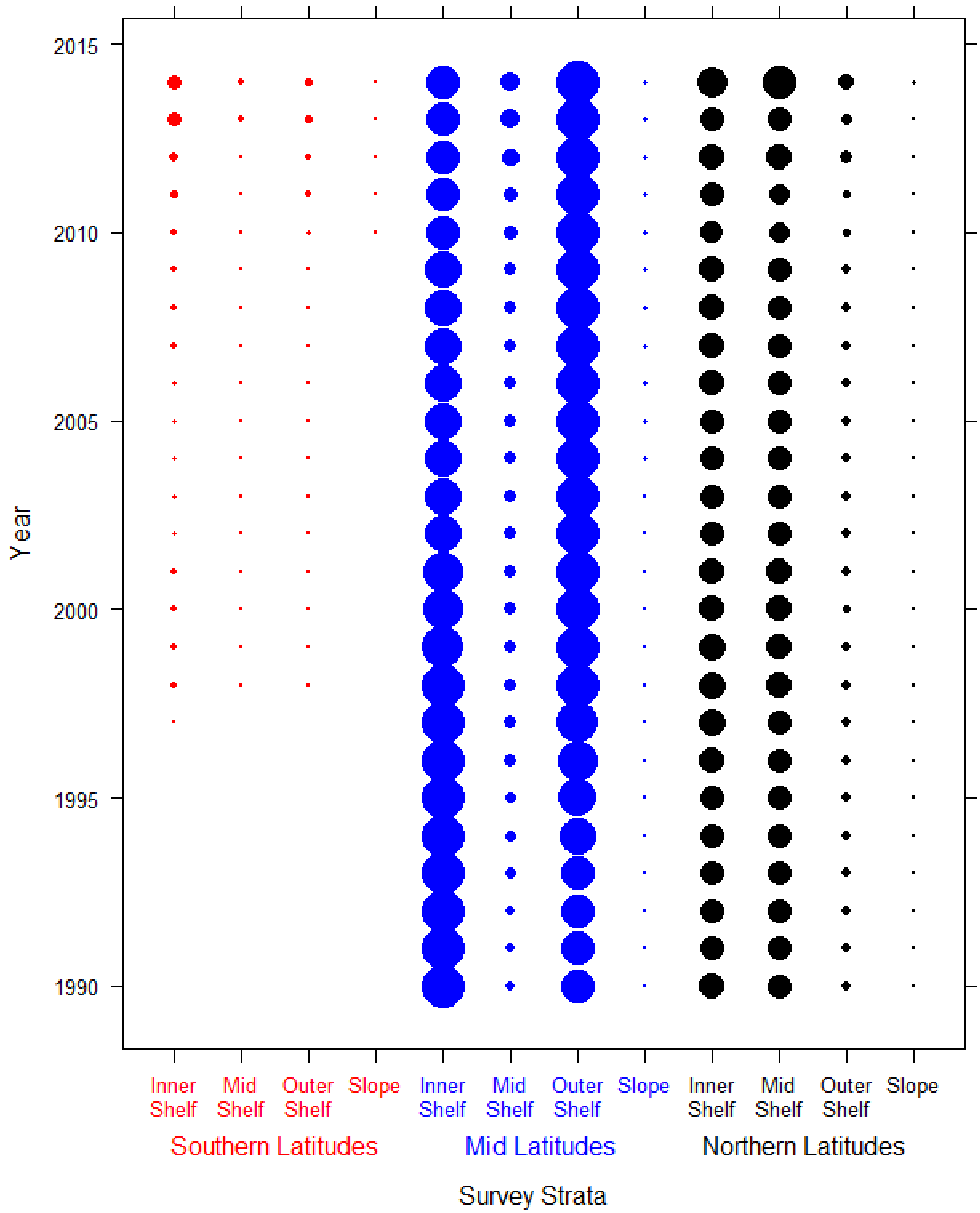

Figure 3: Distribution of SERFS chevron trap universe stations according to latitude and depth strata. Size of each circle in each year is proportional to the strata possessing the maximum number of stations in that year.

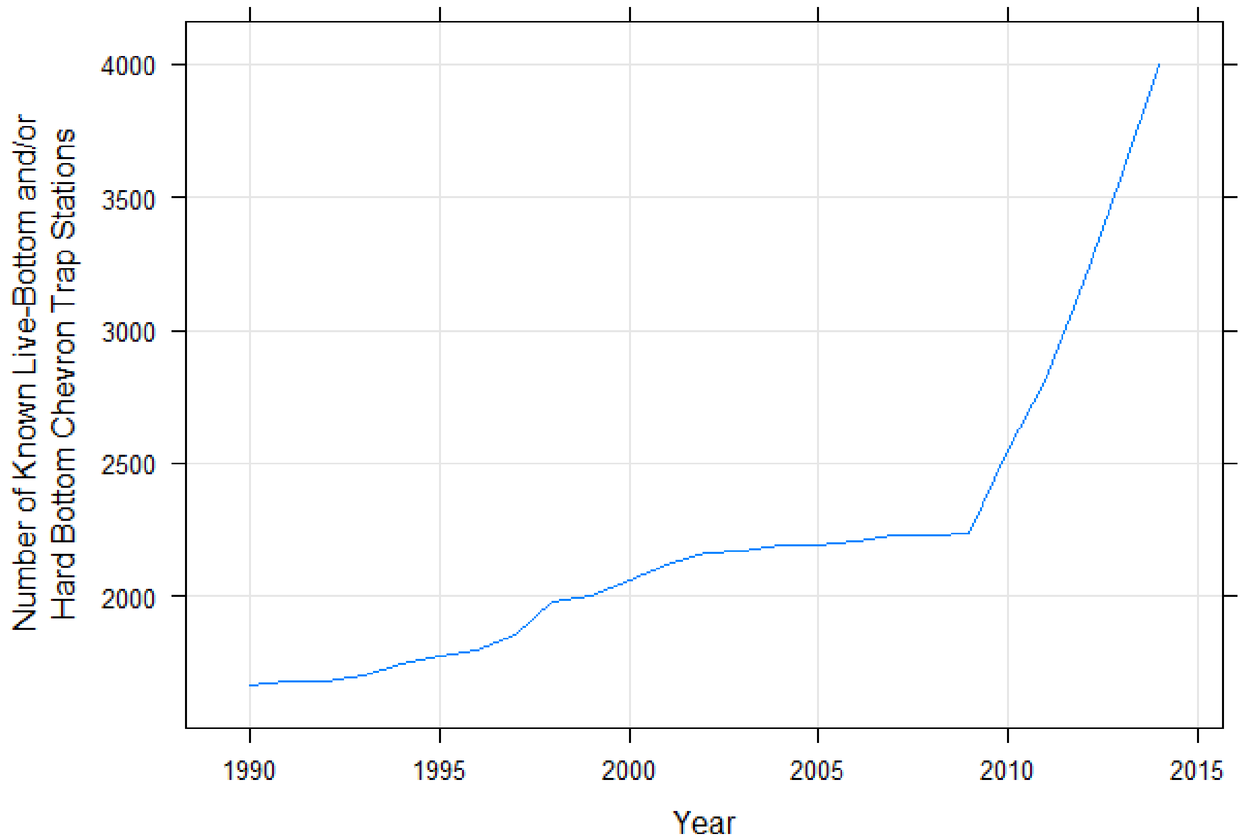

Figure 4: Time series of the number of stations composing the chevron trap station universe (locations with known live-bottom and/or hard-bottom habitat suitable for sampling via chevron traps). The drastic increase in known live-bottom and/or hard bottom stations since 2009 is driven primarily by the geographic expansion in the survey made possible due to the addition of funds via the SEAMAP-SA Reef Fish Complement and SEFIS programs. The chevron trap universe in 2009 represents the traditional MARMAP chevron trap universe, representing the geographic distribution of stations available for random sampling by the SERFS program during all years of the chevron trap index. The chevron trap universe in 2014 represents the current universe of known live-bottom and/or hard-bottom habitat identified by the SERFS program, with many of these new stations being found off the coast of Florida.

