Appendix B: ***Catch and CPUE data***

The commercial catch and length frequency distribution were estimated from ADF&G landing records and dockside sampling (Bowers et al. 2008, 2011). The annual retained catch, total catch, and groundfish (or trawl) discarded mortality are provided in Table 1 for EAG and Table 15 for WAG. The weighted length frequency data were used to distribute the catch into 5-mm size intervals. The length frequency data for a year were weighted by each sampled vessel's catch as follows. The *i*-th length-class frequency was estimated as:

$$\sum_{j=1}^{k} C_j \frac{LF_{j,i}}{\sum_{i=1}^{n} LF_{j,i}} \qquad \text{(B.1)}$$

where k = number of sampled vessels in a year, $LF_{j,i}$ = number of crabs in the *i*-th length-class in the sample from *j*-th vessel, n = number of size classes, C_j = number of crabs caught by *j*-th vessel. Then the relative frequency for the year was calculated and applied to the annual retained catch (in number of crabs) to obtain retained catch by length-class.

The annual total catch (in number of crabs) was estimated by the observer nominal (unstandardized) total CPUE considering all vessels multiplied by the total fishing effort (number of pot lifts). The weighted length frequency of the observer samples across the fleet was estimated using Equation B.1. Observer measurement of crab ranged from 20 to 220 mm CL. To restrict the total number of crabs to the model assumed size range (101–185+ mm CL), the proportion of observer total relative length frequency corresponding to this size range was multiplied by the total catch (number of crabs). This total number of crabs was distributed into length-classes using the weighted relative length frequency. Thus, crab sizes < 101 mm CL were excluded from the model. In addition, all crab >185 mm CL were pooled into a plus length class. Note that the total crab catch by size that went into the model did not consider retained and discard components separately. However, once the model estimated the annual total catch, then retained catch was deducted from this total and multiplied by handling mortality [we used a 20% handling mortality (Siddeek et al. 2005) to obtain the directed fishery discarded (dead) catch].

Observer data have been collected since 1988 (Moore et al. 2000; Barnard et al. 2001; Barnard and Burt 2004; Gaeuman 2011), but data were not comprehensive in the initial years, so a shorter time series of data for the period 1990/91–2014/15 was selected for this analysis. During 1990/91–1994/95, observers were only deployed on catcher-processor vessels. During 1995/96–2004/05, observers were deployed on all fishing vessels during fishing activity. Observers have been deployed on all fishing vessels since 2005/06, but catcher-only vessels are only required to carry observers for a minimum of 50% of their fishing activity during a season; catcher-processor vessels are still required to carry observers during all fishing activity. Onboard observers count and measure all crabs caught and categorize catch as females, sublegal males, retained legal males, and non-retained legal males in a sampled pot. Prior to the 2009/10 season, depending on season, area, and type of fishing vessel, observers were also instructed to sample additional pots in which all crab were only counted and categorized as females, sublegal males, retained legal males, and non-retained legal males, but were not measured. Annual mean nominal CPUEs of retained and total crabs were estimated considering all sampled pots within each season (Tables 2 and 26). For model-fitting following a September 2016 CPT meeting suggestion, the CPUE time series was restricted to 1991/92–2015/16. Length-specific CPUE data collected by observers provides information on a wider size range of the stock than did the commercial catch length frequency data obtained from mostly legal-sized landed males.

There were significant changes in fishing practice due to changes in management regulations (e.g., since 1996/97 constant TAC and since 2005/06 crab rationalization), pot configuration (escape web on the pot door increased to 9” since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two separate observer CPUE time series, 1995/96–2004/05 and 2005/06–2015/16, to estimate CPUE indices for model input. For scenario 3 model, we extended the observer time series to 1991/92.

To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86–1998/99 legal size standardized CPUE as a separate likelihood component in a number of scenarios. Because of the lack of soak time data previous to 1990, we estimated the CPUE index considering a limited set of explanatory variables (e.g., vessel, captain, area, month) and fitting the lognormal GLM to fish ticket data (Tables 3 and 27).

