Standardization of CPUE from Aleutian Islands Golden King Crab Fishery Observer Data

M.S.M. Siddeek1, J. Zheng1, Doug Pengilly2, and Gretchen Bishop1

1 Alaska Department of Fish and Game

Division of Commercial Fisheries

P.O. Box 115526; Juneau, Alaska 99811

2 Alaska Department of Fish and Game

351 Research Court; Kodiak, Alaska 99615

[shareef.siddeek@alaska.gov](mailto:shareef.siddeek@alaska.gov); [jie.zheng@alaska.gov](mailto:jie.zheng@alaska.gov); [doug.pengilly@alaska.gov](mailto:doug.pengilly@alaska.gov); gretchen.bishop@alaska.gov

**Draft summary report prepared for the Crab Plan Team Meeting, April 29-May 3, 2013.**

# Preamble

Our primary task is to standardize the catch-per-unit-effort (CPUE) of observer pot sample data to input to the Aleutian Islands golden king crab (GKC) assessment model (Siddeek et al., 2011). We presented an initial analysis to standardize the observer CPUE data using generalized linear model (GLM) at the May 2012 Crab Plan Team (CPT) meeting. Following CPT recommendations, we applied the GLM and generalized additive model (GAM) to analyze the fish ticket and observer sample data and presented the results at the September 2012 CPT meeting. For the February 2013 crab model workshop, we switched back to GLM because it can handle any nonlinear situation by converting the variable into factors and also GLM is based on sound statistical principles.

Following suggestions made at the February Crab Modeling Workshop, we redid the GLM analysis restricting it to observer pot sample legal size male data and divided the time series into pre (1995/96–2004/05) and post (2005/06–2010/11) rationalization periods. We treated the explanatory variables: Soak, Depth, and product of number of Vessels and mean Soak time, as continuous numeric and used the piecewise-cubic spline to describe their functional forms in the GLM. For one scenario, we departed from lognormal and binomial GLM families to the negative binomial family. We computed yearly CPUE indices with confidence intervals and a number of diagnostic statistics for areas east (EAG) and west (WAG) of 174°W longitudes.

Our analysis did not pick up significant interactions and the standardized CPUE indices were lower than the nominal CPUE indices during the post-rationalization period. The standardized CPUE trends based on the negative binomial family were similar to the CPUE trends of the combination of lognormal and binomial families.

Although observer data have been collected since 1989 (ADF&G, 2011), the quality of data improved in the mid-1990s. This restricted the current analysis to 1995/96–2010/11 data sets. We were unable to use the long-term fish ticket (1985/86–2010/11) data set because it has no soak time information, which played an important role in the post-rationalization period.

## Responses to February 2013 Crab Modeling Workshop comments

**General comments:**

1. Although considerable work was undertaken prior to and during the workshop to standardize catch and effort data to remove factors unrelated to abundance, the workshop noted that there was no guarantee that the resulting standardized indexes would be linearly proportional to abundance. For example, there is no way to be sure that the standardization has removed all of the effects of changes in fishing practices or how pots are set spatially in the fishery for Aleutian Islands golden king crab.

*Response: This comment is related to the stock assessment model. Not considered here.*

**Major recommendations and conclusions:**

1. Only the observer CPUE data should be standardized and used in assessments, because it has associated soak time data. Observer CPUE should be broken into two time series, with rationalization marking the break point and a potential influence of soak time on catch included in the analysis irrespective of whether it is significant.

*Response: We considered this suggestion in this analysis.*

**Future work**

1. For the May CPT meeting, provide a revised CPUE standardization which:

* analyzes pre- and post-rationalization observer data separately;

*Response:* *We considered this suggestion in this analysis.*

* includes soak time as a covariate in all models (binomial and log-normal) irrespective of whether they are selected;

*Response:* *We considered this suggestion in this analysis.*

* uses standard model selection diagnostics (e.g. changes in R2) to select other covariates; and

*Response:* *We considered this suggestion in this analysis.*

* includes all diagnostics (including influence plots) for both the binomial and log-normal components of the analysis in the document.

*Response:* *We considered most of this suggestion in the current analysis. However, we have not* *as of yet used the* (<http://projects.trophia.com/projects/influ/repository/entry/influ.R>.) *diagnostics package. We are in the process of learning and implementing this routine.*

1. The longer-term tasks related to CPUE standardization are:

* consider a model for observer CPUE where Soak Time and Depth are treated as continuous covariates;

*Response:* *We considered this suggestion in this analysis. We used the piecewise-cubic spline* *routine to fit these covariates.*

* identify which types of data points appear in the tails of the q-q plots for the fish ticket data and remove aberrant data points;

*Response:* *We are not considering fish ticket in the current analysis; however, we encountered this problem when splitting observer data into two periods. Specifically, the post-rationalization period data showed this pattern in the q-q plot. We removed some records to correct this. We provide comparative figures in the report.*

* repeat the observer data analyses using an alternative distribution such as the negative binomial; and

*Response:* *We considered the negative binomial family in one scenario.*

* construct a competition covariate which, for each record, is based on the number of real days of fishing for the specific week, statistical area and gear.

*Response:* *We constructed an explanatory variable, based on the product of number of vessels and mean Soak Time, to address this. However, the GLM did not select this explanatory variable.*

# Method

## Preliminary data processing

### Observer Pot Sample Data

We separated the observer data into EAG (fishing area east of 174°W longitudes) and WAG (fishing area west of 174°W longitudes) for CPUE standardization. Anecdotal accounts justify the separation of areas and there is hardly any commercial golden king crab abundance in the non-fishing area between the two regions. After removing some incomplete records, the Aleutian Islands golden king crab observer pot sample data totaled 102,849 records for 1990/91–2010/11, and 70095 for 1995/96–2004/05. We considered the 1995/96–2010/11 data in the analysis because of a gap in the data series (the 1994/95 fishery was not sampled) for EAG and inconsistencies in data recording in previous years. The records were further reduced by trimming Soak Time by 5% and Depth by 1% to remove unreliable entries (Table 1). We split the data series into 1995/96–2004/05 (pre-rationalization) and 2005/06–2010/11 (post-rationalization) periods for analysis. We used the core vessels’ data in the analysis for the legal component.

For EAG, there were 31972 total records (zero and positive catches), and 28669 positive catch records for 1995/96–2004/05 and respectively 4210 and 4120 for 2005/06–2010/11. For WAG, there were 32298 total records and 26685 positive catch records for 1995/96–2004/05 and respectively 5445 and 5158 for 2005/06–2010/11.

We considered the following variables from each record in the model:

*Year* = Federal Fisheries Management Year. This is treated as a factorial predictor variable in the model.

*Month* = A calendar month in a year. This is treated as a factorial predictor variable in the model.

*Vessel* = Identification code for a participating vessel. This is treated as a factorial predictor variable in the model.

*Captain*  = Identification code for Captain. This is treated as a factorial predictor variable in the model.

*Area* = ADFG identification code for a fishing area. This is treated as a factorial predictor variable in the model. This factor variable was reduced to 10 levels defined in the subsequent section.

*Catch* = Number of crabs caught. This is the response variable. We considered two types of crab catch response variables, legal males (retained and non-retained legal-sized crab) and sublegal males. Because the stock assessment model is designed for males only, we did not consider female catch. This is treated as a numeric response variable in the model.

*East/West* = The east/west subdivision code, 1 for east and 2 for west of 174°W longitudes. We subset the data to 1, 2 or 1 & 2 for model fit.

*Depth* = Depth in fathoms. We considered this as an important predictor variable because crab abundance is not uniform by depth. This is treated as a numerical predictor variable in the model.

*Soak* = Soak time in number of days. We considered this an important predictor variable because there were significant changes in soak time duration between pre-and post-rationalization periods (Siddeek et al., 2011). This is treated as a numeric predictor variable in the model.

*Gear* = Identification code for different types of pot gear. Although a single gear (pot) is used in the fishery, the type and configuration varied over the years. Each type of pot has a unique number code (Table 2). We considered this an important predictor variable because gear configuration affects catch efficiency. This is treated as a factorial predictor variable in the model.

*East/WestVesSoak* = product of Number of vessels and average soak days by year. This is treated as a numeric predictor variable in the model.

## Definition of Factor Levels

*Year*: 1995/96–2010/11 for observer pot sample data;

*Month*: 1 to 12;

*Vessel*: Vessel registration number;

*Captain*: Captain identified number code;

*Gear*: Gear codes. These are provided in Table 1; and

*Area*, Ten levels:

Statistical area code 665300– 685334 range is coded as 66;

Statistical area code 695199– 705301 range is coded as 69;

Statistical area code 715129–-735301 range is coded as 71;

Statistical area code 745130–755331 range is coded as 74;

Statistical area code 765099–775201 range is coded as 76;

Statistical area code 785100–795431 range is coded as 78;

Statistical area code 805100–815432 range is coded as 80;

Statistical area code 825099–835301 range is coded as 82;

Statistical area code 845099–865303 range is coded as 84; and

Statistical area code 875199–895331 range is coded as 87.

## Core Vessel Selection

There was a maximum of 162 vessel registration codes in the crab retained catch database during 1985/86–2010/11. The maximum number of vessels dropped to 37 when the period was restricted to 1995/96–2010/11. We used the number of catch delivery instances as surrogate for trips in each year for each vessel. They are plotted in Figure 1 to assess the overlap of different vessels’ fishing activities over time. The percentage catch and vessels declined dramatically when we considered vessels with 3, 5, and 9 trips per year over time (Figure 2 for 1990/91–2010/11 data series, available time series of observer data). We considered the shorter data series (1995/96–2010/11) for analyzing observer pot sample data. We selected five delivery instances per year for at least three years as reasonable to select the core vessels. This set of core vessels produced nearly 93% of the maximum total catches and reduced the number of vessels to 37% of the maximum number of vessels for 1990/91–2010/11. The CPUE trends did not differ significantly for core and total vessels (Figures 3 and 4 for EAG and WAG, respectively).

## CPUE Standardization

We used a stepwise generalized linear model (GLM) procedure to select the best model and estimate a time series of CPUE indices based on the relationship between CPUE and the predictor variables.

Following Quinn and Deriso (1999), we derived the GLM based on the lognormal distribution from the following:

(1)

where *U* is the observed *CPUE*, *U*0  is the reference *CPUE*, *Pij* is a factor *i* at level *j*, and *Xij* takes

a value of 1 when the *j*th level of the factor *Pij* is present and 0 when it is not. The random

error *εijk* for observation *k* is a normal random variable with mean 0, and standard deviation *σ*.

Taking the logarithm of equation (1) yields an additive generalized linear model for lognormal error distribution of *U*:

,

or

. (2)

where *β0*  is the intercept and *βij =* ln(*Pij*).

The model described by equations 1 and 2 is over-parameterized. A common remedial solution is to set a factor coefficient to zero, usually the first, whereupon the remaining *nj*-1 coefficients of each factor *i* represent incremental effects relative to the reference level.

Coefficients obtained by fixing a factor level will differ with the choice of reference level. However, the relative differences among the estimated coefficients will not be affected by the choice of constraint. Following Francis (1999), we transformed the coefficients for factor *i* to “canonical” coefficients over all levels *j* calculated relative to their geometric mean.

We calculated the geometric mean as,

. (3)

The canonical coefficient is

. (4)

As *CPUE* analysis is done in the non-log space, the non-log space canonical coefficient is equivalent to

. (5)

A number of factors contribute to the variation in CPUE, including *Year*, *Month*, *Vessel*, *Captain*, *Depth*, *Soak Time*, *Area*, *Fishing Effort*, etc. Year is usually given special significance as variations between Years are interpreted as relative changes in the annual abundance of the crab. **The resulting series of ‘*Year*’ canonical coefficients is termed as the “Standardized” annual CPUE index.**

For example, consider a fitted model of the form:

.

If x2 is the factor variable Year, then would take on the values when Year is the reference year 0, and when Year is some other year *i*. So, the *CPUE* index for year *i* relative to the reference year 0 is estimated as:

.

So, relative year effects are calculated by dividing the inverse of the fitted model in year *i* by the inverse of the fitted model in base year 0.

We applied a selection procedure to determine the relative importance of these factors in the model. The procedure involves a forward stepwise fitting algorithm which generates regression models iteratively, starting with the simplest model (null model), , and building in complexity subject to a stopping rule designed to include only the most important factors. Following the February 2013 model workshop recommendation, we included the *Soak* time predictor variable in the null model. The reason for this inclusion was that *Soak* time was confounded with Year, dramatically increasing after crab fishery rationalization in 2005/06 (Figure C.1, Appendix C).

We used the following general procedure to fit the models:

1. Fit the GLM with each predictor variable from a maximum set of predictor (factor and numeric) variables against the natural log of *CPUE* (legal male catch per record).
2. Generate an R2 based on model deviance and number of degrees of freedom for each fit as:

(6)

where deviance = a constant-2\*Maximum log likelihood.

1. Select the predictor variable that has the highest R2.
2. Repeat Steps 1 and 2, accumulating the number of selected predictor variables and

increasing the model degrees of freedom until the increase in residual deviance (as

measured by R2) for the final iteration is less than 0.01.

We used piecewise-cubic spline (ns) with a fixed number of degrees of freedom (number of knots=df-2) to fit numeric predictor variables thus avoiding pre-specified functional form.

The lognormal model is applicable for positive catch data. Zero catches are also encountered in observer samples. We also fitted a GLM model based on a binomial distribution and using presence or absence

of crab (success = 1/0) as the dependent variable to the same set of data using the same set of explanatory variables. The selection procedure was the same as that for the lognormal model. The binomial model will provide another series of standardized annual CPUE coefficients that is similar to the series estimated from the lognormal GLM.

We estimated a combined model which integrates the two series of relative annual changes estimated by the lognormal and binomial models using the delta distribution which allowed zero and positive catches (Vignaux 1994; Starr, 2012).

(7)

where

= combined CPUE index for year *y*,

= lognormal CPUE index for year *y*,

= binomial CPUE index for year *y*, and

= proportion of zeros for base year 0.

For comparison with the standardized CPUE index, we also estimated the nominal CPUE (Arithmetic CPUE) and scaled it to the level of the standardized CPUE index.

(8)

(9)

(10)

where is catch and is effort for each record *i* in year *y*; is the geometric mean of the Arithmetic CPUE; andand are Arithmetic CPUE and scaled Arithmetic CPUE for year *y*, respectively.

Following the February 2013 workshop recommendation, we also considered the negative binomial distribution (Zuur et al., 2009) to fit the predictor variables to CPUE data. The rationale for considering an alternative distribution is that CPUE standardization suggests that some of the catches may only be one crab; the assumption of a log-normal distribution gives equal weight to catches of one crab and over 100 crabs; and data are not continuous as assumed by the lognormal distribution.

Let be negative binomial distributed with mean , parameter (dispersion) *k*, and variance of .

The negative binomial family in GLM has a logarithmic link that ensures fitted values are always non-negative (i.e. CPUE >= 0). Therefore,

or (11)

## Bootstrap statistics

The standard errors and confidence bounds for the combined CPUE index are difficult to estimate directly because of the involvement of two different distributions, lognormal and binomial. There are two ways to estimate these statistics, jackknife sample (Manly, 1997; Ralston and Dick, 2003; Doonan, New Zealand personal communication) and bootstrap sample (Efron and Tibshirani, 1986; Jason Cope, Northwest Fisheries Science Center, USA, personal communication). We used the bootstrap procedure because earlier application of jackknife with the vessel removal process produced unreasonably high confidence intervals in recent years of the time series as a result of a dramatic drop in number of vessels. Bootstrap sampling is a process of resampling the data with replacement and estimating the statistics. Because the data is a time series, we randomly sampled the ordered indexes of records for each year, combined them, and allocated the corresponding data records to obtain a resampled data set. We used this bootstrapped data set to estimate a combined index. We obtained 1000 bootstrapped samples and calculated 1000 bootstrap combined CPUE indexes. We used the R codes provided by Jason Cope (Appendix B) for this calculation and estimated confidence intervals using Efron’s method (Efron and Tibshirani, 1986):

97.5 th percentile of the bootstrapped combined CPUE index distribution - 2.5 th percentile of the bootstrapped combined *CPUE* index distribution

## GLM implementation for observer pot sample data analysis

To analyze observer sample data, we first used lognormal GLM on non-zero catches. We used the forward step-wise selection procedure to select the best model. We assumed the null model to be

. (12)

A piece-wise cubic spline with a given degree of freedom (interior knots) was used to fit the Soak Days numerical predictor variable.

The maximum set of model terms offered to the stepwise selection procedure was:

,

(13)

where *CPUE* = number of legal males caught per pot lift (catch/effort) in *i* th record; *EASTVesSoak* = number of vessels multiplied by average soak time for a year; *ns*= piecewise-cubic spline function, and all other predictor variables are self-explanatory by name, and subscripts are either factor levels or different numeric values.

We used a binomial GLM on the catch success (0 or 1) response variable. The maximum set of explanatory variables offered to the stepwise selection procedure was as described above. We used a binomial logit link function in the selection process.

We also used the negative binomial GLM on legal male CPUE. The maximum set of explanatory variables offered to the stepwise selection procedure was the same as on the right hand side of Equation 13, but raw CPUE values (>= 0) were used as the response variable. We used a log link function and a dispersion parameter (*k*) value of two in the selection process. We explored different *k* values, but *k*=2 provided acceptable residual patterns.

## Software Use

We coded in R to analyze the data (Appendices A for GLM and B for bootstrap).

## Results

The distributions of legal crab catch by year in observer data are skewed to the right with significant proportions of zero and positive catches (Figures C.2 and C.3, Appendix C). Thus supporting the families of distributions used in the GLM. Table 3 lists the sample size and Akaike Information Criterion (*AIC*) values for all the predictor variables considered under lognormal and binomial GLMs, respectively. , where *L* = maximum likelihood estimate and *k*=number of parameters (Burnham and Anderson, 2002). The predictor variable Captain produced the lowest AIC for lognormal model whereas Vessel produced the lowest AIC for the binomial model.

The forward GLM selection procedure produced a suite of final models for the EAG and WAG subsets of data for different time periods 1995/04–2004/05 and 2005/06–2010/11 (Table 4). All final models selected the Captain predictor variable. Although the golden king crab fishery is prosecuted with only a single gear type (pots), the gear configuration has changed over the years, so different gear factor levels were considered for the model.

Tables 5 and 6 provide the analysis of deviance values for lognormal and binomial fits for EAG and WAG, respectively. Each table lists the results separately for 1995/96–2004/05 and 2005/06–2010/11 periods. The last column in each Table provides the systematic increase in R2 as each selected predictor variable was added. Lognormal GLM fit on positive catches produced higher R2 values than the binomial GLM fit for both regions.

We considered *Year*:*Captain*, *Year*:*Gear*, *Year*:*Area*, and *Year*:*Month* interactions one at a time for different subsets of data for EAG and WAG legal size catches. Tables 7 and 8 provide the analysis of deviance values for lognormal and binomial fits with *Year*:*Captain* interaction selection for EAG and WAG, respectively. There was an improvement in R2, but not large enough to consider them as base models. Stepwise selection procedure with other interaction terms either did not select the interaction for either model or did not improve R2.

The negative binomial fit slightly improved R2 for the 1995/96–2004/05 data set, but did not improve R2 for the 2005/06–2010/11 data set for either region (Tables 9 and 10). Table 11 compares the annual CPUE index estimates by the combined lognormal and binomial and negative binomial GLM fits. The results are similar for most of the data subsets.

Tables C.12-C.19 in Appendix C list the parameter estimates with standard errors for lognormal and negative binomial fits for 1995/06–2004/05 and 2005/06–2010/11 periods and for east (EAG) and west (WAG) of 174°W longitudes. The parameter estimates are provided in non-log space as well.

Figures 3 and 4 provide comparisons of all vessels’ and core vessels’ CPUE for the 1995/96–2010/11 time period for EAG and WAG, respectively. The CPUE trends are very similar largely due to core vessels are almost identical to all vessels during this time period. Figure 5 depicts the one-to-one relationship between each predictor variable (scatter plot matrices) offered for the EAG model selection. Significant correlations exist between *Year* vs. *VesSoak*, *Month* vs. *VesSoak*, and *Year* vs. *SoakDays*. We did not drop any of the explanatory variables offered for GLM selection based on these plots. The selection process took care of this and dropped highly correlated variables with *Year*, except *SoakDays*, which was forced into the model. Figures 6 and 7 are model diagnostic plots. Figure 6 provides studentized residual plot for the best lognormal fit to legal crab while Figure 7 depicts observed vs. predicted response variable and Pearson residuals vs. predictor variables for the 1995/96–2004/05 period for EAG. Studentized residuals are closer to the 1-1 line indicating that the residuals are nearly normal. The observed vs. predicted *ln(CPUE)* points are widely scattered, which is reflected in low R2 value as well. Pearson residuals plotted against model selected explanatory variables and response variable appear not drastically violating any model assumptions.

The CPUE trend plots are presented in Figure 8 for the 1995/96–2004/05 data series for EAG. We also provide the combined CPUE index trend by bootstrap sampling in the same figure (bottom panel). On the top panel, five CPUE indices: Lognormal (StdIndex), Combined (CombinedIndex), Base (BaseIndex), Arithmetic (ArithIndex), and Binomial (BinomIndex) are shown. Base index considers only the *Year* + *Soak* effect disregarding the influence of all other factor variables. The combined index considers positive and zero catches in the calculation and hence is considered the best among all the indices. The lognormal *CPUE* index trend matches the combined CPUE index trend well. Sharp rise in all CPUE indices is apparent for the 2004/05 season.

Figure 9 provides studentized residual plots for the best lognormal fit to legal crab for the 2005/06–2010/11 data series for EAG. The top panel depicts the residual plot considering the entire core data set for that period and the bottom panel shows the trimmed data set for the same period. Trimming the data improved the residual pattern and the latter data set was used in subsequent analysis for EAG. Figure 10 depicts observed vs. predicted response variable and Pearson residuals vs. predictor variables for the 1995/96–2004/05 period for EAG. Figures 6 and 7 description in the previous paragraph applies to these figures as well.

Figure 11 shows the CPUE index trend plots for the 2005/06–2010/11 data series for EAG. On the top panel, five CPUE indices are plotted and on the bottom panel, bootstrapped combined index with two standard errors are depicted. The binomial CPUE index trend departed from the other trends with a high index value in 2009/10. Overall, the other CPUE index trends are flat during this time period.

Figure 12 depicts the one-to-one relationship between each predictor variable (scatter plot matrices) considered for the WAG model fit. Significant correlations exist between *Year* vs. *SoakDays* and *Year* vs. *VesSoak*. Figure 13 provides studentized residual plot for the best lognormal fit to legal crab while Figure 14 depicts observed vs. predicted response variable and Pearson residuals vs. predictor variables for the 1995/96–2004/05 period for WAG. Figures 6 and 7 description in the previous paragraph applies to these figures as well.

Figure 15 shows the CPUE index trend plots for the 1995/96–2004/05 data series for WAG. On the top panel, five CPUE indices are plotted and on the bottom panel, bootstrapped combined index with two standard errors are depicted. The binomial CPUE index trend matched the other CPUE index trends with a high index value in 1996/97. Overall, the CPUE index trends are flat during this time period.

Figure 16 provides studentized residual plot for the best lognormal fit to legal crab for the 2005/06–2010/11 data series for WAG. The top panel depicts the residual plot considering the entire core data set for that period and the bottom panel shows the trimmed data set for the same period. Trimming the data improved the residual pattern; therefore, the latter data set was used in subsequent analysis for WAG. Figure 17 depicts observed vs. predicted response variable and Pearson residuals vs. predictor variables for the period 2005/06–2010/11 for WAG. Figures 6 and 7 description in the previous paragraph applies to these figures as well.

Figure 18 shows the CPUE trend plots for the 2005/06–2010/11 data series for WAG. On the top panel, five CPUE indices are plotted and on the bottom panel, bootstrapped combined index with two standard errors are depicted. The binomial CPUE index trend departed from the other trends with a high index value in 2008/09. Overall, the other CPUE index trends are flat during this time period.

Figure 19 provides studentized residual plot for the best negative binomial fit to legal crab for the 1995/06–2004/05 data series for EAG. Figure 20 depicts observed vs. predicted response variable and Pearson residuals vs. predictor variables for the period 1995/96–2004/05 for EAG. The observed vs. predicted CPUE points are tighter than those in other similar plots for lognormal fits and reflected on slightly higher R2 value. Figure 7 description in the previous paragraph applies to Figure 20 as well.

Figure 21 shows the CPUE trend plots for the 1995/96–2004/05 data series for EAG. Negative binomial indices with two standard errors are plotted with base and arithmetic indices. The CPUE trends are similar to those seen in Figure 8 with sharp rise in all CPUE indices in 2004/05.

Figure 22 provides studentized residual plot for the best negative binomial fit to legal crab for the 2005/06–2010/11 data series for EAG. There is a slight dip in the lower tail part of the residual distribution. Overall, the points are closer to 1-1 line, not drastically violating the normality assumption. Figure 23 depicts observed vs. predicted response variable and Pearson residuals vs. predictor variables for the period 2005/06–2010/11 for EAG. The observed vs. predicted CPUE points are scattered similar to those observed for the log normal plots and reflected on low R2 value. Figure 7 description in the previous paragraph applies to Figure 23 as well.

Figure 24 shows the CPUE trend plots for the 2005/06–2010/11 data series for EAG. The three (negative binomial, base, and arithmetic) CPUE indices trends are close and flat during this time period.

Figure 25 provides studentized residual plot for the best negative binomial fit to legal crab for the 1995/06–2004/05 data series for WAG. The residuals are closer to the 1-1 line, not violating the normality assumption. Figure 26 depicts observed vs. predicted response variable and Pearson residuals vs. predictor variables for the period 1995/96–2004/05 for WAG. The observed vs. predicted CPUE points are tighter than those in other similar plots for lognormal fits and reflected on slightly higher R2 value. Figure 7 description in the previous paragraph applies to Figure 26 as well.

Figure 27 shows the CPUE trend plots for the 1995/96–2004/05 data series for WAG. The three (negative binomial, base, and arithmetic) CPUE indices trends are close during most seasons and showed increasing trends since 2000. However, the arithmetic index values are lower than other indices during 1995/96 – 1997/98.

Figure 28 provides studentized residual plot for the best negative binomial fit to legal crab for the 2005/06–2010/11 data series for WAG. There is a slight dip in the lower tail part of the residual distribution. Overall, the residuals are closer to the 1-1 line, not drastically violating the normality assumption. Figure 29 depicts observed vs. predicted response variable and Pearson residuals vs. predictor variables for the period 2005/06–2010/11 for WAG. The observed vs. predicted CPUE points are scattered similar to those observed for the log normal plots and reflected on low R2 value. Figure 7 description in the previous paragraph applies to Figure 29 as well.

Figure 30 shows the CPUE trend plots for the 2005/06–2010/11 data series for WAG. The three (negative binomial, base, and arithmetic) CPUE indices trends are close and flat during this time period.

# Discussion

We estimated the time series of standardized combined (lognormal and binomial) and negative binomial observer data CPUE indices separately for two time periods: 1995/96–2004/05 and 2005/06–2010/11, and two regions: EAG and WAG. We provide the combined indices with confidence intervals by the bootstrap procedure. In most cases, standardized CPUE indices were lower than arithmetic CPUE indices. When the soak time was forced into the GLM, standardized CPUE index trends were in most cases flat during the post rationalization period. Soak time dramatically increased after crab rationalization and appeared to be a factor in driving arithmetic CPUE indices up in both areas.

In CPUE standardization, substantial and significant interactions of explanatory variables with Year would prevent the extraction of meaningful yearly CPUE trends using GLM. We investigated the interactions of GLM selected explanatory variables with Year, one at a time. Except for the *Year*:*Captain* interaction, the stepwise selection procedure either did not select the interaction or selected the interaction, with an insignificant increase in R2. The only substantial interaction was for *Year*:*Captain* . However, even for this interaction, the R2 was not significantly higher than that for the best non-interaction model. Highly variable observer data may have suppressed the selection of additional interaction terms with significantly high R2. Interactions of explanatory variables with year are a common problem in CPUE standardization and other researchers have solved the problem by averaging CPUE over interacting variables (Maunder and Punt, 2004) or by incorporating interactions as a random effect variable in a Generalized Linear Mixed Model (Ortiz and Arocha, 2004).

O’Hara and Kotze (2010) argued that log-transformed count data performed poorly except when dispersion was small and mean counts large. The negative binomial is an alternative to the Poisson distribution when there is overdispersion (i.e., when var > mean) (Zuur et al., 2009). Because of the highly scattered nature of observer data, we considered the scenario of using a negative binomial family with a log link function in the GLM to standardize CPUE. The negative binomial distribution only fits into the framework of traditional GLM when the value of dispersion parameter is assumed to be known (Fox and Weisberg, 2011). After testing with different values of the dispersion parameter we fixed it to 2, which provided an acceptable residual pattern. The standardized CPUE trends based on the negative binomial family were similar to the CPUE trends of the combination of lognormal and binomial families and R2 values were slightly higher for the negative binomial for the 1995/96–2004/05 data set, but lower for the 2005/06–2010/11 data set. Thus, there was no clear-cut preference for one model over the other and either family could be used in the GLM to estimate CPUE indices.

Although observer data have been collected since 1989 (ADF&G, 2011), the quality of data improved in the mid-1990s. This restricted the current analysis to 1995/96–2010/11 data sets. We were unable to use the long-term fish ticket (1985/86–2010/11) data set because it has no soak time information, which played an important role in the post-rationalization period.

In conclusion, we identified non-interacting explanatory variable sets to standardize observer CPUE data for Aleutian Islands legal male golden king crab. We also identified the limitations of fish ticket data to produce useful long-term time series of standardized CPUE indices (see Crab Model Workshop Report, NPFMC, 2013). The standardized CPUE indices with their standard errors will be used in the stock assessment model for EAG and WAG.

# Acknowledgements

We thank Lee Hulbert, Vicki Vanek, Heather Fitch, Jason Cope, February 2013 Model workshop members, and industry participants for various technical input and guidance. We also thank Chris Siddon for his time to review this draft.

# References

ADF&G (Alaska Department of Fish and Game). 2011. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward region’s shellfish observer program, 2009/10. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report No. 11-05, Anchorage, Alaska.

Burnham, K.P. and D.R. Anderson 2002. Model selection and multimodal inference: A practical information-theoretic approach, 2nd edition, Springer-Verlag, New York, NY.Efron, B. and R. Tibshirani. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science 1: 54-77.

Francis, R.I.C.C. 1999. The impact of correlations on standardized CPUE indices. New Zealand Fishery Assessment Research Document 1999/42. 30 p. (Unpublished report held in NIWA library, Wellington, New Zealand).

Fox, J. and S. Weisberg. 2011. An R companion to applied regression. Second edition Sage Publications, Inc. 449 p.

Manly, B.F.J. 1997. Randomization, bootstrap and Monte Carlo methods in biology. Second edition Chapman & Hall. 399 p.

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

NPFMC, 2013. North Pacific Fishery Management Council Crab Modeling Workshop Report. NPFMC, Anchorage, Alaska.

O’Hara, R.B. and D.J. Kotze. 2010. Do not log-transform count data. Mothods in Ecology and Evolution, 1(2):118-122.

Ortiz, M., and F. Arocha. 2004. Alternative error distribution models for standardization of catch rates of non-target species from a pelagic longline fishery: billfish species in the Venezuelan tuna longline fishery. Fisheries Research. 70(2-3): 275-297.

Quinn, T.R. and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. 542 p.

Ralston S. and E.J. Dick. 2003. The status of black rockfish (*Sebastes melanops*) off Oregon and Northern California in 2003. Pacific Fishery Management Council, 2130 SW Fifth Ave., Suite 224, Portland, Oregon.

Siddeek, M.S.M., D. Pengilly, and J. Zheng. 2011. Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Model Based Stock Assessment in Fall 2011. Presented at the Fall 2011 Crab Plan Team meeting, AFSC, Seattle.

Starr, P.J. 2012. Standardized CPUE analysis exploration: using the rock lobster voluntary logbook and observer catch sampling programmes. New Zealand Fisheries Assessment Report 2012/34, 75 p.

Vignaux, M. 1994: Catch per unit effort (CPUE) analysis of west coast South Island and Cook Strait spawning hoki fisheries, 1987–1993. N.Z. Fisheries Assessment Research Document 94/11. 29 p. (Unpublished report held in NIWA library, Wellington, New Zealand).

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, New York.