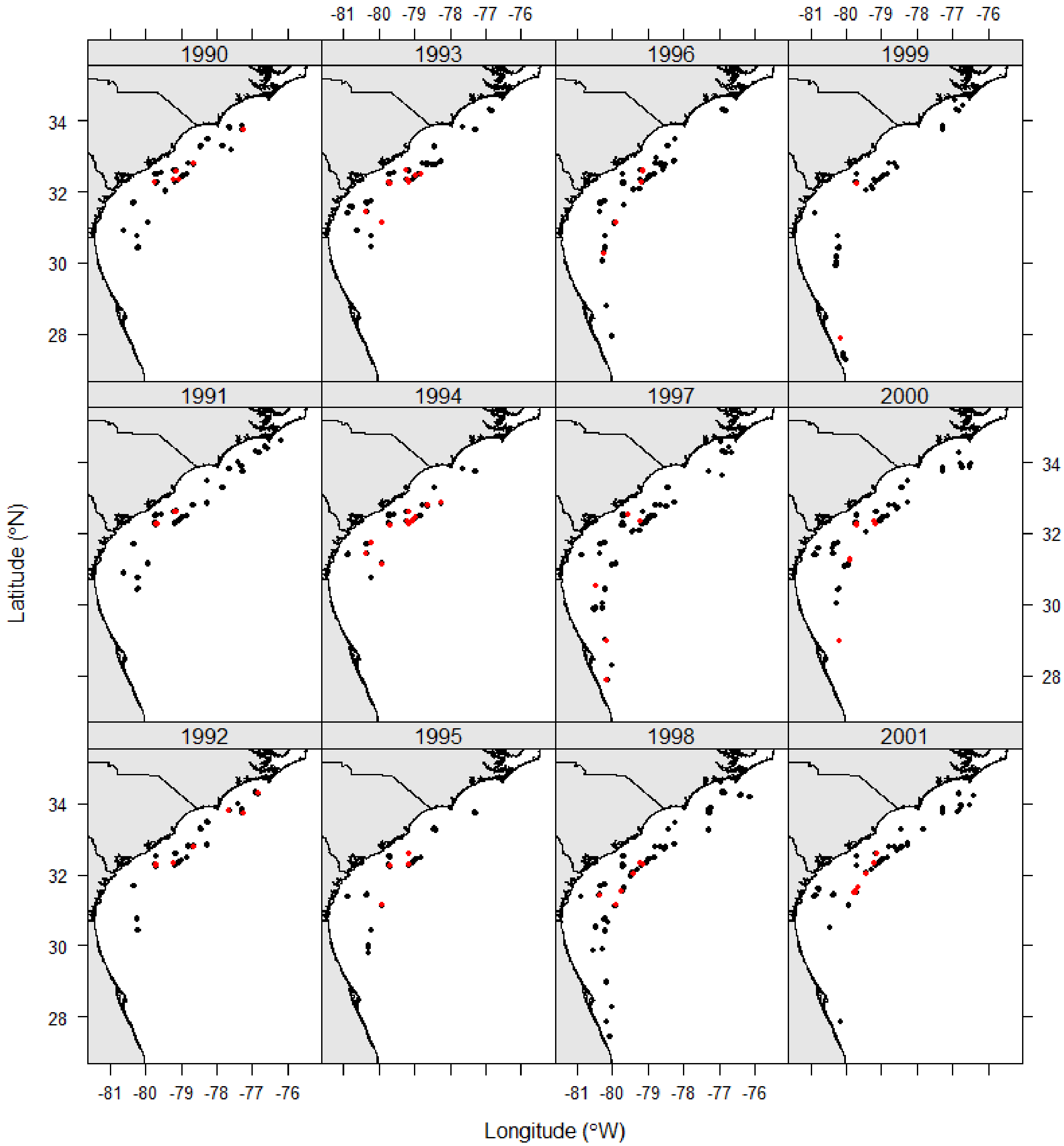

Figure 5: Annual sampling distribution of the SERFS chevron trap survey from 1990-2014 using the SERFS Universe (all valid chevron trap samples from a given year). Black dots represent samples absent of Red Snapper. Red dots represent samples where Red Snapper were captured.

