Relative index of abundance from visual order-of-magnitude REEF surveys applied to Hogfish (*Lachnolaimus maximus*) in the Southeast US

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Introduction

Fisheries independent surveys are often resource limited and tend to focus on high-priority fisheries. When surveys exist for data poor species, they tend to be restricted in either spatial or temporal extent. As a result of these data limitations under growing assessment demands, there has been a growing interest in the potential for using citizen-derived data (Muller and Taylor 2013).

The REEF visual surveys represent a large database of citizen-derived visual surveys from across the globe. These surveys are random-walk "roving" surveys that record fish abundances in order-of-magnitude abundance intervals: none = 0, Single = 1, Few = 2-10, Many = 11-100, and Abundant > 100 (termed SFMA counts; *sensu* Wolfe and Pattengill-Semmens 2013). Different options exist for analyzing these data, including: cumulative link models (ordered logit regression) with flexible thresholds; multinomial models with estimated abundances scaled to the midpoint of the abundance interval; censored regression models (right-censored for 2+ individuals; Porch and Eklund 2003); and other nominal index aggregation approaches.

Recently Wolfe and Pattengill-Semmens (2013) conducted a comparative study of 292 surveys where both the REEF methodology (SFMA ordinal count data) and exact counts were conducted from a single advanced assessment diver (lead author J. Wolfe). Using the count data from 36 species in the surveys, they compared three alternative models to scale the ordinal REEF count data to an arithmetic mean estimate, and found that one model performed consistently better than the others in terms of model selection criteria and variance estimates. Although the analyses were not presented, they discussed a preliminary analyses that found this model performed better than an ordered logit regression on the same data. In addition, they proposed that the estimated parameters from the best-fit model may be generally applicable for scaling the SFMA data to arithmetic means for many species and geographic zones, given that the nature of the REEF methodology is the same across species and zones.

While the Wolfe and Pattengill-Semmens (2013) method applied directly to the observed SFMA data performs well for providing a nominal index of abundance for a particular data grouping (e.g., years, shore versus boat dives, etc.), such estimates should be standardized to account for additional confounding variables that may have influenced the observed abundances on any given dive (e.g., habitat type, visibility, depth, etc.). In this manuscript, we present a technique to standardize the index of abundance using the Wolfe and Pattengill-Semmens (2013) scaling model. For our analyses, we apply their scaling model to the marginal mean predictions of the response probabilities from a multinomial logit model of the SFMA data in order to derive an estimated arithmetic abundance that controls for these confounding variables. This approach was also compared directly to standardization of a censored Poisson model utilizing interval-censoring (2-10) and right censoring (10+).

Methods

Spatial and Temporal Extent

REEF survey data were provided from North Carolina through Texas from 1993 through 2012, with the majority of surveys occurring in the coral reef habitats of the FLK through Broward county. Only those surveys during or after 1994 were included in the analysis due to a limited number of dives when the program began in 1993. Surveys were broken into five primary regions (Figure 1): (1) western and northern Gulf of Mexico (GOM; west of Apalachicola Bay, FL); (2) eastern GOM representing the West Florida Shelf (WFS; Apalachicola Bay to the Florida Keys); (3) Florida Keys (FLK); (4) southeast FL (SEFL; FLK to Indian River); and (5) northeast FL through North Carolina (north of Indian River). Genetic analysis supports three distinct stocks in the region from where samples are available (Seyoum et al. 2014): the WFS (Apalachicola Bay through Southwest FL), representing region (2) above; FLK and SEFL, representing regions (3) and (4) above; and North Carolina, representing region (5) above. Due to differences in the proportion of dives detecting hogfish between regions (3) and (4) (FLK and SEFL), indices of abundance were run for both regions separately and combined. Although a substantial number of surveys were conducted at the Flower Garden Banks in the western GOM, hogfish were rarely encountered west of the Mississippi delta (<1% of surveys); similarly, less than 5% of surveys north of Florida sighted hogfish on a dive (Tables 1, 2). Due to the data inadequacy for the tails in the distribution, indices of abundance were not possible for regions (1) and (5). Attempts were made to standardize these regions but were found to be highly variable and suffer from convergence problems.

Identification of Appropriate Surveys

Despite hogfish being commonly sighted in the core of their distribution in South Florida, there is the potential that particular surveys are conducted in situations where a hogfish would be unlikely to occur (e.g., improper habitat), leading to inflation of the zero observations in the dataset. Given the high diversity of species in the REEF dataset (641 species for focal area), one can use the abundance data of co-occurring species to identify those dives where a hogfish would be likely to occur but was not sighted, given the presence of species often found in association with hogfish (Stephens and MacCall 2004). Different approaches exist to identify the associated species, including logistic regression techniques (Stephens and MacCall 2004) and multivariate clustering (Shertzer and Williams 2008; Muller 2009, O'Hop et al. 2012). Given the high diversity in the REEF dataset and common occurrence of hogfish, we chose to use clustering techniques to identify associated species. First, we divided the dataset into three primary regions (WFS, FLK, SEFL) on which to perform the clustering, given the diversity of species and occurrence of hogfish decreases as one moves further away from the coral reef habitats of the FLK. Attempts to create species clusters for the tails of the distribution separately (W/N GOM and NEFL-NC) failed due to the low occurrence of hogfish in these regions. Second, for each of the three clustering regions, the data were filtered to remove all uncommon species that occurred in less than 5% of the surveys and less than 5% of the time on surveys that recorded hogfish. We chose to use affinity propagation clustering (APC), because it has been shown to perform well relative to other cluster techniques and does not require that the number of cluster be pre-specified (Frey and Dueck 2007). APC automatically chooses an optimal number of clusters in the dataset, thereby providing an objective criterion for which to group associated species. Other criteria exist for choosing the optimal number of clusters (e.g., gap analysis, average silhouette width, scree plots), but these can either be computationally demanding or were found to perform poorly with the high diversity in the REEF dataset. Instead of relying on an objective criterion to choose the optimal number of clusters, one could alternatively choose a subset of species from a branch of a dendrogram produced by hierarchical clustering. However, deciding on which branch hierarchy to include can be relatively subjective. For the APC procedure, we used the Morisita measure of similarity as input, since this measure is recommended for count data and is insensitive to sample sizes (Krebs 1999). Once the associated species within the hogfish cluster were identified for each of the three regions, all surveys on which these species occurred were used as suitable surveys in the subsequent analyses. All multivariate analyses were done with R version 3.0.1, using the vegan package to compute the similarity matrix and the apcluster package for the APC technique.

