Standardized catch rates of red grouper (Epinephelus morio) in the southeast U.S. from headboat logbook data

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Standardized catch rates of red grouper (Epinephelus morio) in the southeast U.S. from headboat logbook data

Sustainable Fisheries Branch*

May 2023

This document describes the SEDAR 86 update to the SEDAR 53 headboat index for red grouper.

General EDA - Headboat effort

The effort patterns for the carolinas (CAR) and Georgia-North Florida (GNF) are fairly constant over time with most trips either being half- or full-day. The majority of trips in South Florida (SF) are half-day trips. The dip in the number of trips from the mid-1990s until the late 2000s in SF is attributed more to reporting than changes in effort (Figure 1). The positive red grouper trips are shown in figure 2.

Data Exclusions

1. Outlier removal

Extreme values occur more frequently in self-reported data because there are limited methods for validating data. Recent SEDAR stock assessments have removed values at the extreme upper tail of distribution for cpue and associated fields for self-reported fishery-dependent data. We excluded trips with the largest 0.5% values for catch in number (> 30) and cpue (> 0.167) for trips that caught red grouper. The number of anglers on a trip can also influence cpue when calculated as fish/angler-hour. Trips with the largest 0.5% values for reported anglers (> 107) were removed. Figure 3 shows the excluded cpue of excluded trips based on outlier definitions by region. Removing a small percentage of the trips with extreme values for variables used to calculate CPUE is an unbiased method to correct for potential errors in self-reported data.

2. Cutoff for number of trips per vessel and number of anglers

Logbooks submitted by vessels that participated infrequently in the fishery are likely to be less accurate and may add noise to the data. Even if a vessel fished infrequently for one year, the number of trips should be greater than 30. We removed vessels that had fewer than 30 trips in the logbook database. It is rare for a headboat to fish with few anglers. There is anecdotal information that headboats would sometimes fish with just the crew and that logbooks for these trips were submitted. Experienced crew are likely to be more efficient at catching fish than paying customers. Captains may also limit distance to reduce fuel costs for trips with few paying customers. Trips with 6 or fewer anglers were excluded.

3. Starting year

For SEDAR 19 the starting year for the headboat index was 1978. The headboat program increased it's range to south Florida by 1978 but the reporting appears to be in the burn-in phase, especially for full-day trips, until 1980. The number of trips reported may not be important if the subsample is unbiased. However, it takes time for vessel captains and crew to develop consistent and accurate reporting skills. This may be especially true for south Florida due to higher species diversity. The total number of reported trips in SF increases dramatically from 1978 - 1980 (Figure 1). The number of reported positive red grouper half-day trips in south Florida increases from 34 in 1978 to 601 in 1979 and then plateaus. The number of positive red grouper full-day trips are 47, 56, and 170 for 1978 - 1980 after which the value ranges from 200-250 for several

*National Marine Fisheries Service, Southeast Fisheries Science Center, 101 Pivers Island Rd, Beaufort, NC 28516

years (Figure 2). The starting year for the headboat index was set to 1980 since south Florida contributes significantly to the positive red grouper trips.

4. Terminal year - spawning closure exclusion

The shallow-water grouper closure (Jan-Apr) took effect in 2010. Comparisons of the median cpue by region for all months and May-Dec shows little difference in median cpue across regions (Figure 4). Removing trips from these months allows us to extend the headboat logbook index until the terminal year of the assessment (2017). The peaks in the number of positive red grouper trips are similar between the seasonal closure and open months prior to the 2010 seasonal closure by region (Figure 5). 2017 was chosen as the terminal year with the removal of all trips from January to April across all years. Additionally, quotas decreased from 436,000 lbs in 2017 to 77,840 lbs in 2018.

5. Trip types

For SEDAR 19, the relatively few multi-day trips were combined with full-day trips and the 3/4-day trips were combined with the half-day trips. Figure 6 shows the noisy positive red grouper median cpue associated with these trip types for the Carolinas (CAR) and Georgia-North Florida (GNF) while South Florida(SF) is fairly stable. It is difficult to determine the number of hours spent fishing on multi-day trips which can add noise to the cpue. Combining trip types with either small sample size or high uncertainty with the more reliable half and full-day trips increases the noise in cpue (Figure 7). There are relatively few positive red grouper trips across all areas for 3/4-, and multi-day trips. Multi-day and 3/4-day trips were removed from all areas. There were relatively few half-day positive red grouper trips in CAR and GNF. The half-day trips in these areas are likely fishing at shallower depths and may be associated with ontogenetic inshore-offshore movements for red grouper. Half-day trips were excluded for CAR and GNF. Half-day trips were retained for south Florida, assuming half-day trips can fish the same areas as a full-day trip due the the narrow shelf. Trip type was retained to calculate the CPUE unit of fish/angler-hour (where hour is defined by trip type), but was dropped as an explanatory variable. This has the added benefit of not using trip type both as a factor, and to calculate the response variable.

Nominal catch rates

Nominal catch rates of positive red grouper trips by year and region from the data as filtered for input into the Stephens and MacCall analysis are shown in figure 8 and 19.

Evaluation of explanatory variables

YEAR - Year was necessarily included, as standardized catch rates by year are the desired outcome. Years modeled were 1980-2017.

AREA - The areas modeled for the SEDAR 19 headboat logbook index were not changed for SEDAR 53. The three areas include the Carolinas (CAR), Georgia and North Florida (to Cape Canveral, FL), South Florida (South of Cape Canaveral, FL). These areas were defined due to shelf characteristics and associated fishing behavior as well as species compositions.

SEASON - Month was used as the within-year factor for SEDAR 19. For SEDAR 53, a third of the months were dropped due to the spawning closure. The patterns in the remaining positive red grouper trips by month and region show few trips in the Carolinas for Nov and Dec. However, Nov and Dec have the most positive red grouper trips for South Florida (Figure 9). The seasonal pattern in cpue across months seems consistent across areas with slightly higher values for Sep. - Dec. compared to May-Aug.(Figures 10 and 11). Season was chosen as the explanatory variable.

VESSEL SIZE (vsize) - A factor was developed for vessel size and crowding separately using the number of anglers. The proxy for vessel size is the maximum anglers reported over all trips for a vessel (Figure 12). This was then divided into four factors based on visual inspection of the density plots into: 1. less than 30 maximum anglers (a.lt30), 2. 30-59 maximum anglers (b.30-59), 3. 60-89 maximum anglers (c.60-89), and 4. 90 or more maximum anglers (d.ge90),(Figure 13).

PERCENT FULL (pctfact) The number of anglers reported for a trip was divided by the maximum number of anglers for a vessel to obtain an estimate of crowding. This was then divided into 4 equally spaced factors; 1. less than 25% full (a.lt25), 25-49% full (b.25-49), 50-74% full (c.50-74), and 75% or more full(d.ge75). The density of percent full by area and the density of cpue associated with each factor are shown in figure 14.

Analytical decisions

1. Subsetting trips - Use Stephens and Maccall (2004) method
2. Species included in Stephens and MacCall approach: limit to snapper-grouper complex and remove species with full-year closures, ID issue, or large shifts in desirability over the index period
3. Apply Stephens and MacCall to Carolinas, Georgia-N.Florida, and S. Florida with Cape Canaveral, FL separating North and South Florida

Subsetting trips

Effective effort was based on those trips from areas where red grouper were available to be caught. Without fine-scale geographic information on fishing location, trips to be included in the analysis must be inferred, which was done here using the method of (Stephens and A. 2004). The method uses multiple logistic regression to estimate a probability for each trip that the focal species was caught, given other species caught on that trip. The method was applied separately for the three regions considered due to species composition shifts. A zoogeographic boundary is apparent near Cape Canaveral (Shertzer, Williams, and J. 2009) which is the break between GNF and SF areas. Another break between the CAR and GNF areas was included to limit the influence of species at the edge of their range (e.g. scup in the North or yellowtail snapper to the South). To avoid undue influence of rare species on regression estimates, species included in each analysis were limited to those occurring in 4% or more of trips. A range of 1% to 5% was considered with 1% including too many species and 5% too few, especially in SF. However, the cutoff had little influence on the trips selected because the species with the highest probabilities (positive and negative) were always included. We limited the species to the snapper-grouper species that were on the headboat logbook forms across all years included in the index. The species listed on logbook forms for the entire period differed by region. Species with management closures were also omitted because the potential for erroneously removing trips likely to have caught red grouper during years of restrictions.

A backwards stepwise AIC procedure (Venables and Ripley 1997) was then used to perform further selection among possible species as predictor variables, where the most general model included all listed species as main effects. In this procedure, a generalized linear model with Bernoulli response was used to relate presence/absence of red grouper in each trip to presence/absence of other species. For the CAR area, stepwise AIC did not eliminate any species; for the GNF sampling area, it eliminated white grunt; for the SF sampling area, it eliminated bluestripped grunt. Regression coefficients of included species for all areas are given in Appendix 1 and shown in figure 15. A trip was then included if its associated probability of catching red grouper was higher than a threshold probability (Figure 15). The threshold was designed to be that which resulted in the same number of predicted and observed positive trips, as suggested by Stephens and MacCall (2004). Retention of positive and zero red grouper trips across factors are shown in Figures 16 - 18.

Standardization

CPUE was modeled using the delta-GLM approach (Lo, L., and J. 1992; Dick 2004; Maunder and Punt 2004). This approach combines two separate generalized linear models (GLMs), one to describe presence/absence of the focal species, and one to describe catch rates of successful trips (trips that caught the focal species). Estimates of variance were based on 1000 bootstrap runs where trips were chosen randomly with replacement (Efron and Tibshirani 1993). All analyses were programmed in R, with much of the code adapted from Dick (2004).

Bernoulli submodel

The bernoulli component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching red snapper on any given trip. Initially, all explanatory variables were included in the model as main effects, and then stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was used to eliminate those variables that did not improve model fit. In this case, the stepwise AIC procedure did not remove any explanatory variables. Diagnostics, based on Pearson residuals, suggested reasonable fits of the Bernoulli submodel (Figure 20).

Positive CPUE submodel

Two parametric distributions were considered for modeling positive values of CPUE, lognormal and gamma. For both distributions, all explanatory variables were initially included as main effects, and then stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was used to eliminate those variables that did not improve model fit. For both lognormal and gamma distributions, the best model fit included all explanatory variables. The two distributions, each with their best set of explanatory variables (all of them), were compared using AIC. Lognormal outperformed gamma, and was therefore applied in the final delta-GLM. Diagnostics suggested reasonable fits of the lognormal submodel (Figures 21 and 22).

Results

The standardized index was similar to the nominal index with the exception of a few years associated with peaks in the catch rate (Figure 23). For 1983 the standardized index was lower than the nominal and the 2005 peak in catch rate was increased in the standardization. There may be concern that management measures, such as the red snapper closure that started in 2009, may influence catchability for red grouper. However, the large decrease in catch rate occurs just prior to 2009, Assessment methods that account for changes in catchability could be implemented over time periods where effort may have been influenced by management measures.

Table 1: Species listed on headboat logbook forms in 1980 for North and South Carolina (CAR) and Georgia - Florida (GFL) which are in the snapper-grouper complex.

CAR	GFL
Gag	Almaco.jack
Greater.amberjack	Blackfin.snapper
Knobbed.porgy	Blue.runner
Red.Grouper	Blueline.Tilefish
Red.Hind	Bluestriped.grunt
Red.porgy	Cubera.snapper
Red.snapper	Gag
Rock.Hind	Gray.snapper
Scamp	Gray.triggerfish
Scup	Graysby
Silk.snapper	Greater.amberjack
Snowy.Grouper	Jolthead.por gy
Tomtate	Knobbed.porgy
Vermilion.snapper	Lane.snapper
Warsaw.Grouper	Mutton.snapper
White.grunt	Queen.triggerfish
Whitebone.porgy	Red.Grouper
Yellowfin.Grouper	Red.Hind
	Red.porgy
	Red.snapper
	Rock.Hind
	Sand.tilefish
	Scamp
	Silk.snapper
	Tomtate
	Vermilion.snapper
	White.grunt
	Whitebone.porgy
	Yellowfin.Grouper
	Yellowmouth.Grouper

Table 2: Species removed from the Stephens and MacCall method for defining red grouper trips due to seasonal or complete closures or ad-hoc evidence of shifts in desireability.

Species.removed
Red.porgy
Gray.triggerfish
Red.snapper
Vermilion.snapper
Mutton.snapper
Snowy.Grouper
Gag
Black.sea.bass
Blueline.tilefish

Table 3: Nominal and standardized CPUE for red grouper 1980-2017 with CVs for stardardized index of abundance.

Year	N	Nominal.CPUE	Relative.nominal	Standardized.CPUE	CV
1980	289	0.00	1.10	1.07	0.14
1981	372	0.00	0.75	0.64	0.13
1982	289	0.00	0.58	0.66	0.26
1983	386	0.01	1.63	1.16	0.09
1984	359	0.00	0.90	0.80	0.12
1985	499	0.00	0.89	0.87	0.09
1986	700	0.00	1.11	0.93	0.06
1987	748	0.00	0.74	0.54	0.06
1988	613	0.00	0.73	0.82	0.08
1989	461	0.00	0.79	0.73	0.10
1990	700	0.00	0.41	0.46	0.09
1991	560	0.00	0.49	0.58	0.12
1992	751	0.00	0.72	0.75	0.09
1993	658	0.00	0.86	0.93	0.07
1994	663	0.00	1.08	1.00	0.08
1995	676	0.00	0.79	0.92	0.11
1996	682	0.01	1.99	1.36	0.08
1997	957	0.00	1.25	1.36	0.03
1998	841	0.01	1.84	1.89	0.05
1999	604	0.01	1.70	1.79	0.03
2000	606	0.01	1.42	1.20	0.06
2001	520	0.00	1.26	1.16	0.12
2002	371	0.00	0.59	0.70	0.09
2003	355	0.00	0.94	1.17	0.15
2004	583	0.01	1.95	1.79	0.07
2005	499	0.01	2.54	3.26	0.06
2006	432	0.01	1.77	2.21	0.08
2007	368	0.01	1.60	1.90	0.11
2008	495	0.00	0.48	0.54	0.10
2009	605	0.00	0.36	0.42	0.10
2010	549	0.00	0.76	0.66	0.08
2011	476	0.00	0.74	0.74	0.09
2012	631	0.00	0.47	0.51	0.10
2013	620	0.00	1.02	0.82	0.09
2014	701	0.00	0.67	0.60	0.09
2015	810	0.00	0.42	0.38	0.09
2016	591	0.00	0.23	0.27	0.10
2017	528	0.00	0.41	0.41	0.14