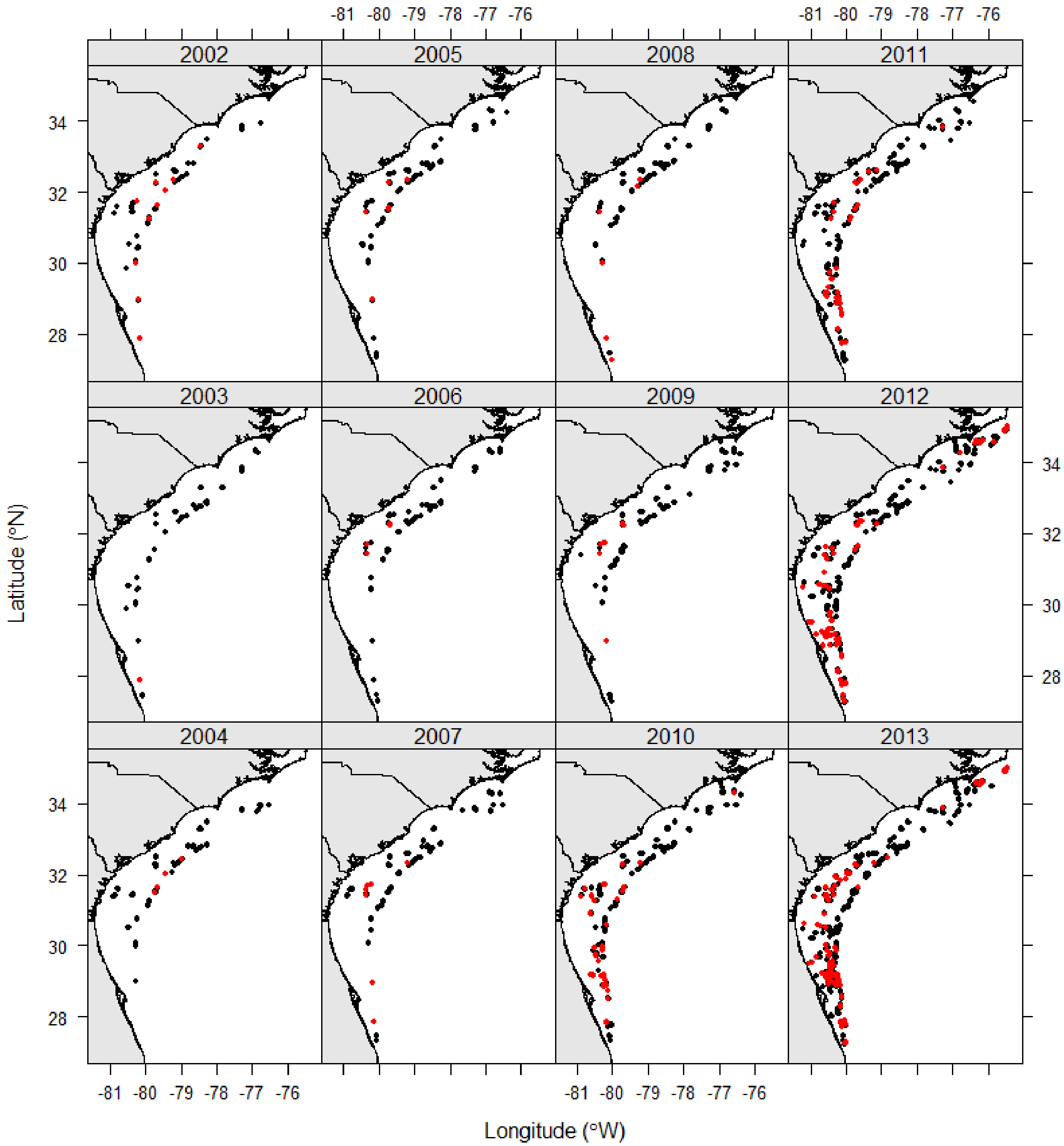

Figure 5: continued

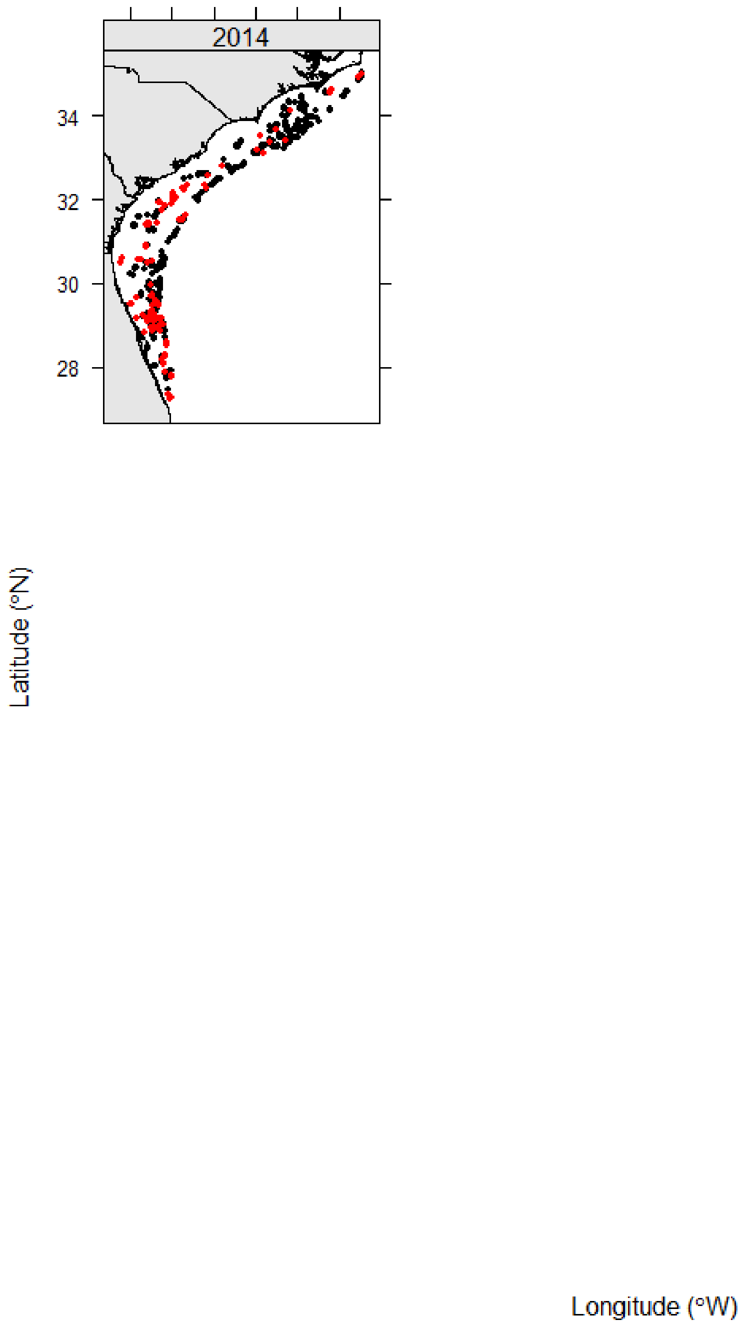

Figure 5: continued

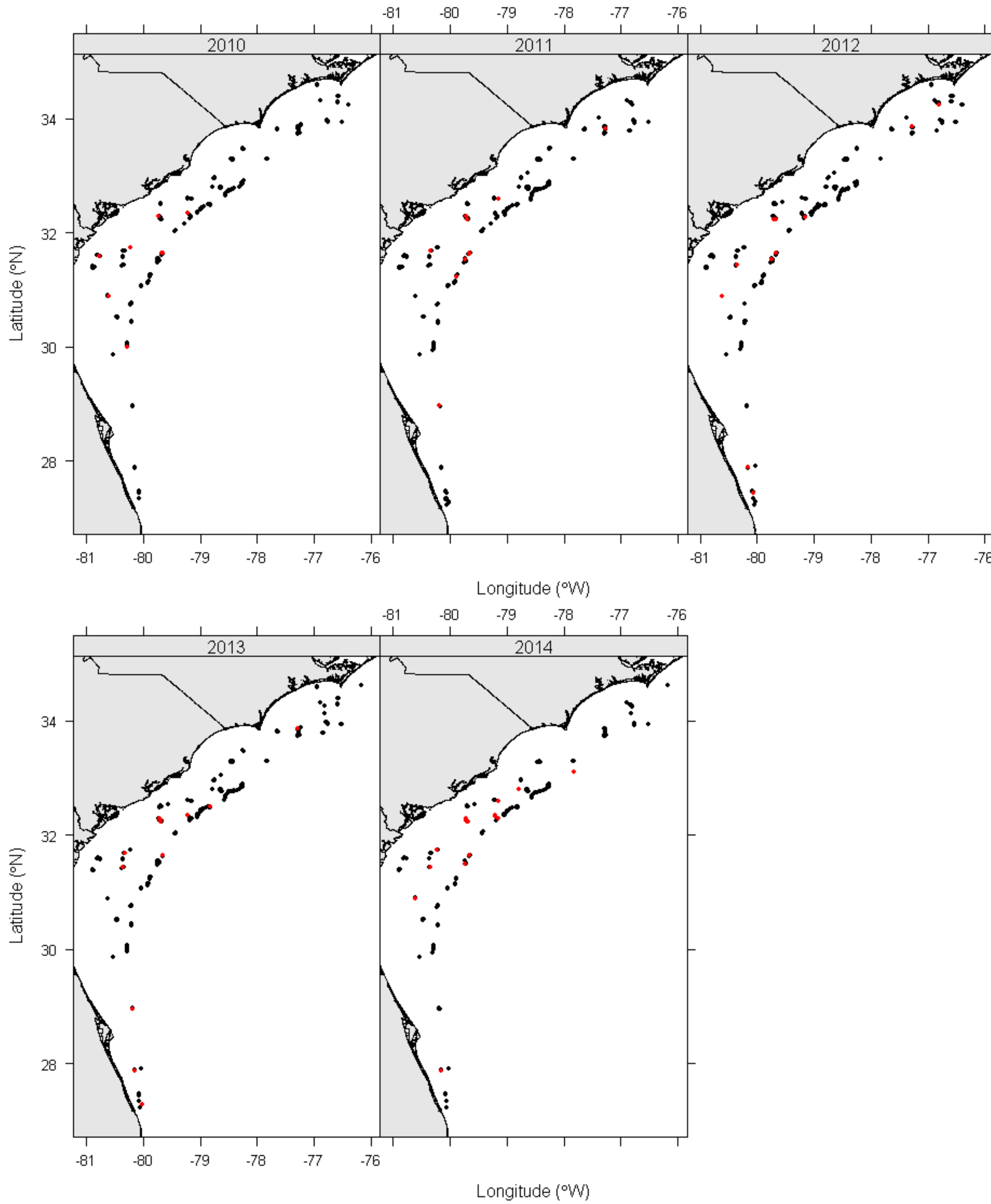

Figure 6: Annual sampling distribution of the SERFS chevron trap survey from 2010-2014 based only on those stations contained within the MARMAP chevron trap station universe at the beginning of the 2010 sampling season (identified as known live-bottom and/or hard-bottom habitat prior to 2010).