# Tables

Table 1. Pre-and post-rationalization periods percentile cut off *Soak* time (day) and *Depth* (fathom) for east (EAG) and west (WAG) of 174°W longitudes. The 5%–95% percentile range for *Soak* time and 1%–99% percentile range for *Depth* were used.

|  |  |  |  |
| --- | --- | --- | --- |
| **Area** | **Variable** | **Percentile range** | |
| **Pre-rationalization (before 2005/06)** | **Post-rationalization (after 2004/05)** |
| EAG | *Soak* (day) | 2–11 | 5–28 |
| *Depth* (fathom) | 75–337 | 75–337 (same) |
| WAG | *Soak* (day) | 2–25 | 9–41 |
| *Depth* (fathom) | 77–308 | 77–308 (same) |

Table 2. Gear code assigned to different types of pot gear by observers during the 1990/91–2010/11 seasons. The yellow highlighted gears are infrequent and not considered as factor levels. (Doug Pengilly, personal communication).

|  |  |  |
| --- | --- | --- |
| **Gear code** | **Pot gear description** | **Total pot samples** |
| -9 | #N/A - not recorded | 66 |
| 1 | Dungeness crab pot, small & round | 2 |
| 2 | Pyramid pot, tunnel openings usually on sides, stackable | 2,107 |
| 3 | Conical pot, opening at top of cone, stackable | 1,998 |
| 4 | 4' X 4' rectangular pot | 60 |
| 5 | 5' X 5' rectangular pot | 16,198 |
| 6 | 6' X 6' rectangular pot | 14,927 |
| 7 | 7' X 7' rectangular pot | 22,242 |
| 8 | 8' X 8' rectangular pot | 1,407 |
| 9 | 5 1/2' X 5 1/2' rectangular pot | 6,339 |
| 10 | 6 1/2' X 6 1/2' rectangular pot | 19,697 |
| 11 | 7 1/2' X 7 1/2' rectangular pot | 375 |
| 12 | Round king crab pot, enlarged version of Dungeness crab pot | 8,257 |
| 13 | 10' X 10' rectangular pot | 466 |
| 14 | 9' X 9' rectangular pot | 1 |
| 15 | 8 1/2' X 8 1/2' rectangular pot | 1 |
| 17 | 8' X 9' rectangular pot | 1 |
| 20 | 7' X 8' rectangular pot | 232 |
| 22 | snail pot | 1 |
| 23 | Dome-shaped pot, tunnel opening on top, often longlined in deep-water fisheries | 6,755 |
| 80 | Historical: Cod pot, any shape pot targeting cod, usually with tunnel fingers | 711 |
| 81 | Historical: Rectangular pot, unknown size, with escape rings | 1,122 |
|  | **Grand total** | **102,965** |

Table 3. AIC values of different explanatory variables considered for the lognormal and binomial models. The data series are for 1995/06–2004/05 and 2005/06–2010/11 periods and for east (EAG) and west (WAG) of 174°W longitudes. n = number of records.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Link** | **Parameter/Variable** | **AIC or sample size (n)** | | | |
| **EAG** | | **WAG** | |
| **1995/06–2004/05** | **2005/06–2010/11** | **1995/06–2004/05** | **2005/06–2010/11** |
| Lognormal | n | 28669 | 4120 | 26685 | 5158 |
| *Year* | 77962 | 9090 | 75139 | 13000 |
| *Soak* | 80857 | 9061 | 74151 | 12905 |
| *Month* | 78500 | 9112 | 75128 | 12973 |
| *Captain* | 77871 | 8956 | 72733 | 12725 |
| *Vessel* | 79845 | 8978 | 72968 | 12753 |
| *Area* | 81040 | 9097 | 75153 | 12788 |
| *Gear* | 76739 | 9102 | 73972 | 12937 |
| *Depth* | 81322 | 9140 | 75855 | 12951 |
| *EastVesSoak* | 81020 | 9139 |  |  |
| *WestVesSoak* |  |  | 75568 | 13015 |
|  |  |  |  |  |  |
| Binomial | n | 31972 | 4210 | 32298 | 5445 |
| *Year* | 20701 | 870 | 29506 | 2223 |
| *Soak* | 21070 | 873 | 29260 | 2251 |
| *Month* | 20841 | 868 | 29316 | 2227 |
| *Captain* | 20262 | 850 | 28254 | 2215 |
| *Vessel* | 20939 | 847 | 28192 | 2205 |
| *Area* | 21121 | 874 | 29325 | 2243 |
| *Gear* | 20191 | 877 | 28870 | 2246 |
| *Depth* | 21062 | 872 | 29710 | 2244 |
| *EastVesSoak* | 21221 | 869 |  |  |
| *WestVesSoak* |  |  | 29777 | 2239 |

Table 4. Step-wise model selection for various scenarios for the Aleutian Islands golden king crab observer data. StepGLM routine was used for selection of variables and final fit. Observer data for 1995/96–2004/05 and 2005/06–2010/11 periods were used.

|  |  |  |
| --- | --- | --- |
| **Area** | **Data series** | **Final model** |
| EAG | 1995/96–2004/05 | *Ln(CPUE)~Year+ns(Soak, df=8)+Gear+Captain +Month* |
| *Binomial(Success)~Year+ns(Soak, df=8)+Captain +Gear* |
| 2005/06–2010/11 | *Ln(CPUE)~Year+ns(Soak, df=8)+Captain+Gear +Month* |
| *Binomial(Success)~Year+ns(Soak, df=8)+Vessel+Month* |
|  |  |  |
| WAG | 1995/96–2004/05 | *Ln(CPUE)~Year+ns(Soak, df=8)+Captain +Gear* |
| *Binomial(Success)~Year+ns(Soak, df=8)+Captain +Gear* |
| 2005/06–2010/11 | *Ln(CPUE)~Year+ns(Soak, df=8)+Captain+Area* |
| *Binomial(Success)~Year+ns(Soak, df=8)+Month* |

Table 5. Analysis of deviance for stepwise lognormal and binomial models selection of the Aleutian Islands golden king crab fishery. The response variable is observer CPUE. Observer legal data from EAG (east of 174°W longitudes) for 1995/96–2004/05 and 2005/06–2010/11 were used. The 2005/06–2010/11 data series was trimmed.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Link** | **Data series** | **Variable** | **df (difference from null)** | **Deviance** | **Residual df** | **Residual deviance** | **R2** |
| Lognormal | 1995/96–2004/05 | *Year*+*Soak* |  |  | 28652 | -33.86 | 0.14 |
|  | *Gear* | -14 | -27.93 | 28638 | -61.79 | 0.21 |
|  | *Captain* | -40 | -79.97 | 28598 | -141.76 | 0.24 |
|  | *Month* | -11 | -21.99 | 28587 | -163.75 | 0.25 |
|  | 2005/06–2010/11 | *Year*+*Soak* |  |  | 4236 | -27.96 | 0.04 |
|  | *Captain* | -8 | -15.97 | 4228 | -43.93 | 0.07 |
|  | *Month* | -7 | -13.99 | 4221 | -57.92 | 0.08 |
|  |  |  |  |  |  |  |  |
| Binomial | 1995/96–2004/05 | *Year* +*Soak* |  |  | 31955 | -33.96 | 0.04 |
|  | *Captain* | -40 | -79.97 | 31915 | -113.93 | 0.07 |
|  | *Gear* | -14 | -27.98 | 31901 | -141.90 | 0.10 |
|  | 2005/06–2010/11 | *Year*+*Soak* |  |  | 4196 | -27.97 | 0.03 |
|  | *Vessel* | -7 | -13.96 | 4189 | -41.93 | 0.07 |
|  | *Month* | -7 | -13.99 | 4182 | -55.92 | 0.08 |

Table 6. Analysis of deviance for stepwise lognormal and binomial models selection of the Aleutian Islands golden king crab fishery. The response variable is observer CPUE. Observer legal data from WAG (west of 174°W longitudes) for 1995/96–2004/05 and 2005/06–2010/11 were used. The 2005/06–2010/11 data series was trimmed.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Link** | **Data series** | **Variable** | **df (difference from null)** | **Deviance** | **Residual df** | **Residual deviance** | **R2** |
| Lognormal | 1995/96–2004/05 | *Year* +*Soak* |  |  | 26667 | -35.91 | 0.09 |
|  | *Captain* | -49 | -97.94 | 26618 | -133.85 | 0.15 |
|  | *Gear* | -14 | -27.98 | 26604 | -161.83 | 0.17 |
|  | 2005/06–2010/11 | *Year*+*Soak* |  |  | 5144 | -27.96 | 0.04 |
|  | *Captain* | -8 | -15.96 | 5136 | -43.92 | 0.07 |
|  | *Area* | -6 | -11.99 | 5130 | -55.91 | 0.09 |
|  |  |  |  |  |  |  |  |
| Binomial | 1995/96–2004/05 | *Year* +*Soak* |  |  | 32280 | -35.97 | 0.03 |
|  | *Captain* | -49 | -97.97 | 32231 | -133.93 | 0.07 |
|  | *Gear* | -14 | -27.99 | 32217 | -161.92 | 0.08 |
|  | 2005/06–2010/11 | *Year*+*Soak* |  |  | 5431 | -27.97 | 0.03 |
|  | *Month* | -9 | -17.99 | 5422 | -45.96 | 0.04 |

Table 7. Analysis of deviance for stepwise lognormal and binomial models selection of the Aleutian Islands golden king crab fishery including *Year*: *Captain* interaction. The response variable is observer CPUE. Observer legal data from EAG (east of 174°W longitudes) for 1995/96–2004/05 and 2005/06–2010/11 were used. The 2005/06–2010/11 data series was trimmed.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Link** | **Data series** | **Variable** | **df (difference from null)** | **Deviance** | **Residual df** | **Residual deviance** | **R2** |
| Lognormal | 1995/96–2004/05 | *Year*+*Soak* |  |  | 28652 | -33.86 | 0.14 |
| *Gear* | -14 | -27.93 | 28638 | -61.79 | 0.21 |
| *Captain* | -40 | -79.97 | 28598 | -141.76 | 0.24 |
| *Year*:*Captain* | -87 | -173.97 | 28511 | -315.73 | 0.27 |
|  | 2005/06–2010/11 | *Year*+*Soak* |  |  | 4106 | -27.96 | 0.04 |
| *Captain* | -8 | -15.96 | 4098 | -43.92 | 0.08 |
| *Gear* | -15 | -29.99 | 4083 | -73.91 | 0.09 |
| *Year*:*Captain* | -5 | -9.99 | 4078 | -83.90 | 0.10 |
|  |  |  |  |  |  |  |  |
| Binomial | 1995/96-2004/05 | *Year*+*Soak* |  |  | 31955 | -33.96 | 0.04 |
| *Captain* | -40 | -79.97 | 31915 | -113.93 | 0.07 |
| *Gear* | -14 | -27.98 | 31901 | -141.90 | 0.10 |
| *Year*:*Captain* | -87 | -173.98 | 31814 | -315.89 | 0.11 |
|  | 2005/06–2010/11 | *Year*+*Soak* |  |  | 4196 | -27.97 | 0.03 |
| *Vessel* | -7 | -13.96 | 4189 | -41.93 | 0.07 |
| *Month* | -7 | -13.99 | 4182 | -55.92 | 0.08 |

Table 8. Analysis of deviance for stepwise lognormal and binomial models selection of the Aleutian Islands golden king crab fishery including *Year*:*Captain* interaction. The response variable is observer CPUE. Observer legal data from WAG (west of 174°W longitudes) for 1995/96–2004/05 and 2005/06–2010/11 were used. The 2005/06–2010/11 data series was trimmed.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Link** | **Data series** | **Variable** | **df (difference from null)** | **Deviance** | **Residual df** | **Residual deviance** | **R2** |
| Lognormal | 1995/96–2004/05 | *Year* +*Soak* |  |  | 26667 | -35.91 | 0.09 |
|  | *Captain* | -49 | -97.94 | 26618 | -133.85 | 0.15 |
|  | *Gear* | -71 | -141.97 | 26547 | -275.81 | 0.19 |
|  | *Year*:*Captain* | -14 | -27.99 | 26533 | -303.81 | 0.20 |
|  | 2005/06–2010/11 | *Year*+*Soak* |  |  | 5144 | -27.96 | 0.04 |
|  | *Captain* | -8 | -15.96 | 5136 | -43.93 | 0.07 |
|  | *Area* | -13 | -25.98 | 5123 | -69.91 | 0.09 |
|  | *Year*:*Captain* | -6 | -11.99 | 5117 | -81.90 | 0.10 |
|  |  |  |  |  |  |  |  |
| Binomial | 1995/96–2004/05 | *Year* +*Soak* |  |  | 32280 | -35.97 | 0.03 |
|  | *Captain* | -49 | -97.97 | 32231 | -133.93 | 0.07 |
|  | *Year*:*Captain* | -71 | -141.98 | 32160 | -275.91 | 0.09 |
|  | 2005/06-2010/11 | *Year*+Soak |  |  | 5431 | -27.97 | 0.03 |
|  | *Month* | -9 | -17.99 | 5422 | -45.96 | 0.04 |

Table 9. Step-wise model selection for various model scenarios including interactions and negative binomial family for the Aleutian Islands golden king crab observer data. StepGLM routine was used for selection of variables and final fit. Observer Data for EAG (east of 174°W longitudes) for 1995/96–2004/05 and 2005/06–2010/11 periods were used. R2 determines the relative merit of each fit. The 2005/06–2010/11 data series was trimmed.

|  |  |  |
| --- | --- | --- |
| **Data series** | **Final model** | **R2** |
| 1995/96–2004/05 | a. *ln(CPUE)~Year+ns(Soak, df=8)+Gear+Captain +Month* | 0.25 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Captain +Gear* | 0.10 |
| b. *ln(CPUE)~Year+ns(Soak, df=8)+Gear+Captain +Year:Gear* | 0.25 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Captain +Gear+Year:Gear* | 0.11 |
| c. *ln(CPUE)~Year+ns(Soak, df=8)+Gear+Captain +Year:Captain* | 0.27 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Captain+Gear+Year:Captain* | 0.11 |
| d. Did not pick up *Year*:*Month* |  |
| e. *Negative Binomial: CPUE~Year+ns(Soak, df=8)+Gear+Captain +Month* | 0.26 |
|  |  |  |
| 2005/06–2010/11 | a. *ln(CPUE)~Year+ns(Soak, df=8)+Captain+Gear +Month* | 0.10 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Vessel+Month* | 0.08 |
| b. *ln(CPUE)~Year+ns(Soak, df=8)+Captain+Gear +Year:Captain* | 0.10 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Vessel+Month* | 0.08 |
| c. Did not pick up *Year:Month*. |  |
| d.*Negative Binomial: CPUE~Year+ns(Soak, df=8)+Captain+Gear +Month* | 0.08 |

Table 10. Step-wise model selection for various model scenarios including interactions and negative binomial family for the Aleutian Islands golden king crab observer data. StepGLM routine was used for selection of variables and final fit. WAG (west of 174°W longitudes) observer data for 1995/96–2004/05 and 2005/06–2010/11 periods were used. R2 determines the relative merit of each fit. The 2005/06–2010/11 data series was trimmed.

|  |  |  |
| --- | --- | --- |
| **Data series** | **Final model** | **R2** |
| 1995/96–2004/05 | a. *ln(CPUE)~Year+ns(Soak, df=8)+Captain +Gear* | 0.17 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Captain +Gear* | 0.08 |
| b. *ln(CPUE)~Year+ns(Soak, df=8)+Captain+Gear +Year:Gear* | 0.18 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Captain +Gear* | 0.08 |
| c. *ln(CPUE)~Year+ns(Soak, df=8)+Captain+Gear +Year:Captain* | 0.20 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Captain +Year:Captain* | 0.09 |
| d. Negative Binomial: CPUE~Year+ns(Soak, df=8)+Captain +Gear | 0.19 |
|  |  |  |
| 2005/06–2010/11 | a. *ln(CPUE)~Year+ns(Soak, df=8)+Captain+Area* | 0.09 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Month* | 0.04 |
| b*. ln(CPUE)~Year+ns(Soak, df=8)+Captain+Area +Year:Captain* | 0.10 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Month* | 0.04 |
| c. *ln(CPUE)~Year+ns(Soak, df=8)+Captain+Area +Year:Area* | 0.11 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Month* | 0.04 |
| d. *ln(CPUE)~Year+ns(Soak, df=8)+Captain+Area* | 0.09 |
| *Binomial(Success)~Year+ns(Soak, df=8)+Month+Year:Month* | 0.08 |
| e.*Negative Binomial: CPUE~Year+ns(Soak,df=8)+Captain+ns(Depth, df=4)* | 0.06 |

Table 11. Comparison of combined lognormal and binomial, and negative binomial CPUE indices with standard errors for EAG (east of 174°W longitudes) and WAG (west of 174°W longitudes) observer data for the two periods, 1995/96-2004/05 and 2005/06-2010/11.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | |  | **Combined Lognormal and Binomial** | | | | |  | | |  | |  | | **Negative Binomial** | | |  | |  | |
|  | | **EAG** | |  | | | | **WAG** |  | | | | **EAG** | |  | | | **WAG** | |  | |
|  | **Combined** | | | | **Standard** | | **Combined** | | | **Standard** | | | | **Combined** | | **Standard** | | | **Combined** | | **Standard** | |
| **Year** | **Index** | | | | | **Error** | **Index** | | | | | **Error** | | **Index** | | | **Error** | | **Index** | **Error** | | |
| 1995 | | 0.8623 | | 0.0009 | | | | 1.1736 | 0.0012 | | | | 0.5618 | | 0.0181 | | | 1.1390 | | 0.0224 | |
| 1996 | | 0.8398 | | 0.0005 | | | | 0.9650 | 0.0007 | | | | 0.5520 | | 0.0148 | | | 0.9622 | | 0.0167 | |
| 1997 | | 0.8392 | | 0.0006 | | | | 0.9686 | 0.0007 | | | | 0.7550 | | 0.0170 | | | 1.0154 | | 0.0196 | |
| 1998 | | 0.9735 | | 0.0006 | | | | 1.1333 | 0.0010 | | | | 0.9793 | | 0.0178 | | | 1.2976 | | 0.0259 | |
| 1999 | | 0.9078 | | 0.0006 | | | | 0.9034 | 0.0006 | | | | 0.9464 | | 0.0173 | | | 0.8788 | | 0.0189 | |
| 2000 | | 0.8530 | | 0.0004 | | | | 0.8424 | 0.0006 | | | | 0.9876 | | 0.0158 | | | 0.8691 | | 0.0191 | |
| 2001 | | 1.1154 | | 0.0007 | | | | 0.8267 | 0.0006 | | | | 1.3149 | | 0.0183 | | | 0.7864 | | 0.0203 | |
| 2002 | | 1.1650 | | 0.0009 | | | | 0.9221 | 0.0008 | | | | 1.3458 | | 0.0205 | | | 0.8974 | | 0.0234 | |
| 2003 | | 1.0298 | | 0.0007 | | | | 1.1422 | 0.0009 | | | | 1.2795 | | 0.0199 | | | 1.0286 | | 0.0208 | |
| 2004 | | 1.6358 | | 0.0017 | | | | 1.2179 | 0.0010 | | | | 2.0608 | | 0.0269 | | | 1.2492 | | 0.0216 | |
|  | |  | |  | | | |  |  | | | |  | |  | | |  | |  | |
| 2005 | | 1.1653 | | 0.0013 | | | | 0.9663 | 0.0011 | | | | 1.0858 | | 0.0217 | | | 1.0552 | | 0.0246 | |
| 2006 | | 0.9409 | | 0.0008 | | | | 0.9412 | 0.0010 | | | | 0.9252 | | 0.0221 | | | 1.0000 | | 0.0268 | |
| 2007 | | 1.1248 | | 0.0010 | | | | 0.9196 | 0.0011 | | | | 1.0638 | | 0.0225 | | | 0.8998 | | 0.0255 | |
| 2008 | | 1.0814 | | 0.0010 | | | | 1.1155 | 0.0010 | | | | 1.0486 | | 0.0260 | | | 1.0408 | | 0.0261 | |
| 2009 | | 0.8825 | | 0.0010 | | | | 1.0640 | 0.0010 | | | | 0.9391 | | 0.0308 | | | 1.0808 | | 0.0280 | |
| 2010 | | 0.8524 | | 0.0011 | | | | 1.0108 | 0.0010 | | | | 0.9502 | | 0.0301 | | | 0.9363 | | 0.0280 | |

# Figures

Figure 1. Golden king crab catch reporting frequency by vessel from Aleutian Islands. Fish ticket data from combined east and west of 174°W for 1985/86–2010/11 were used.

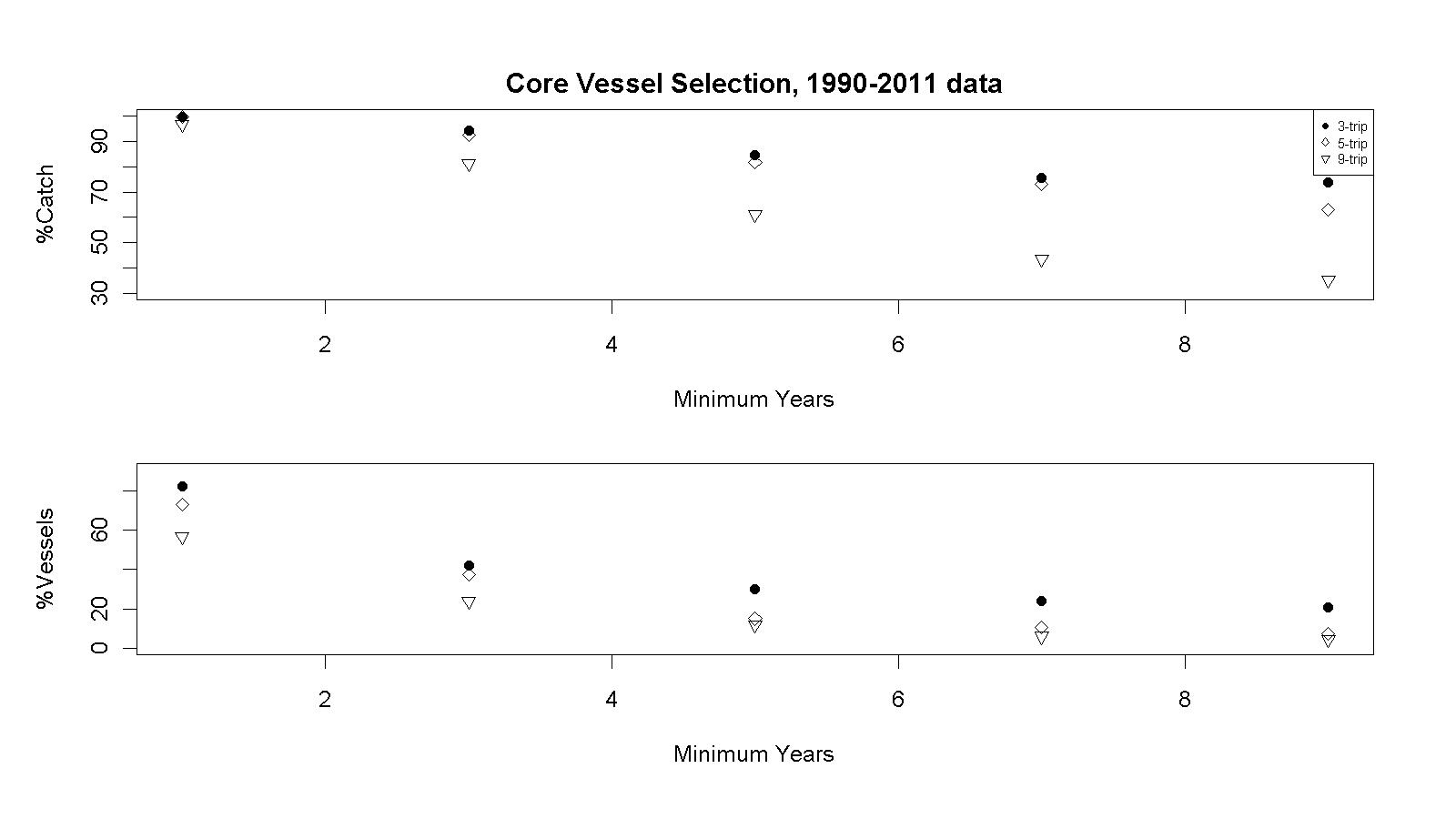


Figure 2. Core vessel selection based for the Aleutian Islands golden king crab fishery. Fish ticket data from combined east and west of 174°W longitudes for 1990/91–2010/11 were used. 3-trip = three trips per year; 5-trip = five trips per year; and 9-trip = nine trips per year. The percentage catch and vessels dropped as the number of minimum years the vessels with those yearly reporting rates increased.

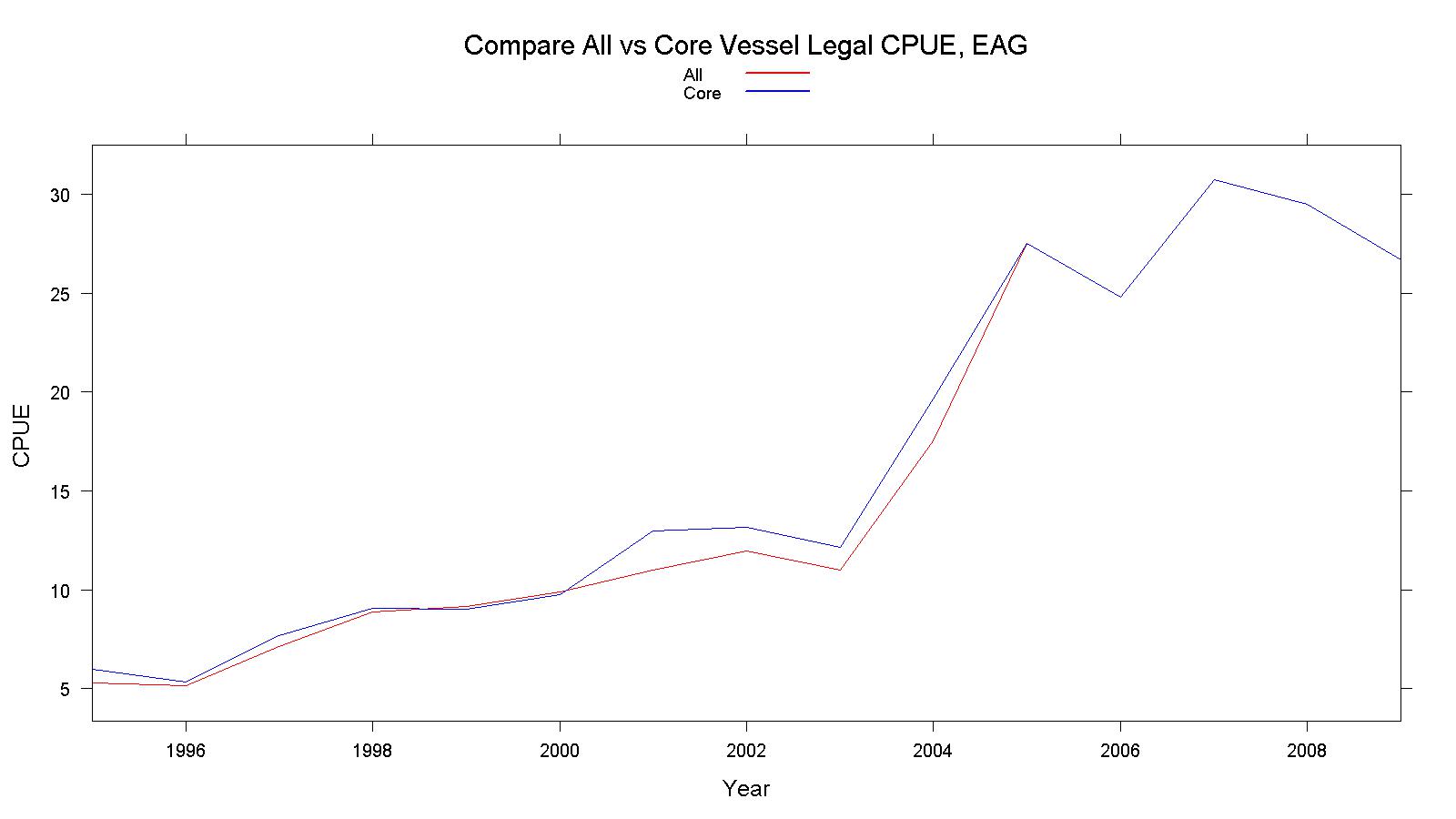


Figure 3. Comparison of legal male CPUE of all vessels and core vessel for 1995/96–2009/10 for EAG (east of 174°W longitudes).

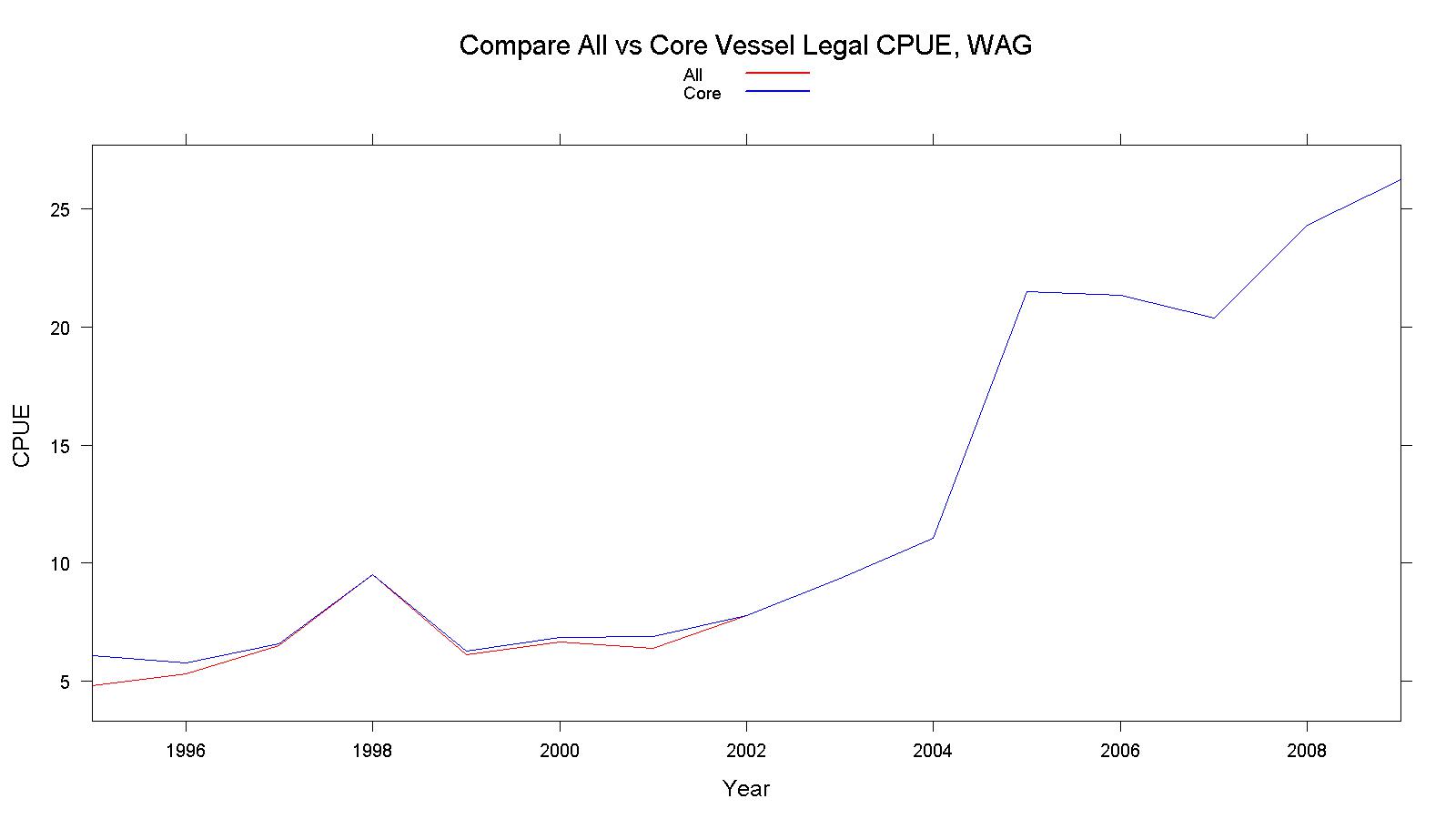


Figure 4. Comparison of legal male CPUE of all vessels and core vessel for 1995/96–2009/10 for WAG (west of 174°W longitudes).

Figure 5. Scatter plot matrices for EAG (east of 174°W longitudes) all vessels’ observer sample predictor variables. Lowess smooth curves are shown in red. High correlations exist between *EastVesSoak* vs. *Year* and *Month*, and *SoakDays* vs. *Year*.

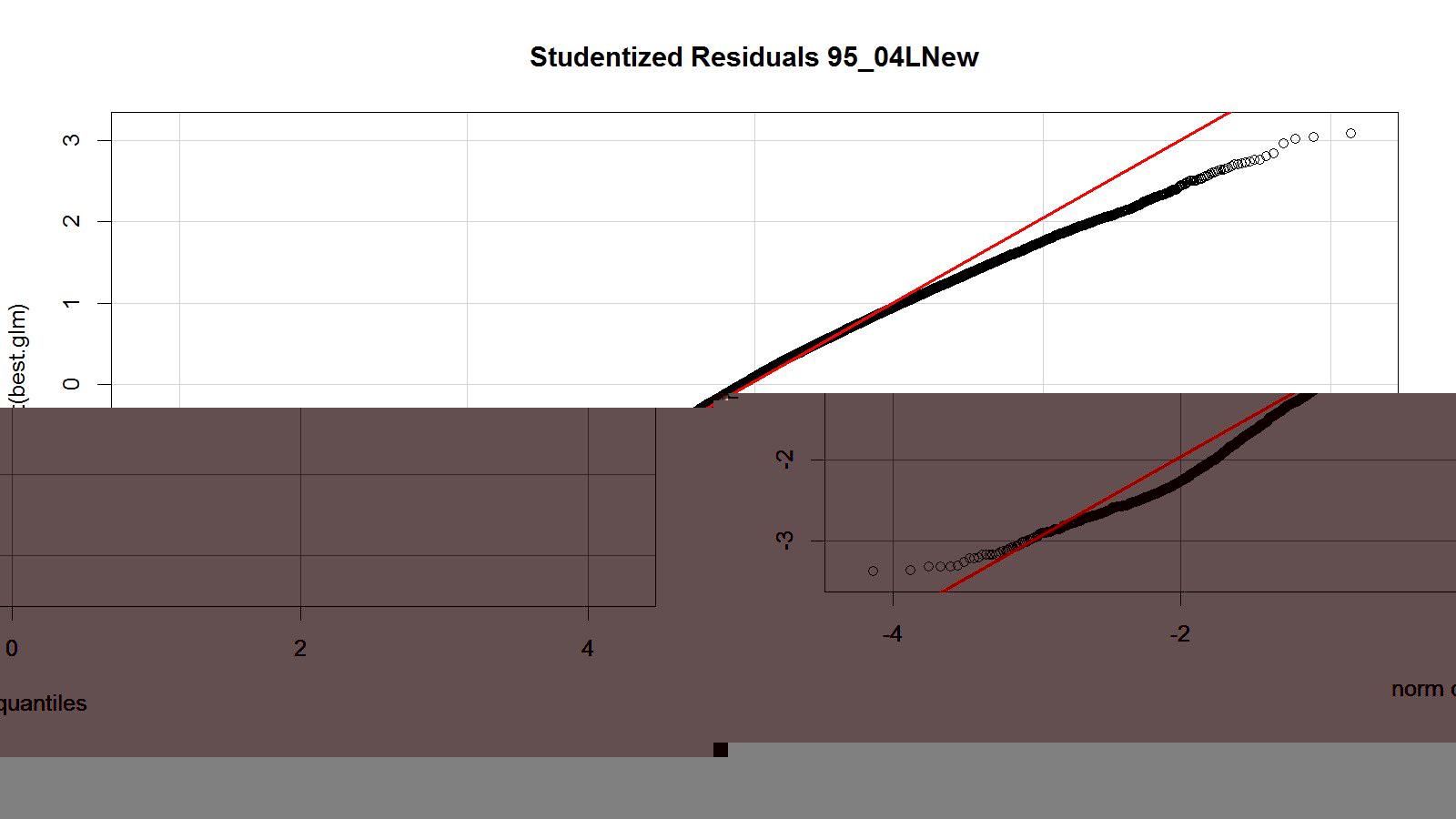
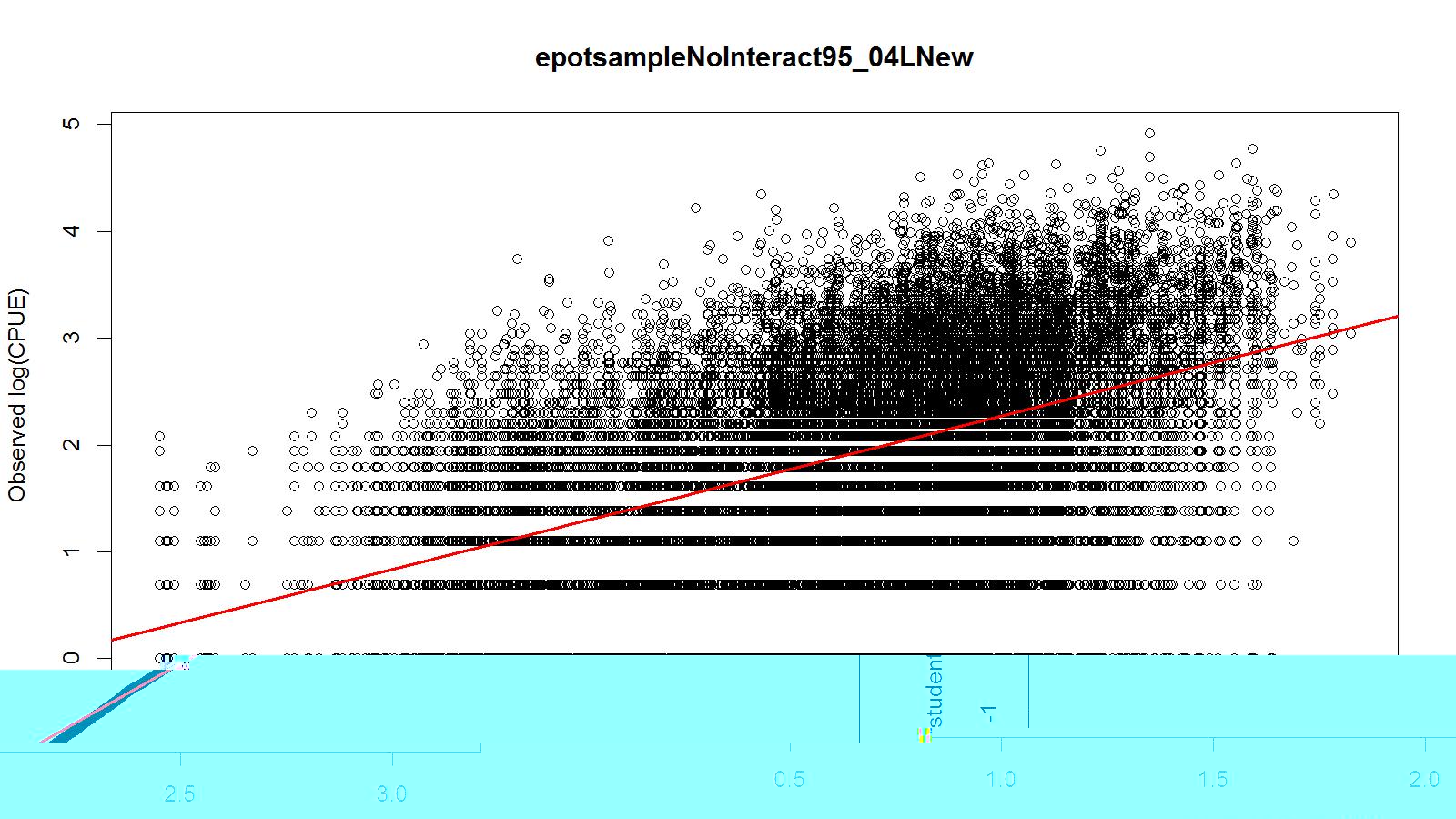


Figure 6. Studentized residual plot of the best lognormal fit model for legal size crab CPUE. Observer data from EAG (east of 174°W longitudes) for 1995/96–2004/05 were used.



