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Indices of abundance for Gulf and Atlantic Hogfish (*Lachnolaimus maximus*) using data from multiple video surveys

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Introduction

Historically, three different stationary video surveys were conducted in the northern Gulf of America (Gulf) to derive abundance estimates of important reef fish stocks. The longest running survey was the SEAMAP reef fish video (SRFV) survey initiated by the NMFS Mississippi Laboratory in 1992, followed in 2005 by the NMFS Panama City laboratory (PC) survey, and finally the Florida Fish and Wildlife Research Institute (FWRI) video survey, which started in 2010. Each survey used standardized sampling and data processing procedures. However, there remained subtle variations in video annotation procedures as well as survey design and spatial coverage that present obvious challenges from an assessment perspective. As such, a new survey initiative was undertaken, the Gulf Fishery Independent Survey of Habitat and Ecosystem Resources (G-FISHER) program, using funds provided by the NOAA RESTORE science program to integrate the three historic surveys under a single, unified design from 2020 onward (Switzer et al 2023).

The initial approach to integrate data from these independently conducted surveys was to generate independent indices for each survey, however, combining indices across datasets likely increases predictive capabilities by allowing for the largest possible sample sizes in model fitting. Previous research has indicated that combining data across changing spatial areas and surveys and using a year only model can yield spurious conclusions regarding stock abundance (Campbell 2004). As such, we used a habitat-based approach (Thompson et al 2022) to combine relative abundance data for generating annual trends for Gulf and Atlantic stocks of Hogfish (*Lachnolaimus maximus*) based on the stock boundaries suggested by recent genetic work (Figure 1; Seyoum et al 2015).

Methods

Historic survey designs:

The SRFV survey primarily targeted high-relief topographic features along the continental shelf from south Texas to south Florida. Site selection followed a stratified random design with strata determined by region and total proportion of reef area in a sampling block of 10 minute latitude X 10 minute longitude in size. Sites were selected at random from known reef areas identified through habitat mapping either with multi-beam or side-scan sonar (Campbell et al 2017).

The PC survey targeted the inner shelf (5-60m), of the northeast Gulf (NMFS statistical zones 6-10). Survey design has changed over time, but since 2010 a two-stage unequal probability design has been used. The survey area was divided into eastern and western sub-regions by Cape San Blas in the Florida Panhandle and further gridded into sampling blocks, which were 5 minutes x 5 minutes in size. Sites were randomly selected and proportionally allocated by region, sub-region, and depth, and site characteristics were described using side-scan sonar prior to video deployments (Gardner et al. 2017).

The FWRI survey initially focused on the regions offshore of Tampa Bay and Charlotte Harbor, FL (i.e., NMFS statistical zones 4 and 5) that were partitioned into inshore or offshore depth strata (depth ranges of 10-36 m and 37-110 m respectively). In 2014, the survey was expanded in 2014 to include NMFS statistical zones 9 and 10, the outer depth limit of the offshore strata increased to180 m, and initial efforts were undertaken to sample artificial reef habitats. This was followed by another spatial expansion in 2016 to cover the entirety of the West Florida Shelf (i.e., NMFS statistical zones 2-10) from 10 to 180 m. It was at this time that artificial reef strata were also formally integrated into the survey universe. For natural reefs, sites were randomly selected and mapped using side scan sonar over a 2.1 km^2 area (Switzer et al 2020; Keenan et al 2022). Video deployment sites were then randomly assigned proportionally across region and depth zones (Thompson et al. 2017). Artificial reef sites were initially selected from a geodatabase of available, known artificial reefs and wrecks occurring with the survey frame. Mapping protocols vary slightly around artificial habitats where the selected reef site is centered within the 2.1 km^2 area and the survey covers 1.3 km East-West and 1.6 km North-South. Video deployment sites are then randomly assigned based on the distribution of presumed artificial reef habitats.

G-FISHER survey design:

Beginning in 2020, Gulf-wide video survey efforts were integrated under a single, novel survey design under the G-FISHER program (Switzer et al. 2023). A stratified-random approach to survey design was adopted based on both spatial and habitat stratification, as other reef fish surveys have utilized this approach to subdivide the survey domain into homogeneous strata and partition population variance (Smith et al. 2011). To do so, a retrospective analysis of data on reef fish assemblages and their habitats was conducted to (1) delineate biologically relevant spatial and habitat strata, and (2) define optimal allocation of sampling effort based on a combination of habitat availability and managed species richness. Spatially, the Gulf survey domain was subdivided into three depth strata (10–25 m, >25–50 m, >50–180 m) and six regional strata (Texas, west Louisiana, east Louisiana, north-central Gulf, Big Bend, and southwest Florida). For both natural and artificial reefs, habitat strata were delineated based on relative relief (low, medium, high) and size of the individual reef feature, although delineation of reef scale differed markedly between natural (<100 m2, 100–1000 m2, >1000 m2) and artificial habitat strata (<25 m2, 25–100 m2, >100 m2). Under the new G-FISHER design, approximately 2,000 reef fish stations are sampled annually with stereo-baited remote underwater video (S-BRUV) camera arrays designed to characterize benthic habitats and provide data on abundance and size composition of reef fishes observed.

Video reads:

All surveys use paired stereo-imaging cameras at each site. All videos are read to identify the maximum number of individuals of each species viewed in a single frame within a 20-minute time frame, often referred to as MaxN or MinCount. Habitat characteristics on video are also noted with the percentage or presence/absence of abiotic and biotic habitat types that may contribute to fish biomass (e.g. sponge, algae, and corals). While some categories were not historically recorded by all three labs (Campbell et al. 2017; Gardner et al. 2017; Thompson et al. 2017), the habitat annotation procedures adopted by G-FISHER are more comprehensive and include habitat variables recorded during any of the three prior surveys.

Fish length measurements:

The methods employed to gather fish length data video records have also evolved over time. Length measurements from the SRFV and PC surveys were initially estimated using parallel lasers attached to the camera system (Campbell et al. 2017; Gardner et al. 2017). However, the fixed mounted lasers resulted in very few usable laser contacts needed to obtain individual length measurement while also mitigating repeated measurements of the same individual. Therefore, both surveys adopted stereo-video methods (2008 and 2010 for SRFV and PC surveys, respectively). From the onset, the FWRI survey used stereo-video methods to obtain length measurements. Length estimates from all three historic surveys were obtained from Vision Measurement System (VMS, Geometrics Inc.) through 2014. From 2015 to present, all length measurements are obtained from the SeaGIS software (SeaGIS Pty. Ltd.).

Data processing:

For all surveys, video reads were excluded if they were unreadable due to turbidity or deployment errors. Sites west of NMFS statistical zone 9 were also excluded from all survey data sets because of a lack of Hogfish observations and portioned into Gulf and Atlantic data sets along the Cape Sable boundary (Figure 1). Data from the SRFV survey collected in 1992 were excluded from index calculations because of differences in counting methods in this first year, and no survey data are available for years 1998-2001 and 2003. For the Atlantic index, data from 2013 and 2015 were also removed because fewer than 10 sites were sampled. Panama City survey data from 2005 was excluded because of an incomplete survey. For both FWRI and G-FISHER, data from both natural and artificial reefs were used but treated as separate surveys for index construction denoted by the suffix "-AR". Because of sporadic effort and few Hogfish observations, data from the FWRI-AR survey prior to 2015 was omitted from the Gulf index and not used for the Atlantic index. For natural reefs, data from 2010 to 2019 was retained for both the Gulf and Atlantic stocks. In the case of G-FISHER, data from both natural and artificial reefs were available for all years (i.e., 2020-2023). Again, however, artificial reef data were excluded from the Atlantic index because of low sample sizes and a lack of Hogfish observations. The same data reduction procedures were applied to the video length data set such that annual size composition vectors were generated solely from stations used to generate standardized indices for each stock. Individual measurements subsequently assigned to 2 cm size bins ranging from 12-80 cm fork length.

Index Construction

Habitat models

To develop a single index of abundance from all surveys for each Hogfish stock, a common habitat variable was created that included each of the separate survey individual variables that could be applied to all the data. This was done so the final index models can account for changing sampling effort and habitat allocation through time rather than limiting the model to be predicted only by year and survey. Habitat classes were determined independently for each survey using a classification and regression tree approach (CART) to classify sites based on the probability of occurrence. This was done because this method accounts for correlations among variables and allows both continuous and categorical data to be included. It has been previously demonstrated to be a useful tool in fisheries ecology and specifically in describing fish-habitat associations (De'Ath and Fabricus 2000; Yates et al. 2016, Thompson et al. 2022).

For these initial analyses, MaxN for each site was reduced to a presence and absence variable and was used as the response variable for habitat designations. Predictor variables included the habitat metrics coded on the video reads (reduced to presence/absence), the latitude and longitude of each site and depth for all four survey sets. For G-FISHER and FWRI, side-scan geoform was also included as a landscape-level habitat variable, with values derived using a modified version of the Coastal and Marine Ecological Classification Standard (CMECS) classification approach. Geoform was not included as a predictor variable for the analysis of SRFV survey data because the habitat mapping for that survey has primarily been conducted utilizing multibeam sonar. At present, comparable habitat classification between side-scan and multibeam is not possible due to differences in scale and differences in the underlying data itself (particularly for low relief strata). We first used a random forest approach to reduce the number of potential variables to be selected from in the final model for each lab's dataset to reduce redundant or correlated variables used in the final indexing model. For the random forest analysis, each survey was modeled separately for the entirety of that dataset. The random forest (RF) analysis fitted 2000 CARTS to the data and then determined each variable's importance, a scale-less number used to indicate the number of final models each variable occurred in and its significance therein. An example of output is given in Figure 4 for the FWRI survey dataset. Note too that the RF input variable for the FWRI-AR and GF-AR surveys were the same as their natural reef counterparts.

From the RF analysis, approximately 50% of the potential variables were retained for each survey given by the importance values for a final CART model. The final model was created by fitting the presence of Hogfish at a site to the independent variables for a training dataset of 80% of the data. The remaining 20% of the data were retained in a test dataset to determine misclassification rates for each of the three models. The proportion of sites with positive Hogfish catches at each terminal node was then evaluated to determine the habitat characteristics defining each survey habitat class. For the Gulf surveys on natural reefs, terminal nodes were partitioned among three classes. If the portion of positive observations for a terminal node was 2 times the overall proportion positive, it was used to define the High proportion positive class. The criteria for terminal nodes with a proportion positive at least half (50%) of the overall proportion positive were used to define the Low proportion positive class, and the criteria associated with the remaining terminal nodes were used to define the Medium proportion positive class. For the Gulf AR and Atlantic survey datasets, only two habitat classes were defined (i.e., High and Low) based on whether the proportion positive for a terminal node was above or below the overall proportion positive. Because this habitat classification procedure was performed independently for each video survey, they are not directly comparable across surveys. All analyses were carried out using R version 4.5.0 (R Core Team 2025) and the partykit package for RF and CART model fitting (Hothorn and Zeileis. 2015).

