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INFERRING SEASONAL MOVEMENTS OF TROPICAL TUNAS BETWEEN REGIONS IN THE EASTERN ATLANTIC OCEAN FROM CATCH PER UNIT EFFORT

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SUMMARY

Catch per unit effort data from the ICCAT Task II database are standardized in eight regions in the eastern Atlantic Ocean for skipjack tuna Katsuwonus pelamis*, yellowfin tuna,* Thunnus albacares*, and bigeye tuna,* T. obesus*. Data are evaluated to describe seasonal changes in relative abundance to inform movement patterns of the three species. Seasonal trends are observed in the three northernmost regions, the Azores, Canary Islands, and Senegal regions. The patterns in these regions suggest a seasonal movement north along the African coastline from the spring through the fall. Each of the three species has different timings of movements. Bigeye tuna begin their movement north first followed by skipjack and yellowfin moving north last, in accordance to their physiological adaptations to cold water. In the regions within the Gulf of Guinea, changes in relative abundance due to movement cannot be distinguished from changes due to recruitment.*

RÉSUMÉ

*Les données de prise par unité d'effort extraites de la base de données de la tâche II de l'ICCAT sont standardisées en huit régions de l'océan Atlantique pour le listao (*Katsuwonus pelamis*), l'albacore (*Thunnus albacares*) et le thon obèse (*T. obesus*). Les données sont évaluées pour décrire les changements saisonniers de l'abondance relative afin de fournir des informations sur les schémas de déplacement de ces trois espèces. Les tendances saisonnières sont observées dans les trois régions les plus septentrionales, les Açores, les îles Canaries et le Sénégal. Les tendances dans ces régions semblent indiquer un déplacement saisonnier vers le Nord le long de la côte africaine du printemps à l'automne. Chacune des trois espèces a différents calendriers de déplacement. Le thon obèse est le premier à se déplacer vers le Nord, suivi du listao et en dernier de l'albacore, ce qui coïncide avec leur adaptation physiologique à l'eau froide. Dans les régions à l'intérieur du golfe de Guinée, les changements de l'abondance relative dus aux déplacements ne peuvent pas être distingués des changements dus au recrutement.*

RESUMEN

*Se ha realizado una estandarización de la de captura por unidad de esfuerzo de la base de datos de Tarea II de ICCAT en ocho regiones del océano Atlántico oriental para el listado (*Katsuwonus pelamis*), el rabil (*Thunnus albacares*) y el patudo (*Thunnus obesus*). Se evaluaron los datos para describir cambios estacionales en la abundancia relativa con el fin de aportar información sobre los patrones de movimiento de las tres especies. Se observan tendencias estacionales en las tres regiones más septentrionales, las regiones de Azores, Canarias y Senegal. Los patrones observados en estas regiones sugieren un movimiento estacional hacia el norte a lo largo de la costa africana desde la primavera hasta el otoño. Cada una de las tres especies se desplaza en diferentes momentos. El patudo es el que primero comienza a desplazarse hacia el norte, seguido por el listado y, finalmente, por el rabil, que es el último que se desplaza hacia el norte, y este ritmo coincide con sus adaptaciones fisiológicas respectivas a las aguas frías. En las regiones dentro del golfo de Guinea, los cambios en la abundancia relativa debidos al movimiento no pueden distinguirse de los cambios debidos al reclutamiento.*

KEYWORDS

Migrations, tuna fisheries, catch/effort, bigeye tuna, yellowfin tuna, skipjack tuna

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1. Introduction

Catch per unit effort data is typically used to track the abundance of a species over time and is generally analyzed on a fleet by fleet basis and then combined to give an estimate of the entire stock status. Another use for CPUE data is to observe trends in fish abundance over the course of a year. When combined with tagging data, this would allow for a more accurate description of fish movement patterns (Fonteneau and Marcille 1993). Using CPUE as an index for abundance can have many pitfalls, including index hyperstability or hyperdepletion, expansion or contraction of the fishery over time, and changes in targeting strategy or fishing efficiency over time (Maunder and Punt 2004, Maunder *et al*. 2006, Carruthers *et al*. 2010). However, aggregating these data to look at patterns of abundance over the course of a year may minimize many of these problems. This method cannot differentiate between the arrival of new animals due to seasonal movements and the increase in CPUE due to recruitment; therefore indices in areas where recruitment occurs cannot be used to describe seasonal movement patterns. Also, this method may be biased when the sizes of captured animals are dependent upon the gear used, and fish may be present in an area even when they are not vulnerable to fishing gears due to their behavior (Fonteneau and Marcille 1993).

The disadvantages to using CPUE to describe seasonal movements of tuna can be reduced by using multiple years of data along with data from a variety of gear which accounts for the entire fished population. CPUE data were analyzed from the ICCAT Task II catch/effort database from 1975-2005, which overlaps with the tagging data used in previous tagging analyses for comparison (Sculley and Die 2014). Positive catch data were analyzed from all gear types to reduce bias from the size selectivity of individual gear types.

2. Methods

Catch per unit effort was extracted from Task II catch and effort data in each of the eight regions of interest between 1975 and 2005 (**Figure 1**). Positive catches in each region was standardized separately using a generalized linear model of the log-transformed CPUE using a Gaussian density distribution and an identity link function with up to five explanatory categorical variables: year, month, type of effort, flag, and gear (**Table 1**). No interactions were included in the model. Zero catches were ignored in this analysis because we were interested in the relative change of abundance over the course of year aggregated temporally across all the years. A stepwise regression estimating the logarithm of the CPUE was used to determine the most parsimonious model for each region using an identity link function. The best model was chosen based upon the lowest AIC value. The best model for most of the regions was the full model, including all five variables and an intercept, although in some regions reduced models were the most parsimonious. Some models dropped year as an explanatory variable, which would not be recommended if the purpose of the standardization was to evaluate trends over time (Maunder and Punt 2004). However, the interest here is the monthly trend, so year was allowed to be dropped if it was not statistically significant.

Fitted values were extracted from the best model and bias-adjusted and transformed back into normal space before values were scaled for comparison. To allow for the comparison of trends between each effort type in each region, the data were normalized. Each effort type subset was divided by the mean CPUE for the corresponding effort, and then all the efforts were recombined to observe trends in the data. These trends in the movement rates will be combined with the results of a quantitative analysis of tagging data to estimate yearly movement rates (Sculley and Die 2014), and will be used to describe when fish move into and out of a region within a year.

3. Results

3.1 Model fitting

The results of the stepwise regression for each region are listed in **Table 2**. For most regions, the full model with all five explanatory variables had the lowest AIC. For regions 1 and 2, reduced models generally had lower AIC values, likely due to the fewer number of fleets fishing in each area. The model for SKJ region 1 dropped the variable for year which was unexpected; however, it is likely due to the low number of observations (222) with positive catch. Model diagnostics for all the three species in each of the eight regions can be found in appendix 1. In general all the models fit the data well.

3.2 Bigeye tuna

There are clear trends in monthly CPUE in the more temperate regions evaluated. In the Azores, BET are primarily caught in April through July, with CPUE peaking in June. There are small catches in November and December, but no catch at all in January and February (**Figure 2**). In the Canary Islands, there is some catch year round, but the primary fishing season is in March – June with a peak in May. In Senegal/Cape Verde Islands, there are larger catches in July – February. CPUE peaks in October and is at a minimum in May. For the other four regions, catches are fairly constant throughout the year, with very little trends in the CPUE.

There are a lot of missing data for the yearly CPUE indices, with both the Azores and Canary Island regions missing >10 years of data (**Figure 3**). Most of this missing data is from the 1990s and the 2000s. In the Azores, the CPUE indices decrease over time, but data from 187-1995 and 2003-2005 are missing from the Task II database. From 1992-1995 and 1997-2005 is missing for the Canary Islands; however, CPUE does appear to increase into the late 1980s. There are no significant trends in the Senegal data, but it varies over time. In North Sherbro, there are lower CPUEs in the 1970s, which then increase into the 1980s and decrease slightly to become relatively constant in the 2000s. CPUE in Sherbro is relatively constant except for a large peak in 1990 and a smaller one in 1994 with a subsequent decrease back to pre-1990 levels. Similar to the Sherbro region, CPUEs are relatively stable throughout both the Cote d'Ivoire and Cape Lopez regions, except for a large increase in CPUE in 1990. In the Equatorial region, CPUE increases into the mid-1980s then decreases again into the 1990s. It is fairly constant into the 2000s.

3.3 Skipjack tuna

Skipjack tuna CPUE also appear to have seasonal trends in the more temperate regions, but trends are present in more regions than for bigeye. In the Azores, there is not enough catch data to draw any conclusions about the seasonal signal. In the Canary Islands, catch is primarily in June through December. CPUE peaks in July and August, with low catches January through May and a minimum in March (**Figure 4**). CPUE peaks in May through June and is large between April and October. There are occasional large catches in November through March, but generally CPUE is small. In North Sherbro, there is a general increase in CPUE over the course of the year, peaking in October and then decreasing to a minimum in February. CPUE peaks in December and January in Sherbro, with a minimum in March and peaks in April in Cote d'Ivoire and is relatively constant throughout the rest of the year. There are no significant trends in CPUE in Cape Lopez and the Equatorial regions.

Like bigeye, the Azores and Canary Islands are missing a large number of years of data in the Task II database (**Figure 5**). In the Azores, the years 1987-1995, 1997, 2000-2001, and 2003-2005 are not available. Further, there are few data points in the years available which causes the CPUE to be fairly constant over time. Similarly, the years 1992-1994, 1997-2001, and 2003-2005 are missing for the Canary Islands region. For the years available, CPUE appears to increase from the 1970s to the early 1980s, drops between 1985 and 1987, and then are very high in 1989-1991. In Senegal, the CPUE increases until 1990, then varies without trend and is low in the 2000s. A similar trend is evident in the North Sherbro and Sherbro regions, with a peak in 1990 and very large CPUEs in 2003 in North Sherbro. In both the Cape Lopez and Equatorial regions, the CPUE varies without trend except for a large CPUE in 1990.

3.4 Yellowfin tuna

Trends in CPUE for yellowfin tuna are much less pronounced than for skipjack and bigeye. Like skipjack, there is not a lot of CPUE data in the Azores, making it impossible to discern any trends. In the Canary Islands, catches are primarily in June through February with two peaks in February and September and October (**Figure 6**). There are very small CPUE in March through May. In Senegal, there is very little change in CPUE over the course of the year. There is a slight increase in CPUE in July through December with a peak in September and October. For the other four regions, there is very little change in CPUE over the course of a year.

Yellowfin yearly CPUE data does not show many significant trends, and like bigeye and skipjack, is missing many years in the Azores and Canary Islands (**Figure 7**). In the Azores, there are only a few data points (~30) available, and data is missing in 1997-1981, 1985-1996, and 2000-2004. This may be because yellowfin are not caught often in the Azores Islands. The Canary Islands are more complete, missing only 1992, 1993, 1997, 1998, 2000, and 2003-2005. Other than very large CPUEs in 2000, there are no significant trends over time. For the other six regions, the CPUE data generally varies without trend, with the exception that there are very large CPUEs in 1990 for all six regions.

4. Discussion

Using CPUE to describe seasonal tuna movements can be a valuable addition to tagging models. The use of CPUE in this manner reduces many of the problems which plagues using CPUE as a relative abundance index. Many of these problems, including hyper stability of the population, expansion of the fishery over time, and changes in targeting strategy or fishing efficiency over time will not impact the trends of CPUE over the course of a year. By aggregating over a large temporal range of data, it is most likely that the seasonal signal, if any, is captured in the analysis. The only drawback to this analysis is that these movements can only be evaluated in regions in which fish are not recruiting to the fishery, as the CPUE standardization cannot differentiate between increases in CPUE due to fish movement and increases in CPUE due to recruitment. For the tropical tunas, this means that in general, only regions north of 10°N and south of 10°S can be evaluated, as this is the area in which tropical tunas are believed to reproduce and recruit to the fishery.

Bigeye tuna take advantage of their more temperate nature and travel into the northern most regions first (**Figure 8,** Brill *et al*. 2005). They appear to leave the Senegal and further south regions in March, with CPUEs peaking in May in the Canary Islands and reaching the Azores in large numbers by June. They are caught in relatively large numbers during the rest of the year in Senegal. Skipjack follow the bigeye in their movements, although offset by a month or two. Skipjack appear to travel north from the equatorial areas and peak in May-June in Senegal, followed by July and August in the Canary Islands, and some skipjack appear to continue north to the Azores in the boreal fall.

Yellowfin tuna are rarely caught in the Azores as it is too cold and they tend to be more tropical than skipjack or bigeye tuna. However, they are caught in small numbers in the boreal fall. Yellowfin appear to take advantage of the warmer surface waters in the Canary Islands in the boreal summer and fall, with catches peaking in September and October, before returning further south to the Senegal area and beyond, where CPUEs are generally constant throughout the year. Bigeye tuna are known to be better adapted for colder water temperatures, therefore it is not surprising that they reach the northernmost regions first, followed by a month or two by skipjack, and then yellowfin reaching the northern most waters when they are at their warmest (Graham 1974, Brill 1994). This pattern is clearly evident in the trends in CPUE between the three more temperate regions, the Azores, the Canary Islands, and Senegal and the Cape Verde Islands.

The CPUE standardization used here ignores many of the changes in the fisheries that have occurred between 1975 and 2005. This includes the expansion of some fisheries, the differentiation between FAD catches and free school catches, and the large increases in catchability due to technological advances and the increased use of FADs. The increases in CPUE in the 1980s and 1990s are likely a function of an increase in catchability for all of the fleets (Fonteneau *et al*. 2000). Also, the relatively stable CPUEs in the late 1990s and early 2000s may be in fact a decrease in population due to the increase in catchability for these fleets. Therefore, these yearly relative abundance indices could give a snapshot of the species in smaller regions, when the limitations of the standardization are taken into account.

Also, this standardization was for positive only, a delta model would be necessary to model zero catches as well. However, the standardization of the CPUE from the Task II data does expose some problems within the Task II database, especially concerning the large amounts of missing data from the 1990s and 2000s in the Azores and Canary Islands regions. The standardization used above removed all catches for which the effort data was missing; therefore it is most likely that the effort data is missing for these years and regions, rather than catch data. Without these data, it is difficult to get a full picture of the movement of tropical tunas and the yearly relative abundance index in these seasonal fisheries.

This simple method of standardizing CPUE to evaluate seasonal movements of tropical tunas is a useful tool, which, when combined with tagging data, can increase our understanding of tuna movements in the Atlantic Ocean. Further, this may be applied to areas without tagging data to better understand the movements in more areas of the Atlantic. This method is only useful in areas without recruitment, however can identify seasonal movements into temperate areas. It also may be useful as a relative abundance index for smaller regions within the Atlantic despite its limitations in addressing potential biases in the data like increases in catchability. In general, the timing of the movements into temperate fishing zones corresponds to the known physiological characteristics of each of the tropical tuna species and can be applied to other areas of the Atlantic as well as the Indian and Pacific Oceans.

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Table 1. List of Generalized Linear Models which were tested for each region and species.

Model	Dependent Variable	Explanatory Variables
Full	log(CPUE)	Year + Month + Effort type + Fleet + gear
1	log(CPUE)	Year + Month + Effort type + Fleet
2	log(CPUE)	Year + Month
3	log(CPUE)	Year + Month + gear
4	log(CPUE)	Month + Effort type
5	log(CPUE)	Year + Fleet
6	log(CPUE)	Year + Effort type
7	log(CPUE)	Month + Effort type + Fleet
8	log(CPUE)	Year + Month + Fleet + Gear
9	log(CPUE)	Year + Month + Effort type + Gear
10	log(CPUE)	Year + Month + Fleet
11	log(CPUE)	Year + Month + Effort type

Table 2. AIC values for the five best fit models for each region and species. Highlighted values are the lowest AIC.

BET					
Model	Full	1	2	3	4
Region 1	349.06	349.06	403.62	347.07	
Region 2	1239.9	1239.9	1532.9	1300.2	
Region 3	18661	19050	23236	19153	
Region 4	33653	33675	47209	34653	
Region 5	35218.6	35217	42374	35787	
Region 6	42108	42277	47046	43462	
Region 7	6735.9	6737.7	8255.3	7982.1	
Region 8	57245	57263	81864	58860	
SKJ					
Region 1	190.61	190.61	203.69	203.69	181.95
Region 2	677.95	677.95	733.73	733.73	
Region3	24243	25529	28598	24592	
Region 4	23804	24439	34047	24439	
Region 5	31173	31179	37055	31586	
Region 6	52904	52973	60760	56167	
Region 7	8333	8335.6	9756.8	8591.2	
Region 8	41193.2	41191.5	61448	42263	
YFT					
Region 1	66.34	66.34	66.34	66.34	
Region 2	585.3	585.3	807.35	661.12	
Region3	22665	22775	27650	23420	
Region 4	35654	35933	60108	36404	
Region 5	40388	40400	54443	41141	
Region 6	60120	60818	71087	62664	
Region 7	9509.4	9510.4	12038	10809	
Region 8	63488	63601	106160	66398	

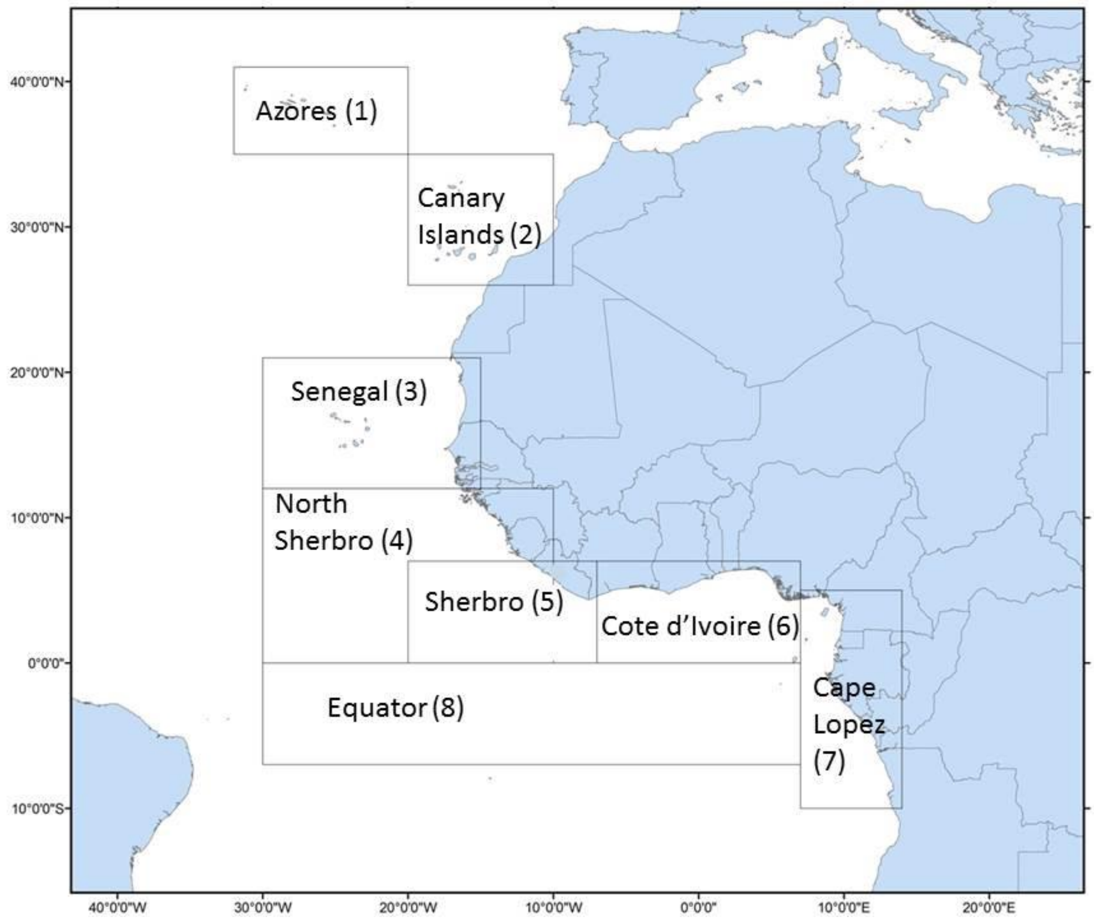

Figure 1. The eight regions analyzed for movement patterns, numbers in parethases indicate region number.