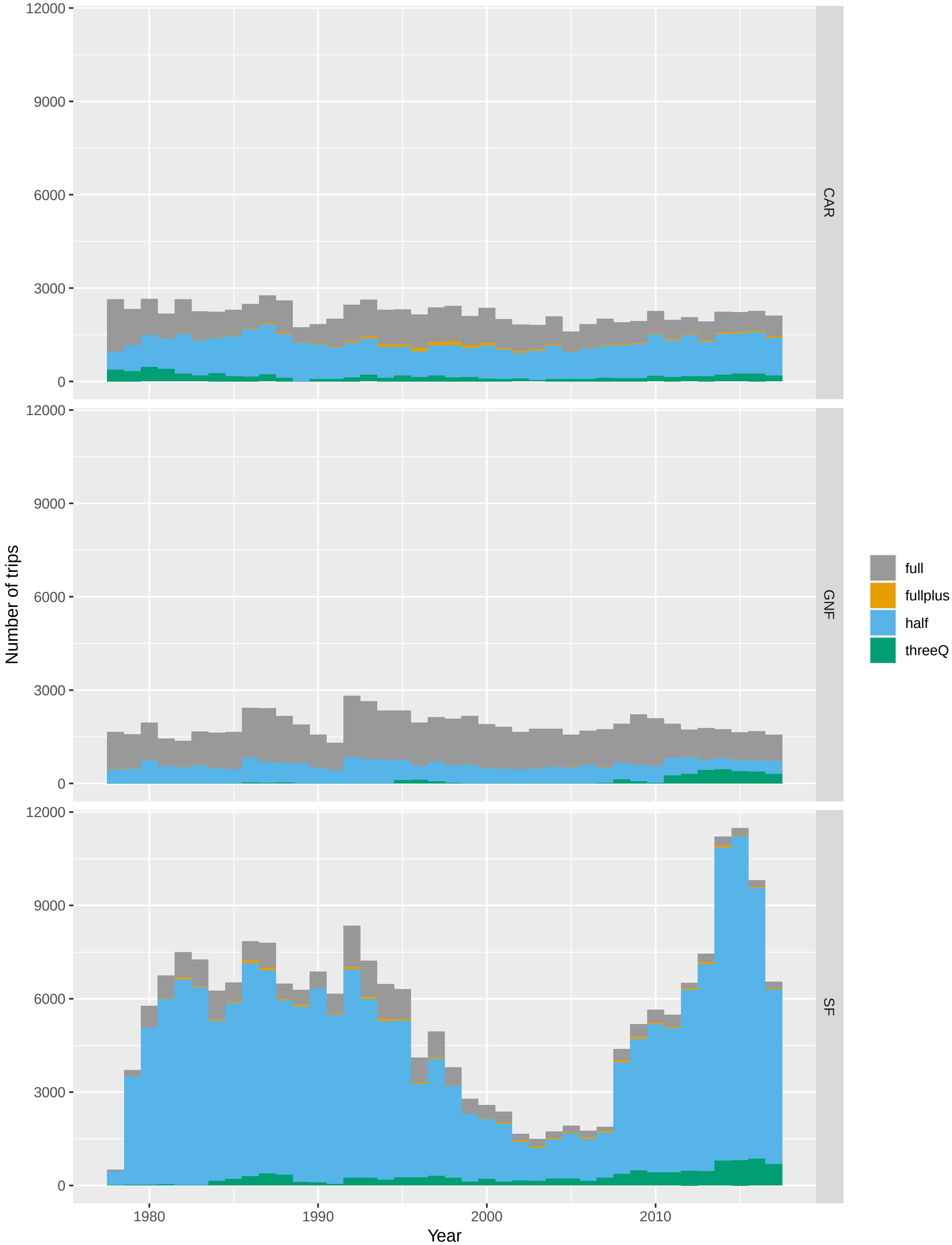


Figure 1: Number of headboat trips that submitted logbooks 1978-2017 for half-day trips (half), full-day trips (full), three-quarter day trips (threeQ), and multiple-day trips ranging from 1.5 to 7 days (fullplus) by region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida).

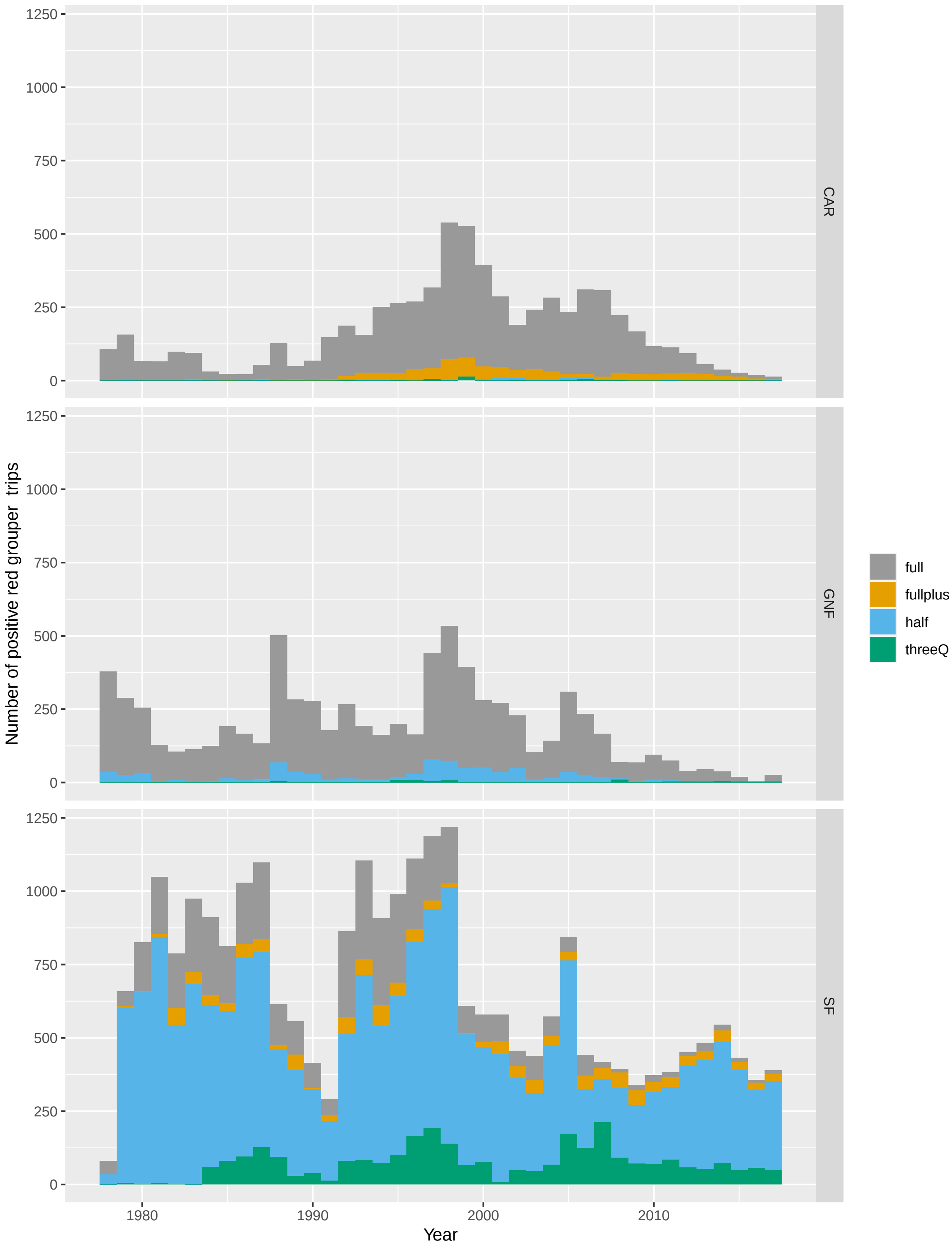


Figure 2: Number of positive red grouper headboat trips that submitted logbooks 1978-2017 for half-day trips (half), full-day trips (full), three-quarter day trips (threeQ), and multiple-day trips ranging from 1.5 to 7 days by region (CARr-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida).

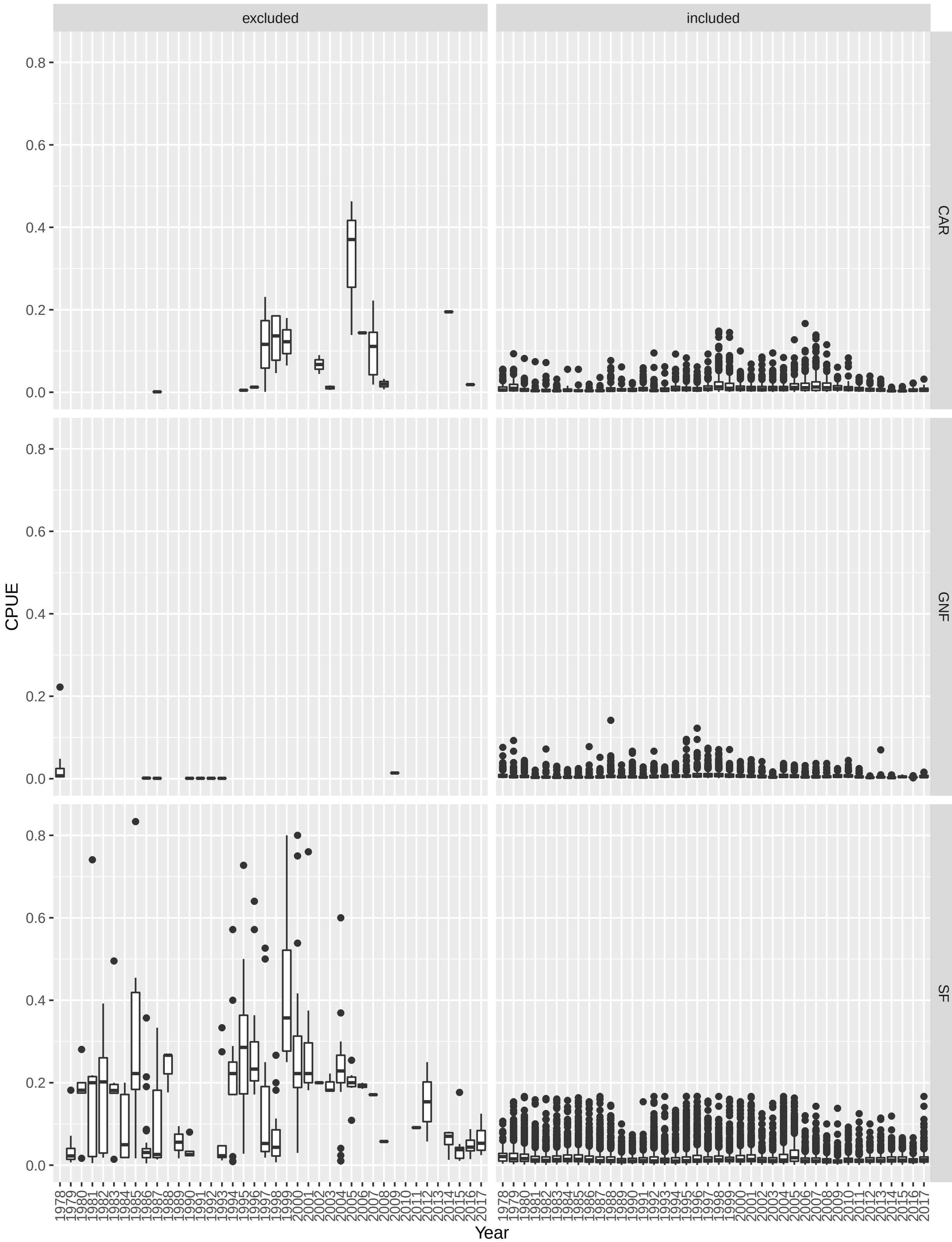


Figure 3: Records determined as outliers (excluded) based on removal of values above the 99.5th percentile for anglers, number of fish caught, and cpue.

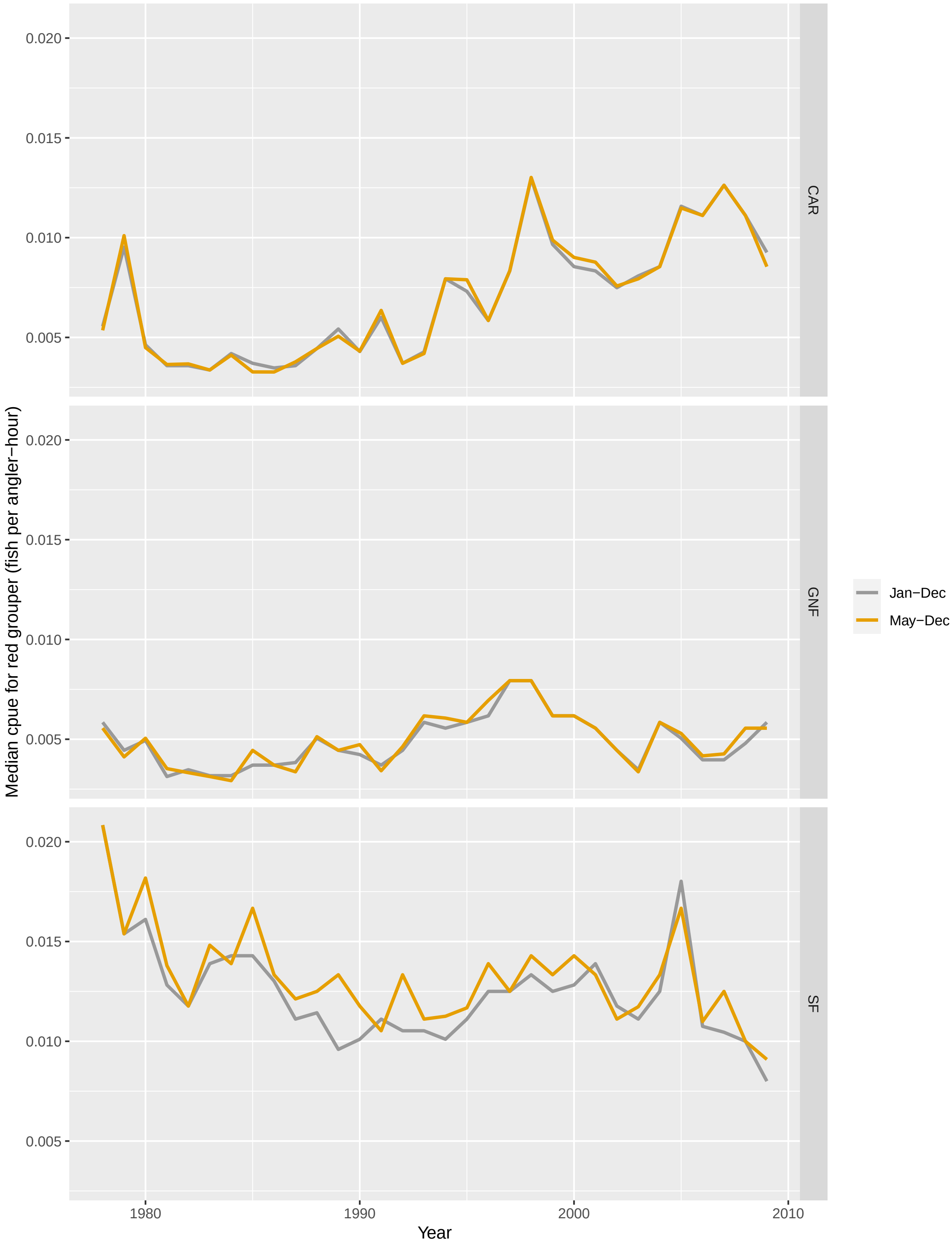


Figure 4: Median nominal red grouper catch rates by region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida) for all months and just May-Dec.