Index model fitting and diagnostics

The final model used to index abundance was fit using a negative binomial in R using the formula:

$$MaxN = Year \times Survey \times Hab$$

Here, Hab is the CART derived habitat class and survey represents the survey that collected the data for each site. To account for the variation in survey area, differences in area mapped with known habitat, and the distribution of High, Medium, and Low proportion positive habitats by survey, the estimated MaxN means provided by the GLM were then adjusted. The known potential survey universe for each of the three was first multiplied by the proportion of habitat microgrids that contained reef habitat to provide an area weight. This was then multiplied by each Year × Survey × Hab combination, providing a weighting factor for each of the mean estimates. The survey area weights used to generate the Gulf and Atlantic Hogfish indices are provided in Tables 1 and 2 respectively. Note that the area estimates are only used to establish a universal scale from which the relative proportion of reef habitat among surveys can be estimated. They should not be interpreted in an absolute sense. The survey-specific habitat weights for each stock are provided in Table 3.

Compilation of length data

As with the habitat-area weighting approach above, annual length compositions were weighted by the habitat class proportion and area weights for each stock. This was accomplished by first calculating the annual bin proportions for each survey and habitat class combination such that length data were placed on comparable scales. The resulting relative frequencies for each survey were then multiplied by their respective habitat and area weights to generate annual length compositions which account for both differences in habitat classes sampled by each survey and the overall survey footprints.

Results and Discussion:

The relative frequency of occurrence for Gulf Hogfish was similar among surveys with occurrence rates of 18% (PC), 10% (FWRI-AR and GF-AR), 9% (GF), 7% (FWRI), and 6% (SRFV) (Table 4 and 5). For Atlantic Hogfish, the relative frequencies of occurrence were slightly higher; 26% (GF), 15% (SRFV) and 10% (FWRI) (Table 6 and 7). Regardless of survey and stock the CART habitat models were surprisingly consistent in terms of the criteria used to define habitat classes (Figures 5-11). Depth, geographic location, substrate relief, and the presence of live-bottom habitat were the primary variables used to define habitat classes for the natural reef surveys. More specifically, High proportion positive sites tended to be shallow, east of the Florida Panhandle, of moderate relief with soft coral/sponge present. Medium proportion positive sites tended to be lower relief live bottom habitat either deeper or west Cape San Blas, and Low proportion positive sites often deeper and/or west of Cape Blas, with little to no substrate relief (Figures 5-8). The FWRI-AR CART only consisted of two terminal nodes, with Low and High proportion positive AR sites being either west or east of Cape San Blas, respectively (bottom panel Figure 7). The GF-AR CART results were slightly more complex with High proportion positive AR sites being those south of the mouth of Tampa Bay with some degree of structural relief and other sites being classified as Low (bottom panel Figure 8). The Atlantic Hogfish CART models were similar to their Gulf natural reef counterparts whereby the distinction between High and Low proportion positive was often based on depth as well as a variable indicative of structural relief or live bottom (Figures 9-11).

The standardized indices of abundance for Gulf and Atlantic Hogfish, including coefficients of variation (CV), are provided in Table 8 and Table 9. For both stocks, CV values indicate good model fit. The highest CV values generally occurred in the earlier years of each time series and steadily decreased as additional surveys appear. The CV values in the final years were ~10% for the Gulf and ~16% for the Atlantic. The Gulf Hogfish index indicates a period of below average abundance from 1993 to 2004, followed by an increase in abundance from 2005 to 2007, and subsequent decline from 2008 to 2014 (Figure 12). From 2015 onward, estimated Gulf Hogfish abundance shows a clear positive trend. Unlike the Gulf Hogfish index, which peaked in 2007, the Atlantic Hogfish index indicates abundance was highest in 1993 and steadily declined into 2008 (Figure 13). From 2009 to present, there was an overall positive trend in Atlantic Hogfish abundance.

Video length measurements of both Gulf and Atlantic Hogfish were relatively sparse, particularly in the years prior to stereo camera deployments (Table 10 and 11). Al Overall distributions of Hogfish lengths were similar among surveys within their respective stocks. The one exception was the SRFV survey which yielded a narrow size distribution (Figures 14-17) but also generated the fewest number of measurements.

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Table 1. The estimated total universe size, amount of habitat, and resulting area weights for each video survey used to standardize Gulf Hogfish abundance by survey habitat class. For the FWRI and GFISHER surveys, reef area estimates and final area weights for artificial reefs are also provided.

Gulf	SRFV	PC	FWRI (2010-2013)	FWRI (2014-2015)	FWRI (2016-2019)	FWRI AR (2016-2019)	GF	GF AR
Total Universe Area (km^2)	20092	19790	46286	55327	126502	126502	126502	126502
Area x Proportion grids with reef	3292	5053	9820	10817	24994	835	24994	835
Time Period Weighting Values								
1993-2005	1.00	--	--	--	--	--	--	--
2006-2009	0.39	0.61	--	--	--	--	--	--
2010-2013	0.18	0.28	0.54	--	--	--	--	--
2014-2015	0.17	0.26	--	0.56	--	--	--	--
2016-2019	0.10	0.15	--	--	0.73	0.02	--	--
2020-2023	--	--	--	--	--	--	0.97	0.03

Table 2. The estimated total universe size, amount of habitat, and resulting area weights for each video survey used to standardize Atlantic Hogfish abundance by survey habitat class.

Atlantic	SRFV	FWRI	GF
Total Universe Area (km^2)	3937	14258	14258
Area x Proportion grids with reef	1297	3663	3663
Time Period Weighting Values			
1993-2015	1.00	--	--
2016-2019	0.26	0.74	--
2020-2023	--	--	1.00

Table 3. Survey-specific habitat weights for Gulf and Atlantic Hogfish.

Stock	**Survey**	**Low**	**Medium**	**High**
Gulf	SRFV	0.52	0.31	0.17
	PC	0.58	0.10	0.32
	FWRI	0.47	0.41	0.12
	FWRI-AR	0.65		0.35
	GFISHER	0.47	0.41	0.12
	GFISHER-AR	0.65		0.35
Atlantic	SRFV	0.45		0.55
	FWRI	0.65		0.35
	GFISHER	0.65		0.35

Table 4. Annual frequency of occurrence of Gulf Hogfish (first number) and sites sampled (second number) for the SEAMAP Reef Fish Video Survey (SRFV), NMFS Panama City (PC), Florida Fish and Wildlife Research Institute (FWRI) and Gulf Fishery Independent Survey of Habitat and Ecosystem Resources (GFISHER). For the FWRI and GFISHER surveys, Hogfish occurrence and effort values are provided separately for natural and artificial reefs. Note the gap in sampling for the SFRV survey for the years of 1998-2001 and 2003.

Year	SRFV	PC	FWRI	FWRI-AR	GFISHER	GFISHER-AR
1993	14/93					
1994	6/66					
1995	5/35					
1996	5/85					
1997	10/129					
2002	10/103					
2004	6/104					
2005	13/170					
2006	8/169	19/87				
2007	8/168	16/44				
2008	8/112	31/83				
2009	10/152	36/104				
2010	8/112	23/138	3/49			
2011	19/200	23/150	21/211			
2012	9/173	30/148	23/214			
2013	3/117	9/86	13/183			
2014	7/148	13/169	17/325			
2015	5/110	12/155	16/326			
2016	4/123	20/153	34/574	5/51		
2017	5/136	28/147	45/497	7/70		
2018	8/115	24/76	39/547	8/96		
2019	10/184	12/94	32/724	14/116		
2020					59/592	19/137
2021					62/803	17/144
2022					73/728	11/167
2023					65/749	16/160

Table 5. Annual frequency of occurrence of Gulf Hogfish (first number) and number of sites sampled (second number) for the habitat classes assigned using survey-specific classification and regression trees (CARTs).

Year	SRFV			PC			FWRI			FWRI AR		GF			GF AR	
	Low	Med	High	Low	Med	High	Low	Med	High	Low	High	Low	Med	High	Low	High
1993	0/28	1/31	13/34													
1994	0/26	0/19	6/21													
1995	0/15	1/9	4/11													
1996	0/29	0/21	5/35													
1997	0/55	3/32	7/42													
2002	0/62	1/15	9/26													
2004	1/62	0/17	5/25													
2005	0/120	5/32	8/18													
2006	0/97	2/48	6/24	0/19	7/26	12/42										
2007	0/106	6/45	2/17	3/15	2/6	11/23										
2008	1/51	4/49	3/12	1/23	2/11	28/49										
2009	0/92	4/42	6/18	4/47	1/6	31/51										
2010	1/73	1/26	6/13	3/93	2/6	18/39	0/27	3/18	0/4							
2011	2/128	7/49	10/23	3/89	2/5	18/56	3/97	5/79	13/35							
2012	0/95	1/51	8/27	3/96	2/11	25/41	0/94	7/87	16/33							
2013	0/56	0/43	3/18	2/64	0/2	7/20	0/78	4/87	9/18							
2014	0/68	2/61	5/19	3/114	1/12	9/43	0/158	4/129	13/38							
2015	0/47	1/47	4/16	0/106	5/21	7/28	0/150	9/151	7/25							
2016	0/54	1/56	3/13	2/101	4/25	14/27	2/256	17/256	15/62	0/31	5/20					
2017	0/40	0/72	5/24	4/86	0/3	24/58	2/179	12/218	31/100	0/46	7/24					
2018	1/49	4/54	3/12	1/24	5/15	18/37	1/265	17/210	21/72	0/74	8/22					
2019	0/109	1/48	9/27	2/64	2/16	8/14	2/399	15/263	15/62	0/67	14/49					
2020												10/349	27/165	22/78	7/118	12/19
2021												8/534	31/195	23/74	7/128	10/16
2022												6/457	28/183	39/88	4/146	7/21
2023												7/505	27/172	31/72	9/146	7/14

Table 6. Annual frequency of occurrence of Atlantic Hogfish (first number) and natural reef sites sampled for the SEAMAP Reef Fish Video Survey (SRFV), Florida Fish and Wildlife Research Institute (FWRI) and Gulf Fishery Independent Survey of Habitat and Ecosystem Resources (GFISHER). Note the gap in sampling for the SFRV survey for the years of 1998-2001 and 2003.

Year	SRFV	FWRI	GFISHER
1993	7/14		
1994	2/21		
1995	5/14		
1996	6/34		
1997	9/33		
2002	8/34		
2004	4/26		
2005	7/58		
2006	7/57		
2007	9/79		
2008	2/55		
2009	4/69		
2010	7/66		
2011	11/75		
2012	8/79		
2013			
2014	6/38		
2015			
2016	5/47	10/89	
2017	9/56	5/93	
2018	10/46	11/120	
2019	18/59	17/116	
2020			44/145
2021			36/147
2022			31/135
2023			32/123

Table 7. Annual frequency of occurrence of Atlantic hogfish (first number) and number of natural reef sites sampled (second number) for the habitat classes assigned using survey-specific classification and regression trees (CARTs).

