Standardized catch rates of scamp and yellowmouth grouper (*Mycteroperca phenax* and *Myteroperca interstitialis*) in the southeast U.S. from headboat logbook data

Sustainable Fisheries Branch

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This document describes the the development of the SEDAR 68 headboat index for scamp and yellowmouth grouper. A consensus decision was made at the stock identification workshop to combine these species (SEDAR 68 Stock ID report).

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 scamp and yellowmouth grouper trips are shown in Figure 2.

Data Exclusions

1. Outlier removal

Extreme values occur more frequently in self-reported data, in part because there are limited methods for validating data. Recent SEDAR stock assessments have removed values at the extreme upper tail of the 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 (> 100) and cpue (> 0.333) for trips that caught scamp and yellowmouth 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 can reduce bias by removing self-reported data that are likely erroneous.

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

The headboat program increased its 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 starting year for the headboat index was set to 1981 since prior to 1981 scamp and yellowmouth grouper

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were reported and lumped with other mycteroperca. The total number of reported trips are reported in (Figure 1). The number of positive scamp and yellowmouth grouper trips tend to decrease in the Carolinas and Georgia-Florida (Figure 2).

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). The peaks in the number of positive scamp and yellowmouth grouper trips are similar between the seasonal closure and open months prior to the 2010 seasonal closure by region (Figure 5). With limited changes to management in the most recent years, 2018 was chosen as the terminal year of this index.

5. Trip types

Figure 6 shows the noisy positive scamp and yellowmouth grouper median cpue associated with these trip types for South Carolina while Georgia- Florida 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 scamp and yellowmouth 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 scamp and yellowmouth grouper trips in the Carolinas. The half-day trips in these areas are likely fishing at shallower depths and may be associated with ontogenetic inshore-offshore movements for scamp and yellowmouth grouper. Half-day trips were excluded for the Carolinas. 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 scamp and yellowmouth grouper trips by year and region from the data as filtered for input into the Stephens and MacCall analysis are shown in Figure 8.

Evaluation of explanatory variables

YEAR - Year was necessarily included, as standardized catch rates by year are the desired outcome. Years modeled were 1981-2018.

AREA - Initially, the three areas include the Carolinas (CAR), Georgia and North Florida (to Cape Canveral, FL), South Florida (South of Cape Canaveral, FL) but due to low number of positive trips from south of Cape Canaveral, FL, the three areas chosen were North Carolina, (NCAR), South Carolina (SCAR) and Georgia-Florida (GAFL). These areas were defined due to shelf characteristics and associated fishing behavior as well as species compositions.

SEASON - A third of the months were dropped due to the spawning closure. The patterns in the remaining positive scamp and yellowmouth grouper trips by month and region show few trips in the Carolinas for Nov and Dec. However, Nov and Dec have the most positive scamp and yellowmouth 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 the number of anglers using the quartiles of the number of anglers across all trips as breaks for the factors. Given the large range of vessel sizes, a trip with 20 anglers could be either almost full or almost empty. Here we develop a factor 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 two factors based on visual inspection of the density plots into: 1. fewer than 60 maximum anglers 2. 60 or more maximum anglers (Figure 18).

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 initially developed using quartiles but upon further inspection of the density plot the factor was then divided into 2 factors; 1. less than 50% full and 50% or more full. The density of percent full by area and the density of cpue associated with each factor are shown in Figure 19.

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 by area to North Carolina, South Carolina and Georgia-Florida

Subsetting trips

Effective effort was based on those trips from areas where scamp and yellowmouth 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 and was considered initially but due to a lack of positive trips this region was combined with Georgia and north Florida. Another break between the North Carolina and South Carolina 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 5% or more of trips for the Carolinas and 3% for Georgia/Florida. A range of 1% to 5% was considered with 1% including too many species and 5% too few, especially in GAFL. 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 (Table 1). Species with management closures were also omitted because the potential for erroneously removing trips likely to have caught scamp and yellowmouth grouper during years of restrictions (Table 2). Gray triggerfish is a species that was less desirable during the early part of the survey and therefore may not be good indicator of scamp and yellowmouth grouper habitat.

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 scamp and yellowmouth grouper in each trip to presence/absence of other species. For the NCAR area, stepwise AIC did not eliminate any species; for the NCAR and SCAR sampling area, it eliminated scup and tomtate; for the GAFL sampling area, it eliminated jolthead porgy, white grunt, knobbed porgy and almaco jack. Regression coefficients of included species for all areas are given in Appendix 1 and shown in figure 13. A trip was then included if its associated probability of catching scamp and yellowmouth grouper was higher than a threshold probability (Figure 13). 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). After applying the Stephens and MacCall method, and the constraints described above, the resulting subsetted data set contained 22,641 trips from the three areas of which 60% were positive. Retention of positive and zero scamp and yellowmouth grouper trips across factors are shown in Figures 14 - 16. The nominal catch rate before and after the subsetting are fairly similar (Figure 17)

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 scamp and yellowmouth grouper 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 remove season as an 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

A sensitivity run was generated using a zero inflated negative binomial (ZINB) model and includes all headboat trips (~10% proportion positive). This sensitivity analysis was an attempt to examine the robustness of the delta-GLM index to address the possible limitations of Stephens and MacCall regarding increased regulations on the snapper grouper complex in the most recent years. This index is plotted in figure 23 along with the standarized delta-GLM index for reference.

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). There may be concern that management measures, such as the scamp and yellowmouth grouper seasonal closure that started in 2009, may influence catchability for scamp. 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 1981 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.porgy
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 scamp and yellowmouth 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 scamp and yellowmouth grouper 1981-2017 with CVs for stardardized index of abundance.

Year	N	Proportion.Positive	Nominal.CPUE	Relative.nominal	Standardized.CPUE	CV
1981	399	0.45	0.01	0.27	0.37	0.12
1982	705	0.60	0.01	0.54	0.76	0.07
1983	846	0.50	0.01	0.40	0.54	0.08
1984	628	0.45	0.01	0.41	0.36	0.10
1985	710	0.50	0.01	0.59	0.86	0.07
1986	910	0.42	0.01	0.39	0.72	0.07
1987	991	0.49	0.01	0.57	0.96	0.06
1988	814	0.62	0.02	0.79	1.09	0.06
1989	374	0.61	0.02	0.93	1.20	0.09
1990	453	0.77	0.03	1.28	1.74	0.07
1991	619	0.73	0.03	1.44	1.67	0.08
1992	858	0.57	0.02	0.96	1.16	0.06
1993	902	0.60	0.02	0.88	0.84	0.06
1994	806	0.67	0.02	1.04	1.12	0.06
1995	801	0.62	0.02	1.14	1.06	0.07
1996	771	0.66	0.02	0.92	1.00	0.06
1997	826	0.74	0.03	1.40	1.45	0.06
1998	868	0.69	0.03	1.61	1.48	0.06
1999	804	0.74	0.04	1.72	2.04	0.05
2000	784	0.75	0.04	1.76	1.84	0.05
2001	694	0.65	0.03	1.36	1.54	0.06
2002	549	0.68	0.03	1.65	1.52	0.07
2003	554	0.64	0.03	1.56	1.51	0.07
2004	492	0.72	0.04	1.97	1.65	0.08
2005	487	0.64	0.03	1.38	1.61	0.07
2006	514	0.67	0.03	1.55	1.31	0.07
2007	588	0.73	0.04	1.95	1.77	0.06
2008	436	0.57	0.02	1.06	0.72	0.10
2009	511	0.61	0.02	0.82	0.63	0.08
2010	483	0.58	0.02	1.05	0.74	0.08
2011	343	0.59	0.01	0.63	0.43	0.09
2012	270	0.57	0.02	0.94	0.46	0.12
2013	369	0.47	0.01	0.54	0.37	0.10
2014	373	0.49	0.01	0.55	0.31	0.10
2015	403	0.46	0.01	0.47	0.34	0.10
2016	355	0.48	0.01	0.49	0.30	0.11
2017	356	0.53	0.01	0.56	0.31	0.10
2018	223	0.59	0.01	0.43	0.22	0.13

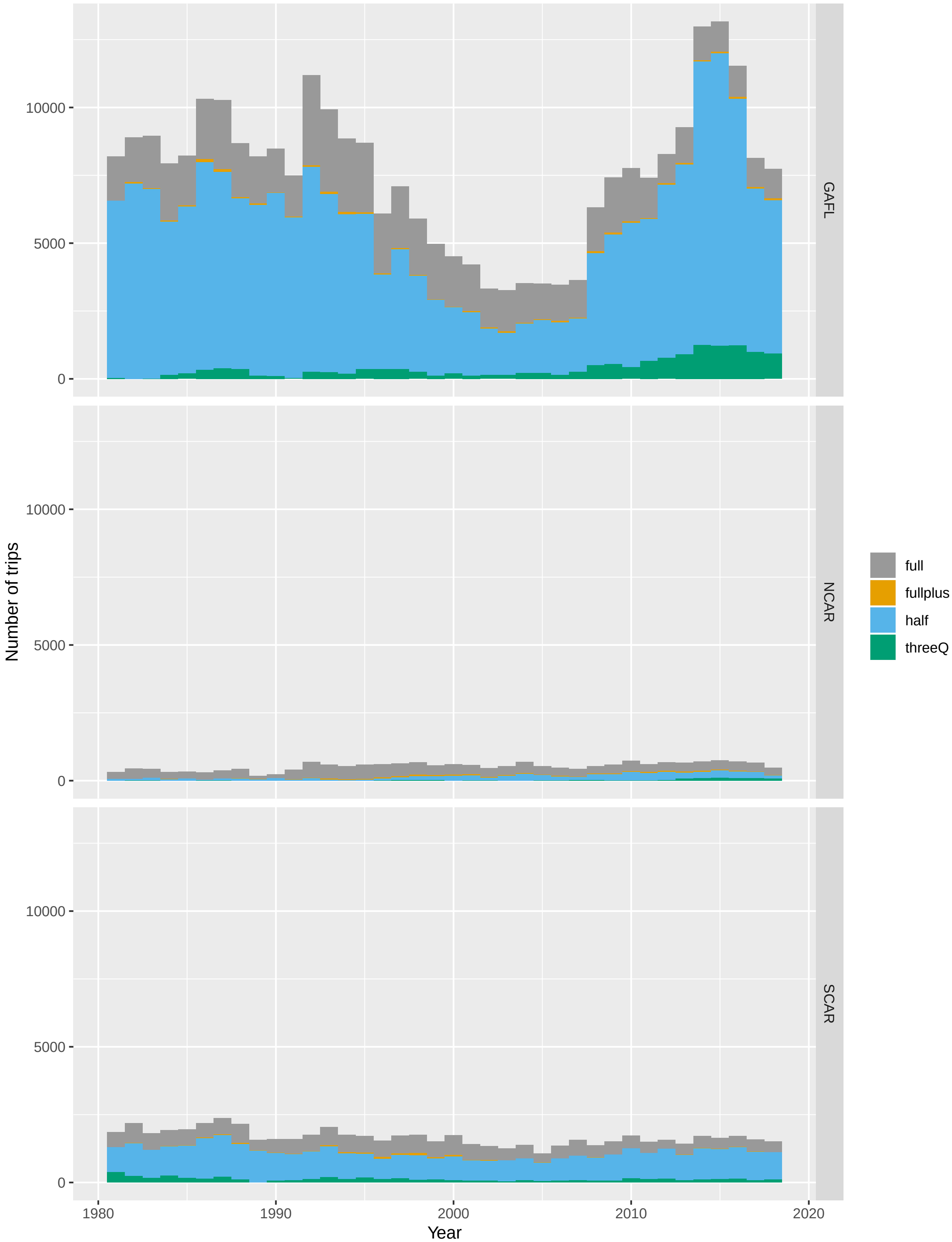


Figure 1: Number of headboat trips that submitted logbooks 1981-2017 for half-day trips (half), full-day trips (full), three-quarter day trips (threeQ), and multiple-day trips ranging from 1.5 to 7 days (fullplus) by region.

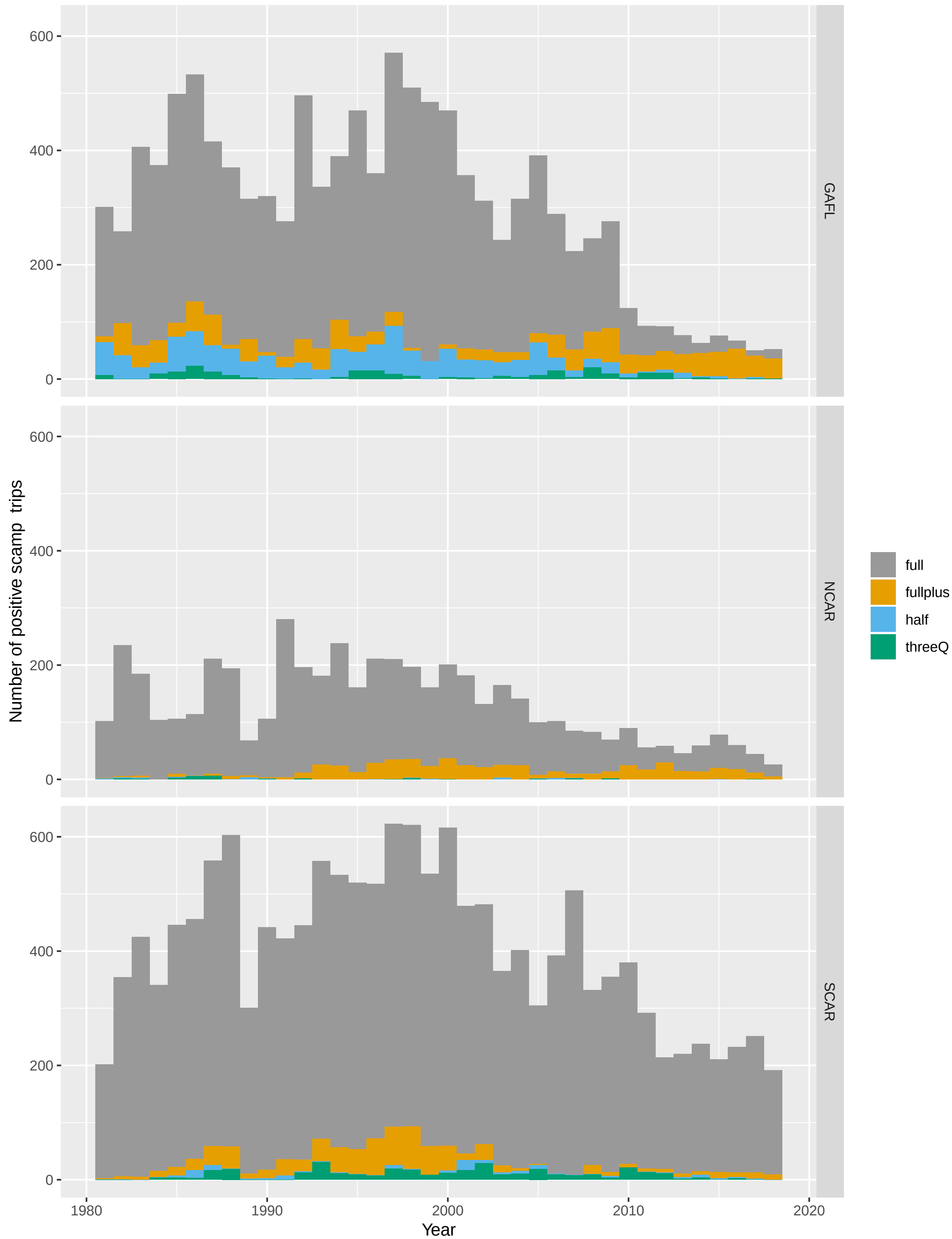


Figure 2: Number of positive scamp and yellowmouth grouper headboat trips that submitted logbooks 1981-2017 for half-day trips (half), full-day trips (full), three-quarter day trips (threeQ), and multiple-day trips ranging from 1.5 to 7 days by region.

