Standardized Catch Rates of Yellowtail Snapper (*Ocyurus chrysurus*) from the U.S. Headboat Fishery in Southeast Florida and the Florida Keys, 1981-2017

Liz Herdter and Shanae Allen

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Standardized Catch Rates of Yellowtail Snapper (*Ocyurus chrysurus*) from the U.S. Headboat Fishery in Southeast Florida and the Florida Keys, 1981-2017.

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Florida Fish and Wildlife Research Institute

SEDAR64

Introduction

Headboats are vessels with a capacity for carrying six or more recreational anglers. The Southeast Region Headboat Survey (SRHS), administered by the SEFSC Laboratory in Beaufort, NC, has operated along the east coast since 1972 and in the Gulf of Mexico since 1986. Catch and effort records from every trip are provided using self-reported logbooks and biological samples are collected from dockside intercepts by port agents. Logbooks are mandatory and required for permit renewal. Each logbook form collects information about number and weight of each species caught, total number of anglers, location fished, trip duration, and, starting in 2004, number of species released and their release condition (alive, dead). Vessels are chosen by port agents in a systematic rotation with the flexibility to sample vessels opportunistically in order to sample all vessels equally each month. Port agents collect information on length and weight of a subsample of fish as well as biological samples (e.g. otoliths, gonads, stomachs) for use in life history studies. The catch and effort information from the logbooks for each trip were used to construct indices of Yellowtail Snapper catch rates in the Florida Keys and Southeast Florida. Generalized linear mixed effects models and a delta-lognormal approach were used to generate the indices.

Methods

Area Descriptions

Three standardized headboat catch rate indices were generated.

1. A catch rate index for southeast Florida (SE_FL) – headboat area 11
2. A catch rate index for the Florida Keys (FL_Keys) – headboat areas 12 and 17
3. A catch rate index for combined Florida Keys and Southeast Florida

To note, areas 12 (Keys) and 17 (Dry Tortugas, vessels docked in the Keys) were consolidated to area 12 starting in 2013. The third index, a single area catch rate, was developed by joining catch records from areas 11, 12, and 17. The standardized index was generated by adding the trip catches together only after all forthcoming filtering and clustering steps had been applied to each area-specific dataset.

New Variables

Additional features (variables) were created using existing variables within the dataset. The new features were *season*, *angler category*, *time of day*, and *trip identification number*. Seasons were defined as winter (January through March), spring (April through June), summer (July through September) and fall (October through December). The numbers of anglers were grouped into four categories based on quantiles such that records were evenly distributed within each category. The time of day variable was derived from the existing *trip* variable. Time of day was defined as night (for ½ day night trips, ½ day night (second trips), ¾ day night and overnight trips) and day for all remaining trip types. Preliminary data filtering was performed prior to any steps described below; please refer to the SEDAR 64 Southeast Region Headboat Survey overview working paper (SEDAR64-DW08) for a discussion of the methods.

Data Filtering

1. Trips were removed if they did not occur between the years 1981 to 2017 and within areas 11, 12, and 17 (resulting in 233,593 trips).
2. Trips were removed if the associated vessel ID made fewer than 11 trips (corresponding to the 5th percentile) over the entire duration of the timeframe (resulting in 233,559 trips).

Furthermore, only trips that were directly or indirectly targeting Yellowtail Snapper were retained in the analysis. Trips that targeted Yellowtail Snapper were identified as those that retained Yellowtail Snapper or any other species that were shown, via statistical methodology described below, to co-occur with Yellowtail Snapper even if Yellowtail Snapper was not retained on the specific trip.

Species Clustering

The suite of co-occurring species (hereafter, species clusters) was identified using hierarchical clustering analysis described by Shertzer and Williams (2008). Hierarchical cluster analysis was performed with average linkage on the Bray-Curtis similarity measure calculated on presence/absence of retained catch data for each species (i.e. total retained species per trip). The number of clusters against the average distance between clusters was visualized and a piecewise regression with one breakpoint was used to determine the inflection point of the plot (Figures 1 and 2). The inflection point was chosen as that with the lowest residual mean square error.

Twenty-one clusters were identified for SE_FL using this method with Yellowtail Snapper clustering (co-occurring with) with 20 species including Almaco Jack, Bigeye, Blue Runner, Dolphin, Graysby, Gray Snapper, Gray Triggerfish, Jolthead Porgy, King Mackerel, Lane Snapper, Little Head Porgy, Little Tunny, Mutton Snapper, Queen Triggerfish, Red Grouper, Remora, Sand Tilefish, Squirrelfish, Vermillion Snapper, and White Grunt (Figure 3).

Thirteen clusters were identified for the Florida Keys area with Yellowtail Snapper clustering (co-occurring with) 23 species including Bigeye, Black Grouper, Blue Runner, Blue Striped Grunt, Cero, Doctorfish, Gag Grouper, Graysby, Gray Snapper, Gray Triggerfish, Hogfish, Jolthead Porgy, Knobbed Porgy, Lane Snapper, Little Head Porgy, Mutton Snapper, Porkfish, Puddingwife Wrasse, Red Grouper, Schoolmaster Snapper, Spotted Moray, Squirrelfish, and White Grunt (Figure 4).

After removing all trips that did not capture at least one of the species in the clusters, 147,504 trips remained for SE_FL and 79,558 trips in the Florida Keys. Importantly, the clustering algorithm was not run for the combined single area trip data. Rather, the catch rate index produced for the single area model was developed by combining the trip data selected from the two areas.

Standardization

CPUE, the number of Yellowtail Snapper retained per trip, was modeled using the delta-glm approach (Dick 2004; Lo et al. 1992; Maunder and Punt 2004). This approach calculates an index as the product of the indices from binomial (probability of retaining the selected species) and positive (trips that retained at least one Yellowtail Snapper) sub-models. Positive CPUE of Yellowtail Snapper was modeled as a lognormal distribution.

Five explanatory variables were evaluated for both the positive and binomial models. These included:

Year – factor with levels 1981 to 2017
Season – factor with four levels (winter, spring, summer, fall)
Angler category – factor with four levels
Hours fished – factor with three levels (5, 7, 10+)
Time of day – factor with two levels (night time (0), day time (1))

Some studies have shown that the experience level of a vessel captain may affect catch rates of species and could be used as an explanatory variable in models examining catch rates. However, the SRHS does not have information on vessel captains as part of its catch records, and only coding for vessel identity is available for use. Because a vessel may report many trips over a year but not always have the same captain for all those trips or any trips in the following years, vessel was included as a random effect in the submodels.

A fixed effects model was fit using generalized least squares (GLS) and restricted maximum likelihood estimation (REML) and compared to a linear mixed effects model (LME) also fit with REML that included a vessel as a random effect. An ANOVA was used to compare the GLS and LME models (Zuur et al. 2009). For all areas, the likelihood ratio test indicated that the mixed effects model with the random vessel effect was significantly better. Therefore, a random vessel effect was included in the positive and binomial sub-models for each region. The R package and function **lmerTest::lmer** was used to produce the positive sub-model and the **lme4::glmer** package and function was used to produce the binomial sub-model for each region.
For both the positive and binomial sub-models, explanatory variables were selected using stepwise forward selection based on AIC. The goal of stepwise selection is to produce a model (overall model) that contains the optimal combination of explanatory variables (which explain a significant amount of variation in the response variable) while also being most parsimonious. Stepwise forward selection starts with a null model that is specified by the practitioner. At the first step, each covariate is added to a null model so that there are n unique models (n = number of covariates). The lowest AIC of the unique models is compared to that of the null model; if it is

lower than the AIC of the null model by at least two points the unique model becomes the new base model (Burnham and Anderson 2002, p. 70). This process repeats itself until no additional covariate reduces the AIC. Finally, each variable was evaluated in terms of its total percent reduction in deviance (in relation to the null model). If the variables did not reduce deviance by at least 0.5% they were excluded from the final model.

Index Generation and Evaluation

Monte Carlo simulations (n=10,000) were used to generate an expected distribution around the least squared mean estimates (year factor) for the proportion data (binomial) and positive data (positive model). The resulting simulants were transformed back to response space using the inverse logit function and exponentiation, respectively. Finally the estimates from the distributions were multiplied together to obtain annual distributions of standardized catch rates. From these simulated distributions, standard deviation, coefficients of variations, and quantiles were calculated.

The **DHARMa** package in R (Hartig 2019) was used to evaluate residuals of the positive and binomial mixed effects model. The DHARMa package produces quantile residuals by simulating synthetic datasets from the fitted model for each observation. It then calculates the cumulative distribution of simulated values[1] for each observed value and returns the corresponding quantile value within which the observation falls- thus, quantile residual (Figure 5). A residual value of 0.5 means that half of the simulated data are higher than the observed value and half are lower. A value of 0.99 would mean that nearly all simulated data are lower than the observed value (Hartig 2019). The choice for producing quantile residuals plots is motivated by the fact that "misspecifications in generalized linear mixed effects models cannot reliably be diagnosed with standard residual plots". Frequently, standard residual plots for generalized mixed models would indicate issues such as non-normality or heteroscedasticity even for a correctly specified model (Hartig 2019).

Results & Discussion

Nominal catch rates were highest in the FL_Keys area and were generally consistent across seasons in both areas indicating no likely seasonality in catch rates (Figures 6, 7, 8). Nominal catch rate in both areas was highest for the 10+ hours fished category as well as for the highest angler category (Figures 6, 7, 8). There is a year*time of day interaction in both areas with catch rates being higher during the day time in the early part of the time series. Starting in 1998 nominal catch rates during the night time in both areas were higher than those during the day (Figures 6, 7, 8) even though the proportion of nighttime trips declined (Tables 10 and 12) which may suggest that higher nighttime catch rates may be due to increasing nighttime catches. We did not account for a year*time of day interaction but suggest that the index should be calculated for daytime-only trips if the entire time period is used in the assessment model.

[1] Simulated observations describes all possible values (and their probability) at the specific predictor combination of the observed value given that the model is correctly specified (Hartig 2019).

The final positive and binomial sub-models were:

<u>SE_FL</u>

Pos: log(retained) = year + timeofday + season + (1|vessel)[2] (Table 1)

Bin: retained = timeofday + year + season + (1|vessel) (Table 2)

<u>FL_Keys</u>

Pos: log(retained) = year + timeofday + (1|vessel) (Table 3)

Bin: retained = year + season + (1|vessel) (Table 4)

<u>Single Area (Continuity)</u>

Pos: log(retained) = year + timeofday + (1|vessel) (Table 5)

Bin: retained = year + timeofday + season + (1|vessel) (Table 6)

Randomized quantile residuals for the positive and binomial sub-models of the SE_FL region appear approximately normally distributed despite the significant deviation from normality indicated by the K-S test and the Q-Q plot (Figures 9, 11). For large sample sizes, the K-S test could imply significant deviations from normality even in the case of minor deviations. There is some pattern, however, in residuals over years as well as hours fished (Figures 10, 12). This same pattern is evident for the FL_Keys model with model fit varying slightly over levels of years and hours fished (Figures 13, 14, 15, 16). The observed annual mean CPUE and modeled CPUE are provided in Tables 7, 8, 9 and plotted in Figures 21-23. Additionally, the number of trips per covariate by year and region are provided in Tables 10 and 12, while Tables 11 and 13 present the number of positive trips (i.e. retained at least one Yellowtail Snapper) by year per covariate and region.

<u>Considerations</u>

The data from the headboat fishery (especially for southeast Florida and during years 1981 to 2008) are plagued by low reporting rates. Significant differences in the number of captain-reported and estimated trips during this time period resulted in an average compliance rate of 50% (Fitzpatrick et al. 2017). Model fit to data within this time period is poor (as seen in residuals across years) likely due to low vessel reporting rates which is evident in Figures 24 and 25.

Therefore, we produced three additional indices with a start year of 2008. For these indices the catch rate is based on total catch of Yellowtail Snapper (retained plus released). The same covariates were evaluated in the positive and binomial sub-models for each region and the indices was generated using Monte Carlo simulations (Appendix A).

The analysis and estimation of catch rates from the headboat fishery may be improved by considering additional covariates such as the maximum number of anglers which could serve as a proxy for vessel size as well as the ‘fullness’ of the vessel which would be an indicator of crowding on a headboat vessel (SFB 2016). Although not available currently, a captain

[2] This notation indicates that vessel is being treated as a random effect in the LME model.

identification number would be a useful metric to adjust for the experience levels of the captains and may be able to explain some variability in catch per vessel over the time period.

References

Allen, S.D. and E.S. Herdter. 2019. Overview of the Southeast Region Headboat Survey and Data Related to Yellowtail Snapper (*Ocyurus chrysurus*). SEDAR64-DW08. SEDAR, North Charleston, SC. 19 pp.

Burnham, K.P. and D.R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. 2nd edn. Springer, Berlin.

Dick, E.J. 2004. Beyond 'lognormal vs. gamma': discrimination among error distributions for generalized linear models. Fisheries Research 70:347-362.

Fitzpatrick, E. E., Williams, E. H., Shertzer, K. W., Siegfried, K. I., Craig, J. K., Cheshire, R. T., and Brennan, K. (2017). The NMFS Southeast Region Headboat Survey: History, Methodology, and Data Integrity. Marine Fisheries Review, 79(1), 1-28.

Hartig, F. 2019. DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R package version 0.2.4.https://CRAN.R-project.org/package=DHARMa

Lo, N.C., L.D. Jacobson, J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Canadian Journal Fisheries and Aquatic Sciences 49:2515-2526.

Maunder, M.N. and A.E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research 70:141-159.

Shertzer, K. W., and E. H. Williams. 2008. Fish assemblages and indicator species: reef fishes off the southeastern United States. Fishery Bulletin 106:257-269.

Sustainable Fisheries Branch – NMFS. 2016. Standardized catch rates of Red Grouper (*Epinephelus morio*) in the southeast U.S. from headboat logbook data. SEDAR53-WP02. SEDAR, North Charleston, SC. 40 pp.

Zuur, A.F., E.N. Ieno, N.J. Walker, A.A. Saveliev, and G.M. Smith. 2009. Mixed Effects Models and Extensions in Ecology with R. Springer Science & Business Media.

Tables

Table 1. Deviance table for the final positive sub-model for the SE_FL area model.

Factor	Deviance	Residual DF	AIC	Loglikelihood	% Deviance Reduced
Null	206220.2	71528	206226.2	-103110	-
year	203834.4	71492	203912.4	-101917	1.11
timeofday	201632.8	71491	201712.8	-100816	1.07
season	200217.7	71488	200303.7	-100109	0.68
hrsfished	199876.5	71486	199966.5	-99938.3	0.16
anglercat	199752.1	71483	199848.1	-99876	0.06

Table 2. Deviance table for the final binomial sub-model for the SE_FL area model.

Factor	Deviance	Residual DF	AIC	Loglikelihood	% Deviance Reduced
Null	172946.6	147502	172950.6	-86473.3	-
timeofday	169818.7	147501	169824.7	-84909.3	1.81
year	167061.8	147465	167139.8	-83530.9	1.57
season	164778	147462	164862	-82389	1.32
hrsfished	164457.7	147460	164545.7	-82228.9	0.18
anglercat	164406.7	147457	164500.7	-82203.4	0.03

Table 3. Deviance table for the final positive sub-model for the FL_Keys area model.

Factor	Deviance	Residual DF	AIC	Loglikelihood	% Deviance Reduced
Null	186668.2	65134	186674.2	-93334.1	-
year	184241.5	65098	184319.5	-92120.7	1.25
timeofday	183207.4	65097	183287.4	-91603.7	0.55
hrsfished	182599.7	65095	182683.7	-91299.9	0.32
anglercat	182287.8	65092	182377.8	-91143.9	0.16
season	181910.8	65089	182006.8	-90955.4	0.2

Table 4. Deviance table for the final binomial sub-model for the FL_Keys area model.

Factor	Deviance	Residual DF	AIC	Loglikelihood	% Deviance Reduced
Null	61133.69	79556	61137.69	-30566.8	-
year	60126.23	79520	60202.23	-30063.1	1.6
season	59789.13	79517	59871.13	-29894.6	0.55
timeofday	59558.9	79516	59642.9	-29779.5	0.38
anglercat	59482.04	79513	59572.04	-29741	0.12
hrsfished	59462.46	79511	59556.46	-29731.2	0.03

Table 5. Deviance table for the final positive sub-model for the single area (continuity) model.

Factor	Deviance	Residual DF	AIC	Loglikelihood	% Deviance Reduced
Null	392981.8	136665	392987.8	-196491	-
year	389859.4	136629	389937.4	-194930	0.77
timeofday	386567	136628	386647	-193283	0.84
season	385346.4	136625	385432.4	-192673	0.31
hrsfished	384855.9	136623	384945.9	-192428	0.12
anglercat	384454.1	136620	384550.1	-192227	0.1

Table 6. Deviance table for the final binomial sub-model for the single area (continuity) model.