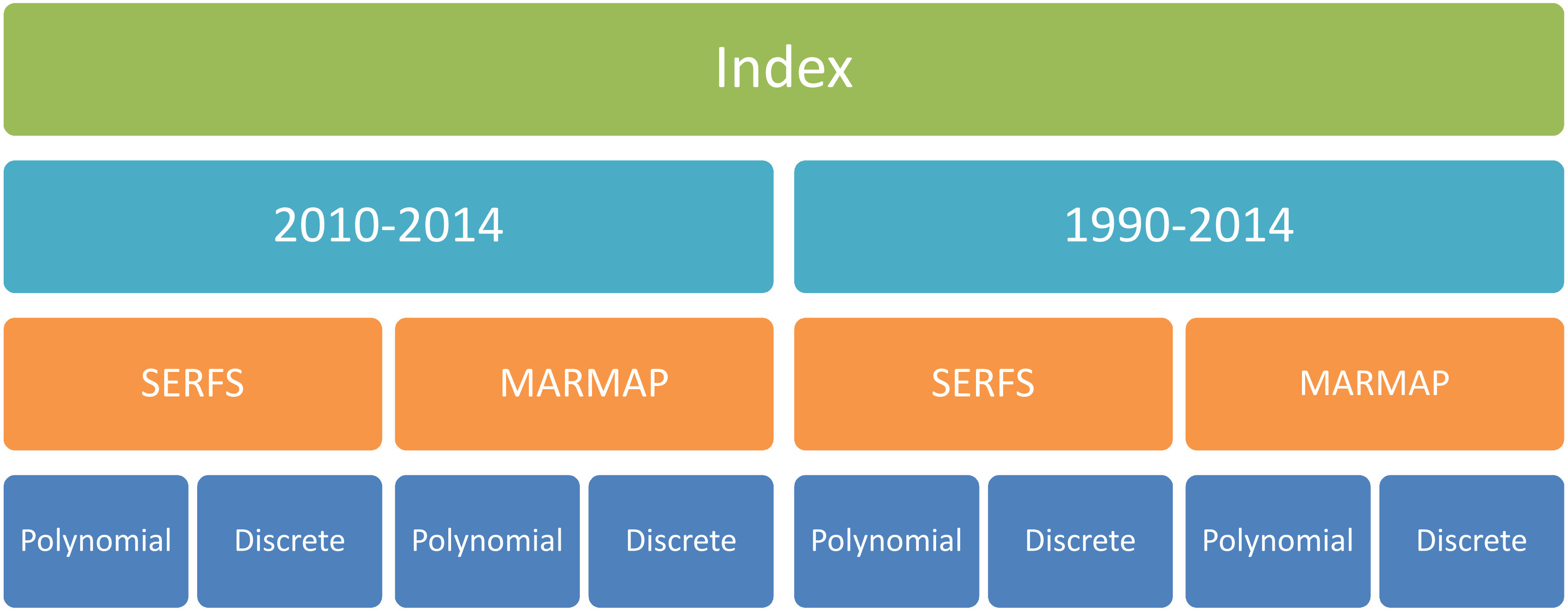

Figure 7: Hierarchical depiction of the eight relative abundance indices considered.

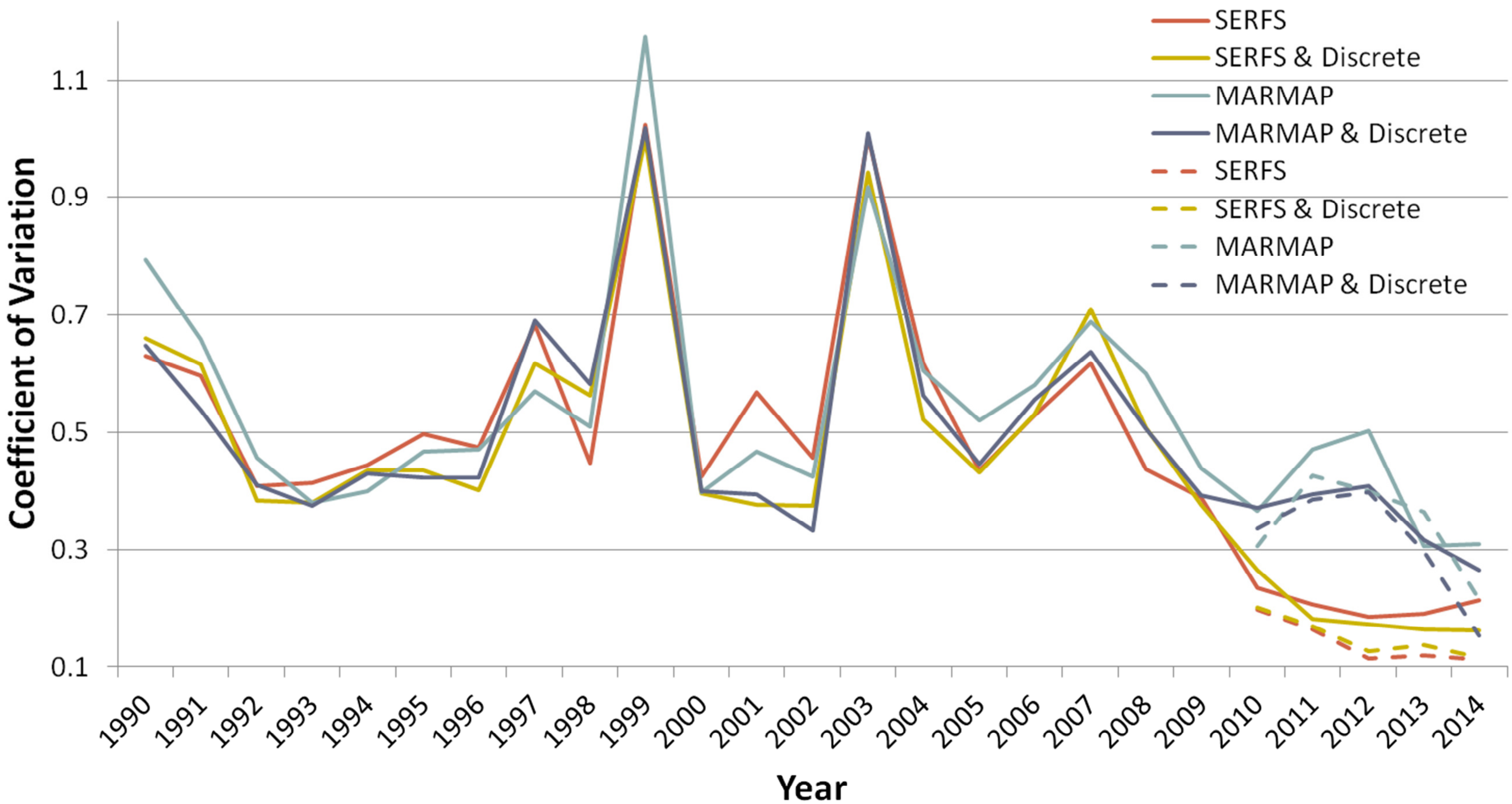

Figure 8: Annual coefficient of variation estimates from each of the eight models considered. Dashed lines represent models based on the restricted time series (2010-2014). Discrete in the legend refers to models using discrete covariates in the model (if missing indicates used covariates modeled as polynomials). SERFS and MARMAP refer to the data set used in the analysis, the SERFS Universe data set and MARMAP universe data set, respectively.