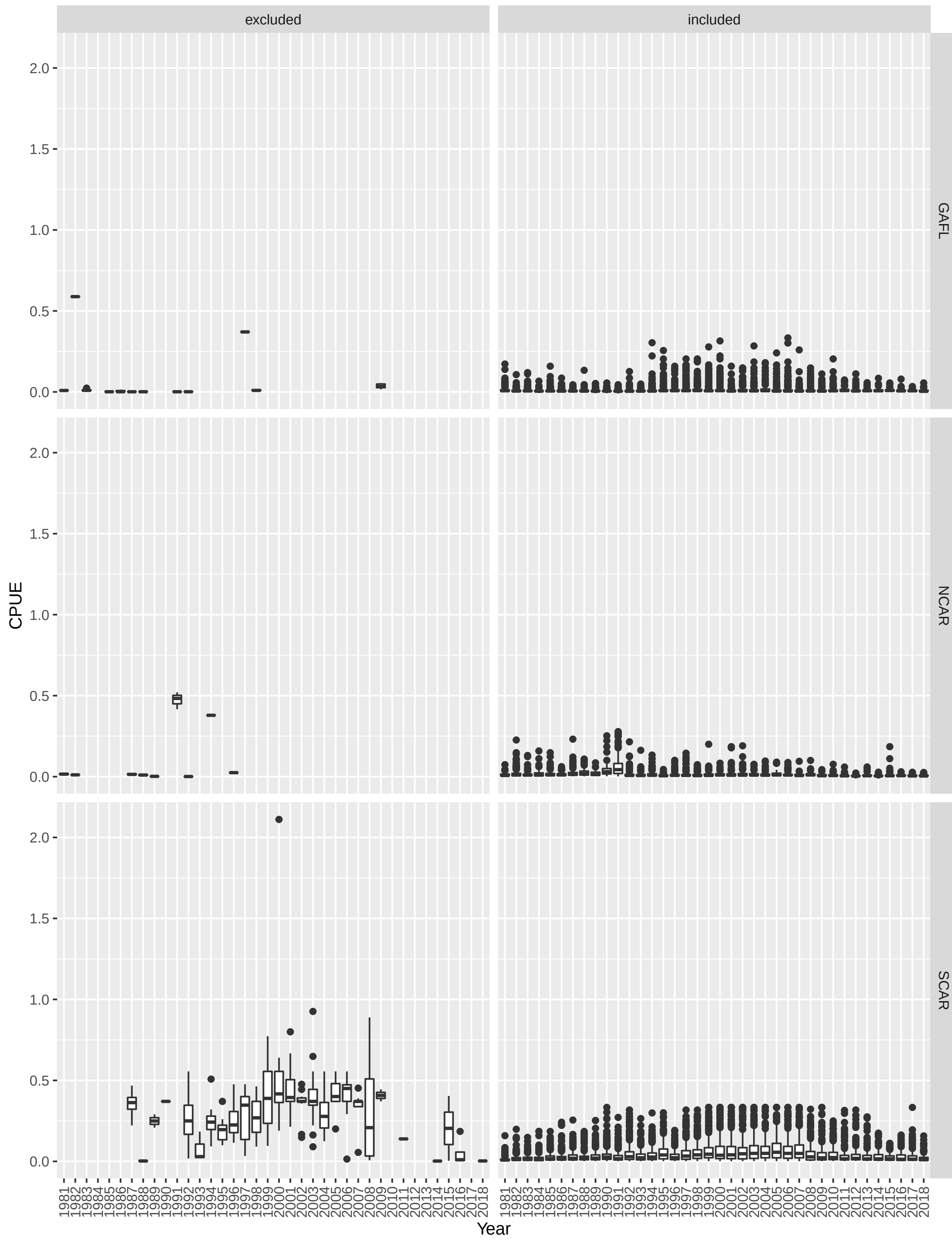


Figure 3: Records determined as outliers (excluded) based on removal of values above the 99.5th percentile for anglers, number of fish caught, and cpue.

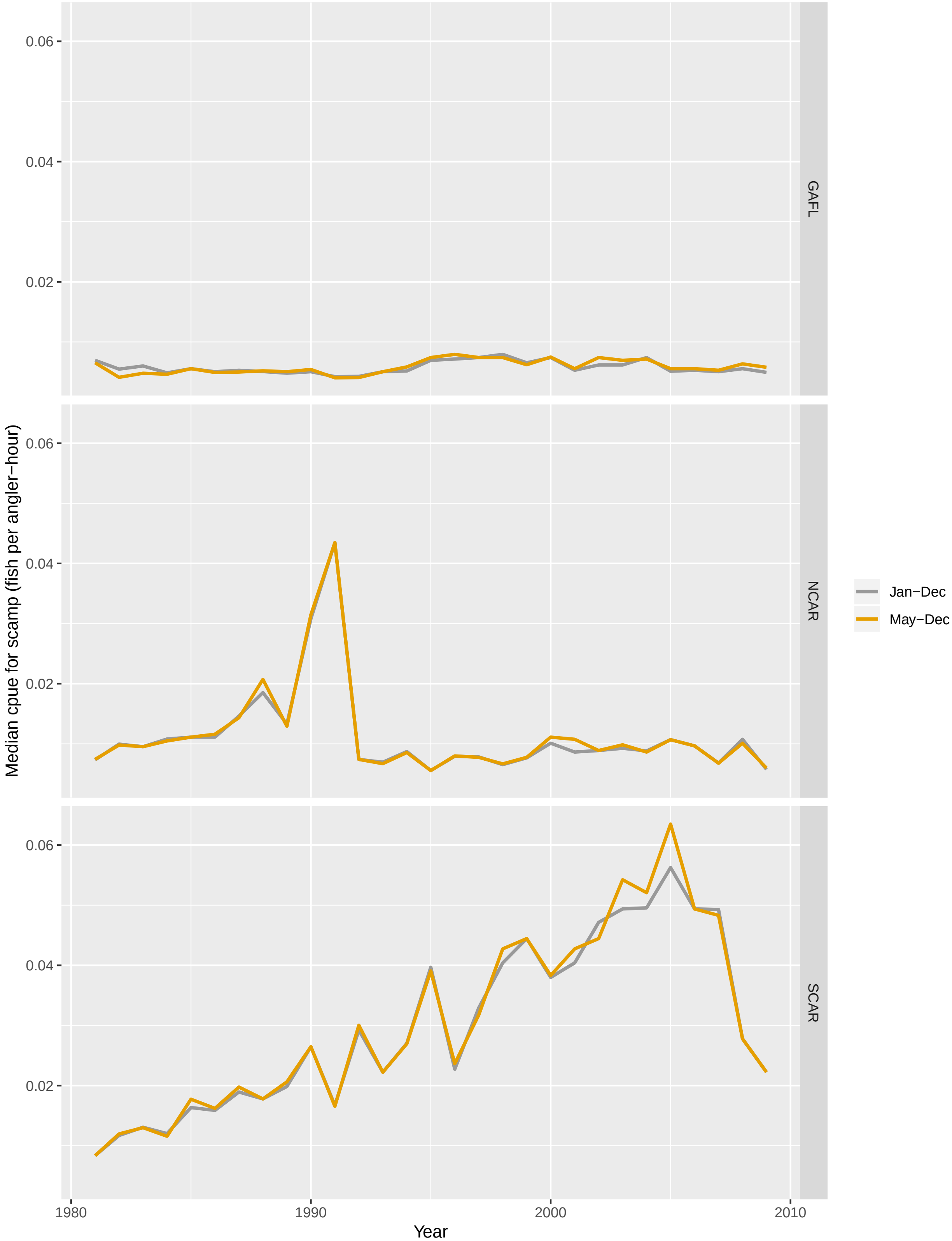


Figure 4: Median nominal scamp and yellowmouth grouper catch rates by region for all months and just May-Dec.

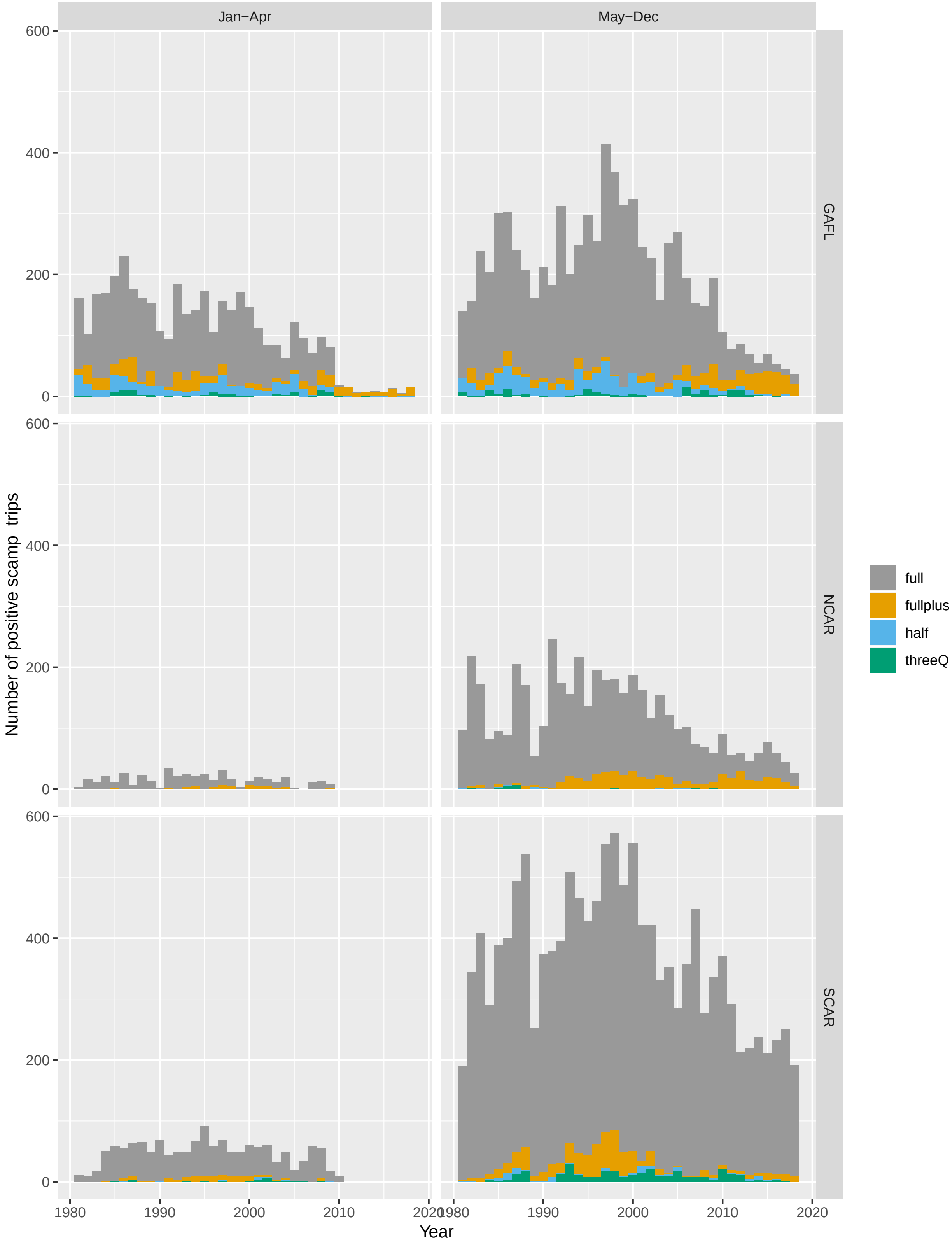


Figure 5: Positive scamp and yellowmouth grouper trips by region and season. January to April is the shallow-water grouper spawning closure season that began in 2010.