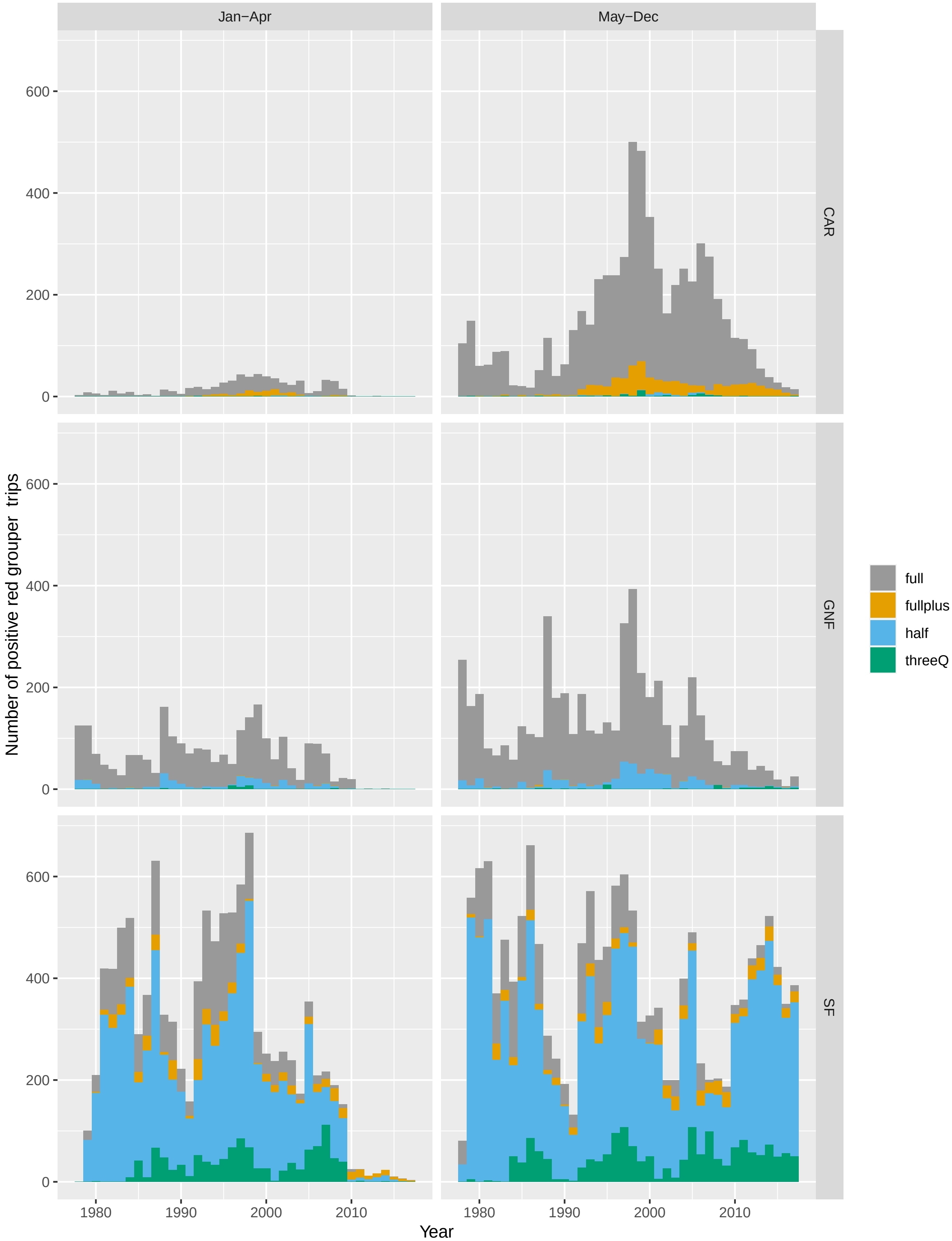


Figure 5: Positive red grouper trips by region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida) and season. January to April is the shallow-water grouper spawning closure season that began in 2010.

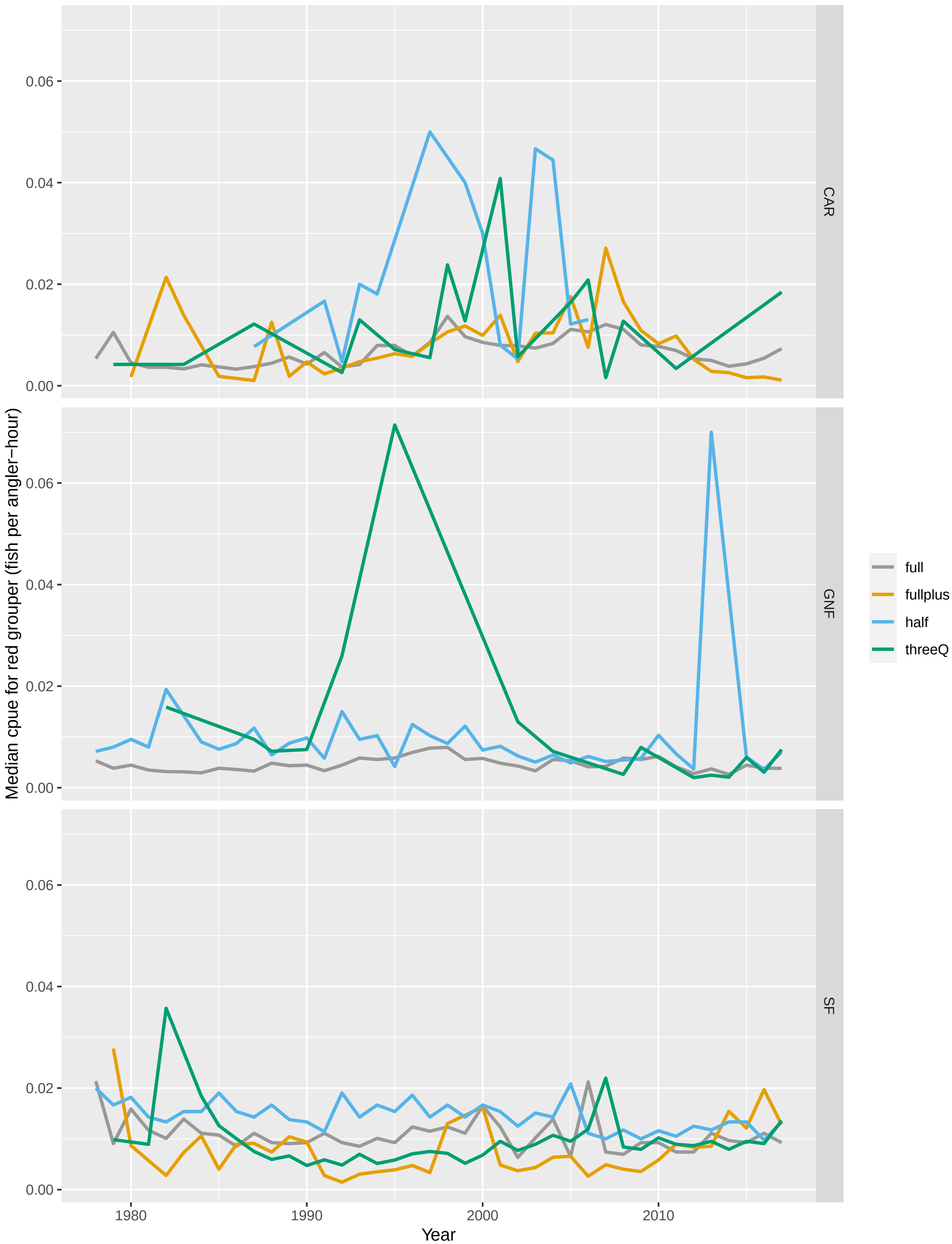


Figure 6: Red grouper cpue by region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida) for May - Dec.

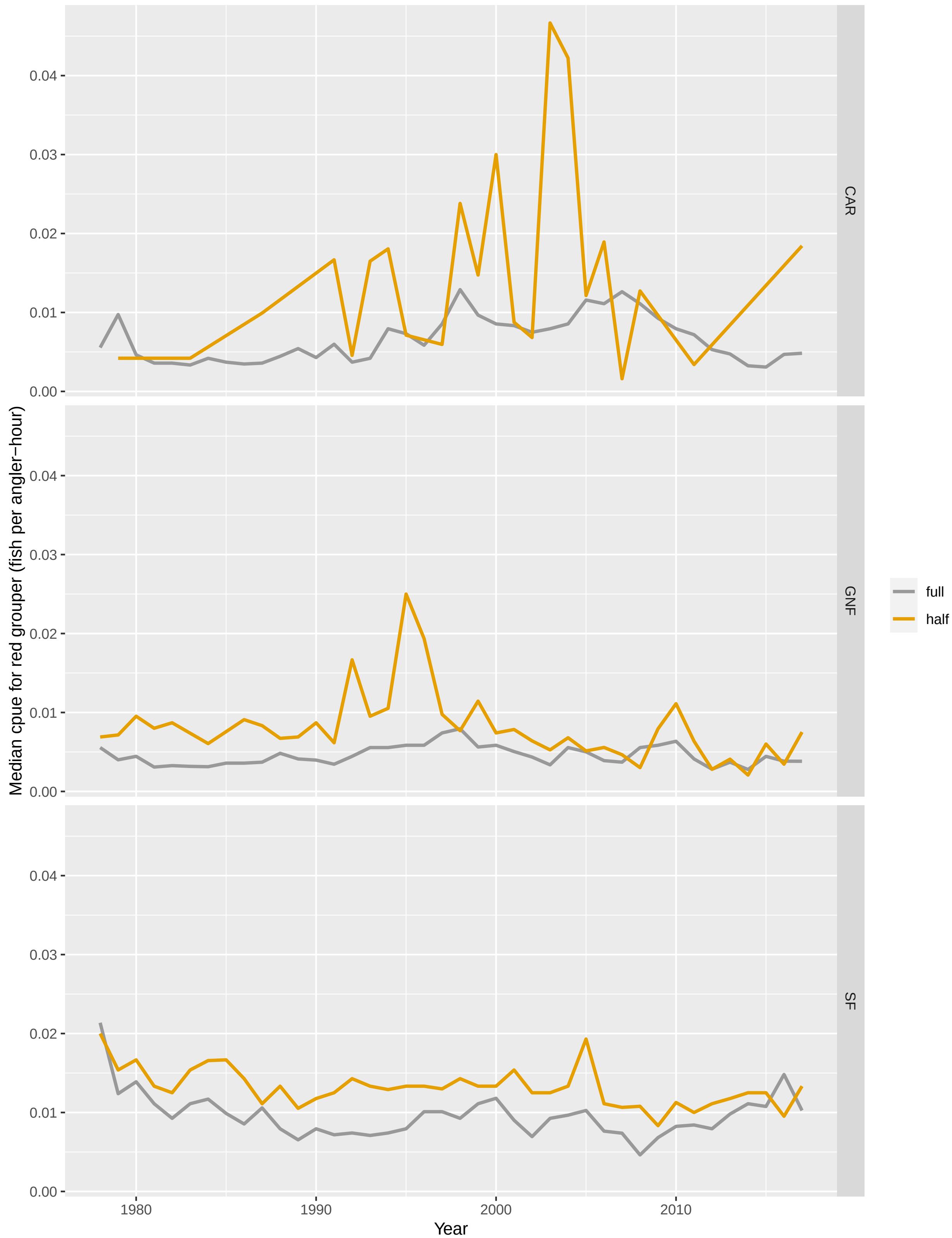


Figure 7: Red grouper cpue by region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida) for May - Dec. Trips are aggregated into full- (includes multi-day trips) and half- (includes 3/4-day) trips. January to April is the shallow-water grouper spawning closure season that began in 2010.

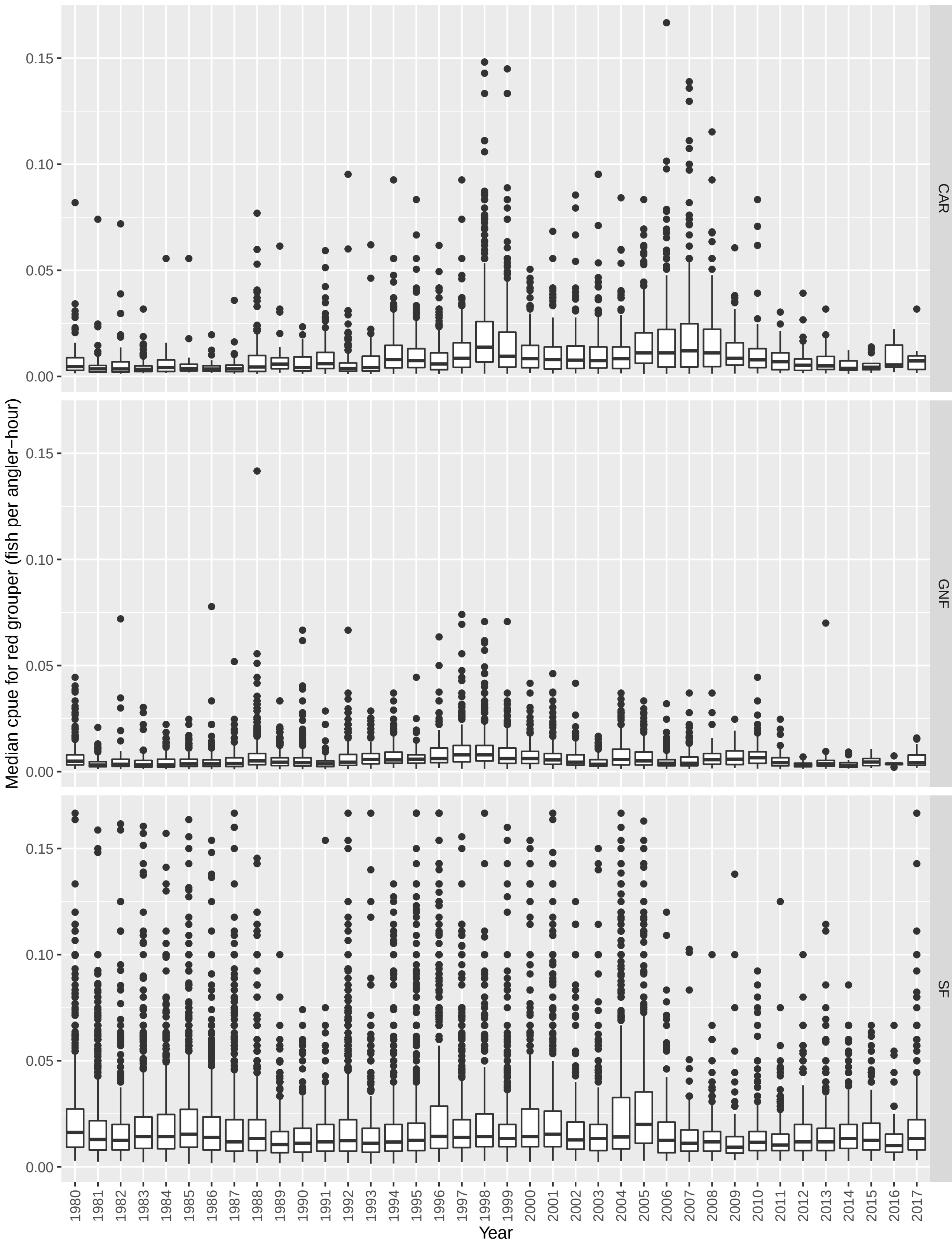


Figure 8: Red grouper cpue by region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida) and season. Multi-day and 3/4-day trips are removed for all regions. Half-day trips are removed for CAR and GNF. Half-day trips and full-day trips are aggregated for SF. Years are limited to 1980-2017.