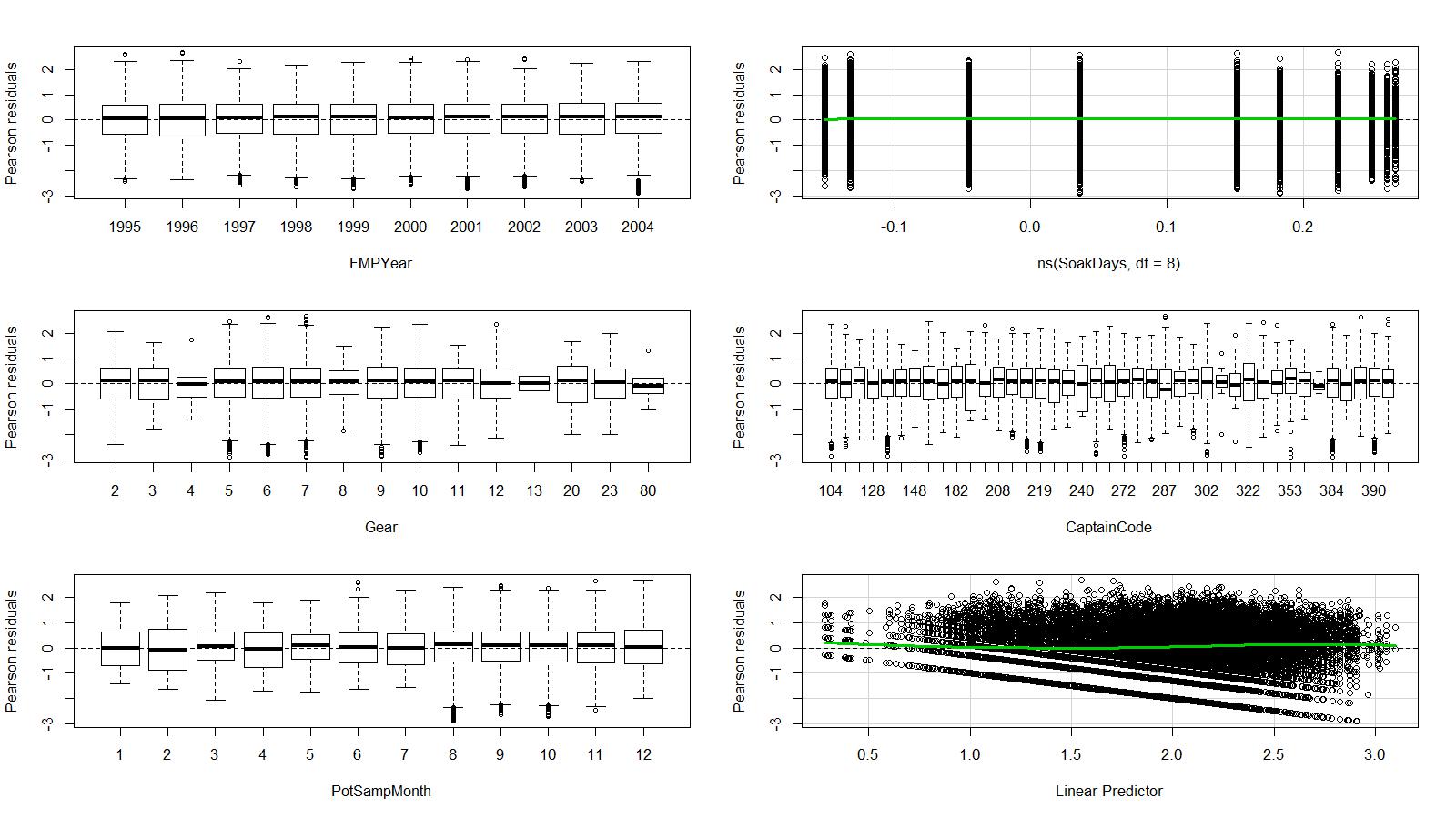


Figure 7. Predicted vs. observed *ln(CPUE)*, Pearson residuals vs. explanatory and response variables of the best lognormal fit model for legal size crab CPUE. Observer data from EAG (east of 174°W longitudes) for 1995/96–2004/05 were used.



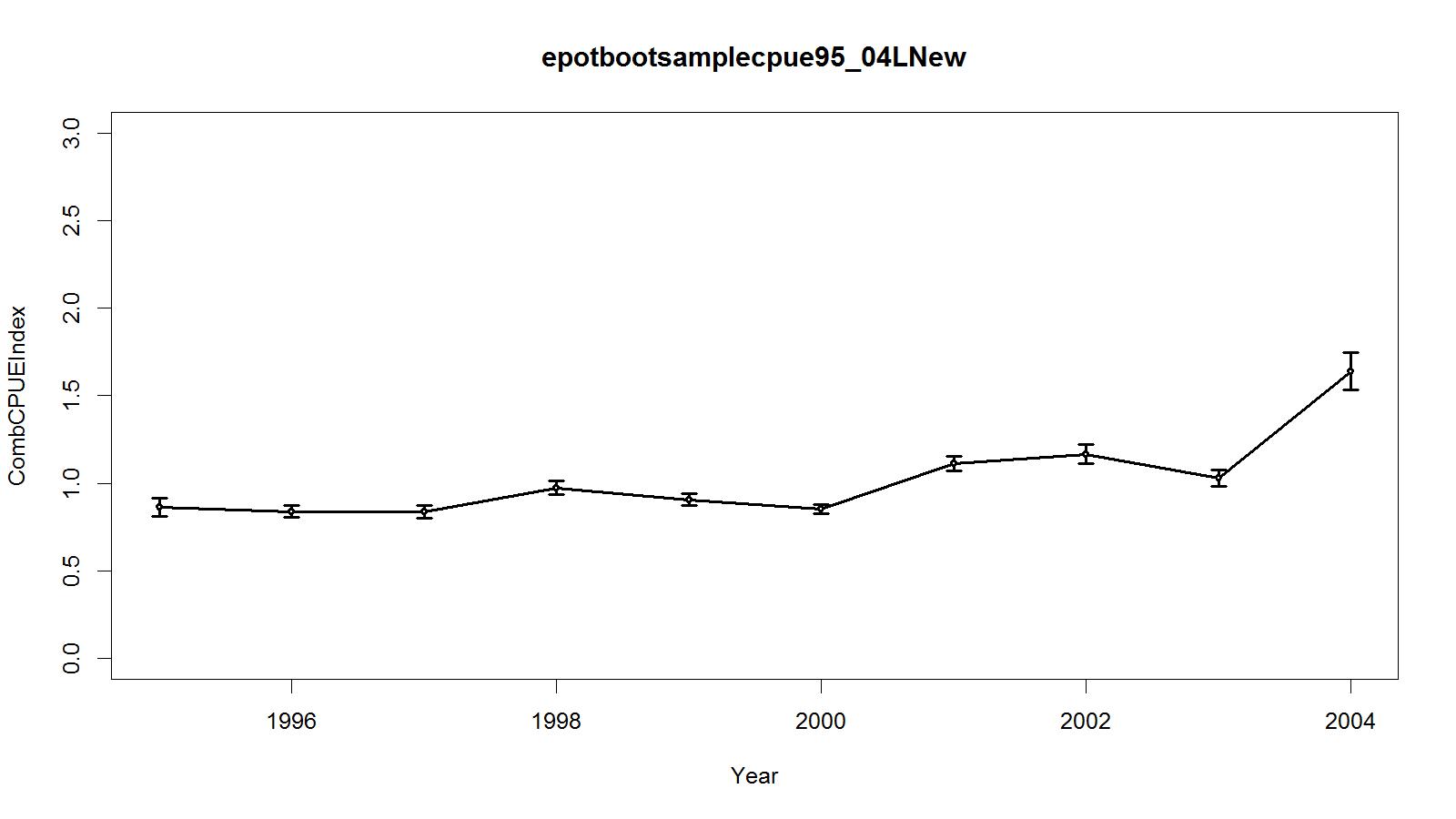
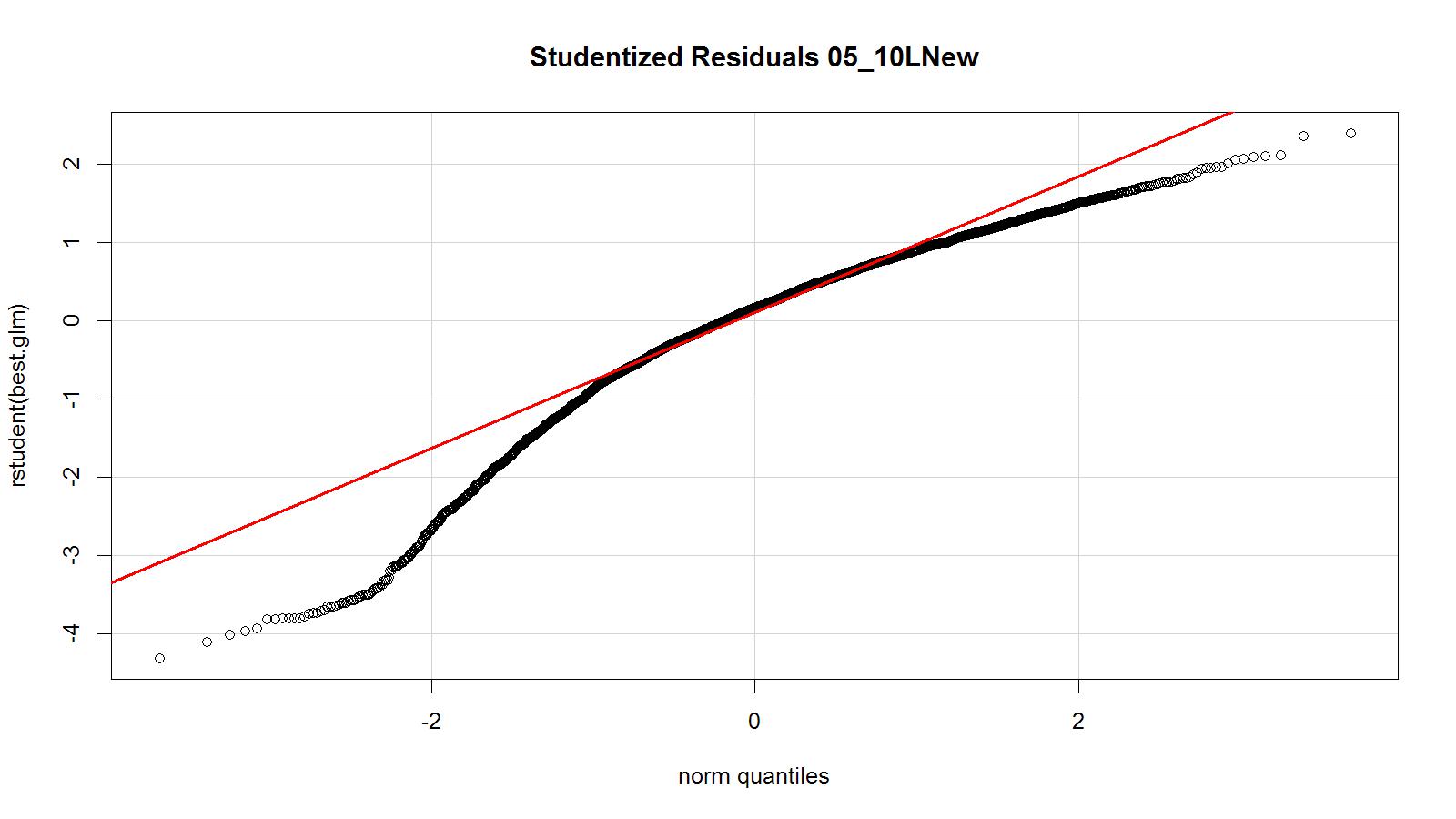


Figure 8. Trends in observer CPUE indices for legal size crab data for the Aleutian Islands golden king crab fishery. Top panel: Standardized Index (Lognormal): black line with two standard errors; Base Index: blue line; and Arithmetic Index: red line. Bottom panel: Bootstrap estimate of combined CPUE index with confidence limits. Observer data from EAG (east of 174°W longitudes) for 1995/96–2004/05 were used.



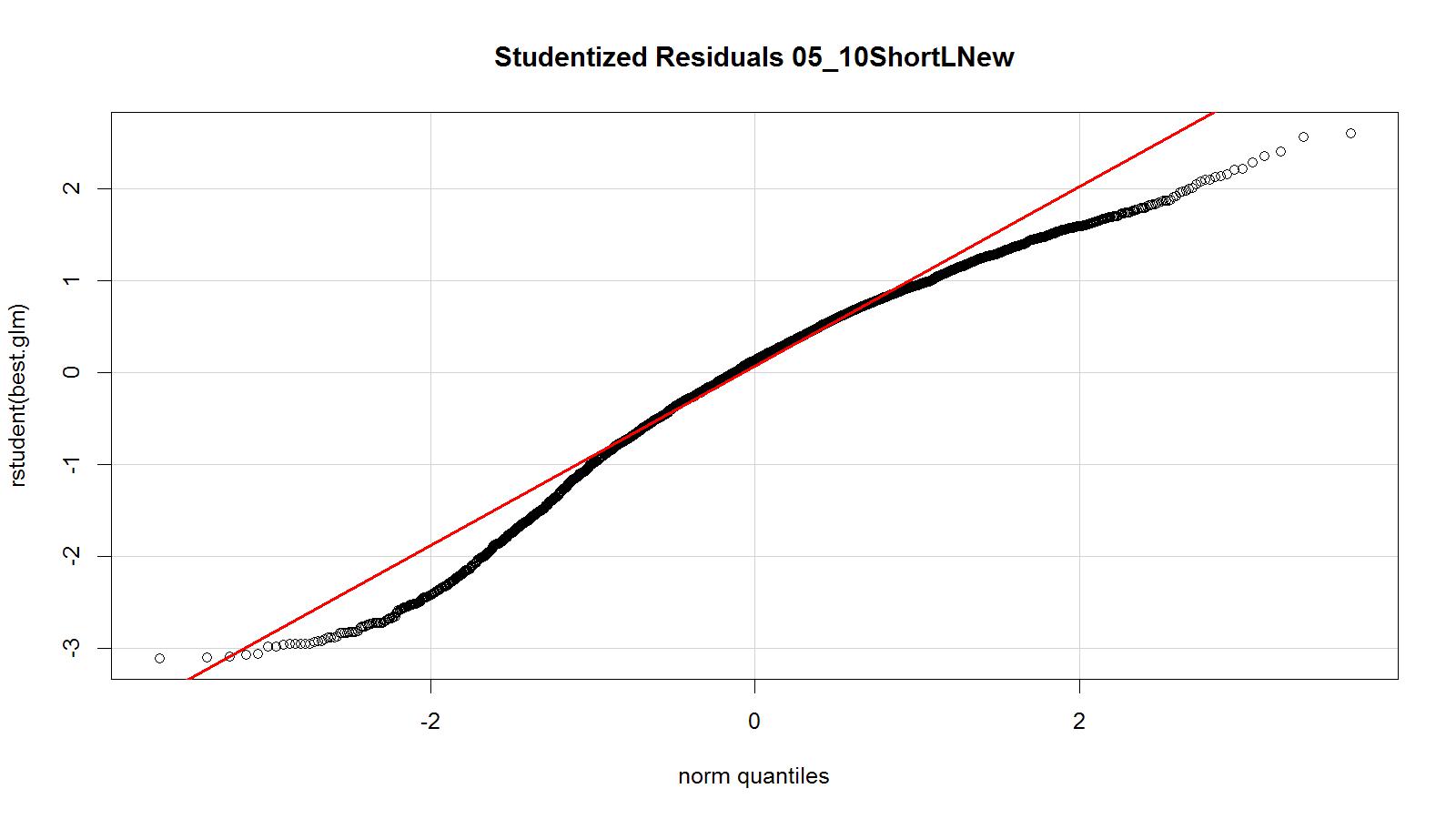
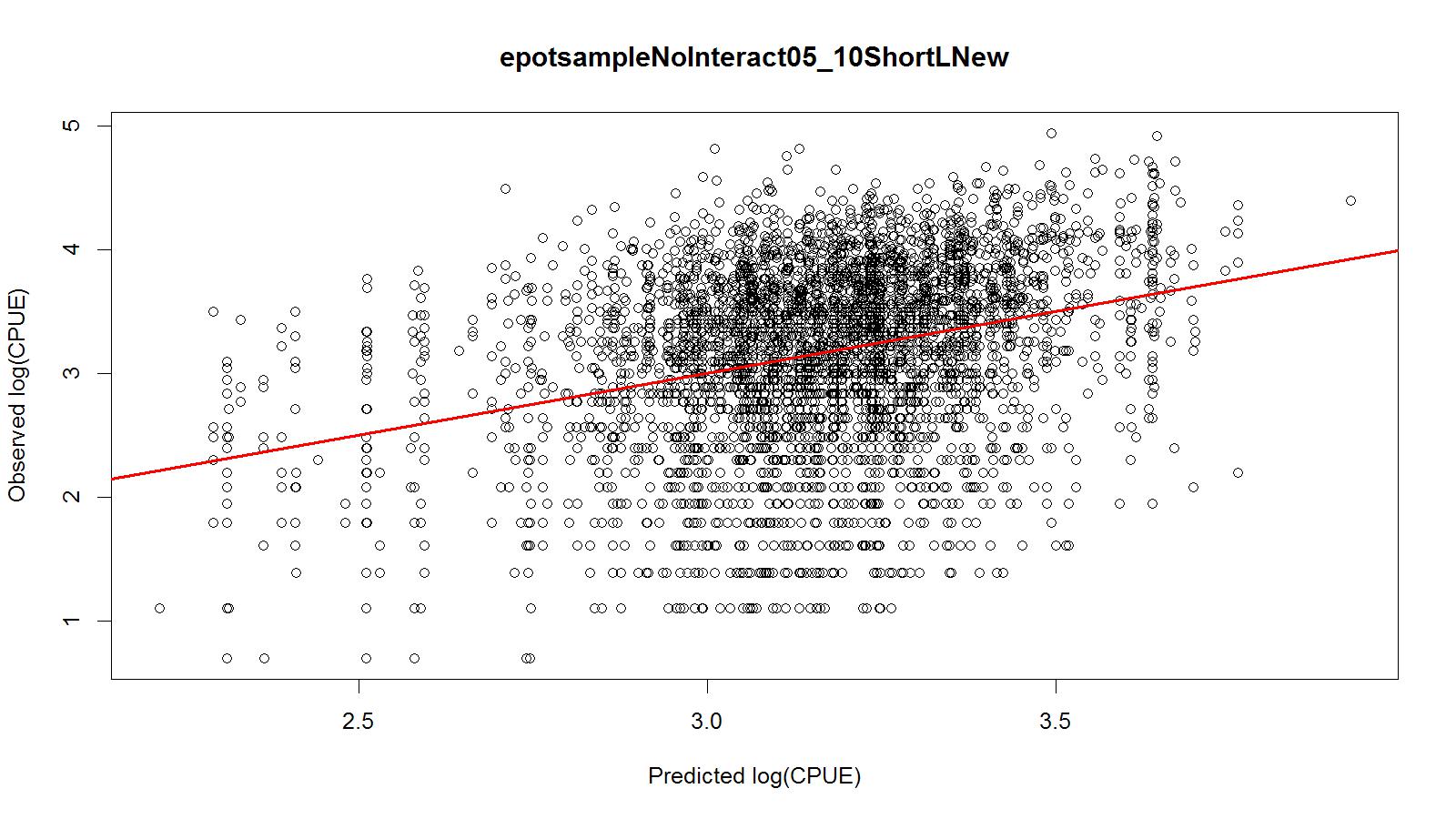


Figure 9. Studentized residual plot of the best lognormal fit model for legal size crab CPUE. Observer data (all core vessel records) from EAG (east of 174°W longitudes) for 2005/06–2010/11 were used. All core vessel records (top panel) and trimmed core vessel data (bottom panel)



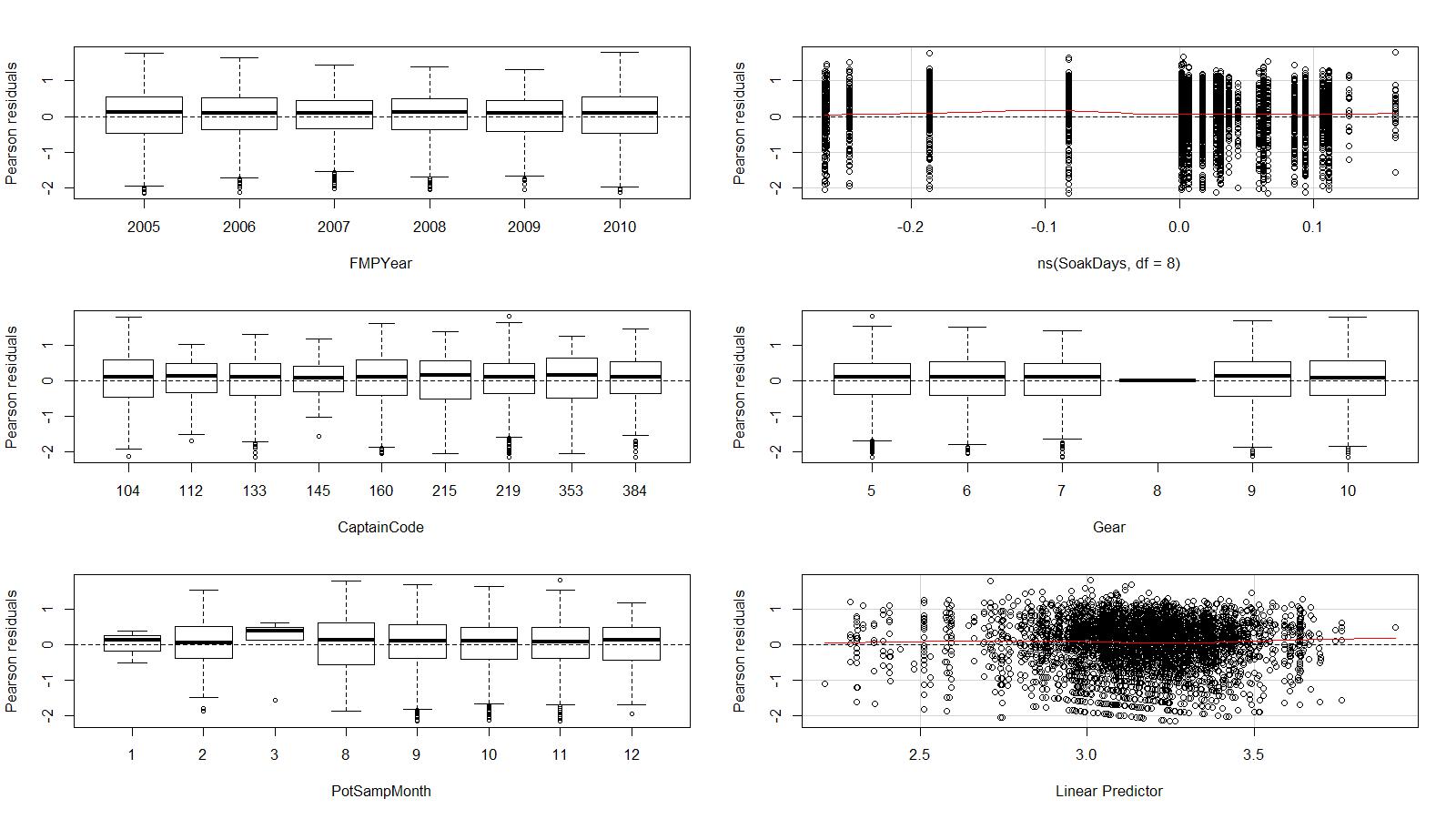
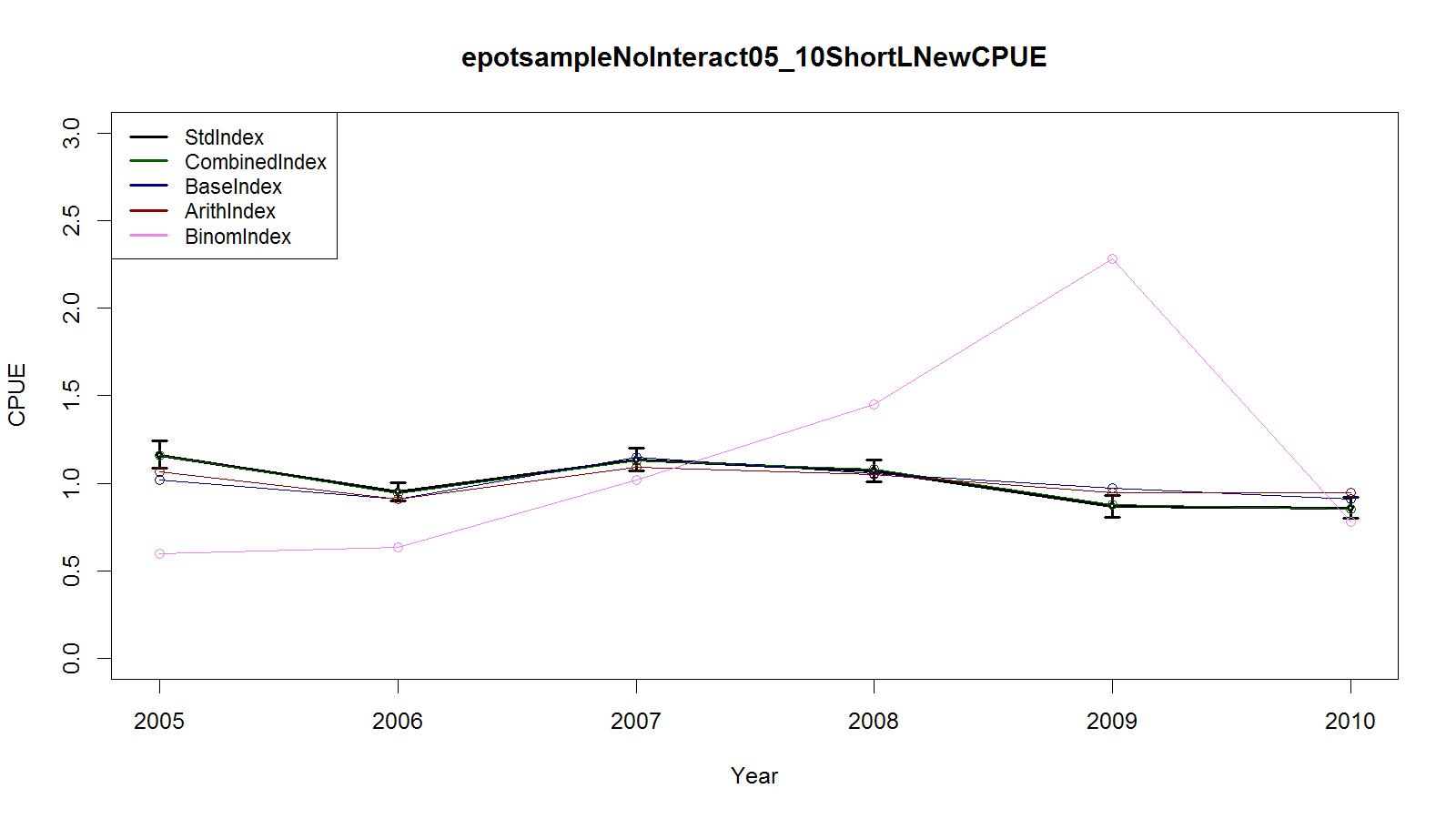


Figure 10. Predicted vs. observed *ln(CPUE)*, Pearson residuals vs. explanatory and response variables of the best lognormal fit model for legal size crab CPUE. Trimmed observer data from EAG (east of 174°W longitudes) for 2005/06–2010/11 were used.



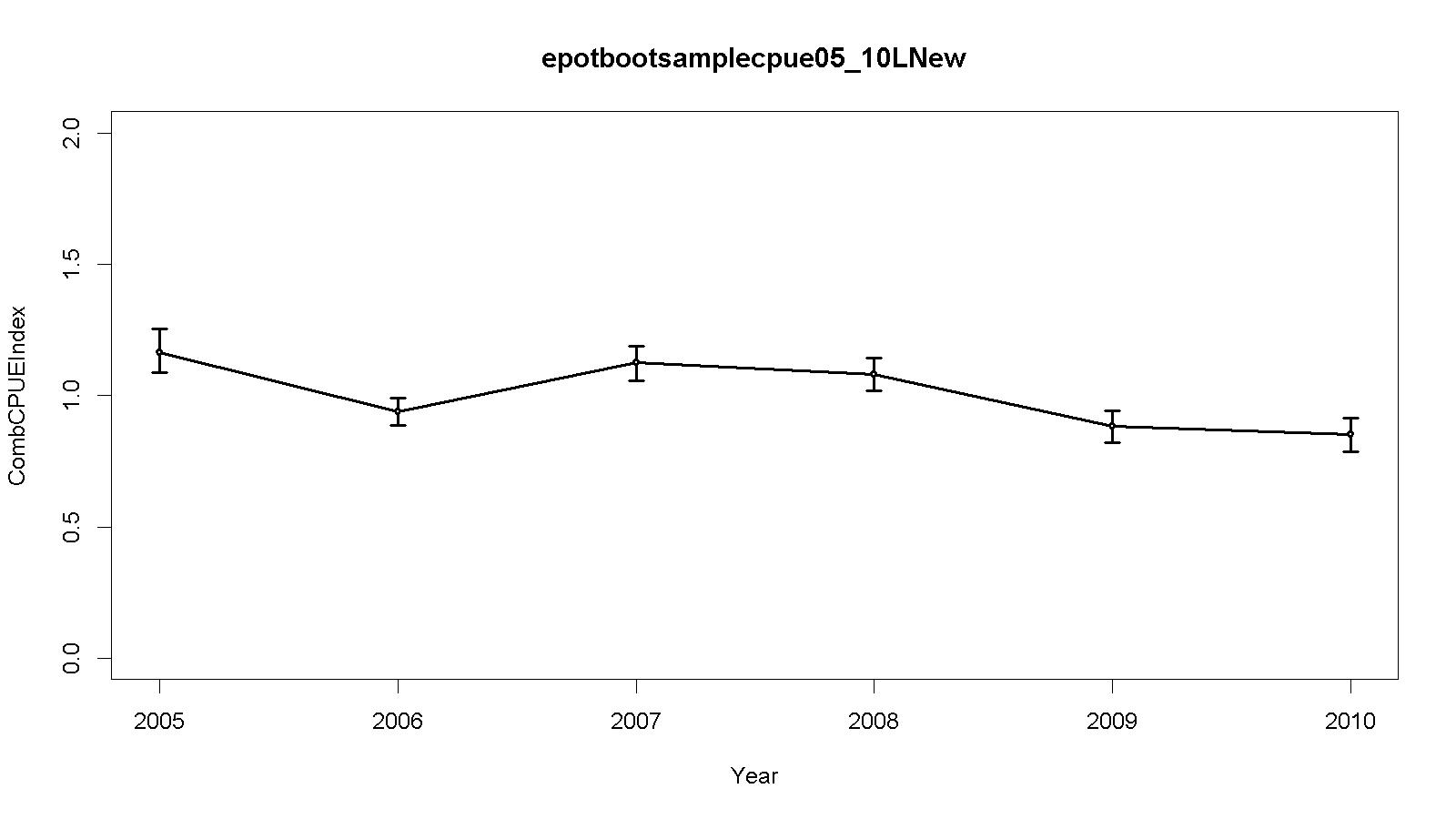


Figure 11. Trends in observer CPUE indices for legal size crab data for the Aleutian Islands golden king crab fishery. Top panel: Standardized Index (Lognormal): black line with two standard errors; Combined Index: green; Base Index: blue line; Binomial index: purple; and Arithmetic Index: red line. Bottom panel: Bootstrap estimate of combined CPUE index with confidence limits. Trimmed observer data from EAG (east of 174°W longitudes) for 2005/06–2010/11 were used.

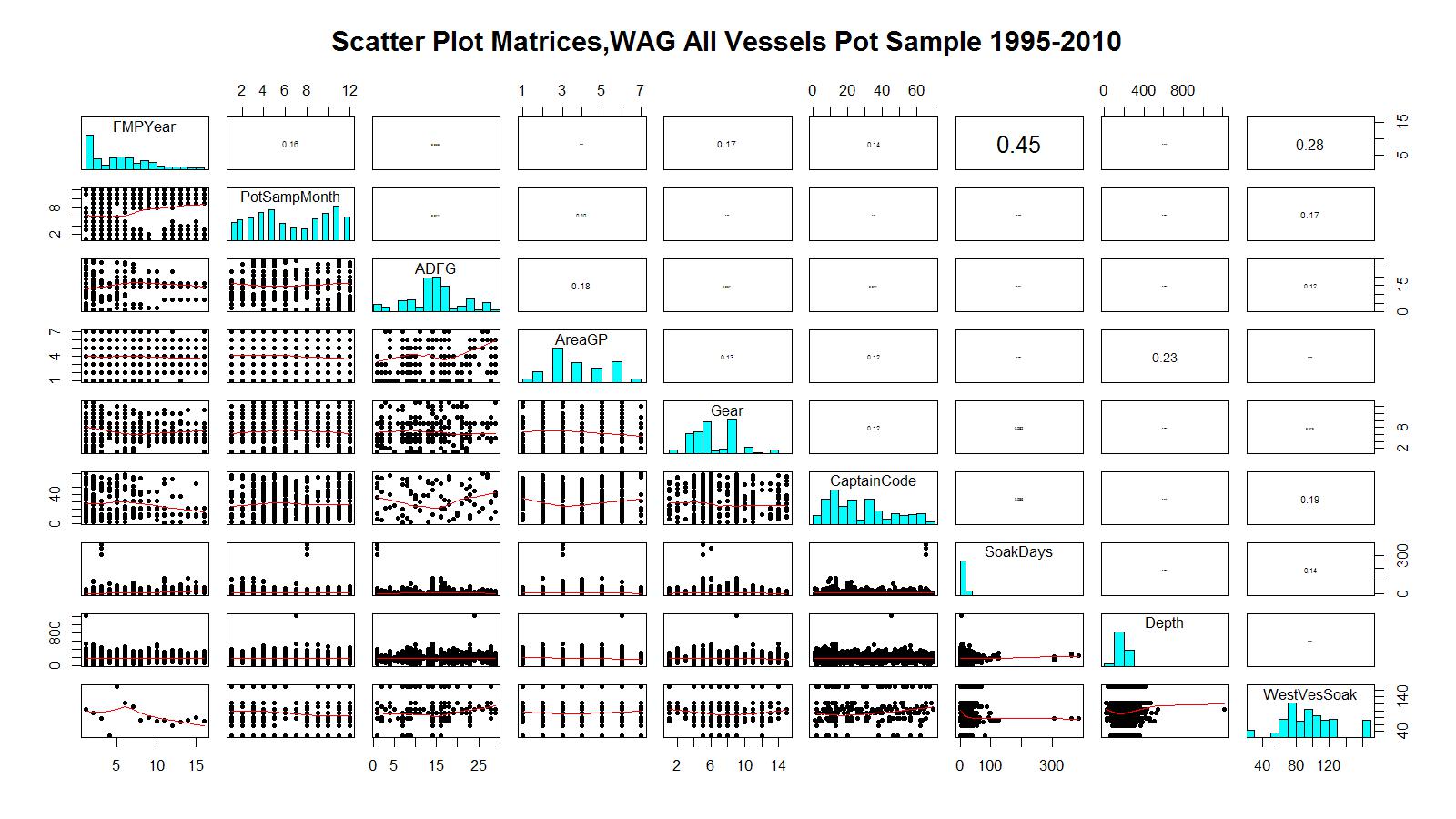


Figure 12. Scatter plot matrices for WAG (west of 174°W longitudes) all vessels’ observer sample predictor variables. Lowess smooth curves are shown in red. High correlations exist between *SoakDays* vs. *Year* and *WestVesSoak* vs. *Year*.