Year	SRFV		FWRI		GF	
	Low	High	Low	High	Low	High
1993	0/0	7/14				
1994	0/13	2/8				
1995	0/1	5/13				
1996	0/14	6/20				
1997	0/2	9/31				
2002	1/3	7/31				
2004	0/5	4/21				
2005	1/35	6/23				
2006	0/27	7/30				
2007	4/45	5/34				
2008	0/30	2/25				
2009	1/35	3/34				
2010	3/34	4/32				
2011	2/43	9/32				
2012	3/46	5/33				
2013						
2014	0/15	6/23				
2015						
2016	2/25	3/22	0/54	10/35		
2017	0/23	9/33	1/69	4/24		
2018	2/19	8/27	0/83	11/37		
2019	0/19	18/40	0/65	17/51		
2020					1/55	43/90
2021					5/70	31/77
2022					6/72	25/63
2023					4/49	28/74

Table 8. Standardized index of abundance, standard error, coefficient of variation and 95% confidence intervals for Gulf Hogfish. Mean-scaled index values and confidence intervals are also provided.

Year	Index	SE	CV	Lower CI	Upper CI	Index scaled	Lower CI scaled	Upper CI scaled
1993	0.0947	0.0272	0.2872	0.0414	0.1480	0.6894	0.6361	0.7427
1994	0.0484	0.0223	0.4603	0.0047	0.0921	0.3524	0.3087	0.3961
1995	0.1268	0.0589	0.4644	0.0114	0.2421	0.9229	0.8076	1.0383
1996	0.0339	0.0140	0.4123	0.0065	0.0613	0.2467	0.2193	0.2741
1997	0.0669	0.0234	0.3506	0.0209	0.1128	0.4870	0.4410	0.5329
2002	0.0858	0.0321	0.3745	0.0228	0.1487	0.6245	0.5615	0.6874
2004	0.0491	0.0203	0.4127	0.0094	0.0888	0.3573	0.3176	0.3970
2005	0.1523	0.0443	0.2910	0.0654	0.2392	1.1092	1.0223	1.1961
2006	0.1413	0.0281	0.1988	0.0862	0.1963	1.0286	0.9735	1.0836
2007	0.3048	0.0730	0.2397	0.1616	0.4480	2.2192	2.0760	2.3624
2008	0.2694	0.0474	0.1761	0.1764	0.3624	1.9614	1.8684	2.0543
2009	0.2496	0.0415	0.1663	0.1682	0.3310	1.8175	1.7361	1.8989
2010	0.1216	0.0288	0.2373	0.0650	0.1781	0.8851	0.8286	0.9416
2011	0.1453	0.0226	0.1558	0.1010	0.1897	1.0583	1.0139	1.1027
2012	0.1810	0.0245	0.1356	0.1329	0.2291	1.3181	1.2700	1.3662
2013	0.1367	0.0291	0.2130	0.0796	0.1938	0.9956	0.9385	1.0527
2014	0.0955	0.0149	0.1566	0.0662	0.1248	0.6952	0.6659	0.7245
2015	0.1113	0.0199	0.1787	0.0723	0.1503	0.8107	0.7717	0.8497
2016	0.1176	0.0155	0.1318	0.0872	0.1480	0.8561	0.8258	0.8865
2017	0.1065	0.0117	0.1103	0.0835	0.1296	0.7758	0.7527	0.7988
2018	0.1315	0.0157	0.1191	0.1008	0.1622	0.9575	0.9268	0.9882
2019	0.1191	0.0182	0.1526	0.0835	0.1547	0.8670	0.8314	0.9026
2020	0.1722	0.0205	0.1189	0.1321	0.2124	1.2541	1.2140	1.2942
2021	0.1415	0.0175	0.1237	0.1072	0.1758	1.0303	0.9960	1.0646
2022	0.1665	0.0194	0.1168	0.1284	0.2046	1.2125	1.1743	1.2506
2023	0.2016	0.0232	0.1149	0.1562	0.2470	1.4678	1.4224	1.5132

Table 9. Standardize index of abundance, standard error, coefficient of variation and 95% confidence intervals for Atlantic Hogfish on natural reefs. Mean-scaled index values and confidence intervals are also provided.

Year	Index	SE	CV	Lower CI	Upper CI	Index scaled	Lower CI scaled	Upper CI scaled
1993	0.3522	0.1247	0.3539	0.1079	0.5966	1.8950	1.6507	2.1393
1994	0.2740	0.1436	0.5242	-0.0075	0.5554	1.4739	1.1924	1.7553
1995	0.2950	0.1173	0.3976	0.0651	0.5249	1.5872	1.3573	1.8172
1996	0.1918	0.0750	0.3908	0.0449	0.3387	1.0317	0.8848	1.1786
1997	0.1767	0.0576	0.3262	0.0638	0.2897	0.9509	0.8379	1.0639
2002	0.2921	0.1638	0.5608	-0.0290	0.6132	1.5714	1.2504	1.8925
2004	0.1305	0.0597	0.4576	0.0134	0.2475	0.7018	0.5848	0.8189
2005	0.1797	0.0662	0.3683	0.0500	0.3094	0.9666	0.8369	1.0963
2006	0.1461	0.0530	0.3628	0.0422	0.2500	0.7861	0.6822	0.8900
2007	0.1208	0.0418	0.3461	0.0388	0.2027	0.6497	0.5678	0.7316
2008	0.0658	0.0384	0.5842	-0.0095	0.1410	0.3537	0.2784	0.4290
2009	0.0774	0.0351	0.4534	0.0086	0.1461	0.4163	0.3475	0.4850
2010	0.1255	0.0453	0.3608	0.0367	0.2143	0.6752	0.5864	0.7639
2011	0.2713	0.0693	0.2553	0.1355	0.4070	1.4593	1.3236	1.5951
2012	0.1488	0.0470	0.3158	0.0567	0.2408	0.8003	0.7082	0.8924
2014	0.1429	0.0598	0.4187	0.0256	0.2602	0.7690	0.6517	0.8863
2016	0.1340	0.0312	0.2328	0.0728	0.1952	0.7209	0.6598	0.7821
2017	0.0936	0.0271	0.2889	0.0406	0.1467	0.5038	0.4507	0.5568
2018	0.1444	0.0313	0.2166	0.0831	0.2057	0.7770	0.7157	0.8383
2019	0.1755	0.0290	0.1653	0.1187	0.2324	0.9444	0.8876	1.0013
2020	0.2150	0.0320	0.1489	0.1523	0.2777	1.1566	1.0938	1.2193
2021	0.2381	0.0375	0.1574	0.1646	0.3116	1.2811	1.2076	1.3546
2022	0.2327	0.0399	0.1715	0.1545	0.3109	1.2517	1.1735	1.3299
2023	0.2372	0.0422	0.1781	0.1544	0.3200	1.2763	1.1935	1.3591

Table 10. Annual number of Gulf Hogfish measurements (first number) and number of stations yielding measurements (second number) for each survey and habitat class. Blank entries denote survey years where no measurements are available.

Year	SRFV			PC			FWRI			FWRI_AR		GF			GF_AR	
	Low	Med	High	Low	Med	High	Low	Med	High	Low	High	Low	Med	High	Low	High
1993																
1994																
1995																
1996																
1997	0/0	0/0	2/2													
2002	0/0	0/0	3/2													
2004	1/1	0/0	7/4													
2005	0/0	1/1	1/1													
2006																
2007	0/0	0/0	1/1													
2008	1/1	3/3	2/2													
2009	0/0	4/4	4/3	2/1	0/0	7/7										
2010				3/1	1/1	8/7	0/0	2/2	0/0							
2011	0/0	5/5	7/6	1/1	1/1	11/8	1/1	2/2	6/5							
2012	0/0	1/1	5/4	3/3	1/1	16/15	0/0	6/4	16/14							
2013	0/0	0/0	2/2				0/0	2/2	7/6							
2014	0/0	0/0	1/1				0/0	6/3	13/10							
2015	0/0	1/1	1/1				0/0	11/8	12/7							
2016	0/0	0/0	3/3	2/2	0/0	3/3	1/1	19/15	25/12	0/0	3/2					
2017	0/0	0/0	3/3	1/1	0/0	18/18	2/2	12/11	32/26	0/0	7/6					
2018	0/0	7/1	0/0	1/1	2/2	9/9	1/1	21/15	27/18	0/0	7/6					
2019				0/0	0/0	3/3	2/2	20/13	23/11	0/0	12/9					
2020												8/8	29/21	28/21	7/5	15/10
2021												9/8	29/24	21/18	5/4	8/7
2022												3/3	26/20	47/33	1/1	4/4
2023												7/5	30/20	39/26	6/6	9/6

Table 11. Annual number of Atlantic Hogfish measurements (first number) and total sites generating measurements (second number) for each survey and habitat class. Blank entries represent years where, if sampling occurred, no measurements were obtained.

Year	SRFV		FWRI		GF	
	Low	High	Low	High	Low	High
1993						
1994						
1995						
1996						
1997						
2002	0/0	1/1				
2004	0/0	3/3				
2005						
2006						
2007						
2008	0/0	1/1				
2009	1/1	1/1				
2010						
2011	1/1	7/5				
2012	3/2	3/3				
2013						
2014	0/0	3/3				
2015						
2016	1/1	1/1	0/0	12/10		
2017	0/0	5/5	1/1	2/2		
2018			0/0	9/8		
2019			0/0	13/12		
2020					1/1	35/30
2021					2/2	18/15
2022					3/3	25/21
2023					0/0	22/16