Factor	Deviance	Residual DF	AIC	Loglikelihood	% Deviance Reduced
Null	234151.5	227060	234155.5	-117076	-
year	230786.3	227024	230862.3	-115393	1.42
timeofday	227631.9	227023	227709.9	-113816	1.35
season	225574.2	227020	225658.2	-112787	0.88
hrsfished	225424.1	227018	225512.1	-112712	0.06
anglercat	225412.1	227015	225506.1	-112706	0

Table 7. Nominal mean CPUE and final modeled index for the SE_FL area model.

Year	NumTrips	NominalMean	Mean	CV
1981	5469	7.13	2.52	0.16
1982	5890	4.5	2.13	0.15
1983	6003	2.81	1.32	0.17
1984	5084	2.81	1.28	0.17
1985	5477	2.05	0.98	0.19
1986	6780	2.73	1.27	0.17
1987	6202	3.18	1.55	0.17
1988	5255	3.96	2.25	0.15
1989	5354	3.72	2.39	0.15
1990	5847	3.80	2.45	0.16
1991	5415	3.67	2.64	0.15
1992	6505	5.57	2.75	0.15
1993	5275	5.13	2.63	0.15
1994	4732	7.19	3.72	0.14
1995	4344	3.74	2.12	0.16
1996	1708	2.47	1.06	0.20
1997	2290	4.14	1.93	0.16
1998	1661	1.96	1.21	0.19
1999	804	1.91	1.38	0.20
2000	831	1.23	1.20	0.24
2001	904	0.80	1.01	0.24
2002	513	0.66	1.10	0.26
2003	369	1.53	1.66	0.23
2004	543	0.99	0.98	0.24
2005	589	1.02	0.76	0.26
2006	460	0.59	0.72	0.30
2007	534	2.97	1.73	0.21
2008	2728	6.70	2.89	0.16
2009	3444	5.31	2.66	0.16
2010	4102	9.08	3.40	0.16
2011	3893	7.37	3.17	0.17
2012	4620	7.08	2.94	0.15
2013	5604	5.32	2.34	0.16
2014	8573	7.62	3.62	0.14
2015	8557	7.11	3.76	0.13
2016	7117	6.94	3.37	0.14
2017	4028	6.61	4.16	0.14

Table 8. Nominal mean CPUE and final modeled index for the FL_Keys area model.

Year	NumTrips	NominalMean	Mean	CV
1981	1904	16.37	19.30	0.20
1982	2115	36.78	25.97	0.20
1983	1788	28.25	18.12	0.21
1984	1825	25.54	13.30	0.21
1985	1395	35.06	17.31	0.21
1986	1776	73.11	18.88	0.20
1987	2271	57.79	19.66	0.21
1988	1627	41.80	18.34	0.20
1989	1612	26.96	23.80	0.20
1990	1915	32.45	41.46	0.20
1991	1816	38.40	39.24	0.20
1992	2713	37.70	33.87	0.20
1993	2854	40.77	36.80	0.20
1994	2689	43.23	42.28	0.19
1995	2853	30.56	35.07	0.20
1996	2833	28.57	30.03	0.20
1997	3097	28.10	31.82	0.20
1998	2552	26.53	28.24	0.20
1999	2252	23.72	27.94	0.20
2000	2138	26.46	28.29	0.20
2001	1723	29.63	26.98	0.20
2002	1275	34.48	26.24	0.20
2003	1224	37.46	32.16	0.20
2004	1286	38.03	38.31	0.21
2005	1444	39.24	47.62	0.20
2006	1461	28.85	32.89	0.20
2007	1523	25.33	29.87	0.20
2008	1907	32.68	32.26	0.20
2009	2019	30.42	31.71	0.20
2010	1949	30.95	28.08	0.20
2011	1958	32.28	33.80	0.20
2012	2201	28.73	32.01	0.20
2013	2574	29.84	35.74	0.20
2014	3290	26.91	30.91	0.20
2015	3534	26.02	30.44	0.19
2016	3172	24.58	27.57	0.19
2017	2993	24.29	28.92	0.19

Table 9. Nominal mean CPUE and final modeled index for the single-area (continuity) model.

Year	NumTrips	NominalMean	Mean	CV
1981	7373	9.51	7.74	0.16
1982	8005	13.03	7.39	0.15
1983	7791	8.65	4.99	0.17
1984	6909	8.81	4.33	0.17
1985	6872	8.75	4.20	0.17
1986	8556	17.34	4.99	0.16
1987	8473	17.82	5.64	0.16
1988	6882	12.91	6.83	0.15
1989	6966	9.10	7.63	0.15
1990	7762	10.87	9.53	0.15
1991	7231	12.39	9.60	0.15
1992	9218	15.03	9.33	0.15
1993	8129	17.64	9.56	0.15
1994	7421	20.25	12.00	0.14
1995	7197	14.37	8.50	0.15
1996	4541	18.76	6.85	0.16
1997	5387	17.92	8.14	0.15
1998	4213	16.84	6.67	0.16
1999	3056	17.98	7.03	0.16
2000	2969	19.40	6.92	0.17
2001	2627	19.71	6.47	0.17
2002	1788	24.78	6.49	0.17
2003	1593	29.14	8.25	0.17
2004	1829	27.04	8.79	0.17
2005	2033	28.17	11.11	0.17
2006	1921	22.08	7.99	0.17
2007	2057	19.52	7.58	0.17
2008	4635	17.39	9.28	0.15
2009	5463	14.59	8.72	0.15
2010	6051	16.12	9.61	0.15
2011	5851	15.7	10.02	0.16
2012	6821	14.07	9.10	0.15
2013	8178	13.04	8.62	0.15
2014	11863	12.97	10.17	0.14
2015	12091	12.64	9.97	0.14
2016	10289	12.38	8.90	0.14
2017	7021	14.15	9.70	0.14

Table 10. Number of trips by year and factor for SE_FL.

*Percent of total trips made during the daytime in relation to those made during nighttime.

	Season				Angler Category				Hours Fished			Time of Day	
Year	1winter	2spring	3summer	4fall	[1,10]	(11,15]	(16,24]	(25,111]	5	7	10+	Daytime*	Nighttime
1981	1327	1469	1435	1238	1201	1117	1343	1808	5227	34	208	3686 (67.4)	1783
1982	1447	1461	1553	1429	1504	1594	1369	1423	5752	1	137	3900 (66.2)	1990
1983	1351	1756	1642	1254	1268	1589	1662	1484	5931	2	70	3955 (65.9)	2048
1984	1339	1443	1325	977	1140	1187	1391	1366	4756	111	217	3482 (68.5)	1602
1985	1457	1643	1337	1040	1111	1303	1460	1603	5163	104	210	3684 (67.3)	1793
1986	1247	1866	2176	1491	1838	1505	1633	1804	6288	168	324	4778 (70.5)	2002
1987	1590	1685	1700	1227	1573	1444	1580	1605	5700	144	358	4442 (71.6)	1760
1988	1386	1528	1265	1076	1800	1221	1142	1092	4892	143	220	3641 (69.3)	1614
1989	1315	1192	1428	1419	1853	1223	1054	1224	5099	49	206	3612 (67.5)	1742
1990	1381	1738	1557	1171	1798	1352	1315	1382	5647	10	190	3849 (65.8)	1998
1991	1429	1523	1494	969	1983	1308	1103	1021	5218	16	181	3545 (65.5)	1870
1992	1372	2047	1904	1182	1852	1723	1617	1313	6132	31	342	4445 (68.3)	2060
1993	1228	1438	1294	1315	1478	1286	1240	1271	5073	39	163	3731 (70.7)	1544
1994	1117	1388	1205	1022	1207	1067	1163	1295	4583	32	117	3369 (71.2)	1363
1995	1176	1326	1038	804	1183	1147	1051	963	4123	75	146	3381 (77.8)	963
1996	701	420	291	296	500	428	432	348	1623	8	77	1320 (77.3)	388
1997	370	559	629	732	595	560	603	532	2177	21	92	1823 (79.6)	467
1998	641	362	384	274	596	428	364	273	1575	56	30	1461 (88.0)	200
1999	238	260	194	112	245	233	194	132	803	NA	1	715 (88.9)	89
2000	56	214	314	247	185	196	265	185	759	71	1	774 (93.1)	57
2001	296	197	229	182	249	218	235	202	776	121	7	878 (97.1)	26
2002	161	161	138	53	118	144	146	105	374	138	1	506 (98.6)	7
2003	123	67	80	99	78	94	115	82	245	122	2	358 (97.0)	11
2004	208	145	87	103	114	144	152	133	392	130	21	528 (97.2)	15
2005	156	192	143	98	122	166	190	111	496	48	45	563 (95.6)	26
2006	89	155	134	82	90	104	136	130	437	19	4	452 (98.3)	8
2007	112	206	132	84	129	150	145	110	531	NA	3	489 (91.6)	45
2008	532	908	812	476	701	772	673	582	2581	71	76	2187 (80.2)	541
2009	960	931	958	595	762	853	939	890	3160	134	150	3084 (89.6)	360
2010	896	1317	915	974	1013	1134	1056	899	3848	143	111	3602 (87.8)	500
2011	1228	1163	898	604	786	930	1059	1118	3648	146	99	3515 (90.3)	378
2012	1059	1384	1302	875	1086	1113	1209	1212	4435	150	35	4069 (88.1)	551
2013	1281	1733	1551	1039	1461	1407	1518	1218	5341	177	86	4977 (88.8)	627
2014	1719	2424	2541	1889	1894	2058	2295	2326	8228	227	118	7052 (82.3)	1521
2015	2163	2491	2413	1490	1810	1951	2339	2457	8211	255	91	6972 (81.5)	1585
2016	1896	2095	1964	1162	1825	1599	1736	1957	6750	298	69	5921 (83.2)	1196
2017	975	1205	1049	799	1583	845	845	755	3646	230	152	3623 (90.0)	405

Table 11. Number of positive trips by year and factor for SE_FL.

	Season				Angler Category				Hours Fished			Time of Day	
Year	1winter	2spring	3summer	4fall	[1,10]	(11,15]	(16,24]	(25,111]	5	7	10+	Daytime*	Nighttime
1981	512	738	914	726	574	567	752	997	2851	3	36	1763	1127
1982	662	871	901	980	796	923	834	861	3394	1	19	2135	1279
1983	614	527	752	837	625	800	749	556	2706	NA	24	1690	1040
1984	549	498	517	621	541	527	590	527	2113	53	19	1361	824
1985	413	391	492	496	437	495	460	400	1731	21	40	1115	677
1986	373	777	914	865	828	717	732	652	2788	66	75	1940	989
1987	594	628	839	784	712	788	746	599	2624	78	143	1958	887
1988	481	748	783	719	883	722	620	506	2503	111	117	1826	905
1989	640	544	757	812	724	657	631	741	2644	36	73	1817	936
1990	596	725	782	574	715	639	623	700	2622	4	51	1668	1009
1991	684	732	666	437	884	583	538	514	2454	11	54	1537	982
1992	594	892	1130	785	823	905	872	801	3243	17	141	2270	1131
1993	604	653	631	836	623	661	666	774	2635	11	78	1865	859
1994	603	713	715	656	496	615	741	835	2634	9	44	1859	828
1995	488	641	523	352	491	525	508	480	1971	5	28	1361	643
1996	159	100	127	130	136	136	124	120	495	6	15	308	208
1997	144	261	313	349	227	281	288	271	1052	5	10	756	311
1998	202	63	69	71	119	110	98	78	401	NA	4	246	159
1999	48	43	54	27	49	51	37	35	172	NA	NA	95	77
2000	2	25	77	31	24	21	47	43	116	19	NA	118	17
2001	35	10	41	42	27	29	40	32	82	45	1	116	12
2002	16	29	24	8	11	23	24	19	30	47	NA	70	7
2003	20	21	17	36	22	24	31	17	50	44	NA	83	11
2004	33	32	10	14	19	27	23	20	69	19	1	74	15
2005	8	58	21	8	17	21	38	19	92	NA	3	75	20
2006	8	12	6	24	18	17	9	6	49	NA	1	42	8
2007	23	38	26	39	37	33	30	26	126	NA	NA	81	45
2008	146	412	465	210	294	332	333	274	1217	7	9	807	426
2009	342	426	517	326	294	422	453	442	1521	39	51	1373	238
2010	244	658	505	591	437	580	552	429	1937	25	36	1558	440
2011	258	629	463	386	301	397	462	576	1684	16	36	1408	328
2012	557	762	733	502	552	619	732	651	2499	42	13	2124	430
2013	565	782	795	606	610	709	808	621	2688	27	33	2257	491
2014	827	1392	1550	1264	922	1228	1436	1447	4885	91	57	3750	1283
2015	1242	1694	1361	1047	936	1203	1480	1725	5173	132	39	4036	1308
2016	1129	1227	1053	769	879	929	1084	1286	4057	105	16	3188	990
2017	427	508	482	444	829	388	324	320	1785	28	48	1482	379

Table 12. Number of trips by year and factor for FL_Keys.

*Percent of total trips made during the daytime in relation to those made during nighttime.

	Season				**Angler Category**				**Hours Fished**			**Time of Day**	
Year	1winter	2spring	3summer	4fall	[1,10]	(11,15]	(16,24]	(25,111]	5	7	10+	Daytime*	Nighttime
1981	545	579	386	394	507	524	441	432	1376	NA	528	1359 (71.4)	545
1982	684	566	477	388	510	607	498	500	1381	1	733	1554 (73.5)	561
1983	603	399	378	408	567	521	383	317	979	NA	809	1415 (79.1)	373
1984	543	356	458	468	601	529	382	313	1028	47	750	1455 (79.7)	370
1985	411	377	344	263	399	361	287	348	843	109	443	1133 (81.2)	262
1986	350	302	574	550	507	398	407	464	1249	129	398	1383 (77.9)	393
1987	717	618	508	428	716	396	495	664	1421	232	618	1767 (77.8)	504
1988	488	473	356	310	297	407	443	480	1080	207	340	1252 (77.0)	375
1989	478	355	367	412	378	395	399	440	1218	59	335	1202 (74.6)	410
1990	502	438	504	471	590	437	405	483	1459	88	368	1479 (77.2)	436
1991	637	474	385	320	623	464	415	314	1304	23	489	1356 (74.7)	460
1992	869	761	535	548	923	601	576	613	1428	217	1068	2161 (79.7)	552
1993	912	677	691	574	908	632	576	738	1578	206	1070	2311 (81.0)	543
1994	880	642	618	549	924	576	538	651	1458	154	1077	2221 (82.6)	468
1995	962	681	613	597	957	719	575	602	1823	175	855	2407 (84.4)	446
1996	890	737	657	549	899	714	578	642	1809	251	773	2403 (84.8)	430
1997	1138	745	631	583	966	833	647	651	2022	278	797	2681 (86.6)	416
1998	879	728	521	424	689	742	612	509	1787	189	576	2214 (86.8)	338
1999	657	528	569	498	757	596	511	388	1645	114	493	1927 (85.6)	325
2000	763	517	447	411	548	641	567	382	1548	140	450	1829 (85.6)	309
2001	458	420	522	323	461	526	429	307	1332	NA	391	1495 (86.8)	228
2002	493	347	240	195	329	390	315	241	986	21	268	1151 (90.3)	124
2003	398	368	242	216	256	298	335	335	918	20	286	1050 (85.8)	174
2004	293	370	322	301	253	286	319	428	965	89	232	1091 (84.8)	195
2005	410	440	321	273	295	290	358	501	1050	166	228	1307 (90.5)	137
2006	474	436	286	265	309	344	331	477	1081	117	263	1353 (92.6)	108
2007	520	366	399	238	370	354	357	442	1094	245	184	1428 (93.8)	95
2008	508	608	385	406	509	485	439	474	1263	302	342	1757 (92.1)	150
2009	561	618	473	367	456	454	534	575	1334	352	333	1856 (91.9)	163
2010	465	575	483	426	476	536	479	458	1286	276	387	1798 (92.3)	151
2011	527	526	513	392	323	417	582	636	1322	286	350	1683 (86.0)	275
2012	556	638	574	433	488	471	577	665	1675	324	202	1854 (84.2)	347
2013	646	675	704	549	650	653	590	681	2029	288	257	2256 (87.7)	318
2014	834	943	861	652	717	843	805	925	2474	573	243	2873 (87.3)	417
2015	921	1014	929	670	899	821	830	984	2761	575	198	3096 (87.6)	438
2016	845	909	802	616	738	772	779	883	2354	583	235	2793 (88.1)	379
2017	862	915	752	464	784	616	710	883	2388	466	139	2667 (89.1)	326

Table 13. Number of positive trips by year and factor for FL_Keys.