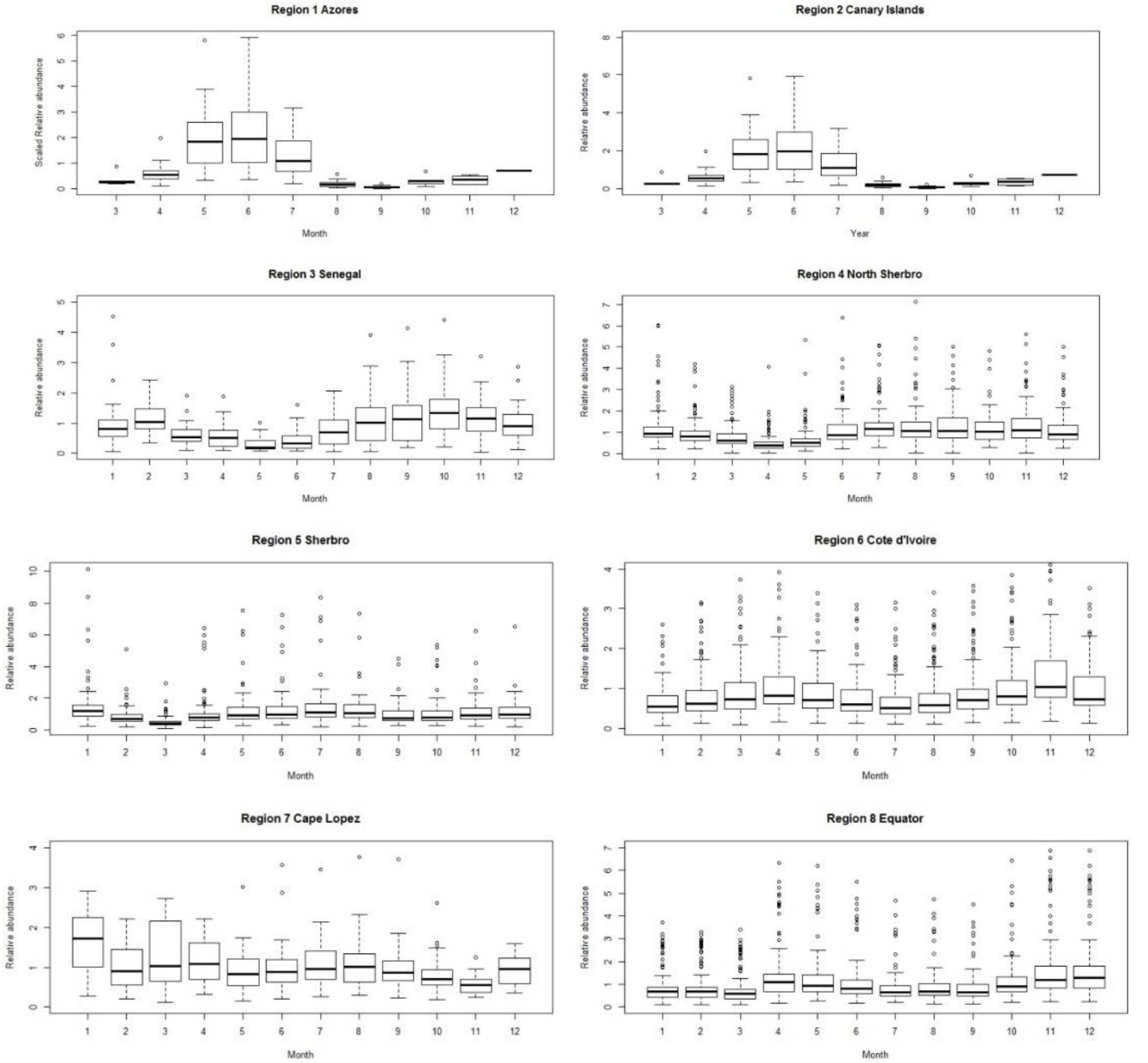

Figure 2. Monthly patterns in standardized CPUE for BET. Values are normalized to the mean for each effort type.

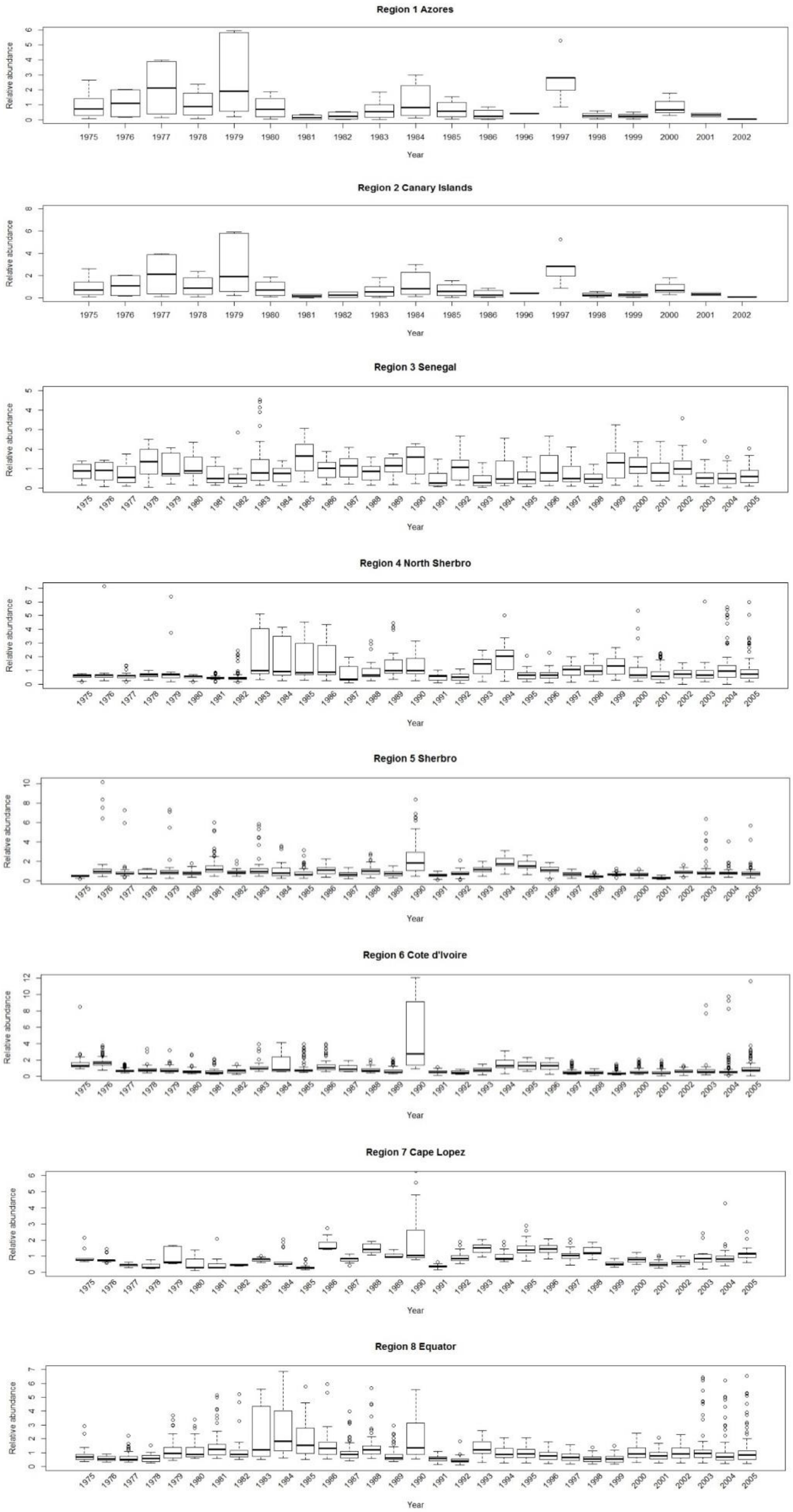

Figure 3. Standardized BET CPUE by year for each region, normalized to the mean of each effort type.

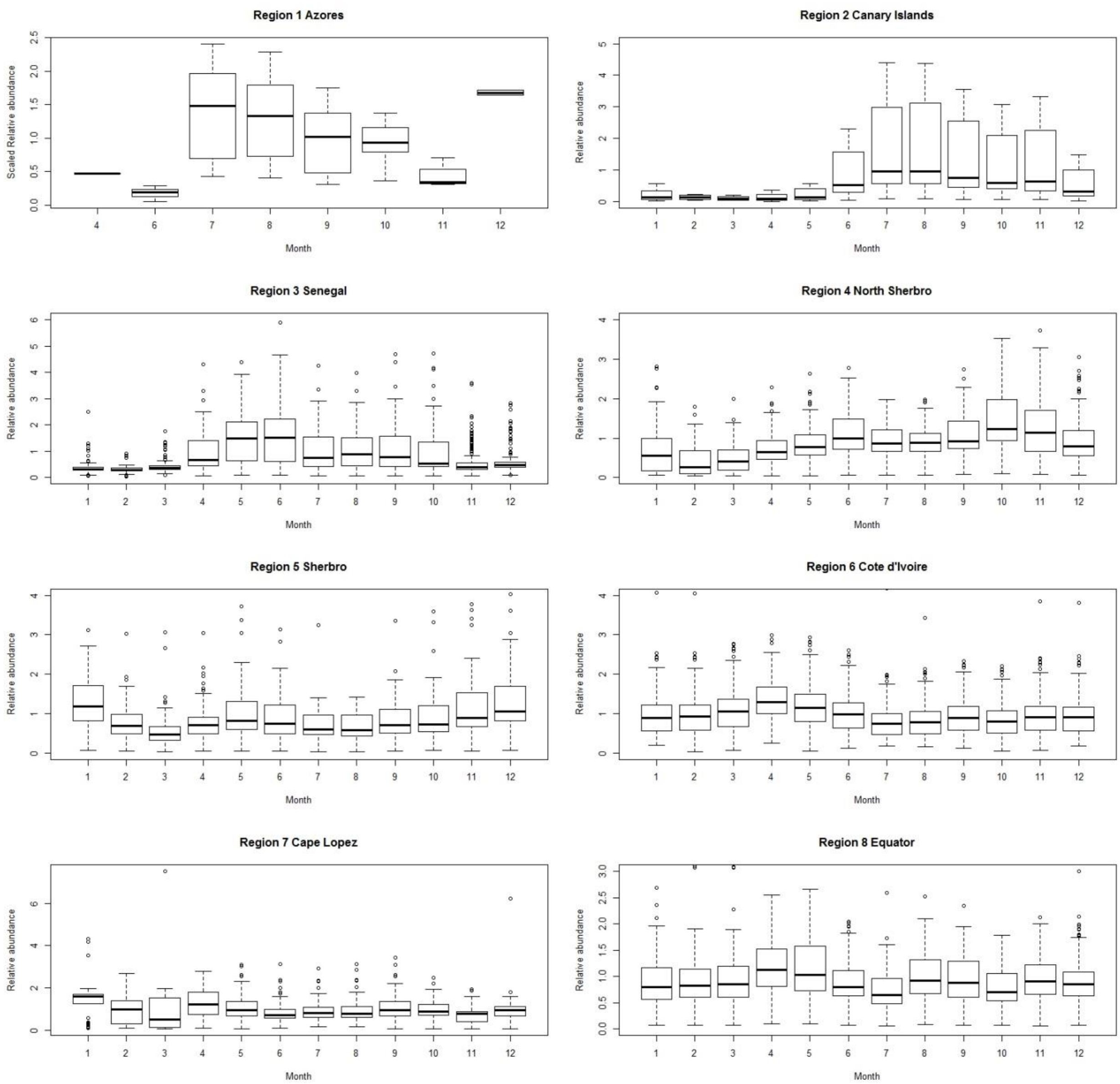

Figure 4. Monthly patterns in standardized CPUE for SKJ. Values are normalized to the mean for each effort type.

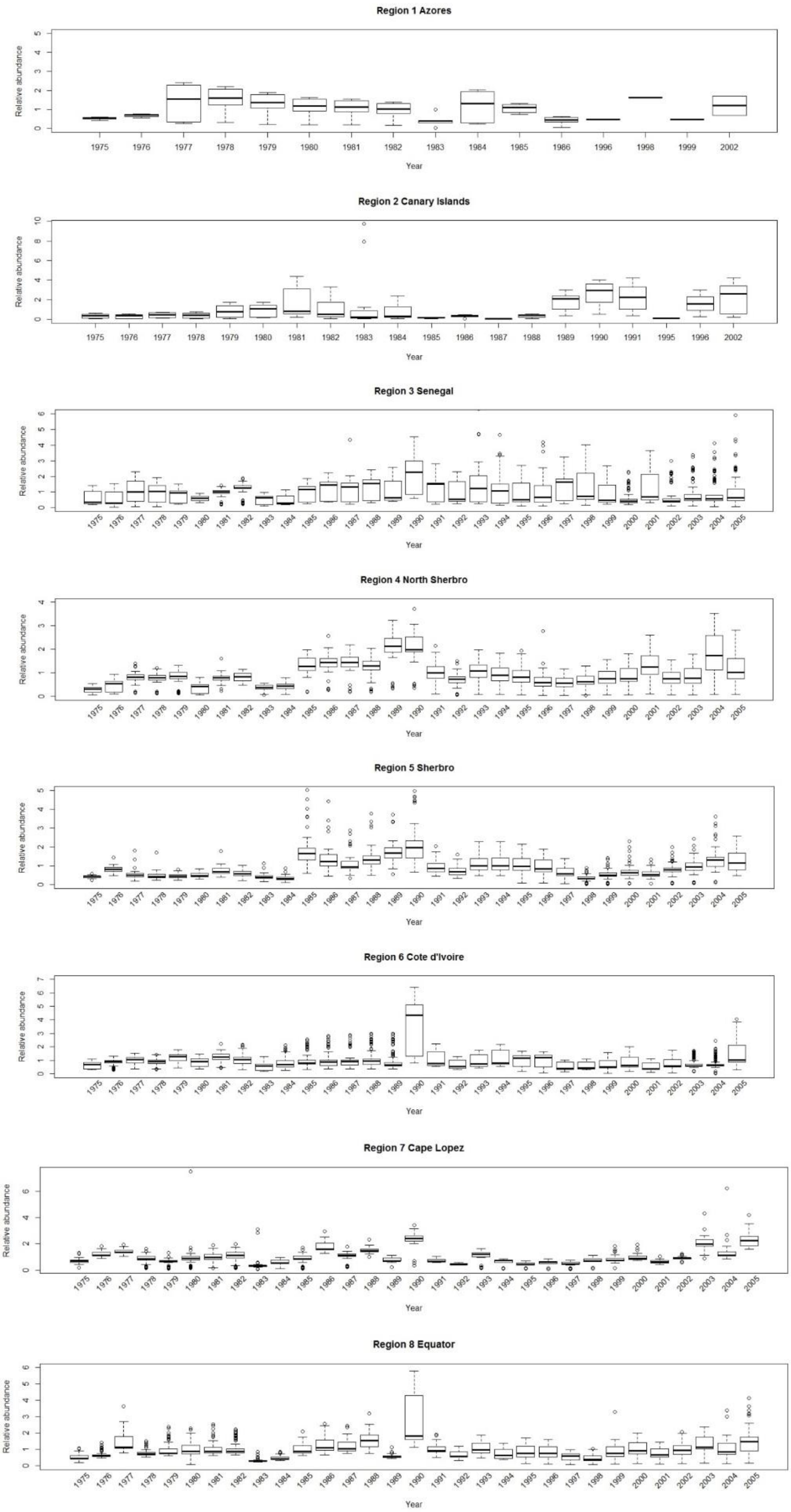

Figure 5. Standardized SKJ CPUE by year for each region, normalized to the mean of each effort type.

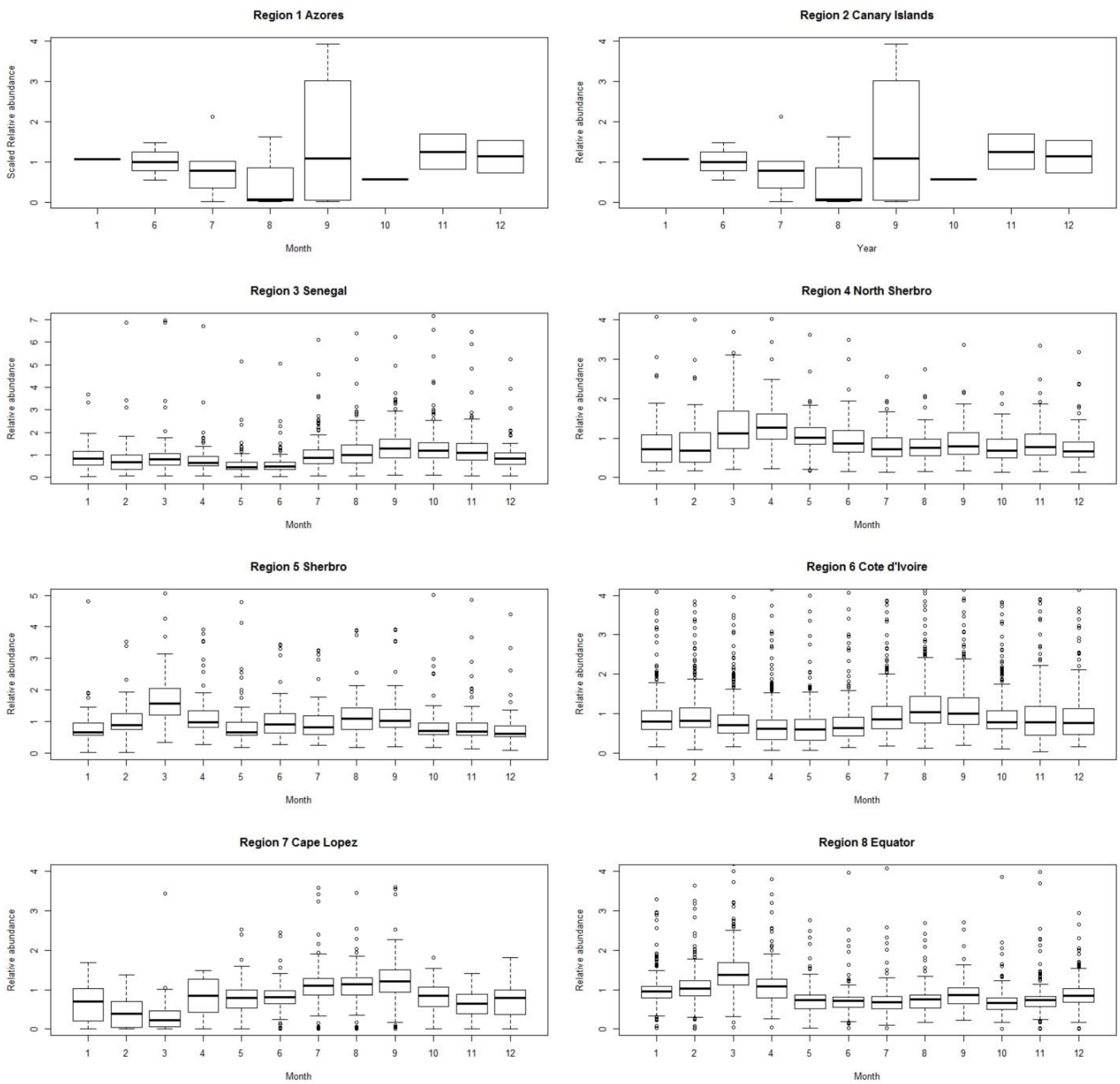

Figure 6. Monthly patterns in standardized CPUE for YFT. Values are normalized to the mean for each effort type.