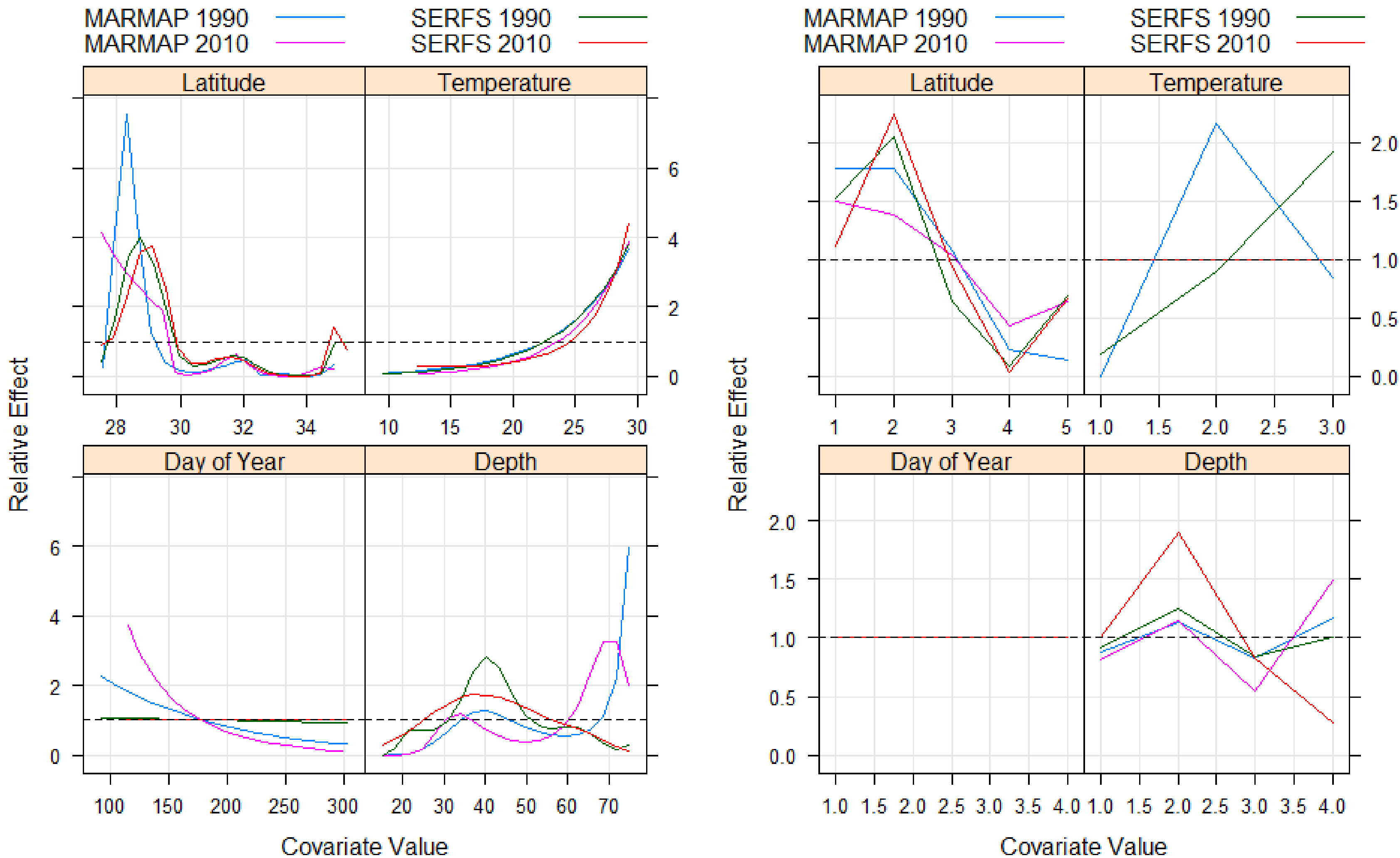

Figure 9: Predicted covariate effects from each of the eight models. Left side presents the covariate effects using continuous covariates modeled as polynomials. Right side presents the covariate effects using discrete covariates, with x-axis numbers representing bin number (refer to Table 4

Year	SERFS Universe			MARMAP Universe		
	# of Traps	Prop. Pos.	# of Fish	# of Traps	Prop. Pos.	# of Fish
1990	300	0.023	23	300	0.023	23
1991	265	0.023	17	265	0.023	17
1992	288	0.028	20	288	0.028	20
1993	391	0.031	31	391	0.031	31
1994	388	0.049	45	388	0.049	45
1995	333	0.021	13	333	0.021	13
1996	365	0.016	6	365	0.016	6
1997	382	0.016	24	382	0.016	24
1998	428	0.019	25	428	0.019	25
1999	216	0.005	1	216	0.005	1
2000	286	0.028	17	286	0.028	17
2001	237	0.03	9	237	0.03	9
2002	238	0.055	33	238	0.055	33
2003	219	0.005	7	219	0.005	7
2004	283	0.014	5	283	0.014	5
2005	303	0.023	12	303	0.023	12
2006	286	0.014	5	286	0.014	5
2007	330	0.024	29	330	0.024	29
2008	297	0.024	19	297	0.024	19
2009	391	0.02	10	391	0.02	10
2010	581	0.069	89	402	0.027	14
2011	674	0.096	116	290	0.028	10
2012	1114	0.125	398	413	0.022	15
2013	1331	0.105	367	423	0.035	22
2014	1429	0.105	614	343	0.07	51
Total	**11355**	**0.059**	**1935**	**8097**	**0.026**	**463**

Table 3: Summary metrics for the two data sets considered in the report. Note the similar annual sample size between the two times using the MARMAP Universe data set. "–" represents NA

Metric	Time Period	SERFS Universe	MARMAP Universe
Annual Sample Size	1990-2009	–	311 (216-428)
	2010-2014	1026 (581-1429)	374 (290-402)

# of Years Proportion Positive > 5%	1990-2009	–	1
	2010-2014	5	1
Avg. Proportion Positive	1990-2009	–	0.023
	2010-2014	0.1	0.036
Avg. Fish/Year	1990-2009	–	18
	2010-2014	317	22
Avg. Fish/Positive Trap	1990-2009	–	2.4
	2010-2014	3	1.7
Nominal Catch/Trap	1990-2009	–	0.0564
	2010-2014	0.3088	0.0599

Table 4). MARMAP and SERFS refer to the use of the MARMAP Universe data set and SERFS Universe data set in the model, respectively. 1990 and 2010 represent the start year of the model in question.