	Season				Angler Category				Hours Fished			Time of Day	
Year	1winter	2spring	3summer	4fall	[1,10]	(11,15]	(16,24]	(25,111]	5	7	10+	Daytime*	Nighttime
1981	342	472	315	250	369	385	333	292	991	NA	388	993	386
1982	477	496	379	230	356	435	376	415	1040	NA	542	1161	421
1983	362	261	274	207	355	343	224	182	512	NA	592	917	187
1984	229	239	347	272	358	323	220	186	518	35	534	923	164
1985	235	278	227	186	267	232	187	240	451	94	381	812	114
1986	228	217	371	403	330	258	286	345	774	123	322	1025	194
1987	478	427	336	313	459	239	322	534	859	225	470	1297	257
1988	381	340	278	246	218	298	335	394	737	191	317	1016	229
1989	369	287	261	278	269	249	299	378	823	56	316	951	244
1990	419	376	339	363	426	327	324	420	1101	86	310	1218	279
1991	504	377	279	252	438	354	351	269	918	23	471	1106	306
1992	769	619	410	461	717	500	484	558	1060	211	988	1875	384
1993	788	570	555	490	724	510	488	681	1204	205	994	2013	390
1994	792	602	528	490	797	525	476	614	1263	154	995	2017	395
1995	804	603	499	527	800	603	487	543	1462	175	796	2015	418
1996	672	671	587	461	736	608	473	574	1439	247	705	1985	406
1997	956	637	514	497	795	704	540	565	1590	276	738	2207	397
1998	728	592	439	357	559	618	504	435	1403	176	537	1800	316
1999	553	467	477	395	631	519	421	321	1306	113	473	1587	305
2000	591	438	397	364	456	523	488	323	1231	140	419	1498	292
2001	339	358	468	291	412	442	350	252	1092	NA	364	1249	207
2002	414	311	209	176	290	336	272	212	830	21	259	991	119
2003	313	320	201	184	220	257	276	265	735	20	263	870	148
2004	241	308	252	236	205	221	267	344	727	89	221	851	186
2005	346	378	266	233	247	225	299	452	840	161	222	1101	122
2006	367	375	257	220	255	277	288	399	923	60	236	1128	91
2007	430	310	312	200	281	283	307	381	917	164	171	1162	90
2008	477	551	348	363	439	445	405	450	1113	288	338	1601	138
2009	460	540	406	332	318	401	478	541	1093	322	323	1581	157
2010	393	493	413	377	377	466	429	404	1073	241	362	1535	141
2011	429	476	441	358	256	355	520	573	1145	248	311	1448	256
2012	483	576	476	376	422	407	491	591	1417	300	194	1580	331
2013	578	573	592	512	583	570	517	585	1752	259	244	1953	302
2014	750	834	739	605	659	748	703	818	2189	518	221	2524	404
2015	821	933	734	576	732	702	737	893	2345	553	166	2646	418
2016	709	782	642	543	615	629	631	801	1913	559	204	2309	367
2017	700	825	679	427	708	546	608	769	2077	439	115	2313	318

Figures

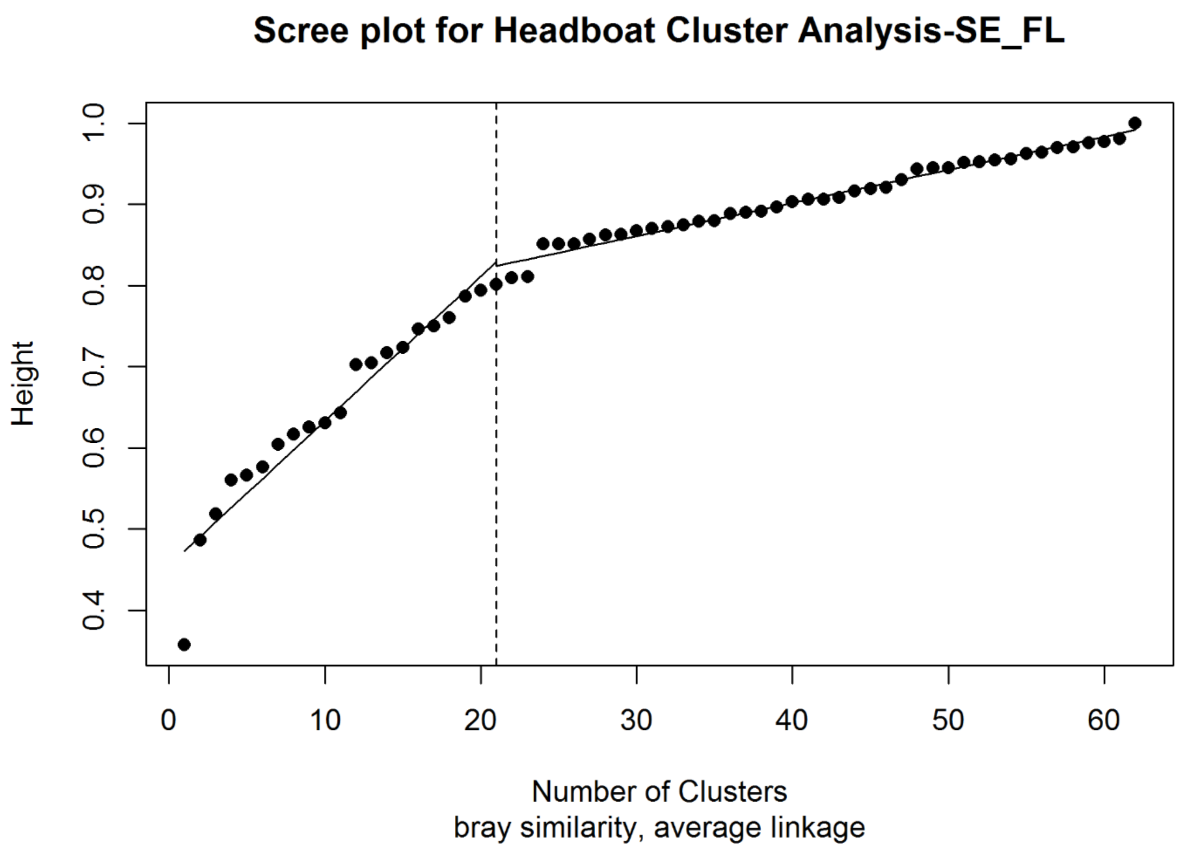


Figure 1. Plot of number of clusters against height from the hierarchical cluster analysis for the southeast Florida area model, where height is the average dissimilarity among species in a cluster with 1 being most similar. Included are the piecewise regression lines (solid line) using a breakpoint (dashed vertical line) that minimized the residual mean square error.

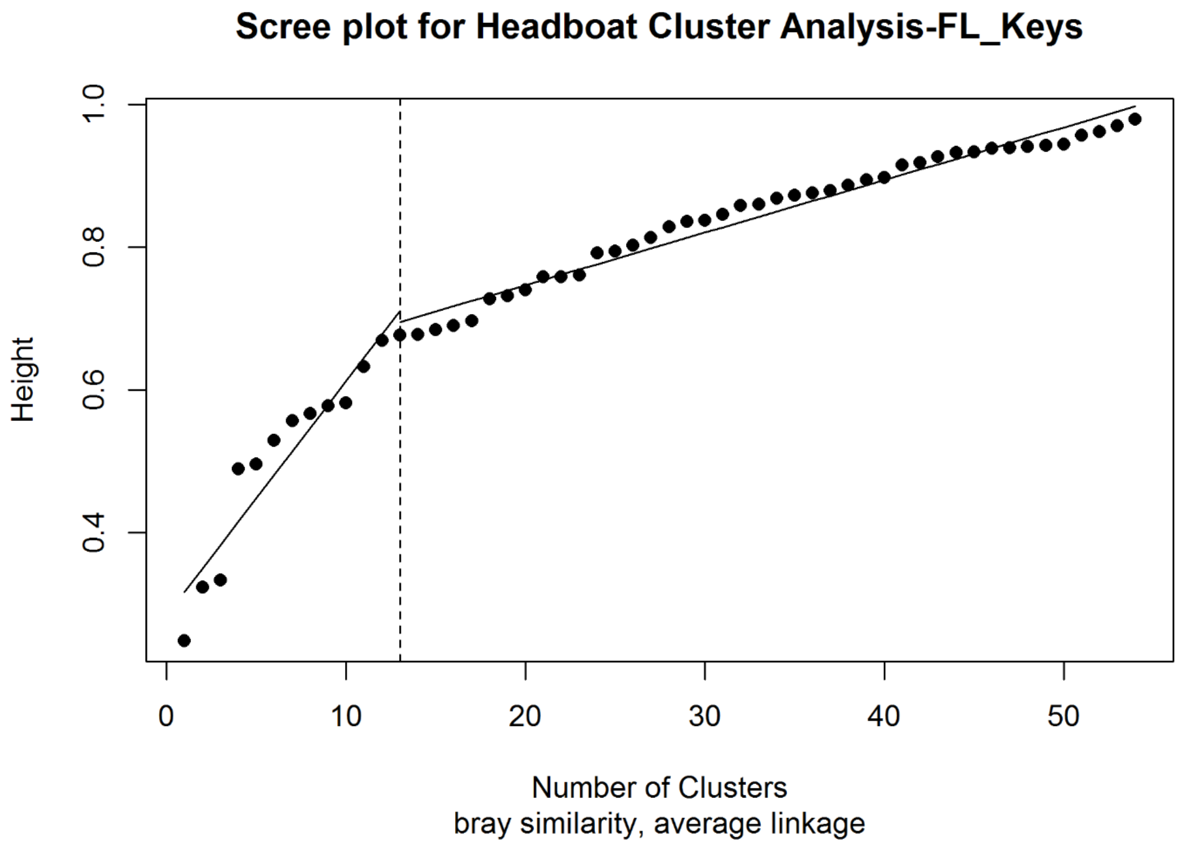


Figure 2. Plot of number of clusters against height from the hierarchical cluster analysis for the Keys area model, where height is the average dissimilarity among species in a cluster with 1 being most similar. Included are the piecewise regression lines (solid line) using a breakpoint (dashed vertical line) that minimized the residual mean square error.

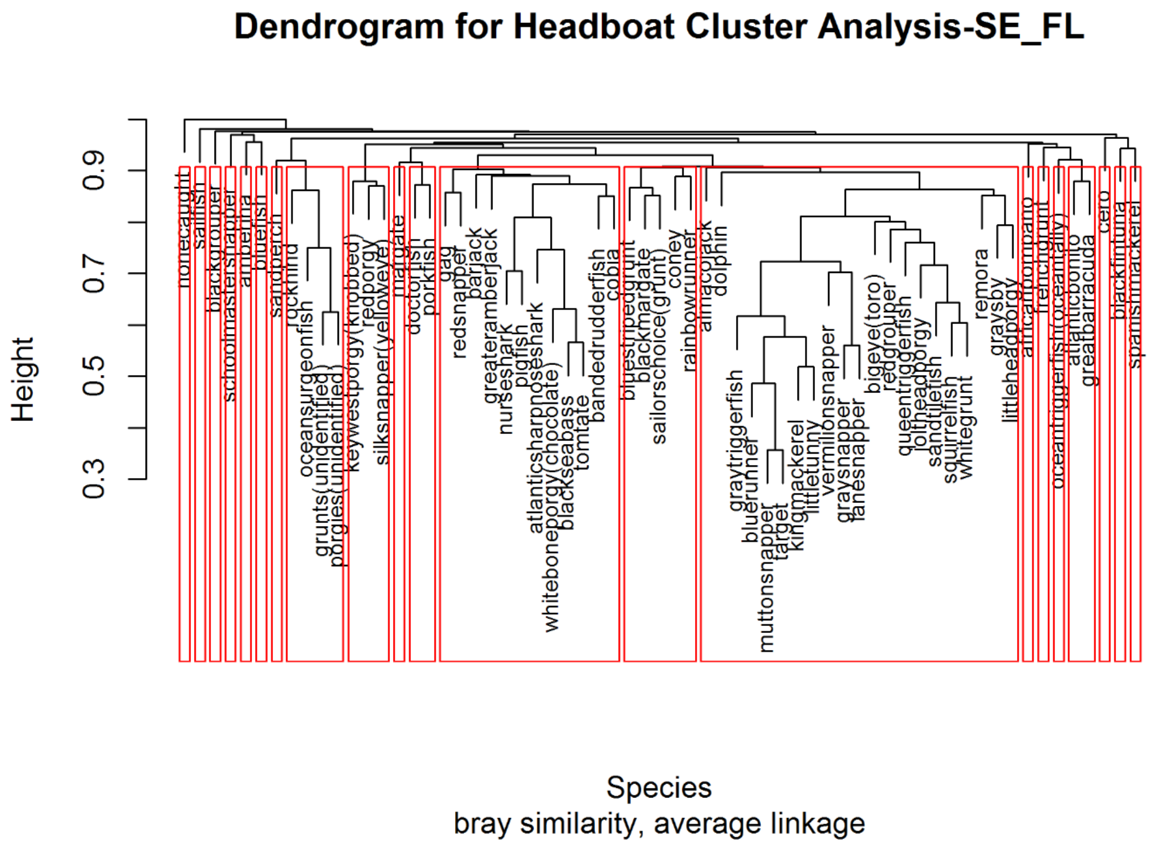


Figure 3. Dendrogram from hierarchical cluster analysis of species in the headboat dataset for the southeast Florida area model. Height measures the average dissimilarity among species within a branch with a value of 1 being most similar. Yellowtail Snapper is represented as ‘target’ in this plot.

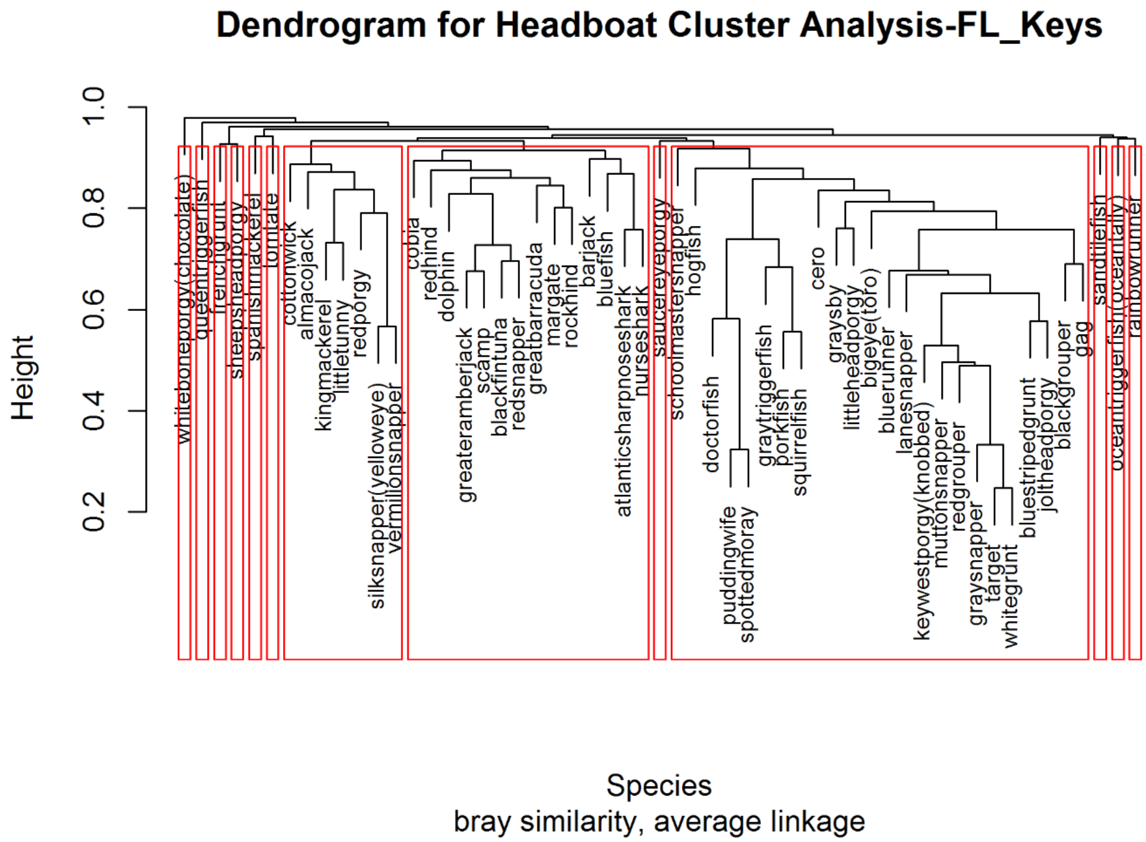


Figure 4. Dendrogram from hierarchical cluster analysis of species in the headboat data for the Keys area model. Height measures the average dissimilarity among species within a branch with a value of 1 being most similar. Yellowtail Snapper is represented as ‘target’ in this plot.