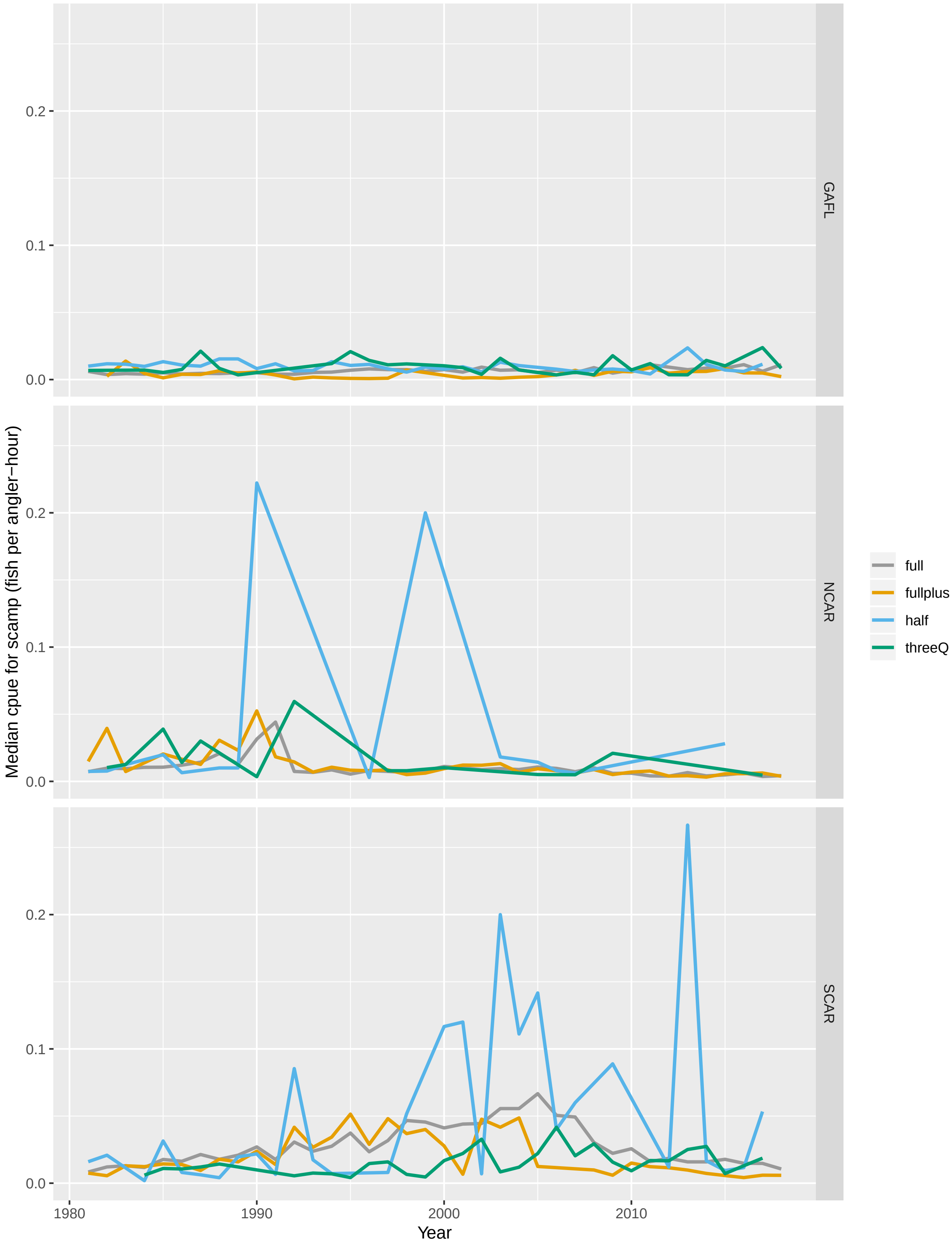


Figure 6: scamp and yellowmouth grouper cpue by region for May - Dec.

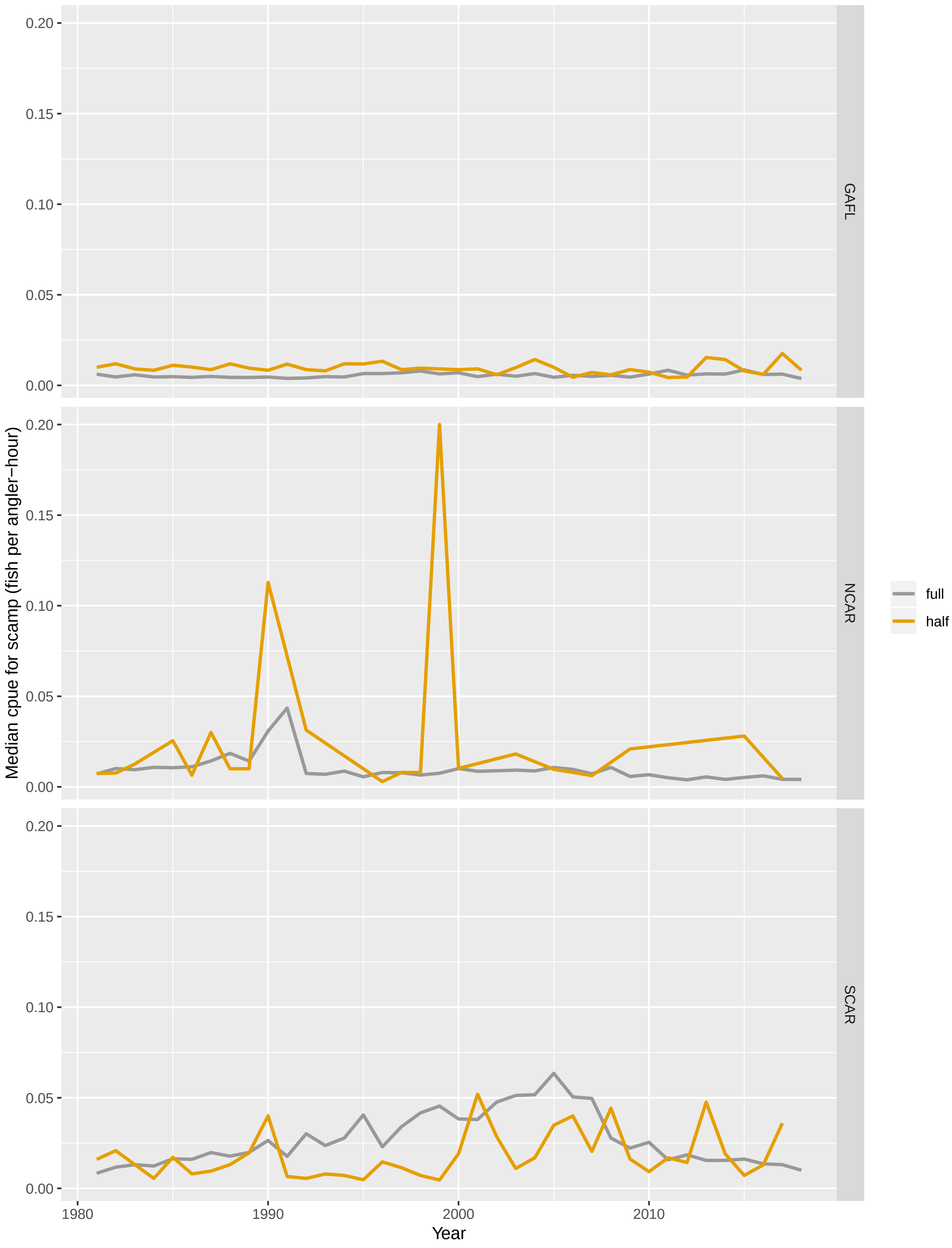


Figure 7: scamp and yellowmouth grouper cpue by region for May - Dec. Trips are aggregated into full- (includes multi-day trips) and half- (includes 3/4-day) trips. January to April is the shallow-water grouper spawning closure season that began in 2010.

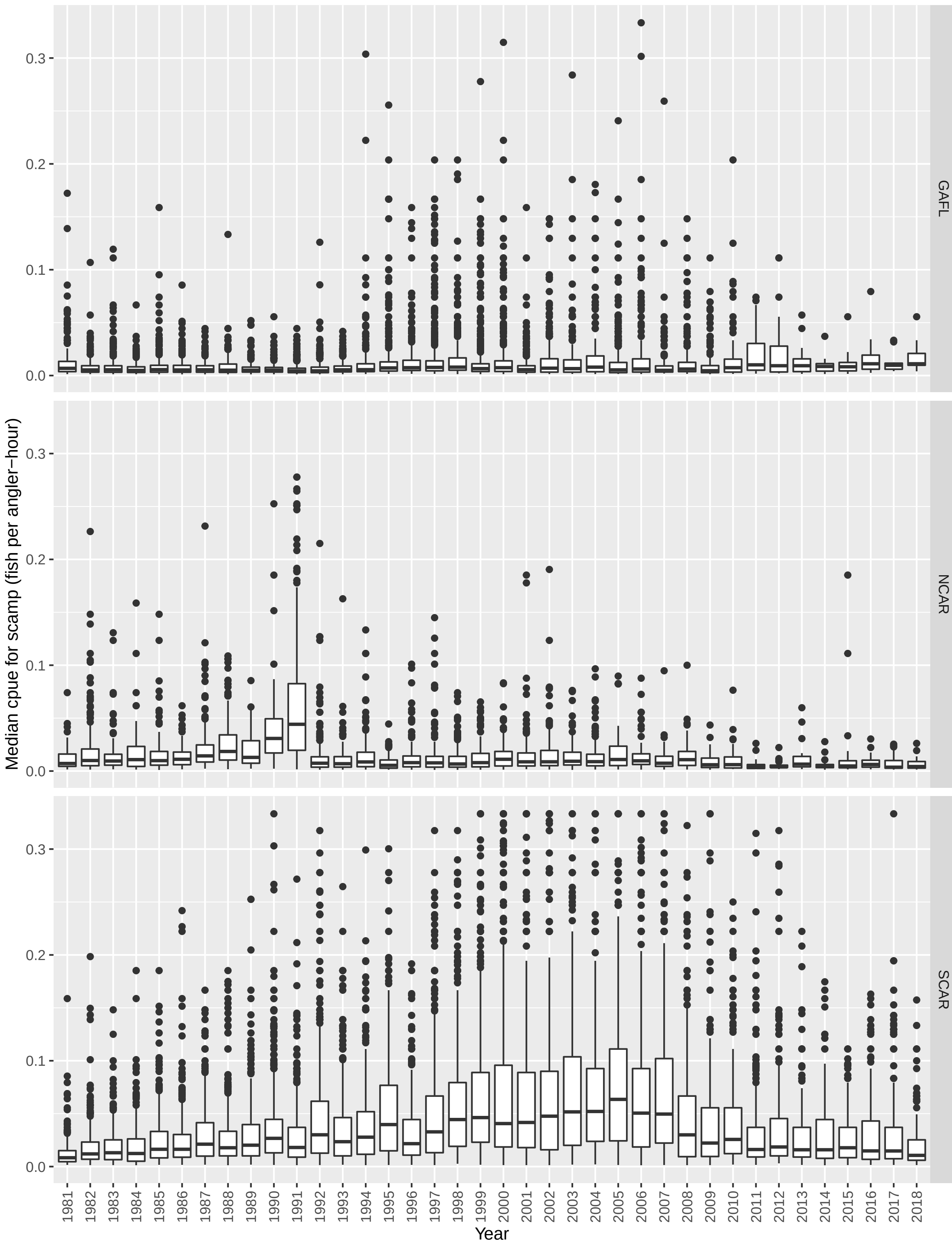


Figure 8: scamp and yellowmouth grouper cpue by region and season. Multi-day and 3/4-day trips are removed for all regions. Half-day trips are removed for CAR and NCAR and SCAR. Half-day trips and full-day trips are aggregated for GAFL. Years are limited to 1981-2015.

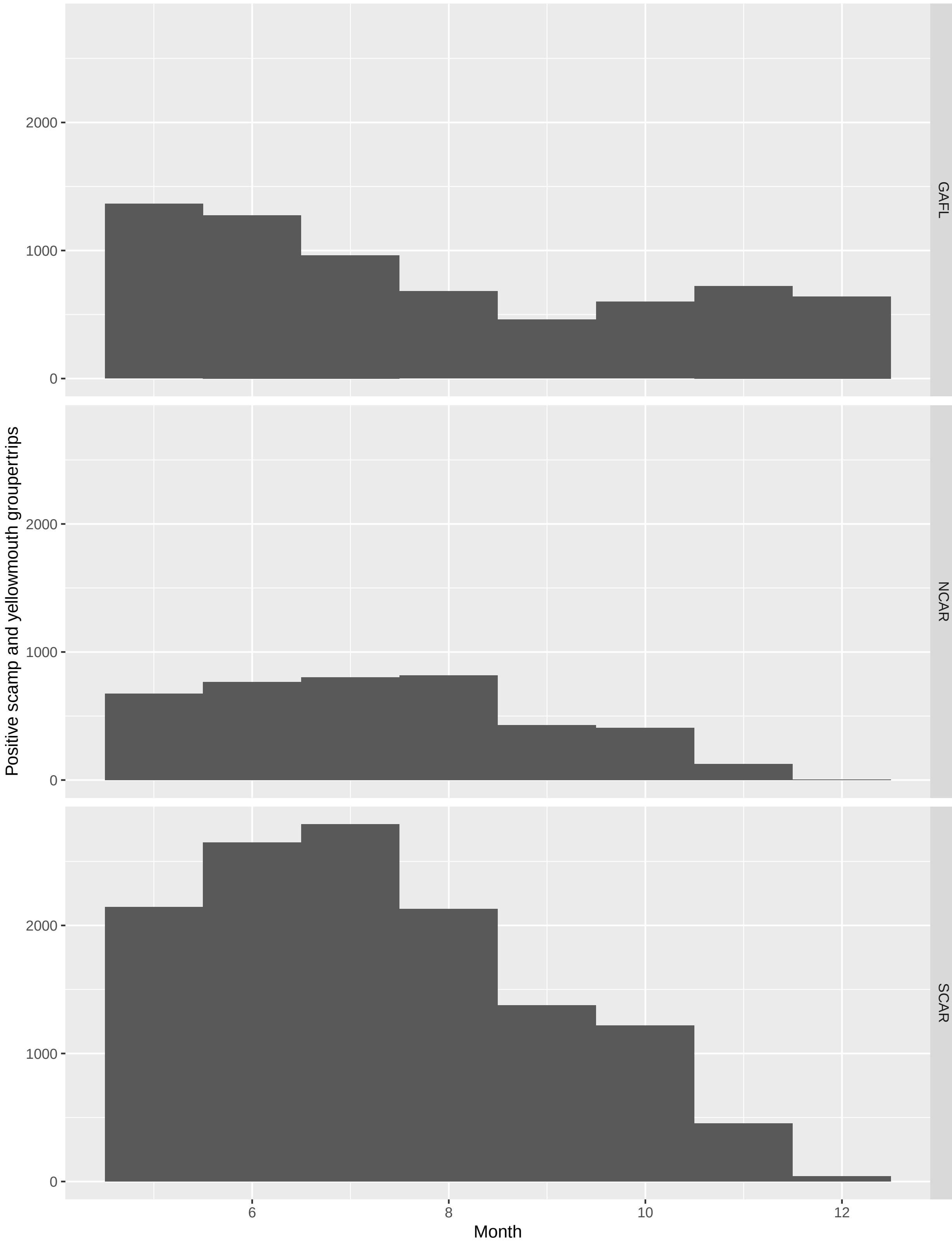


Figure 9: Positive scamp and yellowmouth grouper trips by month and region.