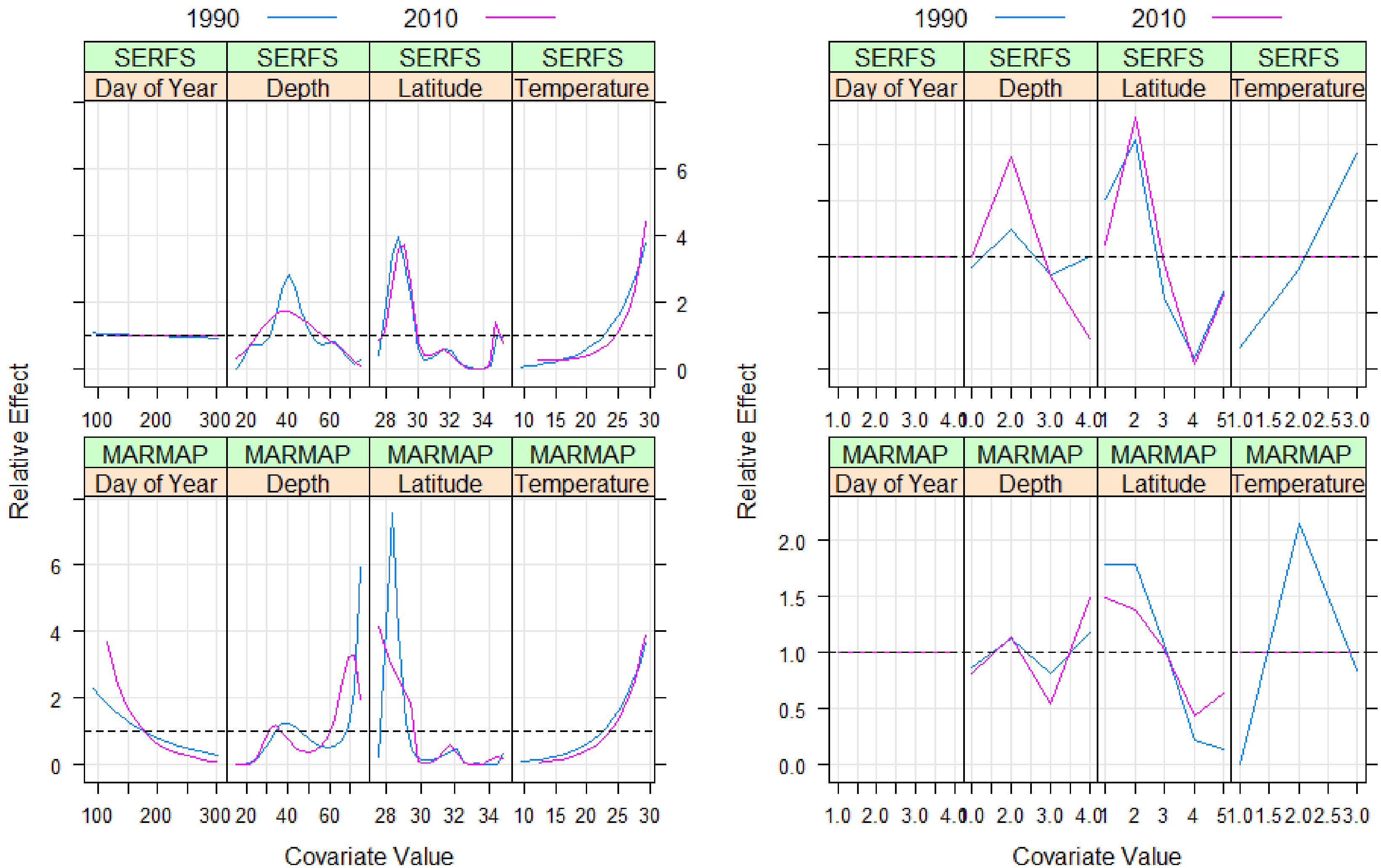

Figure 10: Same data presented in Figure 9, here comparing models with different start years within a given data set.

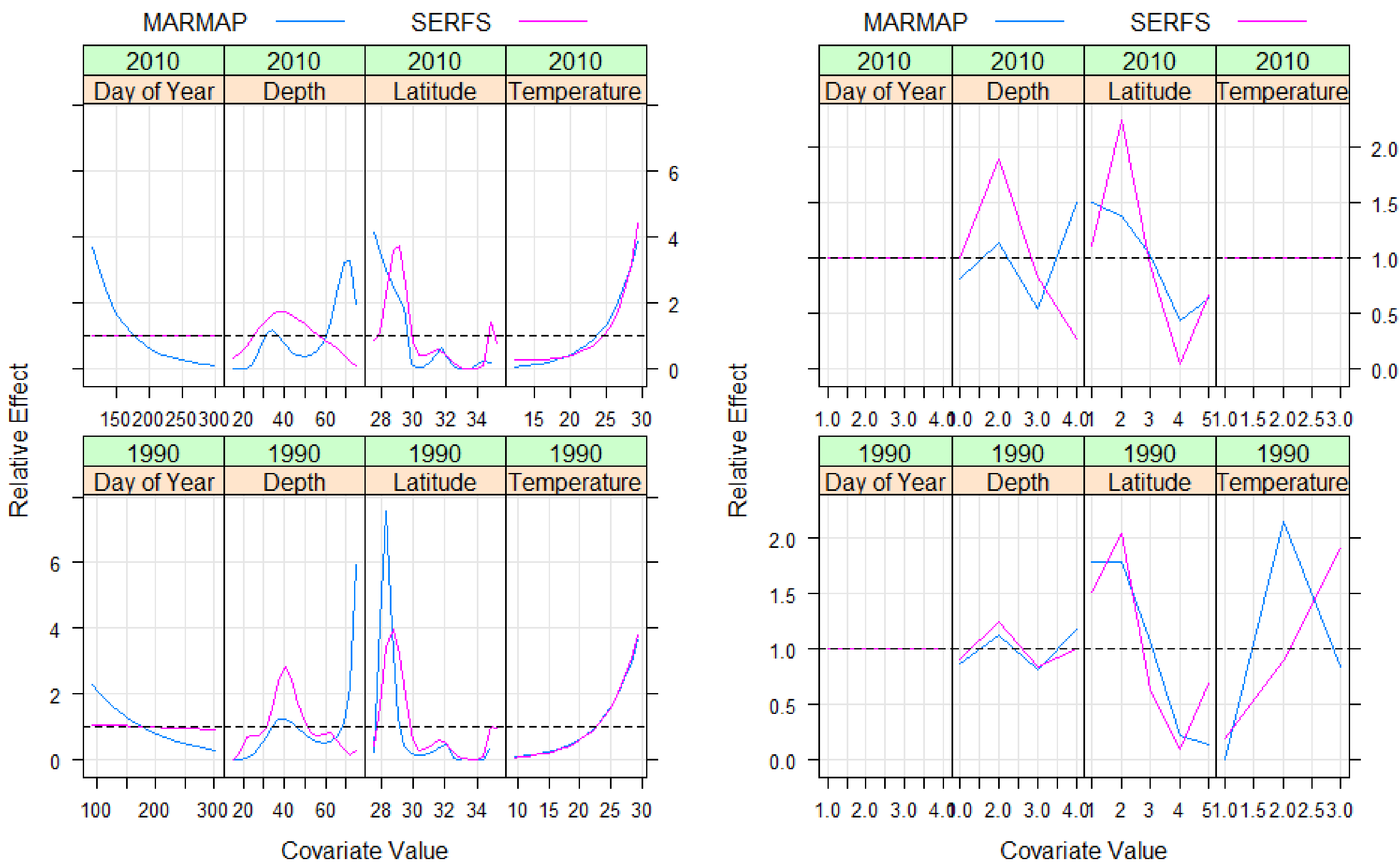

Figure 11: Same data presented in Figure 9, here comparing models using different data sets within a given survey start year.