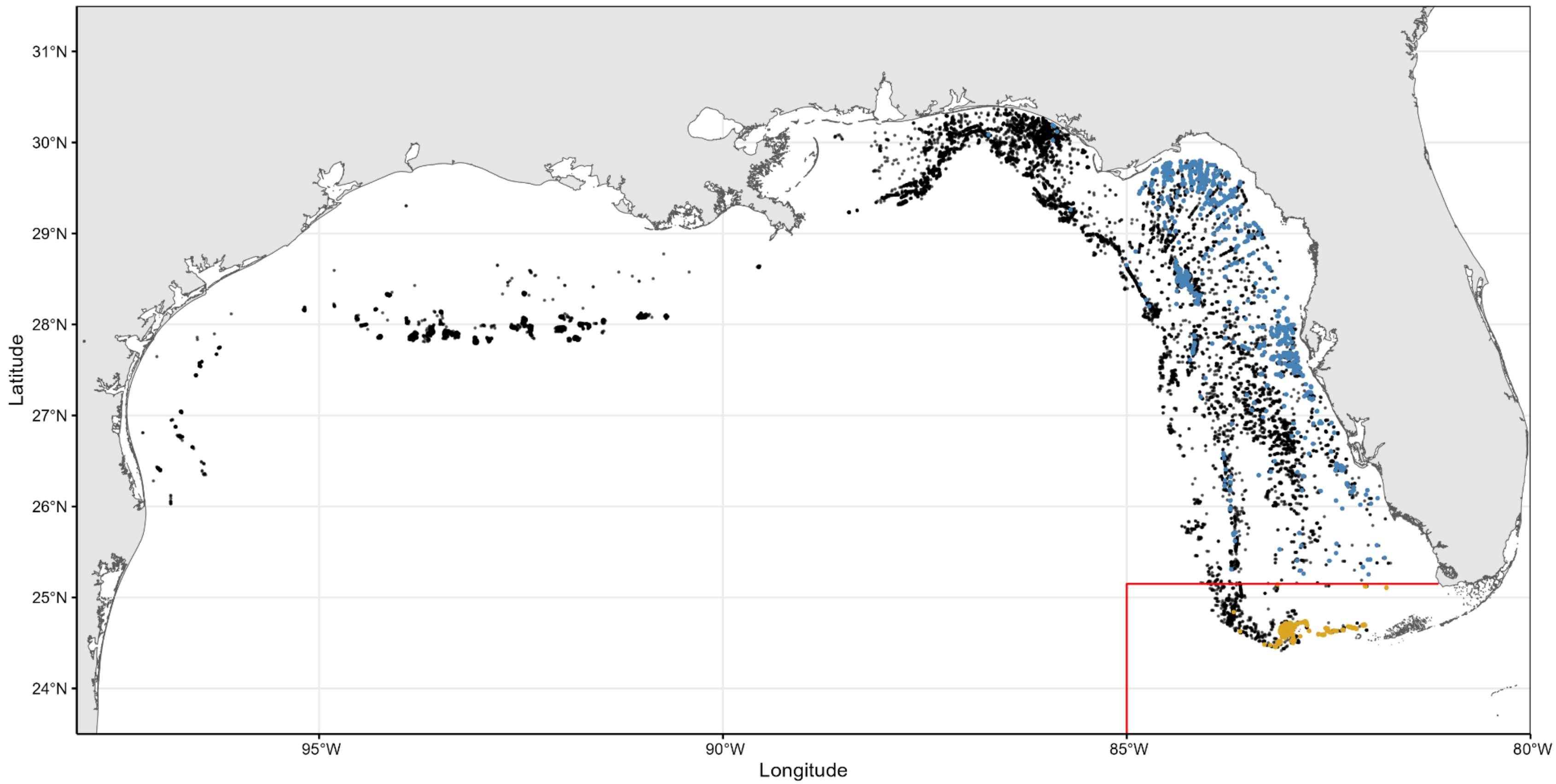


Figure 1. Map of combined video survey effort on natural and artificial reefs from 1993 to 2023 with the boundary between the Gulf and Atlantic Hogfish stock represented by the red line. Black points indicate sampling sites where no hogfish were observed while blue and yellow points indicate the presence of hogfish for the Gulf and Atlantic stocks respectively.

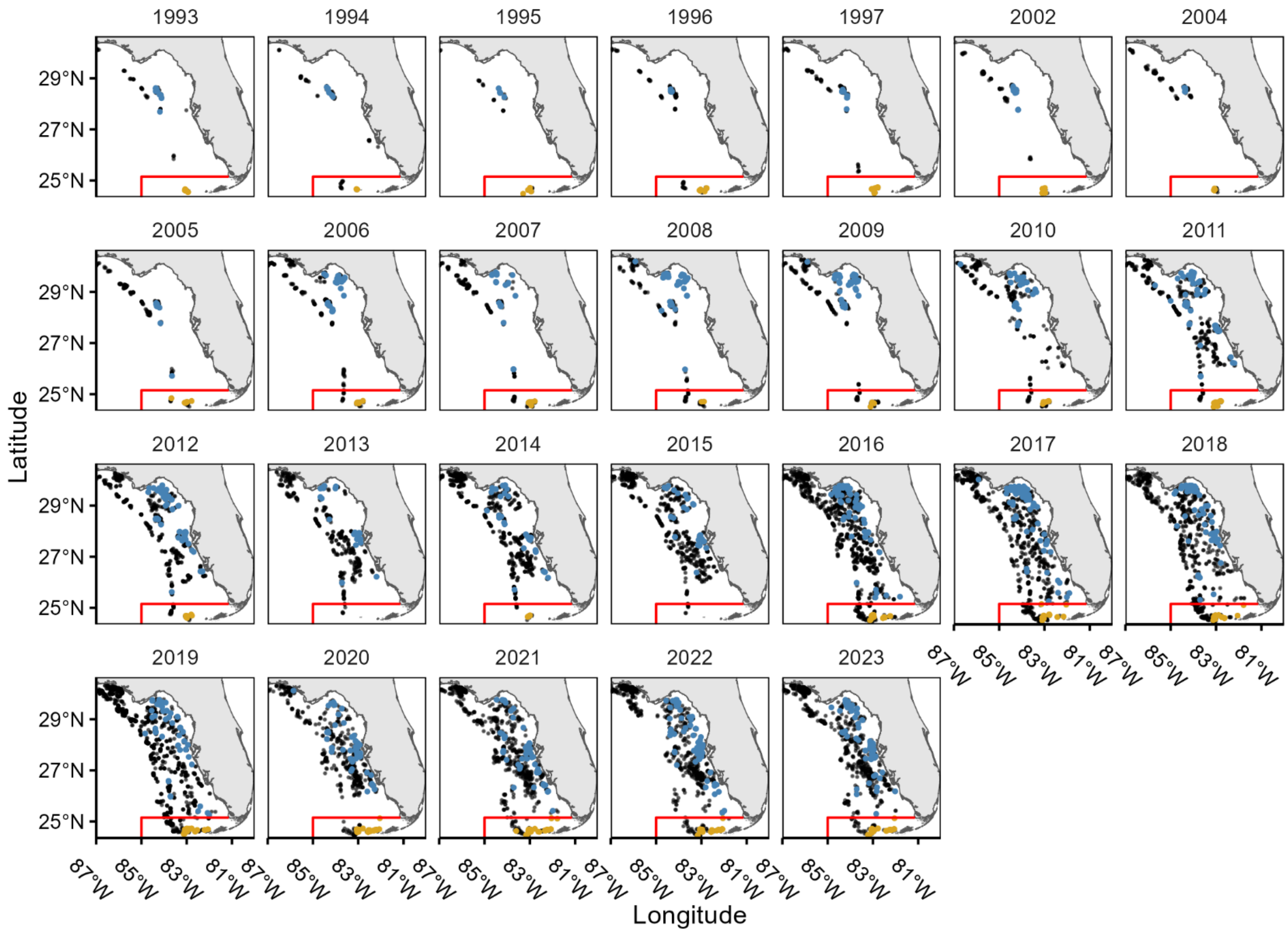


Figure 2. Annual distributions of Hogfish presence absence on natural reefs across all video surveys. The red line denotes the boundary between Gulf and Atlantic stocks. Blue and yellow points indicate the presence of Gulf and Atlantic hogfish respectively and black points represent reefs where hogfish were absent.

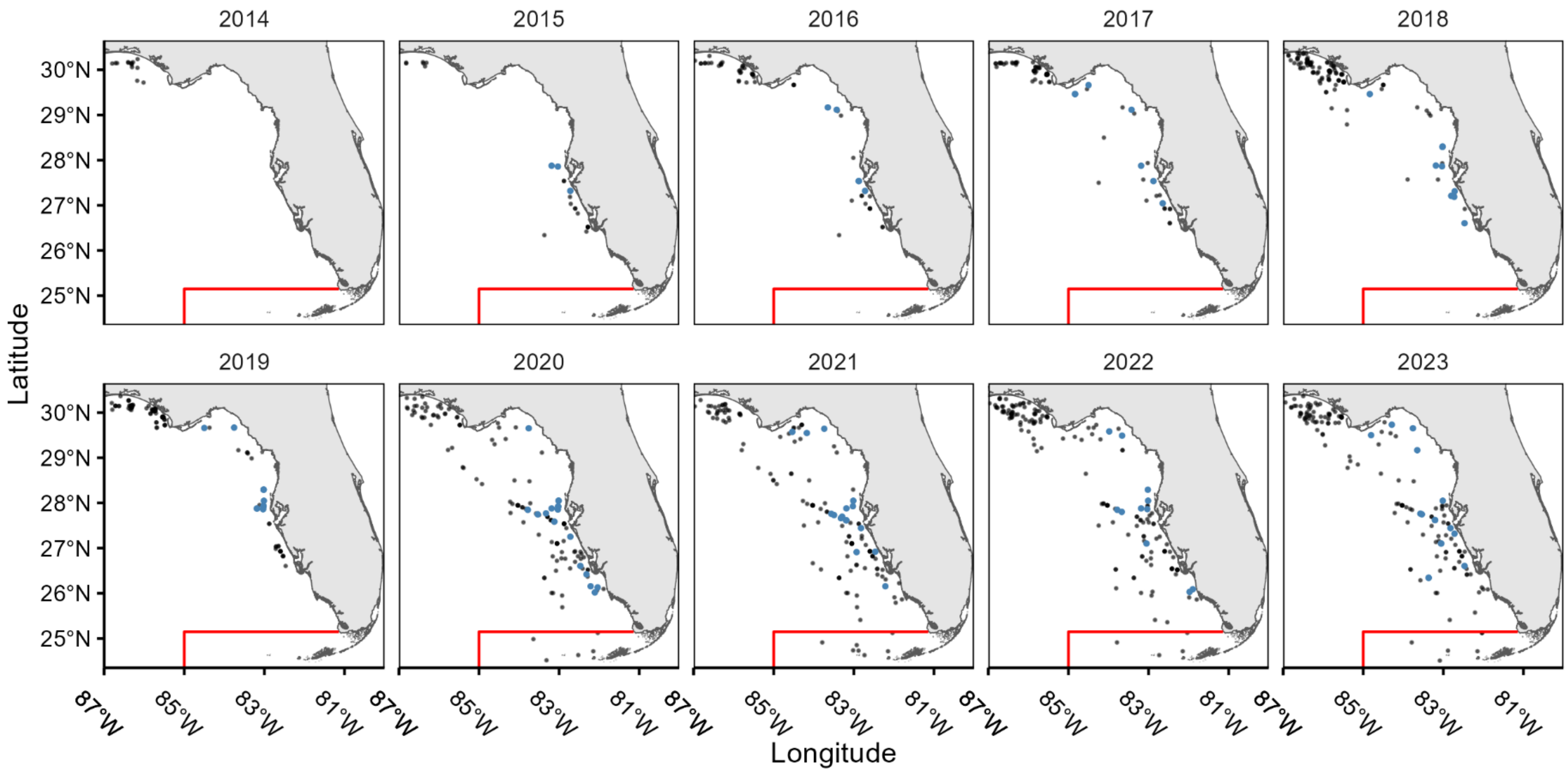


Figure 3. Annual distributions of Hogfish presence absence on artificial reefs across all video surveys. Red line denotes the boundary between Gulf and Atlantic stocks. Blue and yellow points indicate the presence of Gulf and Atlantic hogfish respectively and black points represent reefs where hogfish were absent.