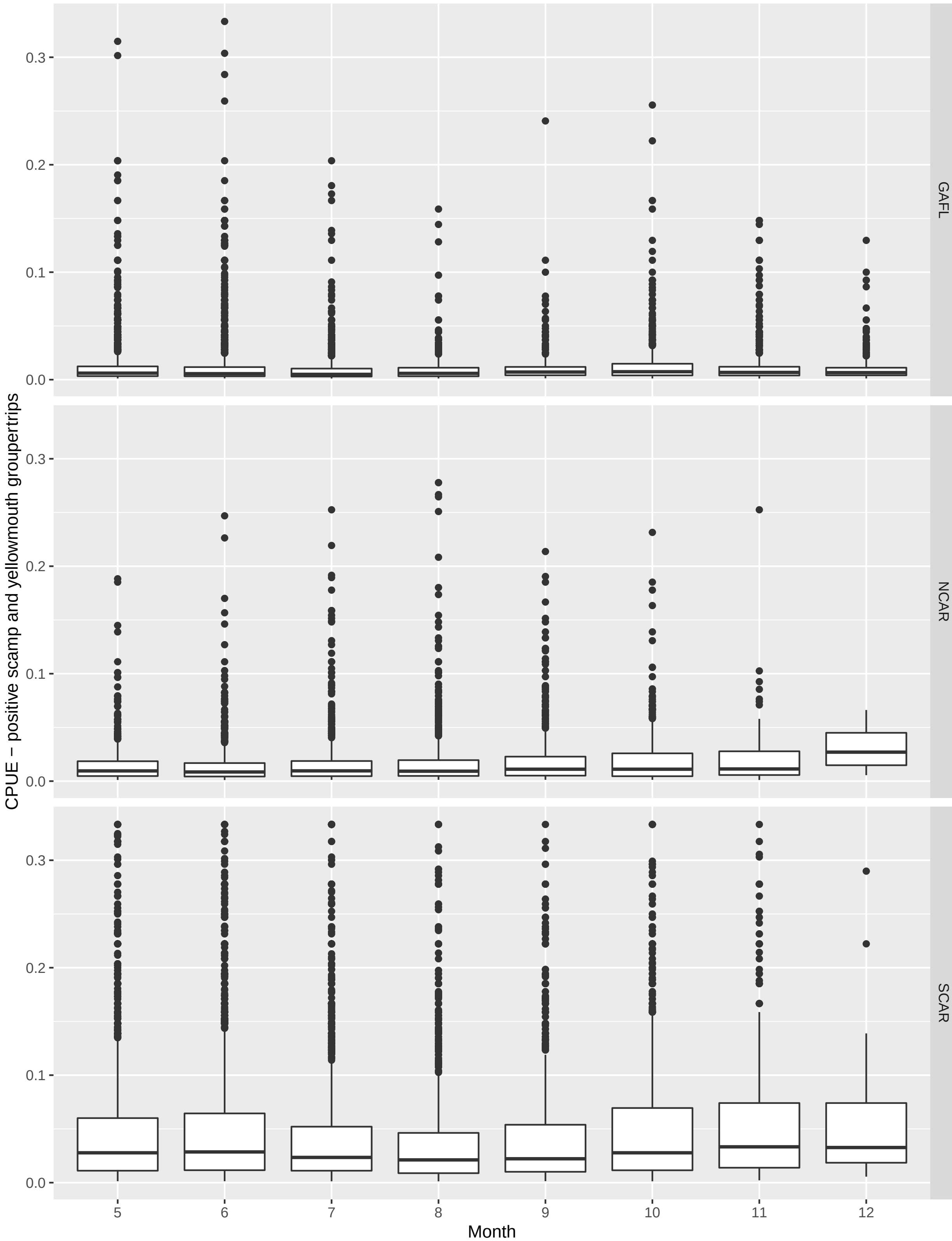


Figure 10: Scamp and yellowmouth grouper cpue for positive trips by month and region.

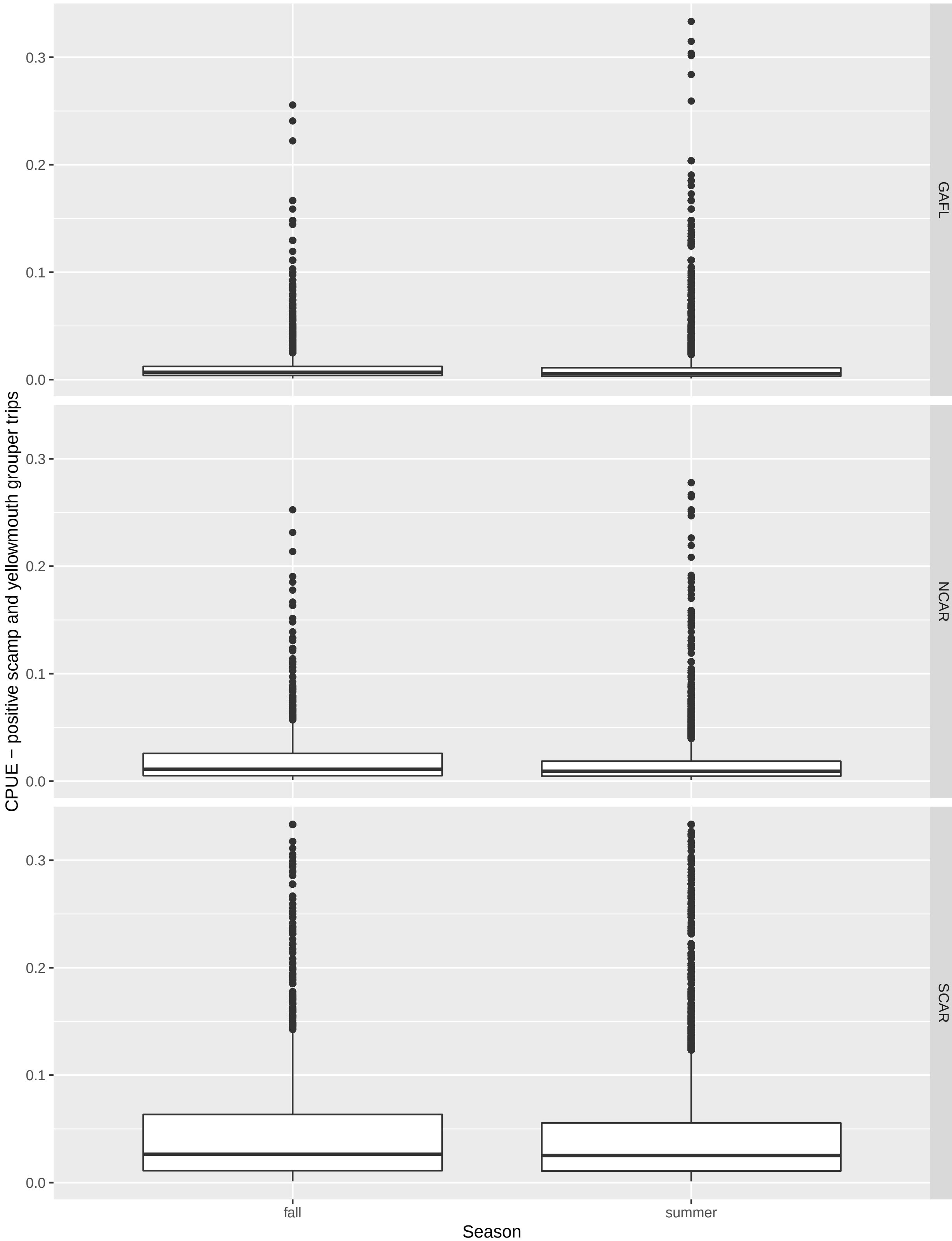


Figure 11: Scamp and yellowmouth grouper cpue for positive trips by season and region.

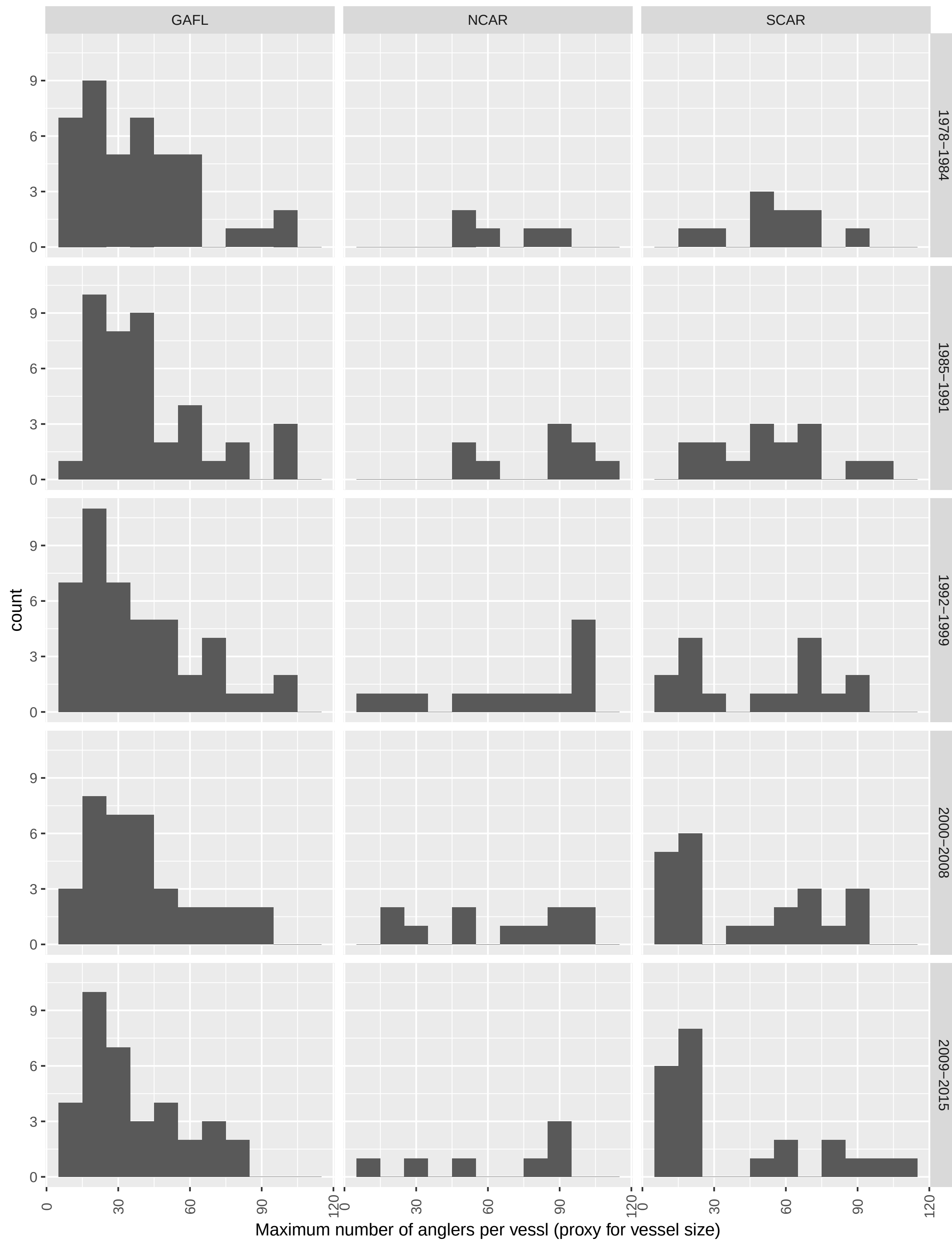


Figure 12: Maximum number of anglers as a proxy for vessel size (single value for each vessel) by region.

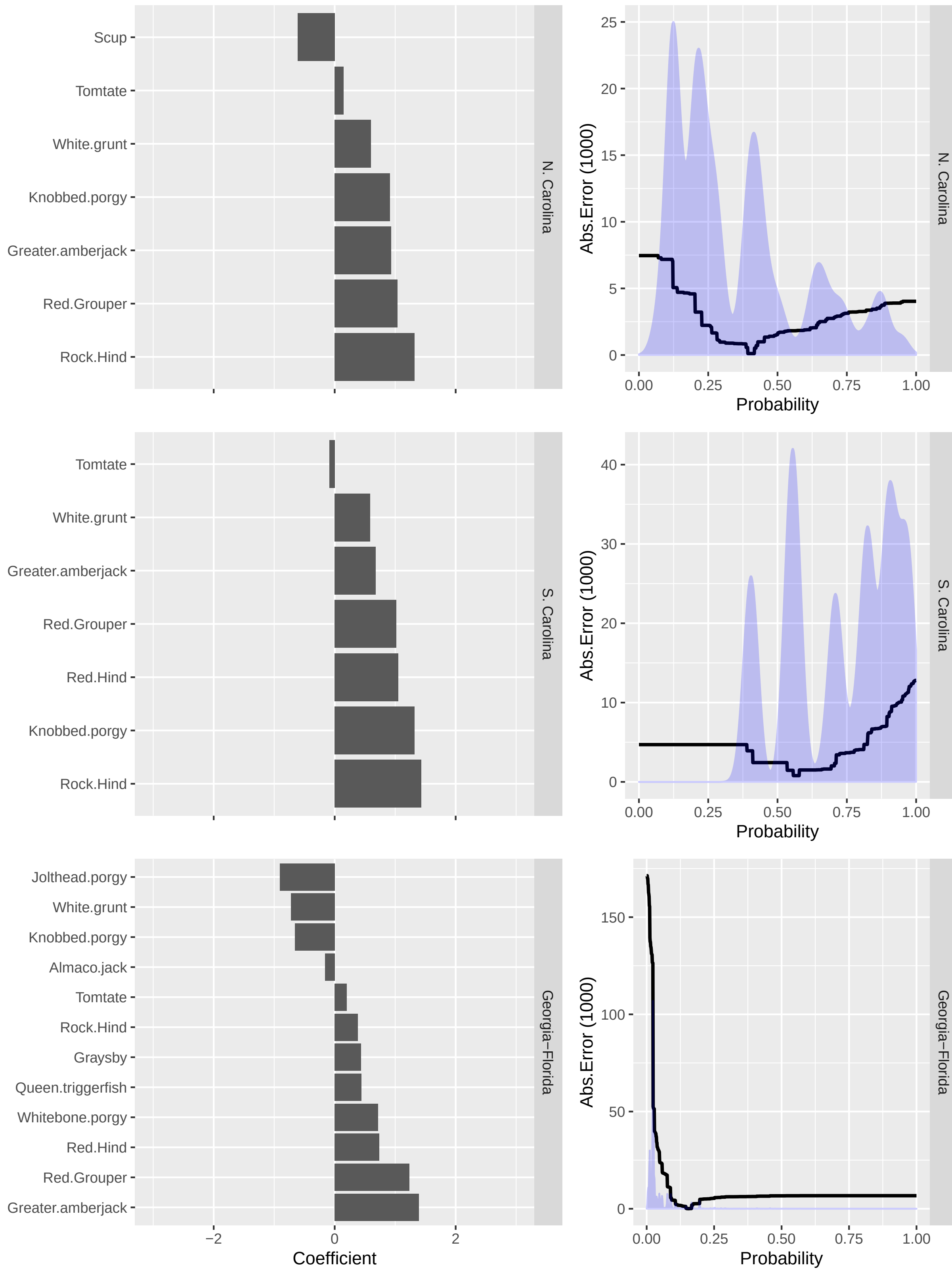


Figure 13: Estimates of species-specific regression coefficients used to predict each trip's probability of catching the focal species on the left panel. The right panel shows the absolute difference between observed and predicted number of positive trips across a range of probability cutoff values. .