When using CPUE indices in the model fit, we compared the predicted with the observed legal male CPUE in the observer CPUE likelihoods because legal male (retained plus non-retained) data are more reliable than total in the observer samples.

Observer CPUE index:

The CPUE standardization followed the GLM fitting procedure (Maunder and Punt 2004; Starr 2012; Siddeek et al. 2016b). We considered the negative binomial GLM on positive and zero catches to select the explanatory variables. The response variable CPUE is the observer sample catch record for a pot haul. The negative binomial model uses the log link function for the GLM fit. Therefore, we assumed the null model to be

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}} \qquad \text{(B.2)}$$

where Year is a factorial variable.

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

$$\ln(\mathrm{CPUE_I}) = \mathrm{Year_{y_i}} + \mathrm{ns(Soak_{si}, df)} + \mathrm{Month_{m_i}} + \mathrm{Area_{ai}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Gear_{gi}} + \mathrm{ns(Depth_{di}, df)} + \mathrm{ns(VesSoak_{vsi}, df)}\ , \qquad \text{(B.3)}$$

where Soak is in unit of days and is numeric; Month, Area code, Vessel code, Captain code, and Gear code are factorial variables; Depth in fathom is a numeric variable;

VesSoak is a numeric variable computed as annual number of vessels times annual mean soak days (to account for other vessels' effect on CPUE); ns=cubic spline, and df = degree of freedom.

We used a log link function and a dispersion parameter (θ) in the GLM fitting process. We used the R^2 criterion for predictor variable selection (Siddeek *et al*. 2016b).

The R^2 formula for explanatory variable selection is as follows:

$$R^2 = \frac{(null\ model\ deviance - added\ parameter\ model\ deviance)}{null\ model\ deviance} \qquad \text{(B.4)}$$

An arbitrary R^2 minimum increment of 0.01 was set to select the model terms.

First we determined the dispersion parameter (θ) by a grid search method (Fox and Weisberg, 2011). The best θ value was obtained at the minimum AIC:

Table B.1. Dispersion parameter search.

	Time Period	θ	AIC
EAG	1991/92–2004/05	1.33	202,505
	1995/96–2004/05	1.33	198,234
	2005/06–2015/16	2.29	53,444
WAG	1991/92–2004/05	0.96	201,561
	1995/96–2004/05	0.98	189,242
	2005/06–2015/16	1.13	86,201

Then we used the optimized dispersion parameter value in the GLM model for individual predictor variable fit to determine appropriate df value based on the minimum AIC:

Table B.2. Predictor variable degree of freedom search.

	Time Period	Predictor Variable	df	AIC
EAG	1991/92–2004/05	Soak	3	212,364
		Depth	16	213,899
		VesSoak	9	209,795
	1995/96–2004/05	Soak	3	207,312
		Depth	16	208,794
		VesSoak	9	204,269
	2005/06–2015/16	Soak	16	54,093
		Depth	11	54,334
		VesSoak	6	54,102
WAG	1991/92–2004/05	Soak	8	205,932
		Depth	39	209,130
		VesSoak	9	208,622
	1995/96–2004/05	Soak	8	193,547
		Depth	38	196,717
		VesSoak	8	196,063
	2005/06–2015/16	Soak	17	86,648
		Depth	10	86,685
		VesSoak	8	86,416

The final models for EAG were:

For scenario 3:

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 3) \quad \text{(B.5)}$$

for the 1991/92–2004/05 period [θ=1.33, $R^2 = 0.2328$ with ns(Soak, 3) forced in]

For other scenarios:

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 3) \quad \text{(B.6)}$$

for the 1995/96–2004/05 period [θ=1.33, $R^2 = 0.2417$ with ns(Soak, 3) forced in]

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 16) + Gear \quad \text{(B.7)}$$

for the 2005/06–2015/16 period ($\theta = 2.29$, $R^2 = 0.1237$).