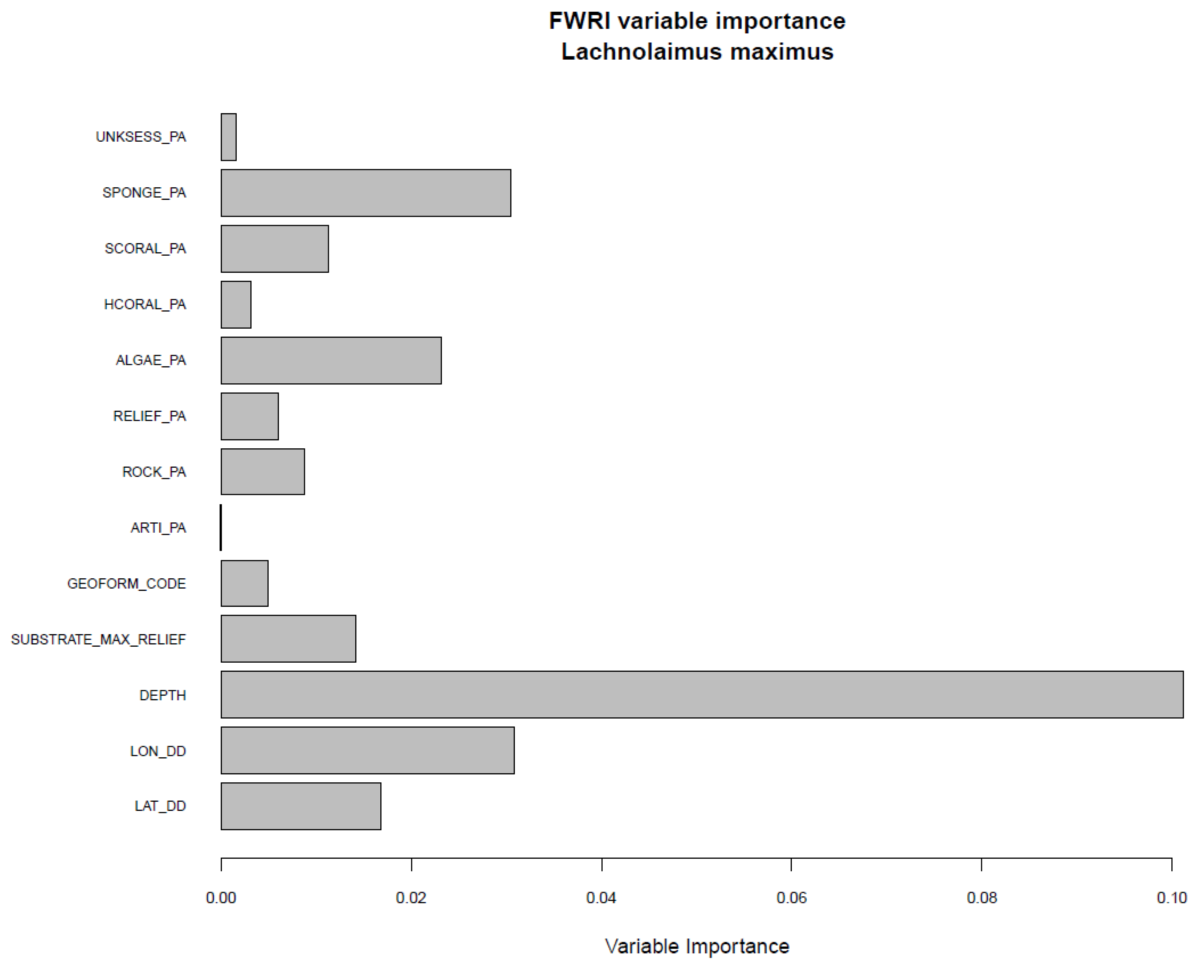


Figure 4. The FWRI random forest varibale importance for Gulf Hogfish.

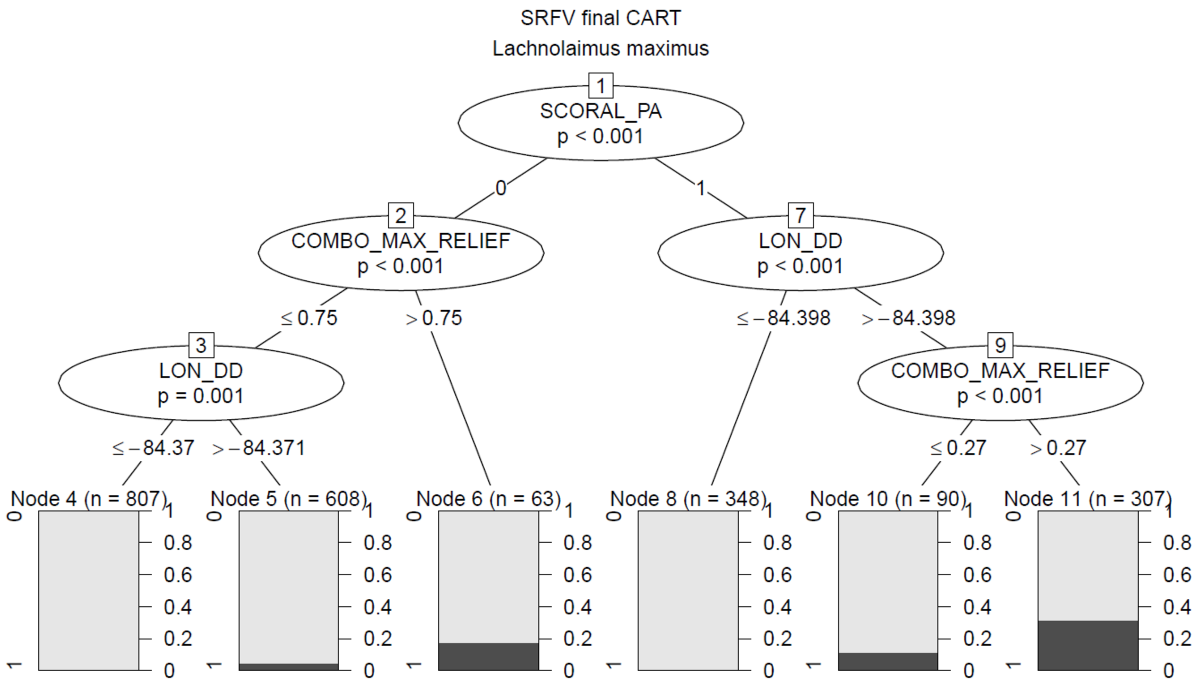


Figure 5.Final SRFV CART model for Gulf Hogfish.

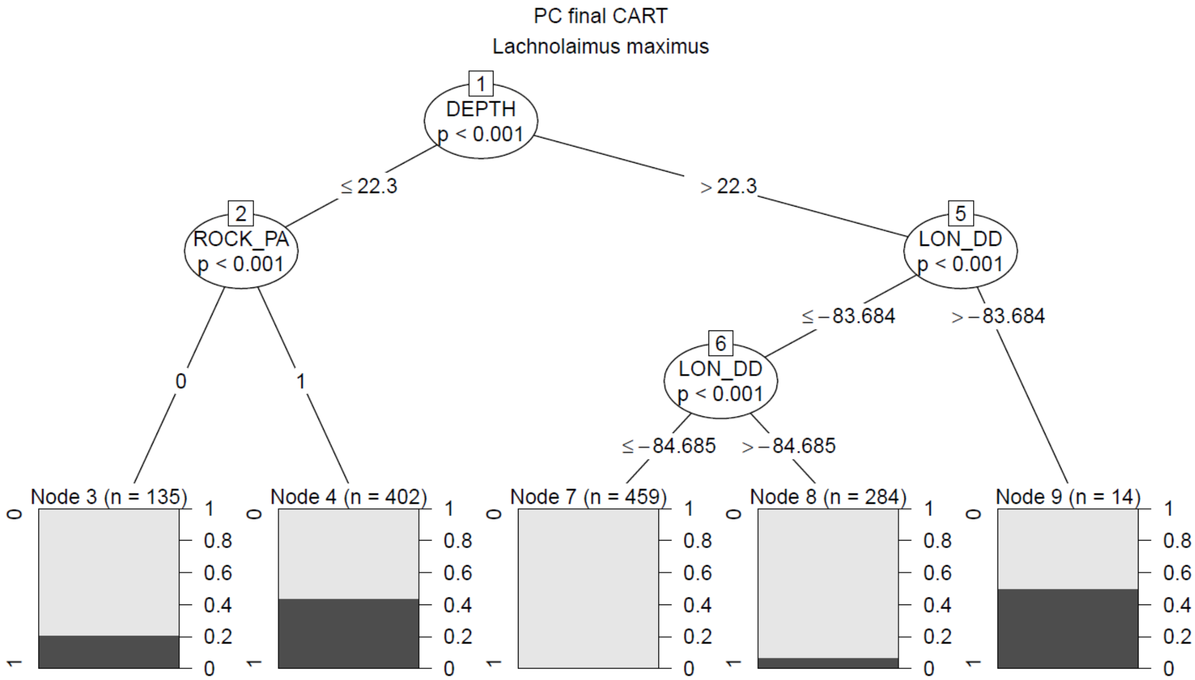
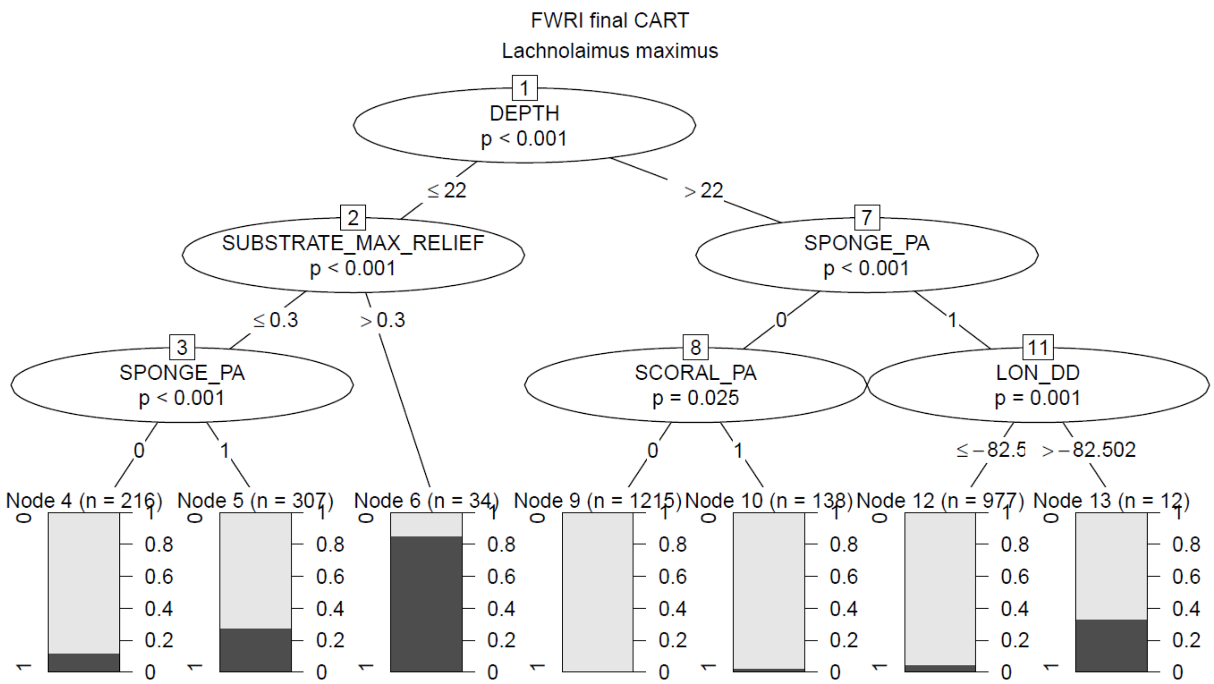


Figure 6. Final PC CART model for Gulf Hogfish.