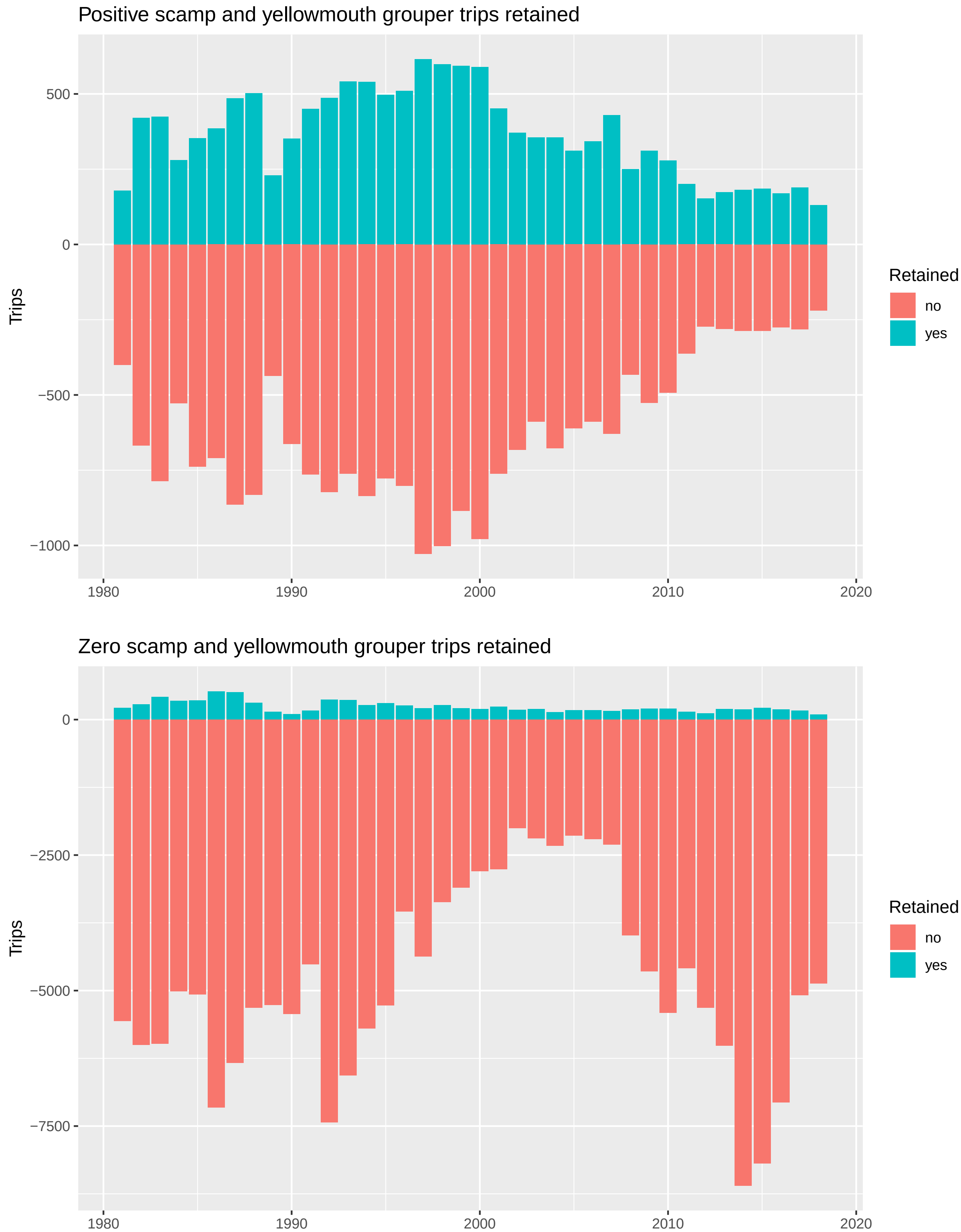


Figure 14: Positive and zero scamp and yellowmouth grouper trips retained after subsetting using Stephens and MacCall approach by year.

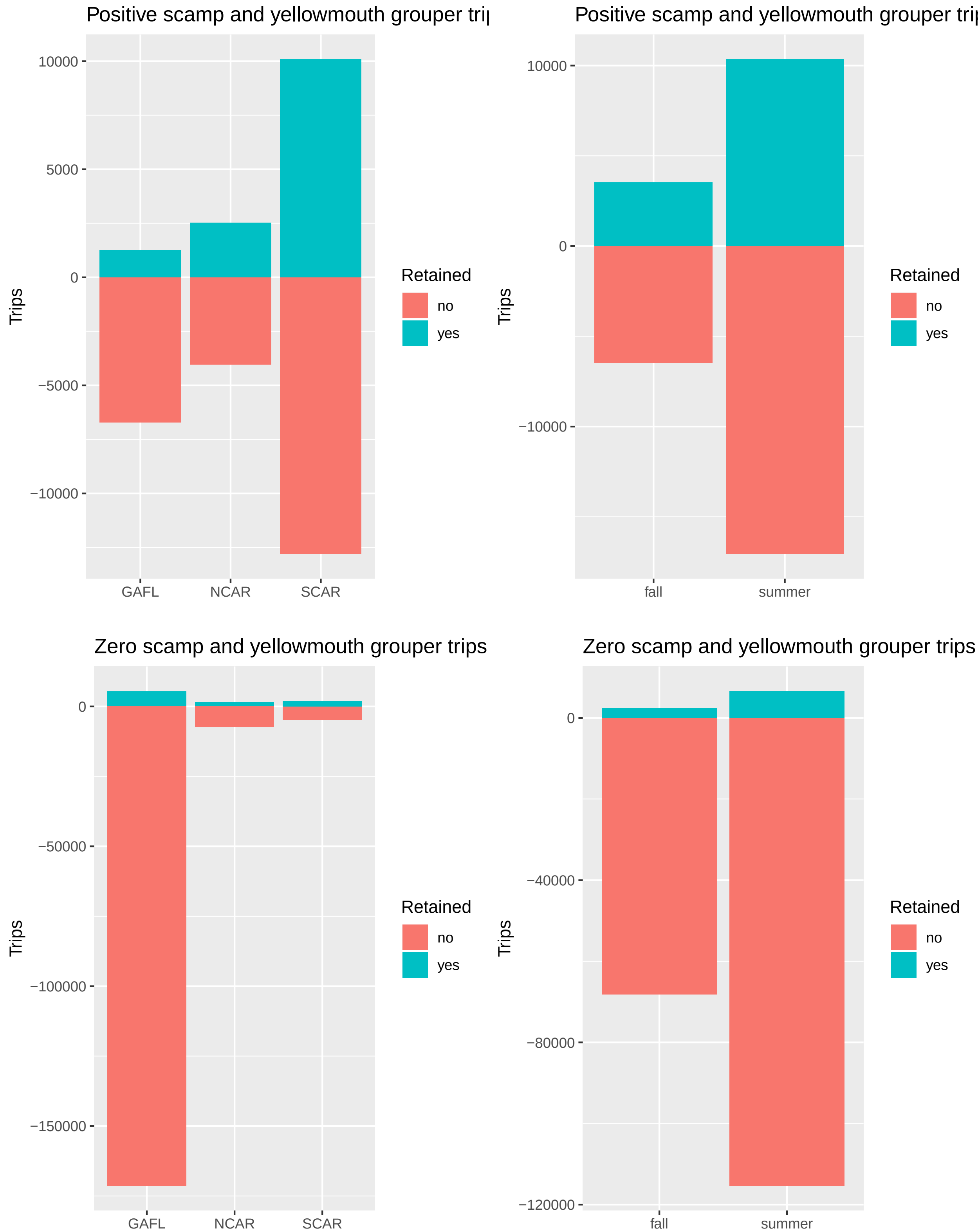


Figure 15: Positive and zero scamp and yellowmouth grouper trips retained after subsetting using Stephens and MacCall approach by area and season.

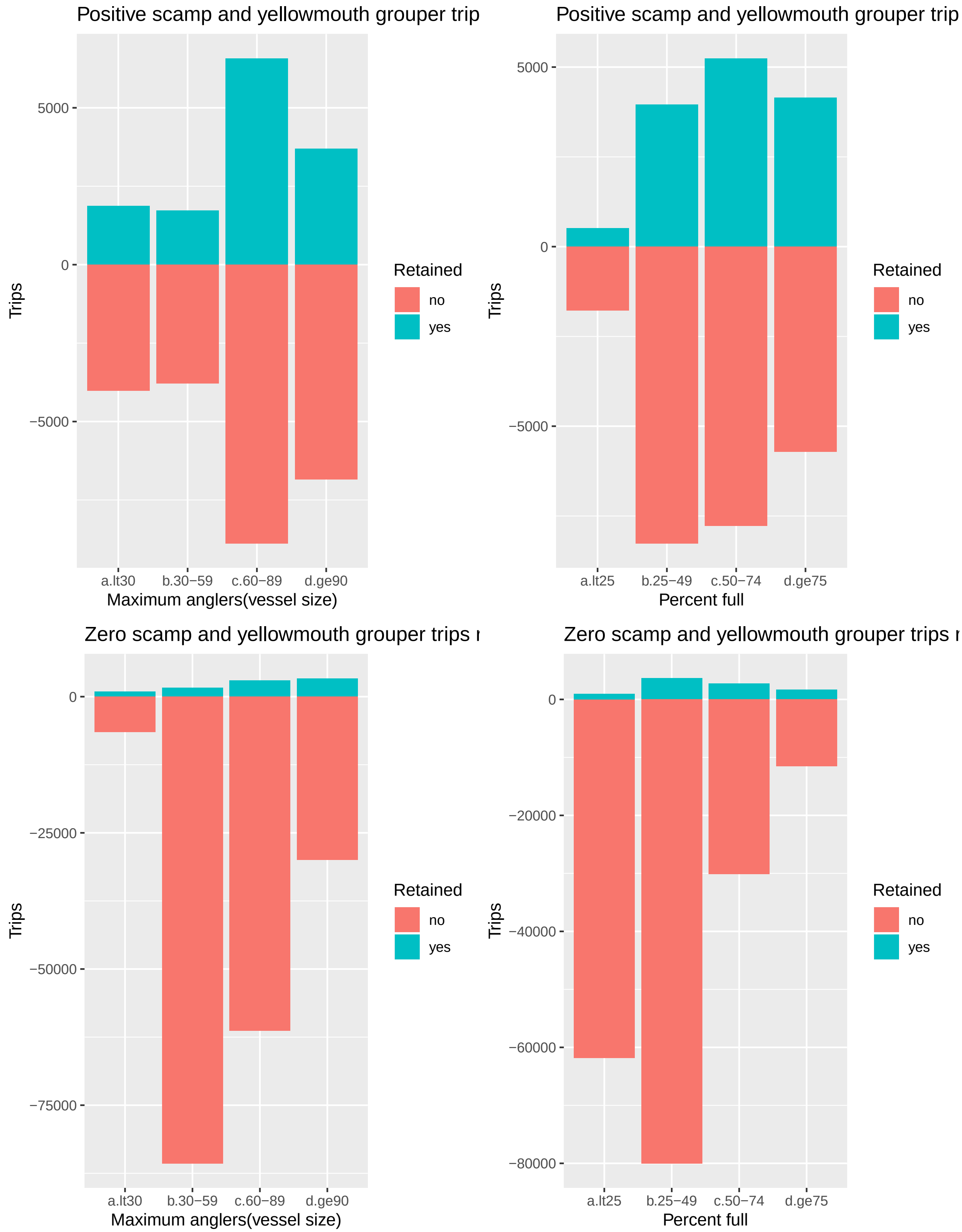


Figure 16: Positive and zero scamp and yellowmouth grouper trips retained after subsetting using Stephens and MacCall approach by factors for maximum anglers and percent full.