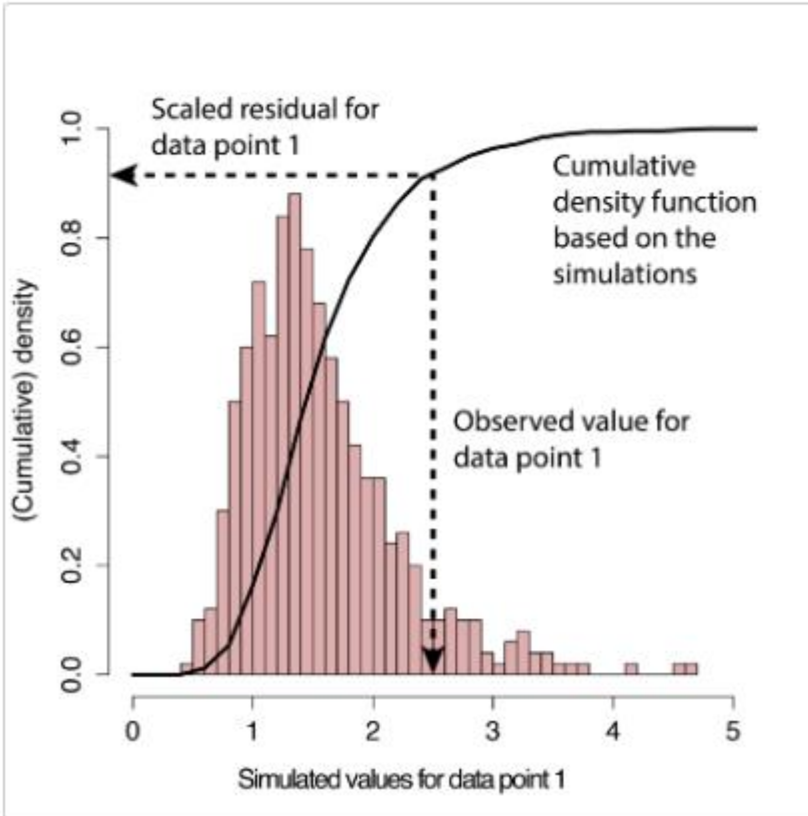


Figure 5. Steps to produce a quantile residual for observed value data point 1 using the DHARMa package. This figure is taken directly from Hartig 2019.

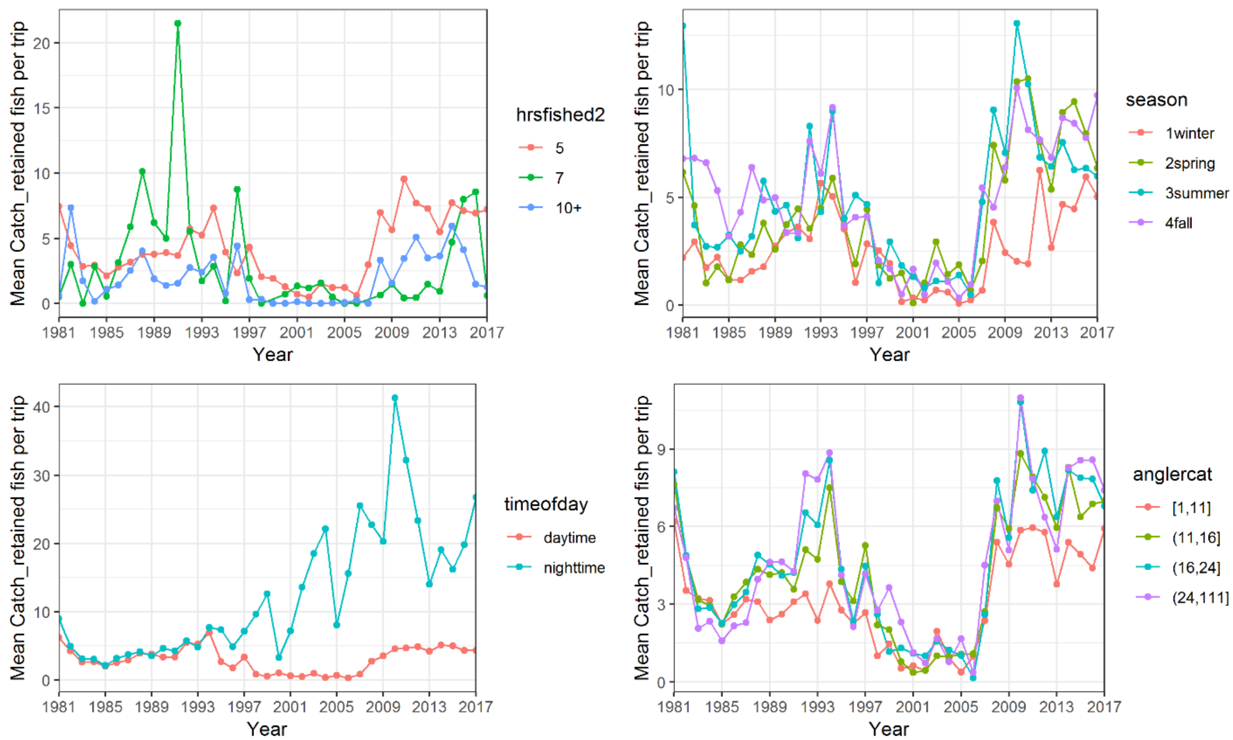


Figure 6. Interaction plots of year and each predictor variable on CPUE for the SE_FL area model.

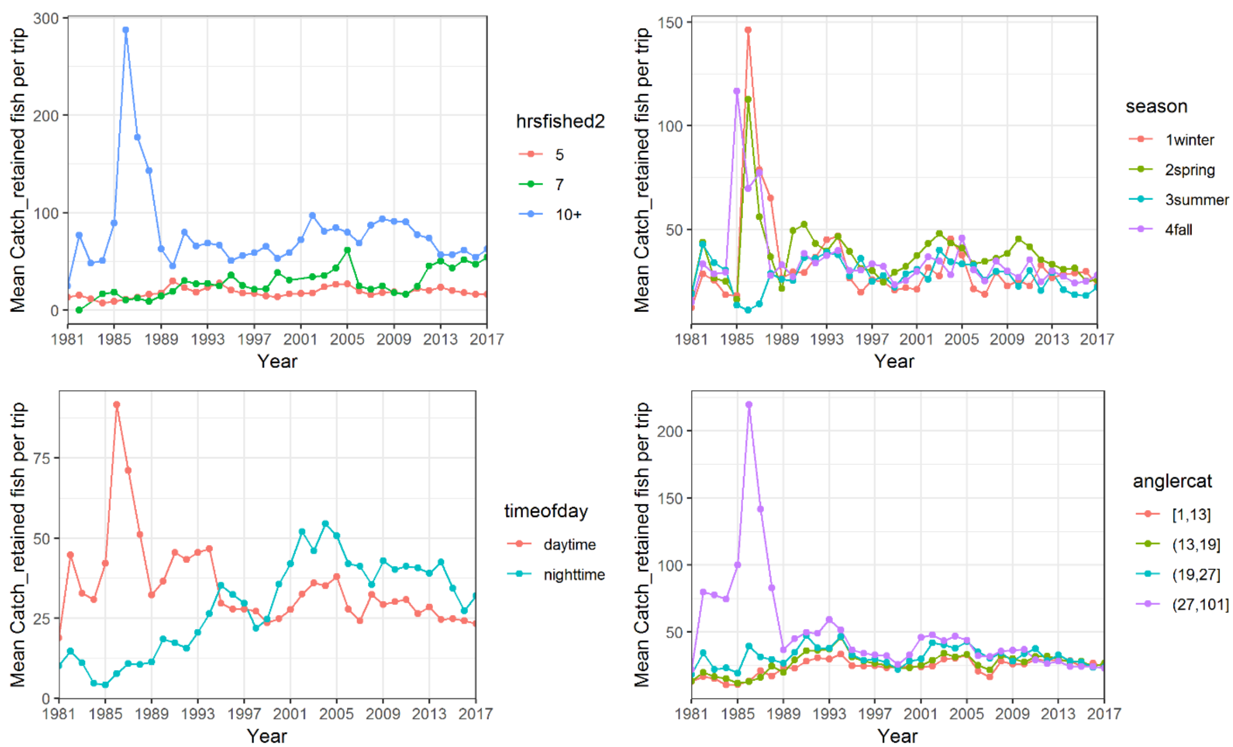


Figure 7. Interaction plots of year and each predictor variable on CPUE for the FL_Keys area model.

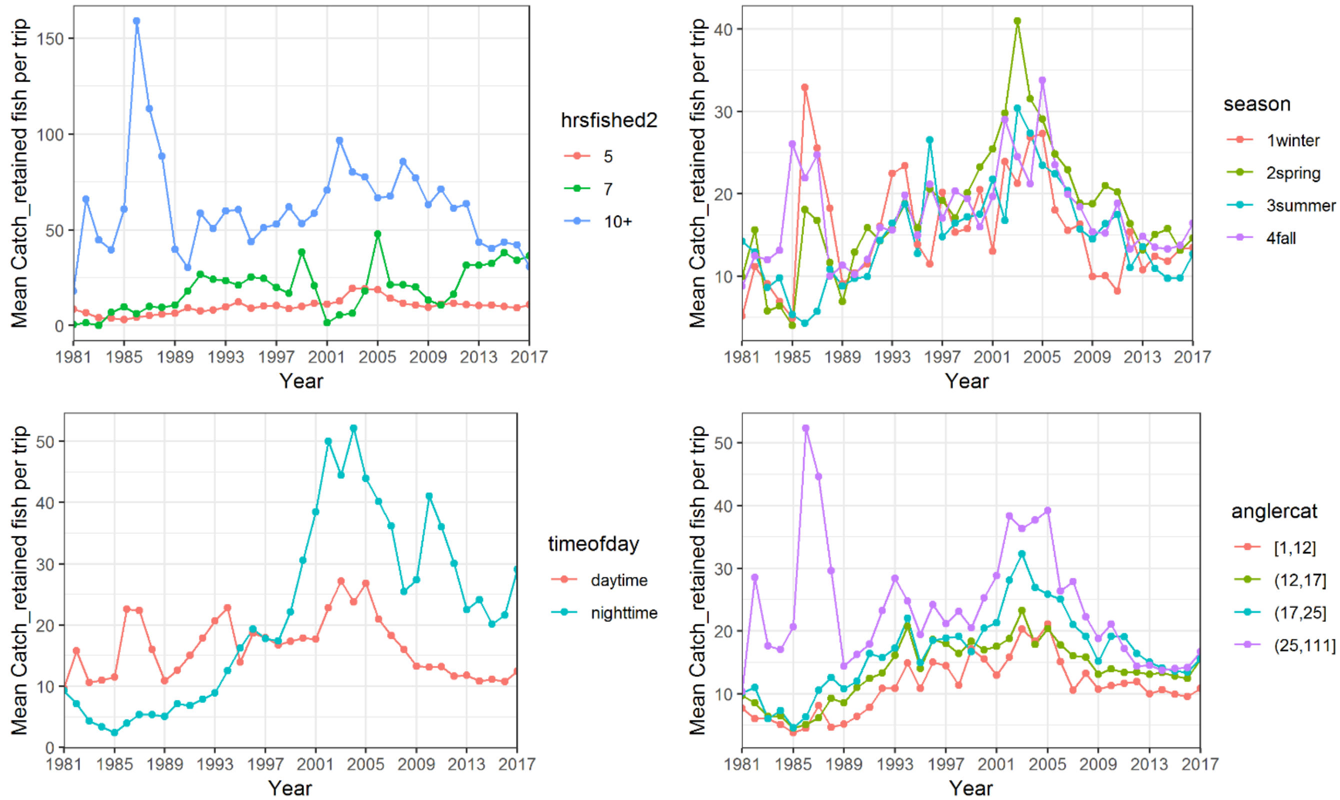


Figure 8. Interaction plots of year and each predictor variable on CPUE for the continuity model.

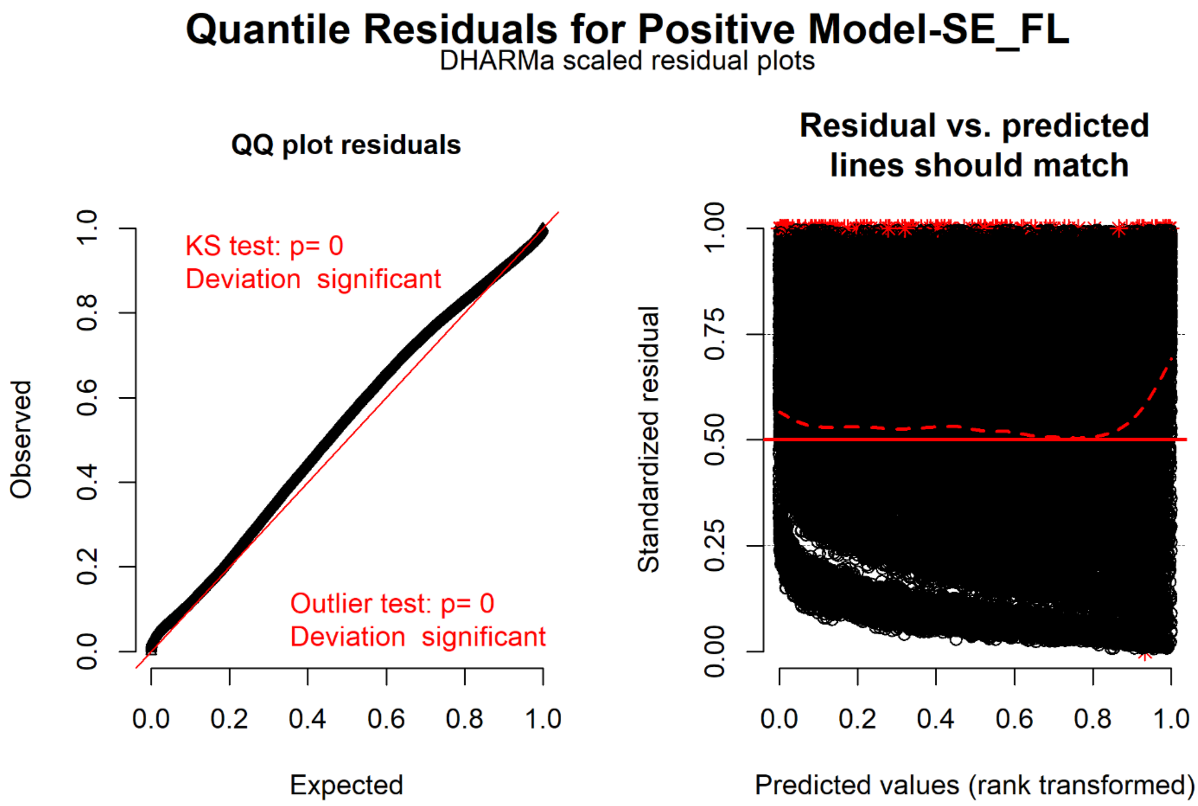


Figure 9. QQ plot residuals for the positive model for SE_FL region.

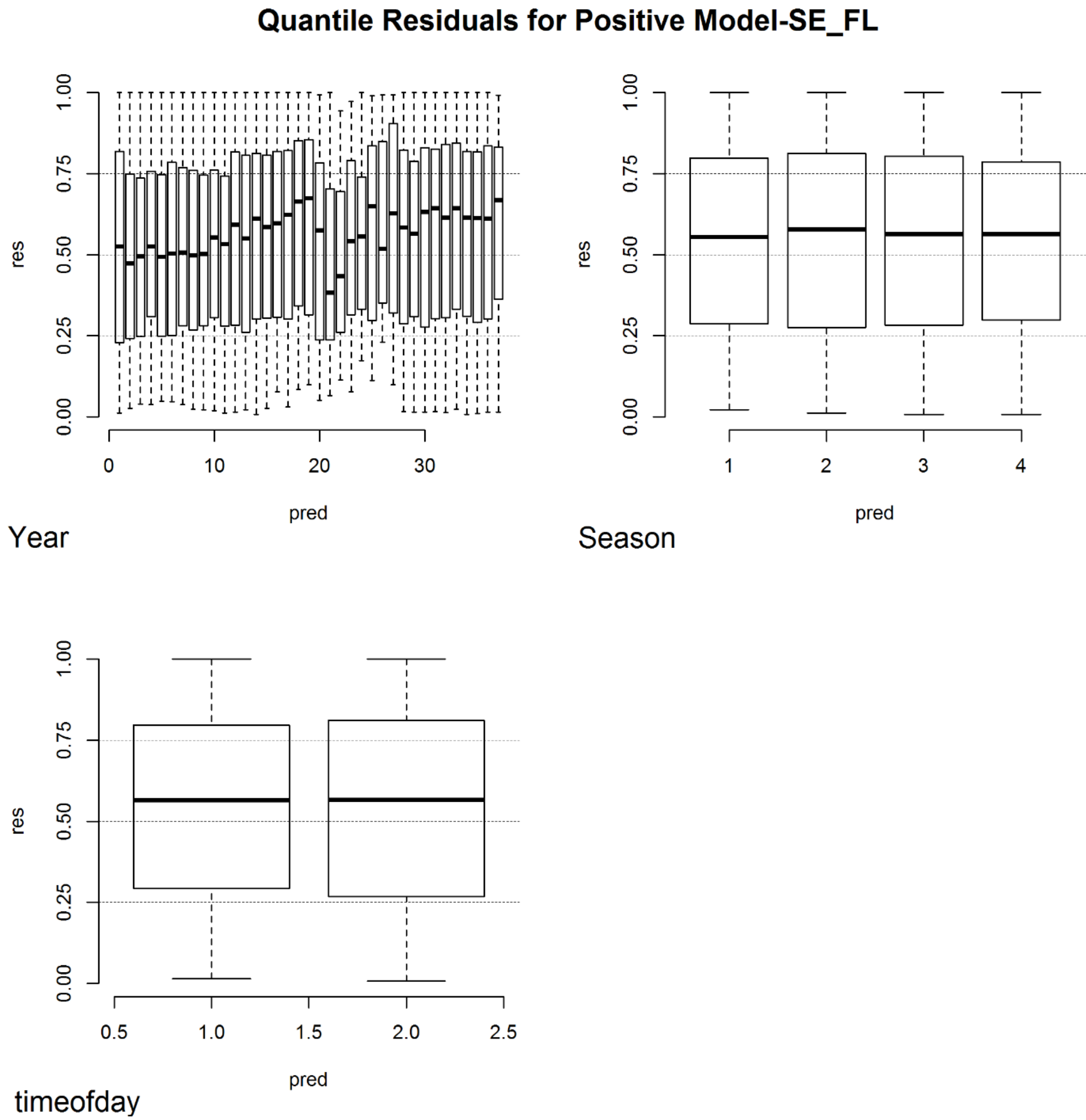


Figure 10. Scaled (quantile) residuals for the positive model for SE_FL. Year has 37 levels (1981 -2017), season has four levels (winter, spring, summer, fall), time of day has two levels (night time, day time).