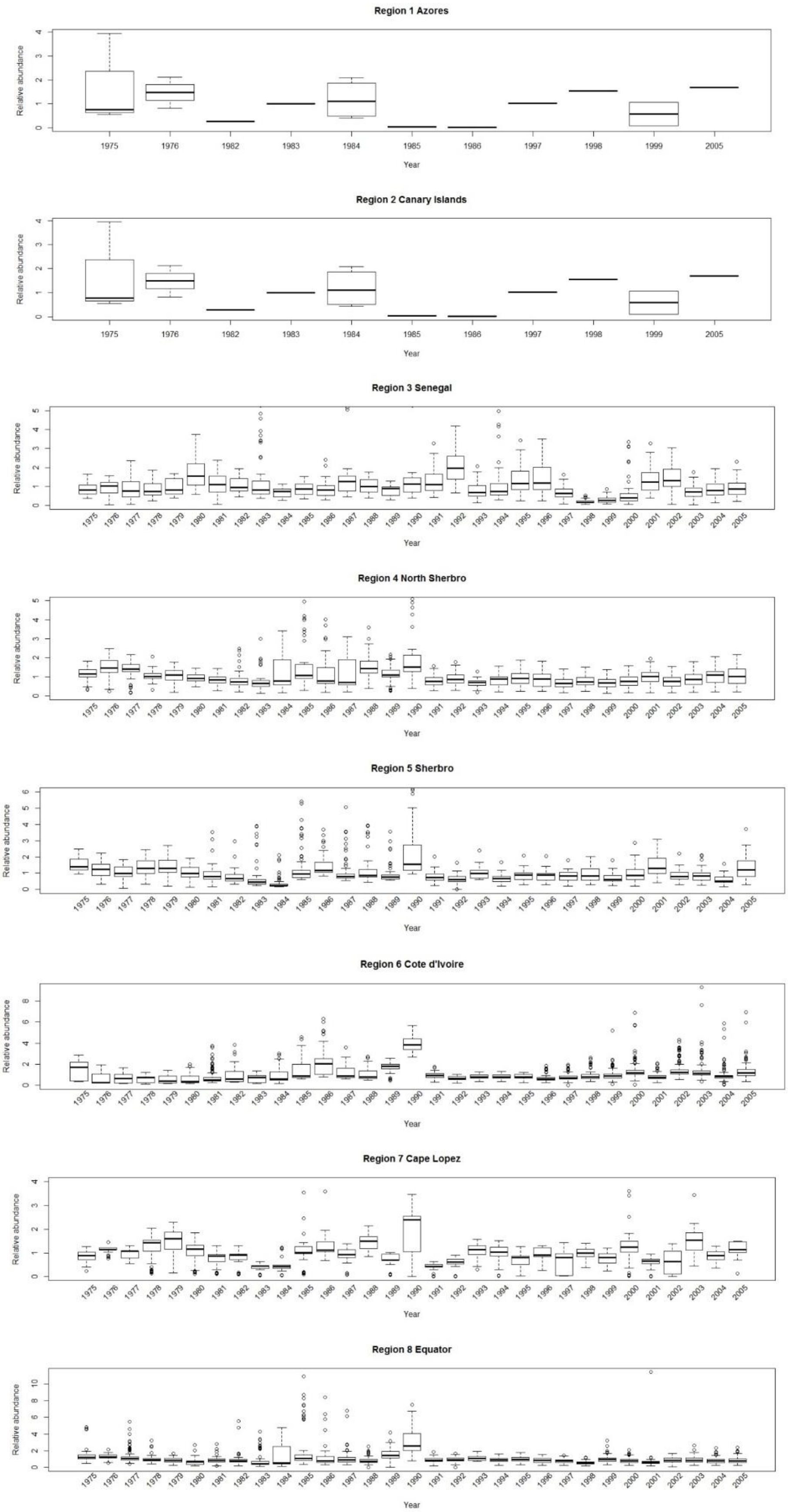

Figure 7. Standardized YFT CPUE by year for each region, normalized to the mean of each effort type.

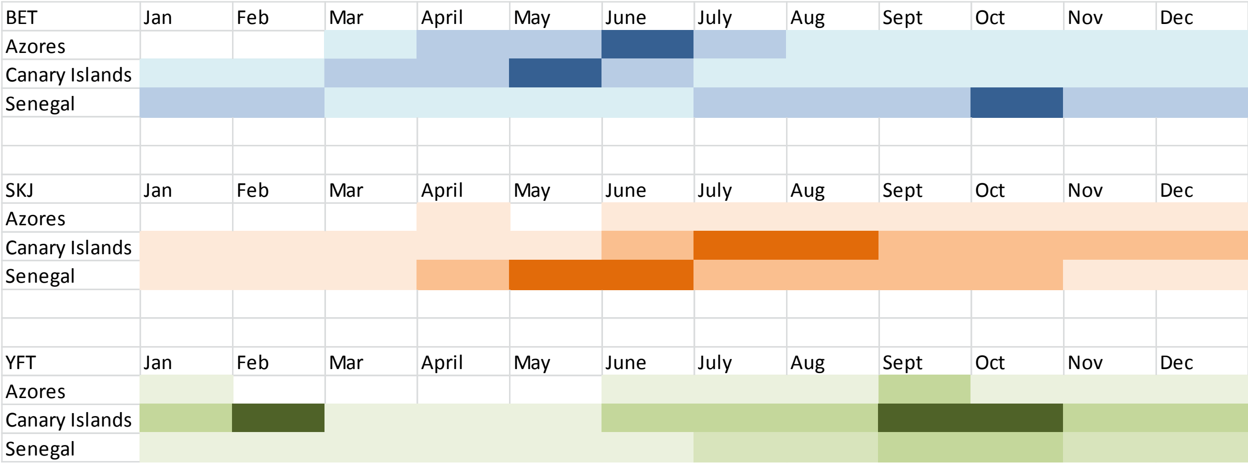

Figure 8. Relative change of CPUE during the year. Colors indicate relative change in CPUE, darkest colors indicate highest CPUEs for the region, medium colors indicate large to medium CPUEs, and lightest colors indicate small but present CPUEs. White colors indicate no CPUE.

CPUE Model Diagnostics

BET

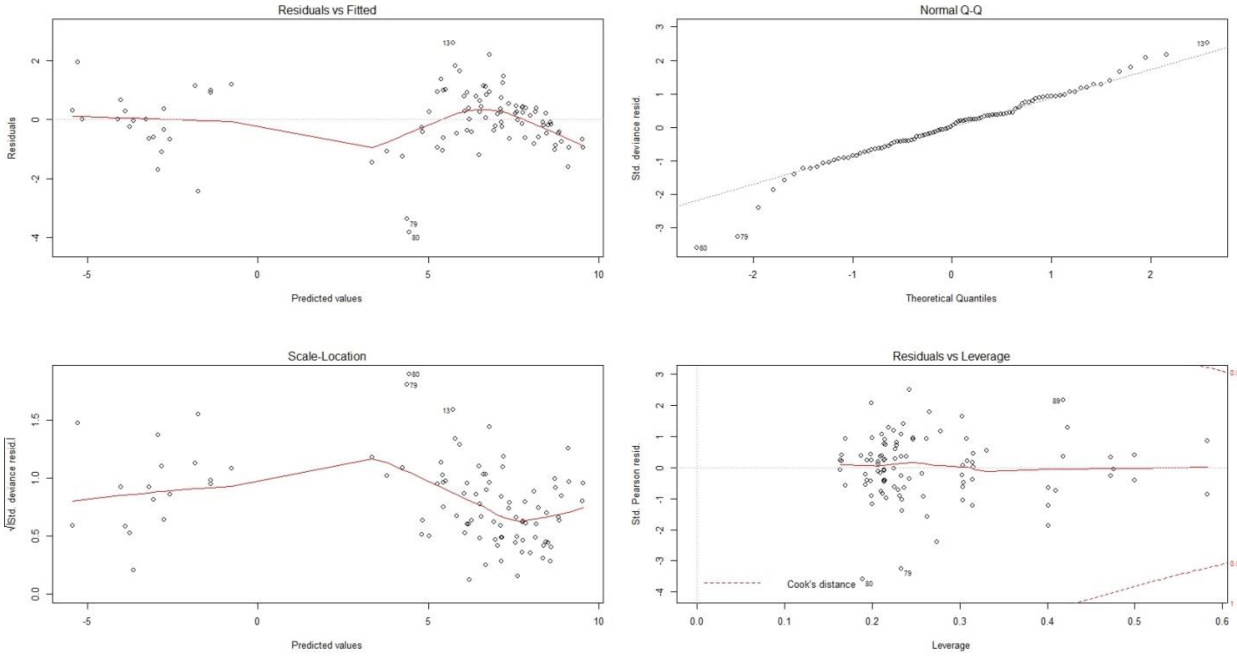

Figure A1. Region 1 – Azores GLM diagnostic plots.

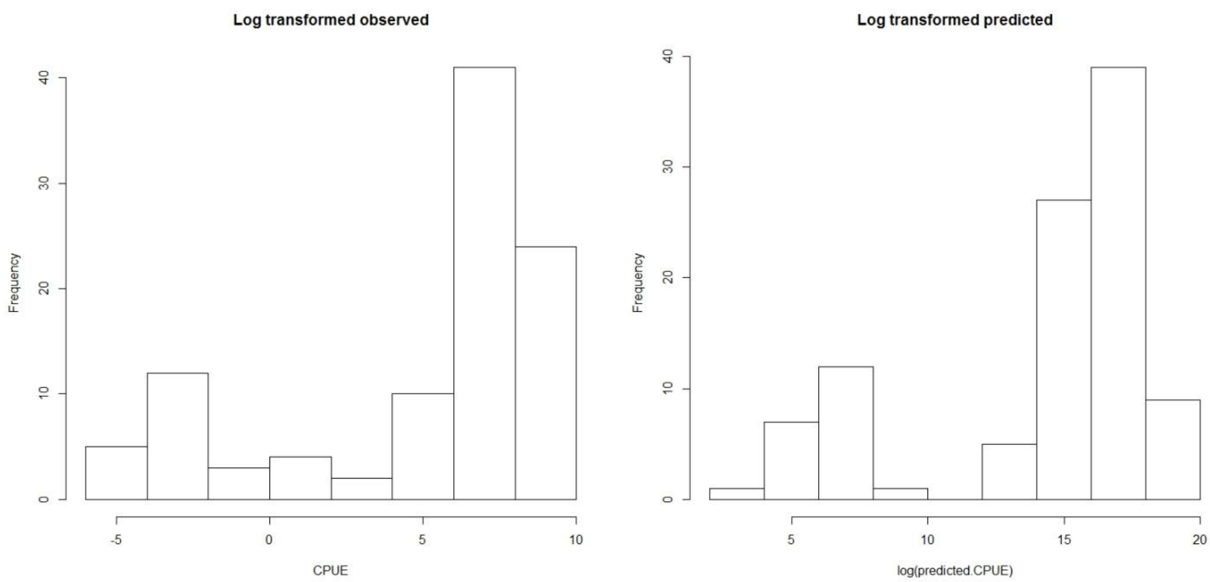

Figure A2. Region 1 – Azores Histograms of Fitted and Observed log transformed CPUE.

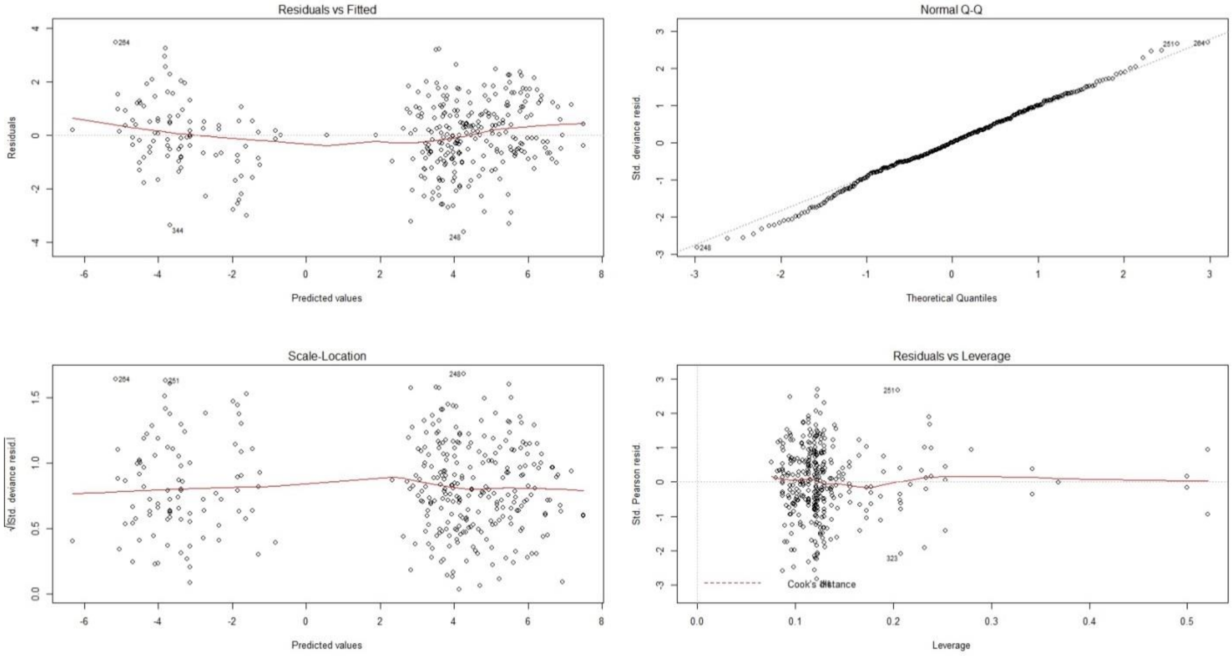

Figure A3. Region 2 – Canary Islands GLM diagnostic plots.

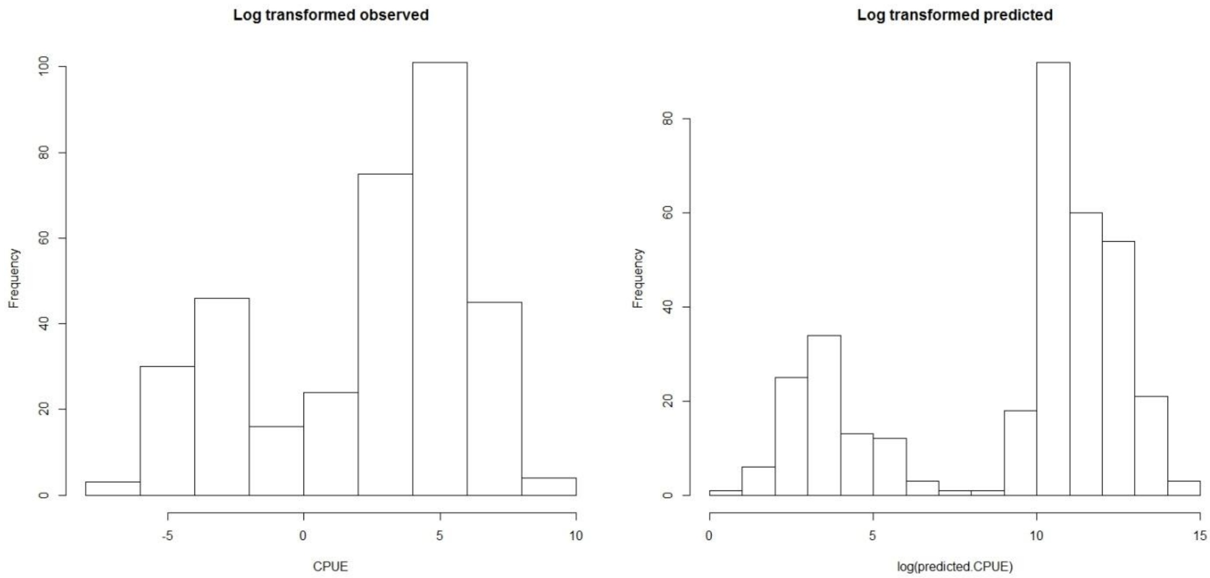

Figure A4. Region 2 – Canary Islands Histograms of Fitted and Observed log transformed CPUE.

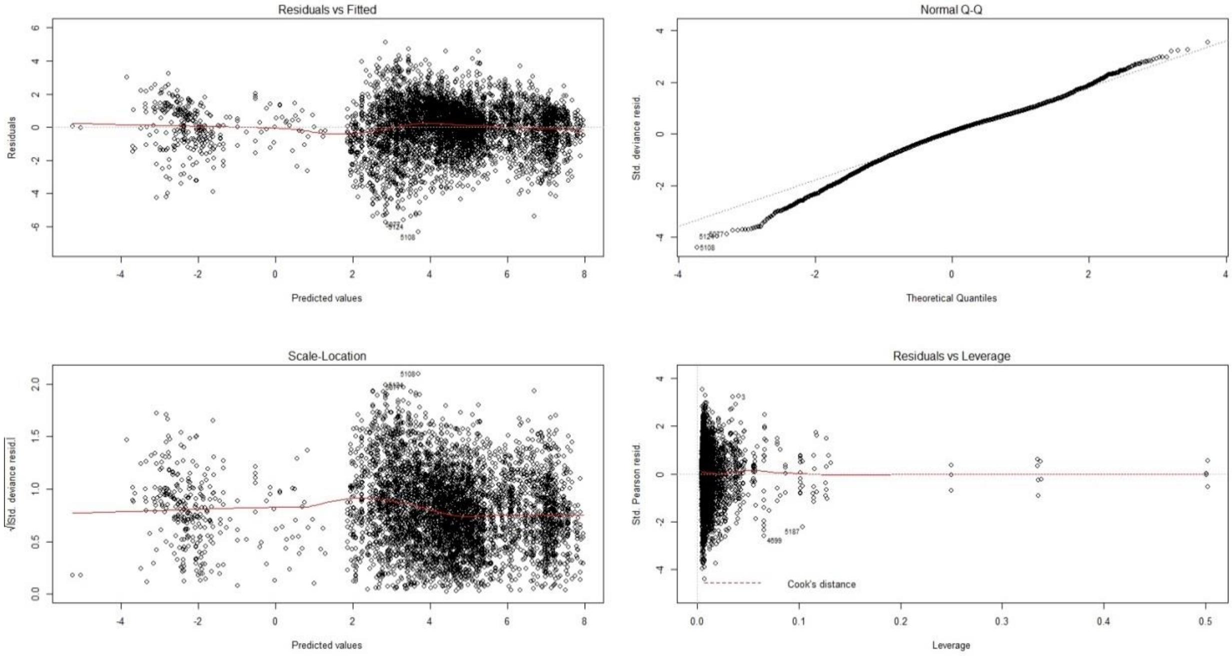

Figure A5. Region 3 – Senegal GLM diagnostic plots.

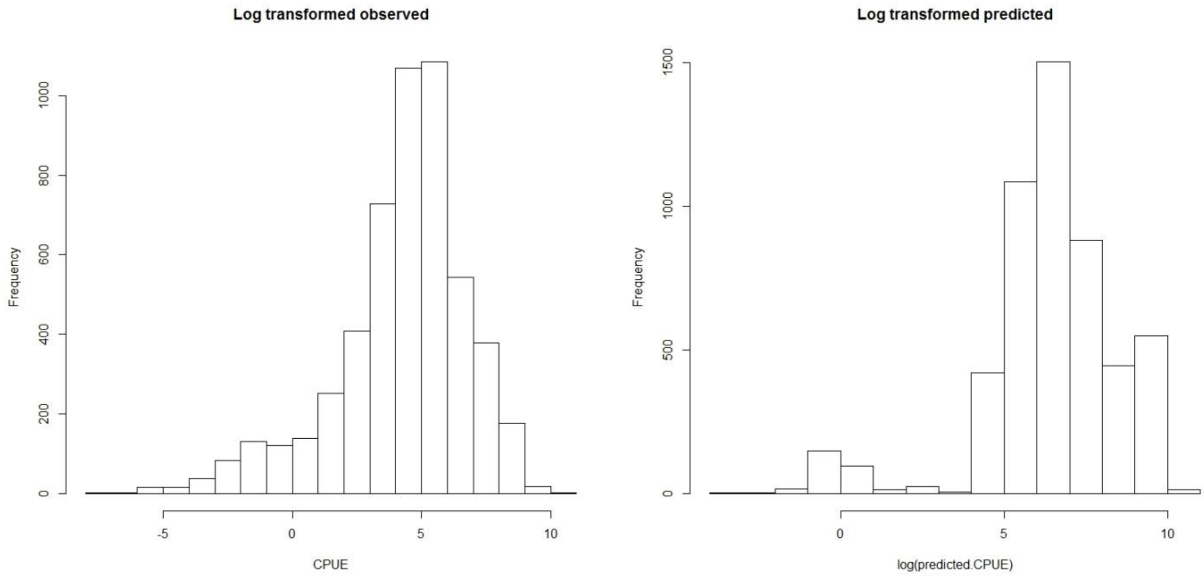

Figure A6. Region 3 – Senegal Histograms of Fitted and Observed log transformed CPUE.