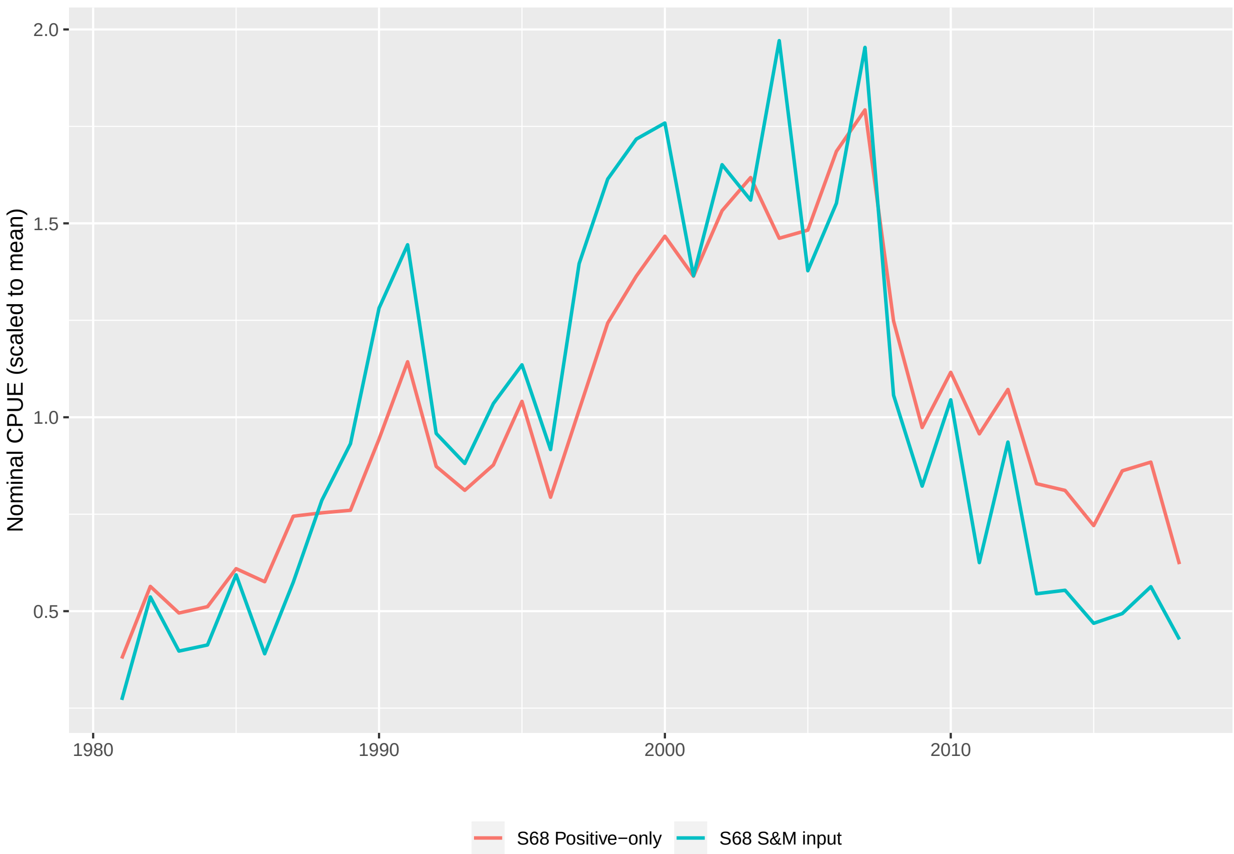


Figure 17: Nominal scamp and yellowmouth grouper cpue for raw data and subsetted trips.

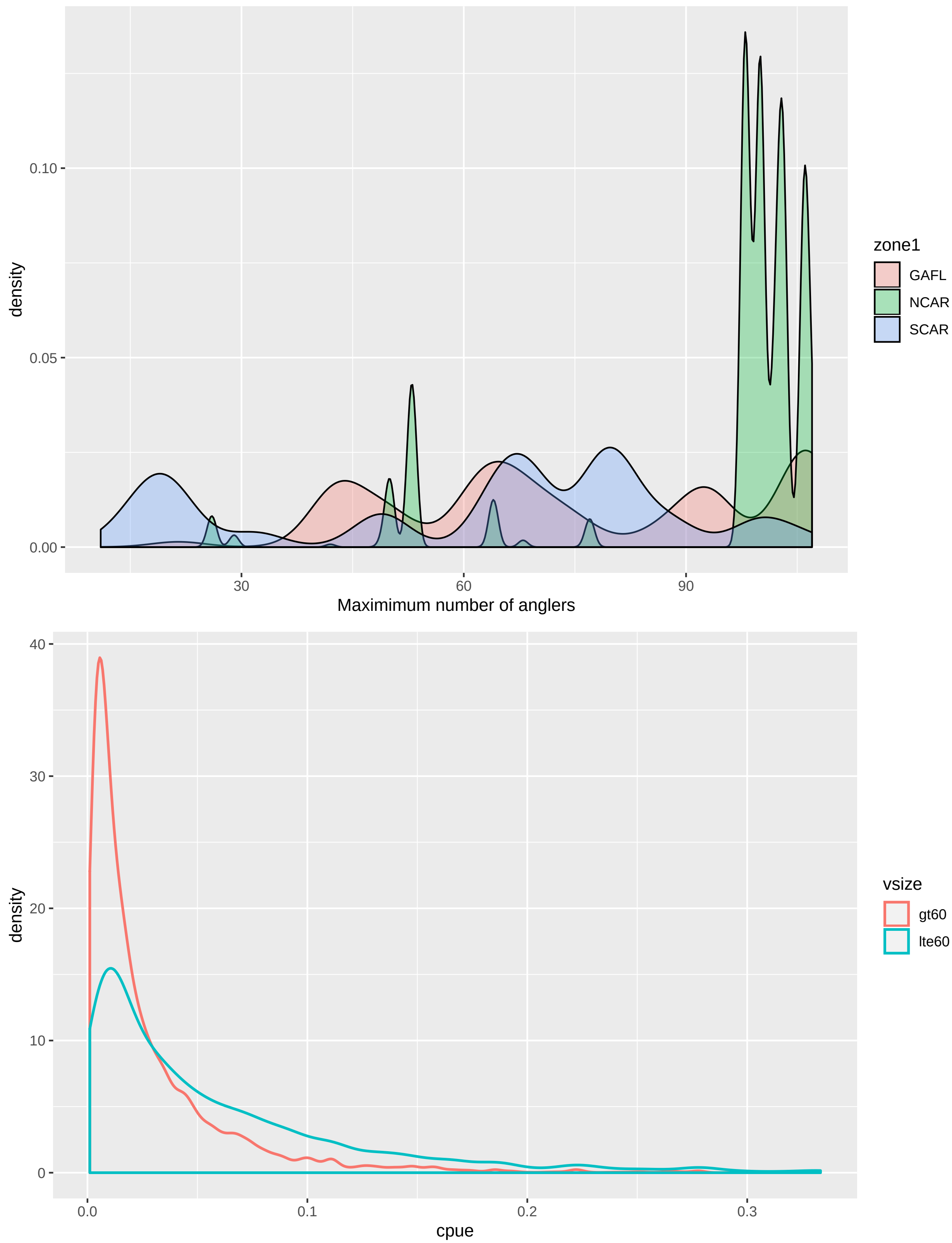
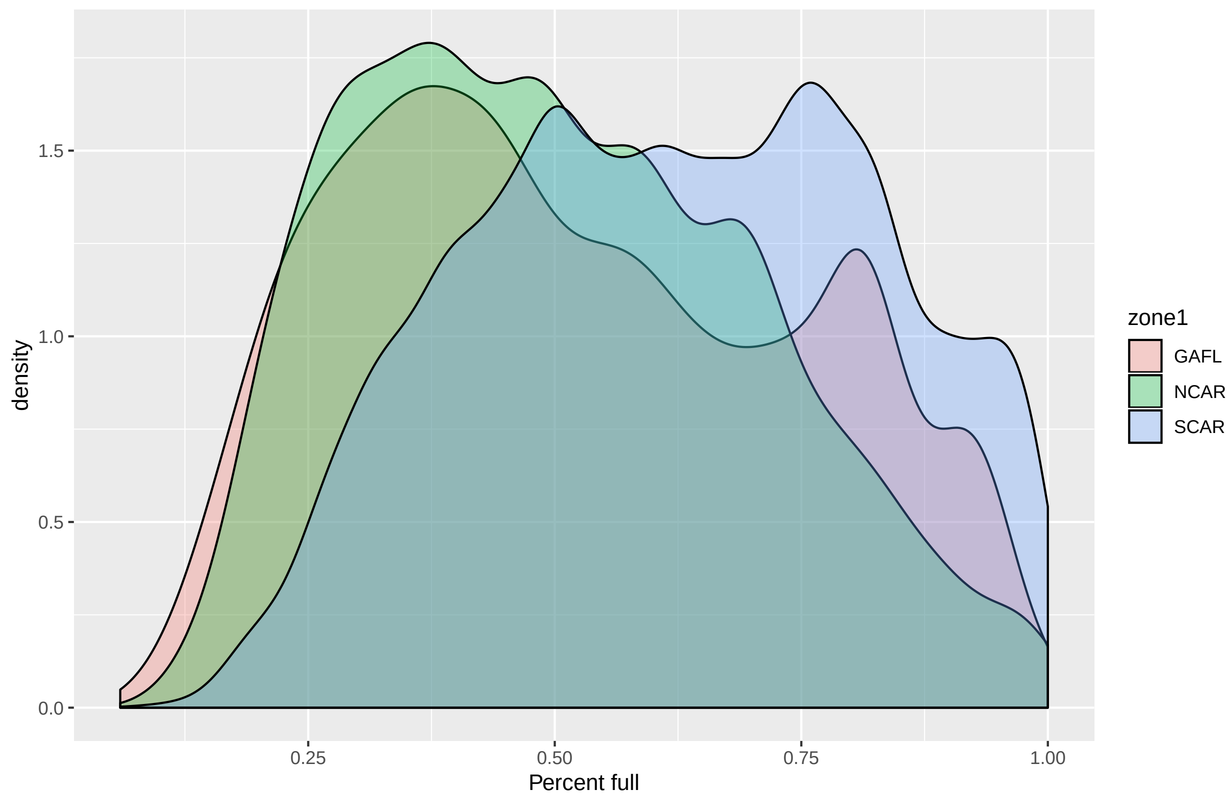


Figure 18: Density of maximum number of anglers across areas and cpue associated the factors for maximum anglers as a proxy for vessel size.



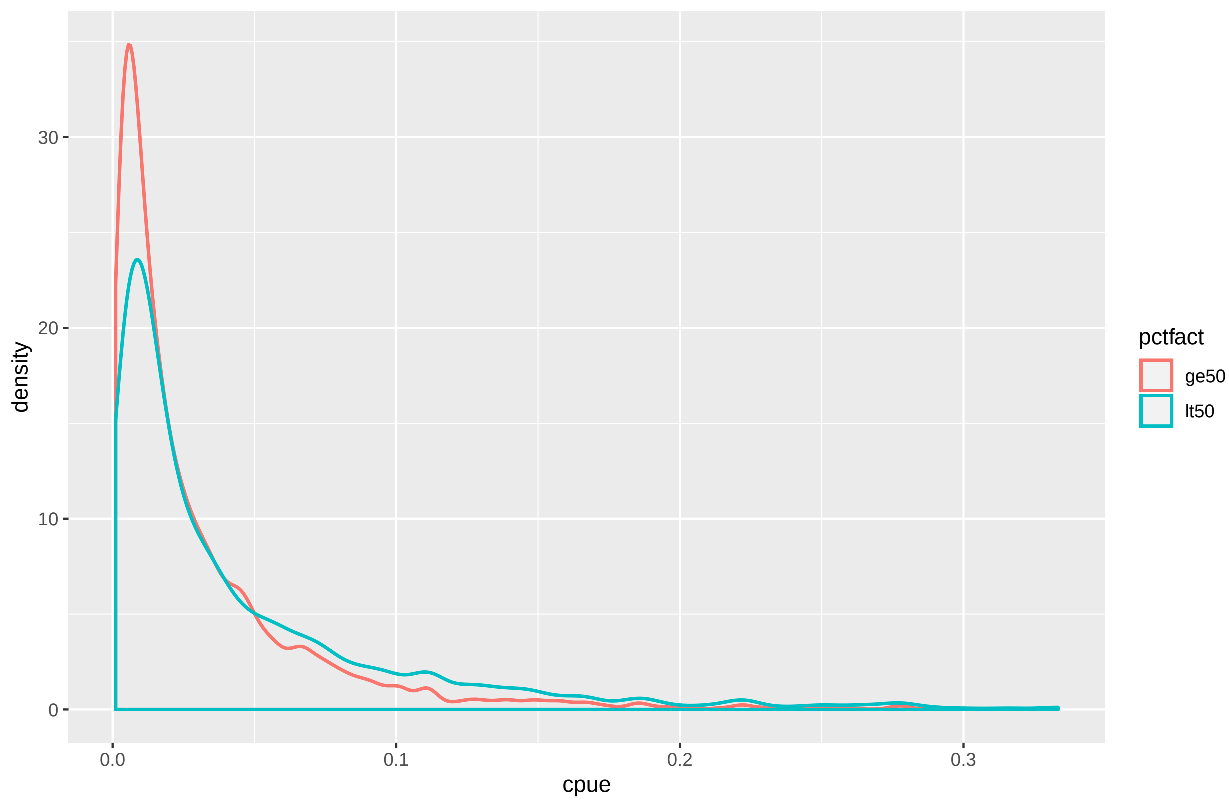


Figure 19: Density of percent full across areas and cpue associated the factors for percent full.