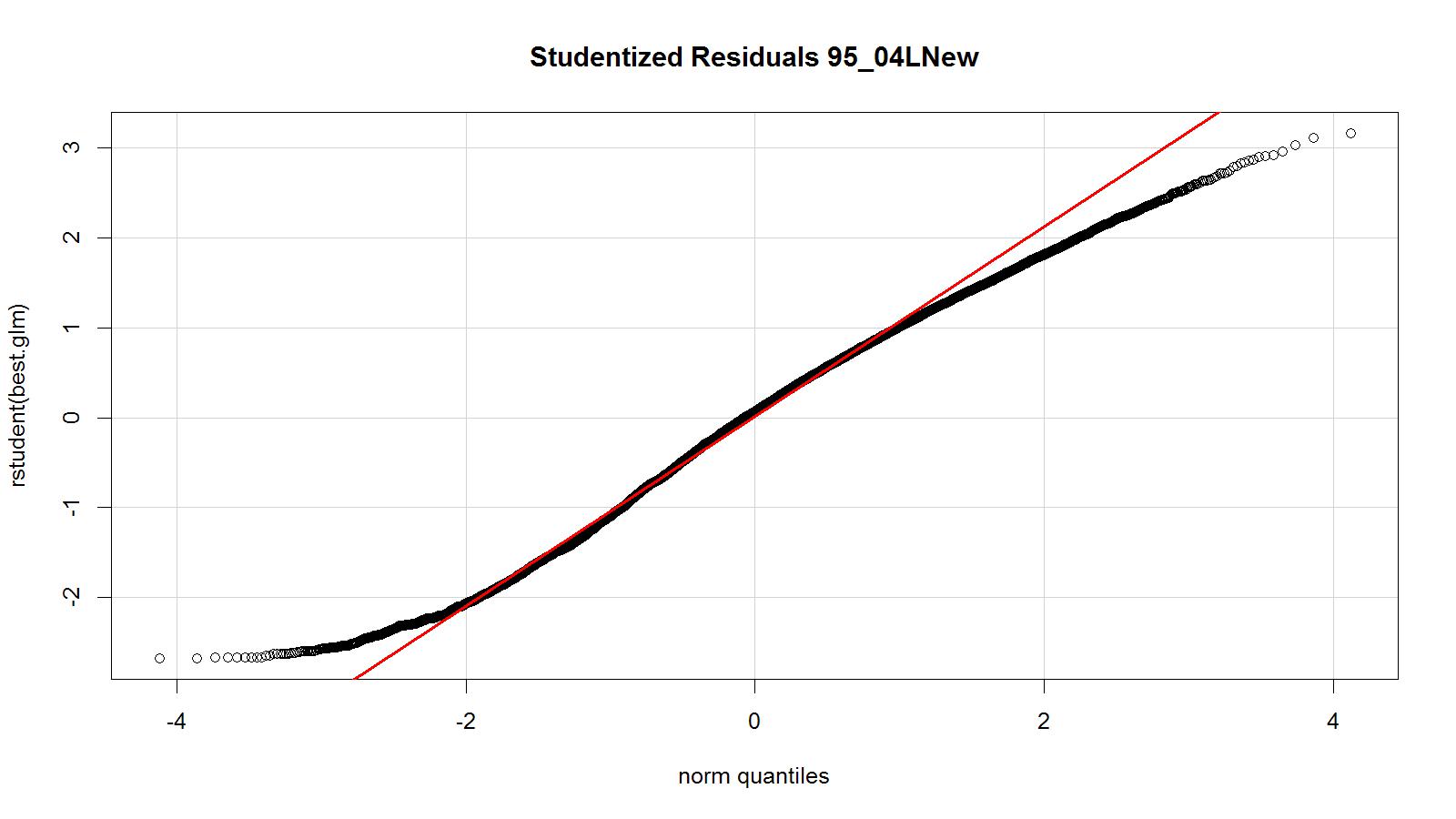
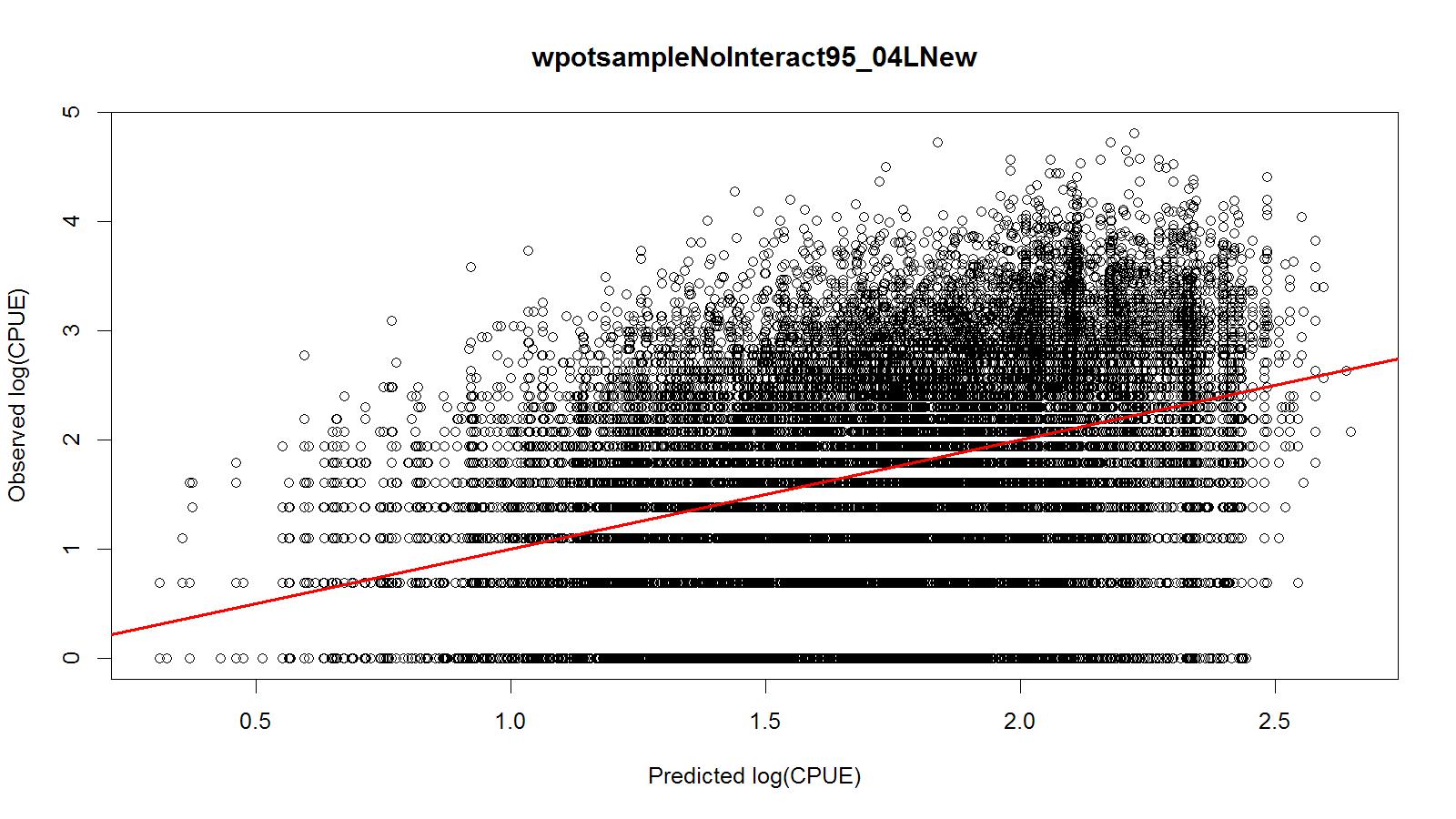


Figure 13. Studentized residual plot of the best lognormal fit model for legal CPUE. Observer data from WAG (west of 174°W longitudes) for 1995/96–2004/05 were used.



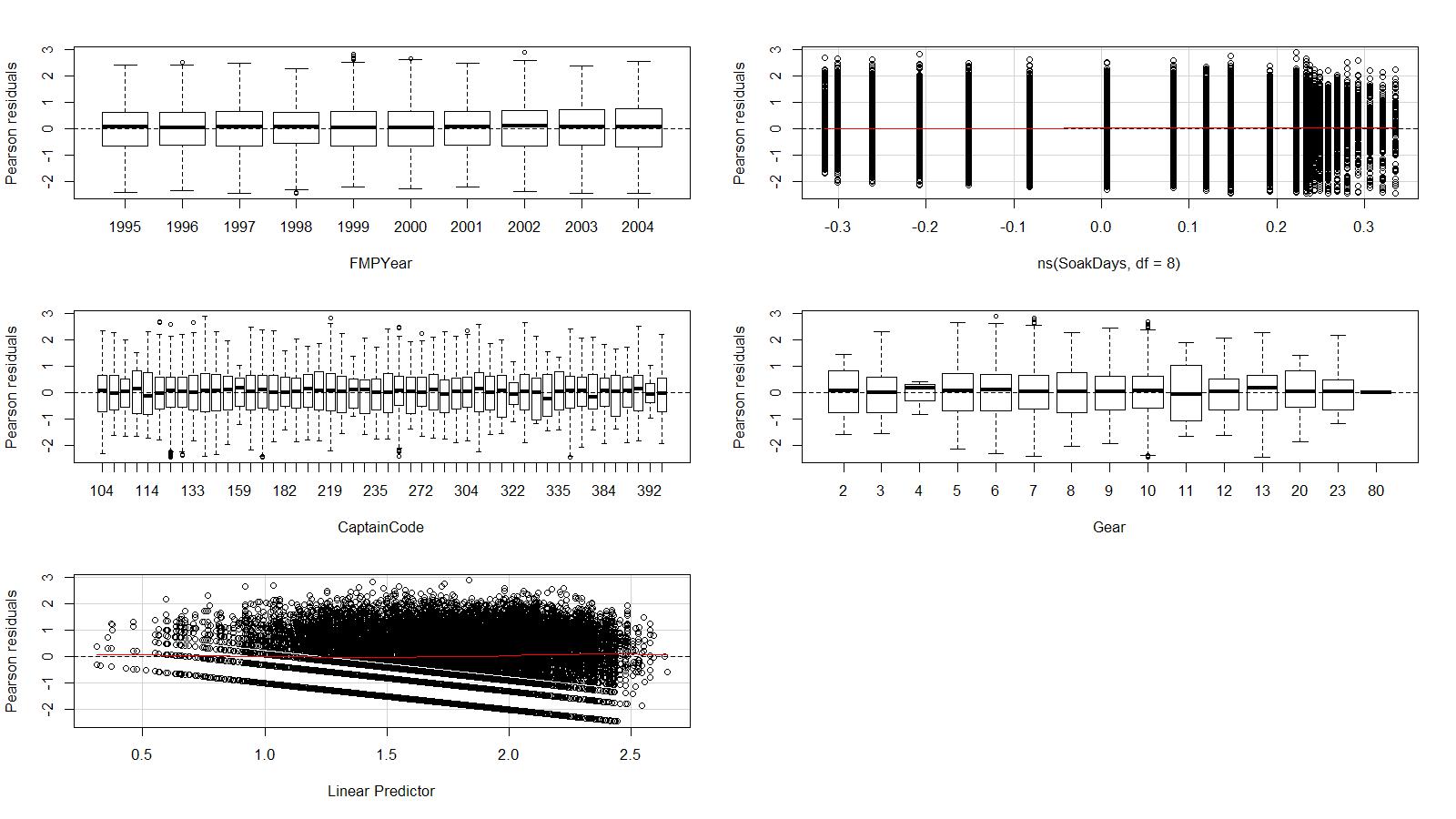
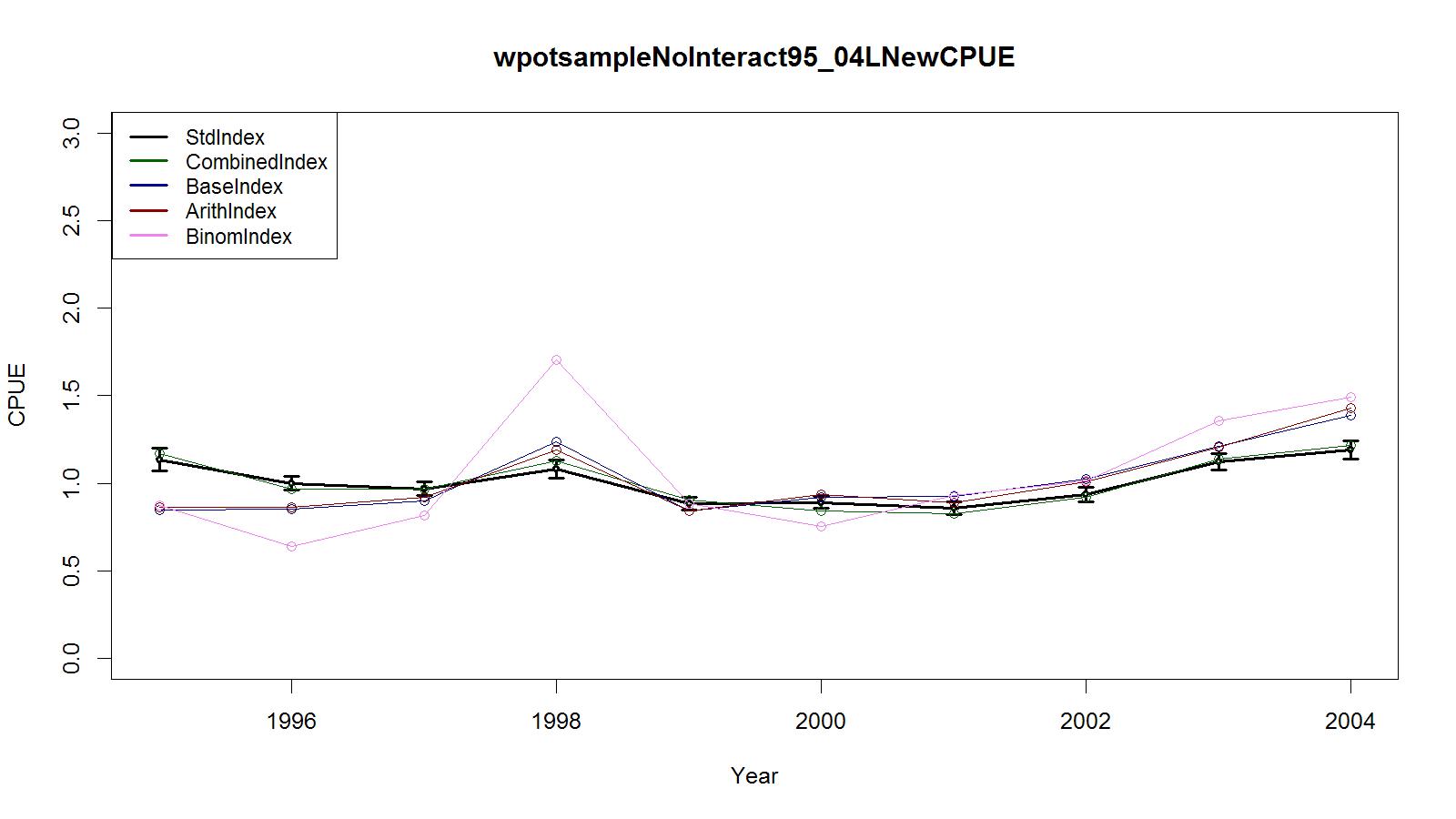


Figure 14. Predicted vs. observed *ln(CPUE)*, Pearson residuals vs. explanatory and response variables of the best lognormal fit model for legal CPUE. Observer data from WAG (west of 174°W longitudes) for 1995/96–2004/05 were used.



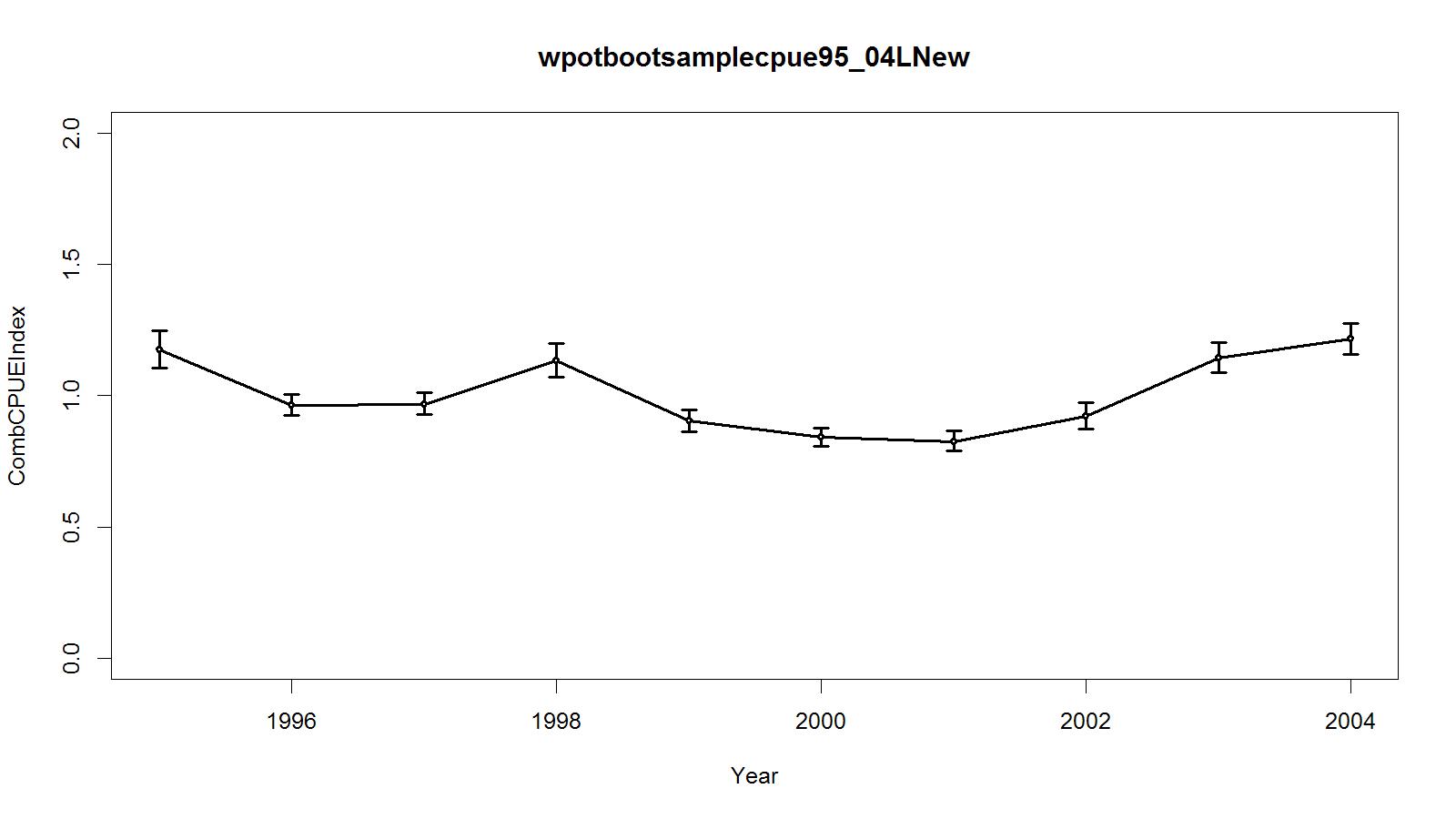
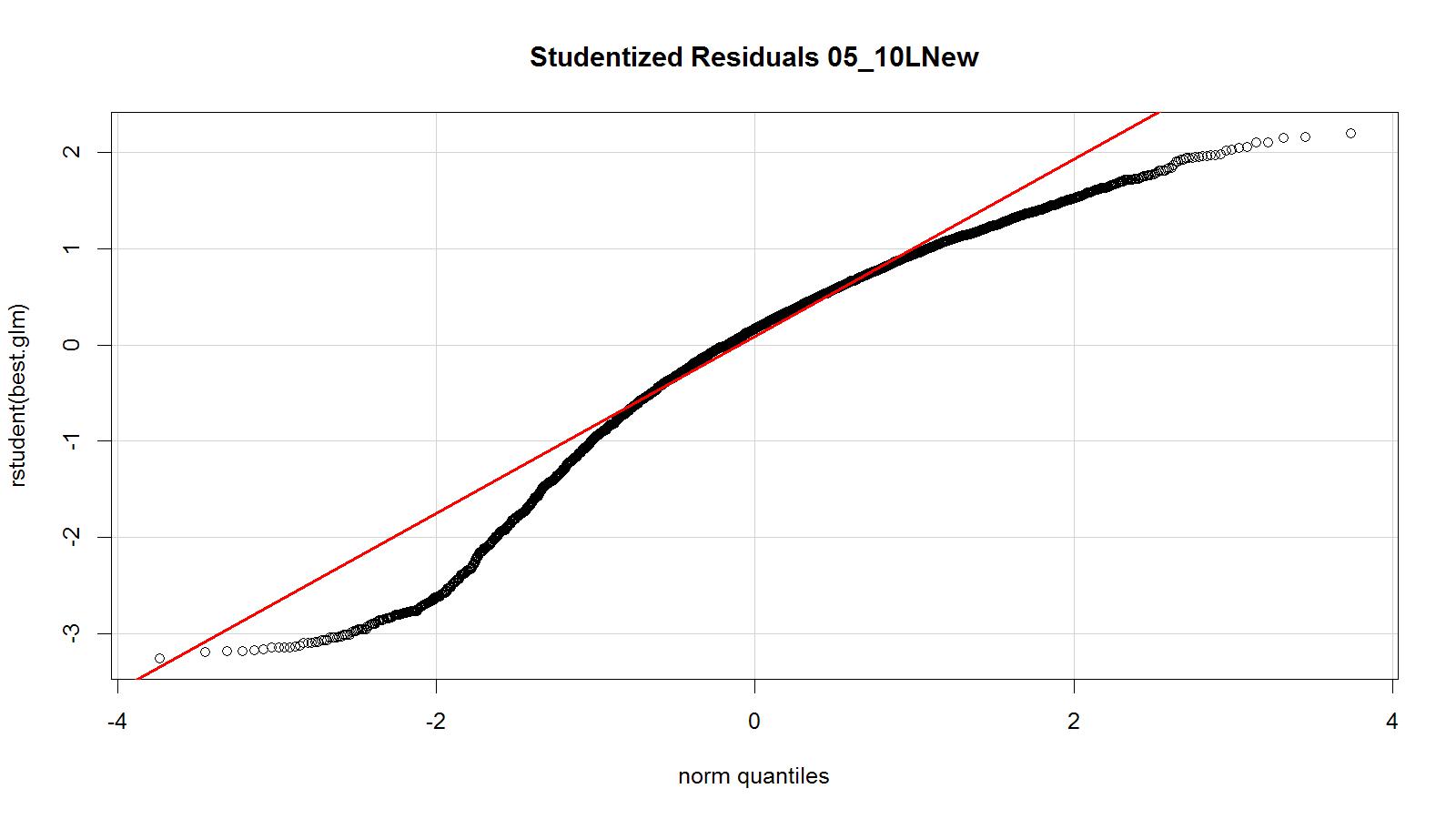


Figure 15. Trends in observer CPUE indices for legal crab data for the Aleutian Islands golden king crab fishery. Top panel: Standardized Index (Lognormal): black line with two standard errors; Combined Index: green; Base Index: blue line; Binomial index: purple; and Arithmetic Index: red line. Bottom panel: Bootstrap estimate of combined CPUE index with confidence limits. Observer data from WAG (west of 174°W longitudes) for 1995/06–2004/05 were used.



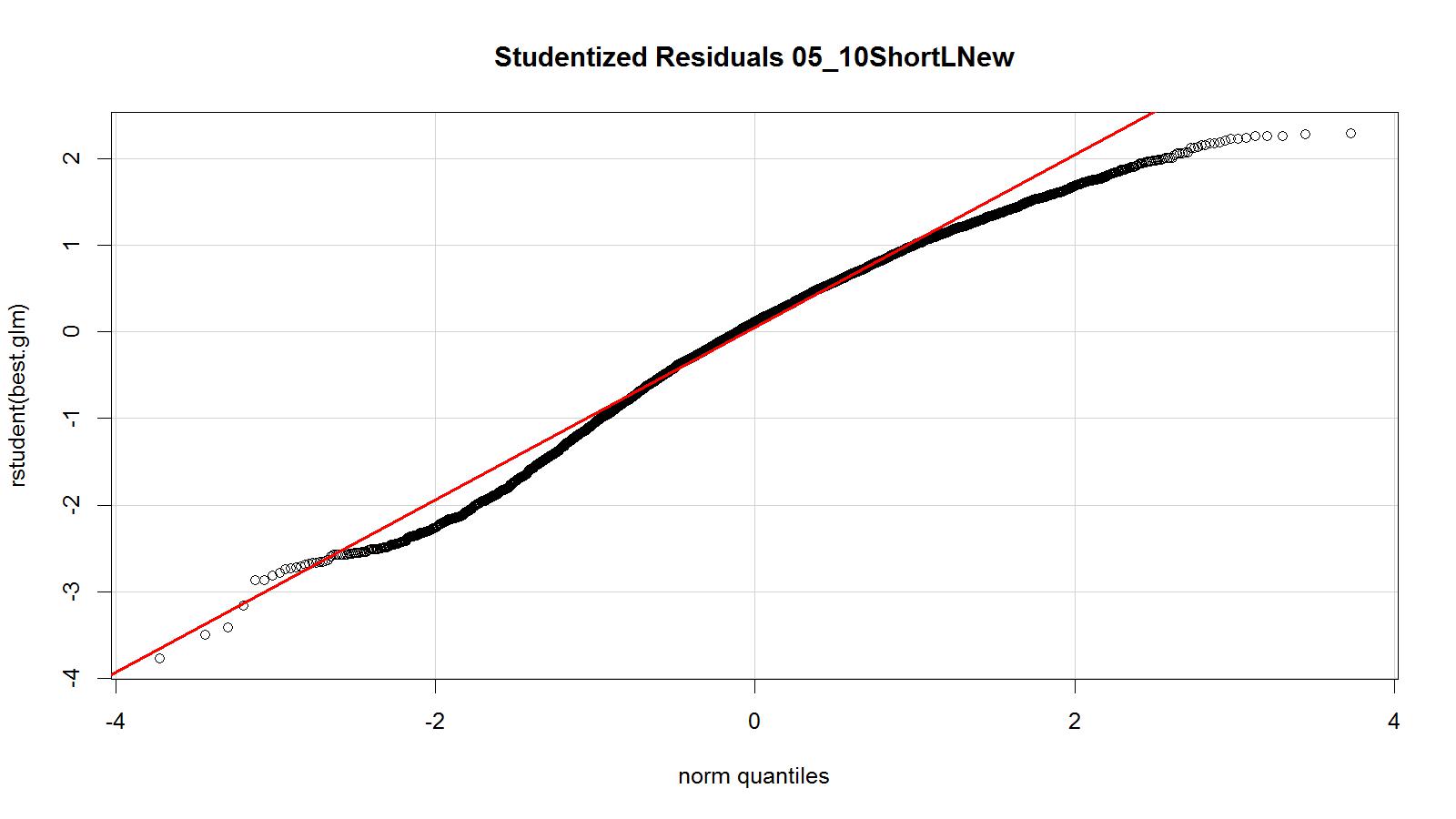
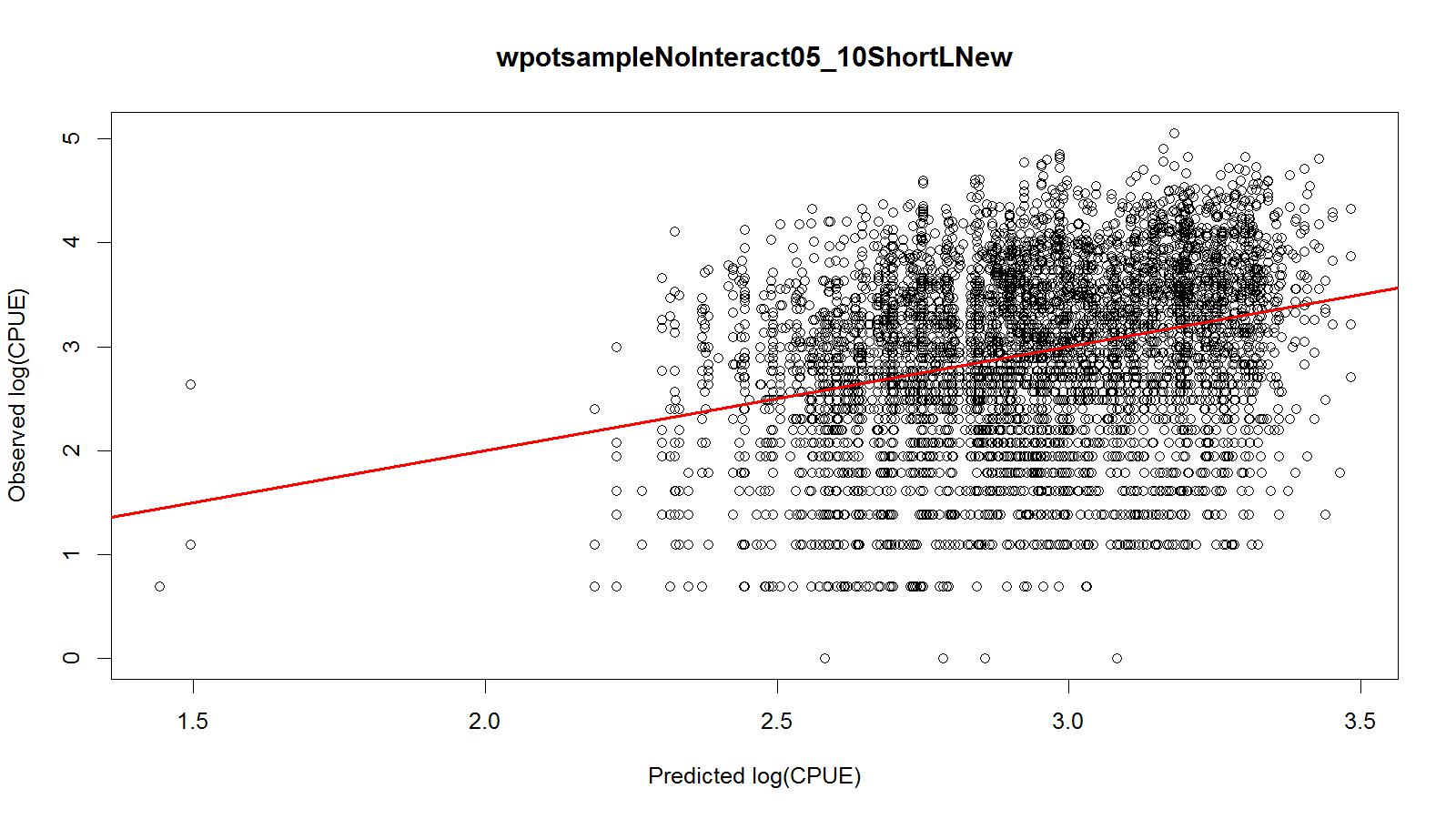


Figure 16. Studentized residual plot of the best lognormal fit model for legal size crab CPUE. Observer data (all core vessel records) from WAG (west of 174°W longitudes) for 2005/06–2010/11 were used. All core vessel records (top panel) and trimmed core vessel data (bottom panel).



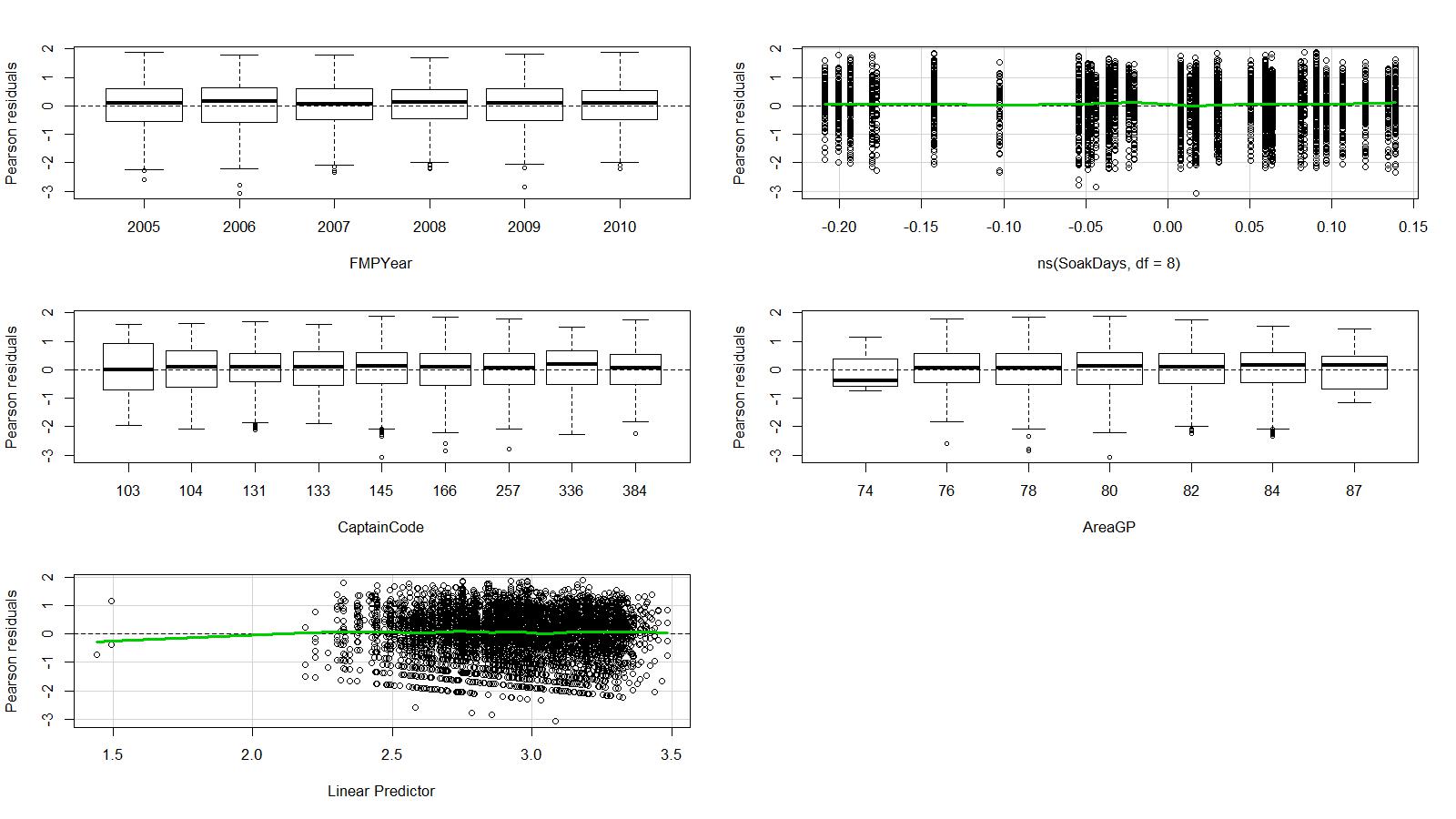
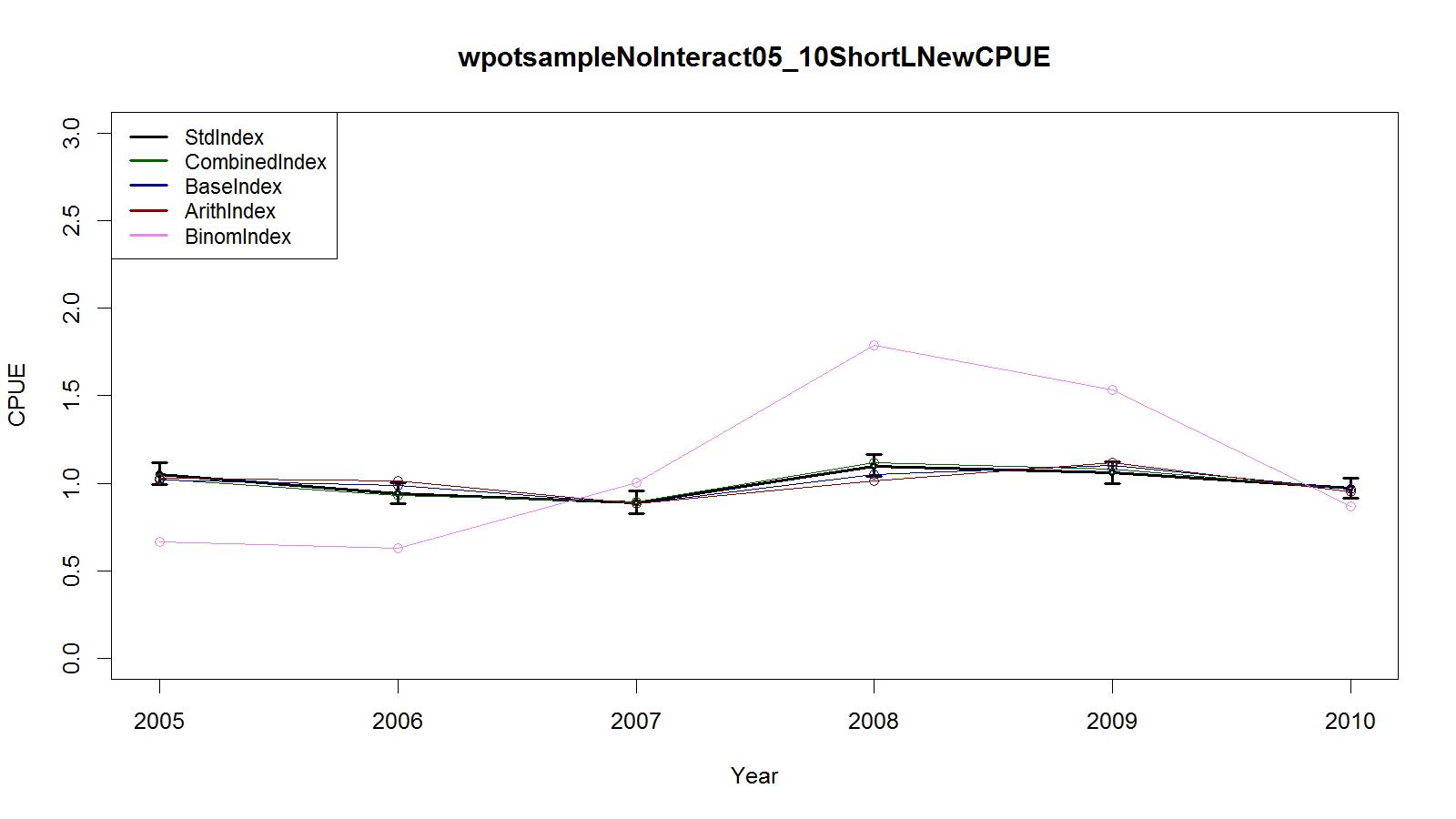


Figure 17. Predicted vs. observed *ln(CPUE)*, Pearson residuals vs. explanatory and response variables of the best lognormal fit model for legal size crab CPUE. Trimmed observer data from WAG (west of 174°W longitudes) for 2005/06–2010/11 were used.