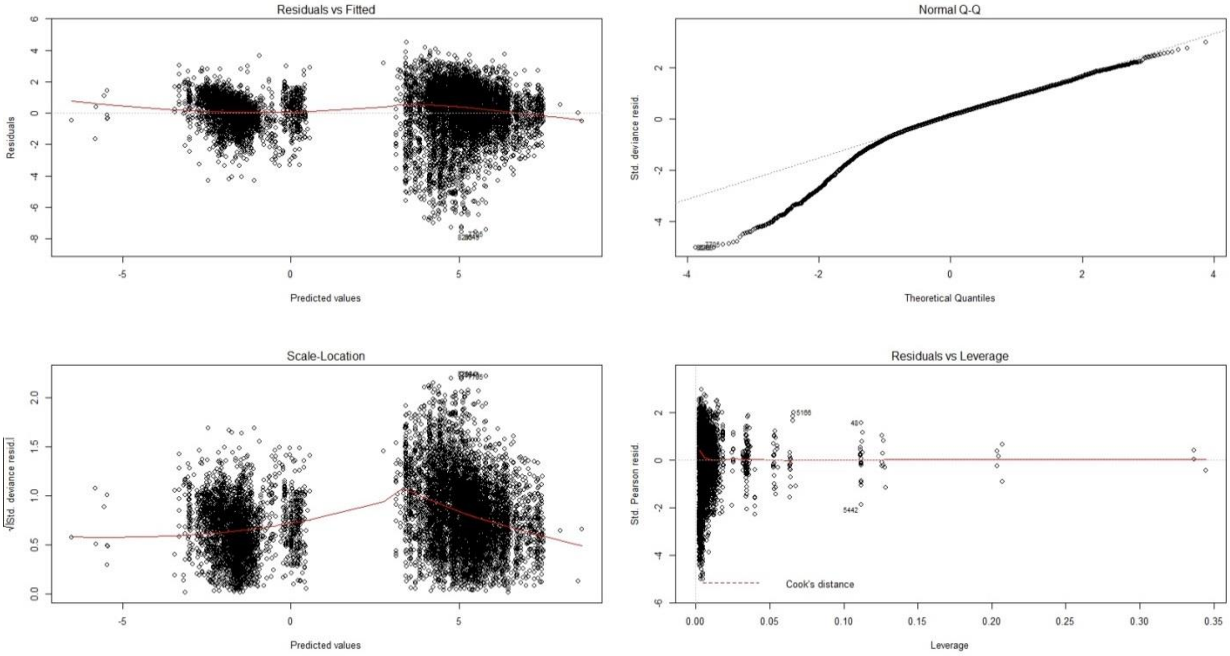

Figure A7. Region 4 – North Sherbro GLM diagnostic plots.

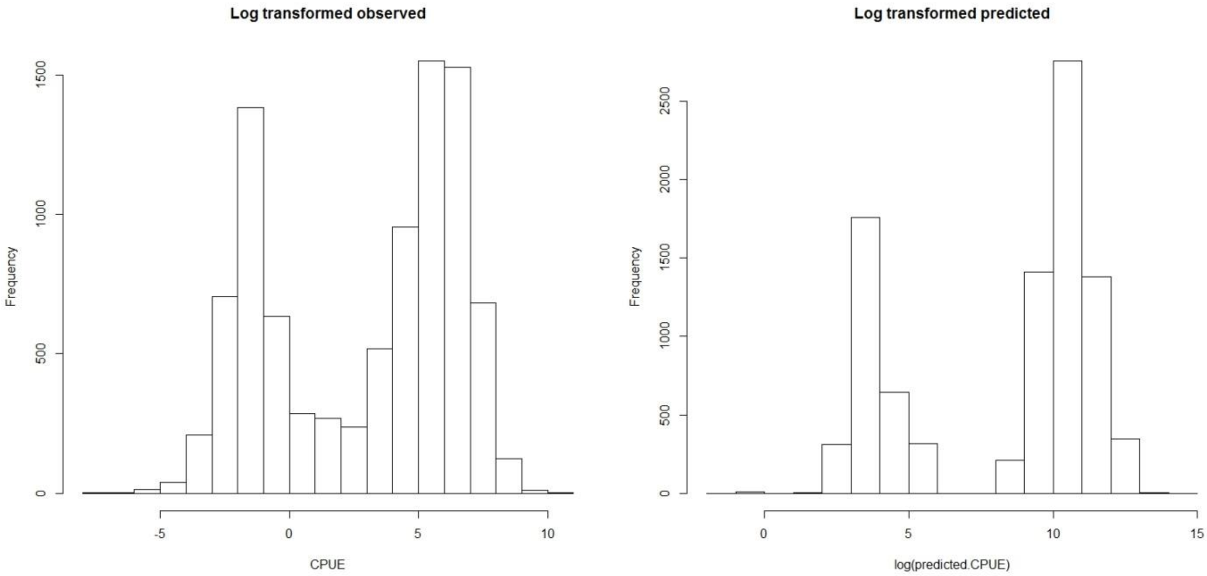

Figure A8. Region 4 – North Sherbro Histograms of Fitted and Observed log transformed CPUE.

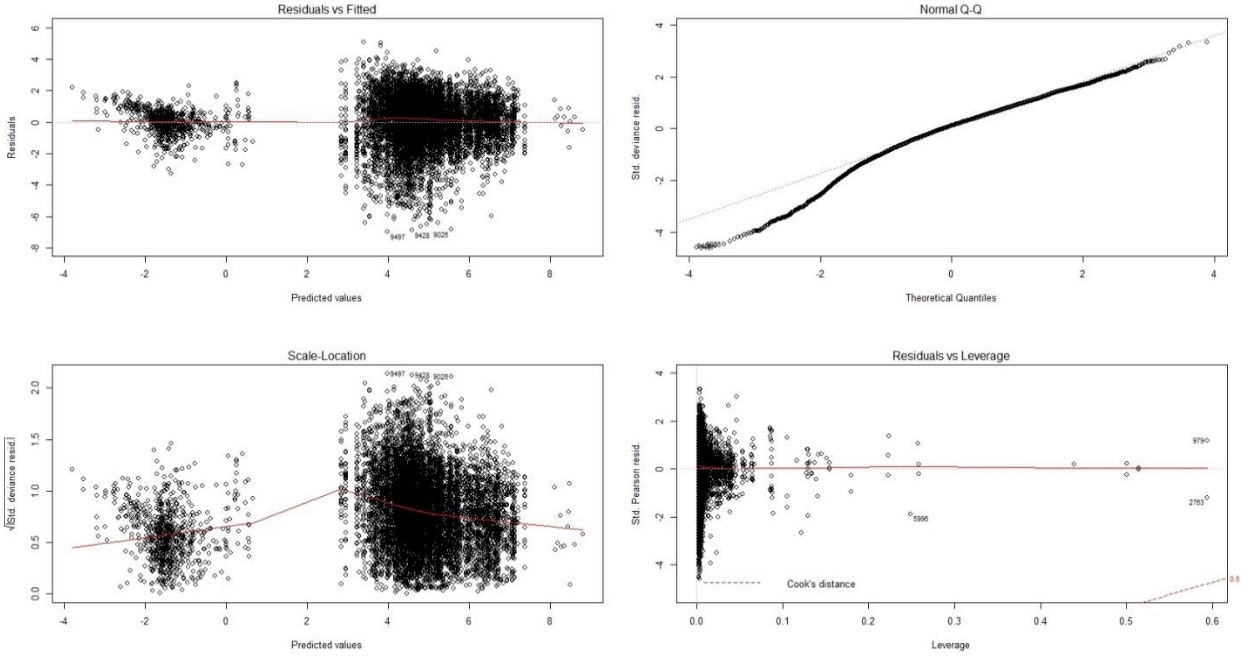

Figure A9. Region 5 - Sherbro GLM diagnostic plots.

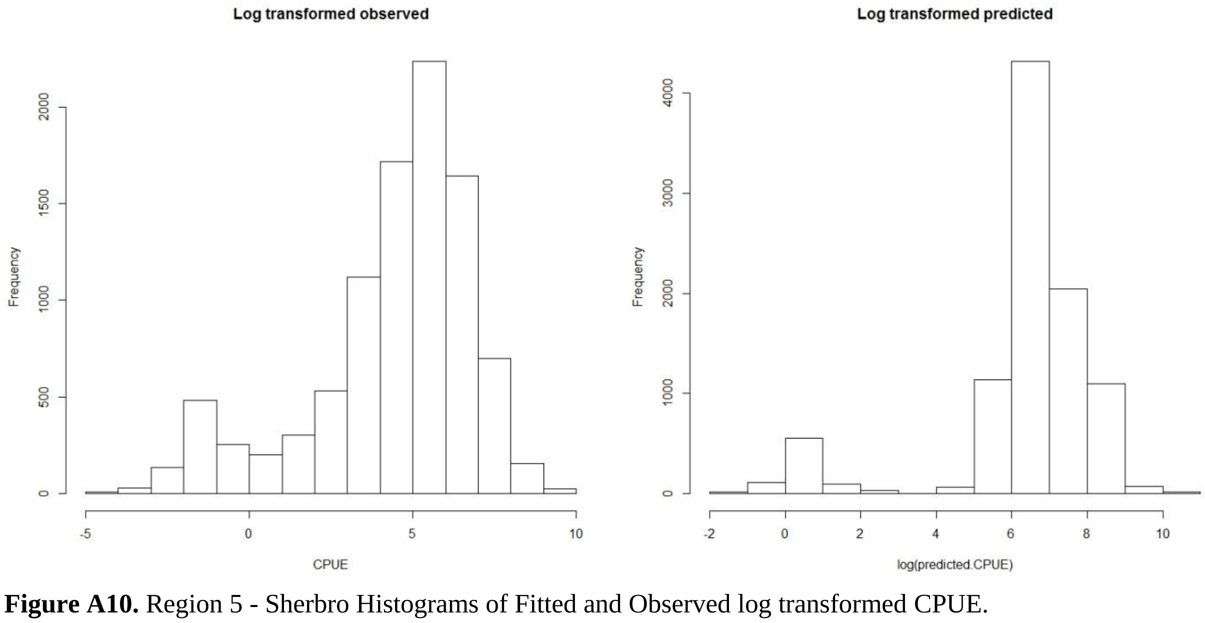

Figure A10. Region 5 - Sherbro Histograms of Fitted and Observed log transformed CPUE.

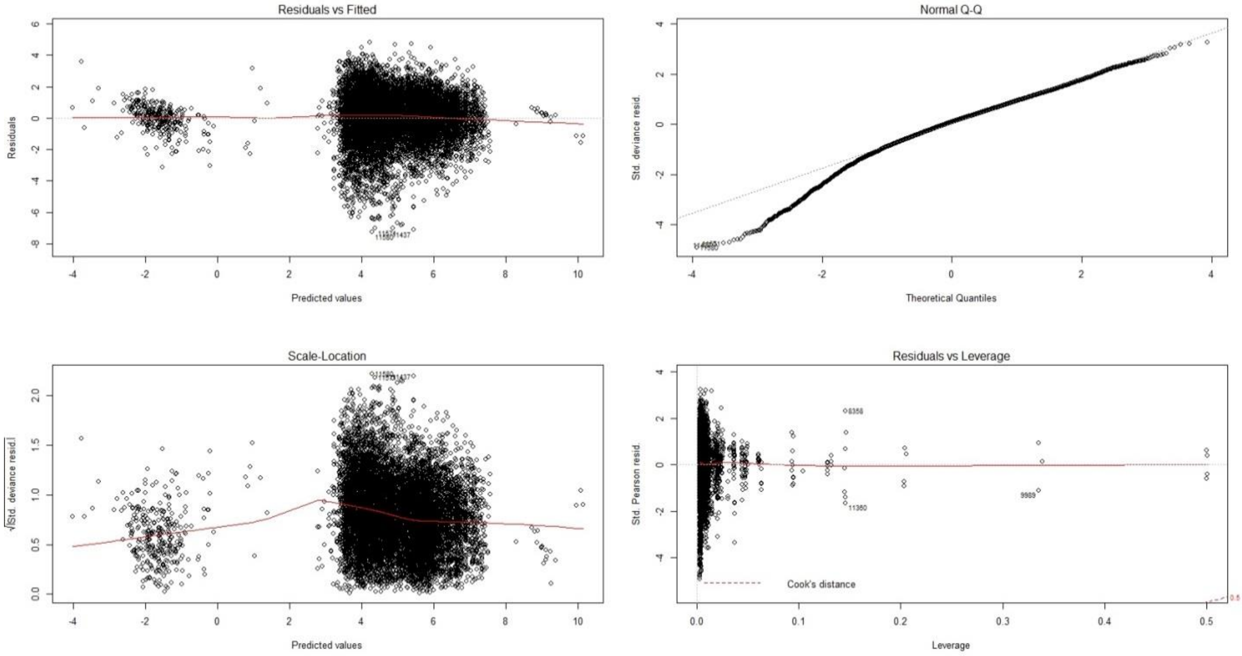

Figure A11. Region 6 – Cote d’Ivoire GLM diagnostic plots.

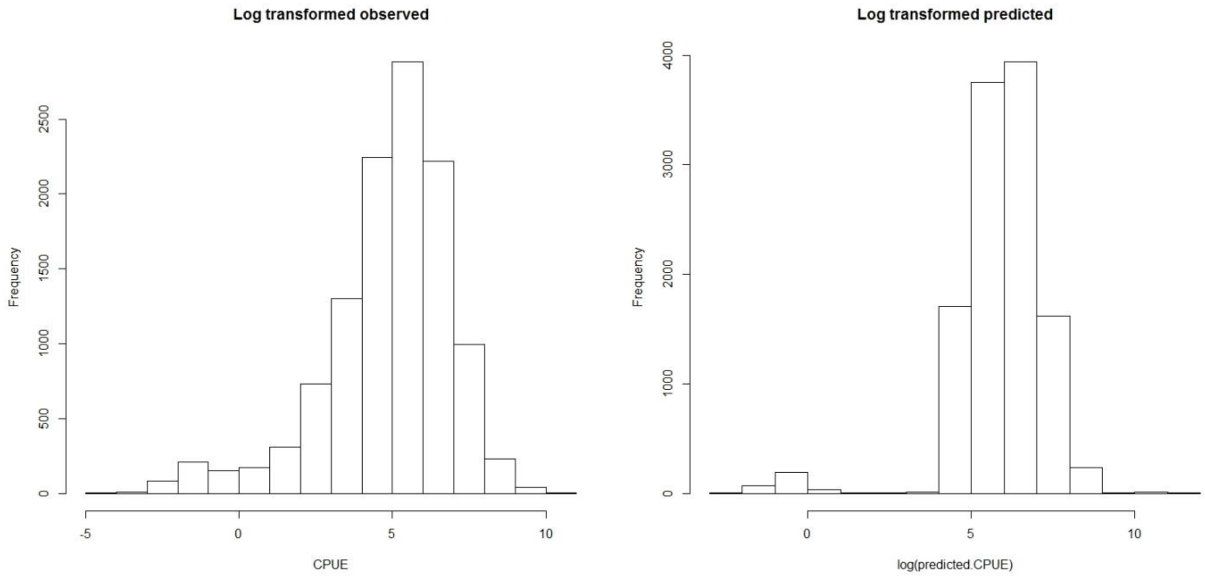

Figure A12. Region 6 – Cote d’Ivoire Histograms of Fitted and Observed log transformed CPUE.

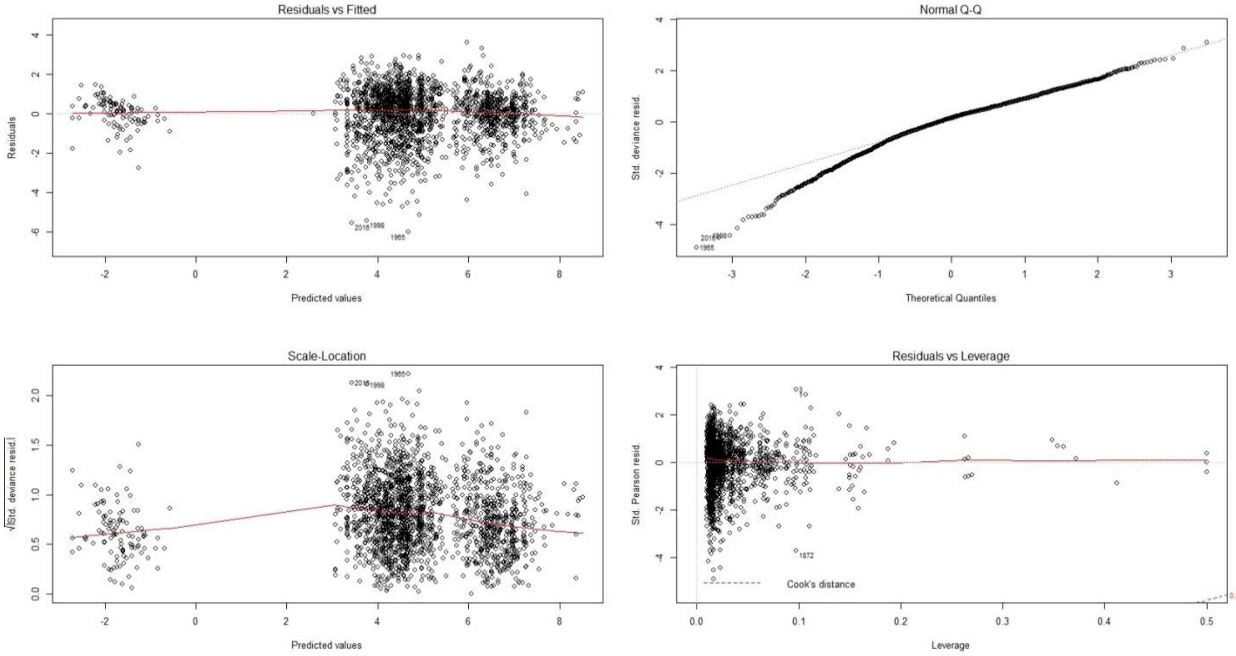

Figure A13. Region 7 – Cape Lopez GLM diagnostic plots.

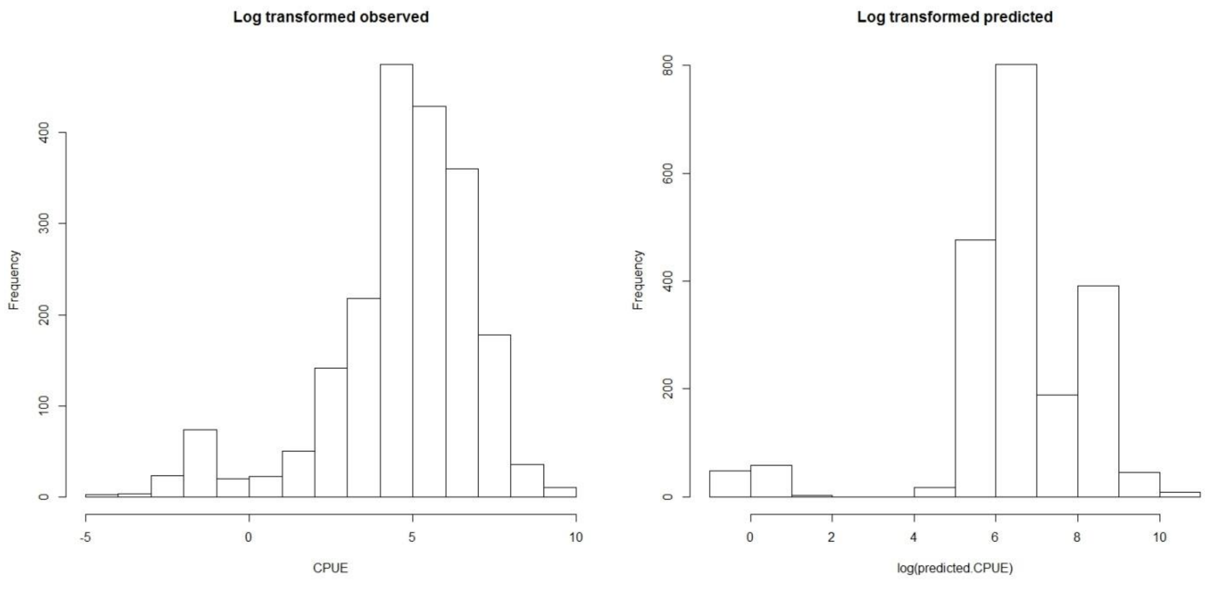

Figure A14. Region 7 – Cape Lopez Histograms of Fitted and Observed log transformed CPUE.