The final models for WAG were:

For scenario 3:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 8) + Gear \quad \text{(B.8)}$$

for the 1991/92–2004/05 period [θ=0.96, $R^2 = 0.1721$]

For other scenarios:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 8) \quad \text{(B.9)}$$

for the 1995/96–2004/05 period [θ=0.98, $R^2 = 0.1783$]

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{ns}(\text{Soak}, 17) \quad \text{(B.10)}$$

for the 2005/06–2015/16 period [θ=1.13, $R^2 = 0.0562$ with $\text{ns}(\text{Soak}, 17)$ forced in]

Figures B.1 and B.15 depict the trends in nominal and standardized CPUE indices for the two CPUE time series for EAG and WAG, respectively. Figures B.2-B.5 and B.16-B.19 show the diagnostic plots for the fits for EAG and WAG, respectively. The deviance and QQ plots support good fits to EAG and WAG data by GLM using the negative binomial error distribution. Figures B.6-B.14 and B.20-B.27 depict CDI plots of the predictor variables for EAG and WAG, respectively.

Fish Ticket CPUE index:

We also fitted the lognormal GLM for the fish ticket retained CPUE time series 1985/86–1998/99 offering Year, Month, Vessel, Captain, and Area as explanatory variables. The final model for EAG was:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Vessel} + \text{Month},\ R^2 = 0.4541 \qquad \text{(B.11)}$$

and those for WAG was:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Vessel},\ R^2 = 0.4561 \qquad \text{(B.12)}$$

The R^2 values for the fish ticket data fits are much higher compared to that for observer data fits.

Figures B.28 and B.30 depict the trends in nominal and standardized CPUE indices for the fish ticket CPUE time series for EAG and WAG, respectively. Figures B.29 and B.31 show the Q–Q plots for the fits for EAG and WAG, respectively. The Q–Q plots support reasonable fits to EAG and WAG data by GLM using the lognormal error distribution.