Standardization Models

Multinomial Scaling Model

In order to standardize an index with respect to the confounding variables, a multinomial logit model was used with the SFMA response set (*Abundance = {0, 1, 2, 3, 4}*) as the dependent variable and a set of potential independent variables recorded from the REEF dives. The final set of independent variables was chosen using a forward selection procedure based on the lowest AIC for the final model. In addition, only those selected variables that reduced the mean deviance relative to the null model by greater than 0.5% were included in the final model. The full suite of possible independent variables in the stepwise procedure included: year, experience level (novice versus advanced), bottom time, surface temperature, visibility, depth, current, season (winter versus summer: Oct. through March, April through Sept.), and habitat. Year was automatically included in each possible model configuration to produce a year-specific estimate of abundance. Year, experience level, and habitat were included as class variables. The 12 possible habitats were aggregated into 6 categories: (1) none and open; (2) grass, sand, and rubble; (3) high profile reef, wall, and ledge; (4) low profile reef and sloping dropoff; (5) artificial reef; and (6) mixed habitat.

To compute the mean estimate of abundance for each year, the predicted probabilities for each potential SFMA response were obtained from the final model at each of the class level combinations and at the mean value for all continuous variables (Ballenger et al. 2013). For example, if the final model included year (class levels for 1994-2012), experience level (class levels for experienced vs. novice), and depth (continuous), a total of 38 model predictions would be generated (19 years by 2 experience levels) at the mean depth across all observations. For the multinomial model, each model prediction is a set of five probabilities, summing to one, for the five possible SFMA responses ({0-4}). The average of all model predictions (e.g., mean predicted response for each of the 38 combinations in the example above), represents the equally weighted mean prediction (i.e., population marginal mean or least-squares mean). These predicted probabilities were then scaled into an arithmetic estimate of abundance following the procedure in Wolfe and Pattengill-Semmens (2013), using the formula:

$$AvgF_{i,y} = \frac{2S_{i,y} + 4.16F_{i,y} + 10M_{i,y}}{S_{i,y} + F_{i,y} + M_{i,y}}$$

$$AvgM_{i,y} = \frac{11F_{i,y} + 33.8M_{i,y} + 100A_{i,y}}{F_{i,y} + M_{i,y} + A_{i,y}}$$

$$AvgA_{i,y} = \frac{200M_{i,y} + 348A_{i,y}}{M_{i,y} + A_{i,y}}$$

$$Mean_y = \frac{\prod_{i=1}^{k} Z_{i,y}\left(\frac{S_{i,y} + AvgF * F_{i,y} + AvgM * M_{i,y} + AvgA * A_{i,y}}{S_{i,y} + F_{i,y} + M_{i,y} + A_{i,y}}\right)}{k}$$

Here, *i* denotes each of the class level combinations (not including year), *y* denotes year, and *k* is the total number of class level combinations (not including year). *Z* is the sighting frequency (i.e., predicted probability of a zero abundance response), and *S*, *F*, *M*, and *A* represent the predicted probabilities for single (1), few (2-10), many (10-100), and abundant (100+) responses.

This index standardization approach was run for the hogfish population independently for the three regions with sufficient data (WFS, FLK, and SEFL), and for the FLK+SEFL region combined, which represents a single genetic stock. For each index, error estimates were obtained through 5000 bootstrap iterations (Ballenger et al. 2013). The multinomial analysis was done using in ‘nnet’ package in R 3.0.1, while the bootrapping analysis used the ‘boot’ package.

Censored Poisson

Following Porch and Eklund (2003), a censored Poisson model was additionally used to standardize an index of abundance in order to compare to the multinomial scaling model. For this analysis, a combination of interval and right censoring was applied to the SFMA. Observations in the Few category (2-10) were modeled as interval censored, and observations in the Many and Abundant categories (10+) were modeled together as right-censored. The censoring approach used the same set of potential explanatory variables as the multinomial approach above and the same forward stepwise selection criteria. The censored Poisson standardization was conducted in R 3.0.1 with the VGAM package, using a survival parameterization for the interval and right censoring (type=”interval2”).

Results and Discussion

Hogfish Distribution

The core of the hogfish distribution was the FLK, with 65.8% of the surveys encountering a hogfish. Hogfish sightings decreased with latitude, with only 46.6% and 24.2% of surveys encountering hogfish on the WFS and in SEFL, respectively. For the tails of the distribution, only 1% and 5.3% of surveys encountered hogfish in the W/N GOM and NFL through NC, respectively (Table 1; Figure 2). The average of the abundance category per survey reef location is shown in Figure 3, demonstrating the core of the hogfish distribution is centered in the Florida Keys with decreasing abundances at higher latitudes. Tables 2-4 present the distributions of surveys among regions for each year, habitat type, and depth range, respectively. In general the REEF program experienced the highest participation during the early to mid 2000's, and has experienced a general drop in surveys beginning in the late 2000's. The surveys have generally been conducted on similar habitats (artificial and natural reef structures) and at similar depths, except in the NEFL through NC region where reef structure is found at deeper depths.

Identification of Appropriate Surveys

The APC technique was performed separately for the WFS, FLK, and SEFL. For the WFS, the APC procedure selected 13 total clusters from a total of 71 species. The species group in which hogfish clustered comprised the second largest cluster with a total of 14 species (Table 5). For the FLK, the APC procedure selected 25 total clusters from a total of 139 species. The species group in which hogfish clustered comprised the largest cluster with a total of 45 species (Table x). For SEFL, the APC procedure selected 16 total clusters from a total of 148 species. The species group in which hogfish clustered comprised the largest cluster with a total of 46 species (Table x). It is not surprising that the APC procedure selected clusters with large numbers of species for the FLK and SEFL regions, given that hogfish are relatively common on reef habitats, and tropical/semi-tropical reefs are some of the most species diverse ecosystems on the planet. As such, the high species clusters often represent the common reef fauna, and the analyses would likely produce similar findings if all surveys were included versus restricting surveys based on the cluster analyses.

Standardization Models

Multinomial Scaling Model

The deviance tables are presented in Tables 6-12. The final predictor variables were chosen to be habitat type, bottom time, and visibility for WFS; experience level and bottom time for the FLK; depth and bottom type for SEFL; and current and habitat type for the combined FLK and SEFL region. Because this was fit using a multinomial model, typical residual diagnostics are not available for this model. The indices of abundance for each of the stocks, along with bootstrap estimates of variability, are presented in Figure 4.