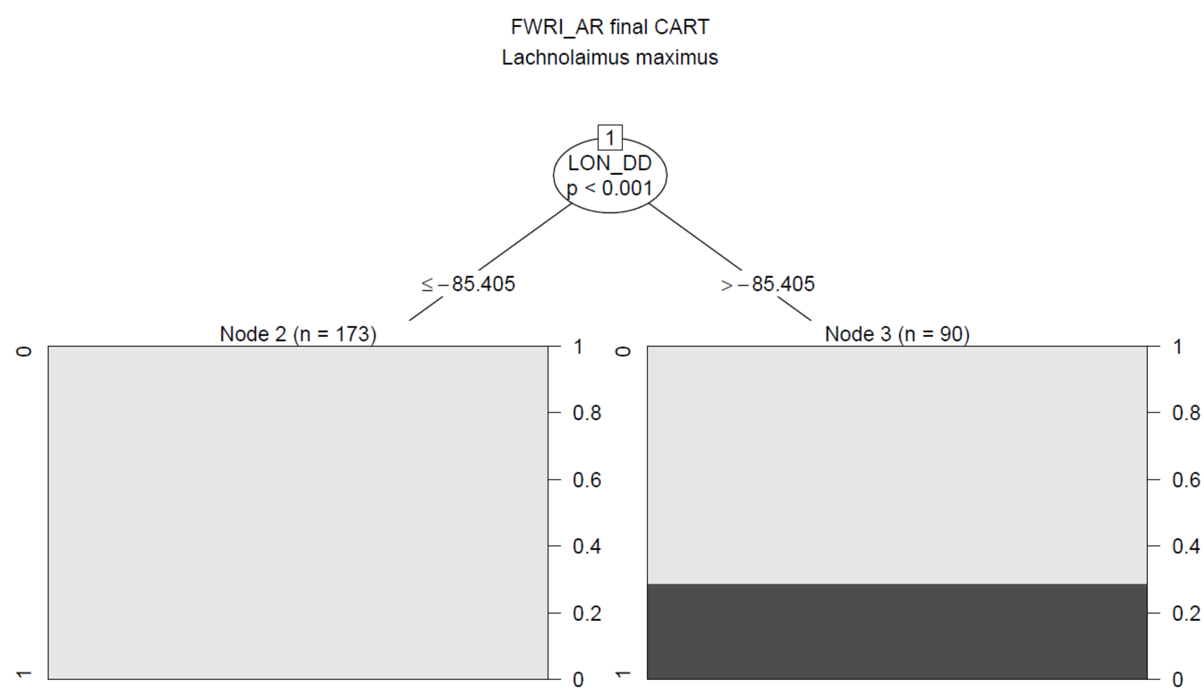


Figure 7. Final FWRI CART models for Gulf Hogfish. Results from the natural and artificial reef surveys are shown on the top plot and bottom plots respectively.

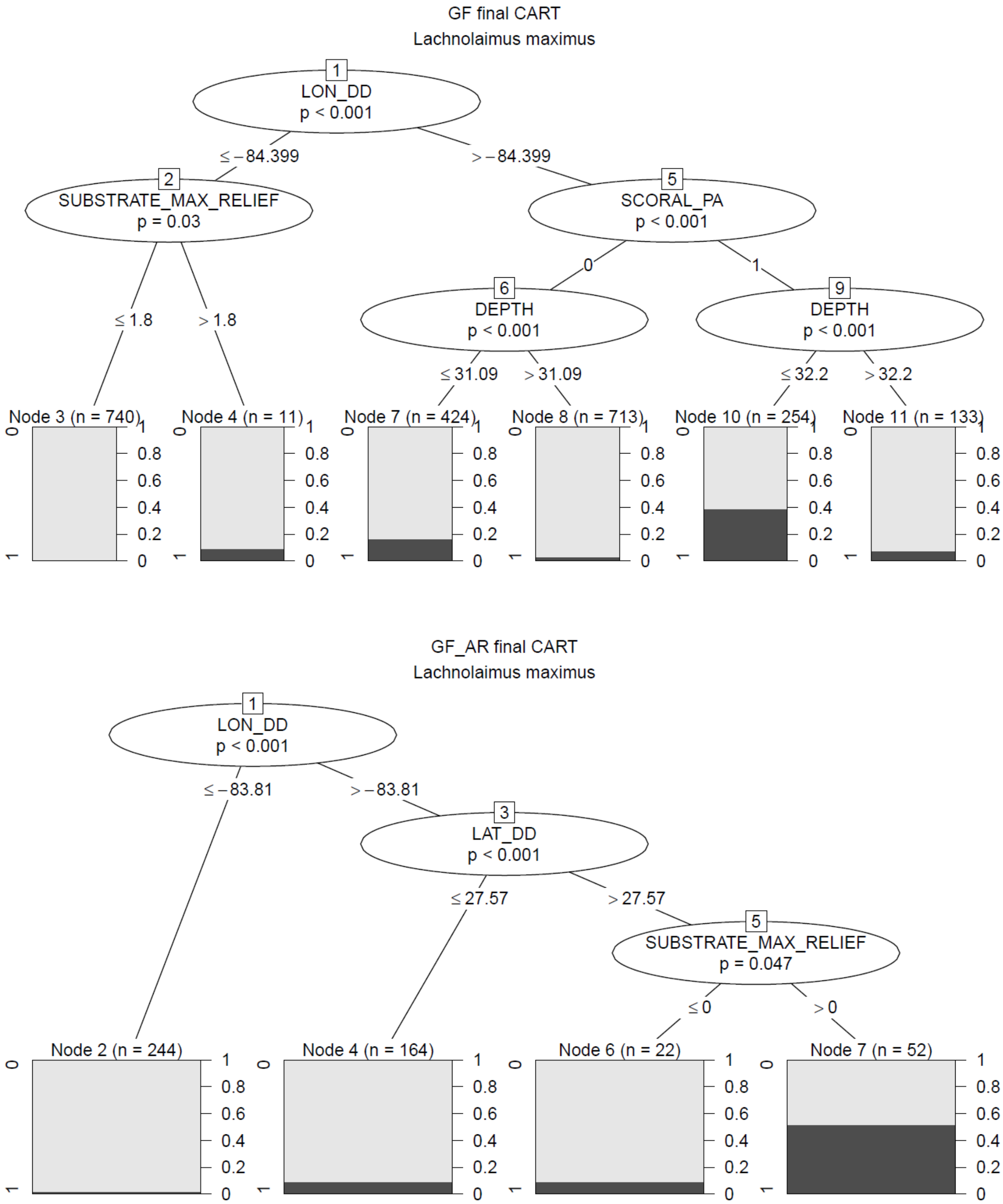


Figure 8. Final G-FISHER CART models for Gulf Hogfish. Results from the natural and artificial reef surveys are shown on the top plot and bottom plots respectively.

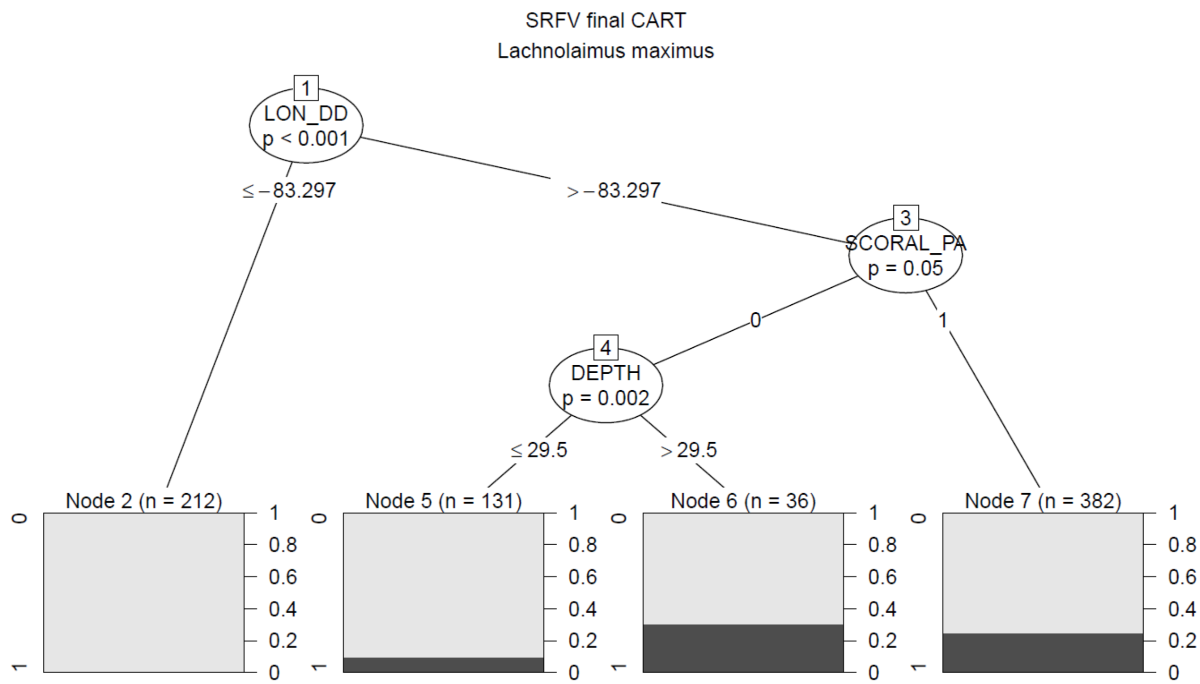


Figure 9. Final SRFV CART model results for Atlantic Hogfish.