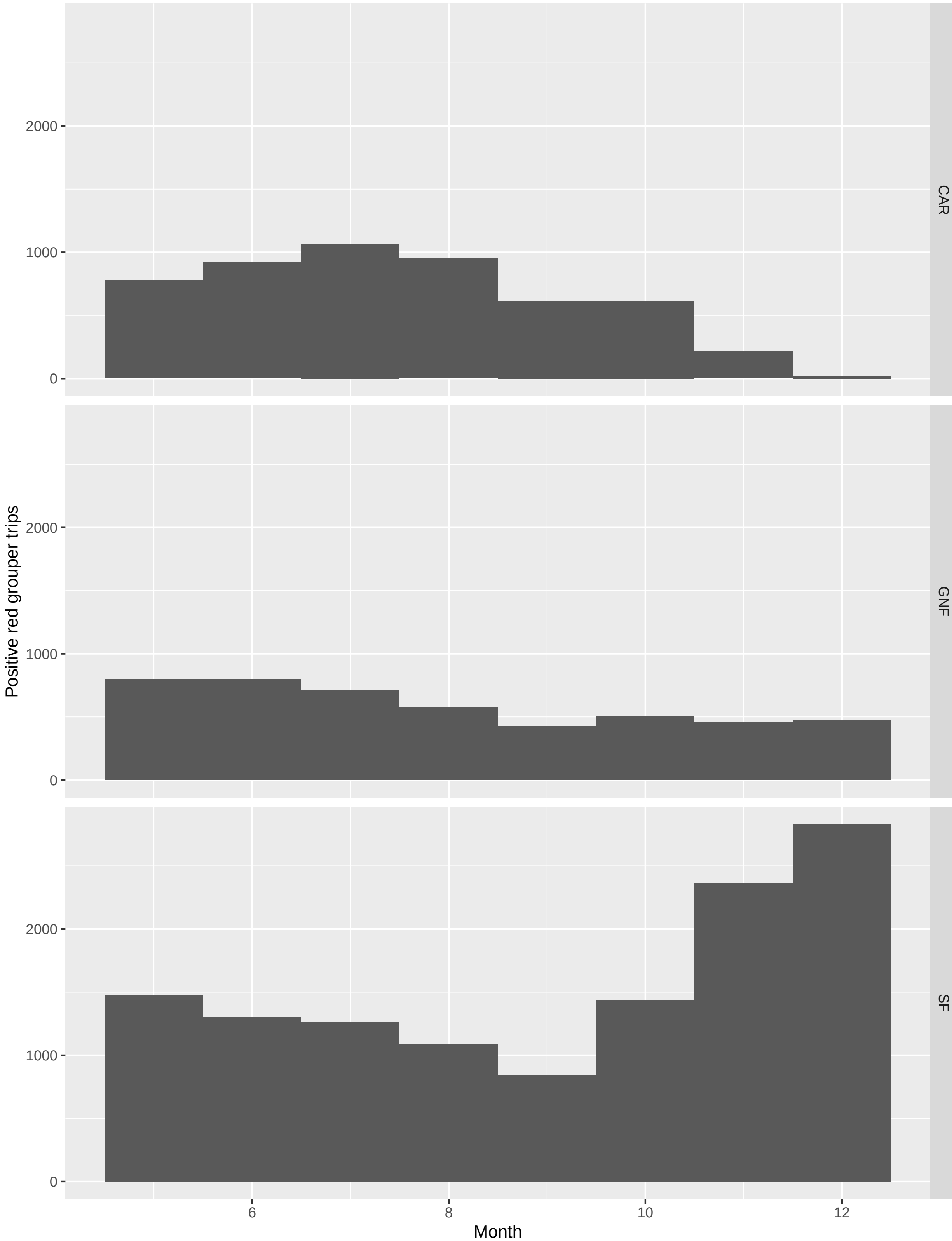


Figure 9: Positive red grouper trips by month and region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida).

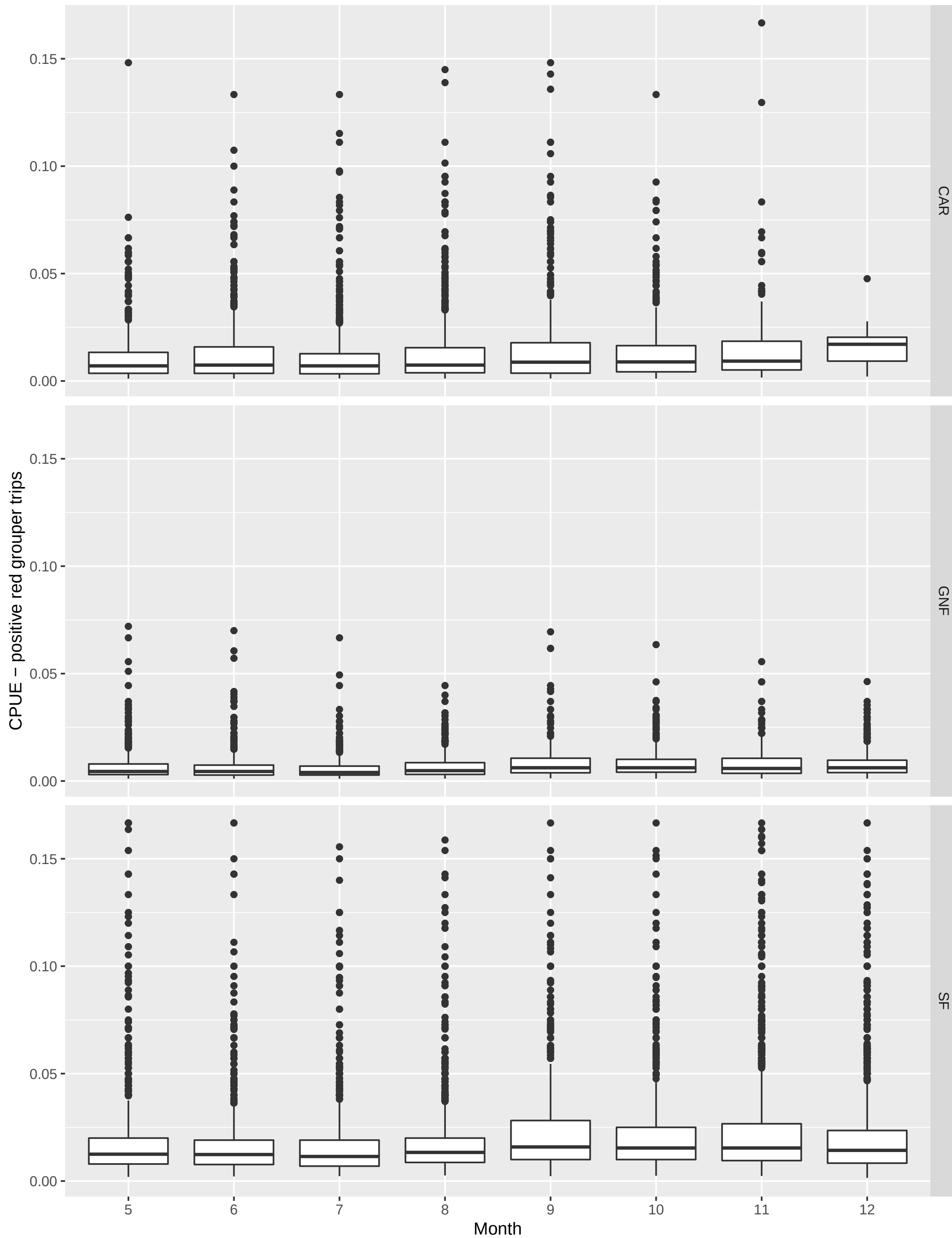


Figure 10: Red grouper cpue for positive trips by month and region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida).

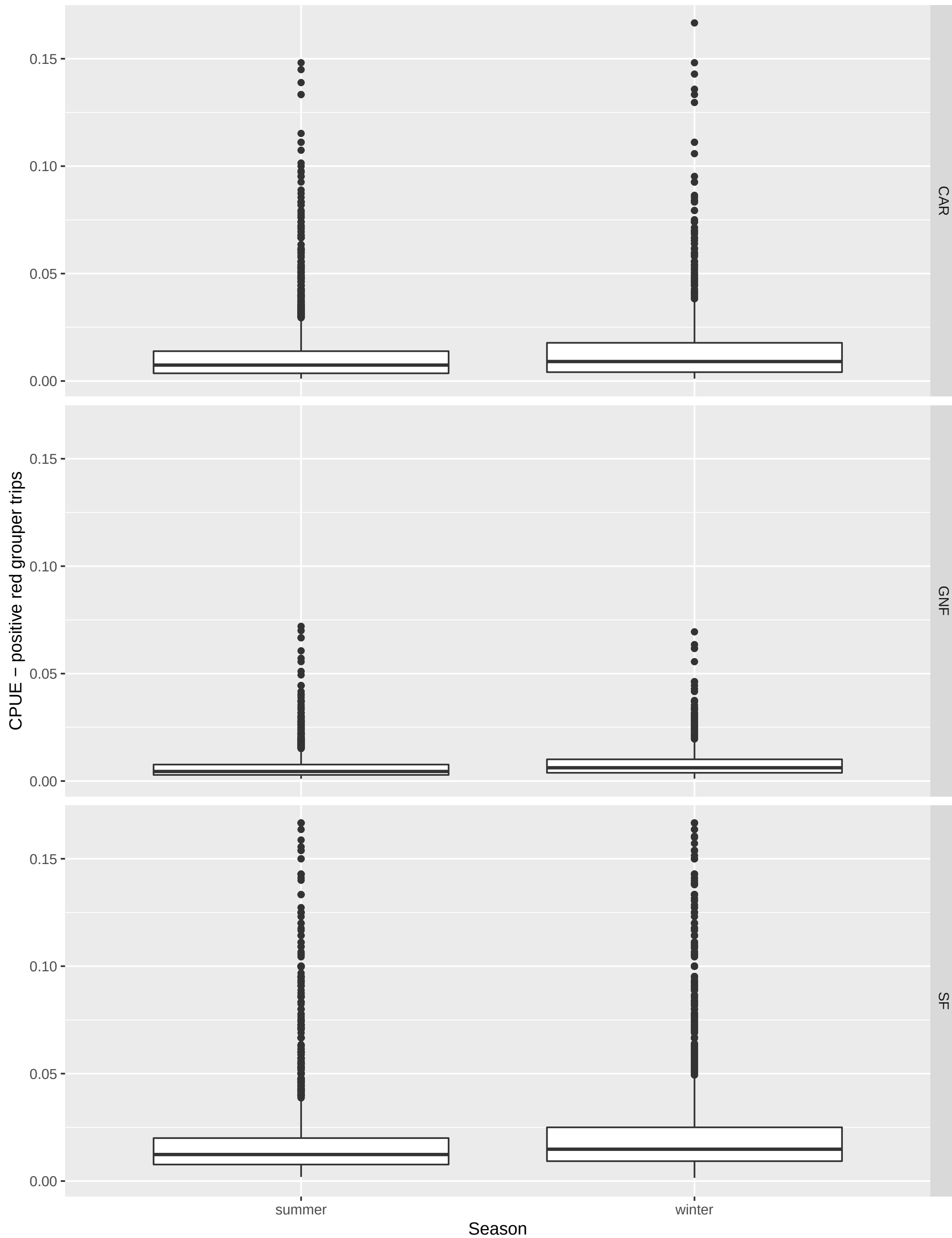


Figure 11: Red grouper cpue for positive trips by season and region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida).

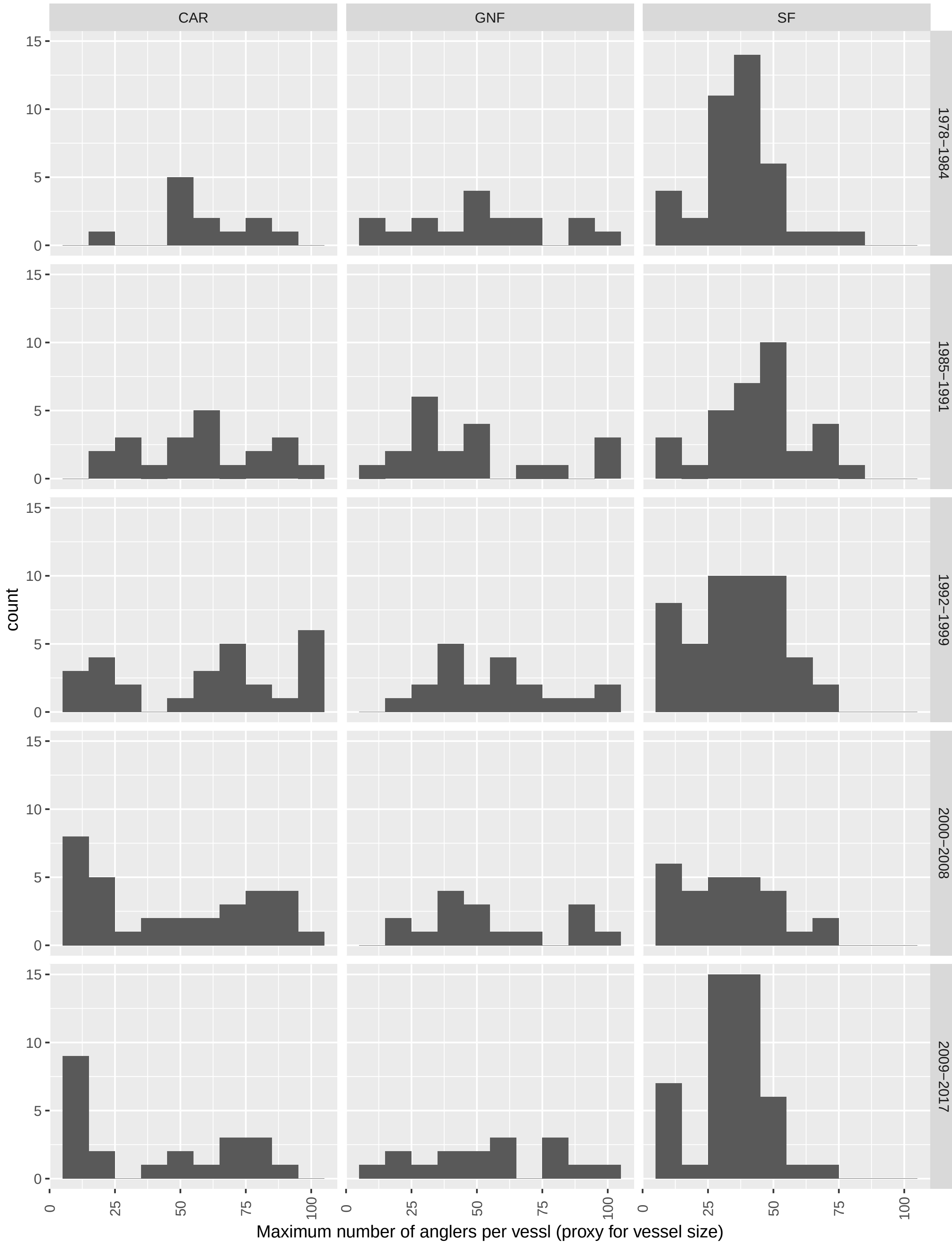


Figure 12: Maximum number of anglers as a proxy for vessel size (single value for each vessel) by region (CAR-carolinas, GNF - Georgia to Cape Canaveral, FL, SF - South florida).