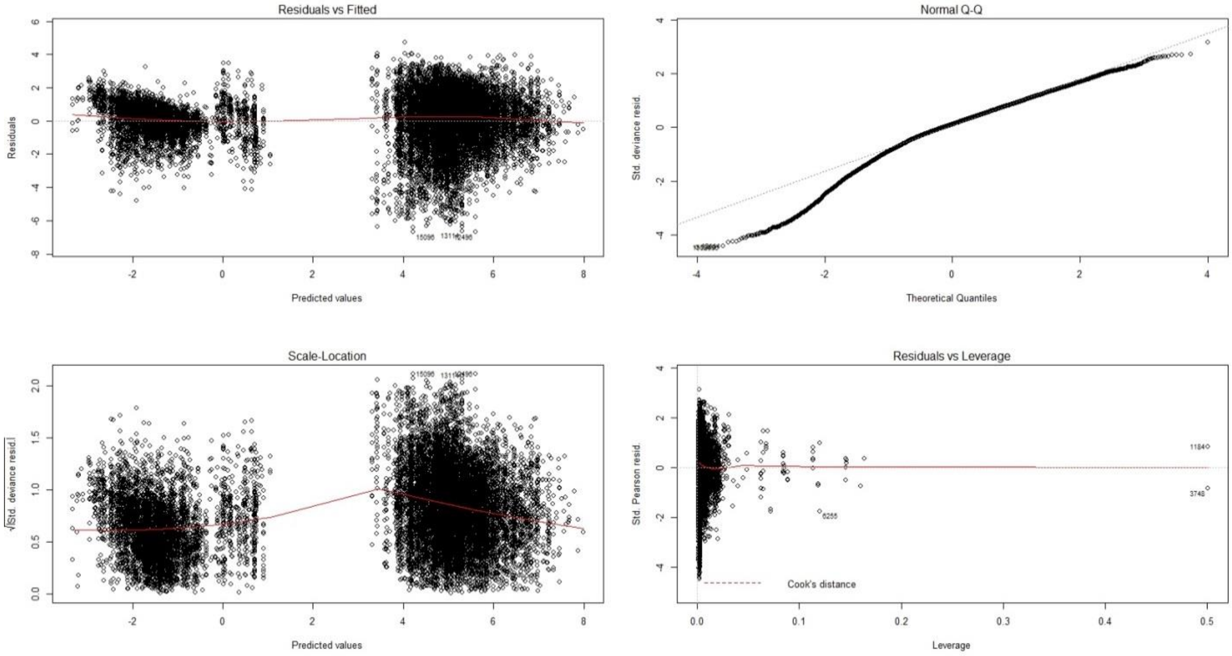

Figure A15. Region 8 – Equator GLM diagnostic plots.

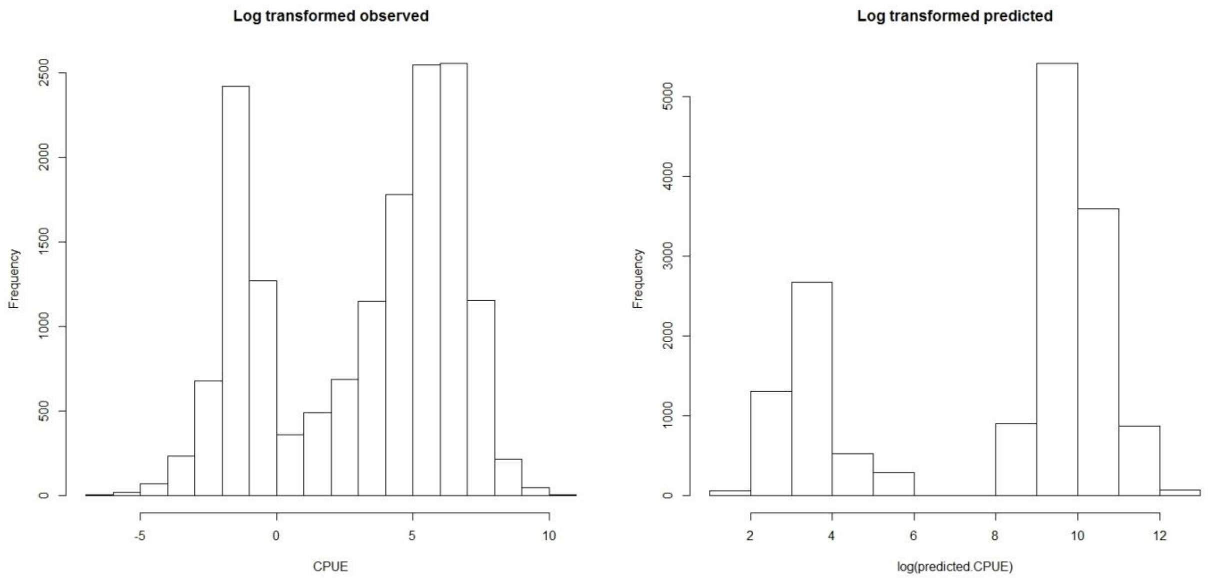

Figure A16. Region 8 - Equator Histograms of Fitted and Observed log transformed CPUE.

SKJ

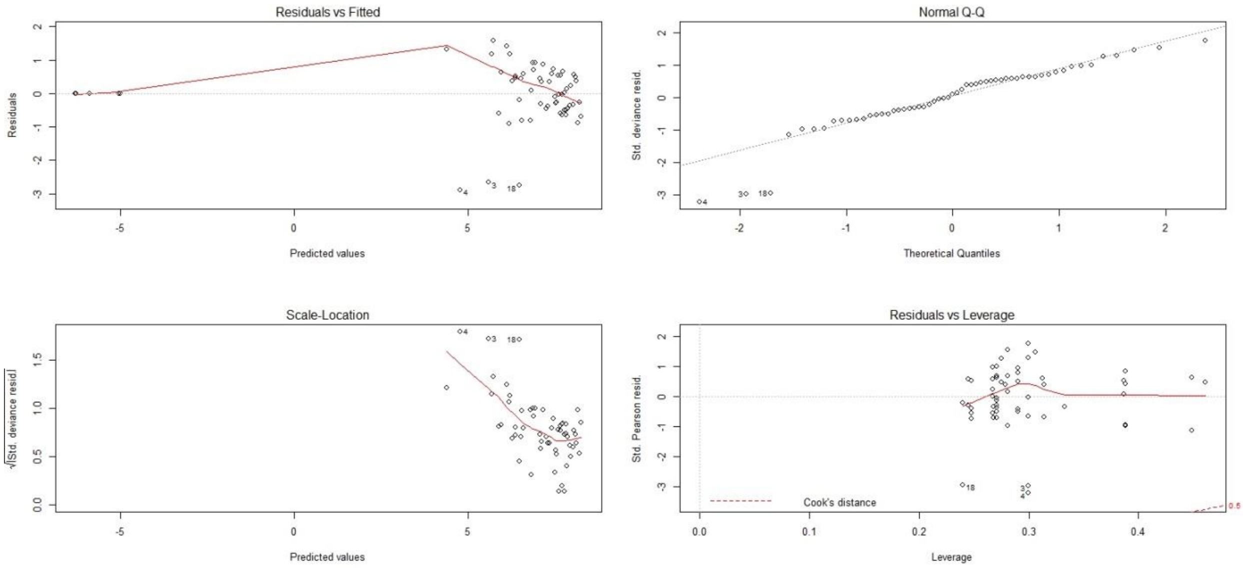

Figure A17. Region 1 – Azores GLM diagnostic plots.

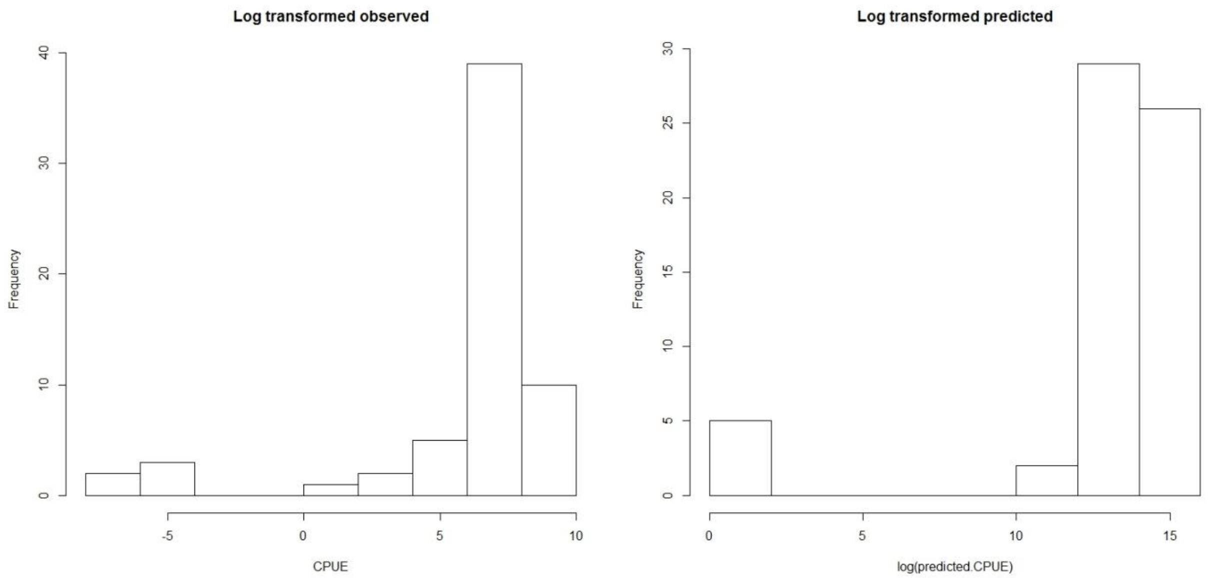

Figure A18. Region 1 – Azores Histograms of Fitted and Observed log transformed CPUE.

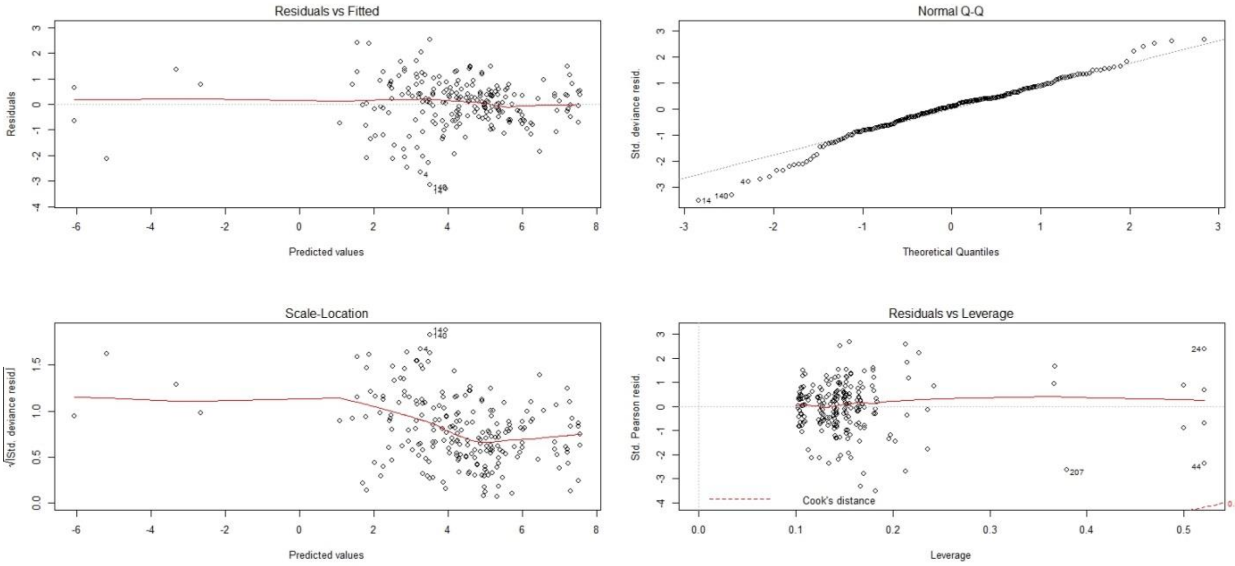

Figure A19. Region 2 – Canary Islands GLM diagnostic plots.

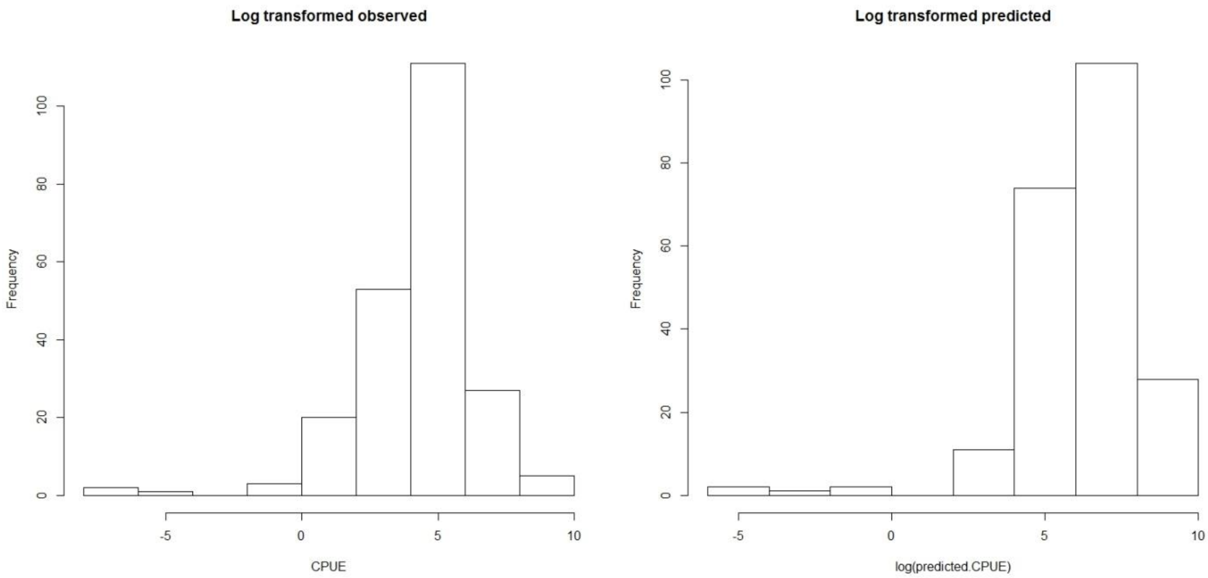

Figure A20. Region 2 – Canary Islands Histograms of Fitted and Observed log transformed CPUE.

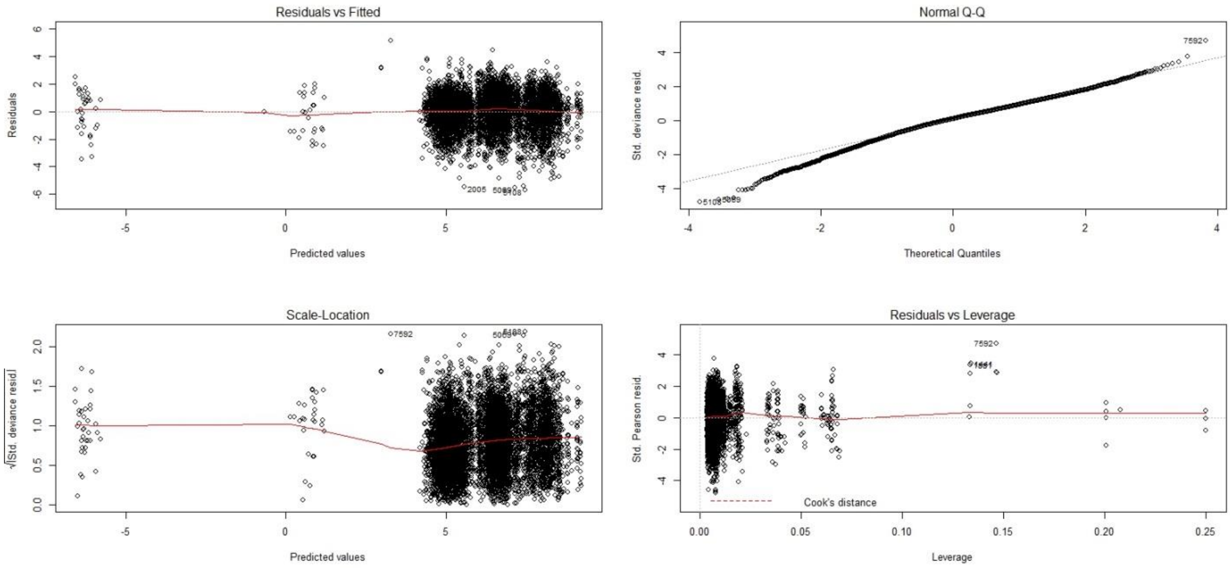

Figure A21. Region 3 – Senegal GLM diagnostic plots.

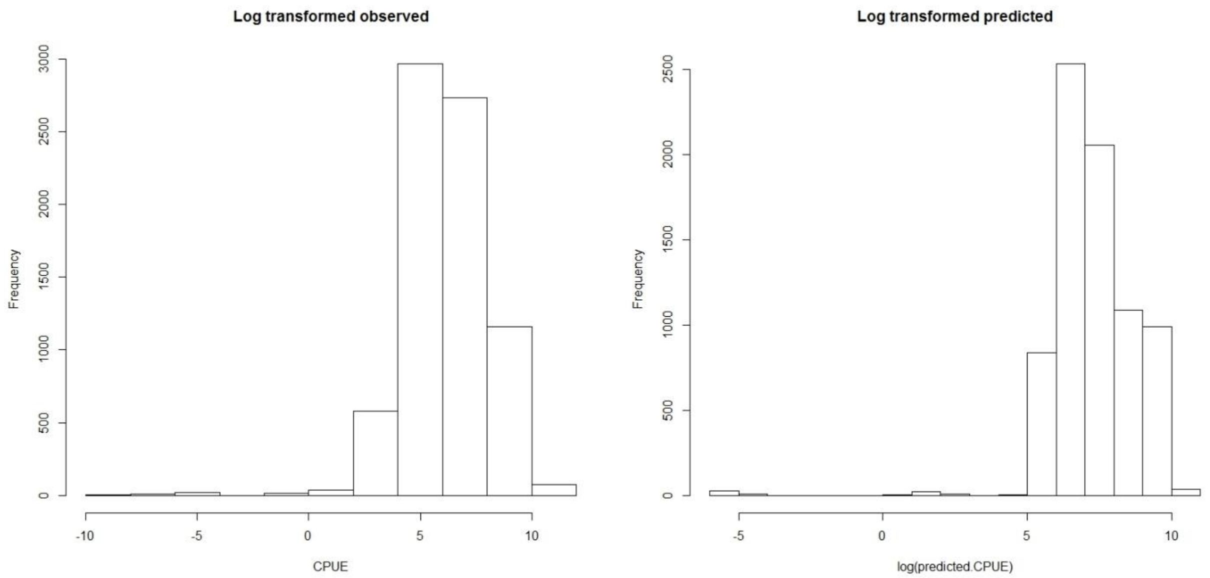

Figure A22. Region 3 – Senegal Histograms of Fitted and Observed log transformed CPUE.