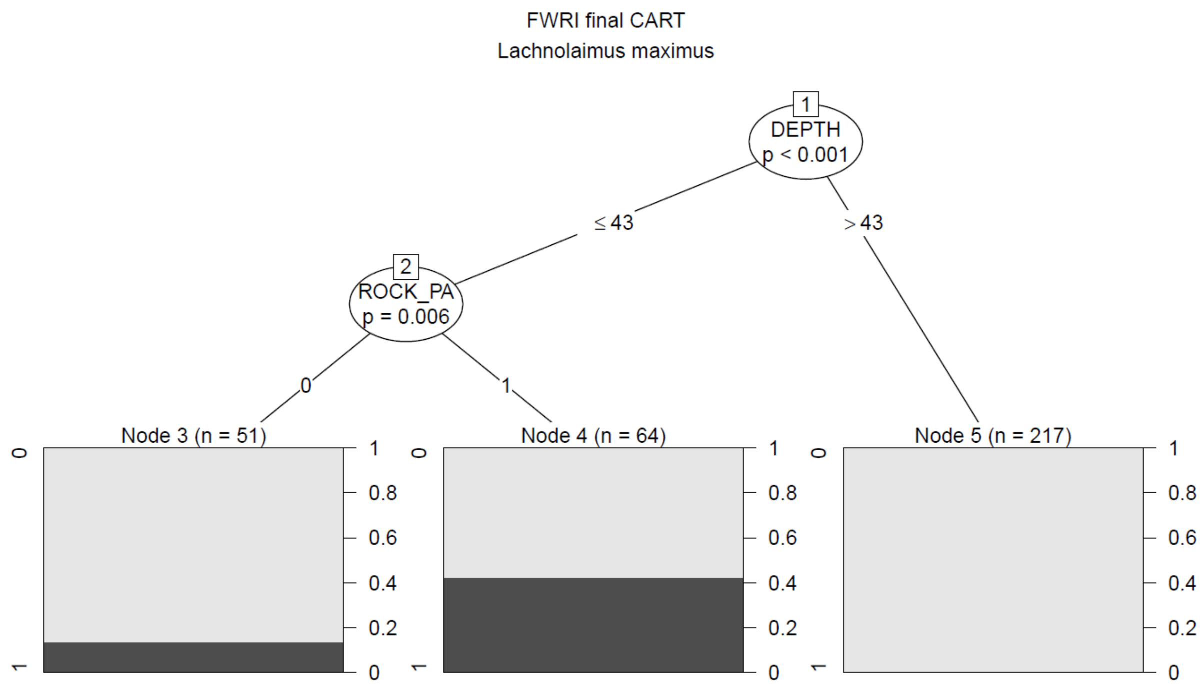


Figure 10. Final FWRI CART model results for Atlantic Hogfish.

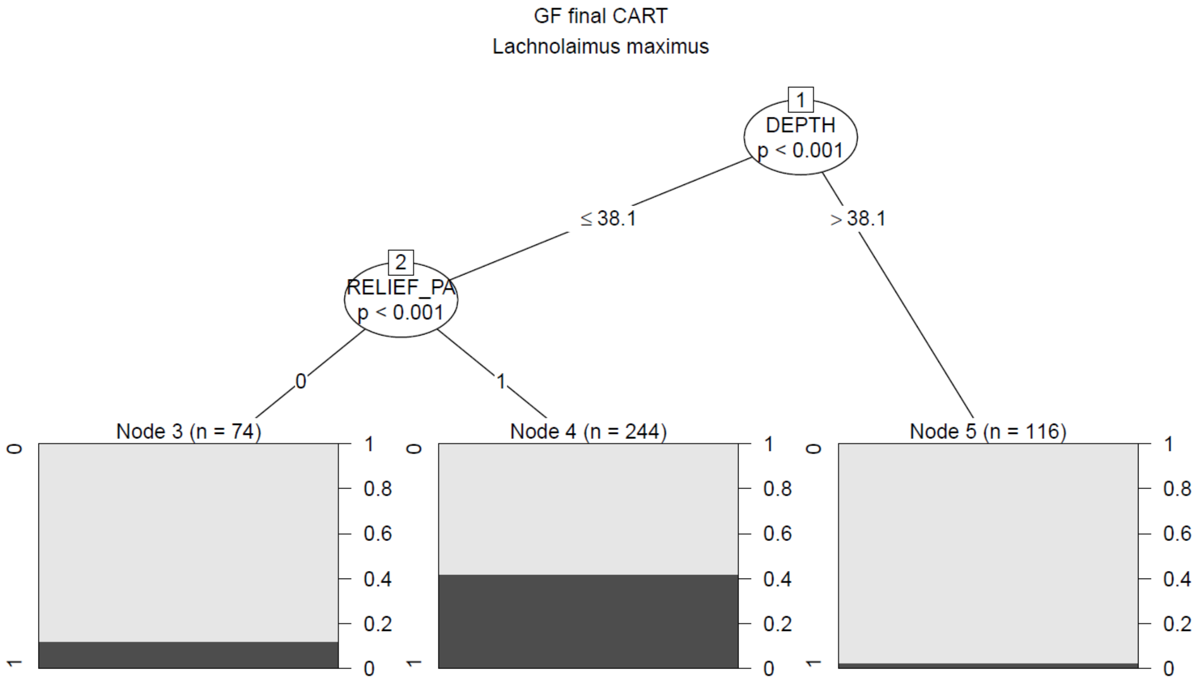


Figure 11. Final G-FISHER CART model results for Atlantic Hogfish.

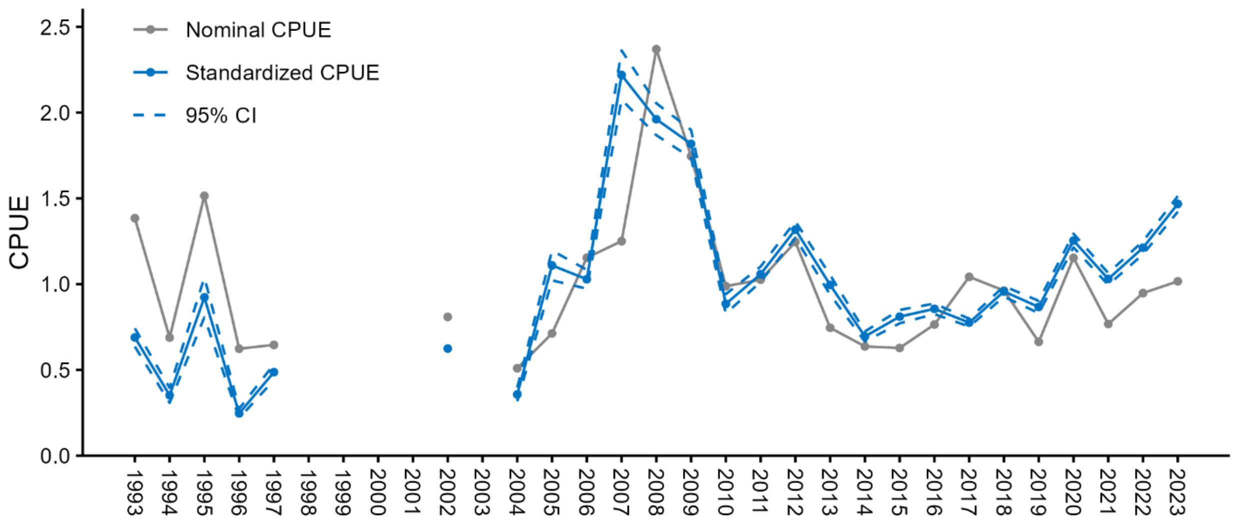


Figure 12. Nominal and standardized (± 95% CI) indices of Gulf Hogfish abundance based on video survey on natural and artificial reefs.

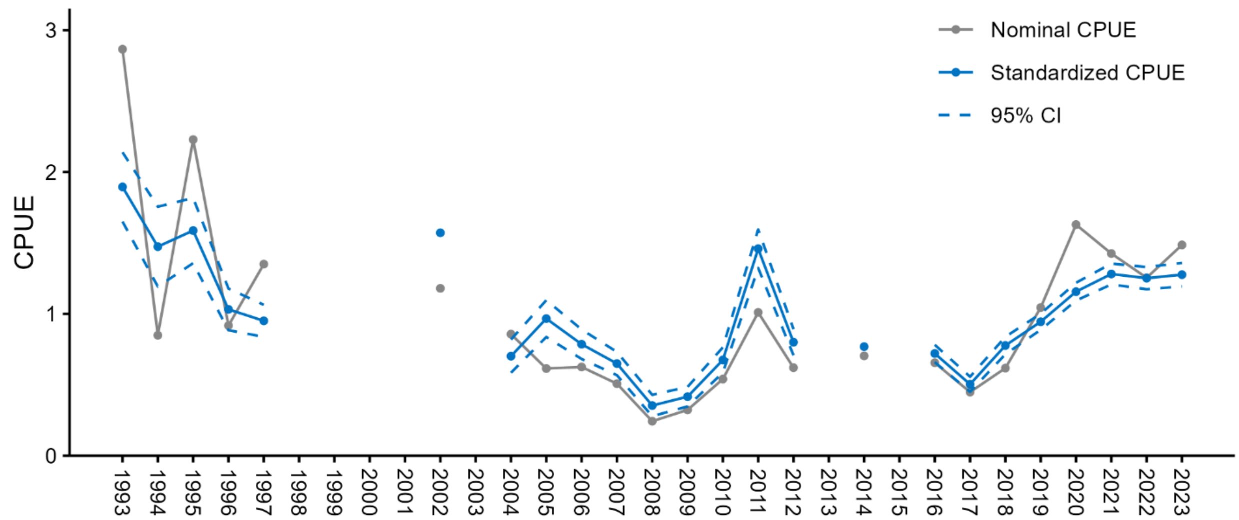


Figure 13. Nominal and standardized (± 95% CI) indices of Atlantic Hogfish abundance based on video survey on natural reefs.

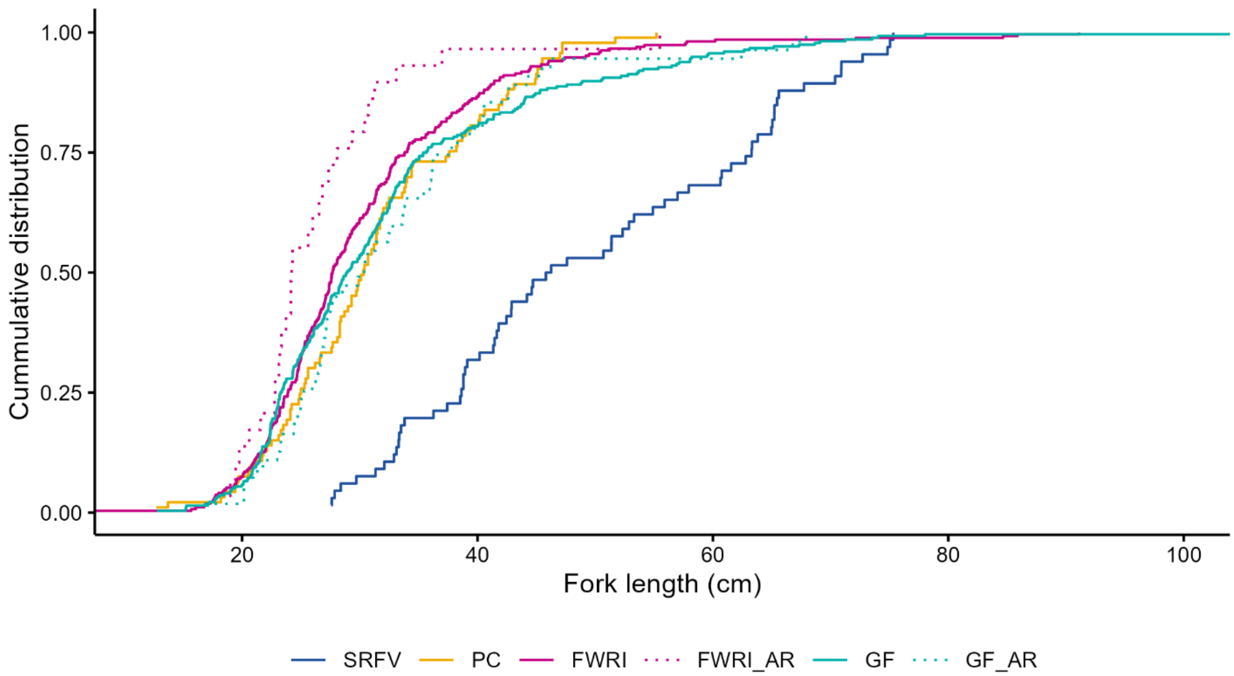


Figure 14. Cumulative frequency distribution of Gulf Hogfish video lengths by survey. A summary of measurement effort can be found in Table 10.