The indices of abundance are presented in Tables 13-19 and Figures 4-5. The index for the WFS was highly variable with steep drops in abundance for particular years (2005, 2009), and subject to large increases or decreases in abundance on particular years. While the steep drop in 2005 could have been related to the red tide event during that year, a similar low would have been expected in 2006. Alternatively, the drop could be a result of the data type (SFMA categories) and sensitivity of this data to low sample sizes. The FLK, SEFL, and FLK+SEFL indices were much less variable than the WFS, resulting from the substantially higher sample sizes in the regions.

In general the multinomial and censored Poisson results were similar, both tracking the nominal abundance relatively well. The multinomial approach was more stable than the censored Poisson as modeled, being able to converge on a solution for the SEFL region as an individual index. The differences in the fitting ability is likely a function of the different R packages used however (nnet and VGAM, respectively), and not representative of the quality of the model type. Without the fitting constraints, the censored Poisson would be preferred since it models the data explicitly accounting for the SFMA response type.

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Table 1. Proportion of total surveys recording each of the five abundance categories (0=none; 1=single; 2=few, 2-10; 3=many, 10-100; 4=abundant, 100+), for each of the five regions through 2012.

Region	Total Surveys	0	1	2	3	4
West/North Gulf of Mexico (W/N GOM)	3530	0.990	0.004	0.005	0.001	0.000
West Florida Shelf (WFS)	1838	0.534	0.135	0.298	0.032	0.001
Florida Keys (FLK)	20950	0.342	0.215	0.406	0.036	0.001
Southeast Florida (SEFL)	11474	0.758	0.128	0.103	0.011	0.001
Northeast Florida through North Carolina (NEFL-NC)	839	0.947	0.021	0.030	0.002	0.000

Table 2. Total number of REEF visual surveys by zone and year.

Year	W/N GOM	WFS	FLK	SEFL	NEFL-NC
1993	0	4	96	1	0
1994	32	12	1296	37	4
1995	279	6	772	35	2
1996	410	22	651	16	2
1997	513	34	943	81	24
1998	200	75	767	134	41
1999	294	127	905	387	53
2000	307	148	977	422	37
2001	404	150	2350	892	50
2002	277	177	2708	1195	107
2003	275	120	1825	1325	133
2004	324	69	1179	802	113
2005	124	50	1110	724	109
2006	131	104	1102	1139	94
2007	129	89	1022	889	94
2008	10	43	606	568	69
2009	30	41	948	525	60
2010	77	48	670	814	62
2011	89	21	499	603	41
2012	95	28	524	585	44

Table 3. Number of surveys with hogfish present and the total number of surveys per habitat type in the five regions.

	Hogfish Present					All Surveys				
	W/N GOM	WFS	FLK	SEFL	NEFL-NC	W/N GOM	WFS	FLK	SEFL	NEFL-NC
Artificial	13	279	1173	464	10	443	740	1964	2300	475
Grass	0	1	19	13	0	1	1	101	73	0
High Profile	11	2	5289	453	2	2399	3	7758	1259	7
Ledge	3	180	465	310	27	48	227	630	1444	293
Low Profile	4	42	2422	731	12	185	79	3734	3285	214
Mixed	2	18	3688	522	5	570	49	5524	2127	19
None	7	82	274	97	3	175	173	505	285	82
Open	0	0	1	0	0	3	2	7	7	0
Rubble	0	27	107	33	1	60	66	194	162	16
Sand	0	3	51	16	0	18	24	102	120	33
Slope	0	1	212	56	0	84	1	277	90	0
Wall	1	2	81	10	0	14	3	154	22	0
Total	41	637	13782	2705	60	4000	1368	20950	11174	1139

Table 4. Number of surveys with hogfish present and the total number of surveys per depth bin in the five regions.

	Hogfish Present					All Surveys				
	W/N GOM	WFS	FLK	SEFL	NEFL-NC	W/N GOM	WFS	FLK	SEFL	NEFL-NC
0-30ft	8	110	9375	1157	0	103	400	14070	5651	16
30-60ft	9	432	3179	948	4	382	705	4599	2833	255
60-90ft	22	92	1009	523	31	3399	246	1763	2442	754
90-120ft	2	3	209	31	25	102	16	479	150	110
120+	0	0	10	46	0	14	1	39	98	4
Total	41	637	13782	2705	60	4000	1368	20950	11174	1139

Table 5. Species clusters for the three condensed regions (Gulf of Mexico, Florida Keys, and Southeast US) used to select those survey trips where a hogfish was likely to occur.

WFS	FLK		SEFL	
Bandtail Puffer	Beaugregory	Rainbow Parrotfish	Banded Butterflyfish	Princess Parrotfish
Beaugregory	Bicolor Damselfish	Redband Parrotfish	Barred Hamlet	Queen Angelfish
Belted Sandfish	Black Grouper	Redlip Blenny	Blackbar Soldierfish	Redtail Parrotfish
Cocoa Damselfish	Blue Tang	Redtail Parrotfish	Blue Chromis	Saucereye Porgy
Cubbyu	Bluehead	Rock Beauty	Blue Hamlet	Scrawled Cowfish
Gray Triggerfish	Bluestriped Grunt	Sailors Choice	Bluehead	Scrawled Filefish
Hogfish	Bridled Goby	Saucereye Porgy	Bluestriped Grunt	Sharpnose Puffer
Red Grouper	Brown Chromis	Schoolmaster	Bridled Goby	Smallmouth Grunt
Sand Diver	Caesar Grunt	Sergeant Major	Brown Chromis	Smooth Trunkfish
Sand Perch	Clown Wrasse	Sharksucker	Butter Hamlet	Smooth Trunkfish
Seaweed Blenny	Cocoa Damselfish	Sharpnose Puffer	Caesar Grunt	Spanish Grunt
Slippery Dick	Dusky Damselfish	Smallmouth Grunt	Coney	Spotfin Butterflyfish
Spottail Pinfish	French Grunt	Spanish Grunt	Creole Wrasse	Spotted Drum
White Grunt	Goldentail Moray	Spotfin Butterflyfish	Foureye Butterflyfish	Spotted Trunkfish
	Goldspot Goby	Spotted Goatfish	French Grunt	Squirrelfish
	Gray Snapper	Squirrelfish	Goldspot Goby	Striped Parrotfish
	Graysby	Threespot Damselfish	Gray Angelfish	Tobaccofish
	Great Barracuda	Tomtate	Harlequin Bass	Tomtate
	Highhat	White Grunt	Hogfish	Trumpetfish
	Hogfish	Yellowtail Damselfish	Honeycomb Cowfish	White Grunt
	Longfin Damselfish	Yellowtail Snapper	Longspine Squirrelfish	Whitespotted Filefish
	Neon Goby		Mahogany Snapper	Yellow Goatfish
	Orangespotted Filefish		Masked Goby	Yellowtail Snapper
	Puddingwife		Ocean Surgeonfish	

Table 6. Model selection criteria for the WFS index in the multinomial scaling model. Only those variables with greater than a 0.5% reduction in deviance, relative to the null model with only year as a variable, were included in the final model.