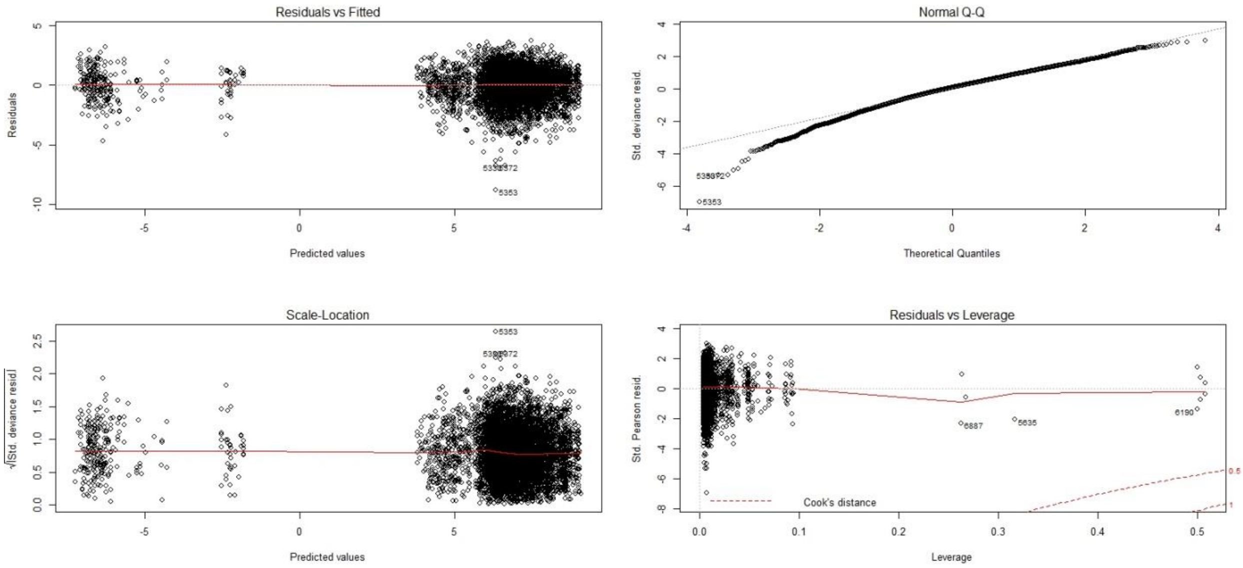

Figure A23. Region 4 – North Sherbro GLM diagnostic plots.

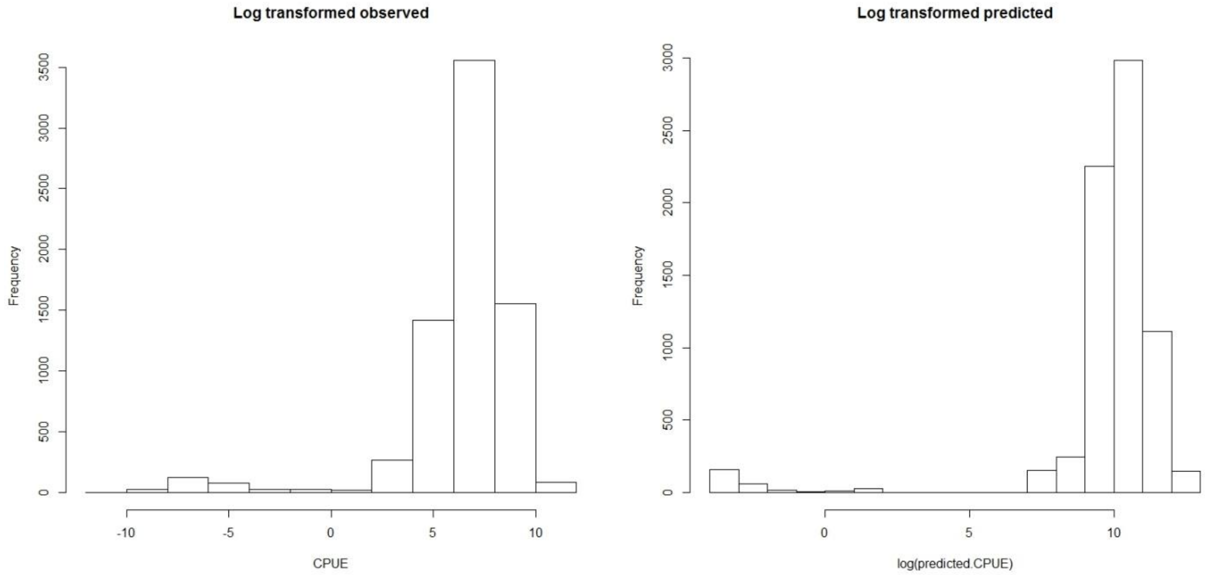

Figure A24. Region 4 – North Sherbro Histograms of Fitted and Observed log transformed CPUE.

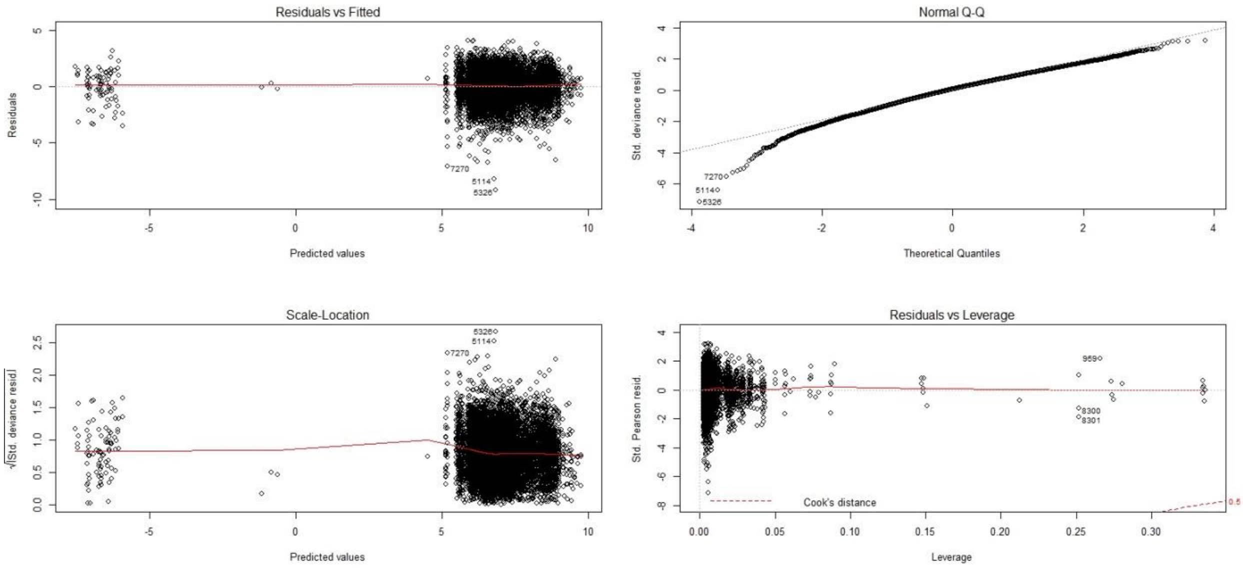

Figure A25. Region 5 - Sherbro GLM diagnostic plots.

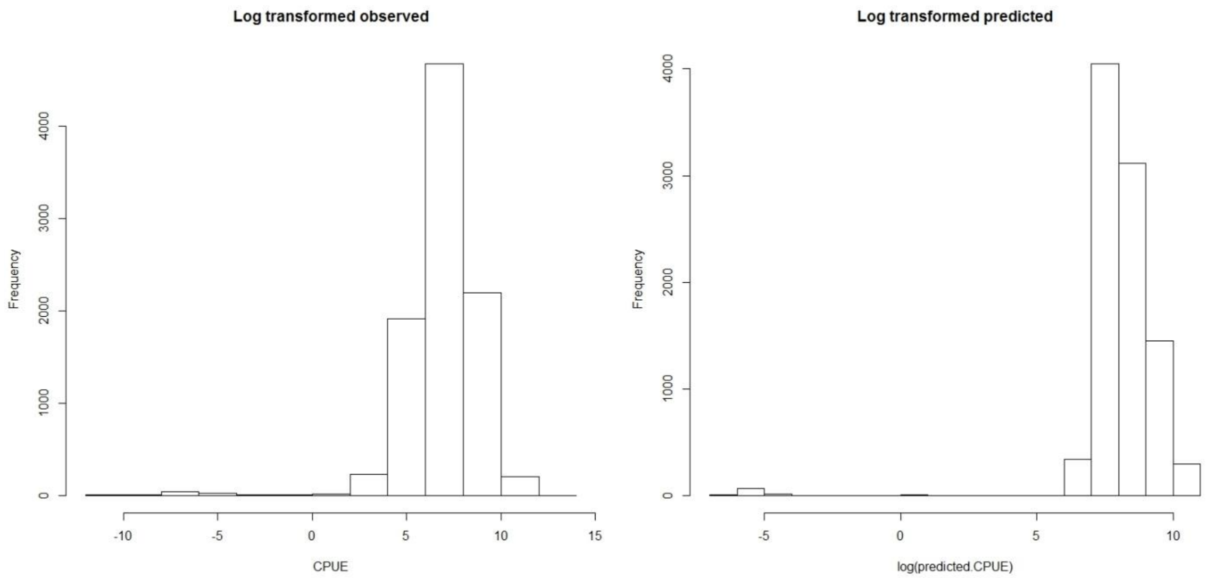

Figure A26. Region 5 - Sherbro Histograms of Fitted and Observed log transformed CPUE.

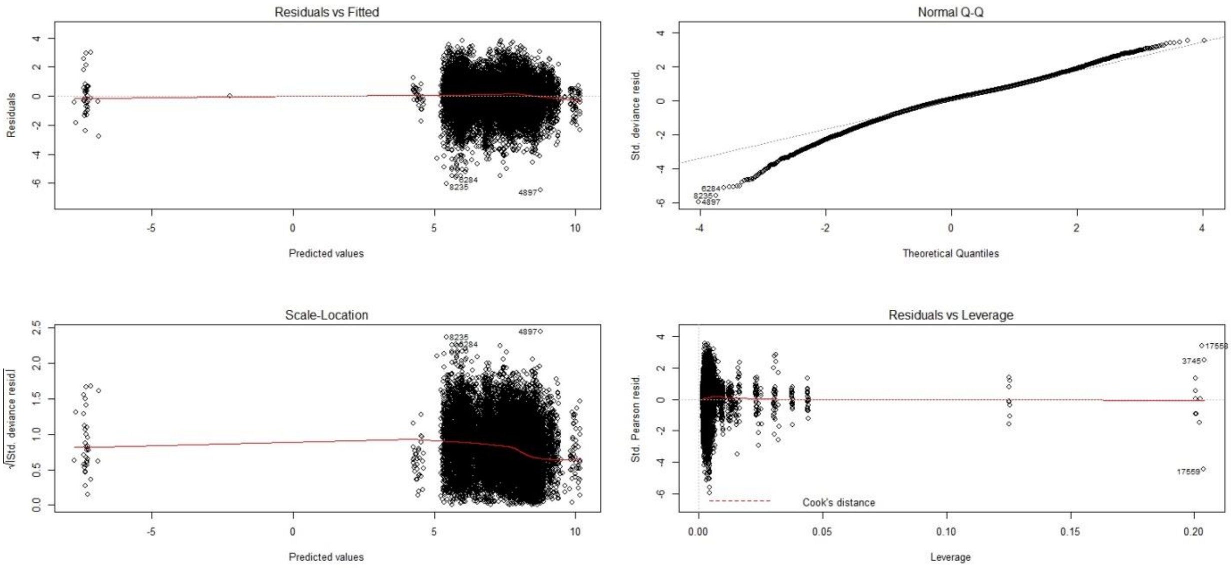

Figure A27. Region 6 – Cote d'Ivoire GLM diagnostic plots.

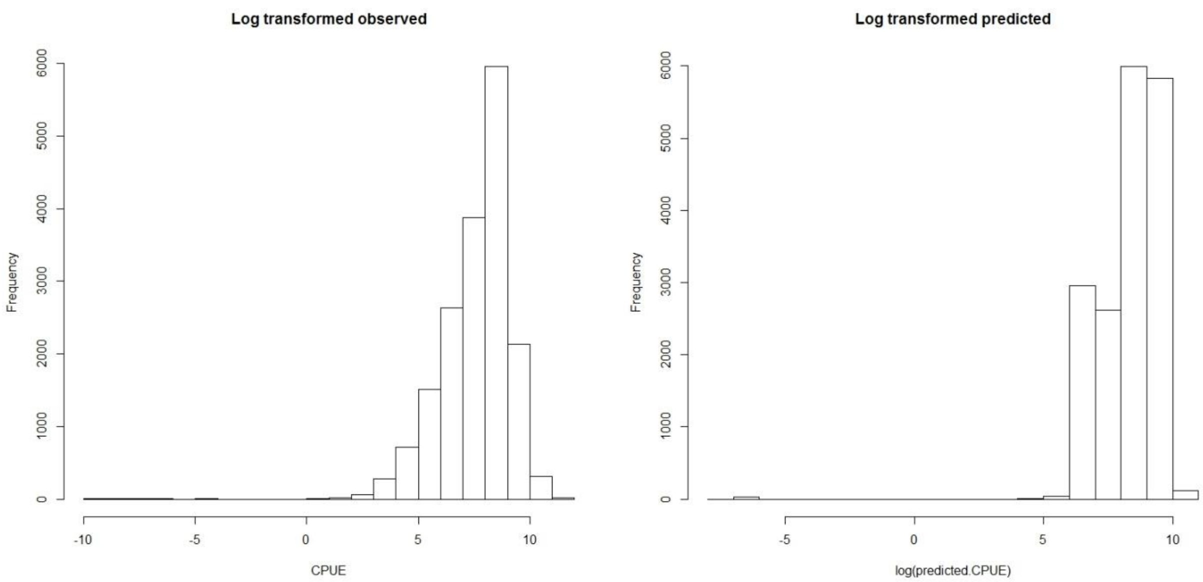

Figure A28. Region 6 – Cote d'Ivoire Histograms of Fitted and Observed log transformed CPUE.

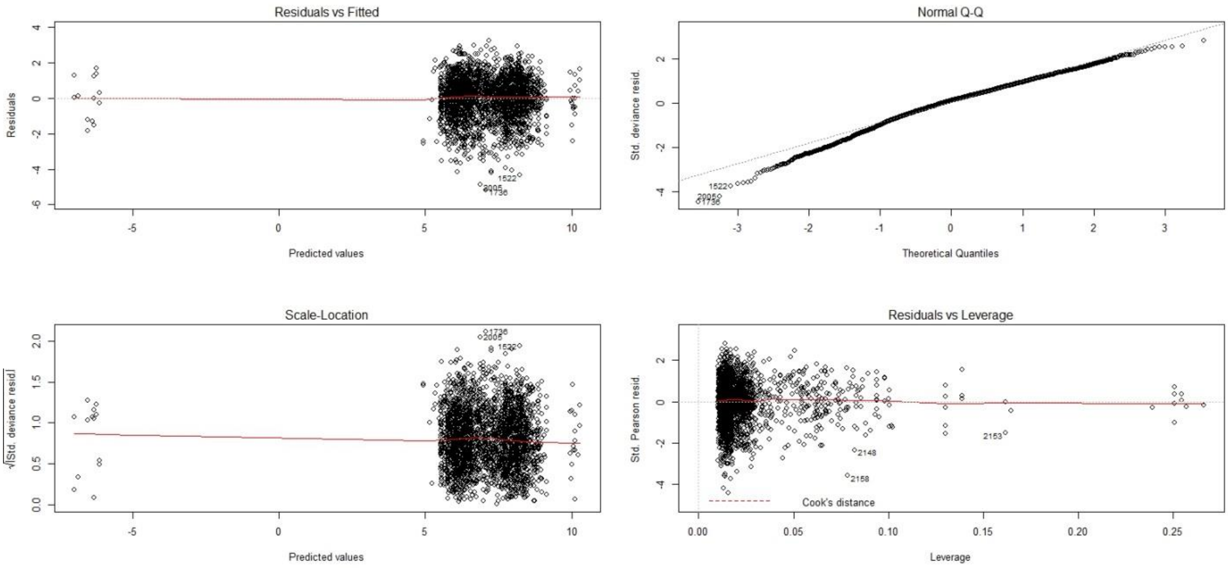

Figure A29. Region 7 – Cape Lopez GLM diagnostic plots.

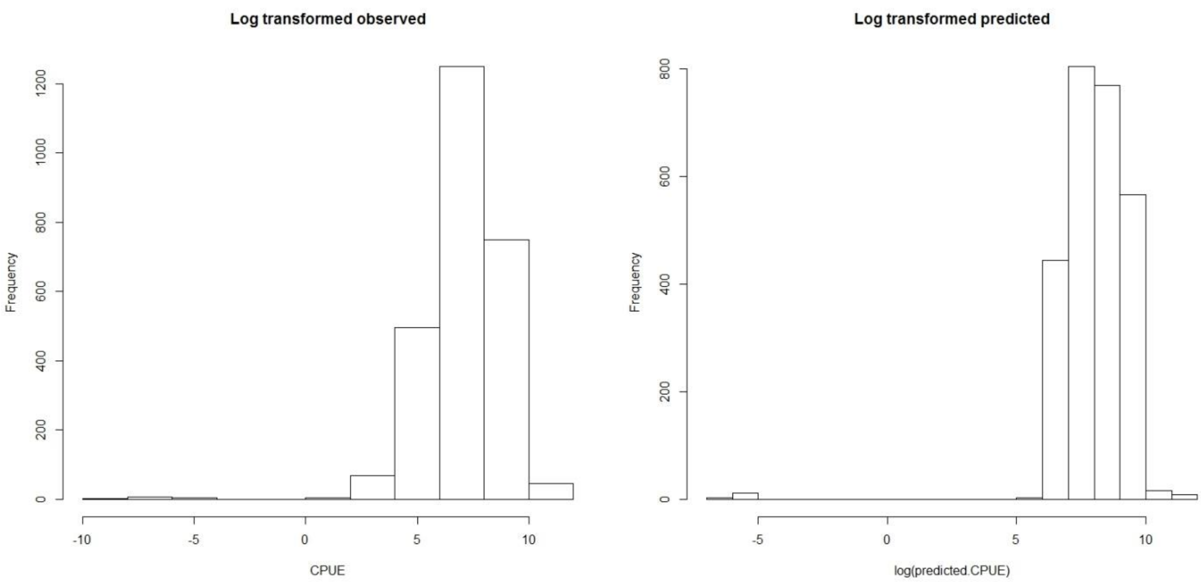

Figure A30. Region 7 – Cape Lopez Histograms of Fitted and Observed log transformed CPUE.

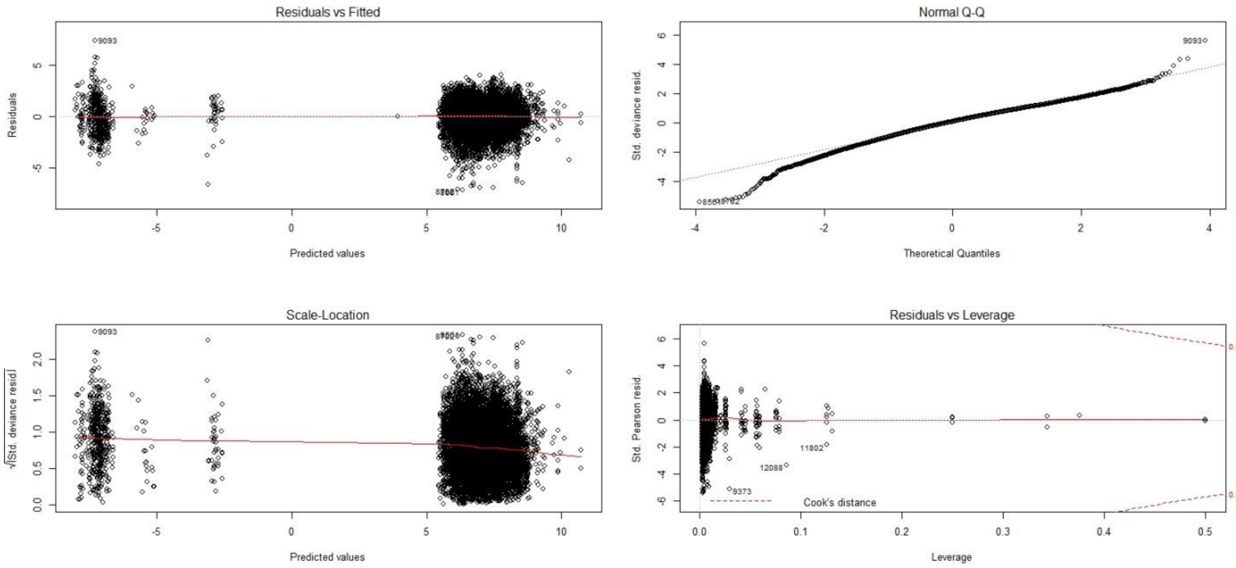

Figure A31. Region 8 – Equator GLM diagnostic plots.