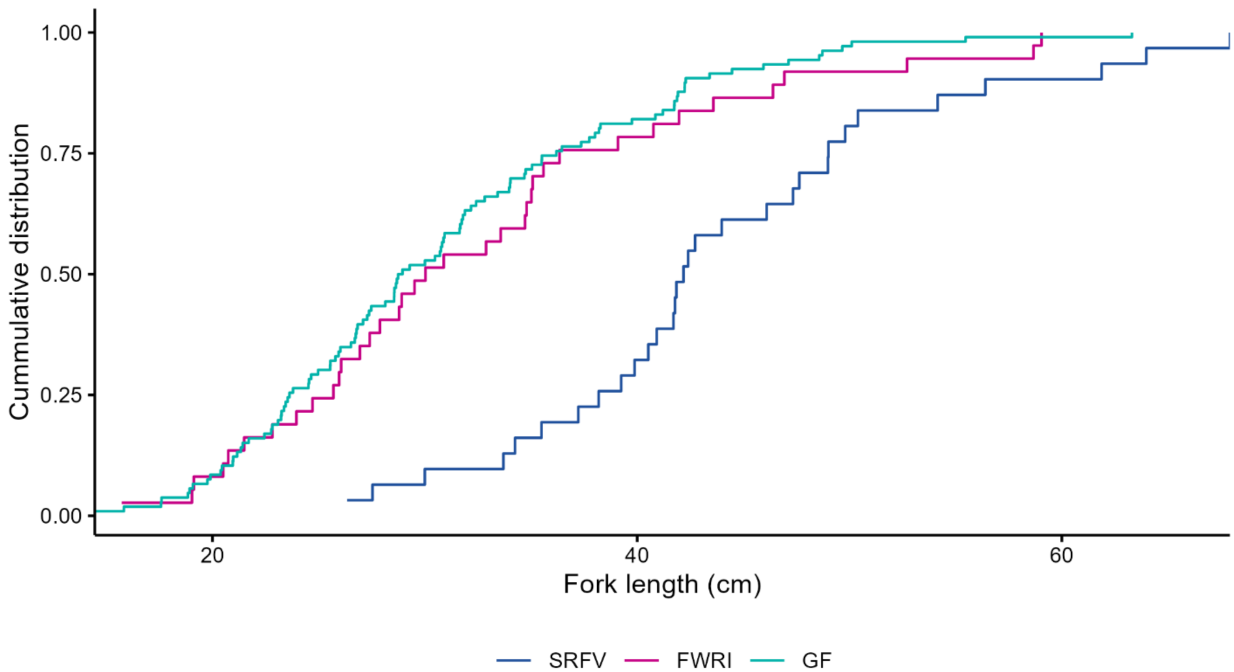


Figure 15. Cumulative frequency distribution of Gulf Hogfish video lengths by survey. A summary of measurement effort can be found in Table 11.

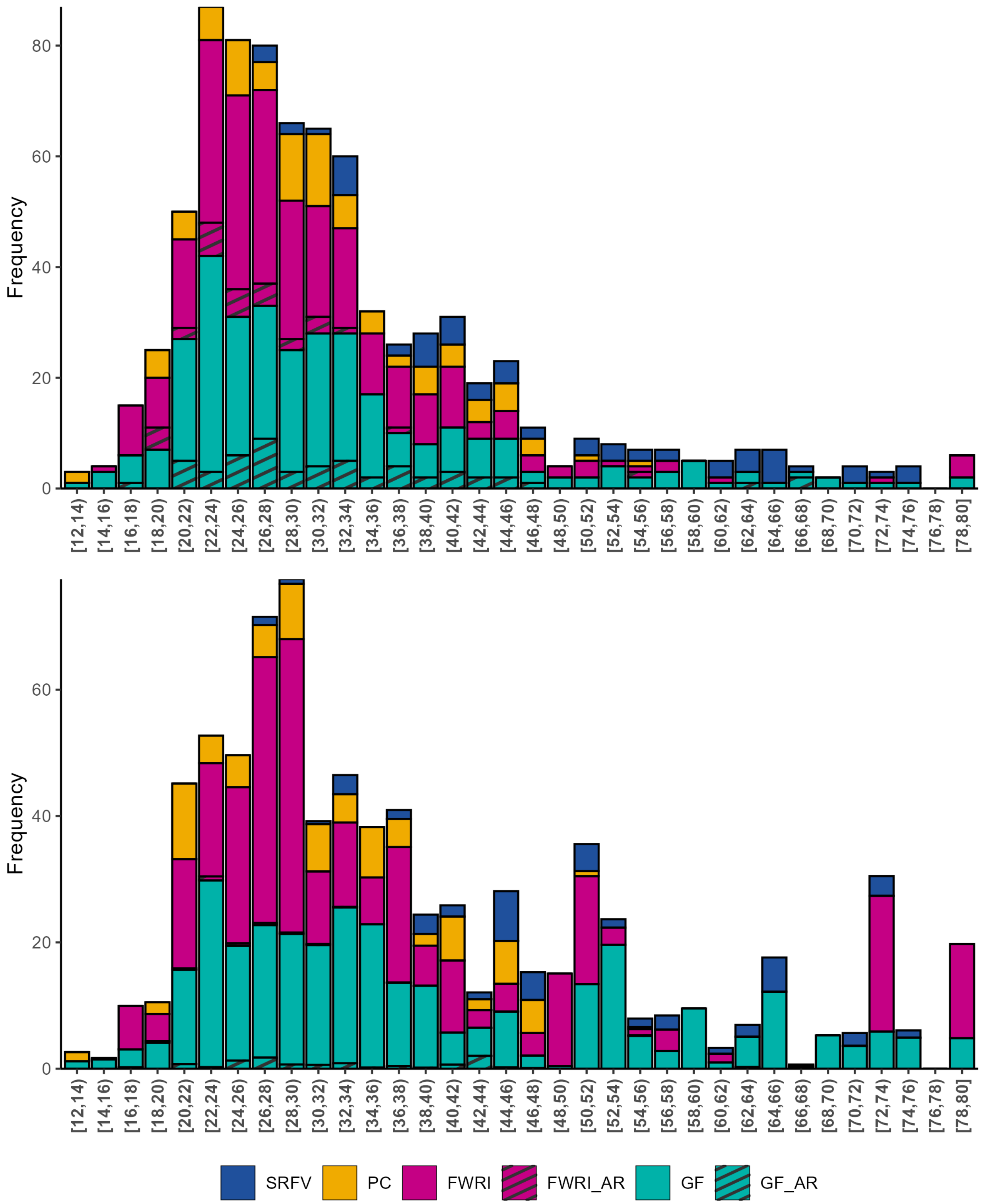


Figure 16. Raw (top panel) and weighted (bottom panel) relative frequency distributions for Gulf Hogfish (2cm length bins).

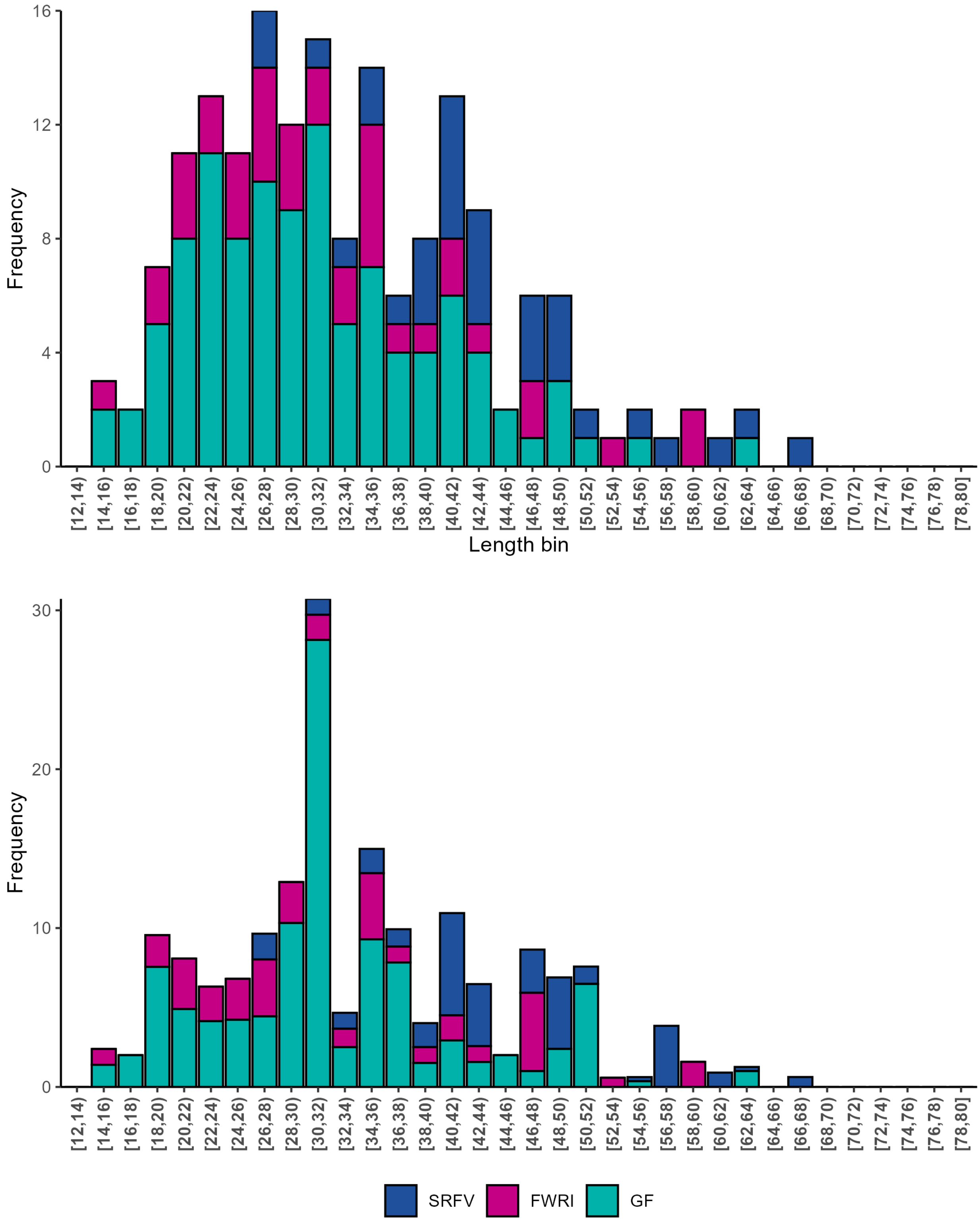


Figure 17. Raw (top panel) and weighted (bottom panel) relative frequency distributions for Atlantic Hogfish (2cm length bins).