Step	Variable	Deviance	Resid. Df	Resid. Dev	AIC	% Reduction
1	Hab	170.281	1026	2157.455	2289.455	5.960266
2	BTime	30.32789	1023	2127.127	2265.127	1.050041
3	Visib	19.15441	1020	2107.973	2251.973	0.56632
4	STemp	6.488359	1017	2101.484	2251.484	0.012684

Table 7. Model selection criteria for the FLK index in the multinomial scaling model. Only those variables with greater than a 0.5% reduction in deviance, relative to the null model with only year as a variable, were included in the final model.

Step	Variable	Deviance	Resid. Df	Resid. Dev	AIC	% Reduction
1	Exp	390.2327	12911	29636.46	29756.46	1.276685
2	BTime	238.5005	12908	29397.96	29523.96	0.771719
3	Hab	139.0297	12893	29258.93	29414.93	0.349816
4	Current	57.21195	12890	29201.72	29363.72	0.168176
5	Depth	27.04073	12887	29174.68	29342.68	0.067562
6	Season	24.93522	12884	29149.74	29323.74	0.060565
7	STemp	17.6281	12881	29132.12	29312.12	0.036196

Table 8. Model selection criteria for the SEFL index in the multinomial scaling model. Only those variables with greater than a 0.5% reduction in deviance, relative to the null model with only year as a variable, were included in the final model.

Step	Variable	Deviance	Resid. Df	Resid. Dev	AIC	% Reduction
1	Depth	155.2825	7754	11182.04	11302.04	1.331498
2	BTime	144.0187	7751	11038.03	11164.03	1.2331
3	Hab	72.99306	7736	10965.03	11121.03	0.456651
4	Season	40.47777	7733	10924.55	11086.55	0.320516
5	Current	31.15404	7730	10893.4	11061.4	0.238239
6	STemp	28.26304	7727	10865.14	11039.14	0.212825
7	Exp	18.86817	7724	10846.27	11026.27	0.129769

Table 9. Model selection criteria for the combined FLK and SEFL index in the multinomial scaling model. Only those variables with greater than a 0.5% reduction in deviance, relative to the null model with only year as a variable, were included in the final model.

Step	Variable	Deviance	Resid. Df	Resid. Dev	AIC	% Reduction
1	Current	612.6237	20725	44644.82	44764.82	1.339363
2	Hab	550.1536	20710	44094.67	44244.67	1.145207
3	Exp	190.2388	20707	43904.43	44060.43	0.406647
4	Visib	109.7561	20704	43794.67	43956.67	0.228725
5	STemp	90.75282	20701	43703.92	43871.92	0.186747
6	Season	105.5377	20698	43598.38	43772.38	0.219517
7	BTime	65.09628	20695	43533.28	43713.28	0.13008
8	Depth	67.73111	20692	43465.55	43651.55	0.13595

Table 10. Model selection criteria for the WFS index in the censored Poisson model. Only those variables with greater than a 0.5% reduction in deviance, relative to the null model with only year as a variable, were included in the final model.

Step	Variable	Deviance	Resid. Df	Resid. Dev	AIC	% Reduction
1	Hab	176	1070	1402	3671	10.70726
2	BTime	27	1069	1375	3601	1.671641
3	Visib	15	1068	1360	3567	0.82728
4	STemp	4	1067	1356	3553	0.23064

Table 11. Model selection criteria for the FLK index in the censored Poisson model. Only those variables with greater than a 0.5% reduction in deviance, relative to the null model with only year as a variable, were included in the final model.

Step	Variable	Deviance	Resid. Df	Resid. Dev	AIC	% Reduction
1	Exp	307	12951	17941	44323	1.675147
2	BTime	228	12950	17713	43829	1.240684
3	Current	84	12949	17629	43685	0.450697

Table 12. Model selection criteria for the combine FLK and SEFL index in the censored Poisson model. Only those variables with greater than a 0.5% reduction in deviance, relative to the null model with only year as a variable, were included in the final model.

Step	Variable	Deviance	Resid. Df	Resid. Dev	AIC	% Reduction
1	Current	598	20765	26713	69863	2.18528
2	Hab	334	20760	26379	69193	1.19947
3	Exp	164	20759	26215	68849	0.59561
4	STemp	103	20758	26112	68588	0.37455

Table 13. Index of abundance for the WFS multinomial scaling model.

year	Total.num.trips	Num.pos	Mean	std.dev	CV
1996	18	14	1.069073	0.411186	0.384619
1997	19	13	1.567447	0.437988	0.279428
1998	70	47	4.267835	2.188715	0.51284
1999	111	41	2.136562	1.150702	0.538577
2000	118	49	3.338532	1.071706	0.321011
2001	99	46	2.234285	0.536497	0.24012
2002	162	77	2.919133	0.830962	0.284661
2003	110	61	3.892962	1.138507	0.292453
2004	62	35	2.608749	1.063964	0.407844
2005	34	9	0.877655	0.312425	0.355977
2006	87	53	3.259059	0.990171	0.303821
2007	63	35	2.98904	0.804513	0.269155
2008	34	20	2.208799	0.360442	0.163185
2009	24	12	0.986612	0.305192	0.309333
2010	34	23	2.381907	1.245926	0.523079
2011	22	10	1.582299	1.289102	0.814702
2012	25	11	0.757233	0.195258	0.257858

Table 14. Index of abundance for the WFS censored Poisson model.