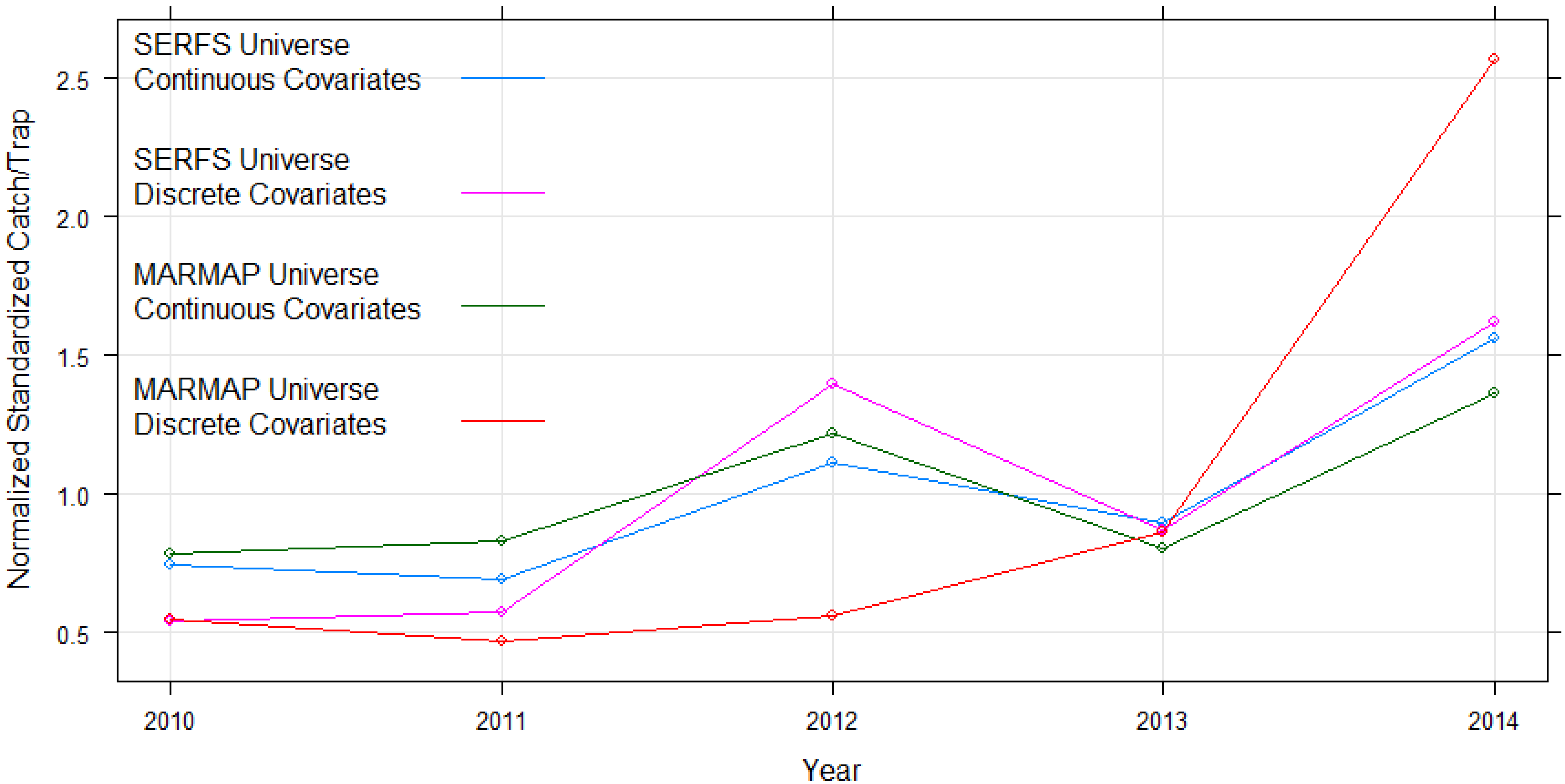

Figure 12: Relative abundance index for Red Snapper based on four different index models using only data from 2010-2014. Continuous covariates refer to models using polynomials.

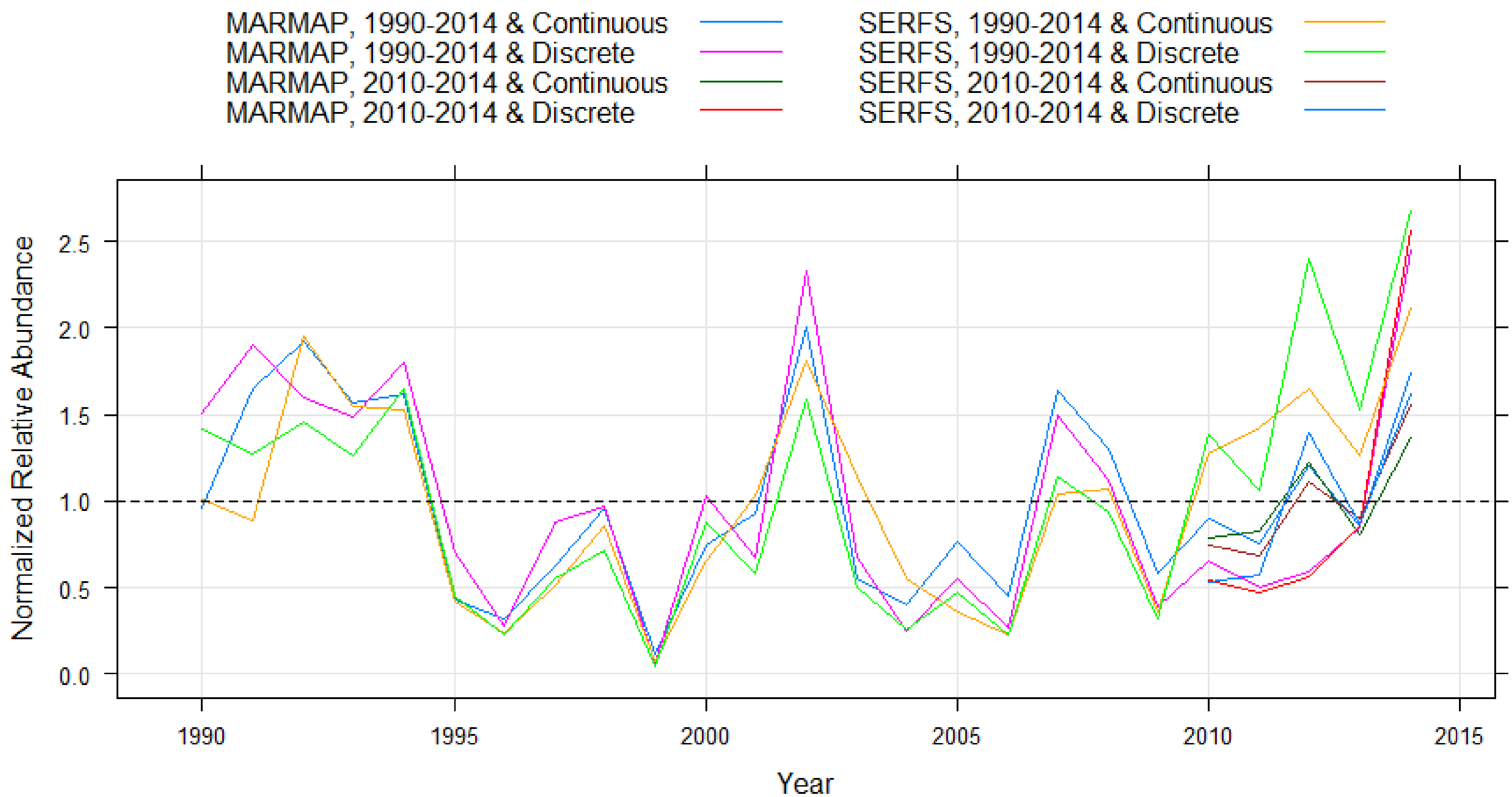

Figure 13: Relative abundance index for Red Snapper based on eight different index models (see Figure 7). Continuous identifies those models using polynomials to model covariates.