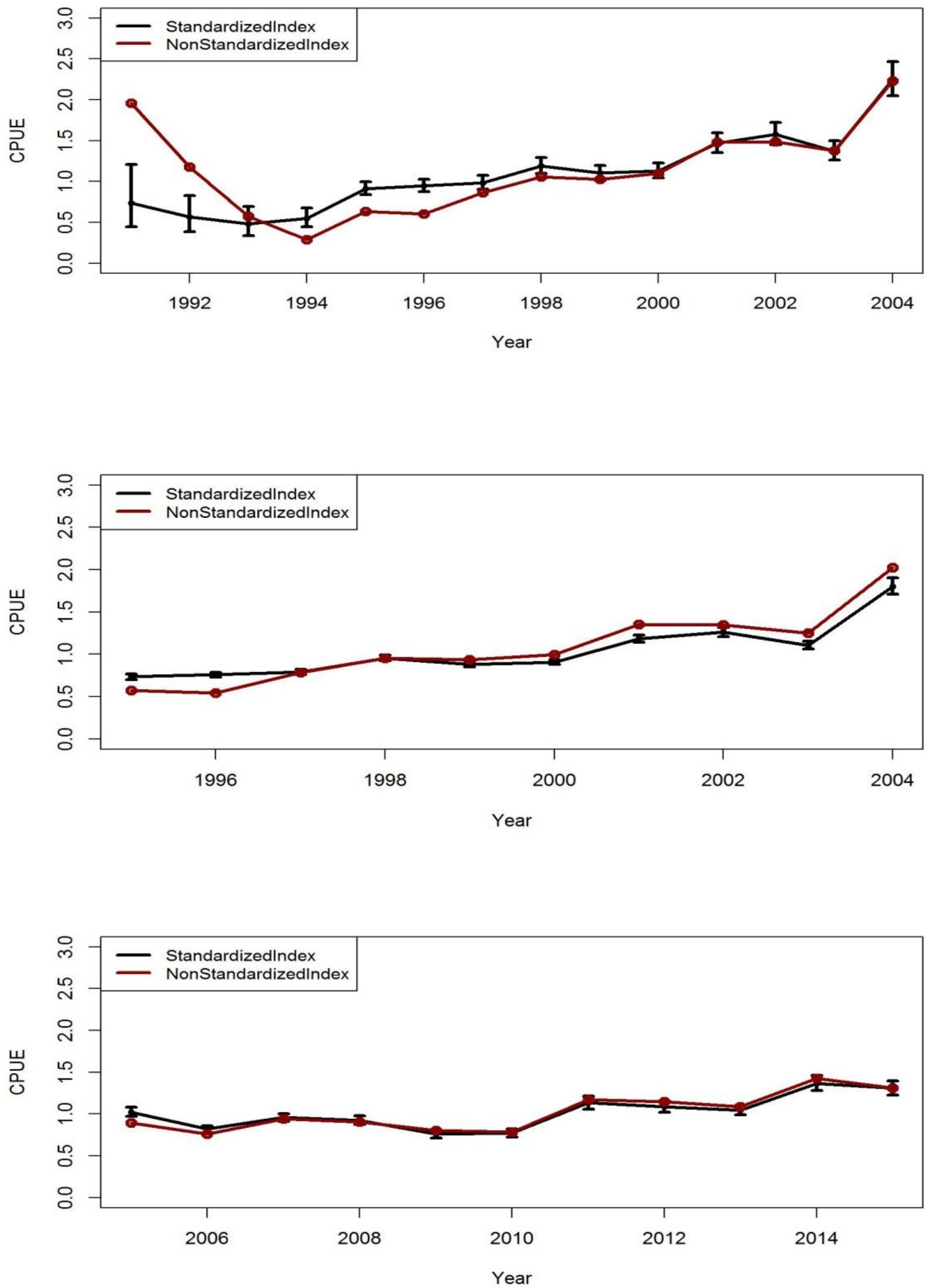


Figure B.1. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from EAG (east of 174 ° W longitude). Top panel: 1991/92–2004/05, middle panel: 1995/96–2004/05, and bottom panel: 2005/06–2015/16. Standardized indices: black line and non-standardized indices: red line.