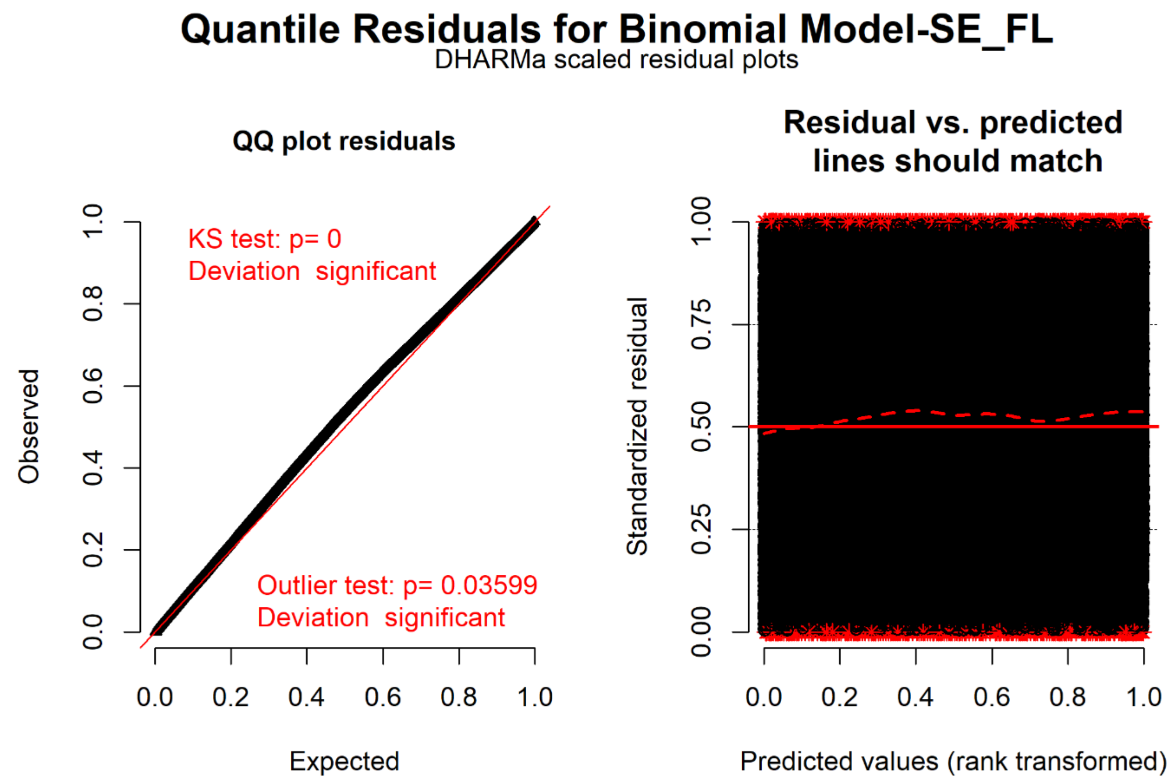


Figure 11. QQ plot residuals for the binomial model for SE_FL region.

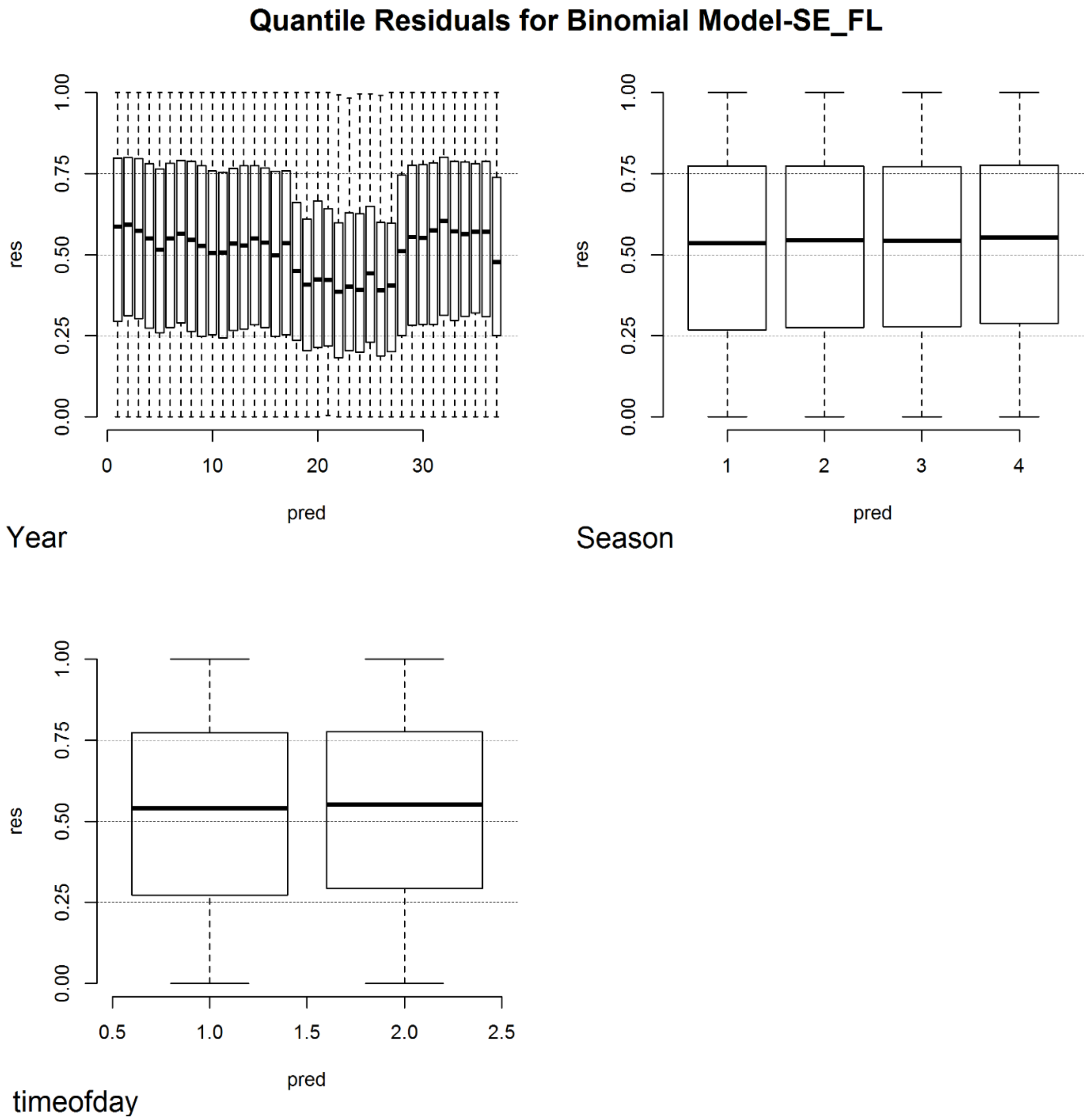


Figure 12. Scaled (quantile) residuals for the binomial model for SE_FL. Year has 37 levels (1981 -2017), season has four levels (winter, spring, summer, fall), and time of day has two levels (night time, day time).

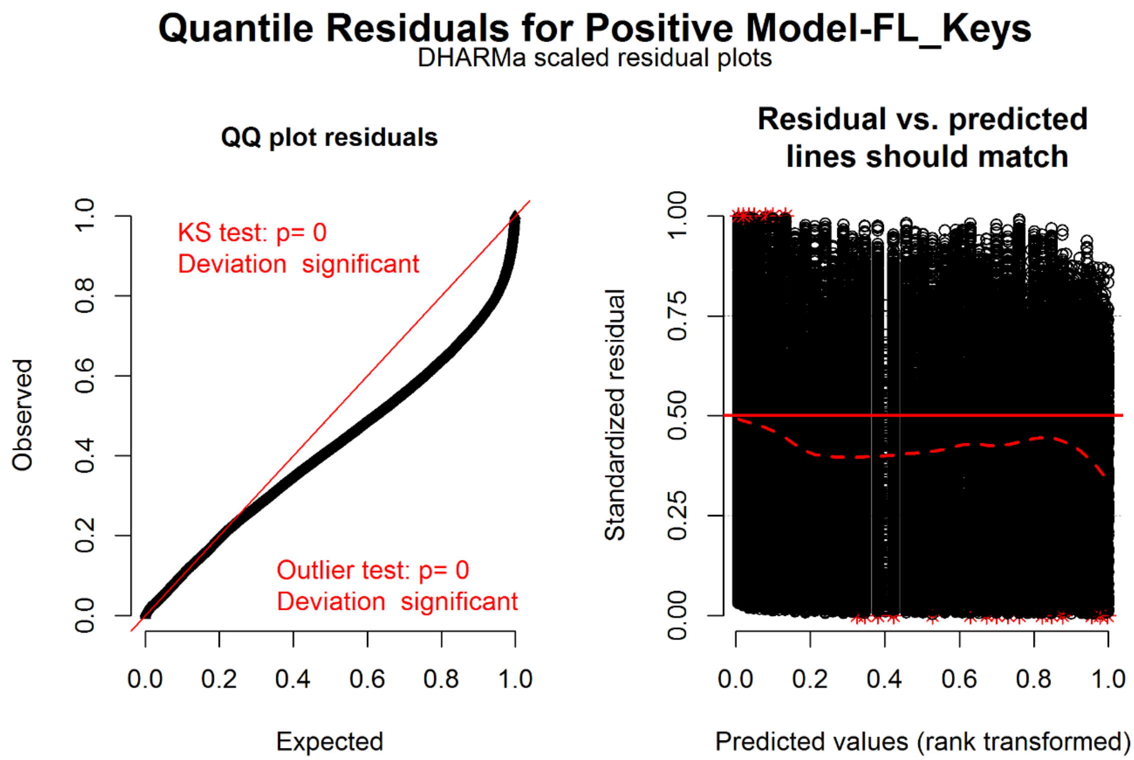


Figure 13. QQ plot residuals for the positive model for FL_Keys region.

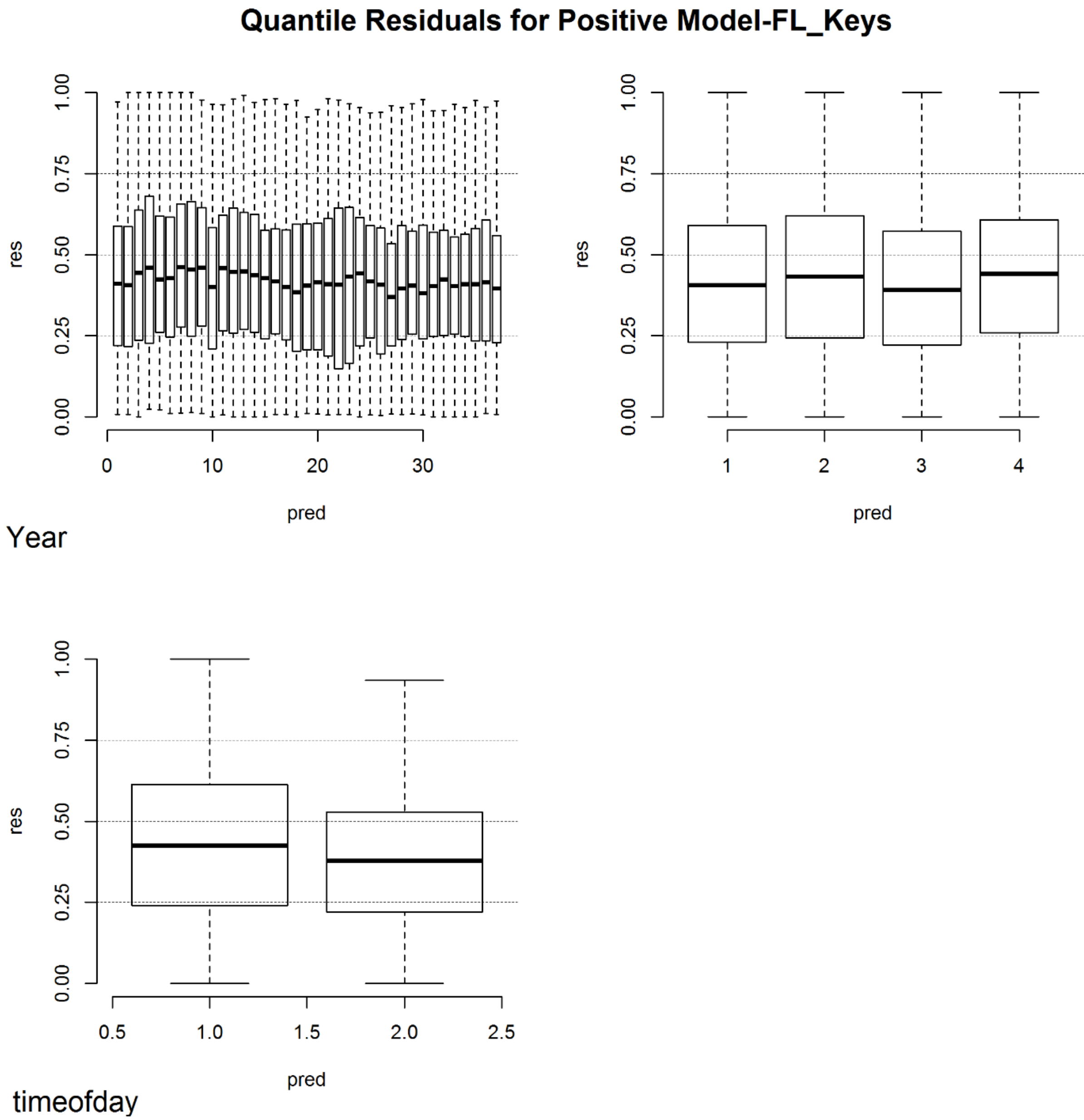


Figure 14. Scaled (quantile) residuals for the positive model for FL_Keys. Year has 37 levels (1981 -2017), season has four levels (winter, spring, summer, fall), and time of day has two levels (night time, day time).