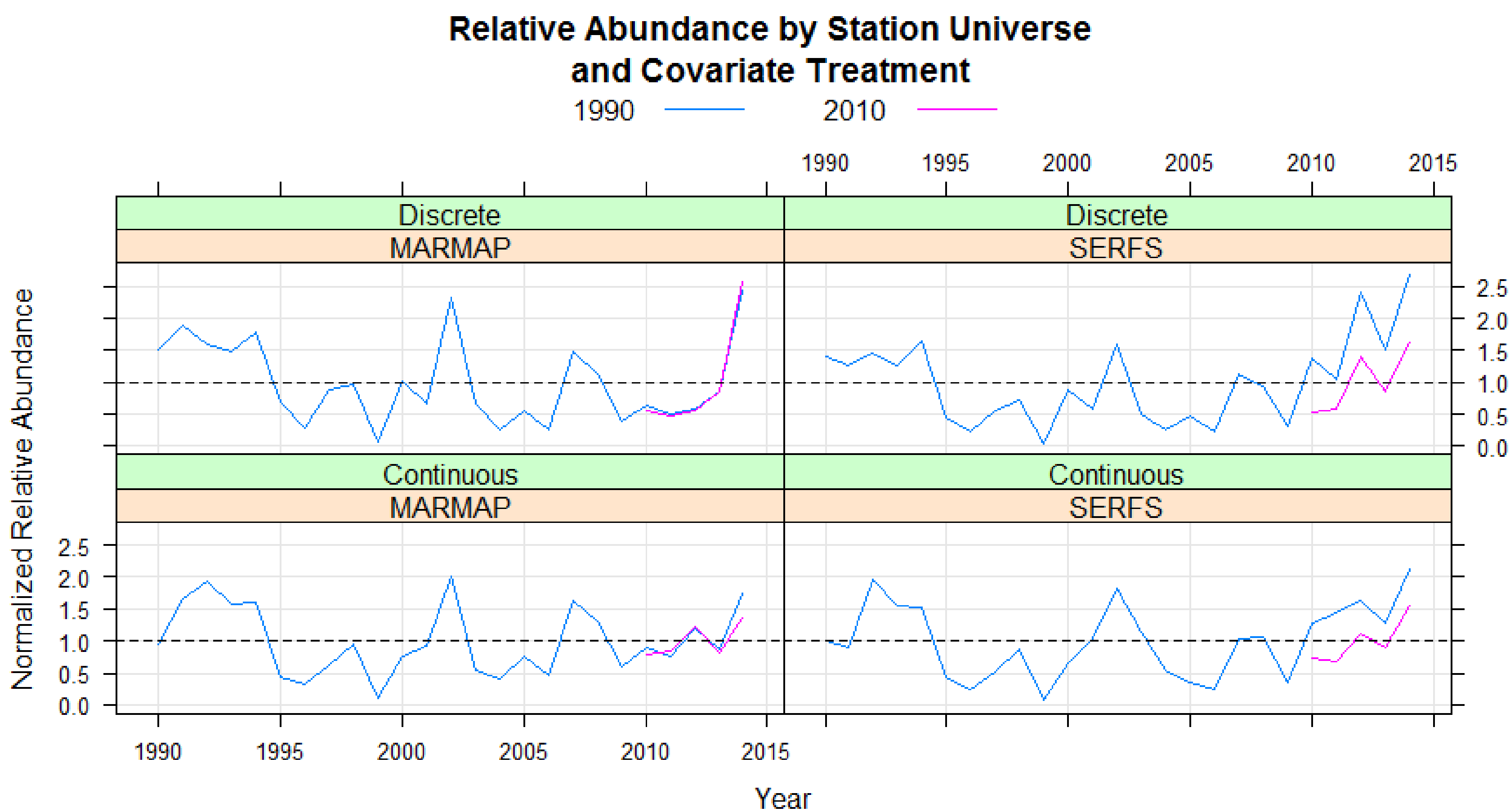

Figure 14: Same data as presented in Figure 13, here comparing pairs of models using the same data set and covariate treatment technique, but different start years.

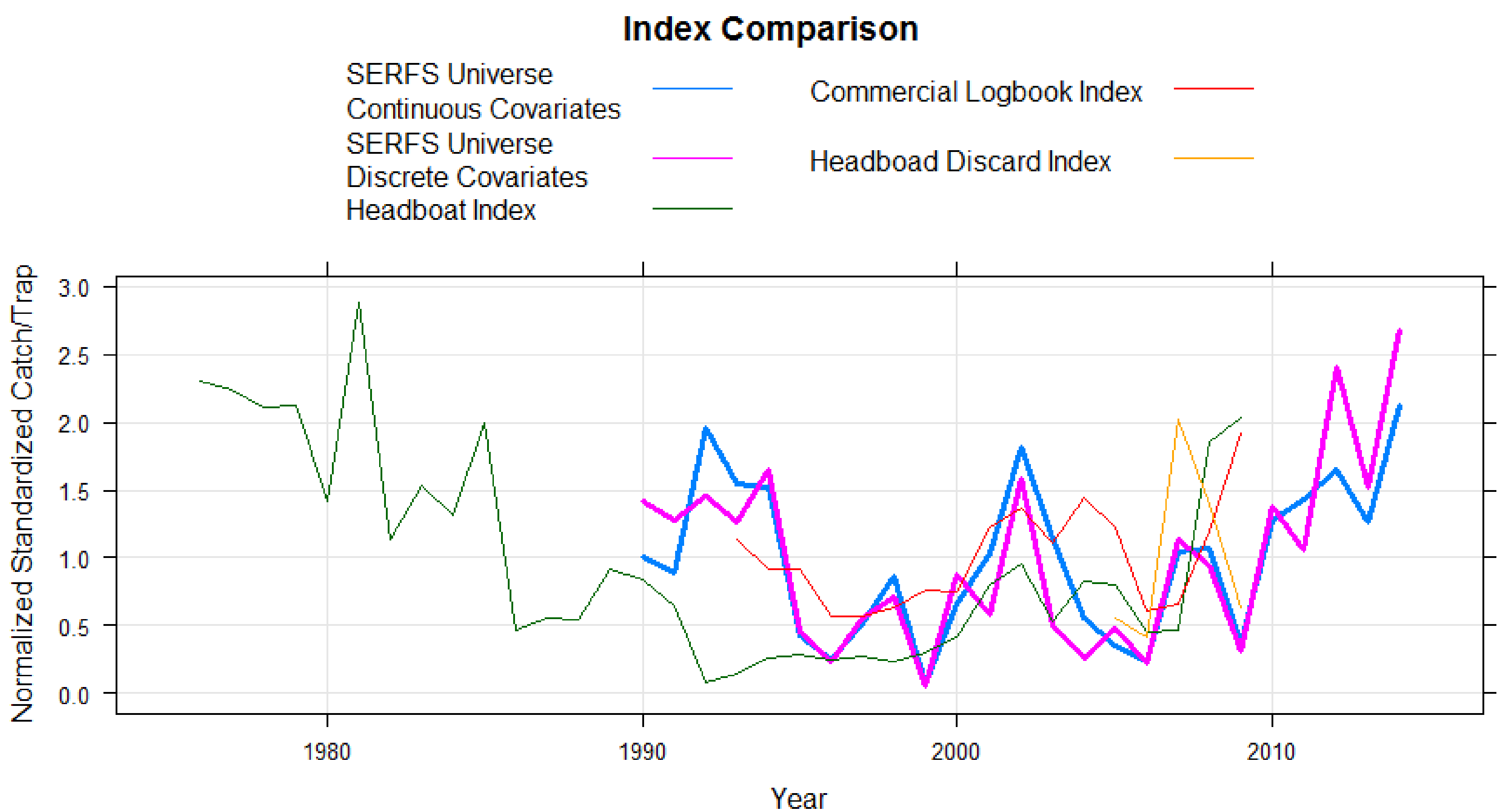

Figure 15: Comparison of the two full time-series indices using the SERFS Universe data set to the three fishery-dependent relative abundance indices of Red Snapper produced for SEDAR 24.