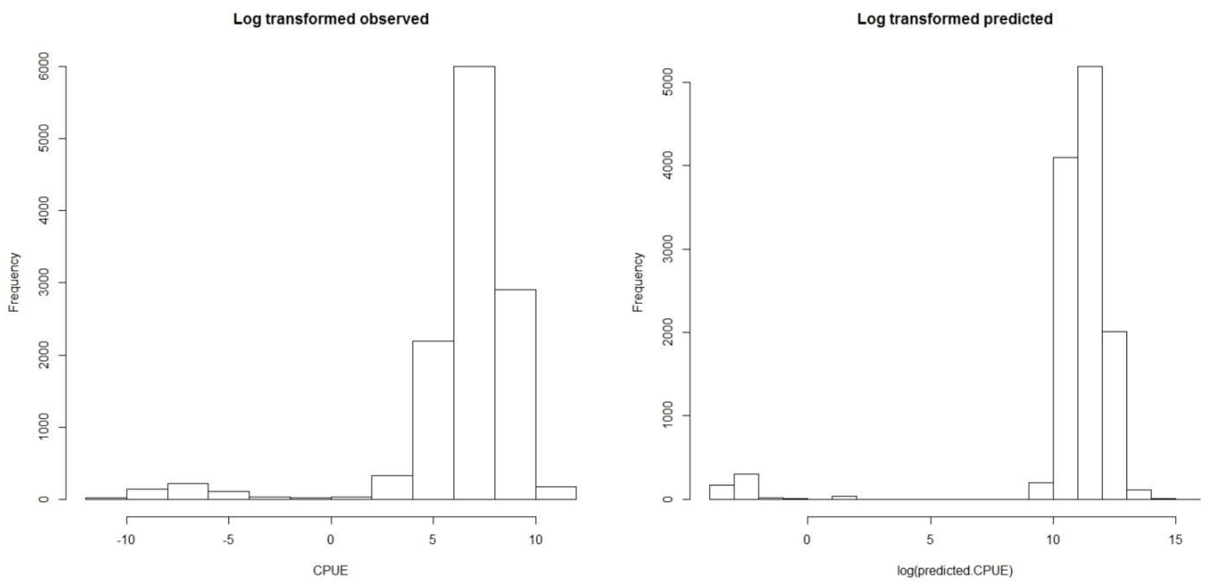

Figure A32. Region 8 - Equator Histograms of Fitted and Observed log transformed CPUE.

YFT

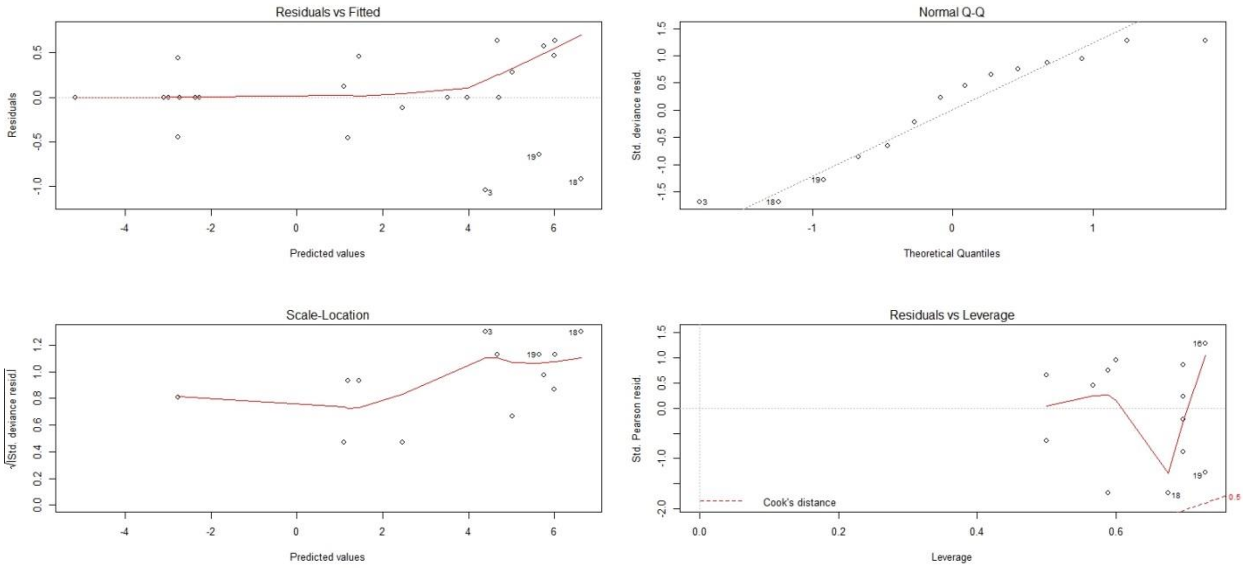

Figure A33. Region 1 – Azores GLM diagnostic plots.

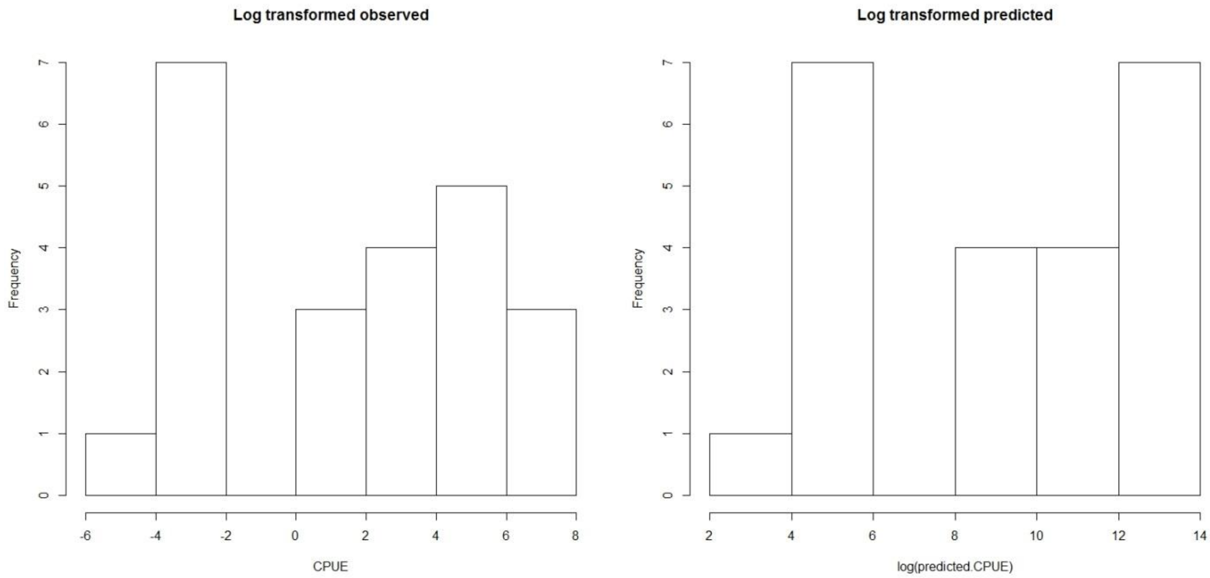

Figure A34. Region 1 – Azores Histograms of Fitted and Observed log transformed CPUE.

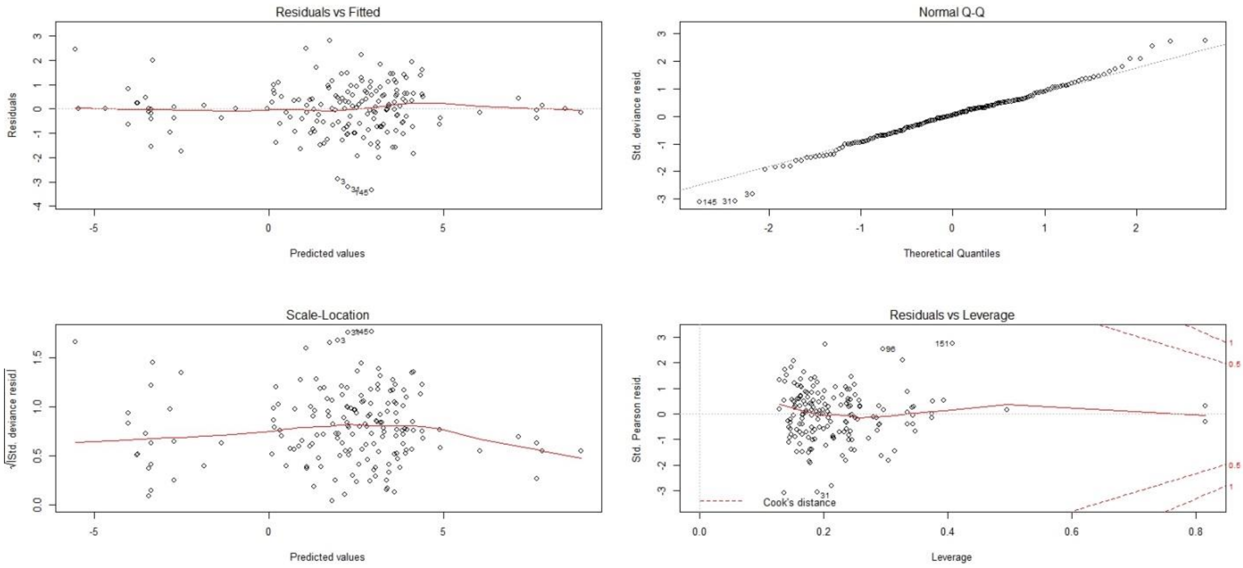

Figure A35. Region 2 – Canary Islands GLM diagnostic plots.

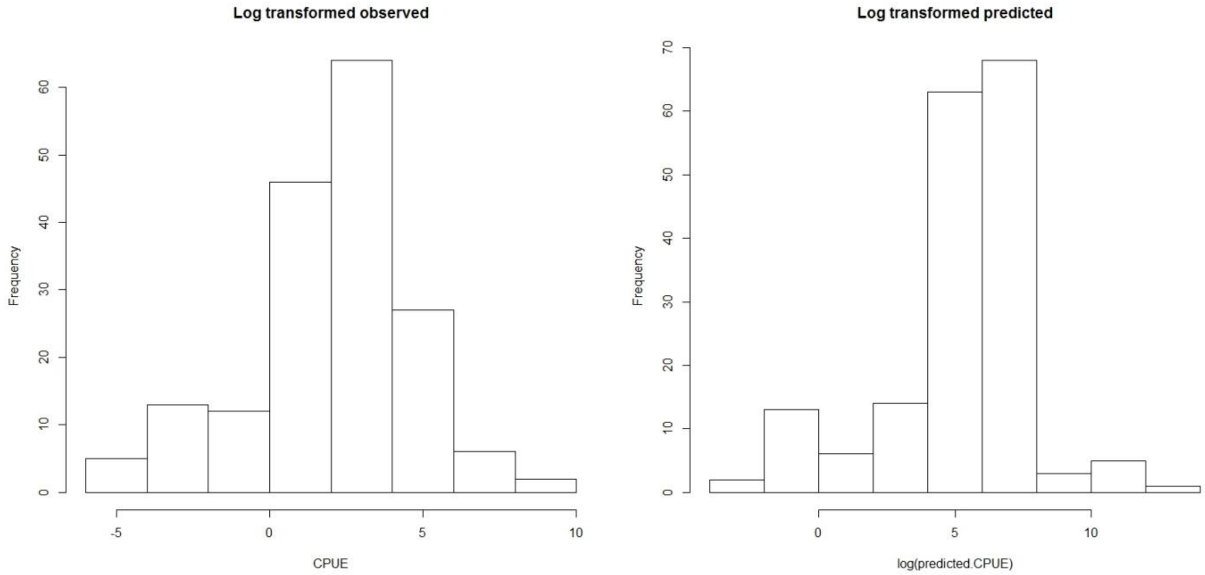

Figure A36. Region 2 – Canary Islands Histograms of Fitted and Observed log transformed CPUE.

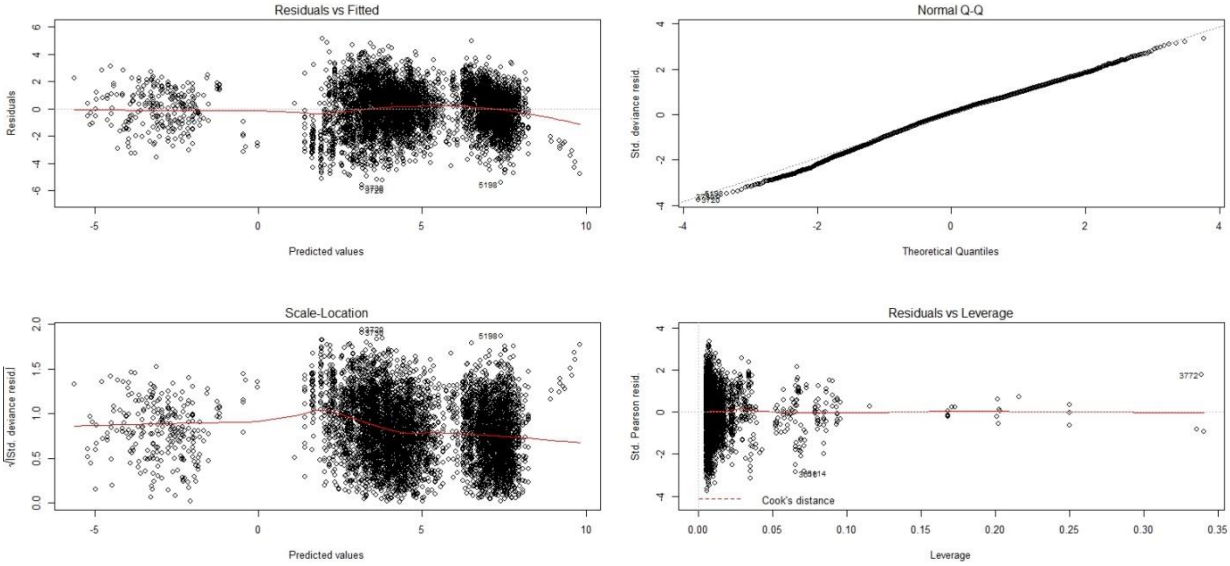

Figure A37. Region 3 – Senegal GLM diagnostic plots.

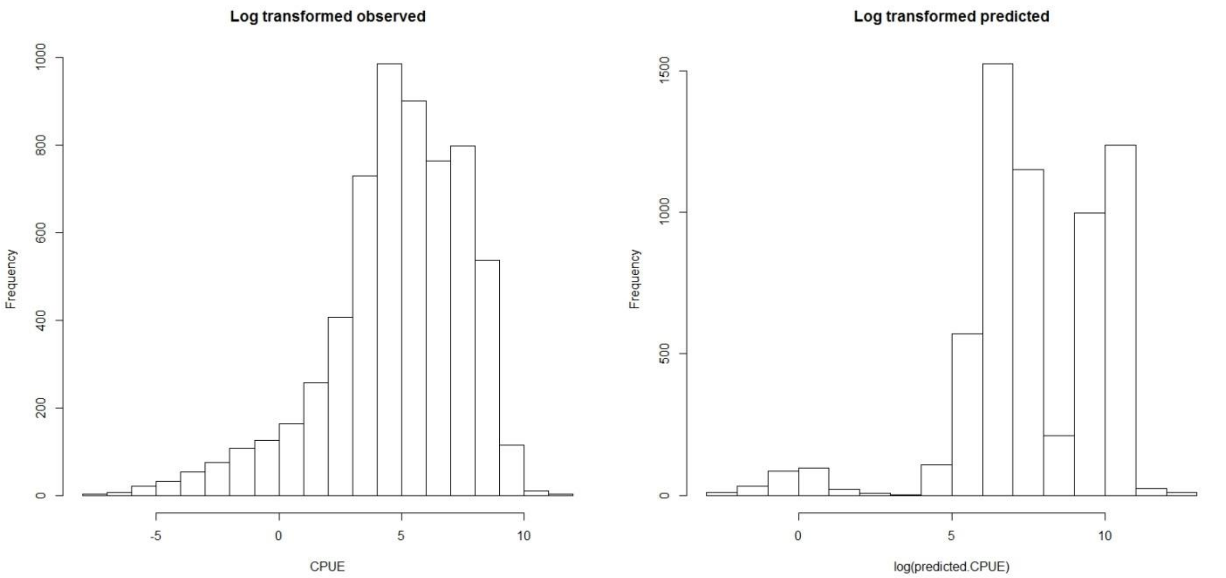

Figure A38. Region 3 – Senegal Histograms of Fitted and Observed log transformed CPUE.

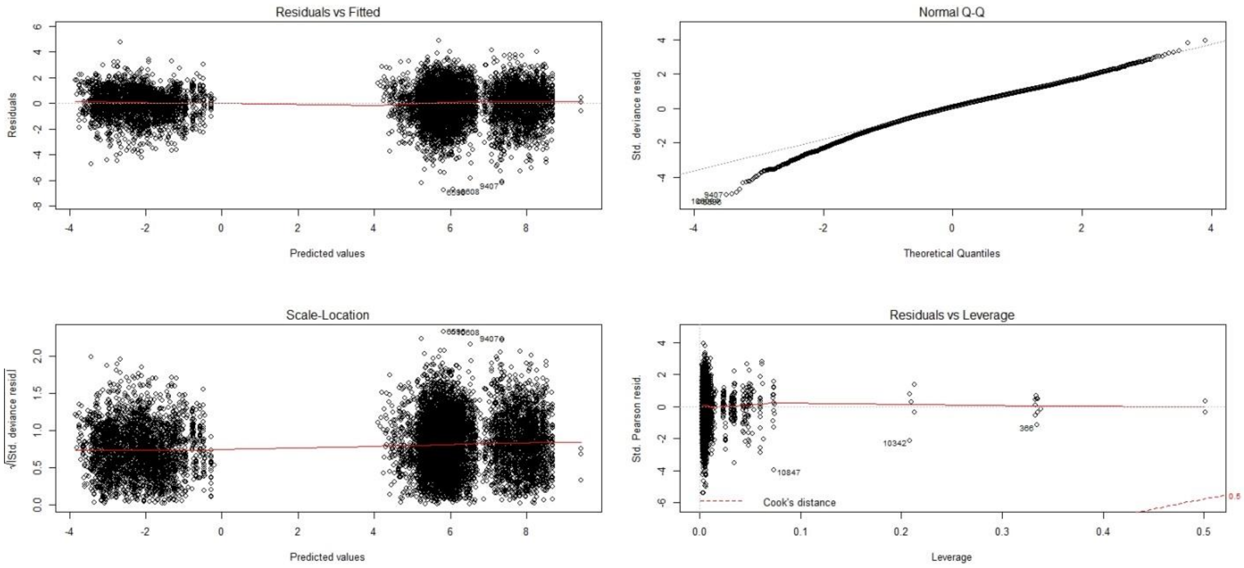

Figure A39. Region 4 – North Sherbro GLM diagnostic plots.