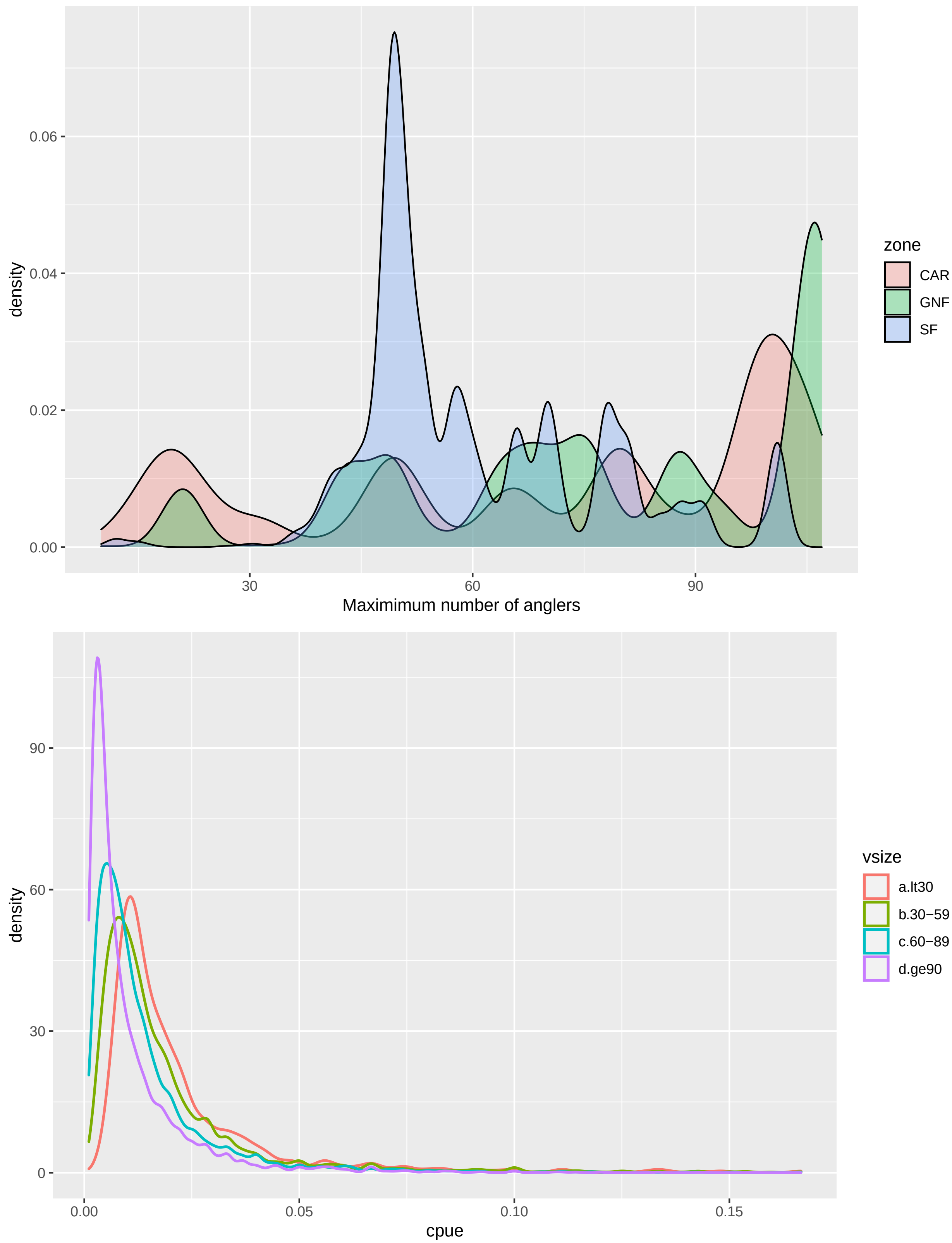


Figure 13: Density of maximum number of anglers across areas and cpue associated the factors for maximum anglers as a proxy for vessel size.

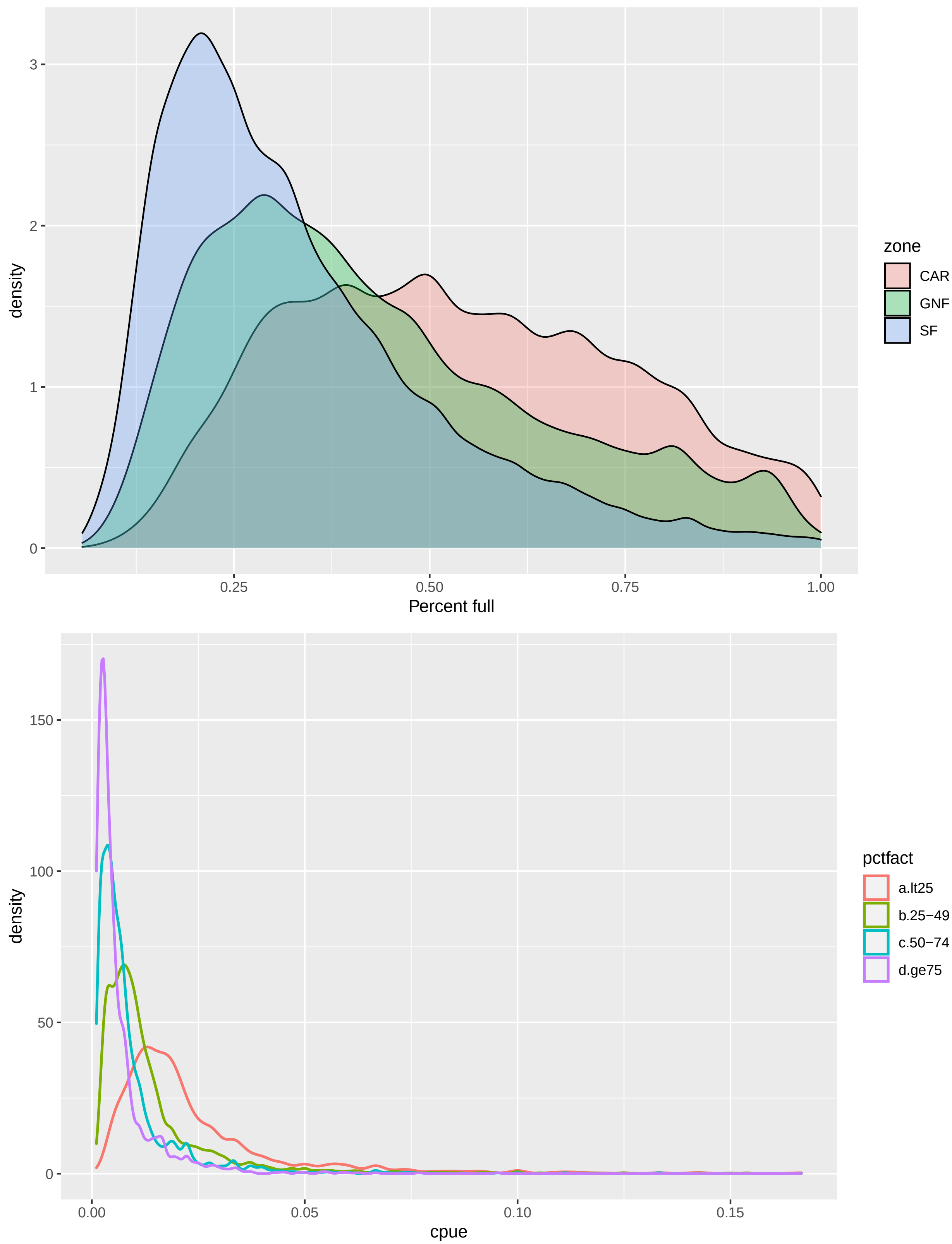


Figure 14: Density of percent full across areas and cpue associated the factors for percent full.

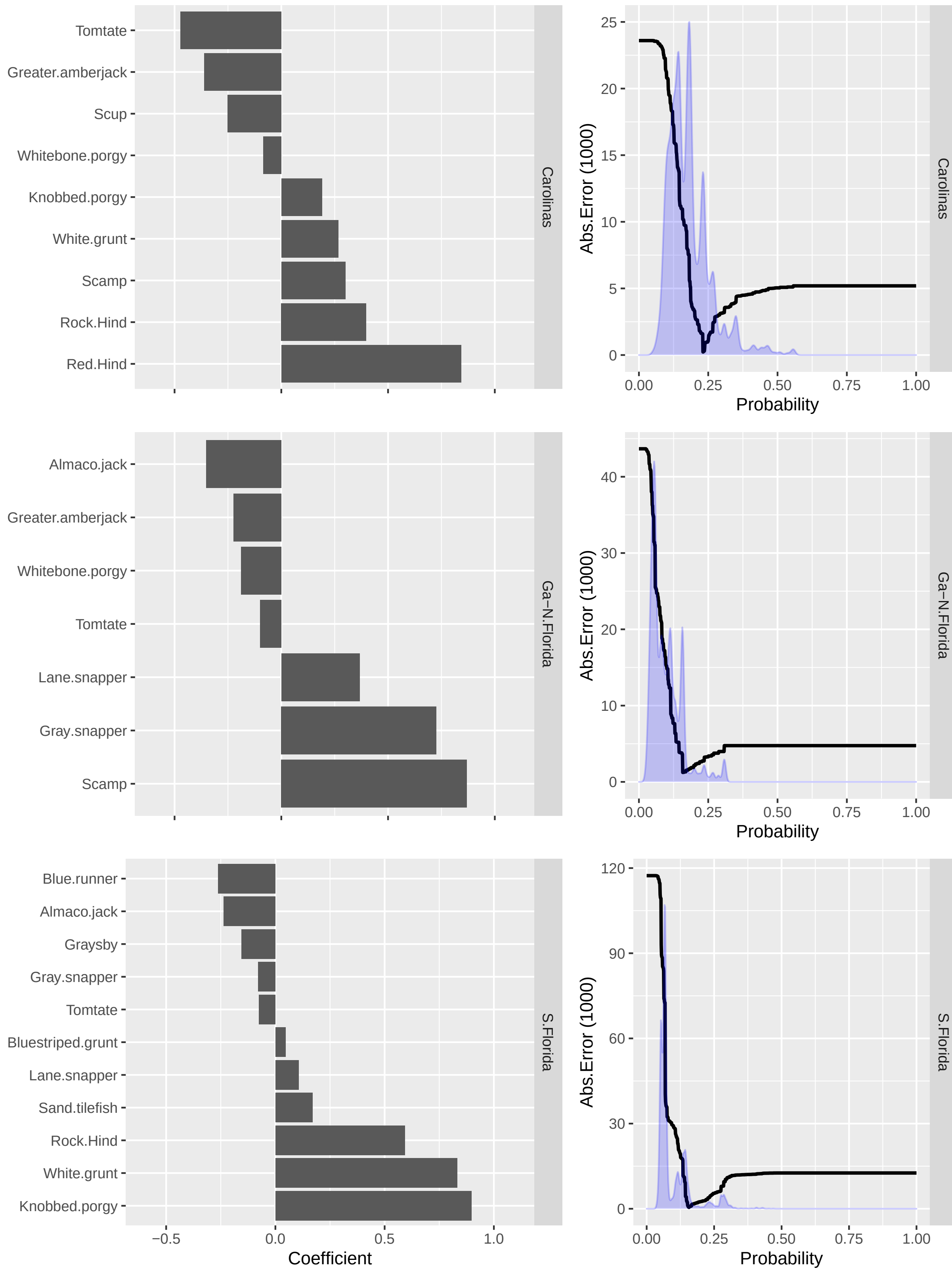


Figure 15: Estimates of species-specific regression coefficients used to predict each trip's probability of catching the focal species on the left panel. The right panel shows the absolute difference between observed and predicted number of positive trips across a range of probability cutoff values. .

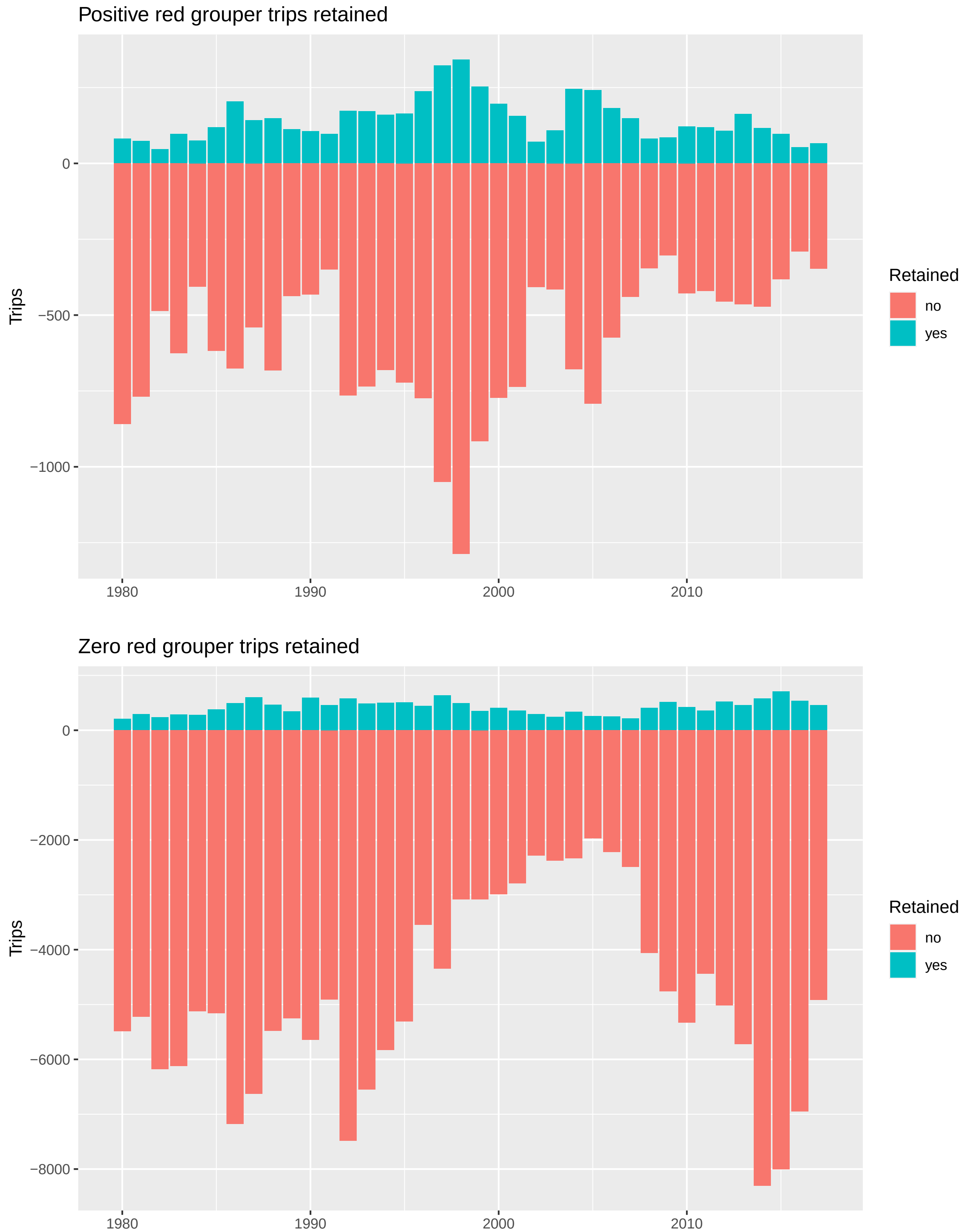


Figure 16: Positive and zero red grouper trips retained after subsetting using Stephens and MacCall approach by year.