year	Total.num.trips	Num.pos	Mean	std.dev	CV
1996	18	14	1.237635	0.377596	0.305095
1997	19	13	1.845836	0.567005	0.307181
1998	70	47	2.40488	0.476145	0.197991
1999	111	41	1.463846	0.33343	0.227777
2000	118	49	2.267839	0.427306	0.18842
2001	99	46	2.284234	0.425785	0.186402
2002	162	77	2.051782	0.317998	0.154986
2003	110	61	2.626852	0.439468	0.167298
2004	62	35	2.57911	0.572857	0.222114
2005	34	9	0.870169	0.322432	0.37054
2006	87	53	3.052478	0.50394	0.165092
2007	63	35	2.995624	0.591306	0.19739
2008	34	20	2.599109	0.582749	0.224211
2009	24	12	1.180342	0.374083	0.316928
2010	34	23	2.184495	0.583976	0.267327
2011	22	10	1.356832	0.528122	0.389232
2012	25	11	0.957944	0.264624	0.276242

Table 15. Index of abundance for the FLK multinomial scaling model.

year	Total.num.trips	Num.pos	Mean	std.dev	CV
1994	1201	609	1.238812	0.062365	0.050343
1995	715	416	1.544508	0.095474	0.061815
1996	584	282	1.240506	0.109314	0.088121
1997	680	421	1.83552	0.119404	0.065052
1998	452	302	2.658775	0.231813	0.087188
1999	538	362	2.064409	0.140372	0.067996
2000	746	486	2.630238	0.163323	0.062094
2001	1588	1081	2.882901	0.117932	0.040907
2002	1643	1211	2.969873	0.111954	0.037697
2003	876	627	2.131483	0.101497	0.047618
2004	534	342	2.092777	0.148625	0.071018
2005	663	404	1.828669	0.119374	0.065279
2006	619	396	1.863916	0.121601	0.065239
2007	493	314	1.792065	0.12248	0.068346
2008	353	231	2.323282	0.193901	0.08346
2009	460	305	2.614551	0.224749	0.085961
2010	315	209	2.791731	0.25878	0.092695
2011	222	170	2.490712	0.19164	0.076942
2012	289	209	2.350956	0.164963	0.070168

Table 16. Index of abundance for the FLK censored Poisson model.

year	Total.num.trips	Num.pos	Mean	std.dev	CV
1994	1201	609	1.257171	0.055342	0.044021
1995	715	416	1.56178	0.081476	0.052169
1996	584	282	1.220529	0.082677	0.067739
1997	680	421	1.78138	0.095208	0.053446
1998	452	302	2.311278	0.150758	0.065227
1999	538	362	2.047692	0.11243	0.054906
2000	746	486	2.40363	0.11823	0.049188
2001	1588	1081	2.684521	0.089996	0.033524
2002	1643	1211	2.804579	0.088877	0.03169
2003	876	627	2.11681	0.087596	0.041381
2004	534	342	2.016297	0.119556	0.059295
2005	663	404	1.793946	0.095463	0.053214
2006	619	396	1.814775	0.099768	0.054976
2007	493	314	1.748284	0.10609	0.060682
2008	353	231	2.233579	0.157039	0.070308
2009	460	305	2.351622	0.156063	0.066364
2010	315	209	2.604755	0.200549	0.076994
2011	222	170	2.623483	0.197624	0.075329
2012	289	209	2.443446	0.160246	0.065582

Table 17. Index of abundance for the SEFL multinomial scaling model.

year	Total.num.trips	Num.pos	Mean	std.dev	CV
1994	21	3	0.194916	0.137864	0.707298
1995	26	7	0.384166	0.180423	0.46965
1996	11	1	0.23698	0.305291	1.288254
1997	59	20	1.703367	0.670571	0.393674
1998	104	33	0.624909	0.180401	0.288683
1999	317	97	0.811387	0.188146	0.231882
2000	336	122	0.819506	0.124579	0.152018
2001	696	247	0.713786	0.085831	0.120247
2002	948	198	0.405756	0.052283	0.128854
2003	1067	236	0.421486	0.048999	0.116253
2004	646	119	0.520101	0.098199	0.188808
2005	530	137	0.723469	0.111952	0.154744
2006	834	239	0.817155	0.097752	0.119624
2007	574	161	0.674286	0.080864	0.119926
2008	319	41	0.400028	0.089706	0.224248
2009	233	35	0.226398	0.044362	0.195947
2010	457	57	0.301003	0.048052	0.159638
2011	297	28	0.157036	0.037398	0.23815
2012	339	62	0.279318	0.043467	0.155618

Table 18. Index of abundance for the FLK+SEFL multinomial scaling model.

year	Total.num.trips	Num.pos	Mean	std.dev	CV
1994	1222	612	1.173837	0.064063	0.054576
1995	741	423	1.156219	0.092241	0.079778
1996	595	283	0.920688	0.087175	0.094685
1997	739	441	1.472047	0.107548	0.07306
1998	556	335	2.138416	0.211448	0.098881
1999	855	459	1.473165	0.116879	0.079339
2000	1082	608	1.926278	0.135878	0.070539
2001	2284	1328	1.901209	0.099433	0.0523
2002	2591	1409	1.775033	0.088028	0.049592
2003	1943	863	1.119545	0.060436	0.053983
2004	1180	461	1.116703	0.088337	0.079105
2005	1193	541	1.162988	0.081675	0.070229
2006	1453	635	1.116863	0.077114	0.069045
2007	1067	475	1.044286	0.069668	0.066714
2008	672	272	1.111771	0.099529	0.089523
2009	693	340	1.466129	0.136187	0.092889
2010	772	266	1.09451	0.106965	0.097729
2011	519	198	0.990004	0.086124	0.086993
2012	628	271	1.076397	0.082686	0.076818

Table 19. Index of abundance for the FLK+SEFL censored Poisson model.

year	Total.num.trips	Num.pos	Mean	std.dev	CV
1994	1222	612	1.258809	0.062089	0.049324
1995	741	423	1.216724	0.069124	0.056812
1996	595	283	0.991147	0.06784	0.068446
1997	739	441	1.37839	0.074571	0.0541
1998	556	335	1.70129	0.109084	0.064118
1999	855	459	1.399072	0.076585	0.05474
2000	1082	608	1.676359	0.079455	0.047397
2001	2284	1328	1.729199	0.062091	0.035908
2002	2591	1409	1.58059	0.055139	0.034885
2003	1943	863	1.030997	0.042152	0.040884
2004	1180	461	0.995913	0.057577	0.057813
2005	1193	541	1.095921	0.056128	0.051215
2006	1453	635	0.992834	0.050471	0.050835
2007	1067	475	0.974473	0.052766	0.054148
2008	672	272	1.026032	0.071323	0.069513
2009	693	340	1.297652	0.083893	0.06465
2010	772	266	0.938027	0.068652	0.073188
2011	519	198	0.918153	0.06608	0.071971
2012	628	271	1.067434	0.069194	0.064823