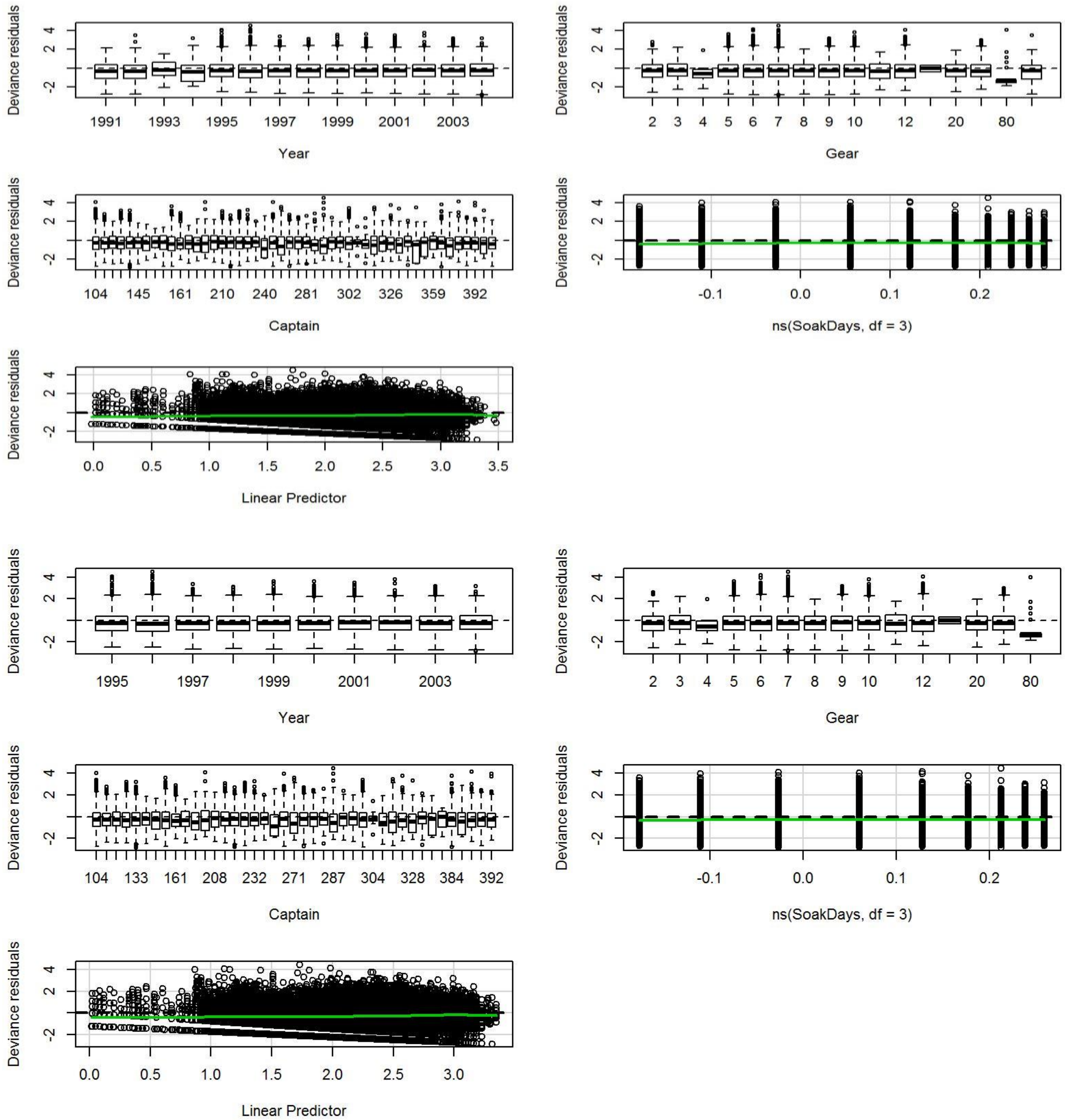


Figure B.2. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from EAG for 1991/92–2004/05 (top) and 1995/96–2004/05 (bottom) periods were used. The solid green lines are the loess smoother through the plotted values.