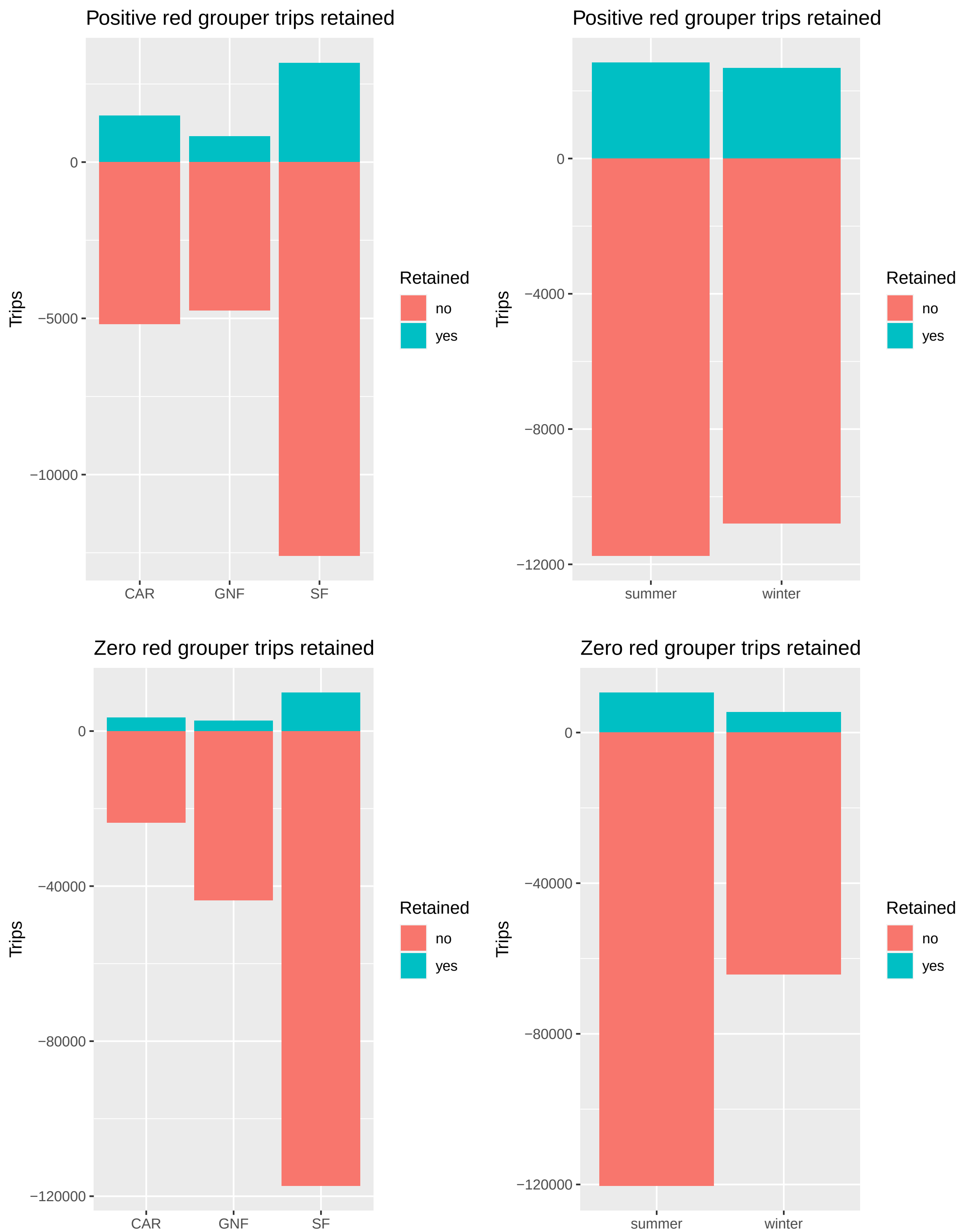


Figure 17: Positive and zero red grouper trips retained after subsetting using Stephens and MacCall approach by area and season.

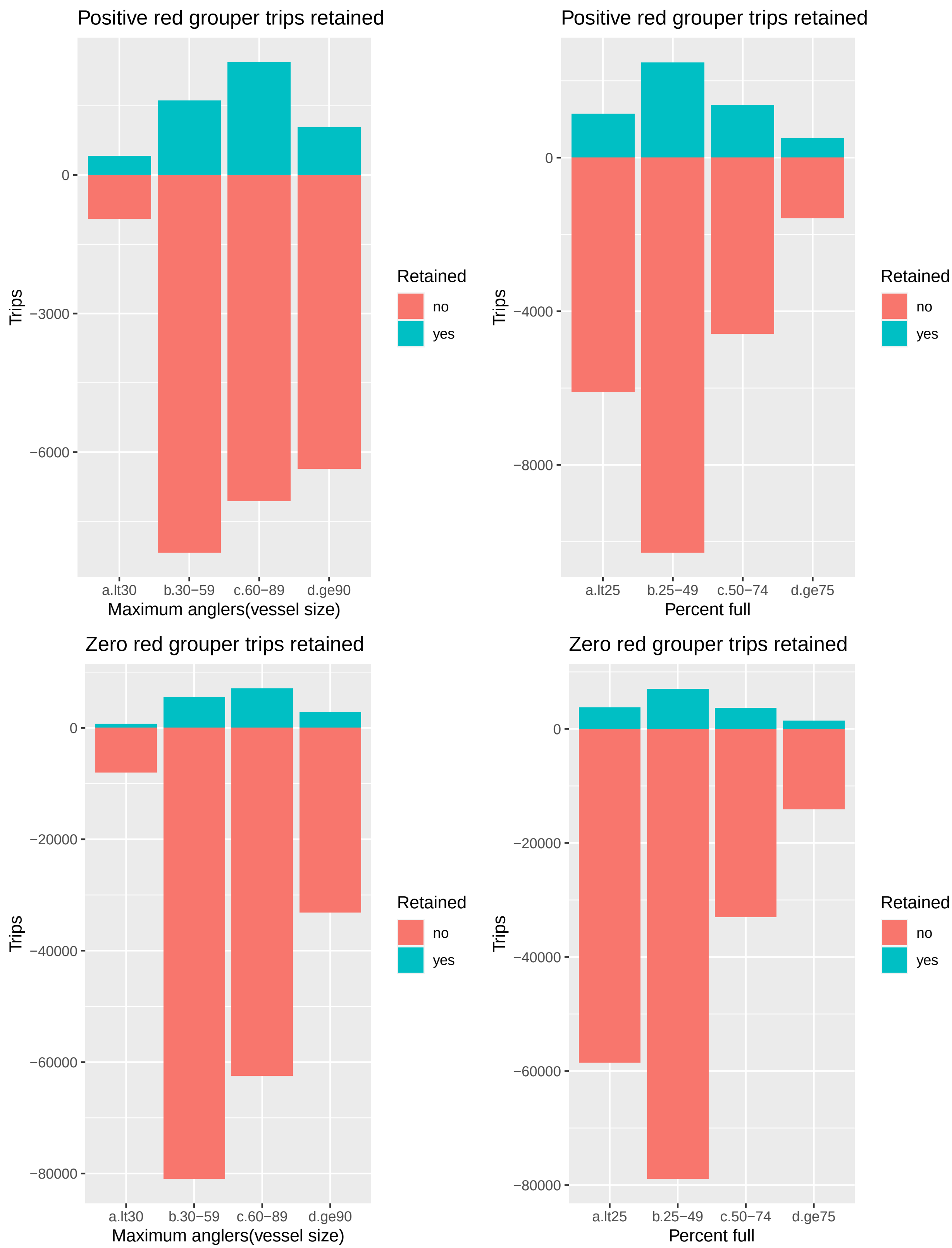


Figure 18: Positive and zero red grouper trips retained after subsetting using Stephens and MacCall approach by factors for maximum anglers and percent full.

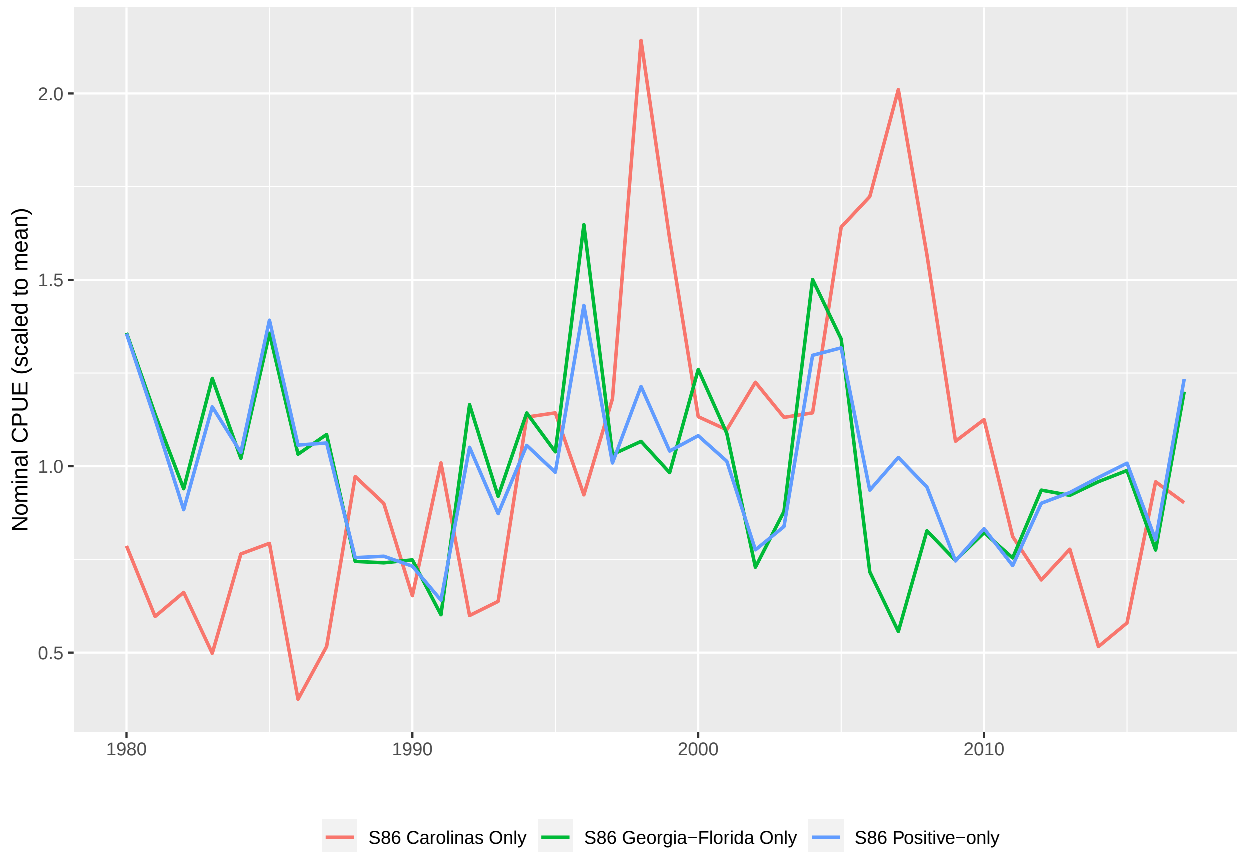


Figure 19: Nominal red grouper cpue for subsetted trips for SEDAR 19, SEDAR 53, and all positve trips.