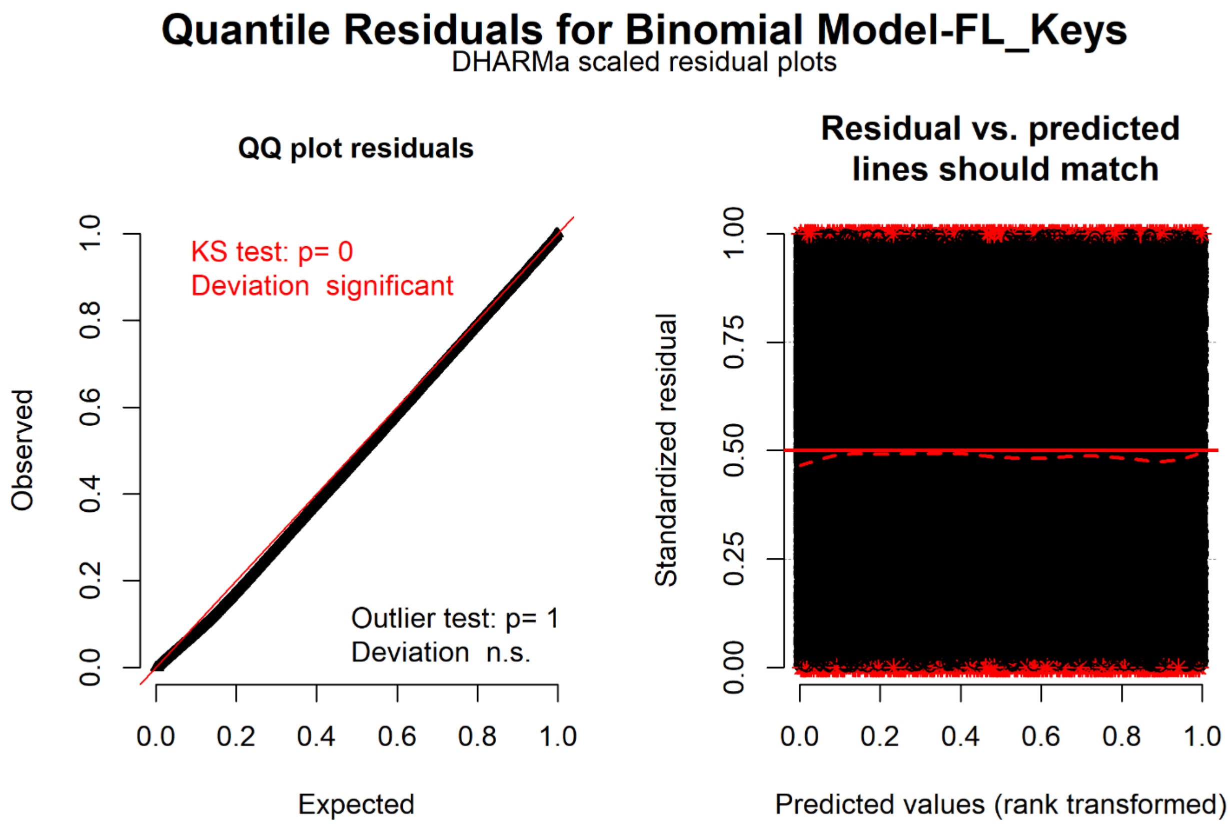


Figure 15. QQ plot residuals for the binomial model for FL_Keys region.

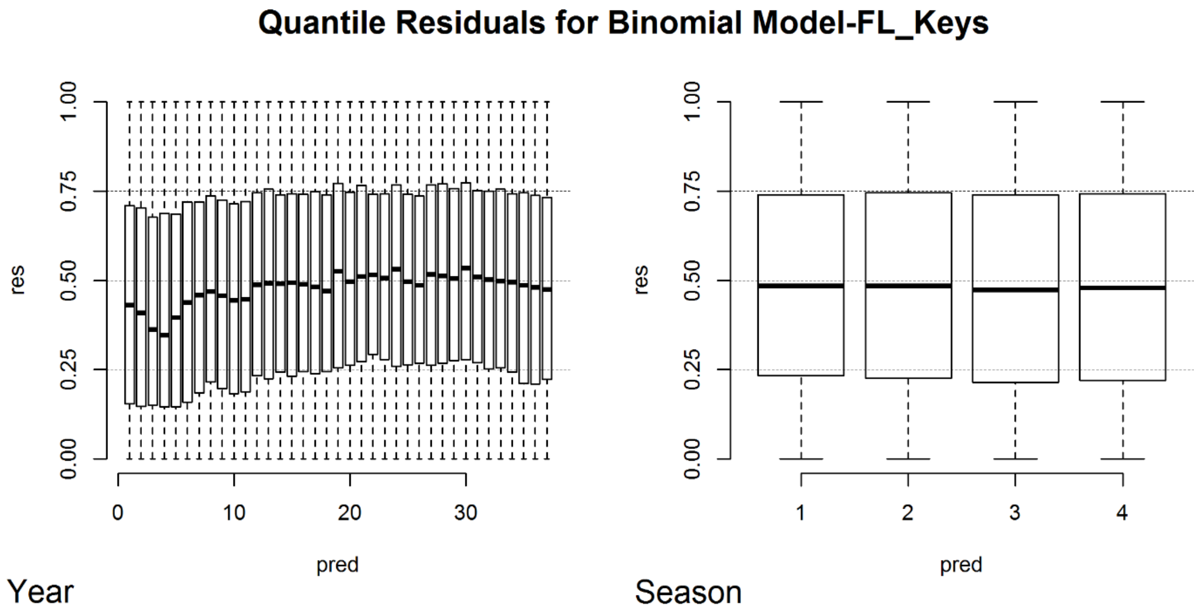


Figure 16. Scaled (quantile) residuals for the binomial model for FL_Keys. Year has 37 levels (1981 -2017) and season has four levels (winter, spring, summer, fall).

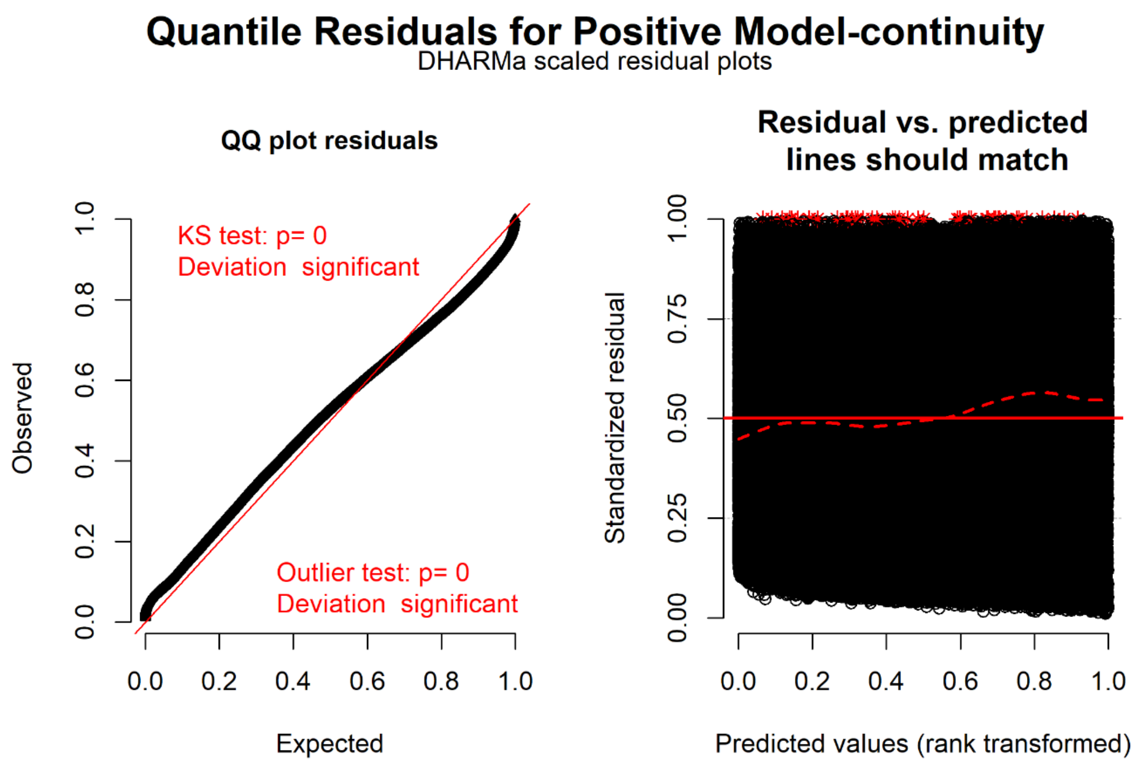


Figure 17. QQ plot residuals for the positive model for single area (continuity) model.

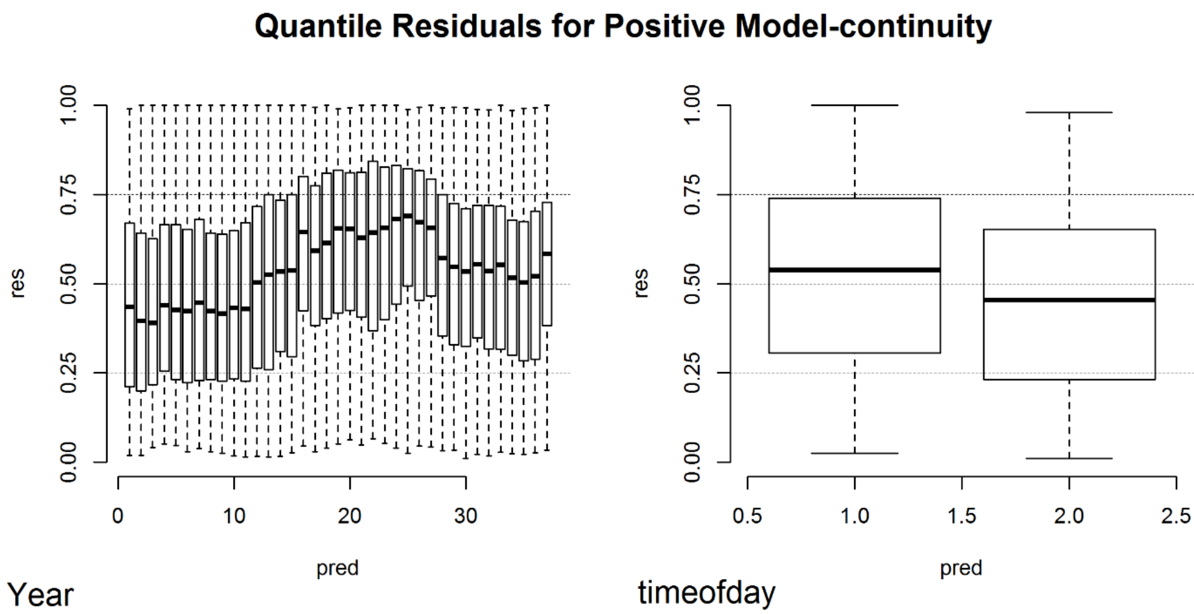


Figure 18. Scaled (quantile) residuals for the positive model for the single area (continuity) model. Year has 37 levels (1981 - 2017), and time of day has two levels (night time, day time).

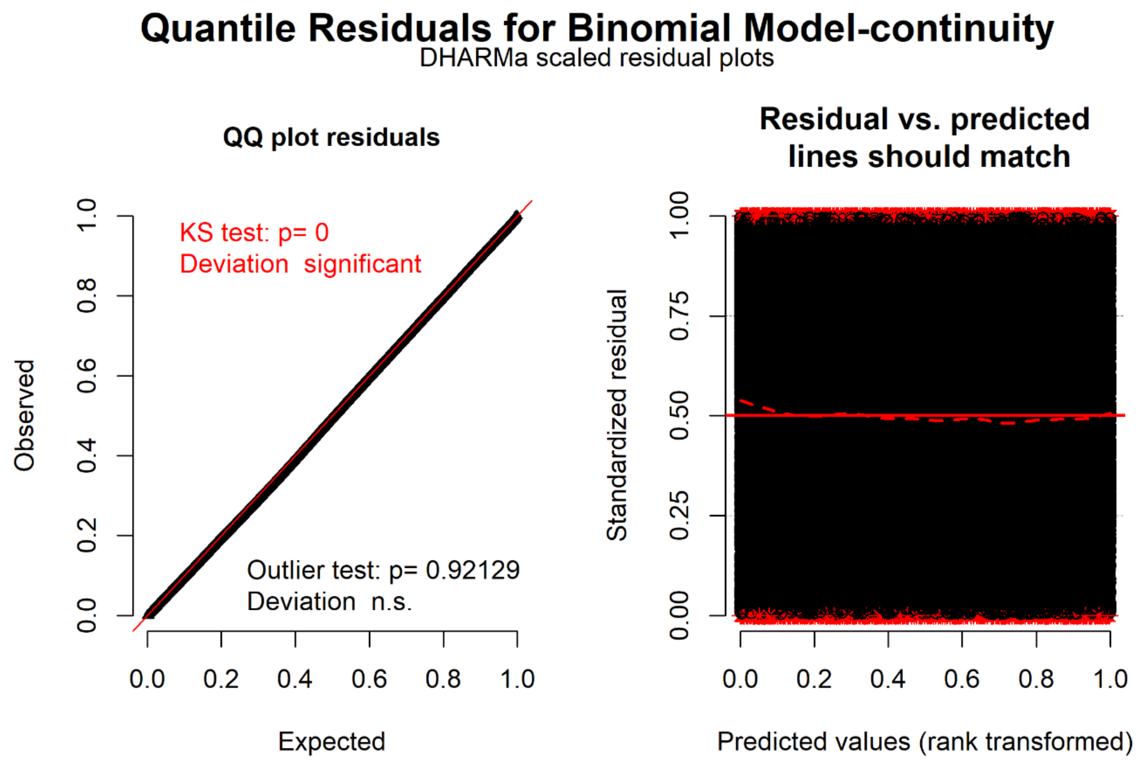


Figure 19. QQ plot residuals for the binomial model for the single area (continuity) model.

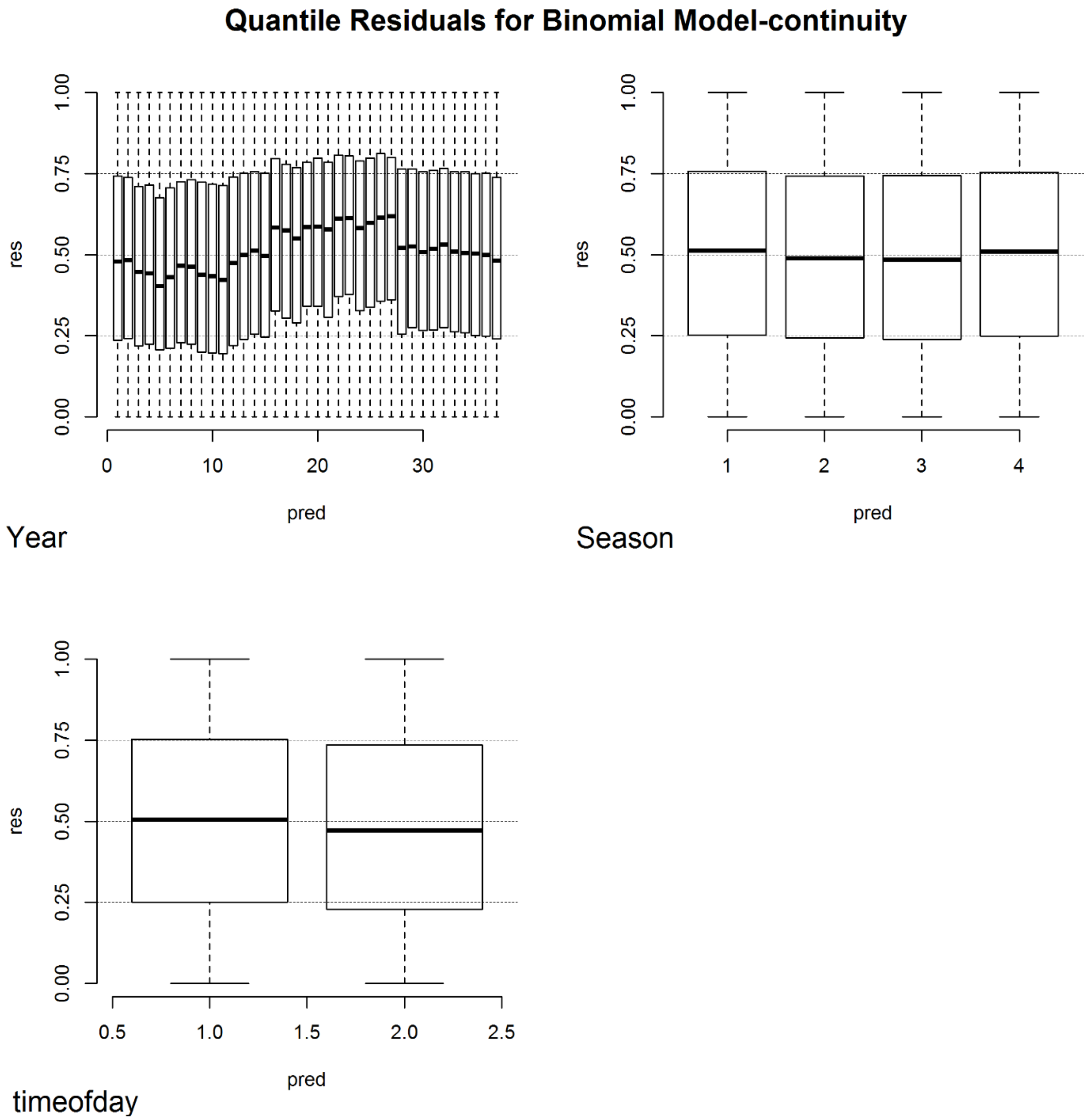


Figure 20. Scaled (quantile) residuals for the binomial model for the single area (continuity) model. Year has 37 levels (1981 - 2017), season has four levels (winter, spring, summer, fall), and time of day has two levels (night time, day time).