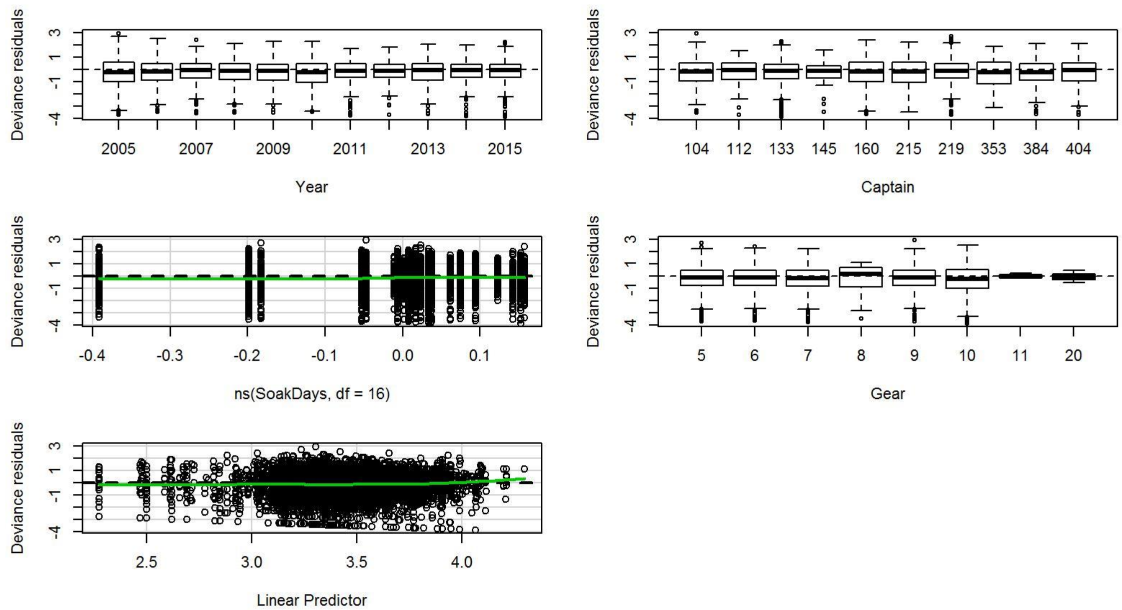
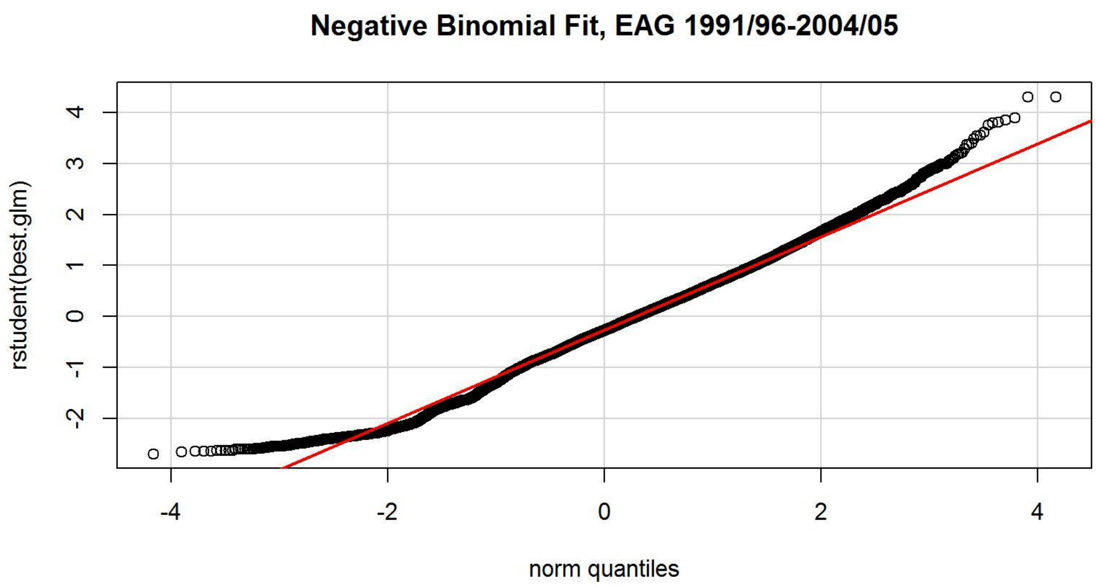


Figure B.3. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from EAG for 2005/06–2015/16 period were used. The solid green lines are the loess smoother through the plotted values.