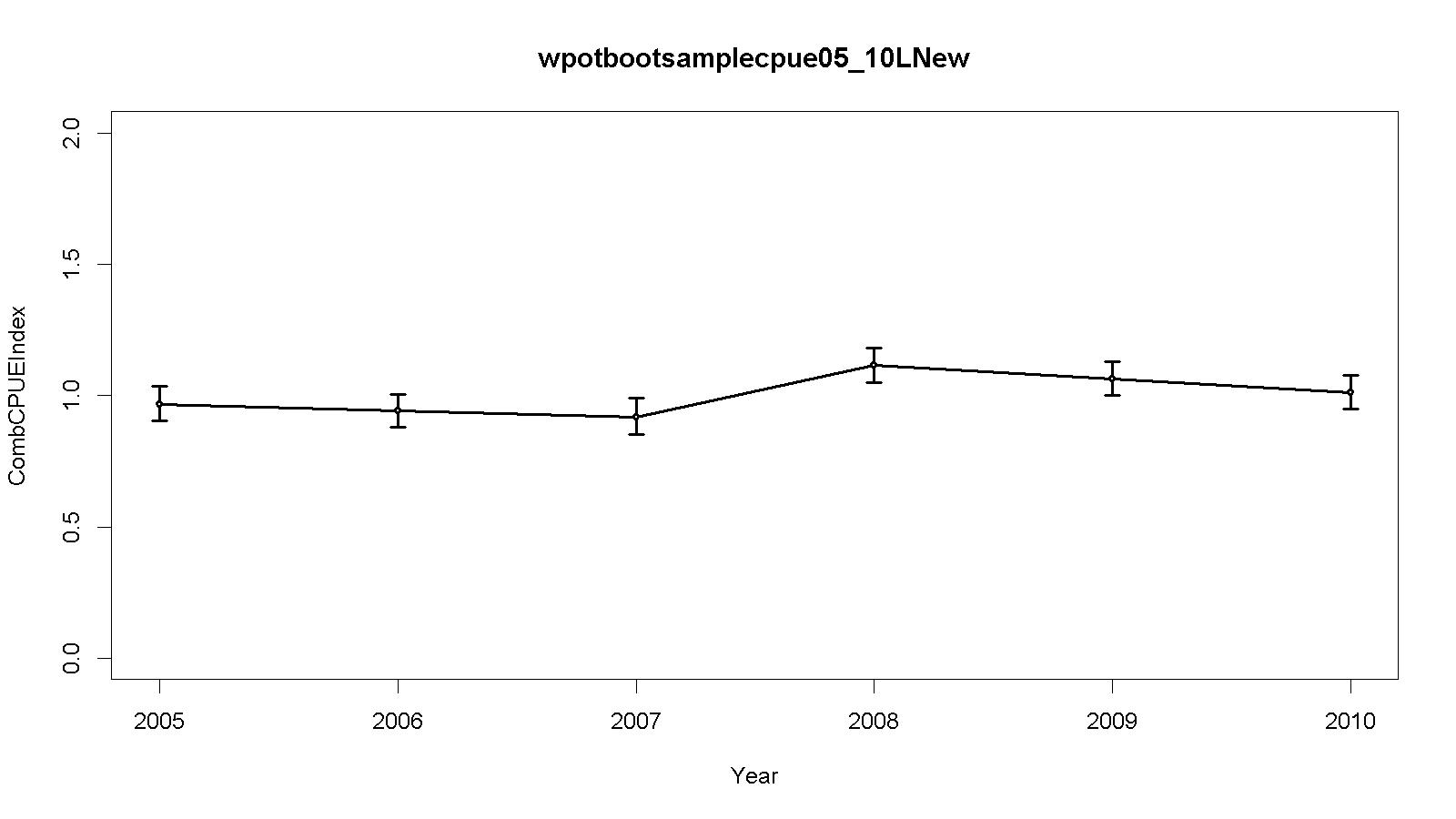


Figure 18. Trends in observer CPUE indices for legal size crab data for the Aleutian Islands golden king crab fishery. Top panel: Standardized Index (Lognormal): black line with two standard errors; Combined Index: green; Base Index: blue line; Binomial index: purple; and Arithmetic Index: red line. Bottom panel: Bootstrap estimate of combined CPUE index with confidence limits. Trimmed observer data from WAG (west of 174°W longitudes) for 2005/06–2010/11 were used.

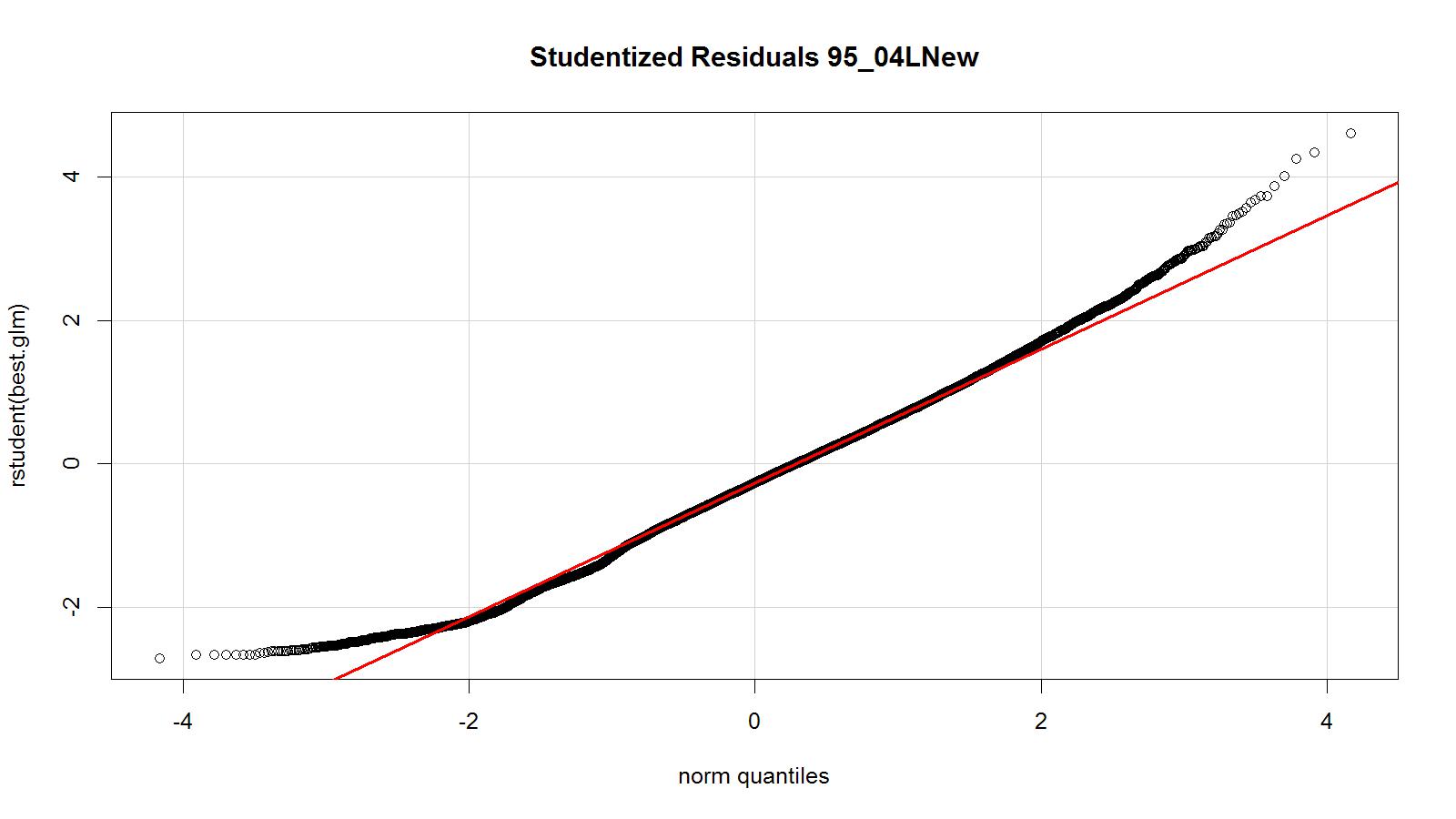


Figure 19. Studentized residual plot of the best negative binomial fit model for legal CPUE. Observer data from EAG (east of 174°W longitudes) for 1995/96–2004/05 were used.

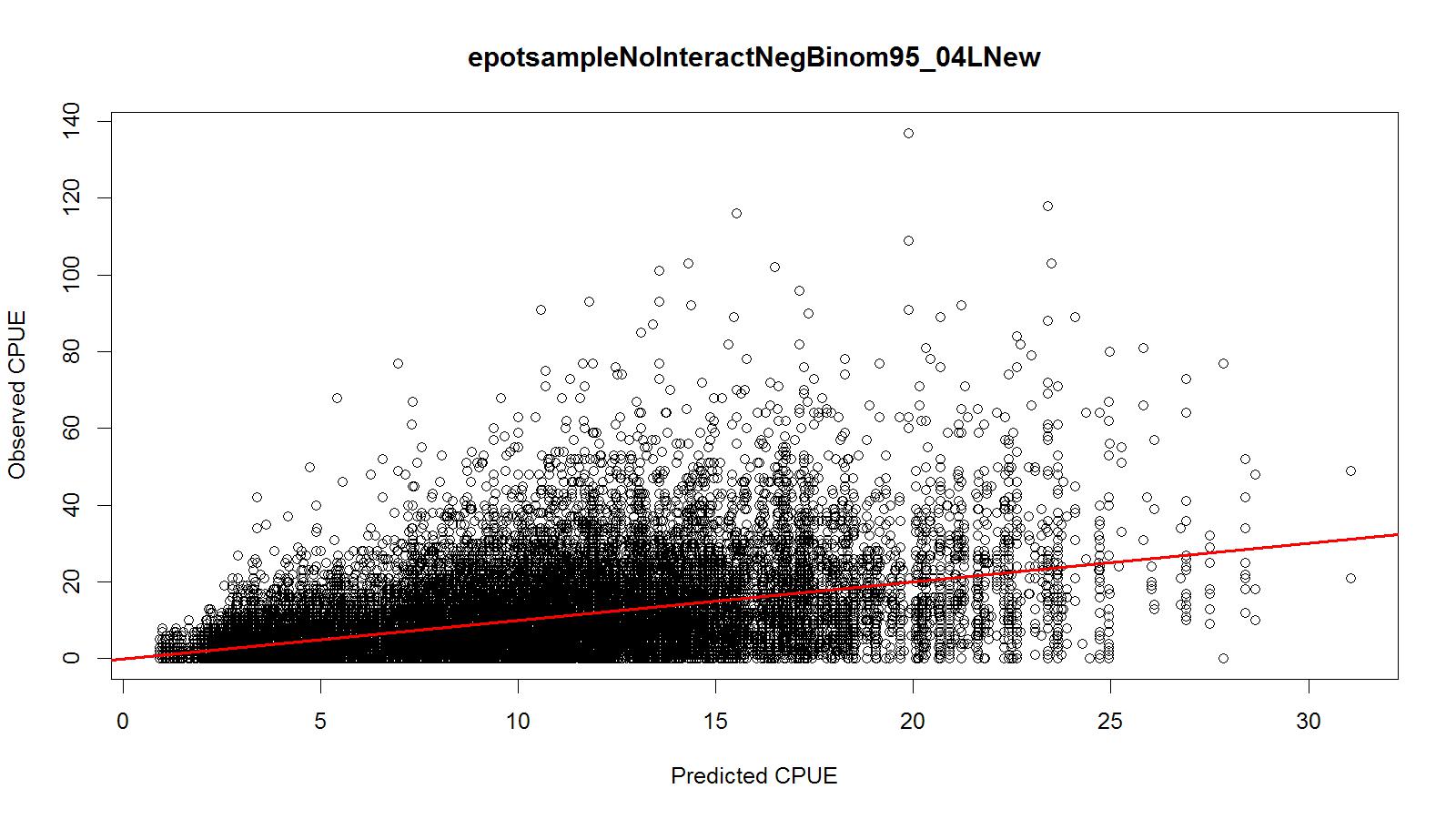




Figure 20. Predicted vs. observed CPUE, Pearson residuals vs. explanatory and response variables of the best negative binomial fit model for legal size crab CPUE. Observer data from EAG (east of 174°W longitudes) for 1995/96–2004/05 were used.

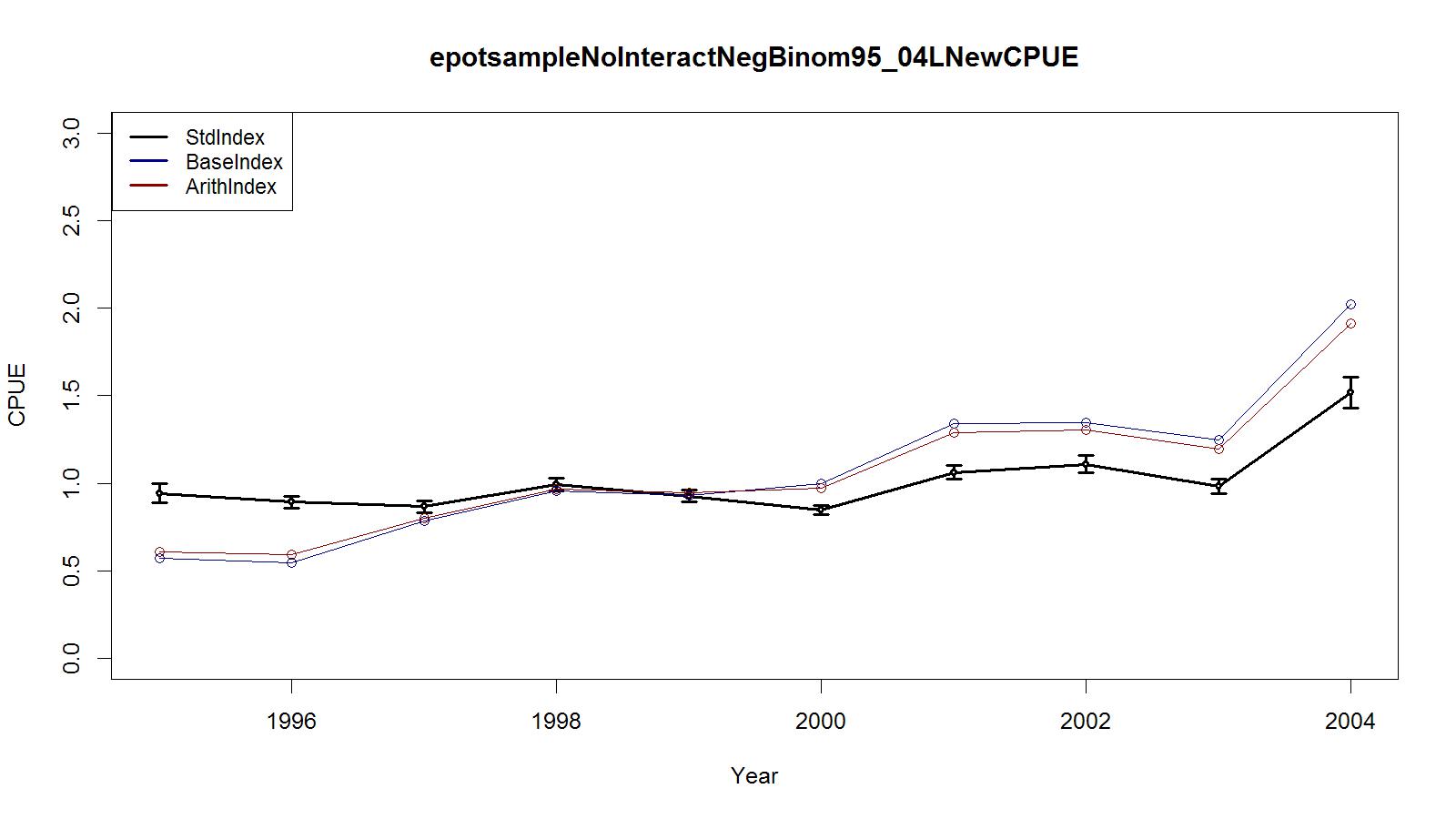


Figure 21. Trends in observer CPUE indices for legal size crab data for the Aleutian Islands golden king crab fishery. Standardized Index (negative binomial): black line with 2 standard errors; Base Index: blue line; and Arithmetic Index: red line. Observer data from EAG (east of 174°W longitudes) for 1995/96–2004/05 were used.

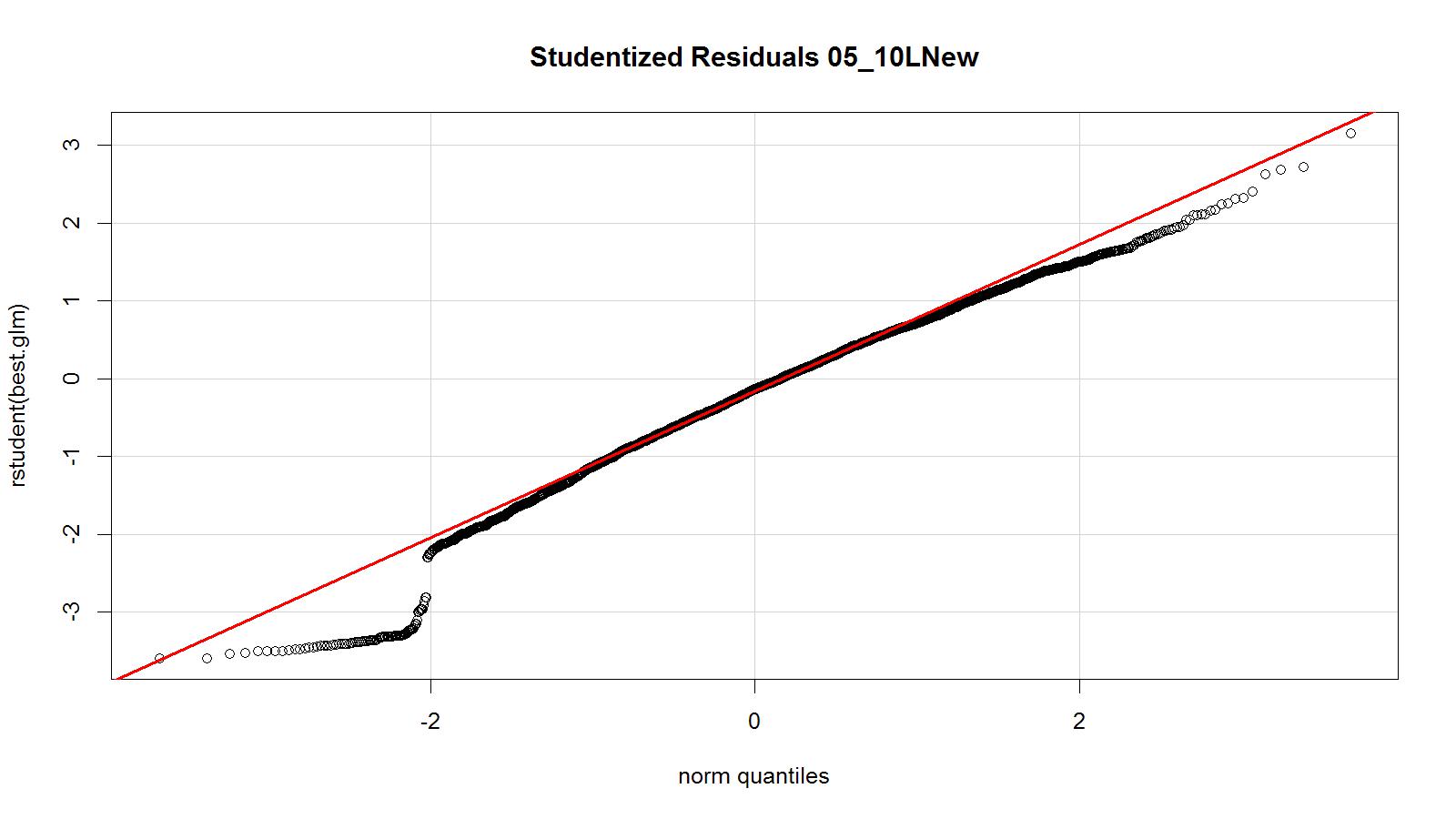
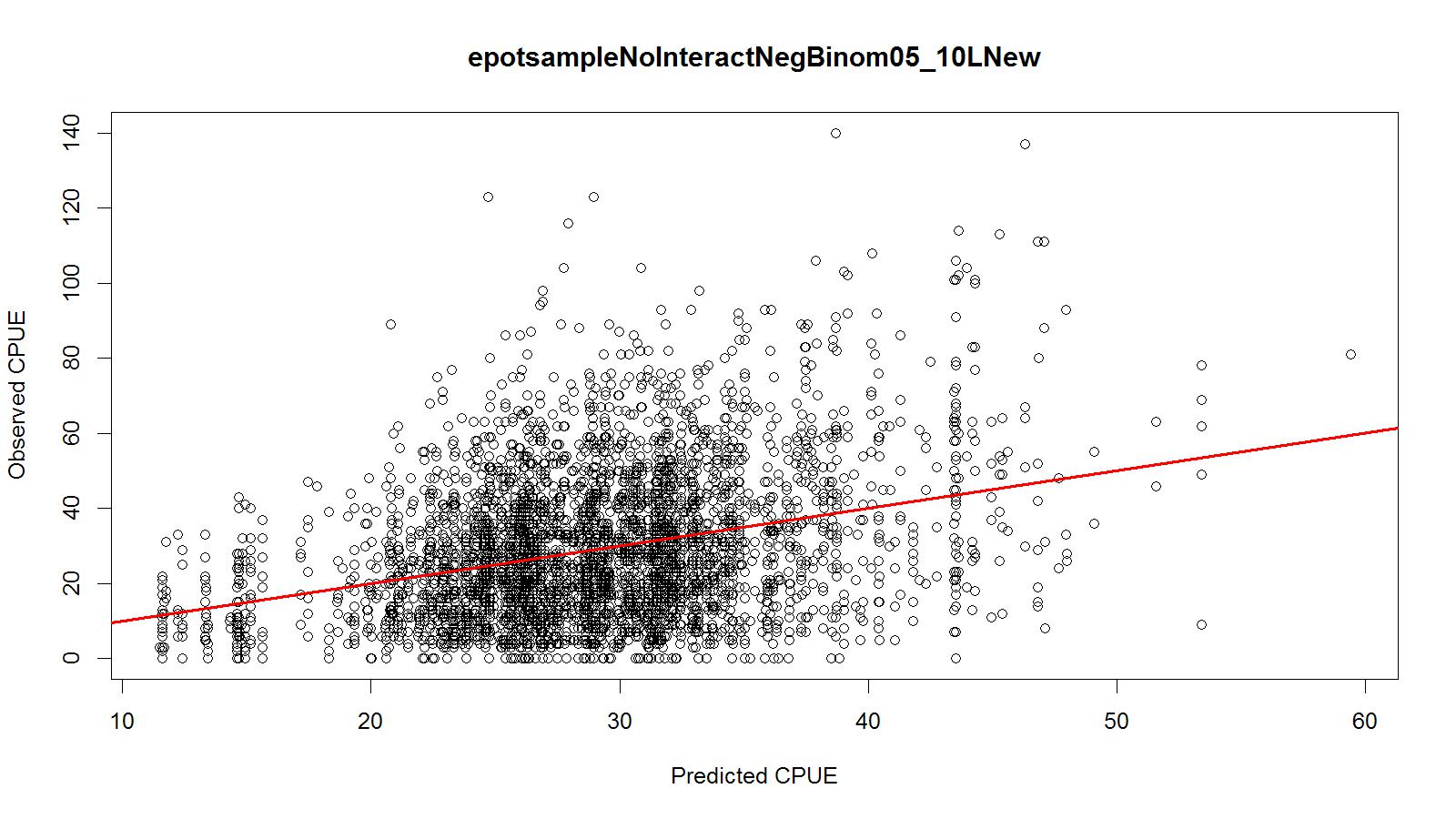


Figure 22. Studentized residual plot of the best negative binomial fit model for legal CPUE. Observer data from EAG (east of 174°W longitudes) for 2005/06–2010/11 were used.



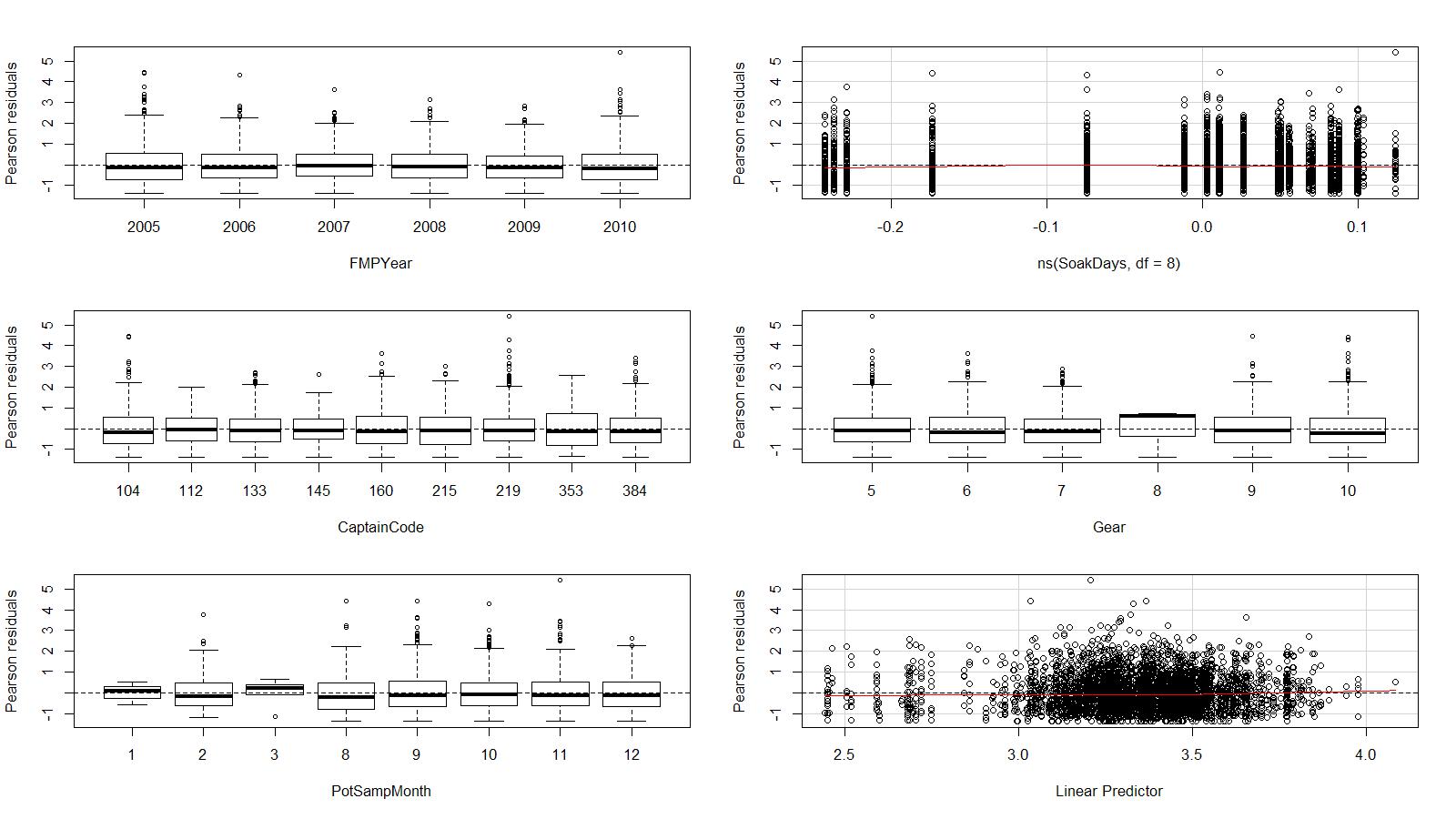


Figure 23. Predicted vs. observed CPUE, Pearson residuals vs. explanatory and response variables of the best negative binomial fit model for legal size crab CPUE. Observer data from EAG (east of 174°W longitudes) for 2005/06–2010/11 were used.

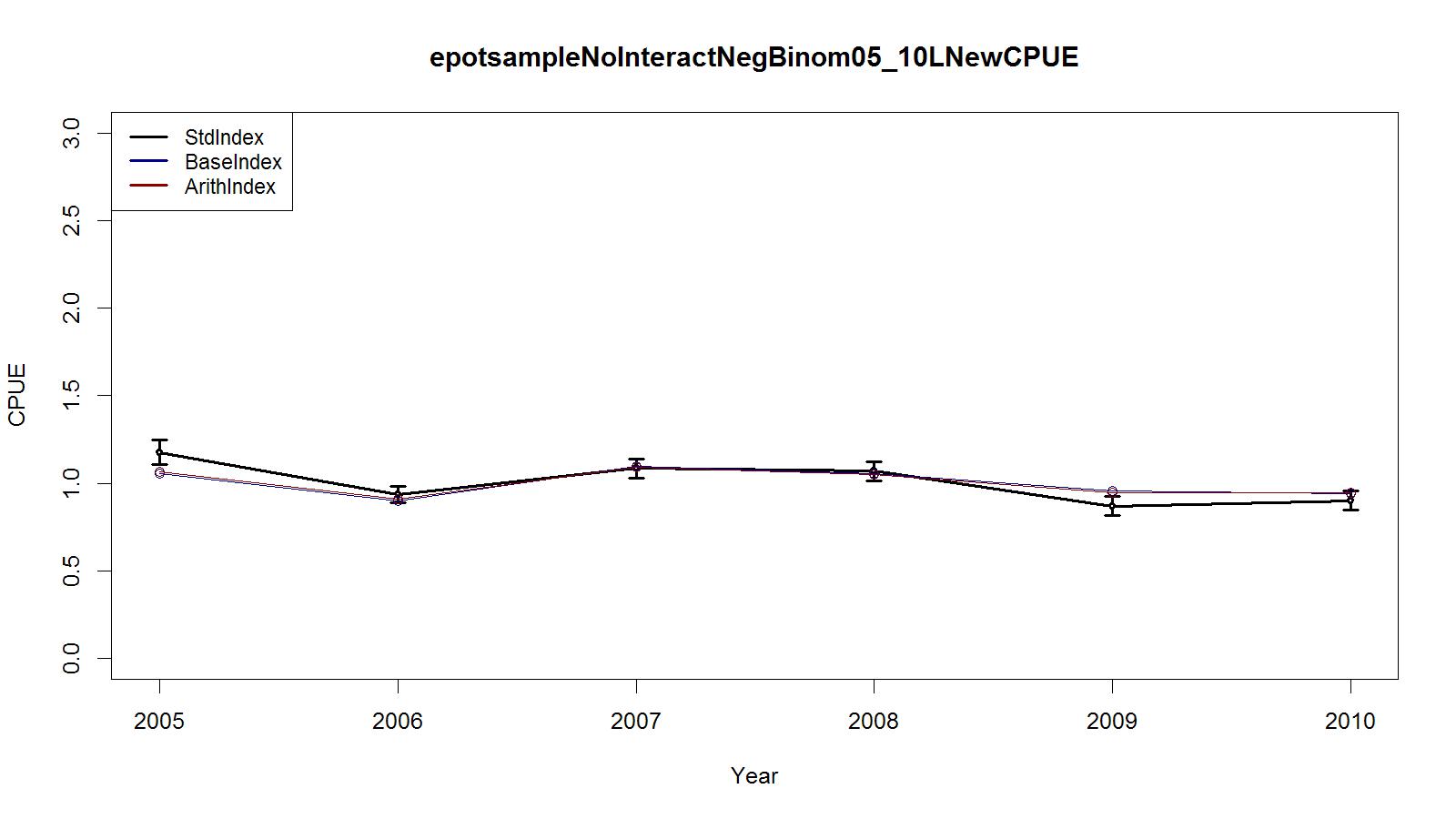


Figure 24. Trends in observer CPUE indices for legal size crab data for the Aleutian Islands golden king crab fishery. Standardized Index (negative binomial): black line with two standard errors; Base Index: blue line; and Arithmetic Index: red line. Observer data from EAG (east of 174°W longitudes) for 2005/06–2010/11 were used.