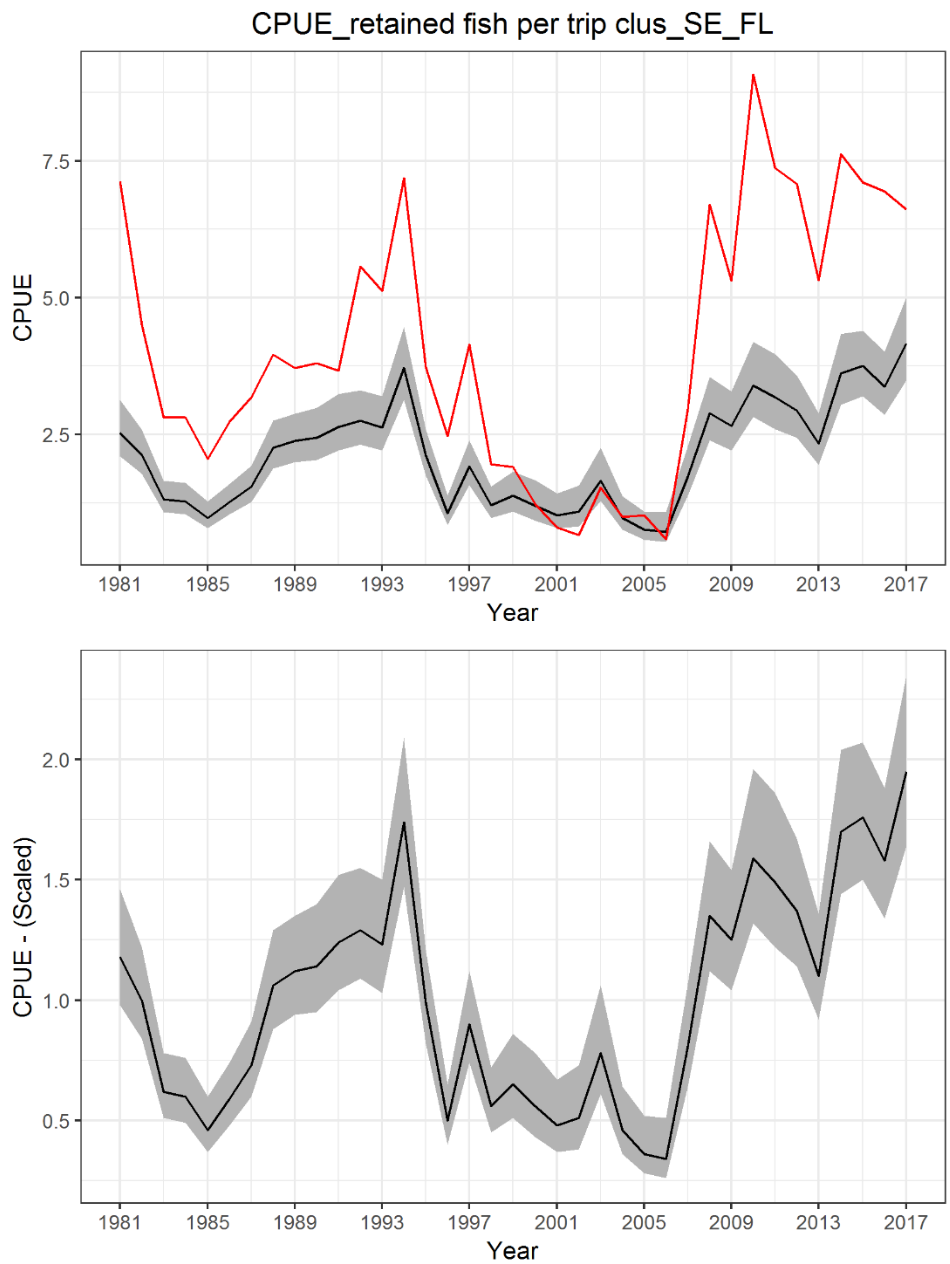


Figure 21. Standardized indices (black line) with 95% confidence intervals (grey ribbon) and nominal CPUE (red line) for SE_FL Yellowtail Snapper headboat catch rate index.

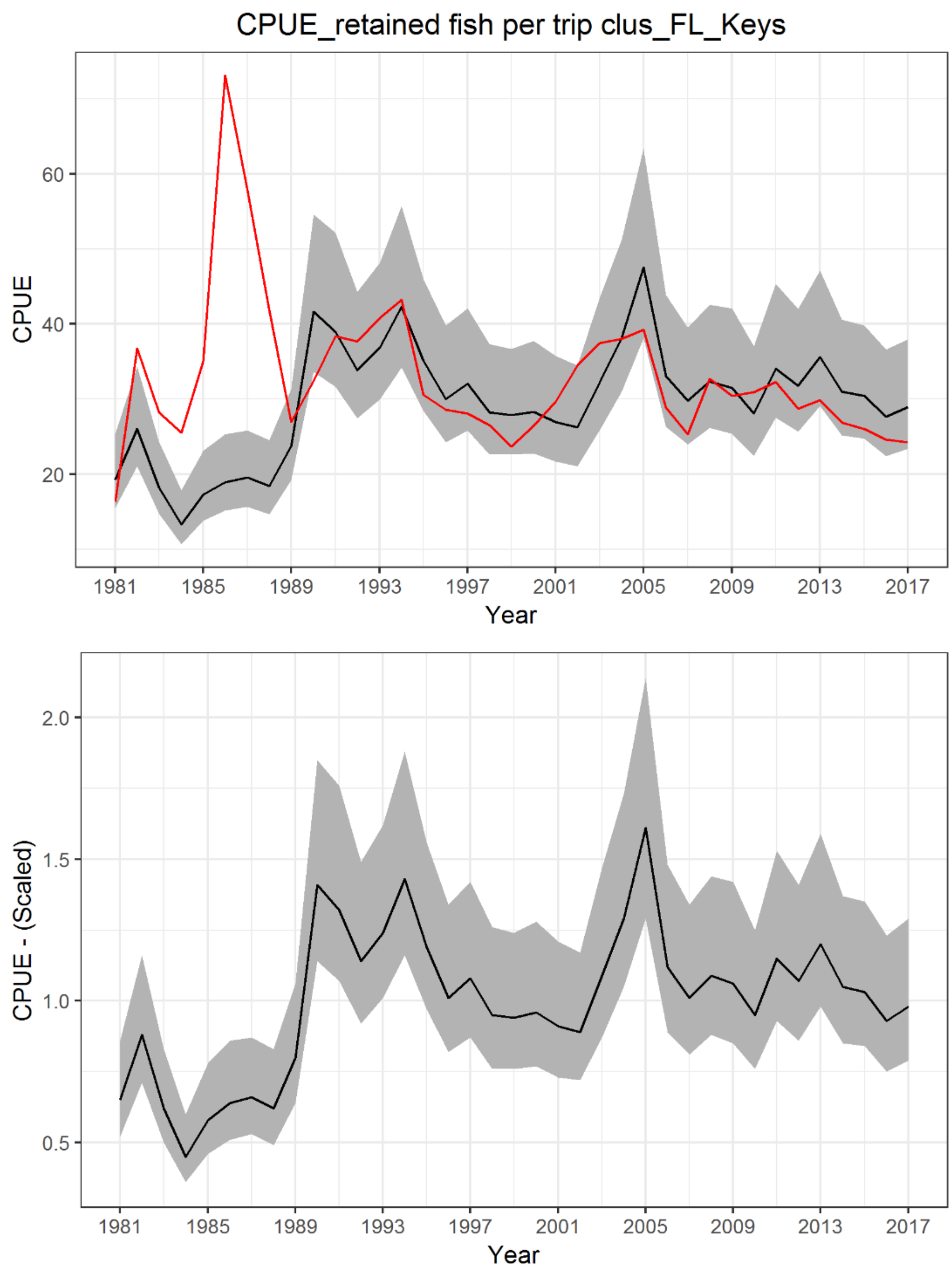


Figure 22. Standardized indices (black line) with 95% confidence intervals (grey ribbon) and nominal CPUE (red line) for FL_Keys Yellowtail Snapper headboat catch rate index.

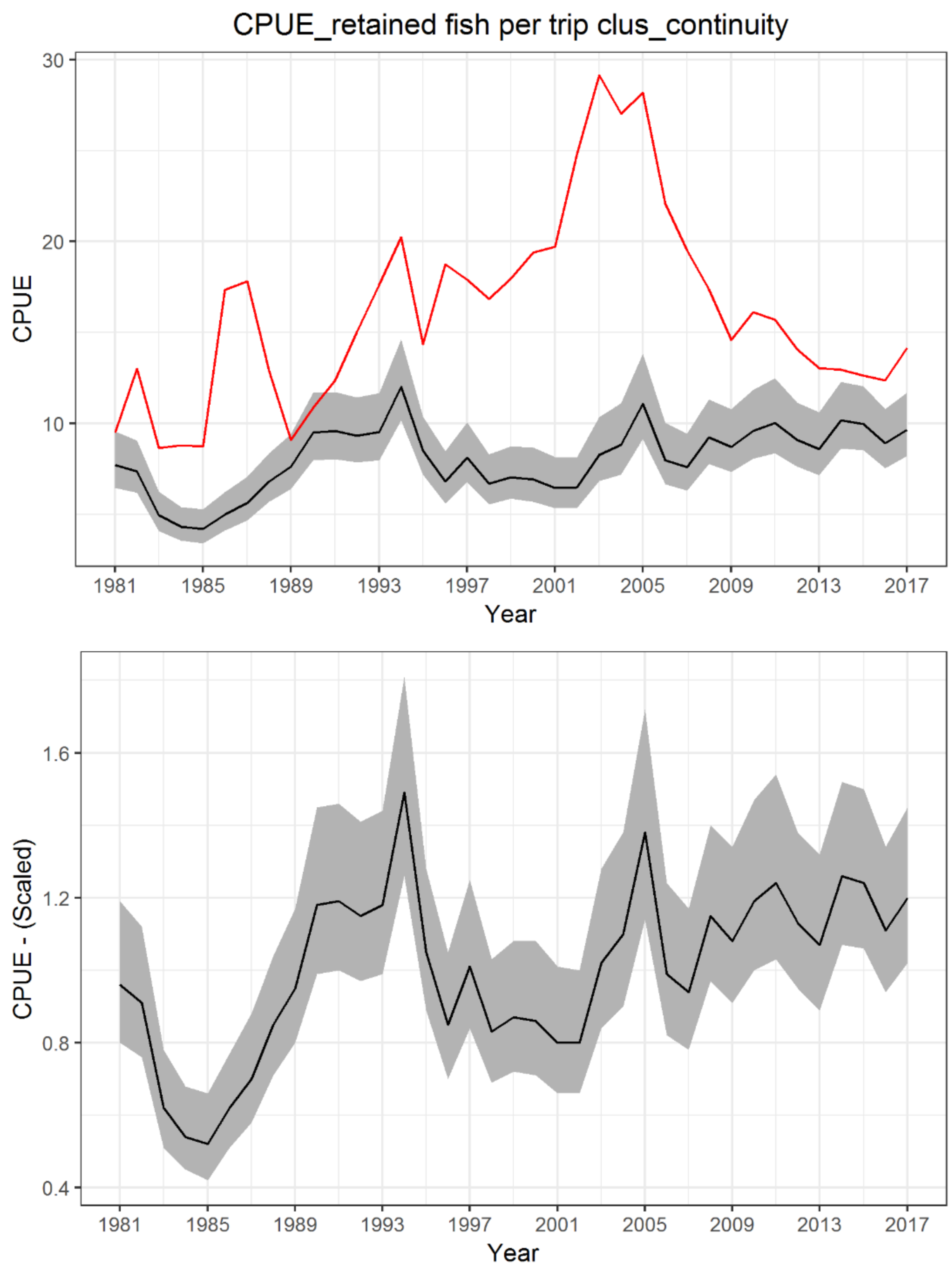


Figure 23. Standardized indices (black line) with 95% confidence intervals (grey ribbon) and nominal CPUE (red line) for the single area (continuity) model Yellowtail Snapper headboat catch rate index.

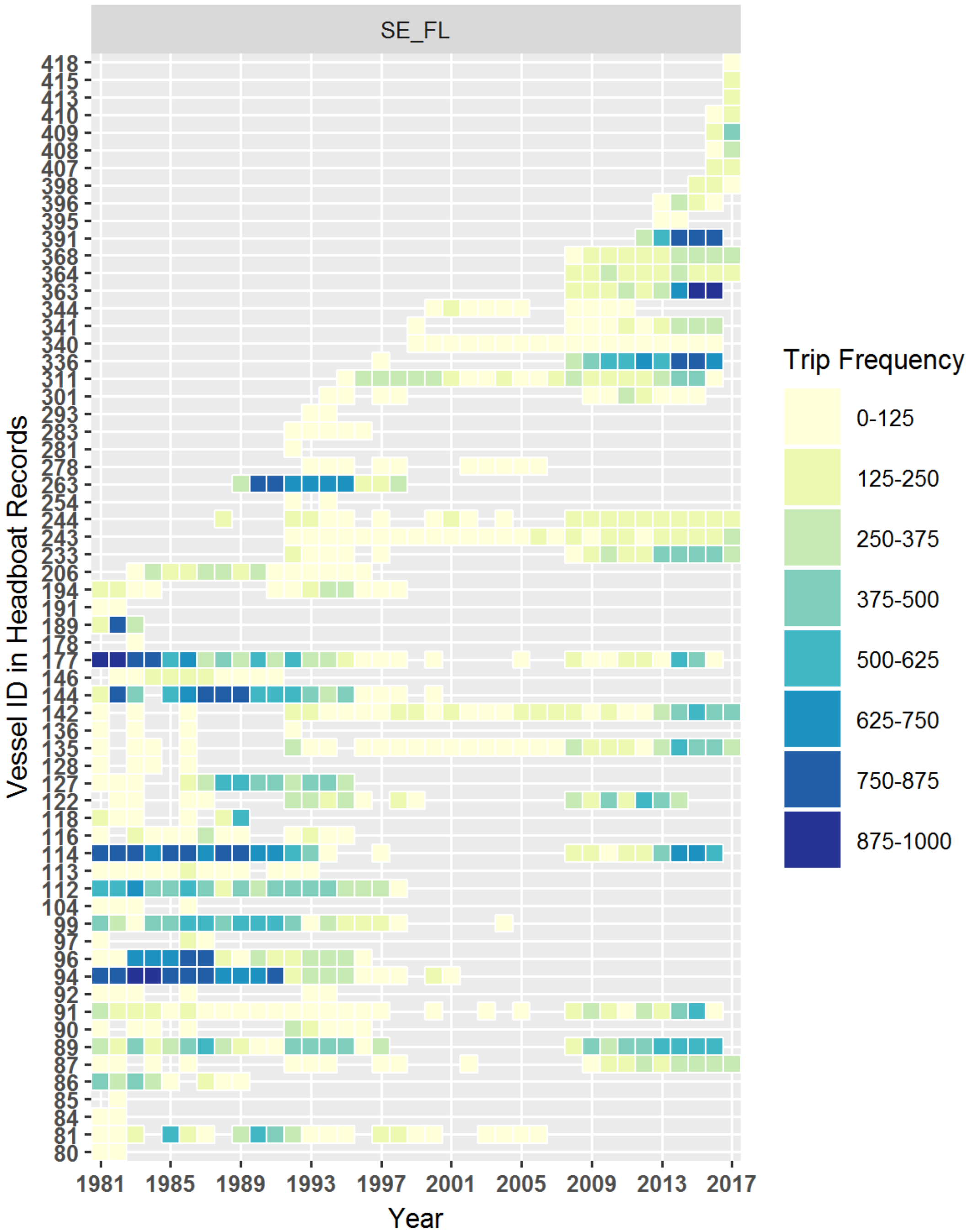


Figure 24. Total number of trips made by each vessel in the headboat registry per year in the SE_FL region.