Figures

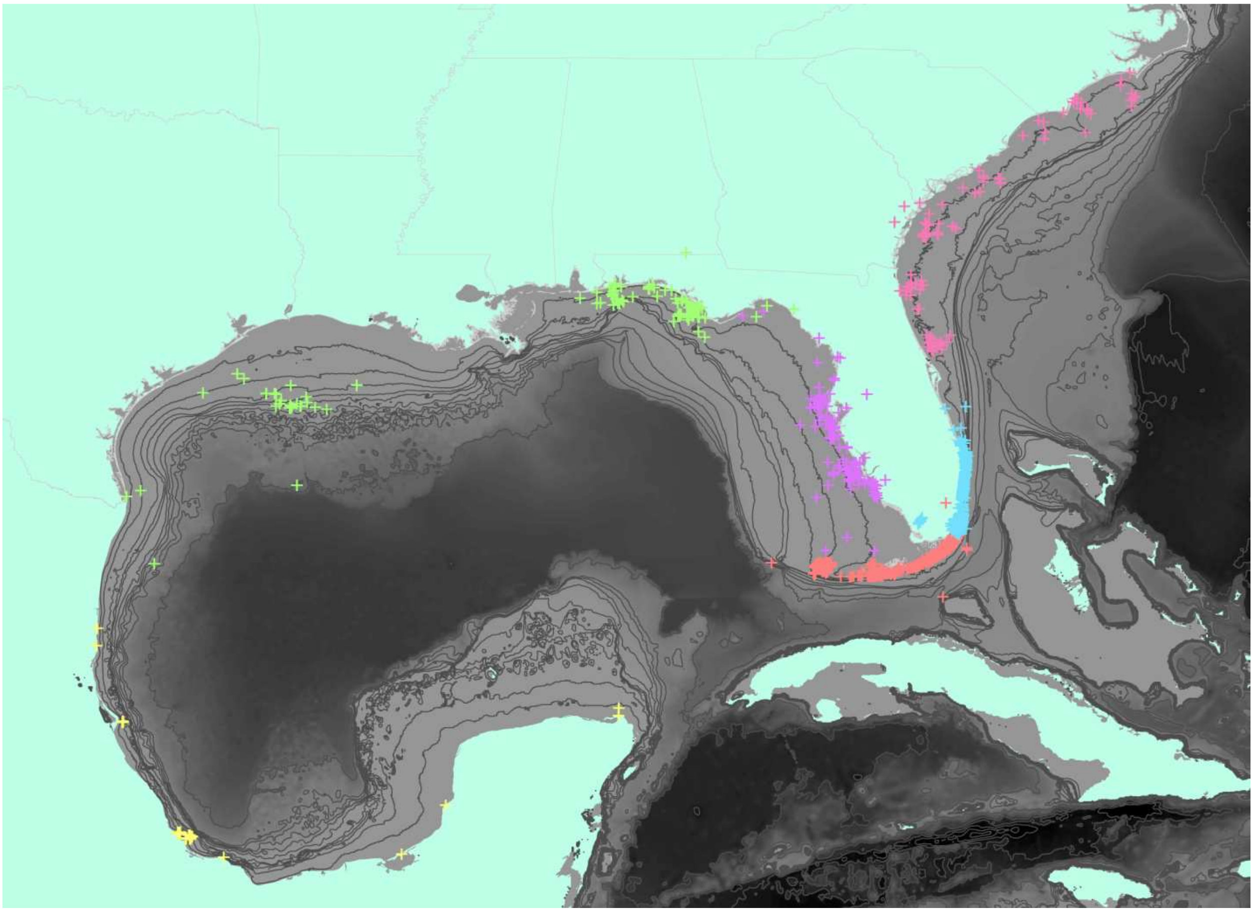

Figure 1. REEF sampling locations, broken down into five primary areas: (1) western and northern Gulf of Mexico (green); (2) west Florida shelf (purple); (3) Florida Keys (red); (4) southest Florida (blue); and (5) northeast Florida through North Carolina (magenta).

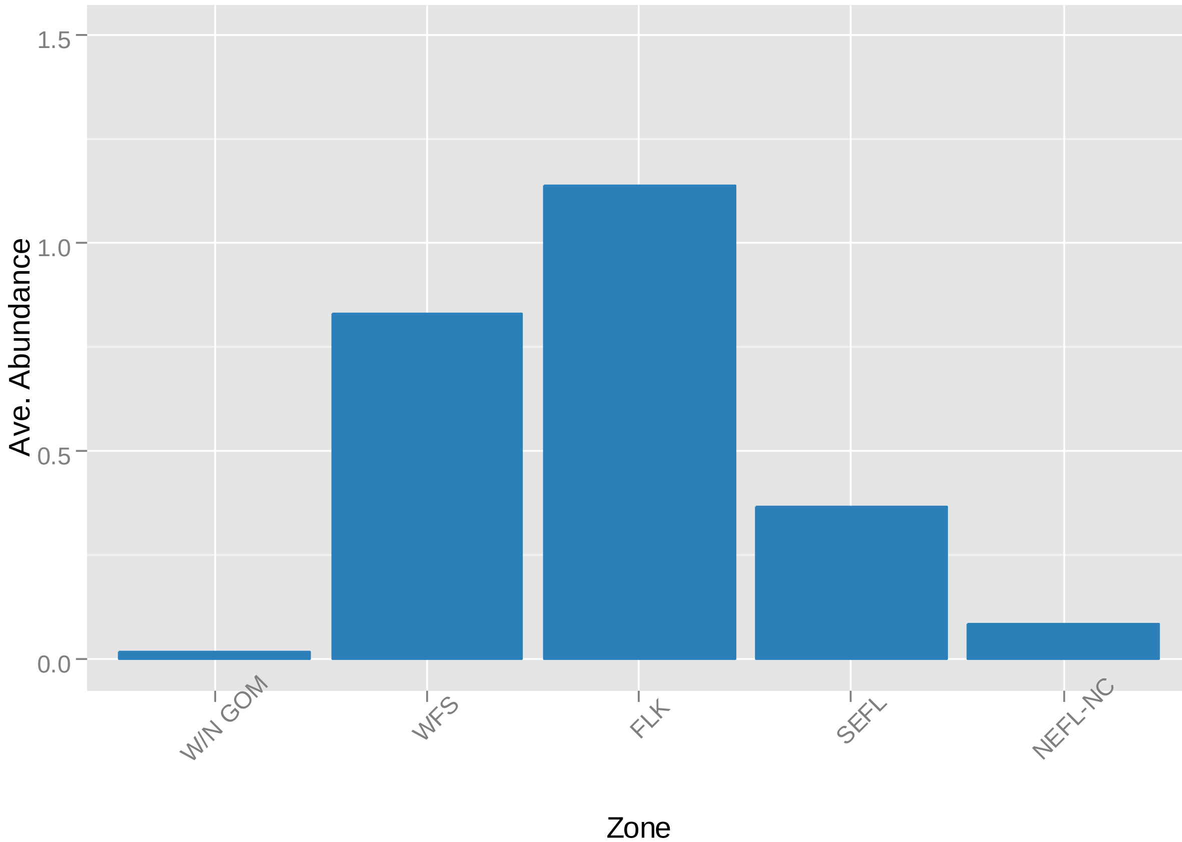

Figure 3. Proportion of surveys with the presence of hogfish for each of the five regions.