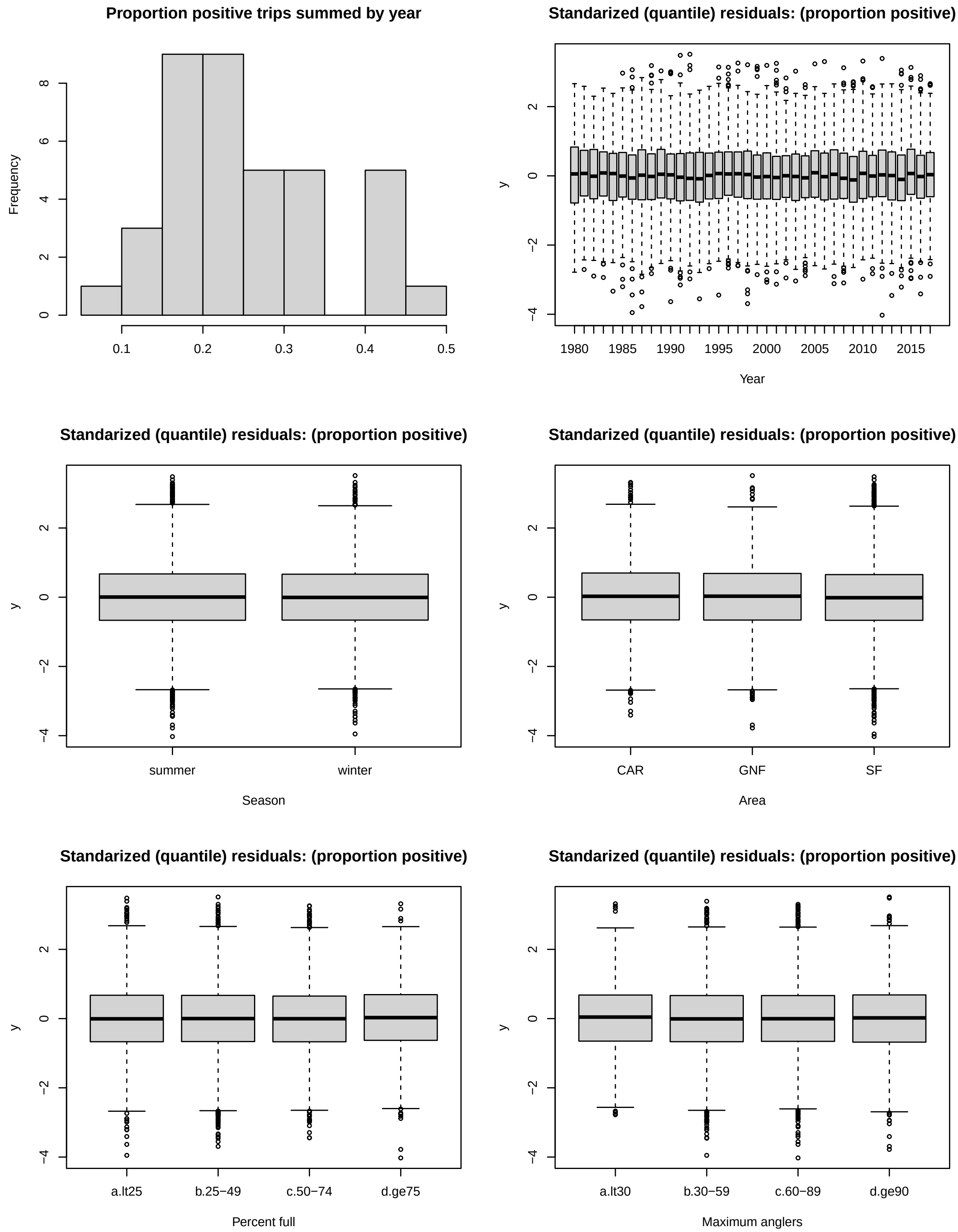


Figure 20: Diagnostics of Bernoulli submodel fits to positive versus zero CPUE data. Box and whisker plots give first, second (median) and third quartiles, as well as limbs that extend to approximately one interquartile range beyond the nearest quartile, and outliers (circles) beyond the limbs. Residuals are standardized (quantile) residuals.

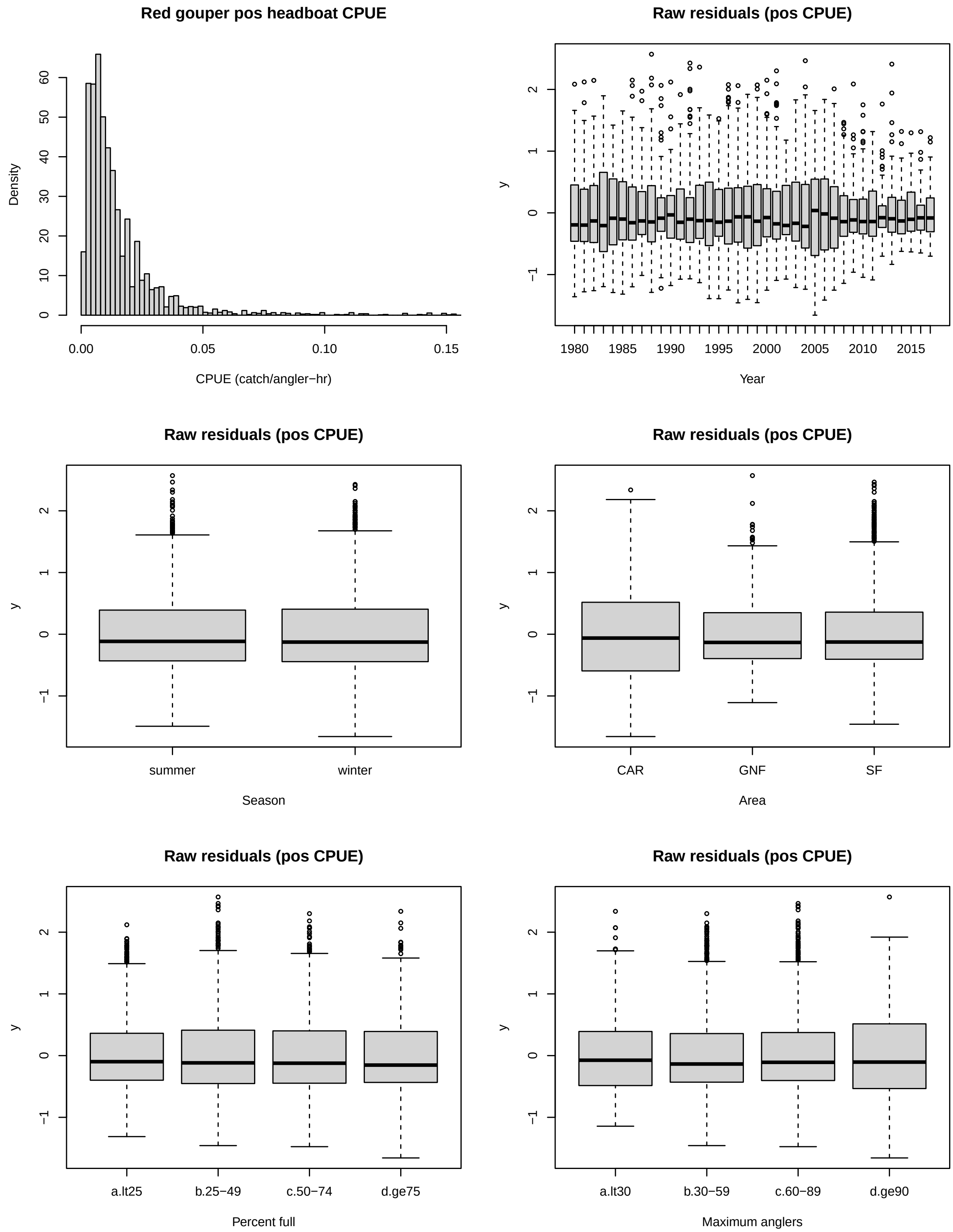
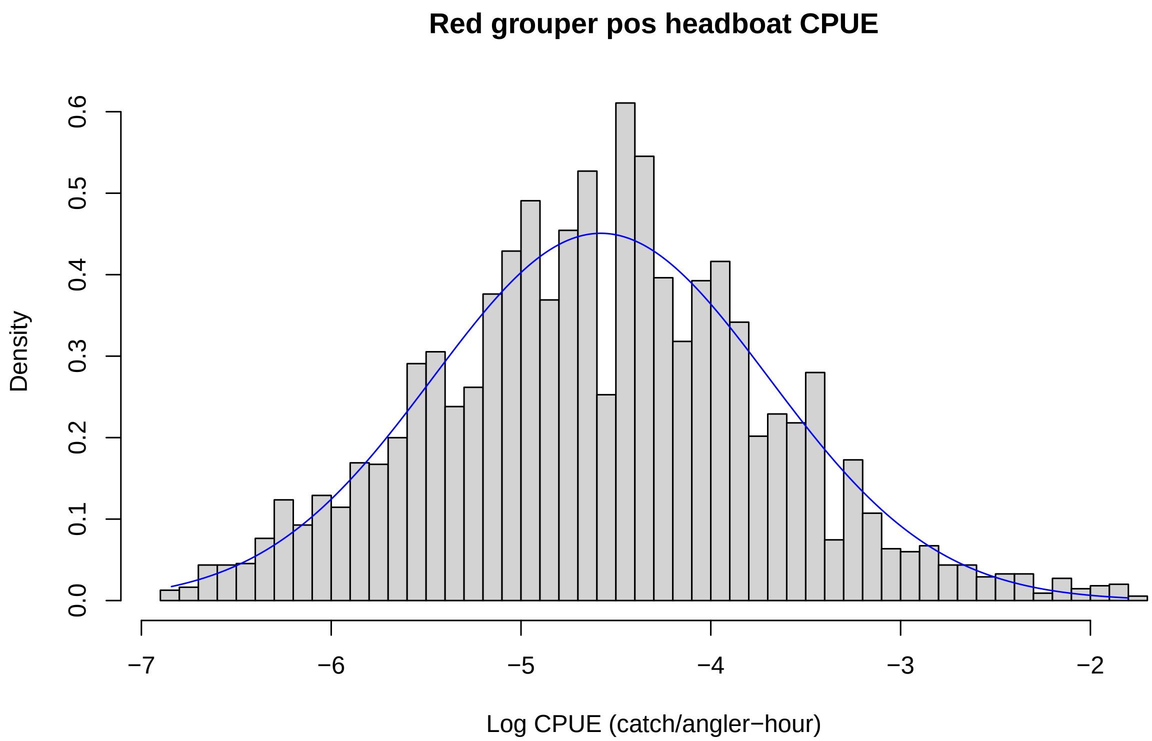


Figure 21: Diagnostics of lognormal submodel fits to positive CPUE data. Top left panel shows the distribution of positive cpue. Box and whisker plots give first, second (median) and third quartiles, as well as limbs that extend to approximately one interquartile range beyond the nearest quartile, and outliers (circles) beyond the limbs. Residuals are raw.



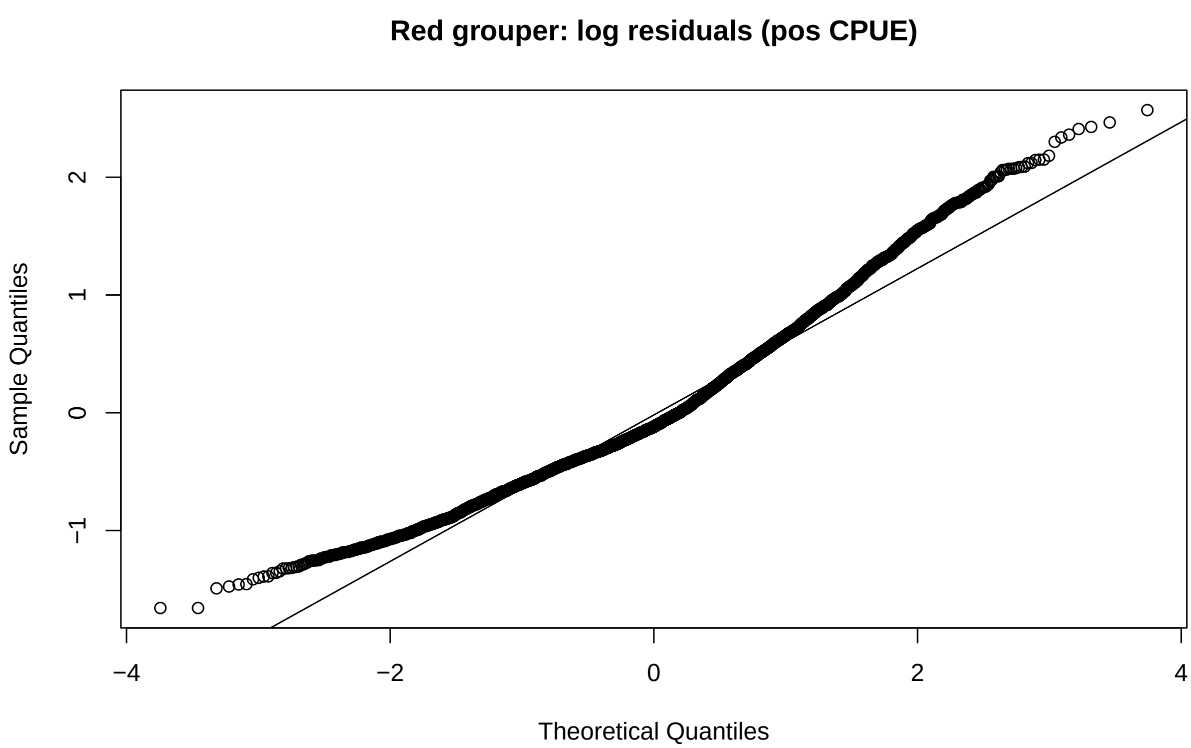


Figure 22: Histogram of empirical log CPUE, with the normal distribution (empirical mean and variance) overlaid. Quantile-quantile plot of residuals from the fitted lognormal submodel to the positive cpue cata.

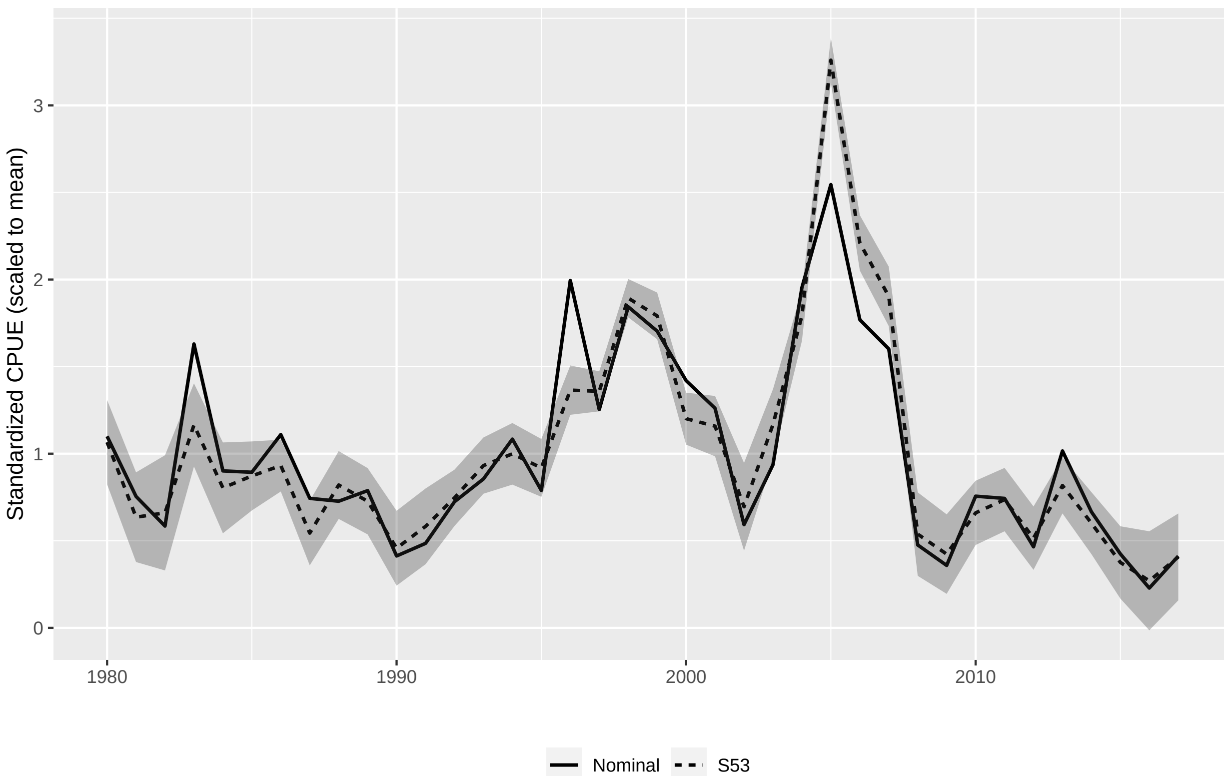


Figure 23: Standardized (dashed) with 95% confidence interval (shaded) and nominal index (solid) red grouper catch rate from headboat logbooks.