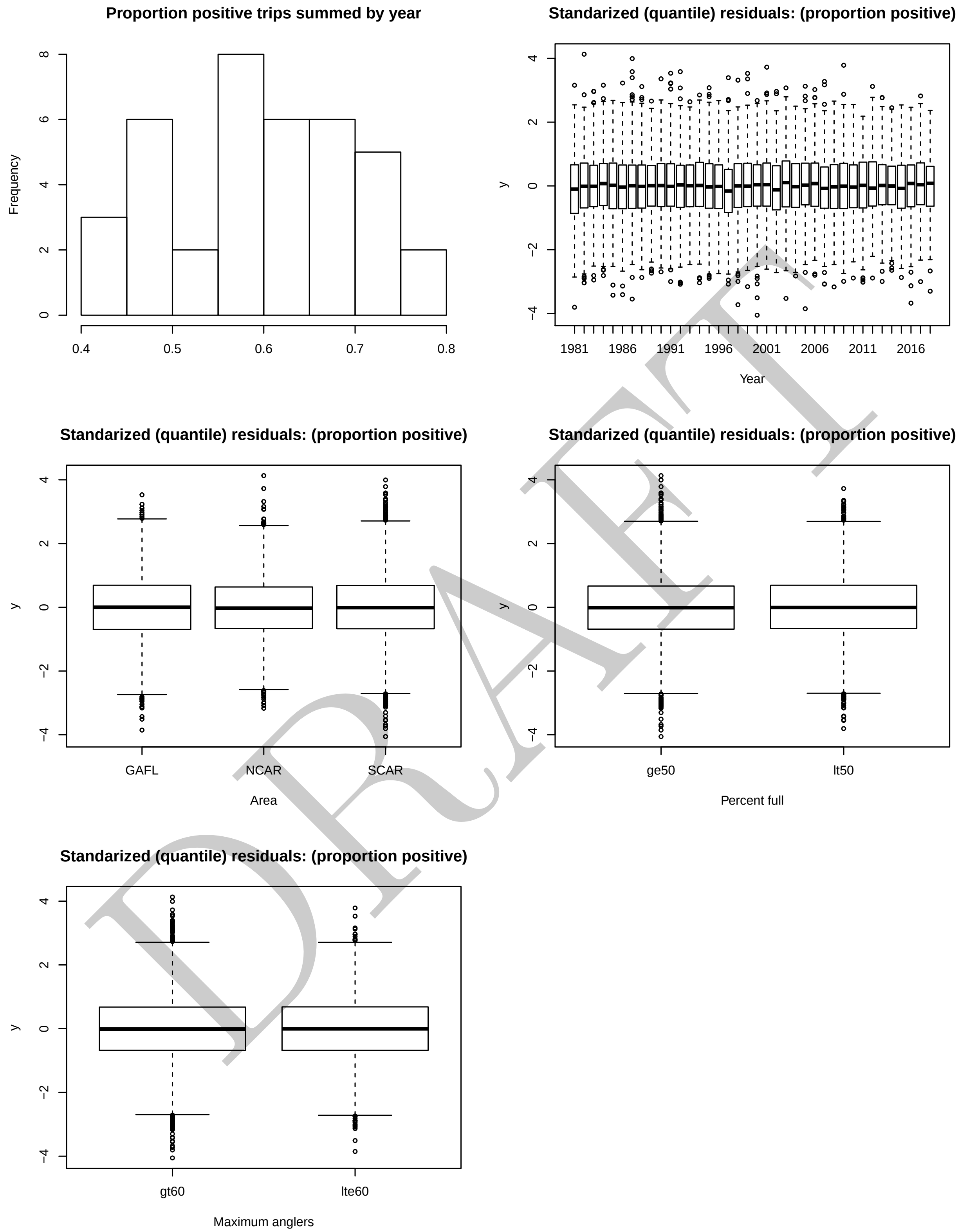


Figure 20: Diagnostics of Bernoulli submodel fits to positive versus zero CPUE data. Box and whisker plots give first, second (median) and third quartiles, as well as limbs that extend to approximately one interquartile range beyond the nearest quartile, and outliers (circles) beyond the limbs. Residuals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

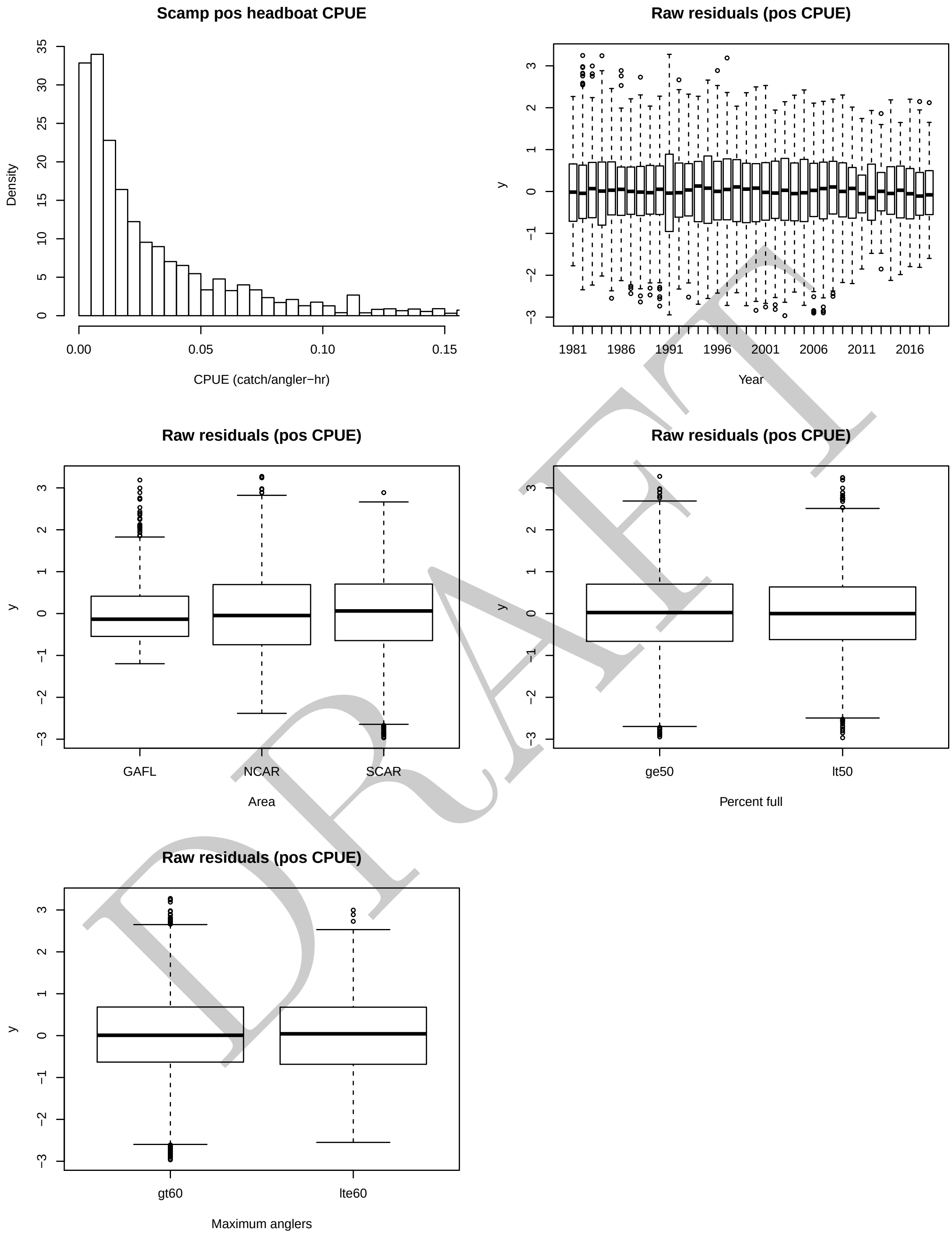
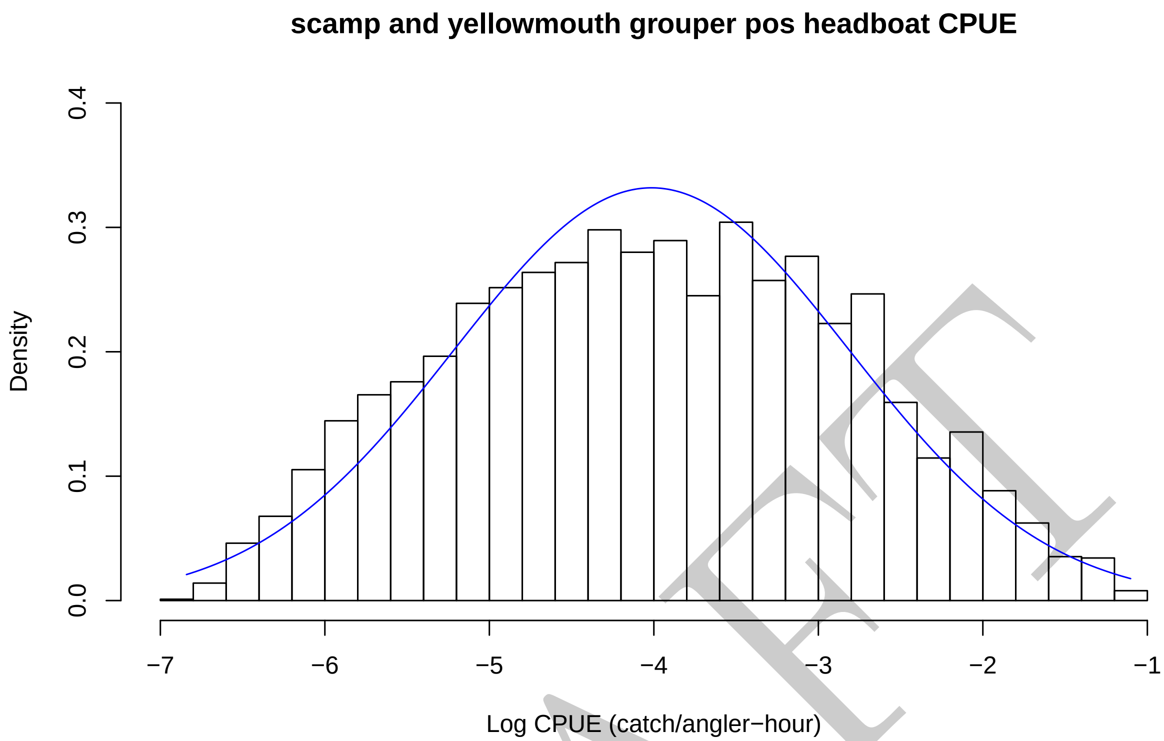


Figure 21: Diagnostics of lognormal submodel fits to positive CPUE data. Top left panel shows the distribution of positive cpue. Box and whisker plots give first, second (median) and third quartiles, as well as limbs that extend to approximately one interquartile range beyond the nearest quartile, and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



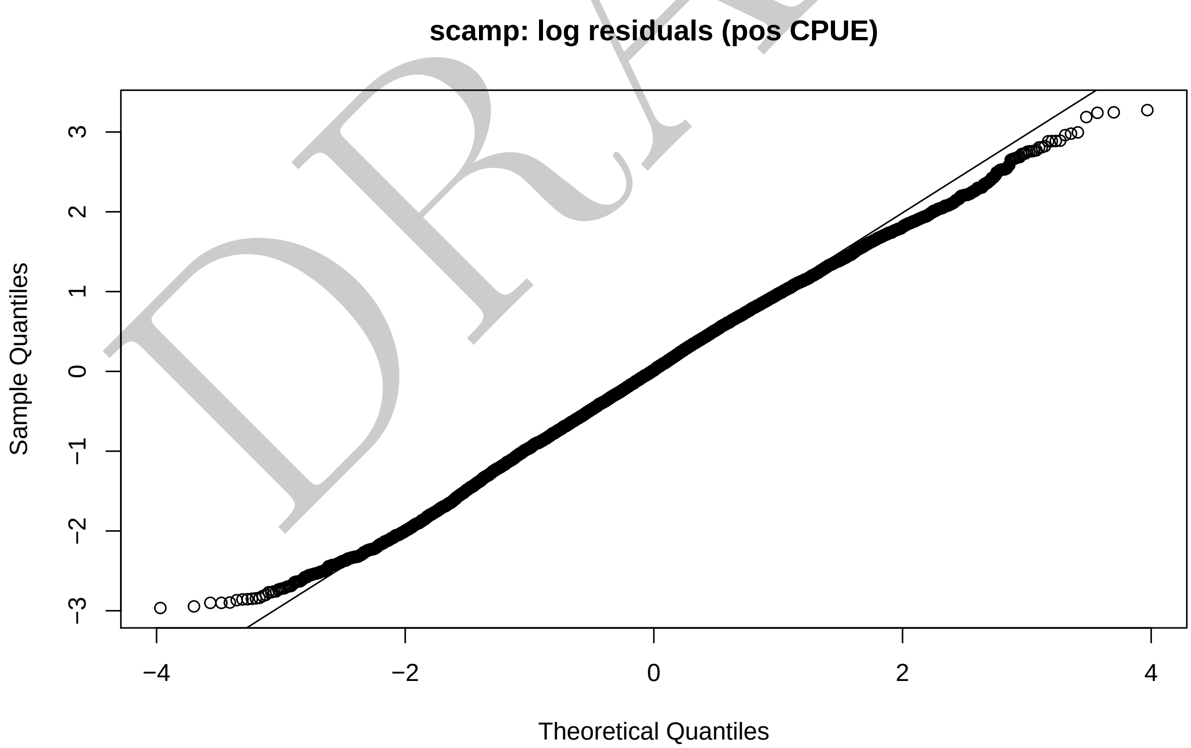


Figure 22: Histogram of empirical log CPUE, with the normal distribution (empirical mean and variance) overlaid. Quantile-quantile plot of residuals from the fitted lognormal submodel to the positive cpue cata.

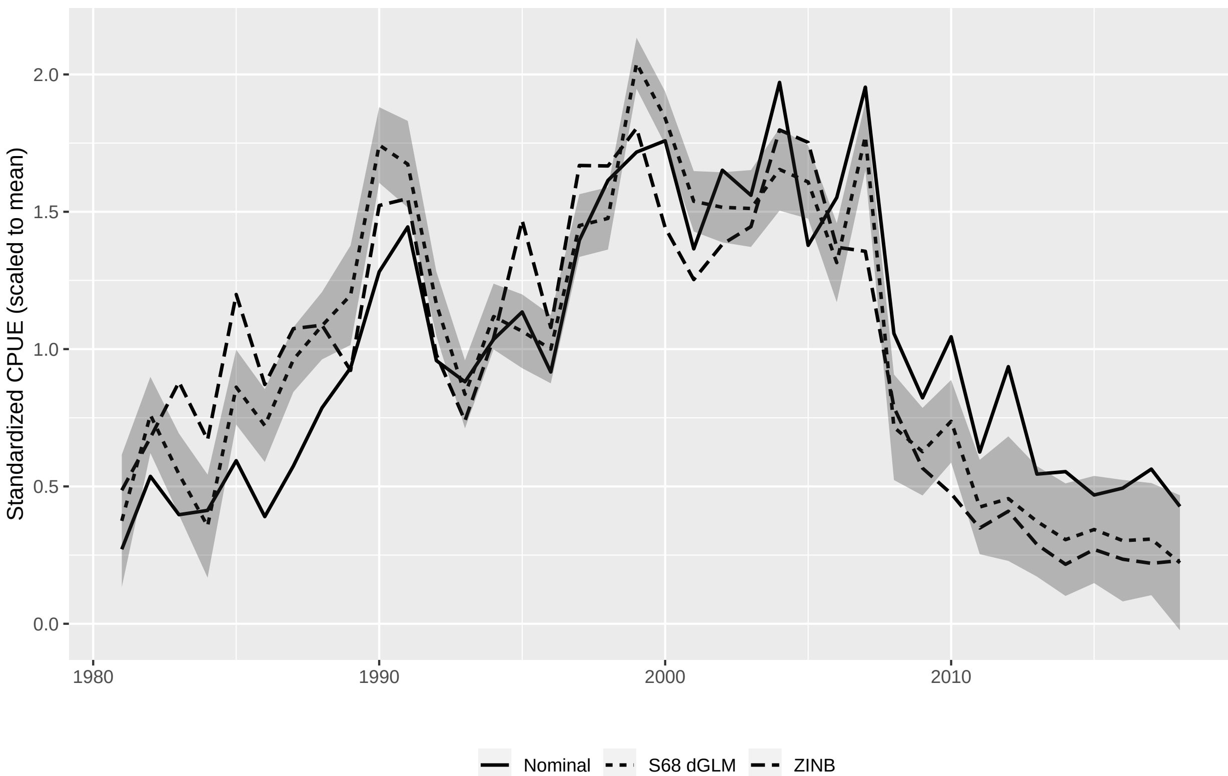


Figure 23: Standardized (dashed) with 95% confidence interval (shaded) and nominal index (solid) scamp and yellowmouth grouper catch rate from headboat logbooks.