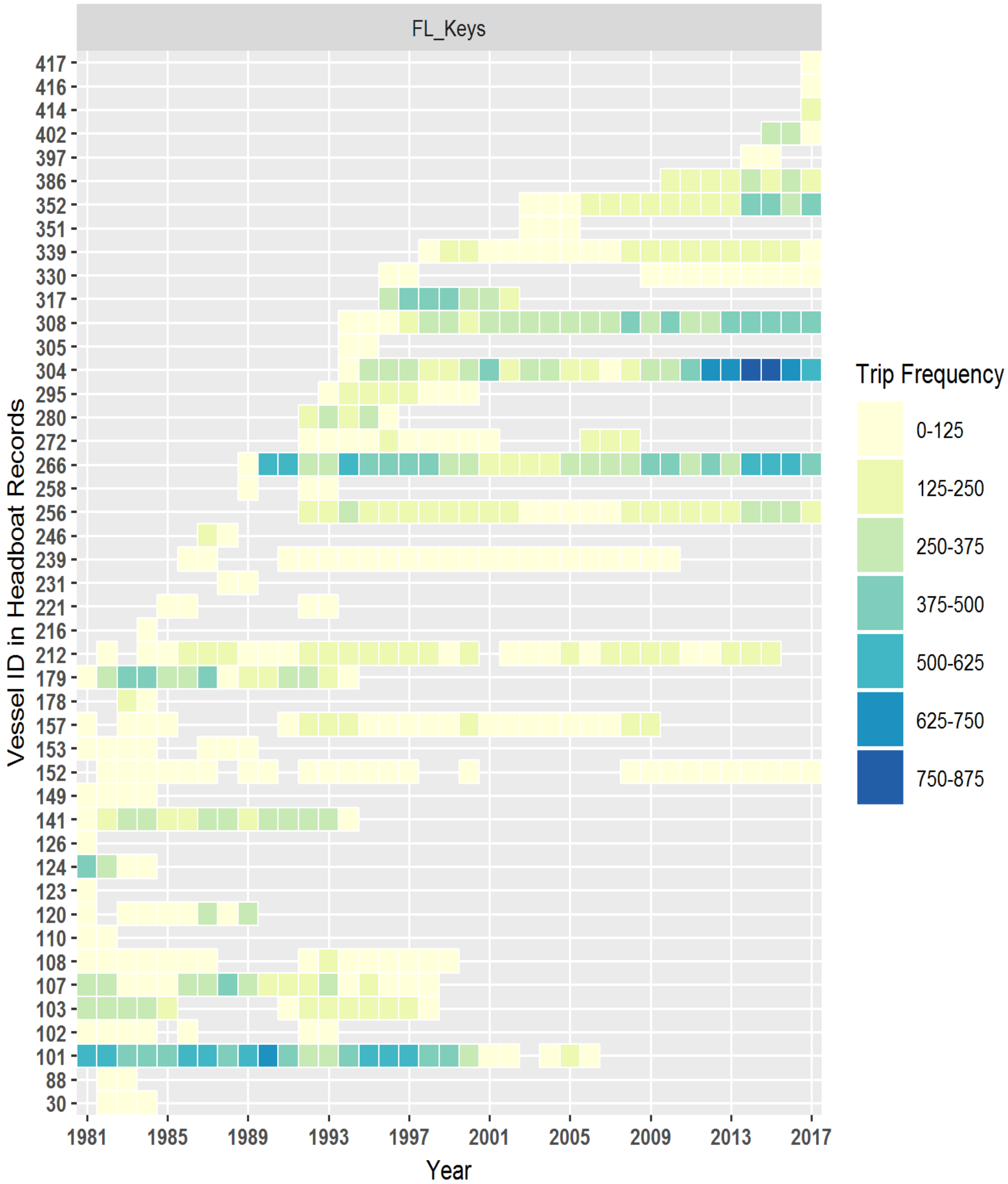


Figure 25. Total number of trips made by each vessel in the headboat registry per year in the FL Keys region.

Appendix A – Total Catch in numerator of CPUE.

Total catch (retained plus releases) was explored as a numerator in CPUE. However, release information is not available for the entire time frame (1981-2017) so a CPUE based on total catch is available only for models with a 2008 start year. The same covariates were evaluated in the positive and binomial sub-models for each region and the index was generated using Monte Carlo simulations as described in the Methods section of this paper.

Table A1. Nominal mean CPUE and final modeled index for the SE_FL model where CPUE is based on total catch and start year is 2008.

Year	NumTrips	NominalMean	Mean	CV
2008	2728	7.14	4.73	0.14
2009	3444	5.76	4.94	0.15
2010	4102	9.78	5.93	0.15
2011	3893	7.72	5.54	0.16
2012	4620	7.96	5.28	0.14
2013	5604	6.55	4.69	0.14
2014	8573	9.00	6.31	0.13
2015	8557	9.41	6.85	0.12
2016	7117	9.03	6.21	0.13
2017	4028	8.12	7.00	0.13

Table A2. Nominal mean CPUE and final modeled index for the FL_Keys model where CPUE is based on total catch and start year is 2008.

Year	NumTrips	NominalMean	Mean	CV
2008	1907	51.17	60.8	0.10
2009	2019	47.53	58.7	0.10
2010	1949	47.65	53.3	0.10
2011	1958	43.46	51.5	0.10
2012	2201	39.55	49.4	0.11
2013	2574	41.90	54.2	0.10
2014	3290	42.58	56.6	0.11
2015	3534	35.84	48	0.11
2016	3172	32.41	39.6	0.11
2017	2993	32.76	39.8	0.11

Table A3. Nominal mean CPUE and final modeled index for the single area (continuity) model where CPUE is based on total catch and start year is 2008.

Year	NumTrips	NominalMean	Mean	CV
2008	4635	25.25	15.34	0.16
2009	5463	21.20	15.25	0.16
2010	6051	21.98	16.05	0.16
2011	5851	19.68	15.28	0.17
2012	6821	18.15	14.29	0.16
2013	8178	17.68	14.08	0.16
2014	11863	18.31	16.61	0.16
2015	12091	17.13	16.06	0.16
2016	10289	16.24	13.91	0.16
2017	7021	18.63	13.85	0.16

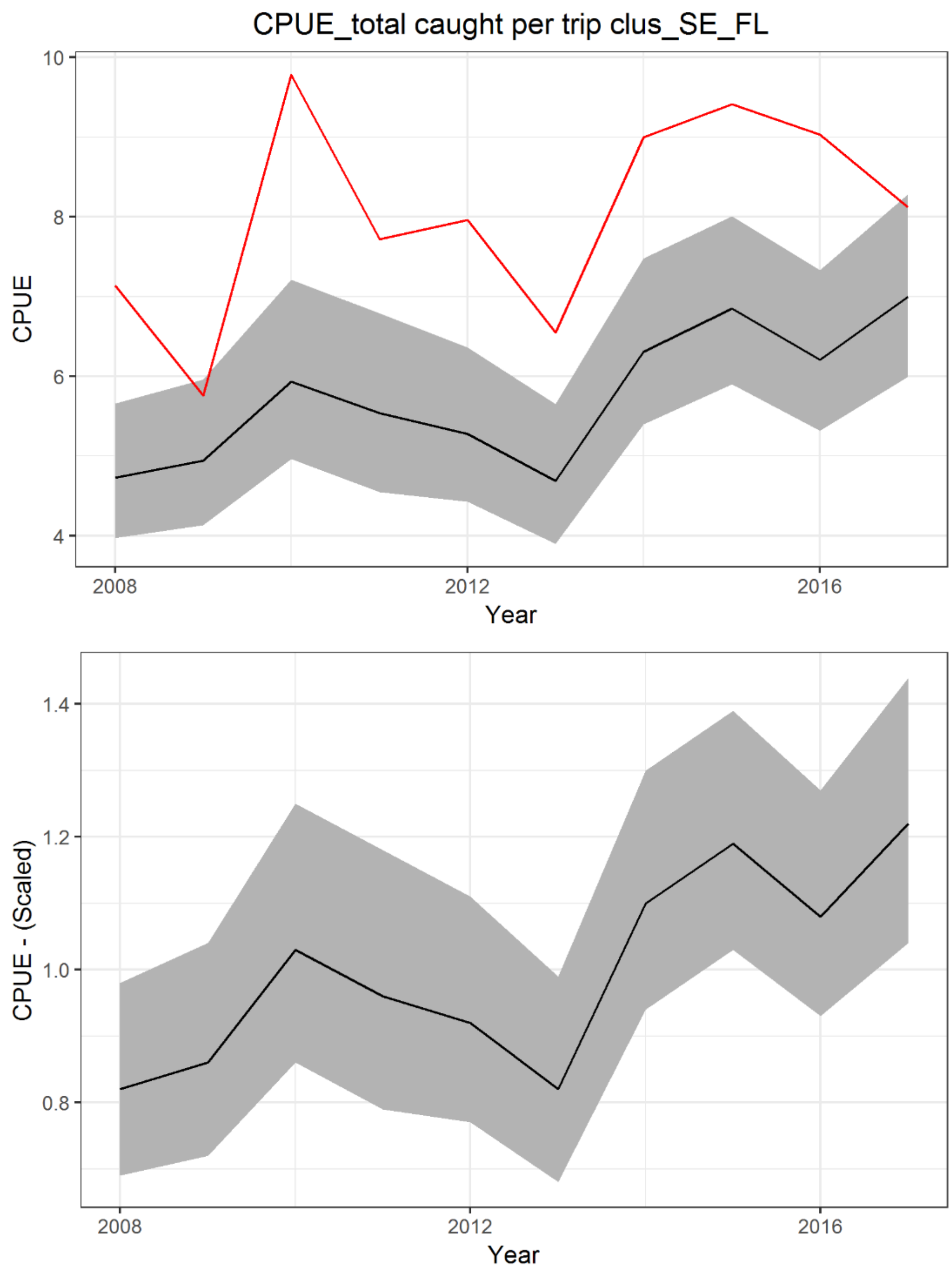


Figure A1. Standardized indices (black line) with 95% confidence intervals (grey ribbon) and nominal CPUE (red line) for SE_FL Yellowtail Snapper headboat catch rate index with total catch in the numerator.

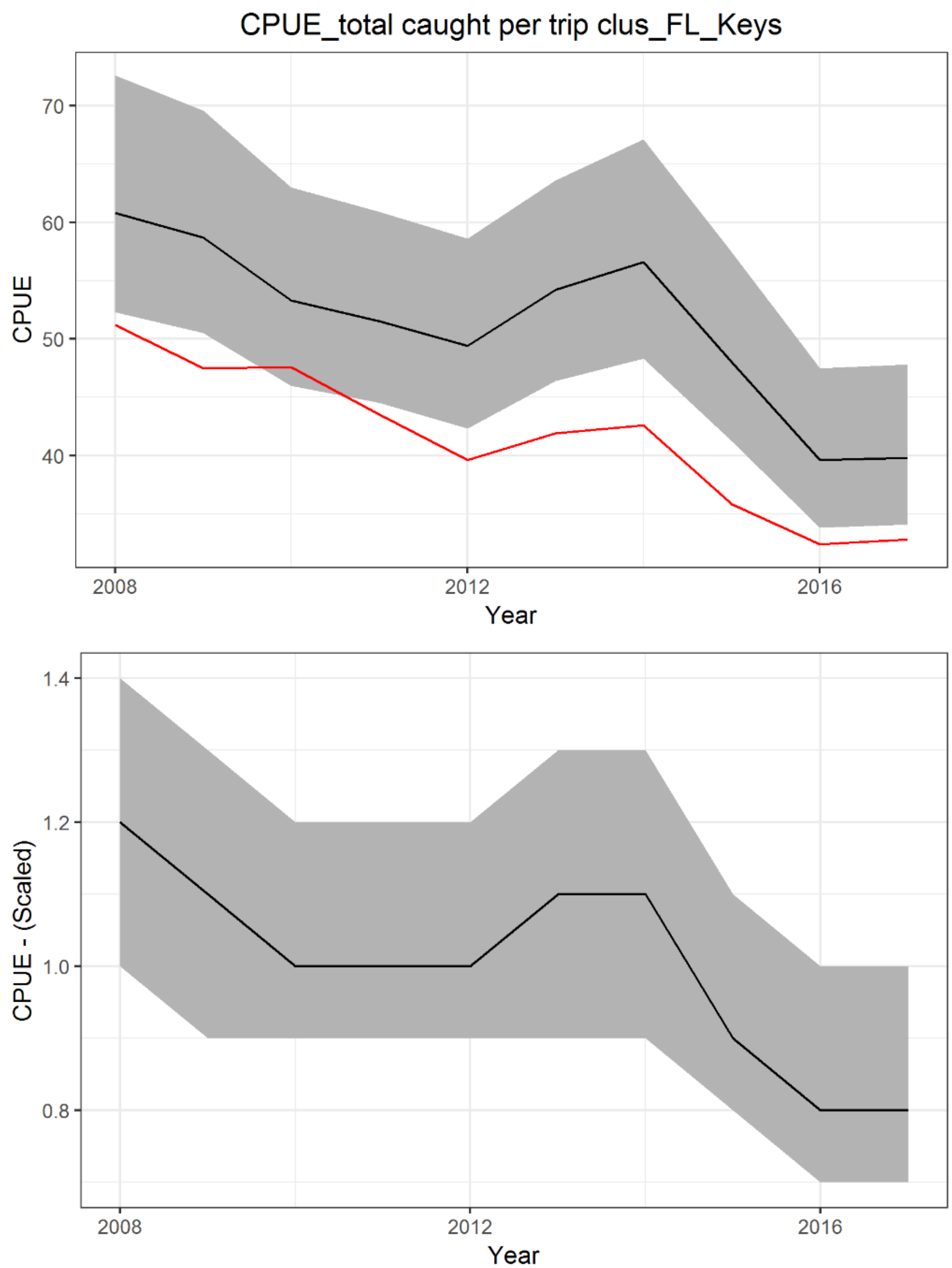
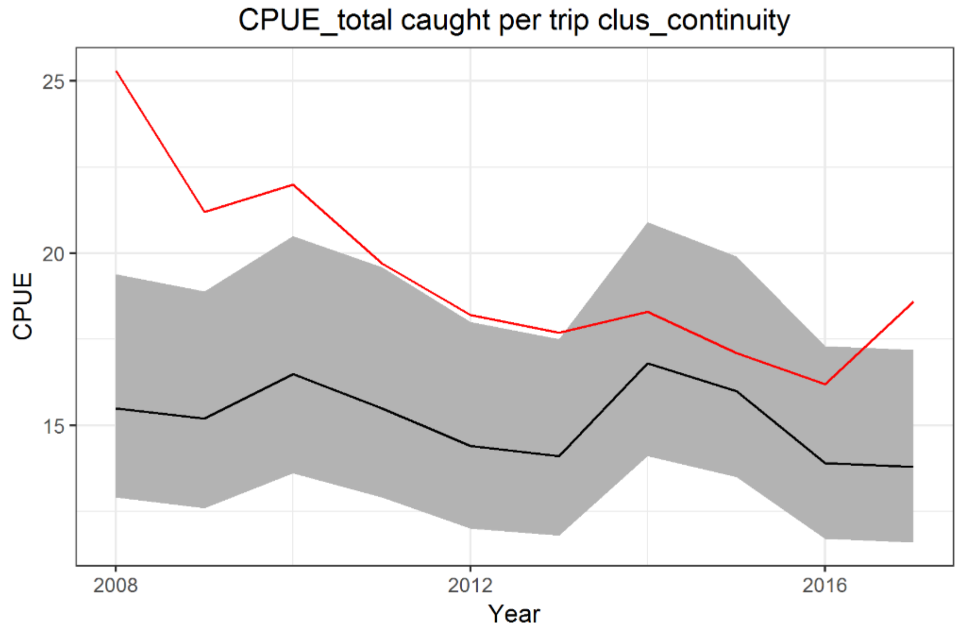


Figure A2. Standardized indices (black line) with 95% confidence intervals (grey ribbon) and nominal CPUE (red line) for FL_Keys Yellowtail Snapper headboat catch rate index with total catch in the numerator.



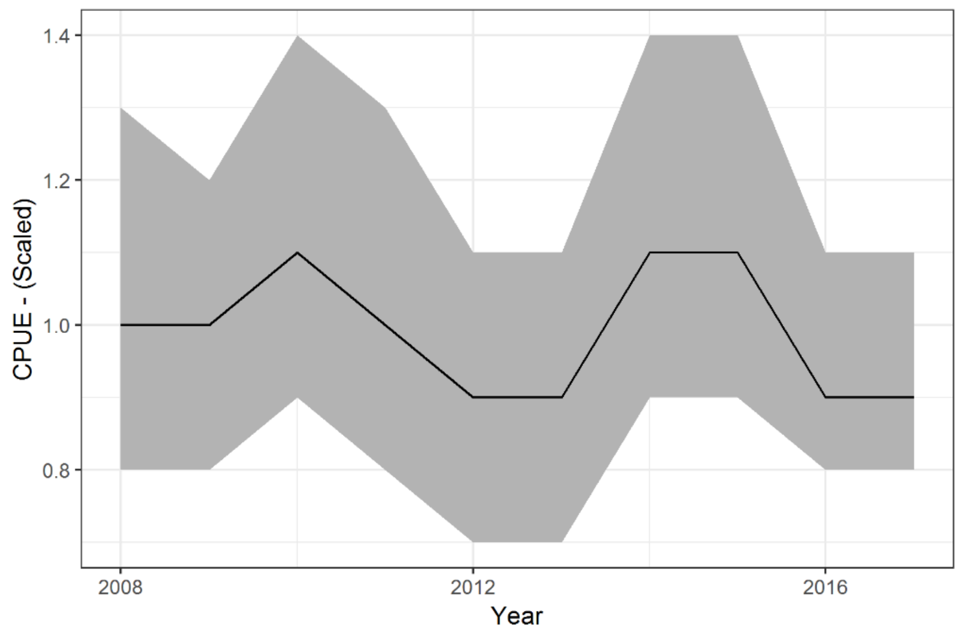


Figure A3. Standardized indices (black line) with 95% confidence intervals (grey ribbon) and nominal CPUE (red line) for the single area (continuity model) Yellowtail Snapper headboat catch rate index with total catch in the numerator.