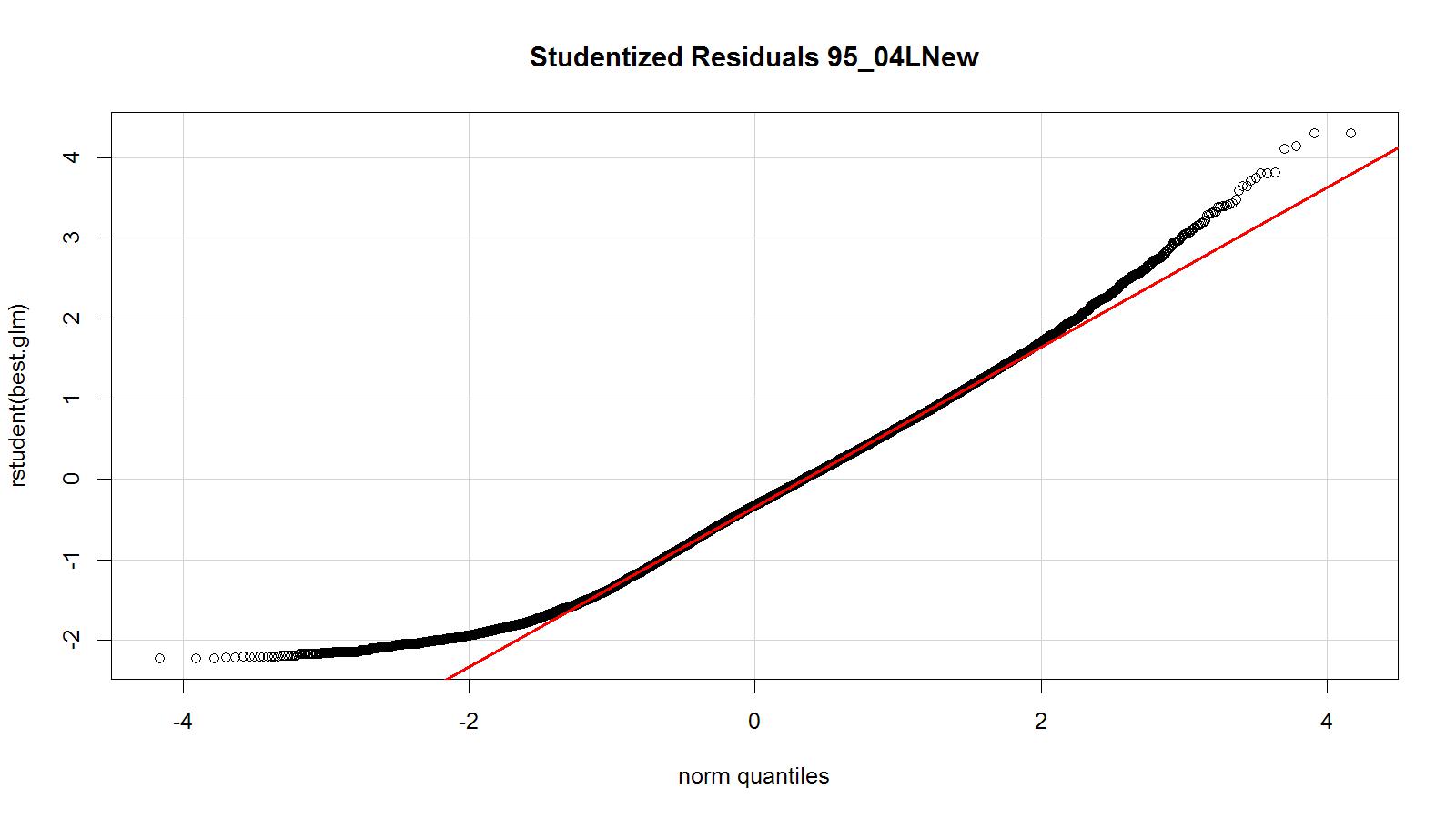
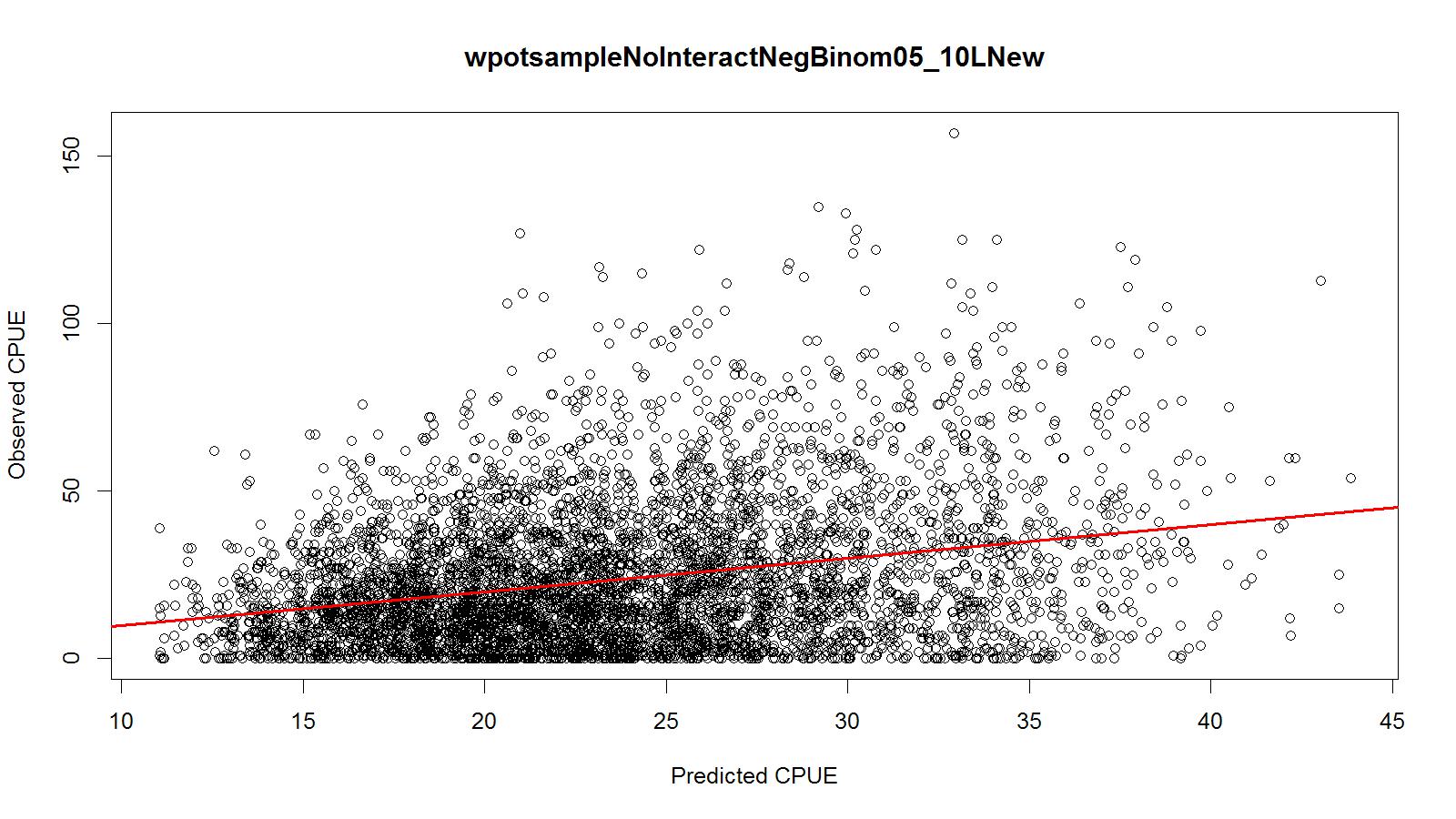


Figure 25. Studentized residual plot of the best negative binomial fit model for legal CPUE. Observer data from WAG (west of 174°W longitudes) for 1995/96–2004/05 were used.



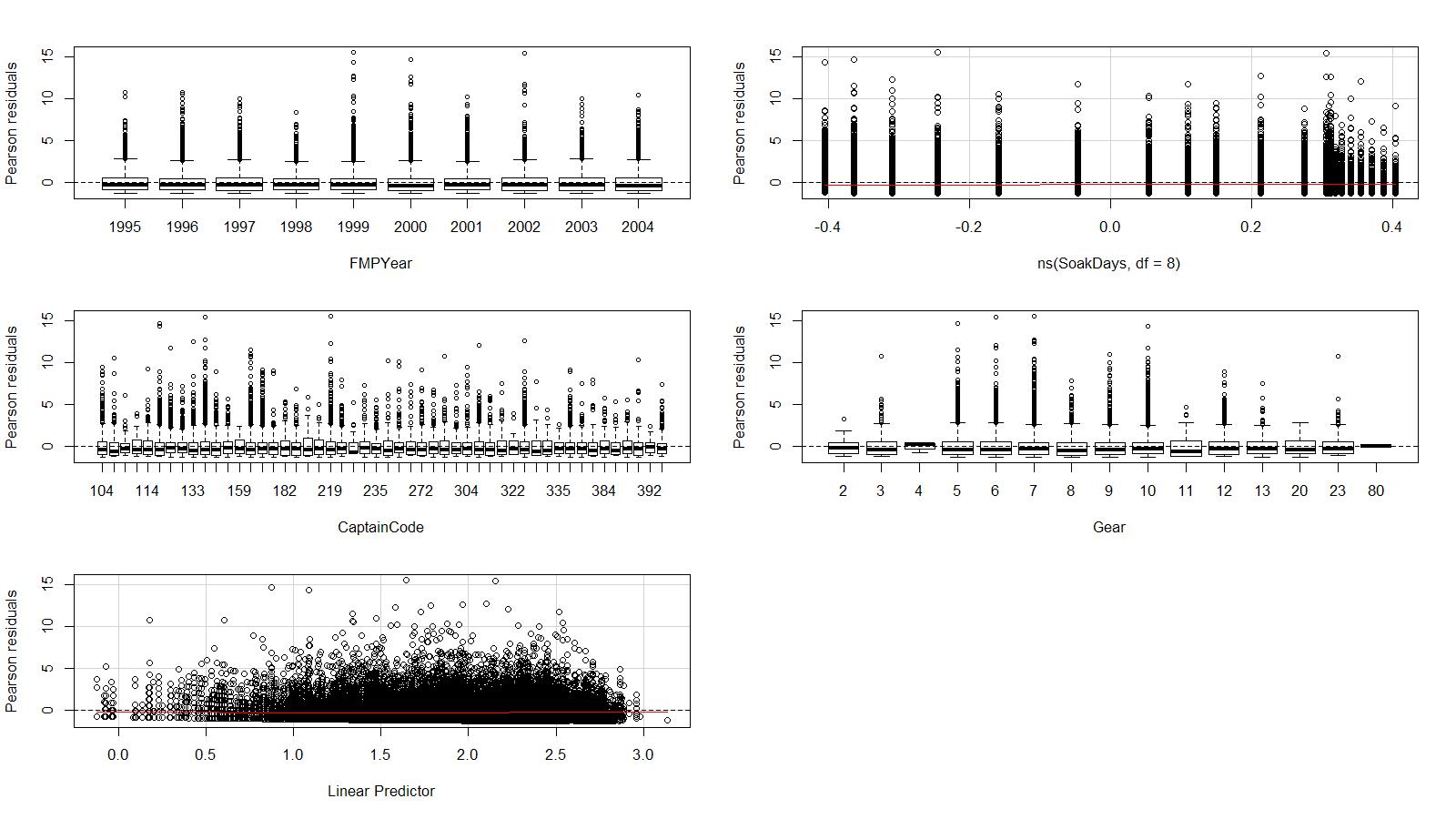


Figure 26. Predicted vs. observed CPUE, Pearson residuals vs. explanatory and response variables of the best negative binomial fit model for legal size crab CPUE. Observer data from WAG (west of 174°W longitudes) for 1995/96–2004/05 were used.

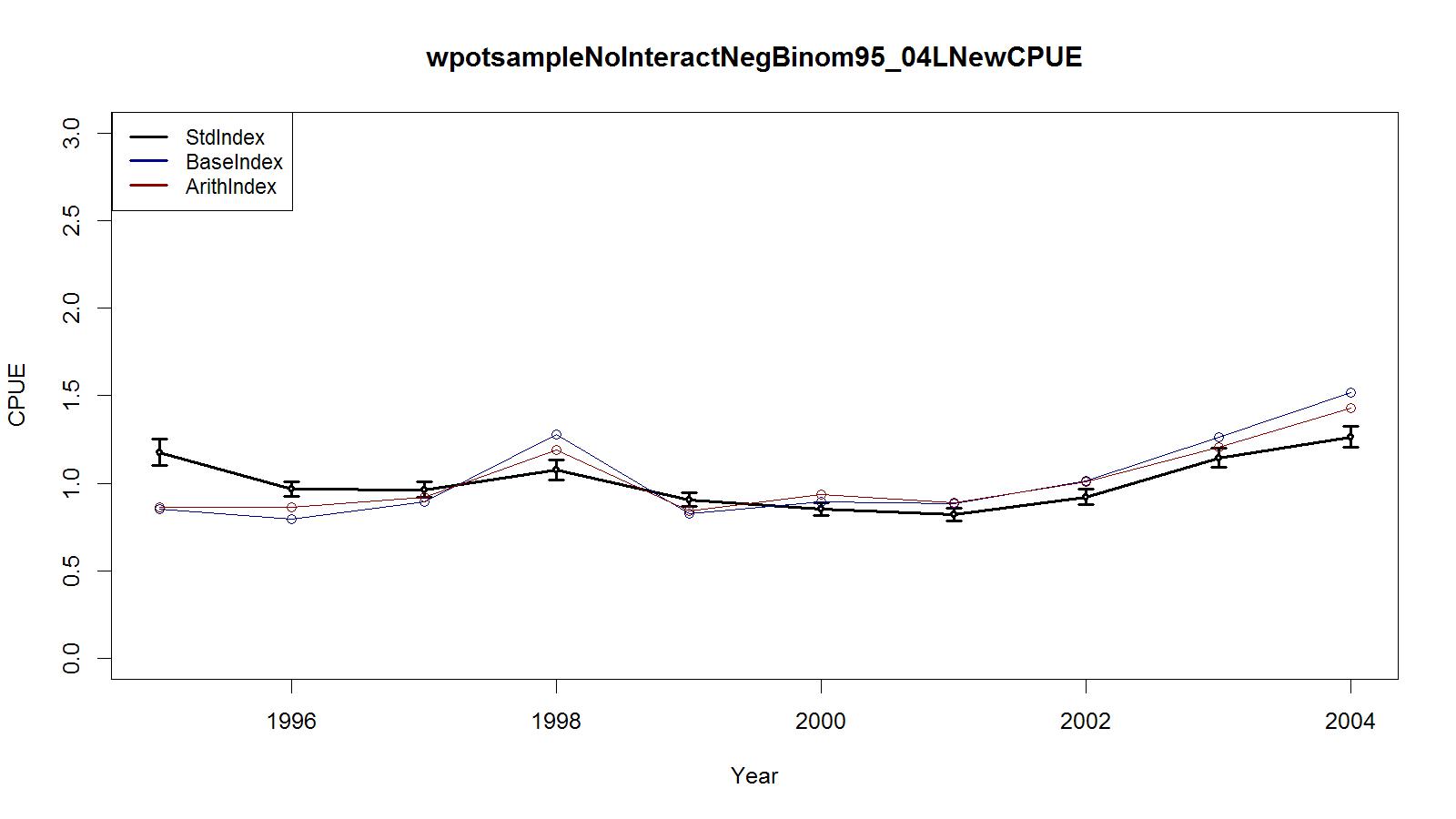


Figure 27. Trends in observer CPUE indices for legal size crab data for the Aleutian Islands golden king crab fishery. Standardized Index (negative binomial): black line with two standard errors; Base Index: blue line; and Arithmetic Index: red line. Observer data from WAG (west of 174°W longitudes) for 1995/96–2004/05 were used.

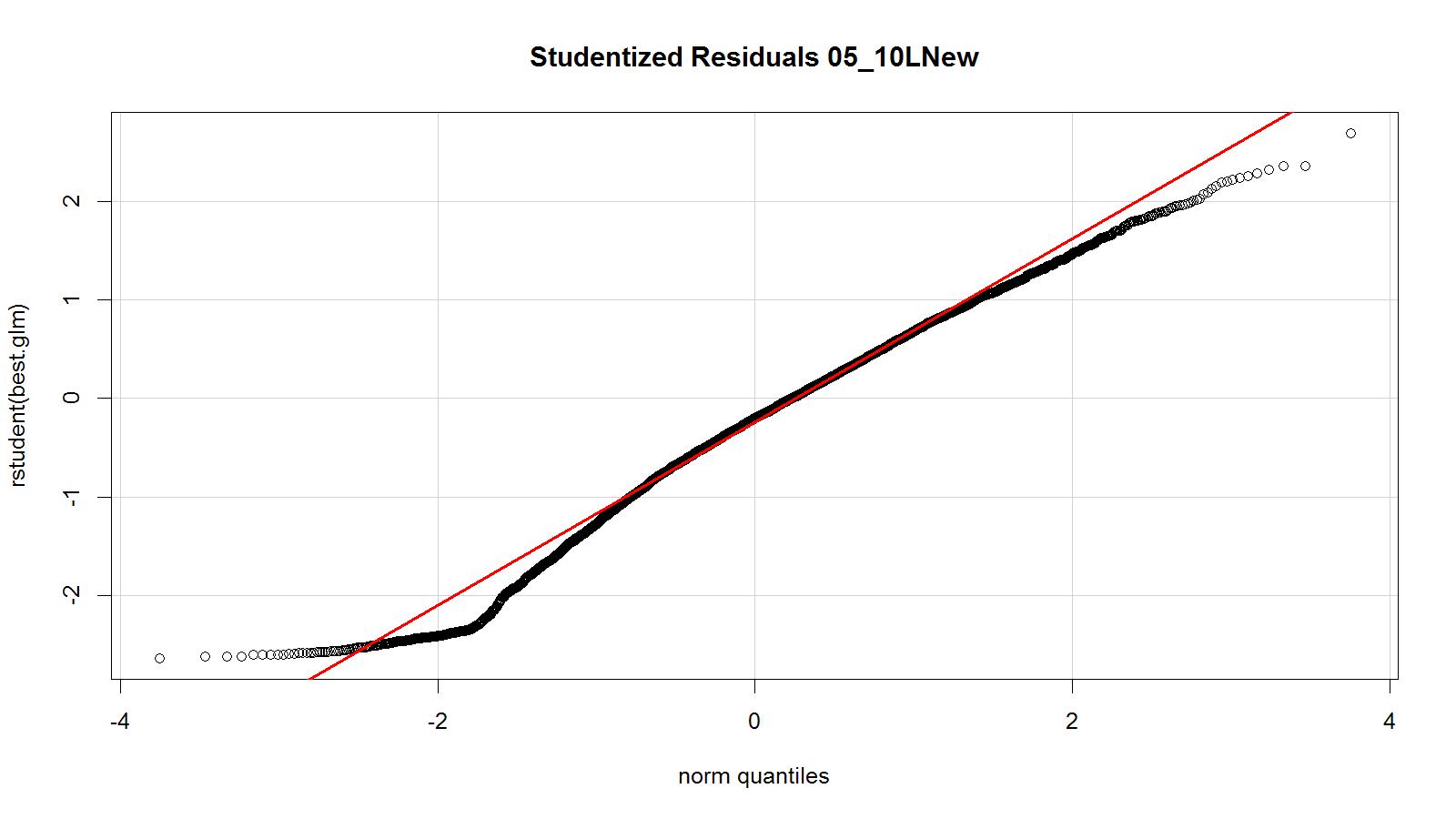


Figure 28. Studentized residual plot of the best negative binomial fit model for legal CPUE. Observer data from WAG (west of 174°W longitudes) for 2005/06–2010/11 were used.

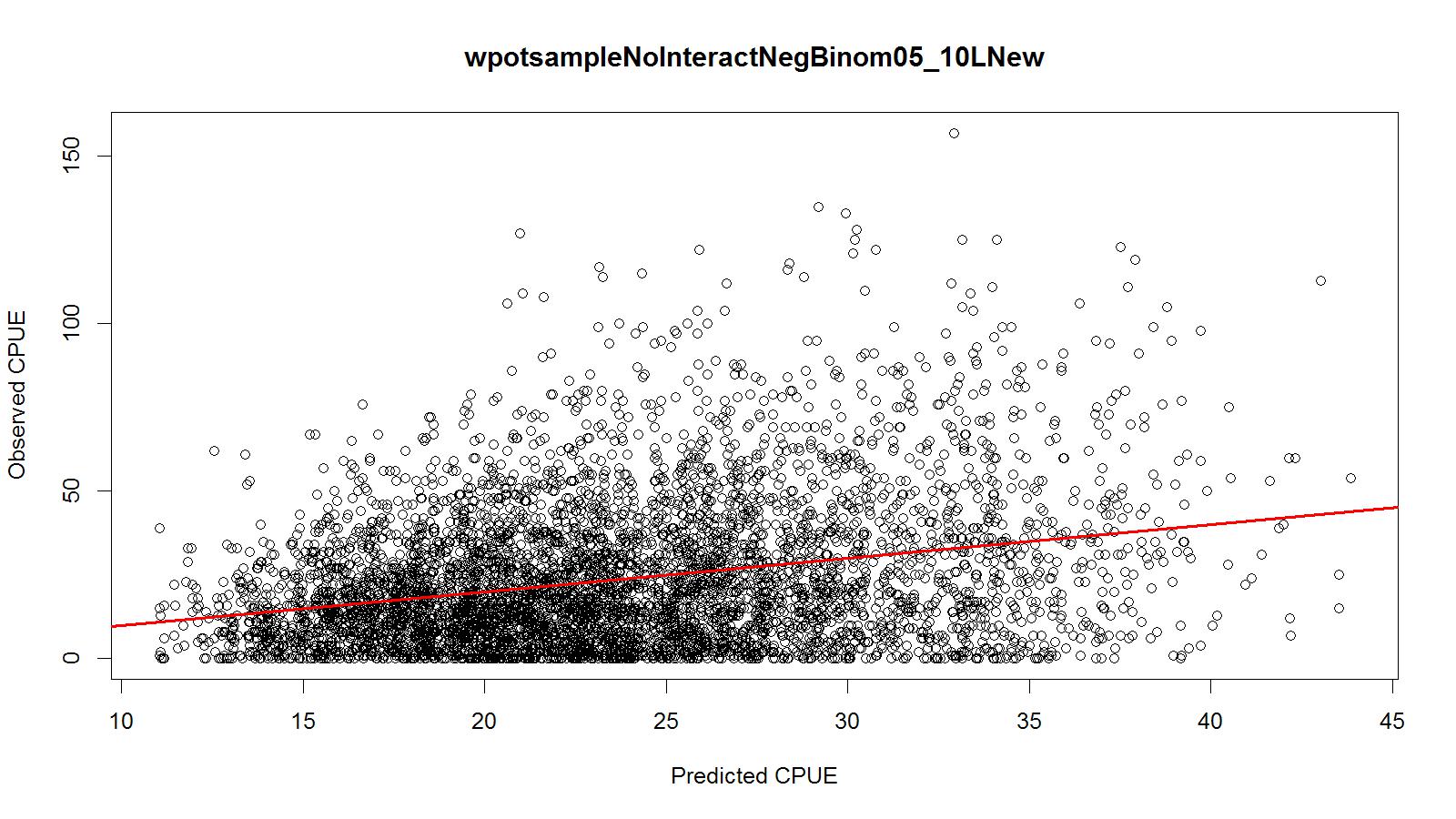
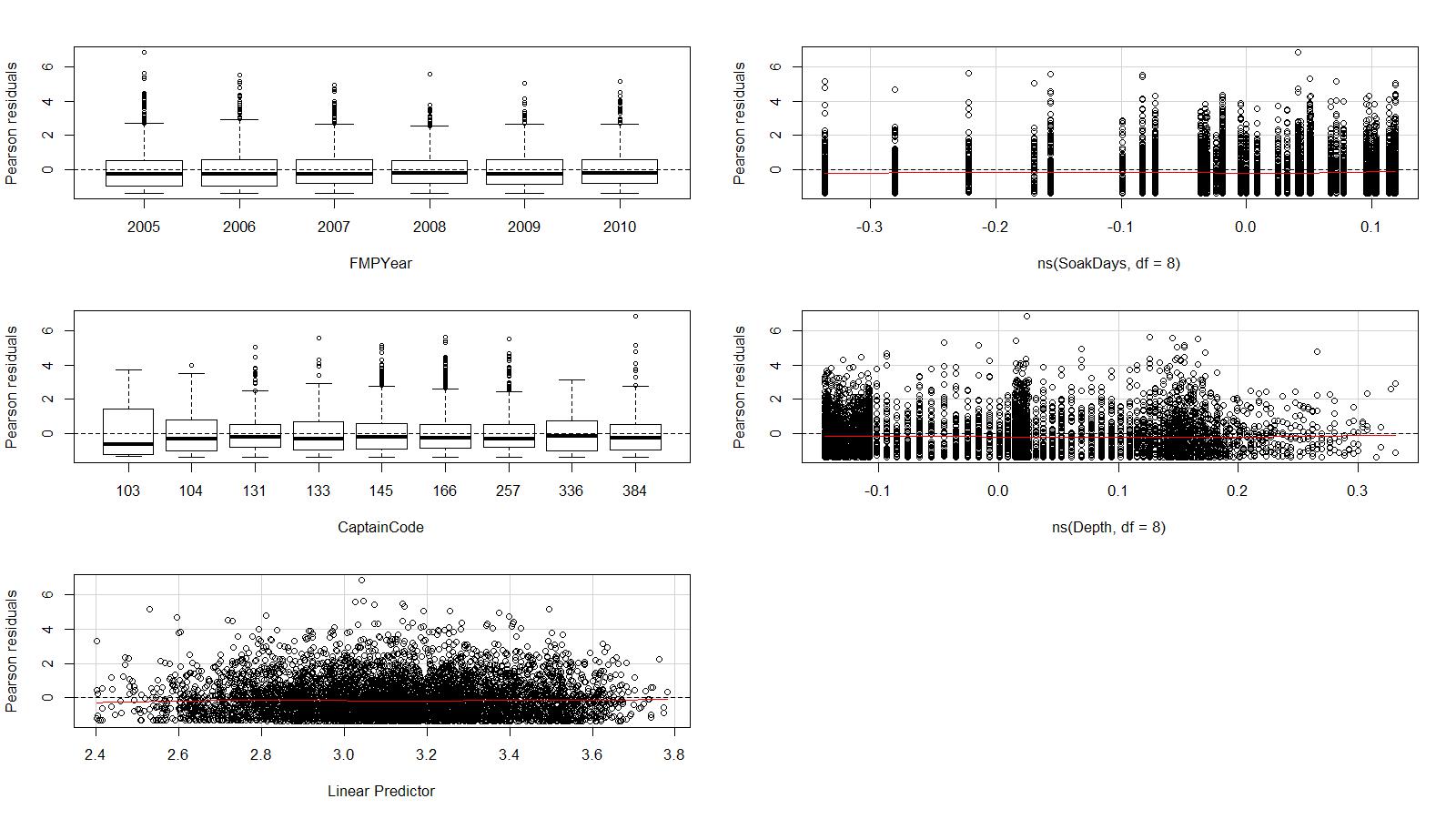
 

Figure 29. Predicted vs. observed CPUE, Pearson residuals vs. explanatory and response variables of the best negative binomial fit model for legal size crab CPUE. Observer data from WAG (west of 174°W longitudes) for 2005/06–2010/11 were used.

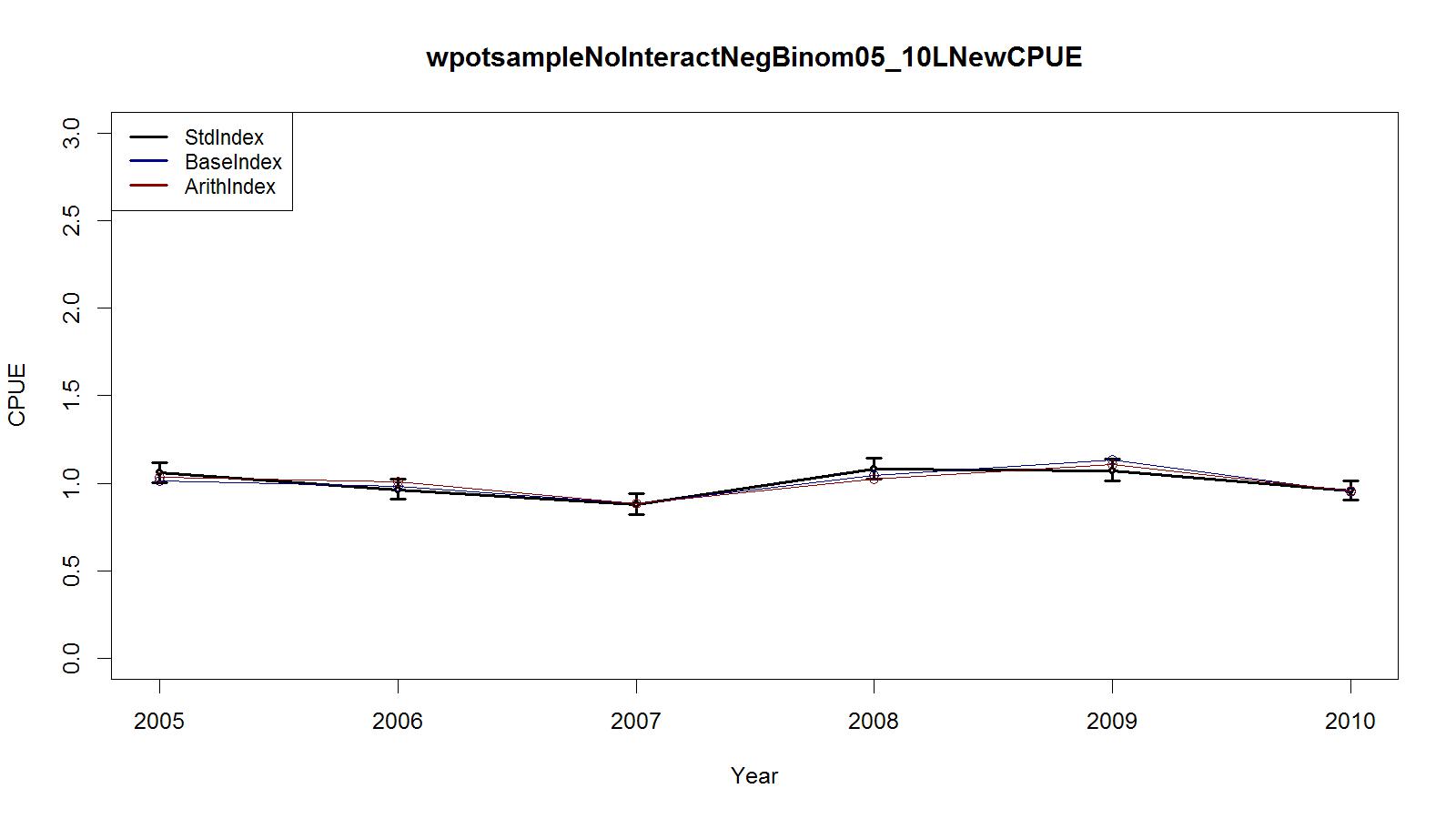


Figure 30. Trends in observer CPUE indices for legal size crab data for the Aleutian Islands golden king crab fishery. Standardized Index (negative binomial): black line with two standard errors; Base Index: blue line; and Arithmetic Index: red line. Observer data from WAG (west of 174°W longitudes) for 2005/06–2010/11 were used.

# Appendix A

R script used in CPUE standardization. The step CPUE (two R code files provided by Paul Starr) and the data file (restricted because of ADF&G privacy policy) are available with the first author.

**# Initial environment variable setting**

options(contrasts=c("contr.treatment", "contr.poly"))

options(object.size =100000000)

#

**# Read the observer data file**

allpotsample<- read.csv("C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/allpotsampleAddAreaTrip95.csv", header=TRUE)

**#Create a data frame with selected variables**

allpotsampleSub<- as.data.frame(list(allpotsample$FMPYear,allpotsample$PotSampMonth,allpotsample$FTPotLifts,allpotsample$ADFG,allpotsample$EastWest, allpotsample$StatArea,allpotsample$Depth,allpotsample$SoakDays,allpotsample$Gear,allpotsample$Sublegal, allpotsample$LegalRet, allpotsample$LegalNR,allpotsample$CaptainCode,allpotsample$AreaGP,allpotsample$Yrsof5Tr,allpotsample$EastVess,allpotsample$WestVess,allpotsample$TotalVess, allpotsample$EastVesSoak,allpotsample$WestVesSoak))

names(allpotsampleSub)<- c("FMPYear","PotSampMonth","FTPotLifts","ADFG","EastWest","StatArea","Depth","SoakDays","Gear","Sublegal", "LegalRet","LegalNR","CaptainCode","AreaGP","Yrsof5Tr","EastVess","WestVess","TotalVess",

"EastVesSoak","WestVesSoak")

**# Restrict the data set to 1995 -2004**

allpotsampleSub<- allpotsampleSub[allpotsampleSub$FMPYear <1995,]

**# Select core data with a minimum five trips per year for three years**

allpotsampleSub<- allpotsampleSub[allpotsampleSub$Yrsof5Tr>=3,]

# Remove records of NA, unusual gear codes, missing value -9 from the data frame

allpotsampleSub<-na.omit(allpotsampleSub)

allpotsampleSub<- allpotsampleSub[allpotsampleSub$FMPYear != -9,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$PotSampMonth != -9,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$EastWest != -9,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$ADFG != -9,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$SoakDays != -9,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$SoakDays != 0,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$StatArea != -9,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$AreaGP != -9,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$Depth != -9,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$Depth != 0,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$Gear != -9,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$Gear != 1,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$Gear != 14,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$Gear != 15,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$Gear != 17,]

allpotsampleSub<- allpotsampleSub[allpotsampleSub$Gear != 22,]

**# Select EAG data**

epotsampleSub<- allpotsampleSub[allpotsampleSub$EastWest==1,]

**# Subset pre rationalization years for EAG**

eprepotsampleSub<- epotsampleSub[epotsampleSub$FMPYear<2005,]

**# 5% and 95% trimmed by pre and post rationalization, and data combined for EAG**

eprepotsampleSubcut <- eprepotsampleSub[eprepotsampleSub$SoakDays>1 & eprepotsampleSub$SoakDays<12,]

epotsampleSubtrim<- eprepotsampleSubcut

**# 1% and 99% trimmed on depth**

epotsampleSubtrim <- epotsampleSubtrim[epotsampleSubtrim$Depth>74 & epotsampleSubtrim$Depth<338,]

**# Change some data frame variables to factors for EAG**

epotsampleSubtrim$FMPYear<- as.factor(epotsampleSubtrim$FMPYear)

epotsampleSubtrim$PotSampMonth<- as.factor(epotsampleSubtrim$PotSampMonth)

epotsampleSubtrim$ADFG<- as.factor(epotsampleSubtrim$ADFG)

epotsampleSubtrim$AreaGP<- as.factor(epotsampleSubtrim$AreaGP)

epotsampleSubtrim$Gear<- as.factor(epotsampleSubtrim$Gear)

epotsampleSubtrim$CaptainCode<- as.factor(epotsampleSubtrim$CaptainCode)

**# Create a column of a selected response variable for analysis**

epotsampleSubtrim$Legals<- epotsampleSubtrim$LegalRet+epotsampleSubtrim$LegalNR

**# Add a (binomial) variable to the data set to reflect success or failure**

epotsampleSubtrim$success[epotsampleSubtrim$Legals>0]<- 1

epotsampleSubtrim$success[epotsampleSubtrim$Legals==0]<- 0

**# Select core data of minimum five trips per year for three years**

datacore<- epotsampleSubtrim

**# Calculate the series of proportions zero (unsuccessful)**

prop.zero<- (table(datacore$FMPYear)-table(datacore$FMPYear[datacore$success==1]))/table(datacore$FMPYear)

**# Subset core data by positive catch values**

datacore1<- datacore[datacore$success==1,]

**# Find the best model from lognormal fit**

library(splines)

glm.object<- glm(log(Legals)~FMPYear+ns(SoakDays,df=8),data=datacore1)

epotsampleout1<- stepCPUE(glm.object,scope=list(upper= ~(FMPYear+ns(SoakDays,df=8)+PotSampMonth+ADFG+CaptainCode+AreaGP+Gear+ns(Depth,df=8)+ns(EastVesSoak,df=4)),lower= ~FMPYear+ns(SoakDays,df=8)),direction="forward",trace=9,r2.change=0.01)

**# Find the best model from negative binomial fit**

# glm.object<- glm(Legals~FMPYear+ns(SoakDays,df=8),family = negative.binomial(2),data=datacore)

# epotsampleout1<- stepCPUE(glm.object,scope=list(upper= ~(FMPYear+ns(SoakDays,df=8)+PotSampMonth+ADFG+CaptainCode+AreaGP+Gear+ns(Depth,df=8) +ns(EastVesSoak,df=8)),lower= ~FMPYear+ns(SoakDays,df=8)), family = negative.binomial(2), direction="forward",trace=9,r2.change=0.01)

# Results from lognormal fit of the best model

# best.glm<- glm(Legals~ FMPYear+ns(SoakDays,df=8)+Gear+CaptainCode+PotSampMonth,family = negative.binomial(2),y=TRUE, data=datacore)

**# Get results from lognormal fit of the best model**

best.glm<- glm(log(Legals)~ FMPYear+ns(SoakDays,df=8)+Gear+CaptainCode+PotSampMonth,y=TRUE, data=datacore1)

**# Get R-squared for the best fit**

Rsq.bestglm<- (best.glm$null.deviance-best.glm$deviance)/best.glm$null.deviance

cat("RSquared for bestglm1=",Rsq.bestglm,"\n") # Get results from the best lognormal model fit

**# Get relative lognormal indices (with the base year =1)**

sumglm<-summary(best.glm)

coefsglm <- exp(as.numeric(c(0, sumglm$coefficients[2:10,1])))

**# Get canonical lognormal indices**

cpue1.glm<-getCPUE(best.glm,2:10, 1995:2004)