Appendix

Results of generalized linear model with Bernoulli response to select species associations with red grouper for the Carolinas.

```
##
## Call:  glm(formula = Red.Grouper ~ Tomtate + White.grunt + Whitebone.porgy +
##     Greater.amberjack + Scamp + Rock.Hind + Knobbed.porgy + Scup +
##     Red.Hind, family = "binomial", data = n.sp.mat.trim)
##
## Coefficients:
##       (Intercept)            Tomtate        White.grunt    Whitebone.porgy
##          -1.77167           -0.47257            0.26657           -0.08403
## Greater.amberjack              Scamp          Rock.Hind      Knobbed.porgy
##          -0.36091            0.30070            0.39805            0.19086
##              Scup           Red.Hind
##          -0.25107            0.84222
##
## Degrees of Freedom: 28791 Total (i.e. Null);  28782 Residual
## Null Deviance:       27170
## Residual Deviance: 26150     AIC: 26170
```

Results of generalized linear model with Bernoulli response to select species associations with red grouper for the Georgia-N.Florida.

```
##
## Call:  glm(formula = Red.Grouper ~ Tomtate + Whitebone.porgy + Greater.amberjack +
##     Scamp + Gray.snapper + Lane.snapper + Almaco.jack, family = "binomial",
##     data = m.sp.mat.trim)
##
## Coefficients:
##       (Intercept)            Tomtate    Whitebone.porgy  Greater.amberjack
##          -2.77269           -0.09978           -0.18829           -0.22397
##             Scamp       Gray.snapper       Lane.snapper        Almaco.jack
##           0.86887            0.72652            0.36726           -0.35098
##
## Degrees of Freedom: 48419 Total (i.e. Null);  48412 Residual
## Null Deviance:       31100
## Residual Deviance: 29560     AIC: 29580
```

Results of generalized linear model with Bernoulli response to select species associations with red grouper for the S. Florida.

```
##
## Call:  glm(formula = Red.Grouper ~ Tomtate + White.grunt + Rock.Hind +
##     Knobbed.porgy + Gray.snapper + Sand.tilefish + Blue.runner +
##     Graysby + Lane.snapper + Almaco.jack + Bluestriped.grunt,
##     family = "binomial", data = s.sp.mat.trim)
##
## Coefficients:
##       (Intercept)            Tomtate        White.grunt          Rock.Hind
##          -2.61580           -0.07591            0.83256            0.59319
##     Knobbed.porgy       Gray.snapper      Sand.tilefish        Blue.runner
##           0.89679           -0.07874            0.16991           -0.26123
##           Graysby       Lane.snapper        Almaco.jack  Bluestriped.grunt
##          -0.15538            0.10584           -0.23635            0.04685
##
```

```
## Degrees of Freedom: 129931 Total (i.e. Null);  129920 Residual
## Null Deviance:       82740
## Residual Deviance: 78000     AIC: 78030
```

Results of lognormal glm to determine factors.

```
##
## Call:  glm(formula = log(cpue) ~ year + zone + season + vsize + pctfact,
##     family = gaussian(link = "identity"), data = dat.pos)
##
## Coefficients:
##    (Intercept)        year1981        year1982        year1983        year1984
##      -3.207490       -0.079617        0.029577        0.250350        0.060065
##       year1985        year1986        year1987        year1988        year1989
##      -0.001077       -0.110059       -0.217148       -0.070756       -0.176476
##       year1990        year1991        year1992        year1993        year1994
##      -0.181131       -0.078637       -0.119292        0.003420        0.168614
##       year1995        year1996        year1997        year1998        year1999
##       0.031640        0.107453        0.098699        0.251403        0.179323
##       year2000        year2001        year2002        year2003        year2004
##       0.035684        0.041125       -0.011953        0.041537        0.184139
##       year2005        year2006        year2007        year2008        year2009
##       0.591411        0.378599        0.248866       -0.085645       -0.180609
##       year2010        year2011        year2012        year2013        year2014
##      -0.130479       -0.131196       -0.163154       -0.101964       -0.049991
##       year2015        year2016        year2017         zoneGNF          zoneSF
##      -0.107954       -0.191596       -0.066983       -0.533890        0.212758
##   seasonwinter    vsizeb.30-59    vsizec.60-89     vsized.ge90  pctfactb.25-49
##       0.090203       -0.623926       -1.072310       -1.204659       -0.528356
## pctfactc.50-74   pctfactd.ge75
##      -1.058753       -1.362593
##
## Degrees of Freedom: 5501 Total (i.e. Null);  5455 Residual
## Null Deviance:       4309
## Residual Deviance: 2301  AIC: 10910
```

Results of gamma glm to determine factors.

```
##
## Call:  glm(formula = cpue ~ year + zone + season + vsize + pctfact,
##     family = Gamma(link = "log"), data = dat.pos)
##
## Coefficients:
##    (Intercept)        year1981        year1982        year1983        year1984
##      -2.940936       -0.145691        0.027527        0.325634        0.007596
##       year1985        year1986        year1987        year1988        year1989
##      -0.052186       -0.140896       -0.340239       -0.044919       -0.279987
##       year1990        year1991        year1992        year1993        year1994
##      -0.275889       -0.188530       -0.115991       -0.064774        0.101131
##       year1995        year1996        year1997        year1998        year1999
##      -0.089804        0.095742        0.020049        0.214186        0.123016
##       year2000        year2001        year2002        year2003        year2004
##      -0.058705        0.013967       -0.163876       -0.041403        0.244159
##       year2005        year2006        year2007        year2008        year2009
##       0.547963        0.320474        0.210625       -0.233586       -0.346371
##       year2010        year2011        year2012        year2013        year2014
```

```
##      -0.283679       -0.315948       -0.376752       -0.252327       -0.242888
##       year2015        year2016        year2017         zoneGNF          zoneSF
##      -0.325299       -0.403104       -0.288128       -0.706096        0.127208
##   seasonwinter    vsizeb.30-59    vsizec.60-89     vsized.ge90  pctfactb.25-49
##       0.122226       -0.509520       -0.989238       -1.120992       -0.506257
## pctfactc.50-74   pctfactd.ge75
##      -1.044415       -1.335454
##
## Degrees of Freedom: 5501 Total (i.e. Null);  5455 Residual
## Null Deviance:       4506
## Residual Deviance: 2604  AIC: -38370
```

Results of binomial glm to determine factors.

```
##
## Call:  glm(formula = cpue ~ year + zone + season + vsize + pctfact,
##     family = "binomial", data = dat.bin)
##
## Coefficients:
##    (Intercept)        year1981        year1982        year1983        year1984
##       -0.94961        -0.58814        -0.67582        -0.22773        -0.46686
##       year1985        year1986        year1987        year1988        year1989
##       -0.27920        -0.03569        -0.61010        -0.26805        -0.28817
##       year1990        year1991        year1992        year1993        year1994
##       -0.86552        -0.69656        -0.32879        -0.19570        -0.32405
##       year1995        year1996        year1997        year1998        year1999
##       -0.25356         0.21058         0.21653         0.51422         0.54390
##       year2000        year2001        year2002        year2003        year2004
##        0.12430         0.06140        -0.56001         0.07301         0.53557
##       year2005        year2006        year2007        year2008        year2009
##        0.90664         0.56387         0.52794        -0.78445        -0.95744
##       year2010        year2011        year2012        year2013        year2014
##       -0.47492        -0.33126        -0.74436        -0.23043        -0.69322
##       year2015        year2016        year2017         zoneGNF          zoneSF
##       -1.18015        -1.45593        -1.13480        -0.28085         0.08868
##   seasonwinter    vsizeb.30-59    vsizec.60-89     vsized.ge90  pctfactb.25-49
##        0.70477        -0.45230        -0.38520        -0.24251         0.17069
## pctfactc.50-74   pctfactd.ge75
##        0.23706         0.18478
##
## Degrees of Freedom: 21547 Total (i.e. Null);  21501 Residual
## Null Deviance:       24480
## Residual Deviance: 22910     AIC: 23010
```

Results of lognormal delta glm to compare models.

```
## $error.distribution
## [1] "Lognormal distribution assumed for positive observations."
##
## $binomial.formula
## [1] "Formula for binomial GLM: cpue ~ year + zone + vsize + pctfact + season"
##
## $positive.formula
## [1] "Formula for gaussian GLM: log(cpue) ~ year + zone + vsize + pctfact + season"
##
## $deltaGLM.index
```

```
##             index jackknife
## 1980 0.0034111216        NA
## 1981 0.0020329211        NA
## 1982 0.0021130340        NA
## 1983 0.0037272359        NA
## 1984 0.0025719754        NA
## 1985 0.0027905812        NA
## 1986 0.0029812731        NA
## 1987 0.0017408761        NA
## 1988 0.0026243713        NA
## 1989 0.0023260505        NA
## 1990 0.0014635384        NA
## 1991 0.0018646105        NA
## 1992 0.0023891764        NA
## 1993 0.0029805912        NA
## 1994 0.0031976503        NA
## 1995 0.0029386688        NA
## 1996 0.0043672676        NA
## 1997 0.0043456873        NA
## 1998 0.0060576647        NA
## 1999 0.0057314075        NA
## 2000 0.0038433905        NA
## 2001 0.0037057882        NA
## 2002 0.0022244623        NA
## 2003 0.0037363506        NA
## 2004 0.0057322265        NA
## 2005 0.0104296445        NA
## 2006 0.0070735263        NA
## 2007 0.0060893583        NA
## 2008 0.0017226911        NA
## 2009 0.0013548908        NA
## 2010 0.0021124735        NA
## 2011 0.0023565176        NA
## 2012 0.0016477836        NA
## 2013 0.0026152823        NA
## 2014 0.0019240286        NA
## 2015 0.0012019125        NA
## 2016 0.0008646896        NA
## 2017 0.0013028377        NA
##
## $pos.effects
## $pos.effects[[1]]
##         CAR         GNF          SF
## 0.012247644 0.007181037 0.015151373
##
## $pos.effects[[2]]
##      a.lt30     b.30-59     c.60-89      d.ge90
## 0.022726081 0.012177467 0.007777256 0.006813147
##
## $pos.effects[[3]]
##      a.lt25     b.25-49     c.50-74      d.ge75
## 0.023005080 0.013563180 0.007980187 0.005889214
##
## $pos.effects[[4]]
```

```
##     summer     winter
## 0.01051905 0.01151201
##
##
## $bin.effects
## $bin.effects[[1]]
##       CAR       GNF        SF
## 0.2705036 0.2187582 0.2883549
##
## $bin.effects[[2]]
##    a.lt30   b.30-59   c.60-89    d.ge90
## 0.3130021 0.2247101 0.2366162 0.2633499
##
## $bin.effects[[3]]
##    a.lt25   b.25-49   c.50-74    d.ge75
## 0.2307192 0.2623934 0.2754391 0.2651289
##
## $bin.effects[[4]]
##    summer    winter
## 0.1964689 0.3309841
##
##
## $data.filter
## [1] "Data filter threshold set at 2 positive observations."
##
## $levels.deleted.by.filter
## $levels.deleted.by.filter$year
## [1] NA
##
## $levels.deleted.by.filter$zone
## [1] NA
##
## $levels.deleted.by.filter$vsize
## [1] NA
##
## $levels.deleted.by.filter$pctfact
## [1] NA
##
## $levels.deleted.by.filter$season
## [1] NA
##
##
## $aic
##                        [,1]
## AIC.binomial   23006.764478
## AIC.lognormal -39481.295596
## sigma.mle          0.646642
```

Results of gamma delta glm to compare models.

```
## $error.distribution
## [1] "Gamma distribution assumed for positive observations."
##
## $binomial.formula
## [1] "Formula for binomial GLM: cpue ~ year + zone + vsize + pctfact + season"
```

```
##
## $positive.formula
## [1] "Formula for Gamma GLM: cpue ~ year + zone + vsize + pctfact + season"
##
## $deltaGLM.index
##            index jackknife
## 1980 0.011687274        NA
## 1981 0.010102769        NA
## 1982 0.012013455        NA
## 1983 0.016185802        NA
## 1984 0.011776392        NA
## 1985 0.011093003        NA
## 1986 0.010151330        NA
## 1987 0.008316668        NA
## 1988 0.011173905        NA
## 1989 0.008833171        NA
## 1990 0.008869436        NA
## 1991 0.009679115        NA
## 1992 0.010407325        NA
## 1993 0.010954242        NA
## 1994 0.012931046        NA
## 1995 0.010683455        NA
## 1996 0.012861558        NA
## 1997 0.011923959        NA
## 1998 0.014478821        NA
## 1999 0.013217171        NA
## 2000 0.011020918        NA
## 2001 0.011851657        NA
## 2002 0.009920714        NA
## 2003 0.011213270        NA
## 2004 0.014919363        NA
## 2005 0.020215777        NA
## 2006 0.016102499        NA
## 2007 0.014427346        NA
## 2008 0.009252690        NA
## 2009 0.008265825        NA
## 2010 0.008800611        NA
## 2011 0.008521162        NA
## 2012 0.008018480        NA
## 2013 0.009080901        NA
## 2014 0.009167024        NA
## 2015 0.008441854        NA
## 2016 0.007809932        NA
## 2017 0.008761549        NA
##
## $pos.effects
## $pos.effects[[1]]
##         CAR         GNF          SF
## 0.013161313 0.006495992 0.014946689
##
## $pos.effects[[2]]
##      a.lt30     b.30-59     c.60-89      d.ge90
## 0.020889703 0.012550197 0.007768047 0.006809129
##
```

```
## $pos.effects[[3]]
##      a.lt25     b.25-49     c.50-74      d.ge75
## 0.022328199 0.013458270 0.007857236 0.005873182
##
## $pos.effects[[4]]
##     summer     winter
## 0.01020835 0.01153553
##
##
## $bin.effects
## $bin.effects[[1]]
## CAR GNF  SF
##   1   1   1
##
## $bin.effects[[2]]
##  a.lt30 b.30-59 c.60-89  d.ge90
##       1       1       1       1
##
## $bin.effects[[3]]
##  a.lt25 b.25-49 c.50-74  d.ge75
##       1       1       1       1
##
## $bin.effects[[4]]
## summer winter
##      1      1
##
##
## $data.filter
## [1] "Data filter threshold set at 2 positive observations."
##
## $levels.deleted.by.filter
## $levels.deleted.by.filter$year
## [1] NA
##
## $levels.deleted.by.filter$zone
## [1] NA
##
## $levels.deleted.by.filter$vsize
## [1] NA
##
## $levels.deleted.by.filter$pctfact
## [1] NA
##
## $levels.deleted.by.filter$season
## [1] NA
##
##
## $aic
##                        [,1]
## AIC.binomial     94.000000
## AIC.gamma    -38383.025763
## shape.mle         2.265253
```

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