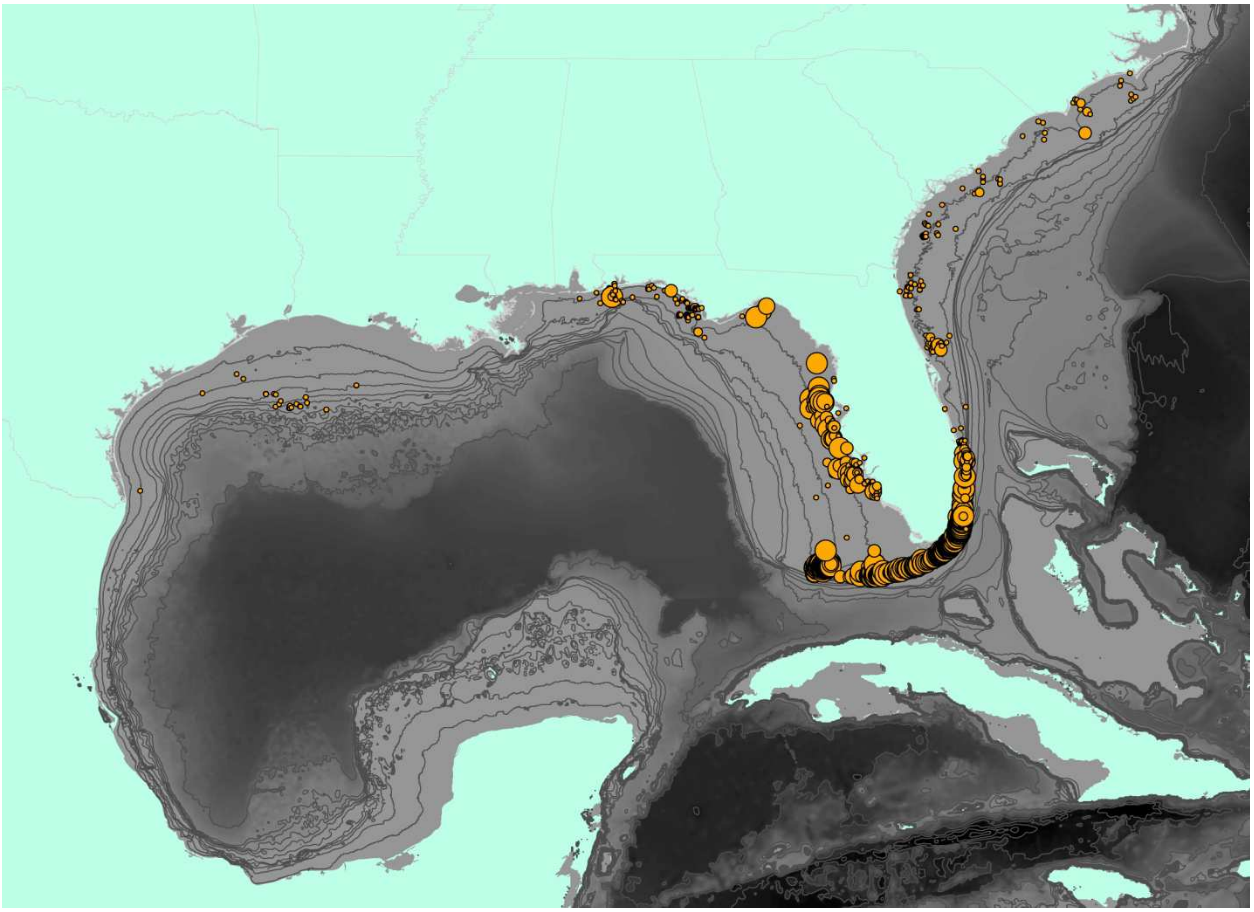

Figure 2. The average abundance category per sampling location, demonstrating the primary range of hogfish is Southeast Florida through the West Florida Shelf.