**# Write the output to a file**

write.csv(cpue1.glm,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractYearlyLnCPUE95.csv",row.names=F)

**# Get base relative lognormal indices (with the base year =1)**

base.glm<-glm(log(Legals)~ FMPYear+ns(SoakDays,df=8), y=TRUE, data=datacore1)

sumglm1<-summary(base.glm)

coefsbaseglm <- exp(as.numeric(c(0, sumglm1$coefficients[2:10,1])))

**# Get canonical lognormal indices for the base index**

cpue2.glm<-getCPUE(base.glm,2:10, 1995:2004)

**# Write the output to a file**

write.csv(cpue2.glm,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractBaseYearLnCPUE95.csv",row.names=F)

**# Find the best model from the binomial fit**

glm.object2<- glm(success~FMPYear+ns(SoakDays,df=8),family=binomial(link=logit),data=datacore)

epotsampleout2<- stepCPUE(glm.object2,scope=list(upper= ~(FMPYear+ns(SoakDays,df=8)+PotSampMonth+ADFG+CaptainCode+AreaGP+Gear+ns(Depth,df=8)+ns(EastVesSoak,df=4)),lower= ~FMPYear+ns(SoakDays,df=8)),family=binomial(link=logit),direction="forward",trace=9,r2.change=0.01)

**## Get results from binomial fit of the best model**

best2.glm<-glm(success ~ FMPYear+ns(SoakDays,df=8)+CaptainCode+Gear,family=binomial(link=logit),y=TRUE,data=datacore)

**## Get R-squared for the best fit**

Rsq.bestglm<- (best2.glm$null.deviance-best2.glm$deviance)/best2.glm$null.deviance

cat("RSquared for bestglm2=",Rsq.bestglm,"\n")

detach(package:splines)

**#Get relative binomial indices (with the base year =1)**

sumglm2<-summary(best2.glm)

coefsbin <- exp(as.numeric(c(0, sumglm2$coefficients[2:10,1])))

**# Get canonical binomial indices**

cpue3.glm<-getCPUE(best2.glm,2:10, 1995:2004)

**# Write the output to a file**

write.csv(cpue3.glm,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractYearlyBinomCPUE95.csv",row.names=F)

**# Get base relative binomial indices (with the base year =1)**

base3.glm<-glm(success~ FMPYear+ns(SoakDays,df=8),family=binomial(link=logit),y=TRUE, data=datacore)

sumglm3<-summary(base3.glm)

coefsbasebin <- exp(as.numeric(c(0, sumglm3$coefficients[2:10,1])))

detach(package:splines)

**# Get canonical binomial indices for the base index**

cpue4.glm<-getCPUE(base3.glm,2:10, 1995:2004)

**# Write the output to a file**

write.csv(cpue4.glm,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractBaseBinomCPUE95.csv",row.names=F)

**# Calculate combined CPUE indices**

n<-length(coefsglm)

Comb<-rep(0,n)

for(i in 1:n){

Comb[i]<-coefsglm[i]/(1-prop.zero[1]\*(1-1/coefsbin[i]))}

**# Get canonical combined indices**

Combined <- Comb/exp(mean(log(Comb)))

**# Write the output to a file**

write.csv(Combined,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractCombCPUE95.csv",row.names=F)

**# Write positive observed CPUE from core data to a file**

write.csv(datacore1,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractCatches95.csv",row.names=F)

**# Calculate Arithmetic CPUE index**

RCPUE<- tapply(datacore1$Legals,datacore1$FMPYear,mean)

GMRCPUE<- exp(mean(log(RCPUE)))

RCPUEdash<- RCPUE/GMRCPUE

**# Write the output to a file**

write.csv(RCPUEdash,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractScaledArithCPUE95.csv",row.names=F)

**# Get parameter estimates with standard errors**

bestglm<- summary(best.glm)

**# Write the output to a file**

write.csv(bestglm$coefficients,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractparameters.csv",row.names=T)

**# Combine various CPUEs into a data frame**

allpotsample.cpue<- as.data.frame(cbind(cpue1.glm$Year,cpue2.glm$Index,RCPUEdash,cpue1.glm$Index,cpue1.glm$Upper,cpue1.glm$Lower,Combined))

names(allpotsample.cpue)<- list("Year", "BaseInd","ArithInd","StdInd", "StdUpper","StdLower","CombInd")

write.csv(allpotsample.cpue,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractcpue95LSc1.csv",row.names=F)

**# Plot various CPUE**

**# Read the file**

epotsample.CPUE<- read.csv("C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractcpue95LSc1.csv",header=T)

**# Set the plotting parameters**

**# Load the gplots package**

library(gplots)

attach(epotsample.CPUE)

jpeg(file="C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractCPUE95Fig1.jpg",width=1600,height=900,res=150)

plotCI(x=Year,y=StdInd,ui=StdUpper,li=StdLower,xlim=c(1995,2004),ylim=c(0,3),type="o",lty="solid",cex=0.5,lwd=2,pch=21,gap=0,sfrac=0.005, xlab="Year",ylab="CPUE", main="epotsampleNoInteract95CPUE")

plotCI(x=Year,y=CombInd,ui=CombUpper,li=CombLower,cex=1,type="o",col="darkgreen",add=TRUE)

plotCI(x=Year,y=BaseInd,ui=NULL,li=NULL,cex=1,type="o",col="darkblue",add=TRUE)

plotCI(x=Year,y=ArithInd,ui=NULL,li=NULL,cex=1,type="o",col="darkred",add=TRUE)legend("topleft",c("StdIndex","CombinedIndex","BaseIndex","ArithIndex"),lty=c("solid","solid","solid","solid"),col=c("black","darkgreen","darkblue","darkred"),lwd=2,cex=0.9)

dev.off()

detach(epotsample.CPUE)

detach(package:gplots)

**# Collect model fit diagnostic values**

Yhat<- best.glm$fitted.values # predicted log(Legals)

Ytemp<- datacore1$Legals

Yobs<- log(Ytemp) # observed log(Legals)

**# Make scatter plot of Yobs vs Yhat**

jpeg(file="C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractObsYPredY95Fig2.jpg",width=1600,height=900,res=150)

plot(Yobs~Yhat,xlab= "Predicted log(CPUE)",ylab="Observed log(CPUE)",main="epotsampleNoInteract")

abline(a=0,b=1,col="red",lwd=2)

dev.off()

**# Plot residuals of log(CPUE)**

library(car)

jpeg(file="C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractCPUEManyRes95Fig3.jpg",width=1600,height=900,res=150)

residualPlots(best.glm,~.,fitted=TRUE,id.method="o") # against all predictors and fitted values

dev.off()

**# Make qqPlot of studentized residuals from the car package**

jpeg(file="C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractCPUEStudentRes95Fig4.jpg",width=1600,height=900,res=150)

qqPlot(rstudent(best.glm),envelope=FALSE,main="Studentized Residuals")

dev.off()

detach(package:car)

**# Make qqnorm plot of residuals from stat package**

jpeg(file="C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractCPUENormRes95Fig5.jpg",width=1600,height=900,res=150)

qqnorm(rstandard(best.glm))

abline(a=0,b=1,col="red",lwd=2)

dev.off()

**# Test for collinearity**

library(car)

epotsampleNoInteract95mod.vif<- vif(best.glm)

**# Write the output to a file**

write.csv(epotsampleNoInteract95mod.vif,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteract95VIF.csv",row.names=T)

detach(package:car)

**# Check adding interactions**

bestglm.add<- add1(best.glm, ~.^2,test="Chisq")

write.csv(bestglm.add,"C:/Users/ssiddeek/Documents/WorkR26Feb13ObserverRev3/epotsampleNoInteractaddinteractions95.csv",row.names=TRUE**)**

elapsed<-proc.time()-ptm

cat("Elapsed time in seconds",elapsed,"\n")

###########

# Appendix B

**# Bootstrap code**

library(lattice)

BootSize=1000 # bootstrap repeat

FileSize<-dim(epotsampleSubtrim) # dimension of the file

index<-FileSize[1] # first column value, number of records

##

epotsumBootSuccesses<- vector(mode="numeric",length=BootSize)

BootIndex<- as.data.frame(matrix(nrow=length(levels(epotsampleSubtrim$FMPYear)),ncol=BootSize))

CombinedIndex<- as.data.frame(matrix(nrow=length(levels(epotsampleSubtrim$FMPYear)),ncol=BootSize))

##

Freqs<-table(epotsampleSubtrim[,1]) # sum of number of observations by year

indexyears<-order(epotsampleSubtrim[,1]) #index number in ascending order

cumyrcounts<-cumsum(Freqs) # cumulative sum by year

## **Resample epotsampleSubtrim**

for (ii in 1:BootSize)

{

print(ii)

Bootrows<-sample(indexyears[1:cumyrcounts[1]],Freqs[1],replace=T) #sample the ordered index numbers for the first year

for (j in 2:length(levels(epotsampleSubtrim$FMPYear)))

{

booti<-sample(indexyears[(cumyrcounts[j-1]+1):cumyrcounts[j]],Freqs[j],replace=T)

Bootrows<-c(Bootrows,booti) # merge the sorted indexes vectors one after the other as one vector

}

BootData<- Rows(epotsampleSubtrim,Bootrows) # extract rows from epotsampleSubtrim by Bootrows index values. This data set will be used for combined CPUE index estimation by Appendix A codes.

#####

**Appendix C**

Table C.12. Parameter estimates for the lognormal GLM fit. EAG observer data for 1995/96–2004/05 were used. The parameter values in the last column are in normal space.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | Estimate | Std. Error | t value | Pr(>|t|) | Exp(Estimate) |
| (Intercept) | 1.035516 | 0.152084 | 6.808854 | 1.00E-11 | 2.81656 |
| FMPYear1996 | -0.02939 | 0.032009 | -0.91817 | 0.35854 | 0.971038 |
| FMPYear1997 | -0.03514 | 0.03499 | -1.00426 | 0.315263 | 0.965471 |
| FMPYear1998 | 0.09494 | 0.034092 | 2.784846 | 0.005359 | 1.099593 |
| FMPYear1999 | 0.03049 | 0.034744 | 0.877564 | 0.380188 | 1.030959 |
| FMPYear2000 | -0.06346 | 0.034514 | -1.83858 | 0.065987 | 0.938516 |
| FMPYear2001 | 0.183604 | 0.037119 | 4.94637 | 7.60E-07 | 1.20154 |
| FMPYear2002 | 0.237922 | 0.040525 | 5.871064 | 4.38E-09 | 1.268611 |
| FMPYear2003 | 0.106752 | 0.03985 | 2.678857 | 0.007392 | 1.112658 |
| FMPYear2004 | 0.55362 | 0.045903 | 12.06078 | 2.05E-33 | 1.739539 |
| ns(SoakDays, df = 8)1 | -0.7894 | 0.08156 | -9.67877 | 4.01E-22 | 0.454115 |
| ns(SoakDays, df = 8)2 | 0.557827 | 0.593858 | 0.939328 | 0.34757 | 1.746873 |
| ns(SoakDays, df = 8)3 | -0.3461 | 0.592942 | -0.58371 | 0.559423 | 0.70744 |
| ns(SoakDays, df = 8)4 | 0.391346 | 0.269653 | 1.451295 | 0.146709 | 1.478969 |
| ns(SoakDays, df = 8)5 | 0.271679 | 0.062461 | 4.349568 | 1.37E-05 | 1.312166 |
| ns(SoakDays, df = 8)6 | 0.069855 | 0.070206 | 0.994999 | 0.319745 | 1.072353 |
| ns(SoakDays, df = 8)7 | 1.166167 | 0.099833 | 11.68118 | 1.88E-31 | 3.209665 |
| Gear3 | -0.14459 | 0.082091 | -1.76132 | 0.078195 | 0.865378 |
| Gear4 | -0.25852 | 0.359237 | -0.71962 | 0.471763 | 0.772197 |
| Gear5 | 0.165041 | 0.061036 | 2.703999 | 0.006855 | 1.179441 |
| Gear6 | 0.126825 | 0.062304 | 2.035589 | 0.041801 | 1.135218 |
| Gear7 | 0.098729 | 0.061767 | 1.598427 | 0.109959 | 1.103768 |
| Gear8 | 0.463379 | 0.118524 | 3.909569 | 9.27E-05 | 1.589435 |
| Gear9 | 0.196069 | 0.062663 | 3.12896 | 0.001756 | 1.216611 |
| Gear10 | 0.152761 | 0.062109 | 2.459551 | 0.013917 | 1.165046 |
| Gear11 | -0.07488 | 0.142475 | -0.52556 | 0.599201 | 0.927856 |
| Gear12 | -0.60241 | 0.062803 | -9.59217 | 9.30E-22 | 0.547488 |
| Gear13 | 1.241137 | 0.617866 | 2.008747 | 0.044573 | 3.459544 |
| Gear20 | 0.054374 | 0.153845 | 0.353432 | 0.723767 | 1.055879 |
| Gear23 | -0.52192 | 0.063121 | -8.26853 | 1.41E-16 | 0.593379 |
| Gear80 | 0.104458 | 0.35978 | 0.29034 | 0.771558 | 1.110109 |
| CaptainCode105 | -0.04366 | 0.039708 | -1.09952 | 0.271549 | 0.957279 |
| CaptainCode108 | 0.113008 | 0.069504 | 1.625921 | 0.103977 | 1.119641 |
| CaptainCode128 | 0.00084 | 0.037787 | 0.022223 | 0.98227 | 1.00084 |
| CaptainCode133 | 0.249058 | 0.032229 | 7.727815 | 1.13E-14 | 1.282816 |
| CaptainCode145 | 0.146246 | 0.101071 | 1.446962 | 0.147918 | 1.157481 |
| CaptainCode148 | -0.12156 | 0.155649 | -0.78098 | 0.434822 | 0.885539 |
| Table C.12 continued. |  |  |  |  |  |
| CaptainCode160 | -0.00948 | 0.028821 | -0.32896 | 0.742188 | 0.990564 |
| CaptainCode161 | 0.234023 | 0.053343 | 4.387109 | 1.15E-05 | 1.263674 |
| CaptainCode182 | -0.22333 | 0.113531 | -1.96712 | 0.049179 | 0.799852 |
| CaptainCode188 | -0.32145 | 0.107418 | -2.99256 | 0.002769 | 0.725093 |
| CaptainCode204 | -0.2095 | 0.06522 | -3.21228 | 0.001318 | 0.810986 |
| CaptainCode208 | 0.219236 | 0.092463 | 2.371064 | 0.017744 | 1.245125 |
| CaptainCode210 | -0.04934 | 0.032972 | -1.49649 | 0.134536 | 0.951856 |
| CaptainCode213 | 0.312407 | 0.031789 | 9.827608 | 9.30E-23 | 1.366711 |
| CaptainCode219 | 0.24228 | 0.029328 | 8.261044 | 1.51E-16 | 1.274151 |
| CaptainCode232 | 0.290674 | 0.042163 | 6.894074 | 5.53E-12 | 1.337328 |
| CaptainCode233 | 0.12816 | 0.08105 | 1.581244 | 0.113833 | 1.136735 |
| CaptainCode240 | -0.80506 | 0.169833 | -4.74031 | 2.14E-06 | 0.447061 |
| CaptainCode247 | -0.05028 | 0.024985 | -2.0125 | 0.044177 | 0.950961 |
| CaptainCode271 | -0.38869 | 0.055145 | -7.04848 | 1.85E-12 | 0.677947 |
| CaptainCode272 | 0.155966 | 0.031972 | 4.878188 | 1.08E-06 | 1.168786 |
| CaptainCode276 | 0.039649 | 0.049145 | 0.806771 | 0.419805 | 1.040445 |
| CaptainCode281 | 0.082119 | 0.069205 | 1.186613 | 0.23539 | 1.085586 |
| CaptainCode287 | -0.22492 | 0.072097 | -3.11969 | 0.001812 | 0.798579 |
| CaptainCode291 | -0.25829 | 0.075189 | -3.4352 | 0.000593 | 0.772372 |
| CaptainCode300 | -0.38629 | 0.069445 | -5.56253 | 2.68E-08 | 0.679575 |
| CaptainCode302 | 0.108539 | 0.028001 | 3.876297 | 0.000106 | 1.114648 |
| CaptainCode304 | 0.119322 | 0.291444 | 0.409416 | 0.682237 | 1.126732 |
| CaptainCode315 | 0.367788 | 0.214002 | 1.71862 | 0.085694 | 1.444536 |
| CaptainCode322 | -0.04889 | 0.046667 | -1.04762 | 0.294822 | 0.952286 |
| CaptainCode326 | -0.23829 | 0.051794 | -4.60067 | 4.23E-06 | 0.787977 |
| CaptainCode328 | -0.06567 | 0.168428 | -0.38989 | 0.696619 | 0.936441 |
| CaptainCode353 | 0.081516 | 0.080423 | 1.013585 | 0.310789 | 1.08493 |
| CaptainCode358 | -0.52708 | 0.220158 | -2.39409 | 0.016668 | 0.590327 |
| CaptainCode359 | 0.194636 | 0.502535 | 0.387309 | 0.69853 | 1.214869 |
| CaptainCode384 | 0.290682 | 0.029604 | 9.819169 | 1.01E-22 | 1.337339 |
| CaptainCode388 | -0.41381 | 0.116926 | -3.53909 | 0.000402 | 0.661126 |
| CaptainCode389 | -0.10476 | 0.040329 | -2.59763 | 0.009392 | 0.900542 |
| CaptainCode390 | 0.644109 | 0.042815 | 15.04417 | 5.91E-51 | 1.90429 |
| CaptainCode392 | -0.15017 | 0.049817 | -3.01435 | 0.002578 | 0.860565 |
| PotSampMonth2 | -0.04834 | 0.214118 | -0.22578 | 0.821378 | 0.952807 |
| PotSampMonth3 | 0.251782 | 0.14595 | 1.725126 | 0.084516 | 1.286315 |
| PotSampMonth4 | 0.06902 | 0.148108 | 0.466008 | 0.641214 | 1.071457 |
| PotSampMonth5 | 0.197232 | 0.144827 | 1.361839 | 0.173259 | 1.218026 |
| PotSampMonth6 | 0.172703 | 0.143324 | 1.204987 | 0.228218 | 1.188513 |
| PotSampMonth7 | 0.10448 | 0.142796 | 0.731674 | 0.464374 | 1.110133 |
| PotSampMonth8 | 0.741089 | 0.140364 | 5.279764 | 1.30E-07 | 2.09822 |
| PotSampMonth9 | 0.611713 | 0.139722 | 4.378068 | 1.20E-05 | 1.843587 |
| PotSampMonth10 | 0.483571 | 0.140065 | 3.452474 | 0.000556 | 1.621856 |
| PotSampMonth11 | 0.373659 | 0.14101 | 2.649874 | 0.008057 | 1.453042 |
| PotSampMonth12 | 0.29241 | 0.143869 | 2.03248 | 0.042114 | 1.339652 |

Table C.13. Parameter estimates for the lognormal GLM fit. Trimmed EAG observer data for 2005/06–2010/11 were used. The parameter values in the last column are in normal space.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | Estimate | Std. Error | t value | Pr(>|t|) | Exp(Estimate) |
| (Intercept) | 2.892074 | 0.444356 | 6.508465 | 8.51E-11 | 18.03067 |
| FMPYear2006 | -0.19956 | 0.041807 | -4.7734 | 1.87E-06 | 0.819091 |
| FMPYear2007 | -0.02428 | 0.048668 | -0.49881 | 0.617939 | 0.976016 |
| FMPYear2008 | -0.08259 | 0.048717 | -1.69522 | 0.090109 | 0.920732 |
| FMPYear2009 | -0.29303 | 0.05714 | -5.12831 | 3.06E-07 | 0.745997 |
| FMPYear2010 | -0.30249 | 0.054284 | -5.57238 | 2.67E-08 | 0.738974 |
| ns(SoakDays, df = 8)1 | 0.331007 | 0.085762 | 3.859587 | 0.000115 | 1.39237 |
| ns(SoakDays, df = 8)2 | 0.255784 | 0.097128 | 2.633474 | 0.008483 | 1.291474 |
| ns(SoakDays, df = 8)3 | 0.271196 | 0.091786 | 2.95466 | 0.003148 | 1.311532 |
| ns(SoakDays, df = 8)4 | 0.326479 | 0.09369 | 3.48466 | 0.000498 | 1.386079 |
| ns(SoakDays, df = 8)5 | 0.414639 | 0.096121 | 4.313714 | 1.64E-05 | 1.513824 |
| ns(SoakDays, df = 8)6 | 0.219674 | 0.092276 | 2.380629 | 0.017329 | 1.245671 |
| ns(SoakDays, df = 8)7 | 0.332052 | 0.174283 | 1.905252 | 0.056817 | 1.393825 |
| ns(SoakDays, df = 8)8 | 0.431744 | 0.108659 | 3.973382 | 7.21E-05 | 1.539941 |
| CaptainCode112 | 0.477117 | 0.092822 | 5.140108 | 2.87E-07 | 1.611422 |
| CaptainCode133 | 0.333466 | 0.051725 | 6.446845 | 1.27E-10 | 1.395797 |
| CaptainCode145 | -0.04686 | 0.155793 | -0.30079 | 0.763591 | 0.95422 |
| CaptainCode160 | 0.183608 | 0.047525 | 3.863392 | 0.000114 | 1.201545 |
| CaptainCode215 | -0.09599 | 0.078812 | -1.21793 | 0.223321 | 0.908476 |
| CaptainCode219 | 0.248512 | 0.038645 | 6.430554 | 1.42E-10 | 1.282116 |
| CaptainCode353 | -0.32218 | 0.072768 | -4.42751 | 9.78E-06 | 0.724568 |
| CaptainCode384 | 0.18138 | 0.056744 | 3.196457 | 0.001402 | 1.19887 |
| Gear6 | 0.150621 | 0.034344 | 4.38568 | 1.19E-05 | 1.162556 |
| Gear7 | 0.284833 | 0.045013 | 6.327801 | 2.75E-10 | 1.32954 |
| Gear8 | 0.943718 | 0.496974 | 1.898928 | 0.057644 | 2.569518 |
| Gear9 | 0.031031 | 0.038806 | 0.79964 | 0.423966 | 1.031517 |
| Gear10 | 0.097338 | 0.038811 | 2.508028 | 0.012179 | 1.102233 |
| PotSampMonth2 | -0.04377 | 0.441777 | -0.09907 | 0.92109 | 0.957178 |
| PotSampMonth3 | 0.491344 | 0.521446 | 0.942271 | 0.34611 | 1.634511 |
| PotSampMonth8 | -0.35594 | 0.443611 | -0.80237 | 0.422387 | 0.700515 |
| PotSampMonth9 | -0.05764 | 0.434779 | -0.13257 | 0.894539 | 0.94399 |
| PotSampMonth10 | -0.10618 | 0.433522 | -0.24491 | 0.806536 | 0.899267 |
| PotSampMonth11 | -0.25214 | 0.433577 | -0.58153 | 0.560916 | 0.777138 |
| PotSampMonth12 | -0.35444 | 0.438066 | -0.80911 | 0.418497 | 0.701563 |

Table C.14. Parameter estimates for the lognormal GLM fit. WAG observer data for 1995/96–2004/05 were used. The parameter values in the last column are in normal space.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | Estimate | Std. Error | t value | Pr(>|t|) | Exp(Estimate) |
| (Intercept) | 1.396927 | 0.190067 | 7.349671 | 2.04E-13 | 4.042758 |
| FMPYear1996 | -0.12765 | 0.031303 | -4.07796 | 4.56E-05 | 0.880159 |
| FMPYear1997 | -0.15839 | 0.034501 | -4.59075 | 4.44E-06 | 0.85352 |
| FMPYear1998 | -0.04995 | 0.038021 | -1.31384 | 0.18891 | 0.951274 |
| FMPYear1999 | -0.25066 | 0.036367 | -6.89233 | 5.61E-12 | 0.77829 |
| FMPYear2000 | -0.2428 | 0.03621 | -6.70519 | 2.05E-11 | 0.78443 |
| FMPYear2001 | -0.2811 | 0.038315 | -7.3366 | 2.25E-13 | 0.754951 |
| FMPYear2002 | -0.19517 | 0.039855 | -4.89689 | 9.79E-07 | 0.822697 |
| FMPYear2003 | -0.01221 | 0.04008 | -0.30473 | 0.760573 | 0.987861 |
| FMPYear2004 | 0.04639 | 0.039988 | 1.160095 | 0.246021 | 1.047483 |
| ns(SoakDays, df = 8)1 | 0.111317 | 0.042993 | 2.589185 | 0.009626 | 1.117749 |
| ns(SoakDays, df = 8)2 | 0.213439 | 0.049082 | 4.348625 | 1.38E-05 | 1.237928 |
| ns(SoakDays, df = 8)3 | 0.432982 | 0.048153 | 8.991836 | 2.59E-19 | 1.541848 |
| ns(SoakDays, df = 8)4 | 0.438766 | 0.042928 | 10.22091 | 1.77E-24 | 1.550793 |
| ns(SoakDays, df = 8)5 | 0.548758 | 0.040664 | 13.49497 | 2.29E-41 | 1.731102 |
| ns(SoakDays, df = 8)6 | 0.54508 | 0.047012 | 11.59459 | 5.21E-31 | 1.724746 |
| ns(SoakDays, df = 8)7 | 0.617519 | 0.070114 | 8.807316 | 1.36E-18 | 1.854321 |
| ns(SoakDays, df = 8)8 | 0.644128 | 0.052651 | 12.23381 | 2.54E-34 | 1.904325 |
| CaptainCode108 | -0.42439 | 0.075813 | -5.59794 | 2.19E-08 | 0.654166 |
| CaptainCode112 | -0.79139 | 0.131041 | -6.03925 | 1.57E-09 | 0.453214 |
| CaptainCode113 | -0.18864 | 0.104271 | -1.8091 | 0.070447 | 0.828087 |
| CaptainCode114 | -0.27008 | 0.074422 | -3.62909 | 0.000285 | 0.763316 |
| CaptainCode128 | -0.49522 | 0.045346 | -10.9209 | 1.05E-27 | 0.609434 |
| CaptainCode130 | 0.240288 | 0.039013 | 6.159252 | 7.41E-10 | 1.271616 |
| CaptainCode131 | 0.159571 | 0.05579 | 2.860212 | 0.004237 | 1.173007 |
| CaptainCode133 | -0.46038 | 0.05785 | -7.95807 | 1.82E-15 | 0.631046 |
| CaptainCode145 | -0.18813 | 0.040967 | -4.59216 | 4.41E-06 | 0.82851 |
| CaptainCode146 | 0.030175 | 0.059649 | 0.505877 | 0.612947 | 1.030635 |
| CaptainCode157 | -0.20474 | 0.050651 | -4.0422 | 5.31E-05 | 0.814858 |
| CaptainCode159 | -0.13764 | 0.247697 | -0.5557 | 0.578424 | 0.871409 |
| CaptainCode160 | -0.20777 | 0.04167 | -4.98609 | 6.20E-07 | 0.812394 |
| CaptainCode166 | 0.009827 | 0.042033 | 0.233797 | 0.815145 | 1.009876 |
| CaptainCode176 | -0.10694 | 0.083572 | -1.2796 | 0.200696 | 0.898581 |
| CaptainCode182 | -0.33489 | 0.097427 | -3.43732 | 0.000588 | 0.715419 |
| CaptainCode188 | -0.35913 | 0.075249 | -4.77252 | 1.83E-06 | 0.698286 |
| CaptainCode210 | -0.22166 | 0.112498 | -1.97031 | 0.048813 | 0.801191 |
| CaptainCode213 | 0.057497 | 0.098728 | 0.582382 | 0.560314 | 1.059183 |
| CaptainCode219 | -0.12903 | 0.040609 | -3.1774 | 0.001488 | 0.878947 |
| CaptainCode230 | -0.79959 | 0.065362 | -12.2333 | 2.55E-34 | 0.449513 |
| CaptainCode232 | -0.41375 | 0.200312 | -2.06555 | 0.038881 | 0.661163 |
| Table C.14 continued. |  |  |  |  |  |
| CaptainCode234 | -0.17518 | 0.077239 | -2.26807 | 0.023333 | 0.839303 |
| CaptainCode235 | -0.3063 | 0.07055 | -4.34159 | 1.42E-05 | 0.736167 |
| CaptainCode244 | -0.34951 | 0.089315 | -3.91322 | 9.13E-05 | 0.705034 |
| CaptainCode257 | 0.129655 | 0.055903 | 2.319297 | 0.020386 | 1.138435 |
| CaptainCode271 | -0.6332 | 0.108504 | -5.83572 | 5.42E-09 | 0.530891 |
| CaptainCode272 | -0.38222 | 0.061299 | -6.23524 | 4.58E-10 | 0.682348 |
| CaptainCode277 | -0.27118 | 0.06871 | -3.94667 | 7.94E-05 | 0.762482 |
| CaptainCode287 | -0.27245 | 0.067011 | -4.06582 | 4.80E-05 | 0.761509 |
| CaptainCode302 | -0.35368 | 0.070174 | -5.04009 | 4.68E-07 | 0.702098 |
| CaptainCode304 | -0.48076 | 0.062863 | -7.64769 | 2.12E-14 | 0.618316 |
| CaptainCode308 | -0.06773 | 0.053604 | -1.26348 | 0.206427 | 0.934515 |
| CaptainCode315 | -0.59392 | 0.076769 | -7.73643 | 1.06E-14 | 0.552159 |
| CaptainCode318 | -0.59709 | 0.072187 | -8.27147 | 1.38E-16 | 0.55041 |
| CaptainCode322 | -0.83517 | 0.213341 | -3.91472 | 9.07E-05 | 0.433801 |
| CaptainCode326 | -0.28234 | 0.045645 | -6.18564 | 6.28E-10 | 0.754014 |
| CaptainCode328 | -0.57598 | 0.146711 | -3.92596 | 8.66E-05 | 0.562154 |
| CaptainCode332 | -0.55586 | 0.154371 | -3.60081 | 0.000318 | 0.573578 |
| CaptainCode335 | -0.48571 | 0.154626 | -3.14117 | 0.001685 | 0.615263 |
| CaptainCode336 | 0.05181 | 0.046293 | 1.119179 | 0.263074 | 1.053176 |
| CaptainCode359 | -0.28909 | 0.069056 | -4.18636 | 2.84E-05 | 0.748943 |
| CaptainCode369 | -0.49536 | 0.10068 | -4.92017 | 8.70E-07 | 0.60935 |
| CaptainCode384 | -0.38852 | 0.068437 | -5.67704 | 1.38E-08 | 0.678059 |
| CaptainCode387 | -0.63145 | 0.107528 | -5.87242 | 4.35E-09 | 0.53182 |
| CaptainCode389 | -0.33181 | 0.060291 | -5.50344 | 3.76E-08 | 0.717624 |
| CaptainCode390 | -0.20501 | 0.086331 | -2.3747 | 0.01757 | 0.814638 |
| CaptainCode392 | -1.06599 | 0.278618 | -3.826 | 0.000131 | 0.344386 |
| CaptainCode394 | -0.0475 | 0.070475 | -0.67404 | 0.500289 | 0.953607 |
| Gear3 | -0.37365 | 0.191896 | -1.94713 | 0.05153 | 0.688221 |
| Gear4 | 0.300787 | 0.496395 | 0.605942 | 0.544559 | 1.350921 |
| Gear5 | 0.247363 | 0.185088 | 1.336463 | 0.181409 | 1.280644 |
| Gear6 | 0.286328 | 0.184117 | 1.55514 | 0.119925 | 1.331529 |
| Gear7 | 0.314143 | 0.183755 | 1.709574 | 0.087356 | 1.369086 |
| Gear8 | 0.168426 | 0.189111 | 0.890623 | 0.37314 | 1.183441 |
| Gear9 | 0.304463 | 0.187229 | 1.626156 | 0.103928 | 1.355897 |
| Gear10 | 0.382989 | 0.183352 | 2.088818 | 0.036734 | 1.466662 |
| Gear11 | 0.48172 | 0.251589 | 1.914712 | 0.05554 | 1.618856 |
| Gear12 | -0.30335 | 0.187086 | -1.62145 | 0.104932 | 0.738339 |
| Gear13 | 0.59903 | 0.191889 | 3.121747 | 0.0018 | 1.820353 |
| Gear20 | 0.289621 | 0.28376 | 1.020654 | 0.307428 | 1.335921 |
| Gear23 | -0.48131 | 0.193835 | -2.48312 | 0.01303 | 0.617971 |
| Gear80 | 0.909787 | 0.934302 | 0.97376 | 0.330184 | 2.483793 |

Table C.15. Parameter estimates for the lognormal GLM fit. Trimmed WAG observer data for 2005/06–2010/11 were used. The parameter values in the last column are in normal space.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | Estimate | Std. Error | t value | Pr(>|t|) | Exp(Estimate) |
| (Intercept) | 1.018982 | 0.517257 | 1.969974 | 0.048895 | 2.770374 |
| FMPYear2006 | -0.11154 | 0.047233 | -2.36141 | 0.018243 | 0.894459 |
| FMPYear2007 | -0.16812 | 0.053412 | -3.14762 | 0.001655 | 0.845253 |
| FMPYear2008 | 0.043794 | 0.042094 | 1.040372 | 0.298216 | 1.044767 |
| FMPYear2009 | 0.005884 | 0.042997 | 0.136837 | 0.891165 | 1.005901 |
| FMPYear2010 | -0.07938 | 0.045047 | -1.76216 | 0.078101 | 0.923689 |
| ns(SoakDays, df = 8)1 | 0.351592 | 0.085672 | 4.103924 | 4.13E-05 | 1.421328 |
| ns(SoakDays, df = 8)2 | 0.067497 | 0.097584 | 0.691679 | 0.489171 | 1.069827 |
| ns(SoakDays, df = 8)3 | 0.231995 | 0.089577 | 2.589894 | 0.009628 | 1.261114 |
| ns(SoakDays, df = 8)4 | 0.342895 | 0.107069 | 3.202569 | 0.00137 | 1.409021 |
| ns(SoakDays, df = 8)5 | -0.01345 | 0.108116 | -0.12436 | 0.901031 | 0.986644 |
| ns(SoakDays, df = 8)6 | 0.504855 | 0.085732 | 5.888766 | 4.14E-09 | 1.656745 |
| ns(SoakDays, df = 8)7 | 0.108075 | 0.175382 | 0.616224 | 0.537774 | 1.114131 |
| ns(SoakDays, df = 8)8 | 0.047592 | 0.086373 | 0.551009 | 0.581651 | 1.048743 |
| CaptainCode104 | 0.160733 | 0.211964 | 0.758304 | 0.448304 | 1.174372 |
| CaptainCode131 | 0.116482 | 0.198551 | 0.586661 | 0.557457 | 1.123538 |
| CaptainCode133 | 0.224929 | 0.199771 | 1.125938 | 0.260245 | 1.252234 |
| CaptainCode145 | 0.556053 | 0.193638 | 2.871617 | 0.004101 | 1.743777 |
| CaptainCode166 | 0.388809 | 0.194875 | 1.995176 | 0.046076 | 1.475223 |
| CaptainCode257 | 0.446013 | 0.201298 | 2.215684 | 0.026757 | 1.562072 |
| CaptainCode336 | 0.340469 | 0.20048 | 1.698269 | 0.089518 | 1.405607 |
| CaptainCode384 | 0.232033 | 0.201142 | 1.15358 | 0.248726 | 1.261161 |
| AreaGP76 | 1.047835 | 0.476189 | 2.200462 | 0.027819 | 2.851471 |
| AreaGP78 | 1.304807 | 0.474791 | 2.748173 | 0.006014 | 3.686977 |
| AreaGP80 | 1.420243 | 0.475884 | 2.984433 | 0.002854 | 4.138127 |
| AreaGP82 | 1.482946 | 0.477296 | 3.106972 | 0.0019 | 4.405906 |
| AreaGP84 | 1.544903 | 0.477214 | 3.237336 | 0.001214 | 4.687517 |
| AreaGP87 | 1.167703 | 0.527029 | 2.215633 | 0.02676 | 3.214599 |