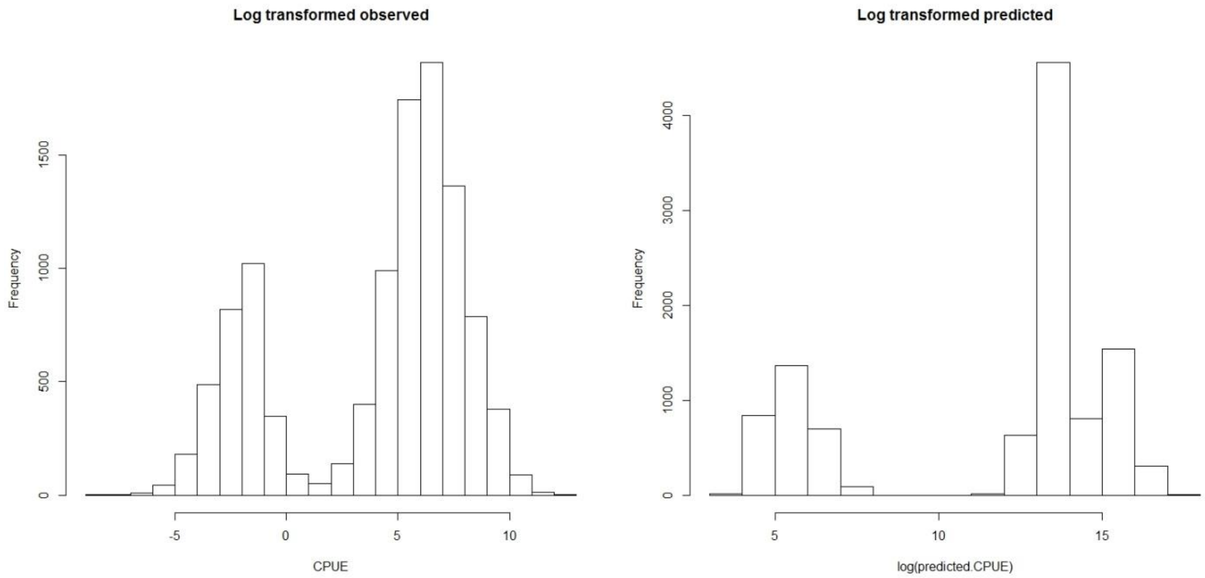

Figure A40. Region 4 – North Sherbro Histograms of Fitted and Observed log transformed CPUE

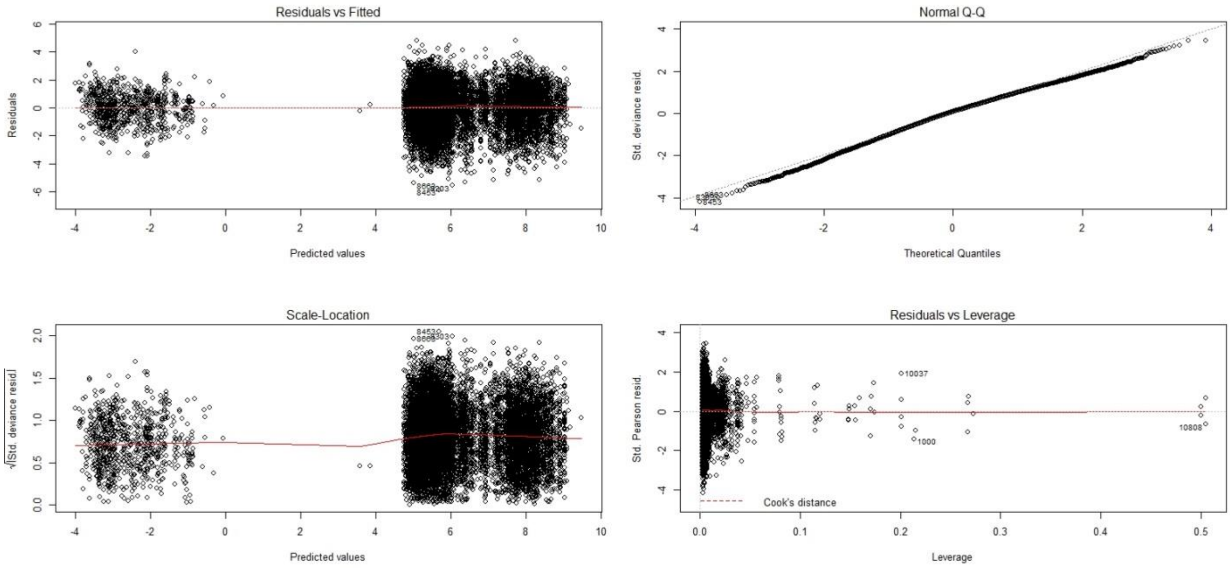

Figure A41. Region 5 - Sherbro GLM diagnostic plots.

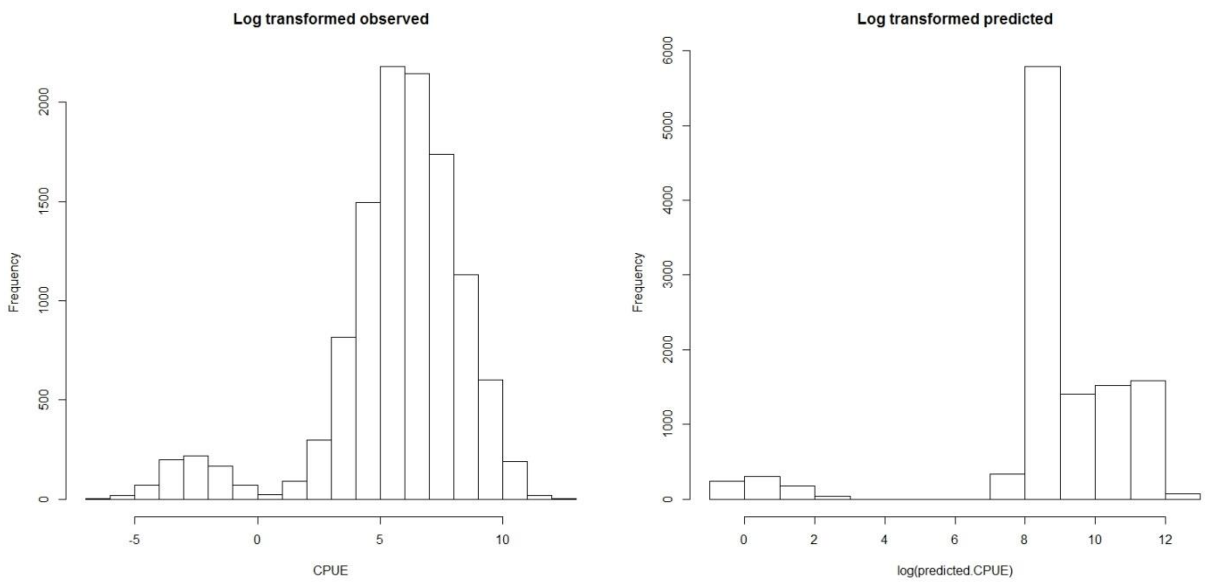

Figure A42. Region 5 - Sherbro Histograms of Fitted and Observed log transformed CPUE.

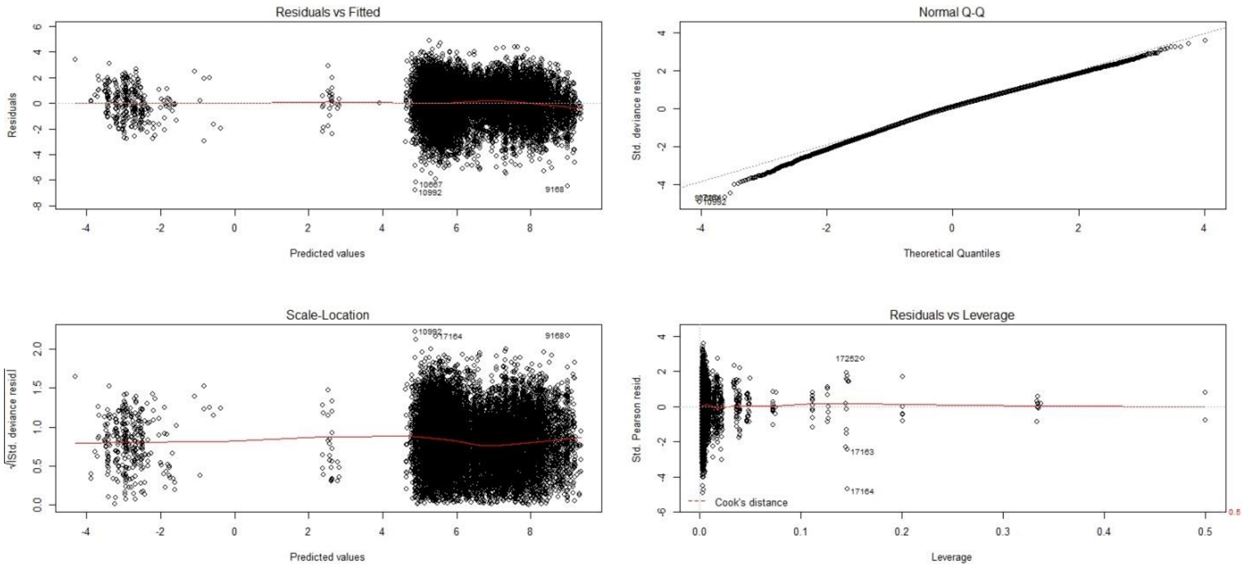

Figure A43. Region 6 – Cote d'Ivoire GLM diagnostic plots**.**

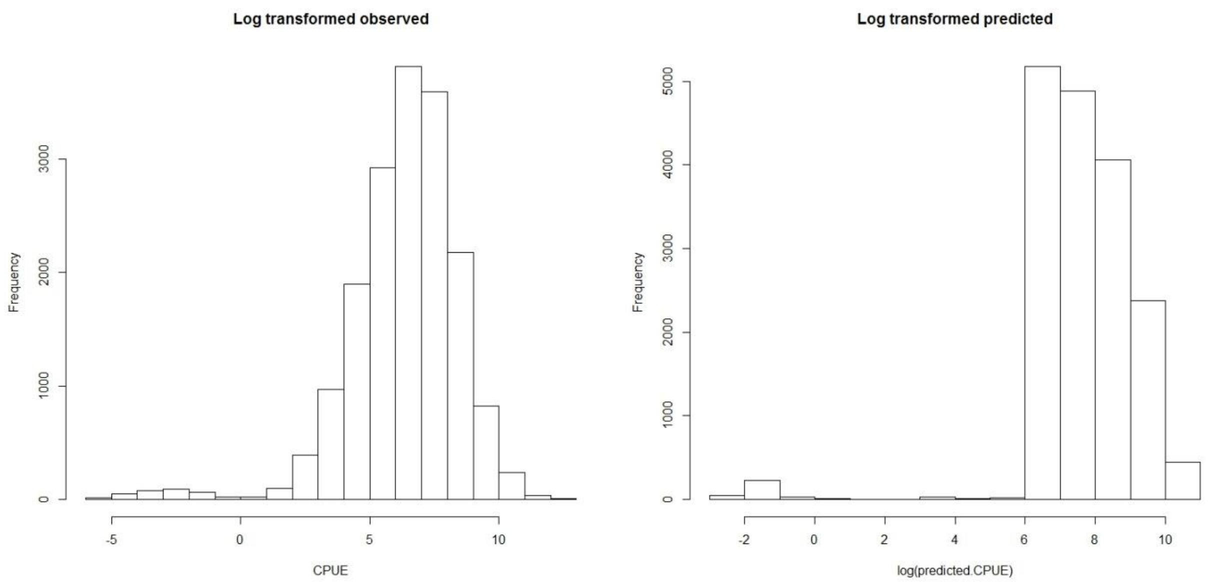

Figure A44. Region 6 – Cote d'Ivoire Histograms of Fitted and Observed log transformed CPUE

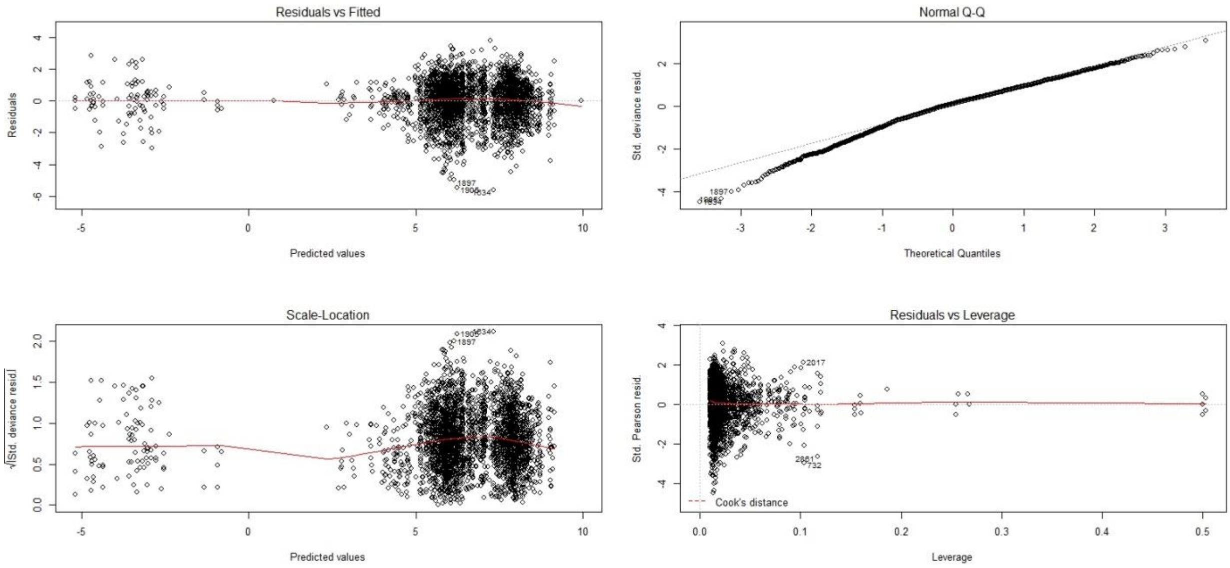

Figure A45. Region 7 – Cape Lopez GLM diagnostic plots.

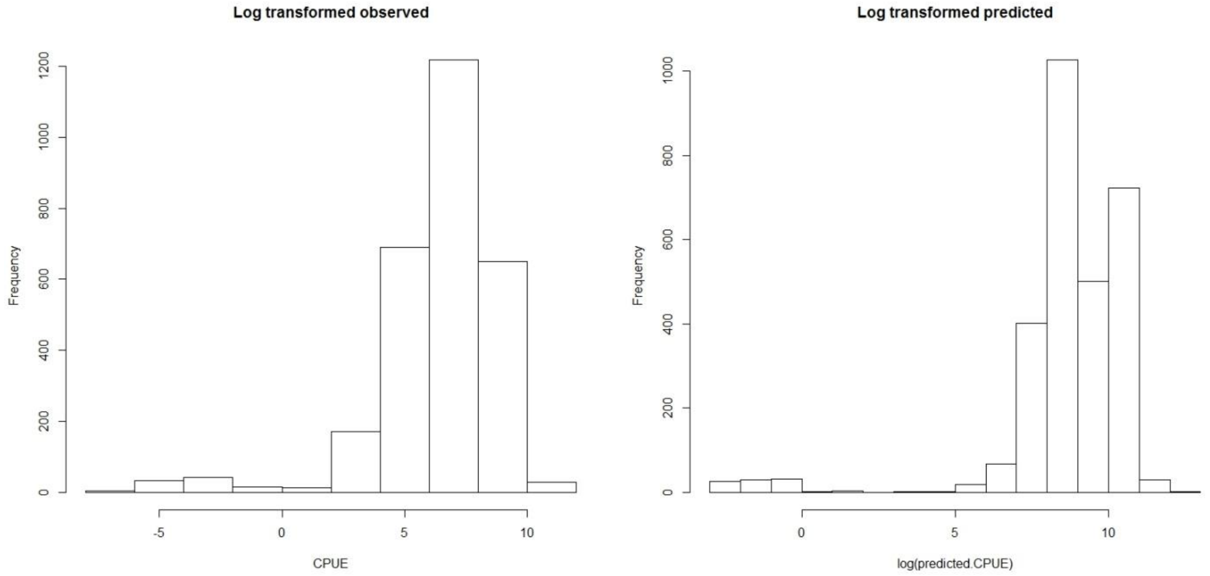

Figure A46. Region 7 – Cape Lopez Histograms of Fitted and Observed log transformed CPUE.

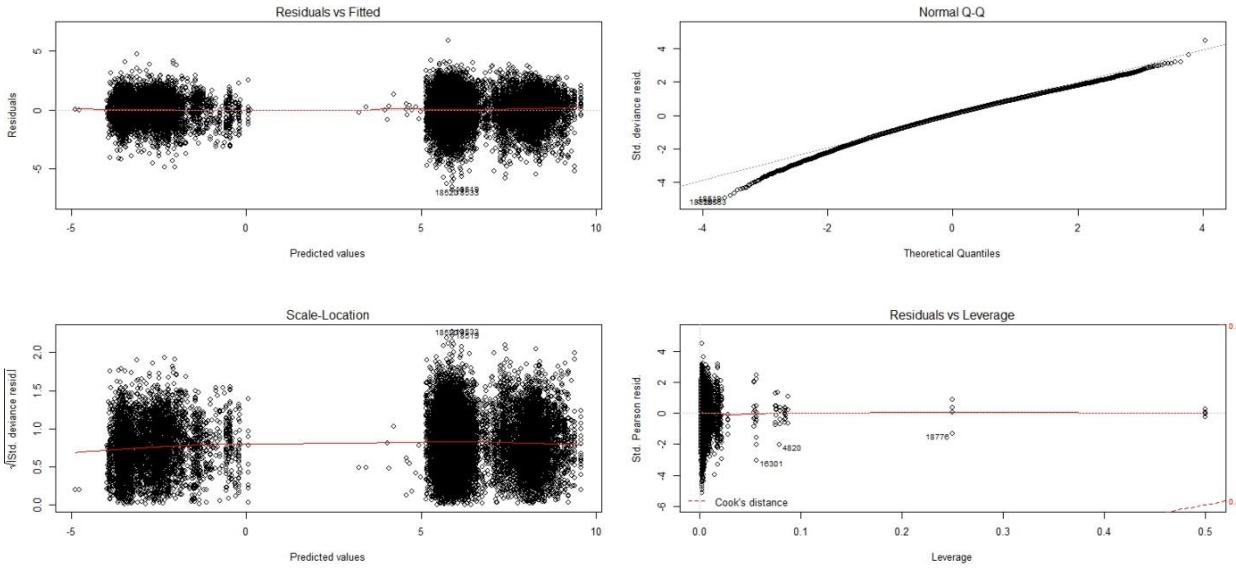

Figure A47. Region 8 – Equator GLM diagnostic plots.

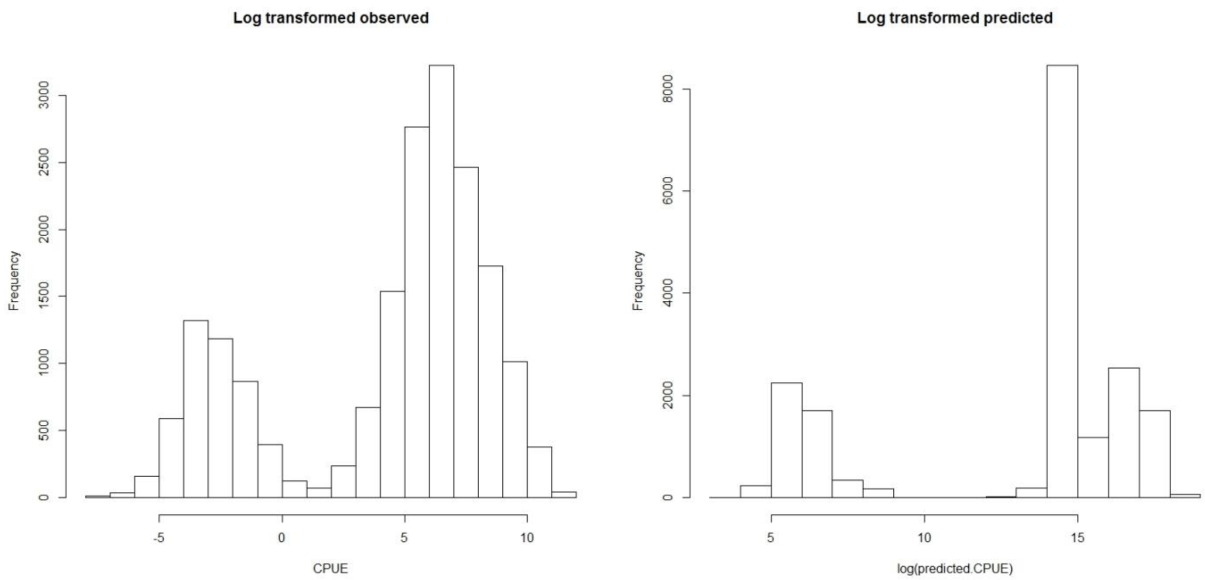

Figure A48. Region 8 - Equator Histograms of Fitted and Observed log transformed CPUE.