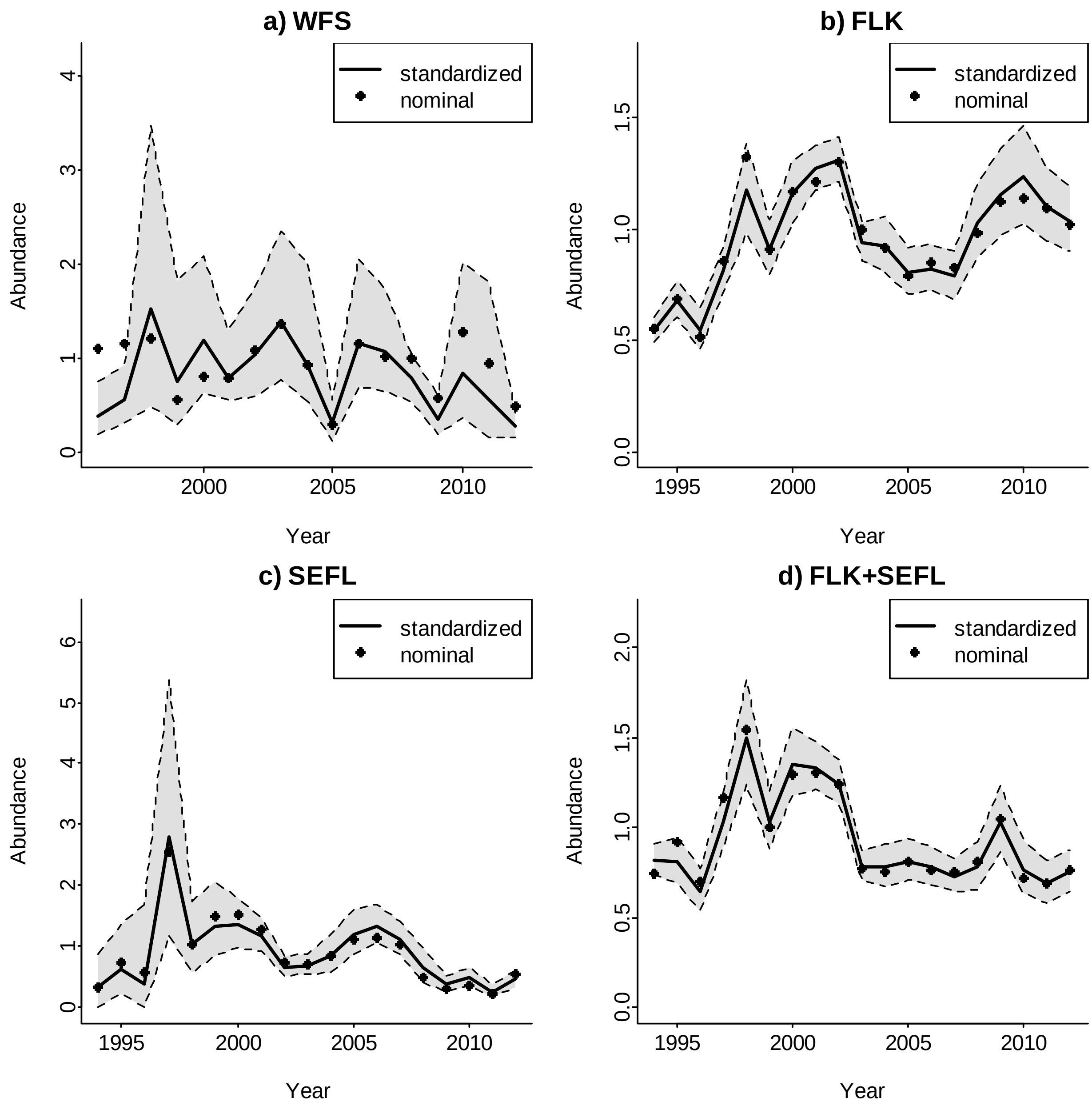

Figure 4. Indices of abundance from the multinomial scaling model for the three survey regions (a-c) and for the FLK+SEFL combined stock (d).

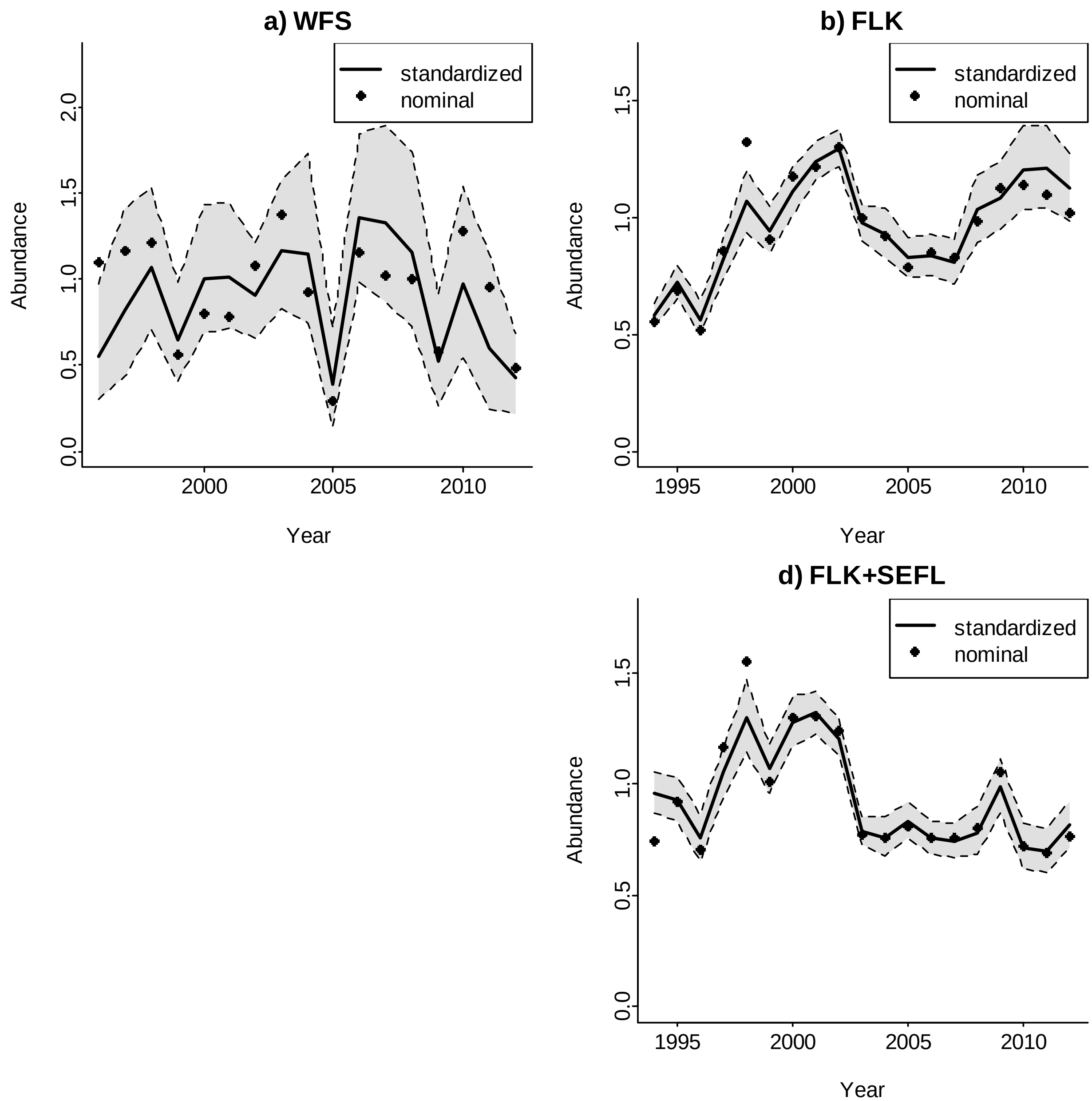

Figure 5. Indices of abundance from the censored Poisson model for the three survey regions (a-c) and for the FLK+SEFL combined stock (d). Note: the null model for SEFL (with Year as the single predictor) did not converge; therefore, no results are shown.