Table C.16. Parameter estimates for the Negative binomial GLM fit. EAG observer data for 1995/96–2004/05 were used. The parameter values in the last column are in normal space.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Parameter | Estimate | Std. Error | t value | Pr(>|t|) | Exp(Estimate) | |
| (Intercept) | 1.218103 | 0.163677 | 7.442128 | 1.02E-13 | 3.380768 |  |
| FMPYear1996 | -0.05218 | 0.033193 | -1.57211 | 0.115935 | 0.949156 |  |
| FMPYear1997 | -0.08305 | 0.036136 | -2.2983 | 0.021551 | 0.920303 |  |
| FMPYear1998 | 0.053119 | 0.035043 | 1.515817 | 0.129576 | 1.054555 |  |
| FMPYear1999 | -0.01626 | 0.035655 | -0.45615 | 0.648287 | 0.983868 |  |
| FMPYear2000 | -0.10386 | 0.035479 | -2.92746 | 0.00342 | 0.901348 |  |
| FMPYear2001 | 0.119393 | 0.037902 | 3.150014 | 0.001634 | 1.126812 |  |
| FMPYear2002 | 0.163406 | 0.041198 | 3.966337 | 7.31E-05 | 1.177515 |  |
| FMPYear2003 | 0.042082 | 0.040561 | 1.037497 | 0.299512 | 1.04298 |  |
| FMPYear2004 | 0.476019 | 0.04621 | 10.30111 | 7.62E-25 | 1.609654 |  |
| ns(SoakDays, df = 8)1 | -0.92745 | 0.083618 | -11.0915 | 1.56E-28 | 0.39556 |  |
| ns(SoakDays, df = 8)2 | 0.32087 | 0.606353 | 0.529181 | 0.596684 | 1.378327 |  |
| ns(SoakDays, df = 8)3 | 0.021615 | 0.605472 | 0.035699 | 0.971523 | 1.02185 |  |
| ns(SoakDays, df = 8)4 | 0.344998 | 0.275375 | 1.252831 | 0.210276 | 1.411987 |  |
| ns(SoakDays, df = 8)5 | 0.374938 | 0.063913 | 5.866342 | 4.50E-09 | 1.454902 |  |
| ns(SoakDays, df = 8)6 | -0.00104 | 0.071884 | -0.01443 | 0.988488 | 0.998963 |  |
| ns(SoakDays, df = 8)7 | 1.497533 | 0.102436 | 14.6192 | 3.04E-48 | 4.470645 |  |
| Gear3 | -0.30062 | 0.084467 | -3.55908 | 0.000373 | 0.740357 |  |
| Gear4 | -0.28551 | 0.358091 | -0.79731 | 0.425277 | 0.751631 |  |
| Gear5 | 0.163484 | 0.061863 | 2.6427 | 0.008229 | 1.177607 |  |
| Gear6 | 0.15916 | 0.062817 | 2.533721 | 0.011291 | 1.172526 |  |
| Gear7 | 0.133788 | 0.062235 | 2.149701 | 0.031586 | 1.14315 |  |
| Gear8 | 0.389156 | 0.116065 | 3.35292 | 0.000801 | 1.475734 |  |
| Gear9 | 0.190411 | 0.063342 | 3.006071 | 0.002649 | 1.209747 |  |
| Gear10 | 0.183871 | 0.062434 | 2.94503 | 0.003232 | 1.201861 |  |
| Gear11 | -0.03672 | 0.146091 | -0.25132 | 0.801568 | 0.96395 |  |
| Gear12 | -0.83203 | 0.063697 | -13.0623 | 6.80E-39 | 0.435164 |  |
| Gear13 | 1.043902 | 0.626813 | 1.665412 | 0.09584 | 2.840279 |  |
| Gear20 | 0.09901 | 0.15886 | 0.623256 | 0.533121 | 1.104078 |  |
| Gear23 | -0.74972 | 0.064144 | -11.6879 | 1.70E-31 | 0.472501 |  |
| Gear80 | -1.09012 | 0.256145 | -4.25586 | 2.09E-05 | 0.336177 |  |
| CaptainCode105 | -0.05226 | 0.041318 | -1.26486 | 0.205929 | 0.949081 |  |
| CaptainCode108 | 0.084454 | 0.071129 | 1.187343 | 0.235101 | 1.088123 |  |
| CaptainCode128 | -0.04062 | 0.038866 | -1.04503 | 0.296019 | 0.960198 |  |
| CaptainCode133 | 0.210189 | 0.032726 | 6.422742 | 1.36E-10 | 1.233911 |  |
| CaptainCode145 | 0.075394 | 0.102553 | 0.735172 | 0.46224 | 1.078309 |  |
| CaptainCode148 | -0.40404 | 0.15941 | -2.53459 | 0.011263 | 0.667618 |  |
| CaptainCode160 | 0.034106 | 0.029251 | 1.16599 | 0.243627 | 1.034694 |  |
| CaptainCode161 | 0.364667 | 0.057023 | 6.395142 | 1.63E-10 | 1.440035 |  |
| CaptainCode182 | -0.2484 | 0.115687 | -2.14714 | 0.031789 | 0.78005 |  |
| Table C.16 continued. |  |  |  |  |  |  |
| CaptainCode188 | -0.22857 | 0.114694 | -1.99288 | 0.046283 | 0.795669 |  |
| CaptainCode204 | -0.44783 | 0.071556 | -6.25845 | 3.94E-10 | 0.639015 |  |
| CaptainCode208 | 0.196197 | 0.097095 | 2.020672 | 0.043322 | 1.216767 |  |
| CaptainCode210 | -0.08569 | 0.034848 | -2.45884 | 0.013944 | 0.917882 |  |
| CaptainCode213 | 0.293384 | 0.032284 | 9.087551 | 1.07E-19 | 1.340958 |  |
| CaptainCode219 | 0.257328 | 0.030229 | 8.512563 | 1.77E-17 | 1.293469 |  |
| CaptainCode232 | 0.43029 | 0.045488 | 9.45947 | 3.30E-21 | 1.537704 |  |
| CaptainCode233 | 0.0819 | 0.087692 | 0.933951 | 0.350336 | 1.085347 |  |
| CaptainCode240 | -0.90745 | 0.164196 | -5.52666 | 3.29E-08 | 0.403551 |  |
| CaptainCode247 | -0.06715 | 0.025567 | -2.62643 | 0.008633 | 0.935055 |  |
| CaptainCode271 | -0.54292 | 0.054171 | -10.0224 | 1.32E-23 | 0.581047 |  |
| CaptainCode272 | 0.11137 | 0.032591 | 3.417174 | 0.000634 | 1.117809 |  |
| CaptainCode276 | 0.003705 | 0.049443 | 0.074925 | 0.940275 | 1.003711 |  |
| CaptainCode281 | 0.082045 | 0.070939 | 1.156542 | 0.247468 | 1.085504 |  |
| CaptainCode287 | -0.38352 | 0.073807 | -5.19621 | 2.05E-07 | 0.681461 |  |
| CaptainCode291 | -0.40125 | 0.079719 | -5.03331 | 4.85E-07 | 0.669484 |  |
| CaptainCode300 | -0.45939 | 0.071612 | -6.41502 | 1.43E-10 | 0.631668 |  |
| CaptainCode302 | 0.216957 | 0.028614 | 7.58209 | 3.49E-14 | 1.242291 |  |
| CaptainCode304 | 0.152168 | 0.308814 | 0.492749 | 0.622194 | 1.164355 |  |
| CaptainCode315 | 0.438529 | 0.214104 | 2.048211 | 0.040547 | 1.550425 |  |
| CaptainCode322 | -0.00281 | 0.045221 | -0.06205 | 0.950523 | 0.997198 |  |
| CaptainCode326 | -0.24619 | 0.053623 | -4.59119 | 4.42E-06 | 0.781771 |  |
| CaptainCode328 | -0.10663 | 0.167112 | -0.63809 | 0.523421 | 0.898856 |  |
| CaptainCode353 | 0.055683 | 0.080072 | 0.695412 | 0.486802 | 1.057262 |  |
| CaptainCode358 | -0.81782 | 0.225187 | -3.63172 | 0.000282 | 0.441394 |  |
| CaptainCode359 | -0.21614 | 0.522002 | -0.41406 | 0.67883 | 0.805621 |  |
| CaptainCode384 | 0.264878 | 0.029906 | 8.857113 | 8.63E-19 | 1.303271 |  |
| CaptainCode388 | -0.72308 | 0.116234 | -6.22094 | 5.00E-10 | 0.485254 |  |
| CaptainCode389 | -0.15865 | 0.041408 | -3.83145 | 0.000128 | 0.853293 |  |
| CaptainCode390 | 0.671935 | 0.04266 | 15.75112 | 1.09E-55 | 1.958023 |  |
| CaptainCode392 | -0.21474 | 0.051615 | -4.16039 | 3.19E-05 | 0.806754 |  |
| PotSampMonth2 | -0.19054 | 0.220475 | -0.86425 | 0.387458 | 0.826509 |  |
| PotSampMonth3 | 0.218775 | 0.158377 | 1.381354 | 0.16718 | 1.244551 |  |
| PotSampMonth4 | 4.50E-05 | 0.161484 | 0.000279 | 0.999778 | 1.000045 |  |
| PotSampMonth5 | 0.158691 | 0.15782 | 1.005515 | 0.314657 | 1.171975 |  |
| PotSampMonth6 | 0.148826 | 0.156259 | 0.952432 | 0.340885 | 1.160471 |  |
| PotSampMonth7 | 0.036972 | 0.155527 | 0.237723 | 0.812098 | 1.037664 |  |
| PotSampMonth8 | 0.845602 | 0.152621 | 5.540532 | 3.04E-08 | 2.32938 |  |
| PotSampMonth9 | 0.681285 | 0.152033 | 4.481159 | 7.45E-06 | 1.976415 |  |
| PotSampMonth10 | 0.527042 | 0.152356 | 3.459282 | 0.000542 | 1.693914 |  |
| PotSampMonth11 | 0.399826 | 0.15333 | 2.607618 | 0.009122 | 1.491565 |  |
| PotSampMonth12 | 0.332321 | 0.156133 | 2.128448 | 0.033308 | 1.3942 |  |

Table C.17. Parameter estimates for the Negative binomial GLM fit. EAG observer data for 2005/06–2010/11 were used. The parameter values in the last column are in normal space.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | Estimate | Std. Error | t value | Pr(>|t|) | Exp(Estimate) |
| (Intercept) | 3.147169 | 0.418581 | 7.518657 | 6.69E-14 | 23.27009 |
| FMPYear2006 | -0.22274 | 0.038586 | -5.77264 | 8.35E-09 | 0.800322 |
| FMPYear2007 | -0.03938 | 0.044951 | -0.87597 | 0.381094 | 0.961389 |
| FMPYear2008 | -0.07934 | 0.044831 | -1.76986 | 0.076822 | 0.923722 |
| FMPYear2009 | -0.28421 | 0.052654 | -5.39773 | 7.11E-08 | 0.752608 |
| FMPYear2010 | -0.25097 | 0.0499 | -5.02936 | 5.12E-07 | 0.778048 |
| ns(SoakDays, df = 8)1 | 0.334072 | 0.079022 | 4.227585 | 2.41E-05 | 1.396643 |
| ns(SoakDays, df = 8)2 | 0.235126 | 0.089604 | 2.62406 | 0.00872 | 1.265068 |
| ns(SoakDays, df = 8)3 | 0.217132 | 0.084403 | 2.572551 | 0.010128 | 1.242508 |
| ns(SoakDays, df = 8)4 | 0.288567 | 0.086407 | 3.339616 | 0.000846 | 1.334513 |
| ns(SoakDays, df = 8)5 | 0.357145 | 0.088628 | 4.029696 | 5.68E-05 | 1.429243 |
| ns(SoakDays, df = 8)6 | 0.273051 | 0.084635 | 3.226211 | 0.001264 | 1.313968 |
| ns(SoakDays, df = 8)7 | 0.253874 | 0.159816 | 1.588535 | 0.112239 | 1.289009 |
| ns(SoakDays, df = 8)8 | 0.325246 | 0.097787 | 3.326077 | 0.000888 | 1.384371 |
| CaptainCode112 | 0.436723 | 0.085132 | 5.12996 | 3.03E-07 | 1.547627 |
| CaptainCode133 | 0.291495 | 0.04779 | 6.099476 | 1.16E-09 | 1.338426 |
| CaptainCode145 | -0.22028 | 0.143642 | -1.53351 | 0.125223 | 0.802296 |
| CaptainCode160 | 0.142226 | 0.043684 | 3.255826 | 0.001139 | 1.152837 |
| CaptainCode215 | -0.09391 | 0.072193 | -1.30081 | 0.193393 | 0.910366 |
| CaptainCode219 | 0.234317 | 0.035914 | 6.524483 | 7.61E-11 | 1.264045 |
| CaptainCode353 | -0.38693 | 0.067143 | -5.76268 | 8.86E-09 | 0.679141 |
| CaptainCode384 | 0.174066 | 0.052489 | 3.316203 | 0.00092 | 1.190134 |
| Gear6 | 0.173306 | 0.031701 | 5.466832 | 4.84E-08 | 1.18923 |
| Gear7 | 0.307127 | 0.041462 | 7.407502 | 1.54E-13 | 1.359514 |
| Gear8 | 0.126328 | 0.346705 | 0.364366 | 0.715603 | 1.134654 |
| Gear9 | 0.046807 | 0.035814 | 1.306954 | 0.191298 | 1.04792 |
| Gear10 | 0.130167 | 0.035798 | 3.636162 | 0.00028 | 1.139019 |
| PotSampMonth2 | -0.05824 | 0.416611 | -0.1398 | 0.888822 | 0.94342 |
| PotSampMonth3 | 0.746144 | 0.489612 | 1.523949 | 0.127595 | 2.108853 |
| PotSampMonth8 | -0.38806 | 0.417621 | -0.92921 | 0.352831 | 0.678373 |
| PotSampMonth9 | -0.11644 | 0.41001 | -0.28398 | 0.776436 | 0.890086 |
| PotSampMonth10 | -0.16693 | 0.408897 | -0.40825 | 0.683108 | 0.846256 |
| PotSampMonth11 | -0.30374 | 0.408941 | -0.74275 | 0.457671 | 0.738051 |
| PotSampMonth12 | -0.38121 | 0.412573 | -0.92398 | 0.355547 | 0.683034 |

Table C.18. Parameter estimates for the Negative binomial GLM fit. WAG observer data for 1995/96–2004/05 were used. The parameter values in the last column are in normal space.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | Estimate | Std. Error | t value | Pr(>|t|) | Exp(Estimate) |
| (Intercept) | 1.59689 | 0.217352 | 7.347032 | 2.07E-13 | 4.937652 |
| FMPYear1996 | -0.19584 | 0.034651 | -5.65186 | 1.60E-08 | 0.822143 |
| FMPYear1997 | -0.19872 | 0.038205 | -5.20142 | 1.99E-07 | 0.819779 |
| FMPYear1998 | -0.08992 | 0.042181 | -2.13177 | 0.033033 | 0.914004 |
| FMPYear1999 | -0.26067 | 0.040527 | -6.43219 | 1.28E-10 | 0.770532 |
| FMPYear2000 | -0.32001 | 0.039996 | -8.00106 | 1.27E-15 | 0.726142 |
| FMPYear2001 | -0.35976 | 0.042306 | -8.50368 | 1.91E-17 | 0.697847 |
| FMPYear2002 | -0.2423 | 0.043901 | -5.51931 | 3.43E-08 | 0.784819 |
| FMPYear2003 | -0.02499 | 0.043967 | -0.56847 | 0.569718 | 0.975316 |
| FMPYear2004 | 0.073062 | 0.043847 | 1.666306 | 0.095662 | 1.075797 |
| ns(SoakDays, df = 8)1 | 0.112837 | 0.049229 | 2.292099 | 0.021906 | 1.119449 |
| ns(SoakDays, df = 8)2 | 0.220748 | 0.055688 | 3.964017 | 7.39E-05 | 1.247009 |
| ns(SoakDays, df = 8)3 | 0.501958 | 0.051504 | 9.745928 | 2.06E-22 | 1.651953 |
| ns(SoakDays, df = 8)4 | 0.531104 | 0.047801 | 11.1107 | 1.25E-28 | 1.700808 |
| ns(SoakDays, df = 8)5 | 0.734678 | 0.045676 | 16.08472 | 5.50E-58 | 2.084811 |
| ns(SoakDays, df = 8)6 | 0.674149 | 0.050146 | 13.44372 | 4.33E-41 | 1.962363 |
| ns(SoakDays, df = 8)7 | 0.791 | 0.075859 | 10.42727 | 2.04E-25 | 2.205601 |
| ns(SoakDays, df = 8)8 | 0.789522 | 0.057285 | 13.78224 | 4.32E-43 | 2.202343 |
| CaptainCode108 | -0.73885 | 0.081027 | -9.11858 | 8.04E-20 | 0.477662 |
| CaptainCode112 | -0.94082 | 0.157151 | -5.98675 | 2.16E-09 | 0.390307 |
| CaptainCode113 | -0.29404 | 0.11575 | -2.54032 | 0.01108 | 0.745244 |
| CaptainCode114 | -0.33378 | 0.082164 | -4.06235 | 4.87E-05 | 0.716212 |
| CaptainCode128 | -0.68521 | 0.049949 | -13.7181 | 1.04E-42 | 0.503985 |
| CaptainCode130 | 0.212448 | 0.043031 | 4.937061 | 7.97E-07 | 1.236702 |
| CaptainCode131 | 0.159496 | 0.06206 | 2.570008 | 0.010174 | 1.17292 |
| CaptainCode133 | -0.59904 | 0.063129 | -9.48921 | 2.48E-21 | 0.549338 |
| CaptainCode145 | -0.18106 | 0.044516 | -4.06722 | 4.77E-05 | 0.834389 |
| CaptainCode146 | 0.034991 | 0.06394 | 0.547259 | 0.584205 | 1.035611 |
| CaptainCode157 | -0.18588 | 0.05722 | -3.24847 | 0.001161 | 0.830376 |
| CaptainCode159 | -0.5964 | 0.264417 | -2.25553 | 0.024107 | 0.550791 |
| CaptainCode160 | -0.30187 | 0.045059 | -6.69952 | 2.13E-11 | 0.739434 |
| CaptainCode166 | -0.05463 | 0.045785 | -1.19312 | 0.232832 | 0.946839 |
| CaptainCode176 | -0.08123 | 0.09274 | -0.8759 | 0.381094 | 0.921981 |
| CaptainCode182 | -0.6833 | 0.105666 | -6.46657 | 1.02E-10 | 0.504949 |
| CaptainCode188 | -0.49727 | 0.083025 | -5.98941 | 2.13E-09 | 0.60819 |
| CaptainCode210 | -0.53145 | 0.120405 | -4.41384 | 1.02E-05 | 0.587753 |
| CaptainCode213 | 0.037241 | 0.110153 | 0.338086 | 0.735301 | 1.037943 |
| CaptainCode219 | -0.18095 | 0.043574 | -4.15268 | 3.29E-05 | 0.834477 |
| CaptainCode230 | -0.94148 | 0.073073 | -12.884 | 6.87E-38 | 0.390049 |
| CaptainCode232 | -0.80007 | 0.245271 | -3.26198 | 0.001108 | 0.449298 |
| Table C.18 Continued. |  |  |  |  |  |
| CaptainCode234 | -0.02394 | 0.089445 | -0.26768 | 0.788949 | 0.976342 |
| CaptainCode235 | -0.29481 | 0.083294 | -3.53945 | 0.000402 | 0.744671 |
| CaptainCode244 | -0.43707 | 0.096459 | -4.53118 | 5.89E-06 | 0.645924 |
| CaptainCode257 | 0.053239 | 0.061559 | 0.864847 | 0.387129 | 1.054681 |
| CaptainCode271 | -1.07143 | 0.118955 | -9.00701 | 2.23E-19 | 0.34252 |
| CaptainCode272 | -0.5673 | 0.068059 | -8.33549 | 8.02E-17 | 0.567052 |
| CaptainCode277 | -0.30384 | 0.077046 | -3.94359 | 8.04E-05 | 0.737982 |
| CaptainCode287 | -0.40408 | 0.077448 | -5.21746 | 1.83E-07 | 0.66759 |
| CaptainCode302 | -0.44937 | 0.079344 | -5.66356 | 1.50E-08 | 0.638029 |
| CaptainCode304 | -0.62722 | 0.070179 | -8.93744 | 4.19E-19 | 0.534075 |
| CaptainCode308 | -0.08199 | 0.058051 | -1.41239 | 0.157844 | 0.921281 |
| CaptainCode315 | -0.8532 | 0.084513 | -10.0955 | 6.28E-24 | 0.426048 |
| CaptainCode318 | -0.88208 | 0.08113 | -10.8724 | 1.74E-27 | 0.413921 |
| CaptainCode322 | -1.55568 | 0.241803 | -6.43367 | 1.26E-10 | 0.211046 |
| CaptainCode326 | -0.35172 | 0.049875 | -7.052 | 1.80E-12 | 0.70348 |
| CaptainCode328 | -0.7469 | 0.165467 | -4.5139 | 6.39E-06 | 0.473832 |
| CaptainCode332 | -0.92528 | 0.174173 | -5.31241 | 1.09E-07 | 0.396421 |
| CaptainCode335 | -0.57568 | 0.180856 | -3.18309 | 0.001458 | 0.562321 |
| CaptainCode336 | 0.052042 | 0.050829 | 1.023857 | 0.30591 | 1.053419 |
| CaptainCode359 | -0.42799 | 0.076819 | -5.57136 | 2.55E-08 | 0.651819 |
| CaptainCode369 | -0.69958 | 0.108627 | -6.44019 | 1.21E-10 | 0.496795 |
| CaptainCode384 | -0.59688 | 0.076766 | -7.77522 | 7.76E-15 | 0.550529 |
| CaptainCode387 | -0.9666 | 0.121707 | -7.94202 | 2.05E-15 | 0.380374 |
| CaptainCode389 | -0.42697 | 0.068941 | -6.19328 | 5.96E-10 | 0.652483 |
| CaptainCode390 | -0.2464 | 0.09398 | -2.6218 | 0.008751 | 0.781613 |
| CaptainCode392 | -1.47791 | 0.333658 | -4.42943 | 9.48E-06 | 0.228113 |
| CaptainCode394 | -0.07989 | 0.078542 | -1.01721 | 0.309063 | 0.923214 |
| Gear3 | -0.63088 | 0.219686 | -2.87172 | 0.004085 | 0.532124 |
| Gear4 | 0.296611 | 0.620877 | 0.477729 | 0.632846 | 1.345292 |
| Gear5 | 0.240684 | 0.211766 | 1.13656 | 0.255731 | 1.27212 |
| Gear6 | 0.270192 | 0.210839 | 1.281508 | 0.200024 | 1.310216 |
| Gear7 | 0.329475 | 0.210464 | 1.565467 | 0.117483 | 1.390237 |
| Gear8 | 0.162046 | 0.215955 | 0.750369 | 0.453038 | 1.175915 |
| Gear9 | 0.323254 | 0.214101 | 1.509819 | 0.131099 | 1.381616 |
| Gear10 | 0.436639 | 0.209969 | 2.079536 | 0.037576 | 1.547497 |
| Gear11 | 0.848411 | 0.280168 | 3.028225 | 0.002462 | 2.335931 |
| Gear12 | -0.67232 | 0.213899 | -3.14319 | 0.001673 | 0.51052 |
| Gear13 | 0.61184 | 0.218912 | 2.794914 | 0.005194 | 1.843821 |
| Gear20 | 0.389056 | 0.319626 | 1.217221 | 0.223529 | 1.475587 |
| Gear23 | -0.96356 | 0.222716 | -4.32641 | 1.52E-05 | 0.381532 |
| Gear80 | 0.386412 | 1.050337 | 0.367894 | 0.712955 | 1.471692 |

Table C.19. Parameter estimates for the Negative binomial GLM fit. WAG observer data for 2005/06–2010/11 were used. The parameter values in the last column are in normal space.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | Estimate | Std. Error | t value | Pr(>|t|) | Exp(Estimate) |
| (Intercept) | 2.782401 | 0.224934 | 12.36988 | 1.06E-34 | 16.15777 |
| FMPYear2006 | -0.09448 | 0.044854 | -2.1064 | 0.035213 | 0.909845 |
| FMPYear2007 | -0.18366 | 0.050846 | -3.61204 | 0.000306 | 0.83222 |
| FMPYear2008 | 0.021105 | 0.040756 | 0.517831 | 0.604596 | 1.021329 |
| FMPYear2009 | 0.012897 | 0.041287 | 0.312384 | 0.75476 | 1.012981 |
| FMPYear2010 | -0.10195 | 0.042883 | -2.37741 | 0.017467 | 0.903075 |
| ns(SoakDays, df = 8)1 | 0.49245 | 0.08262 | 5.960394 | 2.67E-09 | 1.63632 |
| ns(SoakDays, df = 8)2 | 0.182572 | 0.093299 | 1.956847 | 0.050414 | 1.200301 |
| ns(SoakDays, df = 8)3 | 0.439988 | 0.085019 | 5.175203 | 2.35E-07 | 1.552689 |
| ns(SoakDays, df = 8)4 | 0.496361 | 0.101317 | 4.899083 | 9.89E-07 | 1.642732 |
| ns(SoakDays, df = 8)5 | 0.169466 | 0.105618 | 1.604516 | 0.108656 | 1.184672 |
| ns(SoakDays, df = 8)6 | 0.533488 | 0.084686 | 6.299612 | 3.21E-10 | 1.704868 |
| ns(SoakDays, df = 8)7 | 0.483082 | 0.166805 | 2.896094 | 0.003793 | 1.621063 |
| ns(SoakDays, df = 8)8 | 0.051444 | 0.084275 | 0.61043 | 0.541602 | 1.05279 |
| CaptainCode104 | 0.140728 | 0.189637 | 0.742091 | 0.458063 | 1.151112 |
| CaptainCode131 | 0.116178 | 0.177929 | 0.652945 | 0.513818 | 1.123195 |
| CaptainCode133 | 0.228867 | 0.177162 | 1.291853 | 0.19646 | 1.257175 |
| CaptainCode145 | 0.581111 | 0.171784 | 3.38279 | 0.000722 | 1.788023 |
| CaptainCode166 | 0.353586 | 0.1737 | 2.03561 | 0.041836 | 1.424165 |
| CaptainCode257 | 0.364926 | 0.179465 | 2.033407 | 0.042058 | 1.440407 |
| CaptainCode336 | 0.321389 | 0.179846 | 1.787021 | 0.073987 | 1.379042 |
| CaptainCode384 | 0.189354 | 0.180087 | 1.051459 | 0.293092 | 1.208469 |
| ns(Depth, df = 8)1 | -0.19218 | 0.12216 | -1.57315 | 0.115739 | 0.825161 |
| ns(Depth, df = 8)2 | -0.35594 | 0.153222 | -2.32307 | 0.02021 | 0.700511 |
| ns(Depth, df = 8)3 | -0.26504 | 0.140527 | -1.88604 | 0.059341 | 0.767176 |
| ns(Depth, df = 8)4 | -0.45269 | 0.145044 | -3.12102 | 0.001811 | 0.635918 |
| ns(Depth, df = 8)5 | -0.48759 | 0.13956 | -3.49374 | 0.00048 | 0.614107 |
| ns(Depth, df = 8)6 | -0.34577 | 0.106466 | -3.24769 | 0.00117 | 0.707676 |
| ns(Depth, df = 8)7 | -0.59441 | 0.302735 | -1.96346 | 0.049641 | 0.55189 |
| ns(Depth, df = 8)8 | -0.39343 | 0.156378 | -2.51587 | 0.011901 | 0.674742 |

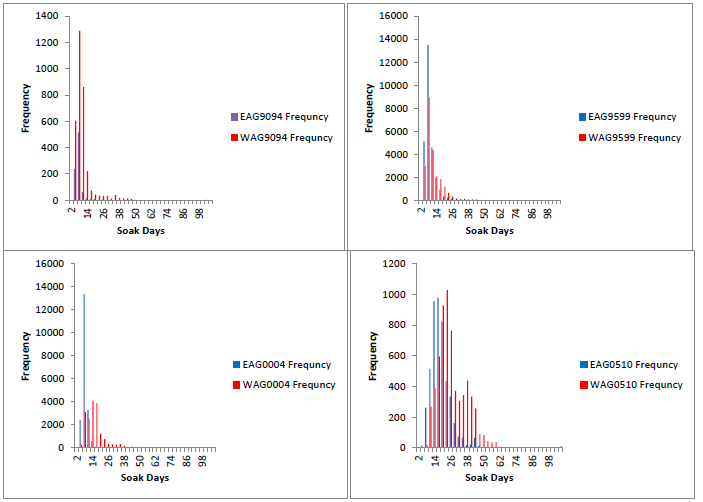


Figure C.1. Histograms of soak times by area (EAG and WAG) for five-year periods. Note that the y-axes are different scales.

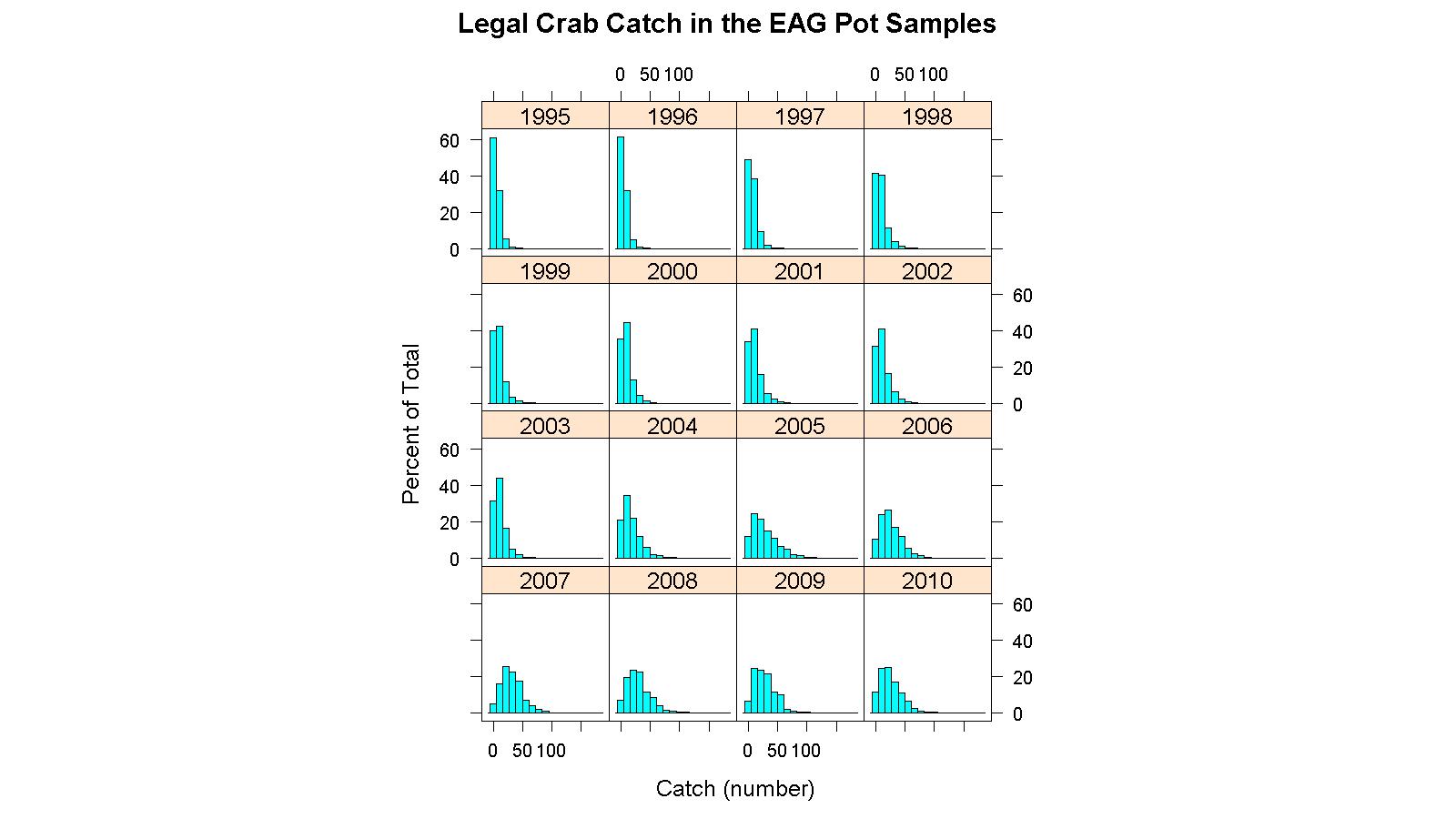


Figure C.2. Frequency distribution of legal crab catch in observer data by year for EAG.

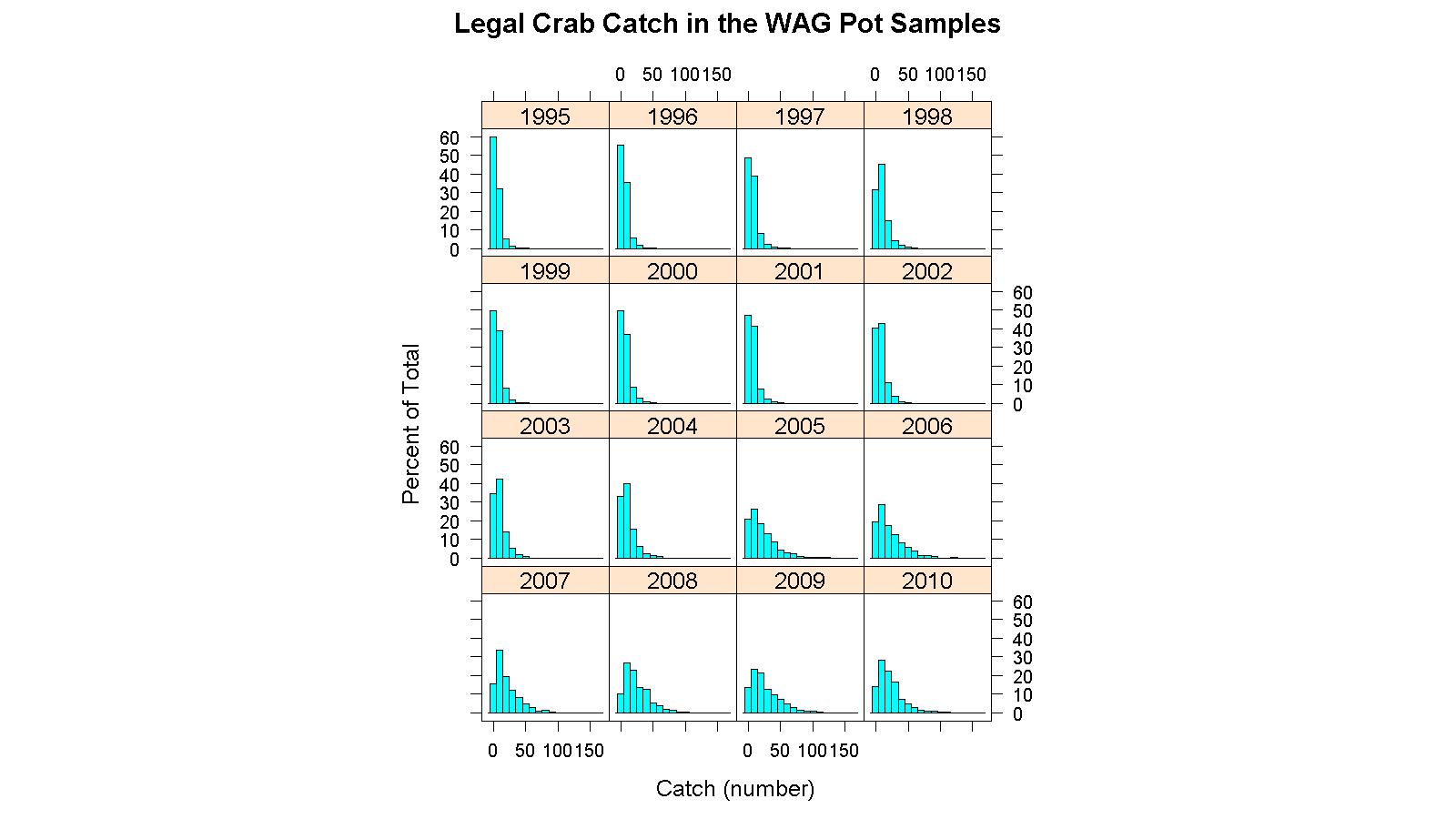


Figure C.3. Frequency distribution of legal crab catch in observer data by year for WAG.