Appendix

Results of generalized linear model with Bernoulli response to select species associations with scamp and yellowmouth grouper for the North Carolina.

```
##
## Call:  glm(formula = Scamp ~ Tomtate + White.grunt + Greater.amberjack +
##     Red.Grouper + Rock.Hind + Knobbed.porgy + Scup, family = "binomial",
##     data = n.sp.mat.trim)
##
## Coefficients:
##       (Intercept)            Tomtate        White.grunt
##           -1.9720             0.1476             0.5990
## Greater.amberjack        Red.Grouper          Rock.Hind
##            0.9369             1.0363             1.3218
##     Knobbed.porgy               Scup
##            0.9131            -0.6147
##
## Degrees of Freedom: 11495 Total (i.e. Null);  11488 Residual
## Null Deviance:       14900
## Residual Deviance: 12180     AIC: 12200
```

Results of generalized linear model with Bernoulli response to select species associations with scamp and yellowmouth grouper for the South Carolina.

```
##
## Call:  glm(formula = Scamp ~ Tomtate + White.grunt + Greater.amberjack +
##     Red.Grouper + Rock.Hind + Knobbed.porgy + Red.Hind, family = "binomial",
##     data = m.sp.mat.trim)
##
## Coefficients:
##       (Intercept)            Tomtate        White.grunt
##          -0.36084           -0.08767            0.58734
## Greater.amberjack        Red.Grouper          Rock.Hind
##           0.67722            1.02112            1.42908
##     Knobbed.porgy           Red.Hind
##           1.32242            1.04903
##
## Degrees of Freedom: 17499 Total (i.e. Null);  17492 Residual
## Null Deviance:       20370
## Residual Deviance: 16810     AIC: 16830
```

Results of generalized linear model with Bernoulli response to select species associations with scamp and yellowmouth grouper for the Georgia-Florida.

```
##
## Call:  glm(formula = Scamp ~ Tomtate + White.grunt + Whitebone.porgy +
##     Greater.amberjack + Red.Grouper + Rock.Hind + Knobbed.porgy +
##     Red.Hind + Queen.triggerfish + Jolthead.porgy + Graysby +
##     Almaco.jack, family = "binomial", data = s.sp.mat.trim)
##
## Coefficients:
##       (Intercept)            Tomtate        White.grunt
##           -3.7214             0.1996            -0.7237
##   Whitebone.porgy  Greater.amberjack        Red.Grouper
##            0.7176             1.3940             1.2373
##         Rock.Hind      Knobbed.porgy           Red.Hind
```

```
##           0.3808            -0.6587             0.7346
## Queen.triggerfish     Jolthead.porgy            Graysby
##           0.4442            -0.9083             0.4350
##       Almaco.jack
##          -0.1618
##
## Degrees of Freedom: 178060 Total (i.e. Null);  178048 Residual
## Null Deviance:       57170
## Residual Deviance: 51160     AIC: 51190
```

Results of lognormal glm to determine factors.

```
##
## Call:  glm(formula = log(cpue) ~ year + zone1 + vsize + pctfact, family = gaussian(link = "identity")
##     data = dat.pos)
##
## Coefficients:
## (Intercept)     year1982     year1983     year1984     year1985
##  -6.5616884    0.3142673    0.2021760   -0.0345187    0.4967259
##    year1986     year1987     year1988     year1989     year1990
##   0.3297060    0.6758017    0.6515659    0.7820054    0.9204437
##    year1991     year1992     year1993     year1994     year1995
##   0.9940820    0.7545781    0.6095546    0.7406975    0.8374805
##    year1996     year1997     year1998     year1999     year2000
##   0.6669491    0.8172514    0.9833658    1.0399913    0.9224135
##    year2001     year2002     year2003     year2004     year2005
##   0.8300869    0.8759458    1.0531158    1.1204793    0.8773249
##    year2006     year2007     year2008     year2009     year2010
##   0.9040501    1.0432749    0.5352914    0.2822455    0.4597247
##    year2011     year2012     year2013     year2014     year2015
##   0.0008962    0.3464014    0.2406264    0.1035749    0.1048681
##    year2016     year2017     year2018    zone1NCAR    zone1SCAR
##  -0.0080540    0.0098040   -0.2813736    1.0121188    1.8616929
##  vsizelte60  pctfactlt50
##   0.6637927    0.5031117
##
## Degrees of Freedom: 13873 Total (i.e. Null);  13832 Residual
## Null Deviance:       20060
## Residual Deviance: 12680     AIC: 38210
```

Results of gamma glm to determine factors.

```
##
## Call:  glm(formula = cpue ~ year + zone1 + vsize + pctfact, family = Gamma(link = "log"),
##     data = dat.pos)
##
## Coefficients:
## (Intercept)     year1982     year1983     year1984     year1985
##   -6.183622     0.416049     0.162067     0.048431     0.415205
##    year1986     year1987     year1988     year1989     year1990
##    0.263258     0.550643     0.548028     0.655189     0.848887
##    year1991     year1992     year1993     year1994     year1995
##    1.253820     0.766398     0.521321     0.674017     0.885368
##    year1996     year1997     year1998     year1999     year2000
##    0.623614     0.825243     0.910294     0.972940     0.817850
##    year2001     year2002     year2003     year2004     year2005
```

```
##    0.762330     0.808664     1.024983     1.142518     0.858629
##    year2006     year2007     year2008     year2009     year2010
##    0.846112     1.004425     0.479494     0.163280     0.322197
##    year2011     year2012     year2013     year2014     year2015
##   -0.188584     0.243010     0.006165    -0.052942    -0.090897
##    year2016     year2017     year2018    zone1NCAR    zone1SCAR
##   -0.122632    -0.116024    -0.475389     1.180960     1.968256
##  vsizelte60  pctfactlt50
##    0.657799     0.489639
##
## Degrees of Freedom: 13873 Total (i.e. Null);  13832 Residual
## Null Deviance:       18720
## Residual Deviance: 11940     AIC: -72060
```

Results of binomial glm to determine factors.

```
##
## Call:  glm(formula = cpue ~ year + zone1 + vsize + pctfact, family = "binomial",
##     data = dat.bin)
##
## Coefficients:
## (Intercept)     year1982     year1983     year1984     year1985
##    -1.69626      0.72395      0.28724     -0.02812      0.60143
##    year1986     year1987     year1988     year1989     year1990
##     0.58060      0.46378      0.76523      0.69252      1.30672
##    year1991     year1992     year1993     year1994     year1995
##     0.98247      0.69390      0.32453      0.63738      0.35153
##    year1996     year1997     year1998     year1999     year2000
##     0.55817      1.07052      0.71137      1.43239      1.48343
##    year2001     year2002     year2003     year2004     year2005
##     1.20105      1.03336      0.61406      0.66140      1.19349
##    year2006     year2007     year2008     year2009     year2010
##     0.63371      1.00758      0.18368      0.39722      0.37009
##    year2011     year2012     year2013     year2014     year2015
##     0.20662     -0.22929     -0.36544     -0.44819     -0.29001
##    year2016     year2017     year2018    zone1NCAR    zone1SCAR
##    -0.30846     -0.30776     -0.35984      1.88576      3.31106
##  vsizelte60  pctfactlt50
##    -0.62522     -0.52292
##
## Degrees of Freedom: 22868 Total (i.e. Null);  22827 Residual
## Null Deviance:       30650
## Residual Deviance: 21310     AIC: 21400
```

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 + zone1 + vsize + pctfact"
##
## $positive.formula
## [1] "Formula for gaussian GLM: log(cpue) ~ year + zone1 + vsize + pctfact"
##
## $deltaGLM.index
```

```
##             index jackknife
## 1981 0.003849842        NA
## 1982 0.007812482        NA
## 1983 0.005594270        NA
## 1984 0.003653434        NA
## 1985 0.008852774        NA
## 1986 0.007415489        NA
## 1987 0.009882811        NA
## 1988 0.011151066        NA
## 1989 0.012293594        NA
## 1990 0.017912385        NA
## 1991 0.017195101        NA
## 1992 0.011968631        NA
## 1993 0.008584218        NA
## 1994 0.011495417        NA
## 1995 0.010942945        NA
## 1996 0.010275656        NA
## 1997 0.014898729        NA
## 1998 0.015166568        NA
## 1999 0.020971511        NA
## 2000 0.018918387        NA
## 2001 0.015806781        NA
## 2002 0.015581130        NA
## 2003 0.015536887        NA
## 2004 0.016997584        NA
## 2005 0.016528711        NA
## 2006 0.013511710        NA
## 2007 0.018238838        NA
## 2008 0.007354443        NA
## 2009 0.006437707        NA
## 2010 0.007576395        NA
## 2011 0.004368104        NA
## 2012 0.004681808        NA
## 2013 0.003830338        NA
## 2014 0.003146582        NA
## 2015 0.003526417        NA
## 2016 0.003109577        NA
## 2017 0.003167166        NA
## 2018 0.002281732        NA
##
## $pos.effects
## $pos.effects[[1]]
##        GAFL        NCAR        SCAR
## 0.007000656 0.019261776 0.045046562
##
## $pos.effects[[2]]
##       gt60      lte60
## 0.01309257 0.02542765
##
## $pos.effects[[3]]
##       ge50       lt50
## 0.01418784 0.02346469
##
##
```

```
## $bin.effects
## $bin.effects[[1]]
##      GAFL      NCAR      SCAR
## 0.1449528 0.5277242 0.8229272
##
## $bin.effects[[2]]
##      gt60     lte60
## 0.5671259 0.4121489
##
## $bin.effects[[3]]
##      ge50      lt50
## 0.5545284 0.4245949
##
##
## $data.filter
## [1] "Data filter threshold set at 2 positive observations."
##
## $levels.deleted.by.filter
## $levels.deleted.by.filter$year
## [1] NA
##
## $levels.deleted.by.filter$zone1
## [1] NA
##
## $levels.deleted.by.filter$vsize
## [1] NA
##
## $levels.deleted.by.filter$pctfact
## [1] NA
##
##
## $aic
##                         [,1]
## AIC.binomial   2.139806e+04
## AIC.lognormal -7.317014e+04
## sigma.mle      9.561671e-01
```

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 + zone1 + vsize + pctfact"
##
## $positive.formula
## [1] "Formula for Gamma GLM: cpue ~ year + zone1 + vsize + pctfact"
##
## $deltaGLM.index
##            index jackknife
## 1981 0.010460342        NA
## 1982 0.015857460        NA
## 1983 0.012300722        NA
## 1984 0.010979416        NA
## 1985 0.015844083        NA
```

```
## 1986 0.013610611         NA
## 1987 0.018142075         NA
## 1988 0.018094699         NA
## 1989 0.020141463         NA
## 1990 0.024446279         NA
## 1991 0.036649934         NA
## 1992 0.022510672         NA
## 1993 0.017617839         NA
## 1994 0.020524276         NA
## 1995 0.025354568         NA
## 1996 0.019515419         NA
## 1997 0.023875056         NA
## 1998 0.025994501         NA
## 1999 0.027675056         NA
## 2000 0.023699197         NA
## 2001 0.022419277         NA
## 2002 0.023482497         NA
## 2003 0.029153488         NA
## 2004 0.032789528         NA
## 2005 0.024685609         NA
## 2006 0.024378549         NA
## 2007 0.028560264         NA
## 2008 0.016896146         NA
## 2009 0.012315658         NA
## 2010 0.014436916         NA
## 2011 0.008662537         NA
## 2012 0.013337784         NA
## 2013 0.010525032         NA
## 2014 0.009920955         NA
## 2015 0.009551463         NA
## 2016 0.009253110         NA
## 2017 0.009314453         NA
## 2018 0.006502600         NA
##
## $pos.effects
## $pos.effects[[1]]
##        GAFL        NCAR        SCAR
## 0.006000869 0.019547825 0.042955316
##
## $pos.effects[[2]]
##       gt60      lte60
## 0.01233873 0.02382041
##
## $pos.effects[[3]]
##       ge50       lt50
## 0.01342104 0.02189947
##
##
## $bin.effects
## $bin.effects[[1]]
## GAFL NCAR SCAR
##    1    1    1
##
## $bin.effects[[2]]
```

```
##  gt60 lte60
##     1     1
##
## $bin.effects[[3]]
## ge50 lt50
##    1    1
##
##
## $data.filter
## [1] "Data filter threshold set at 2 positive observations."
##
## $levels.deleted.by.filter
## $levels.deleted.by.filter$year
## [1] NA
##
## $levels.deleted.by.filter$zone1
## [1] NA
##
## $levels.deleted.by.filter$vsize
## [1] NA
##
## $levels.deleted.by.filter$pctfact
## [1] NA
##
##
## $aic
##                        [,1]
## AIC.binomial     84.000000
## AIC.gamma    -72168.786280
## shape.mle         1.303313
```

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