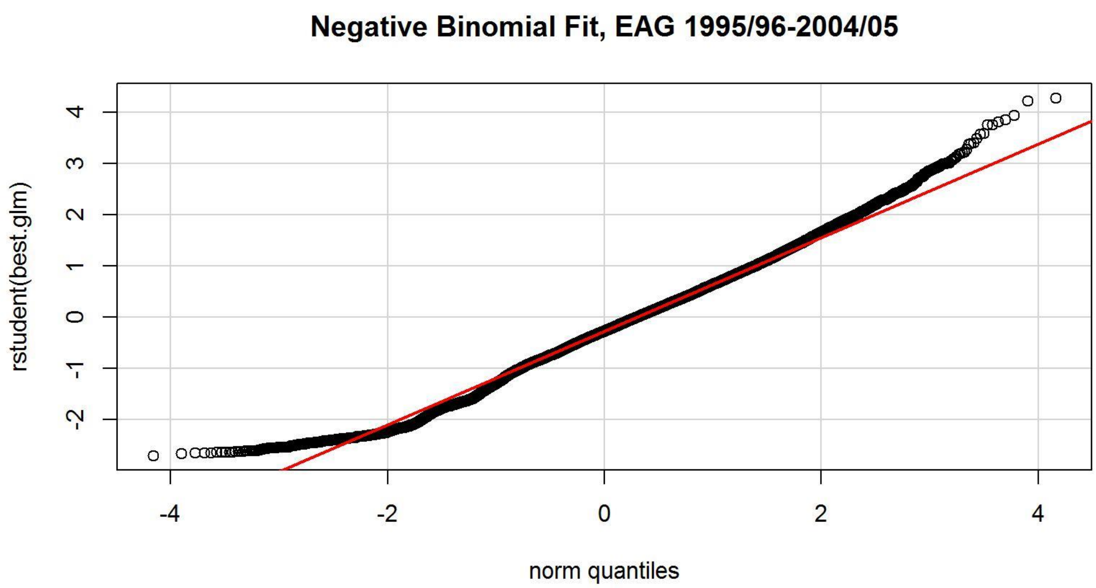


Figure B.4. Studentized residual plots for negative binomial GLM fit to EAG golden king crab observer CPUE data for legal size male crab. Top panel is for 1991/92–2004/05 and bottom panel is for 1995/96–2004/05.

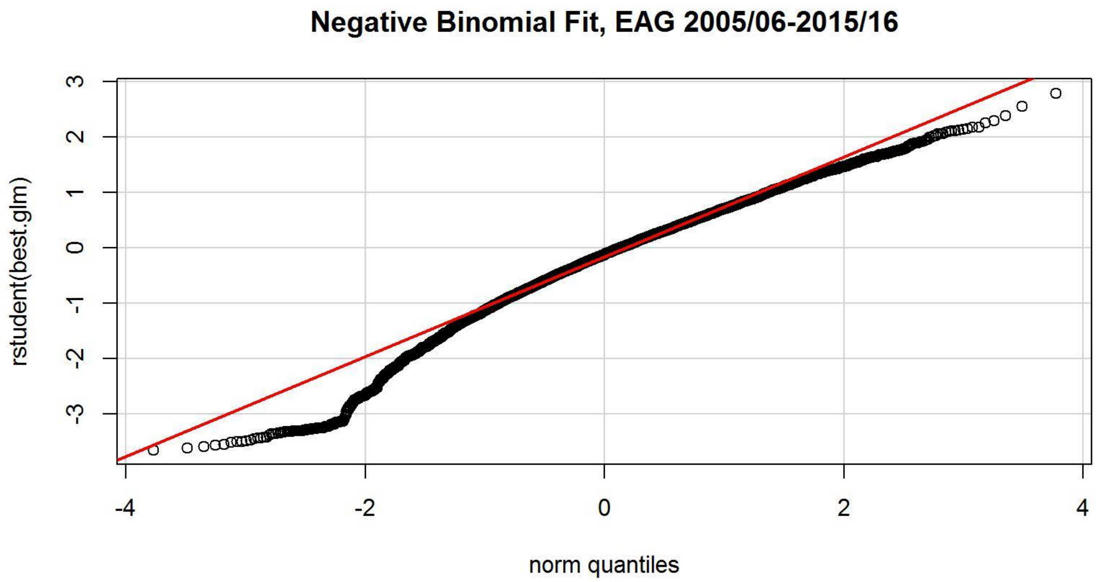


Figure B.5. Studentized residual plots for negative binomial GLM fit to EAG golden king crab observer CPUE data for legal size male crab in 2005/06–2015/16.

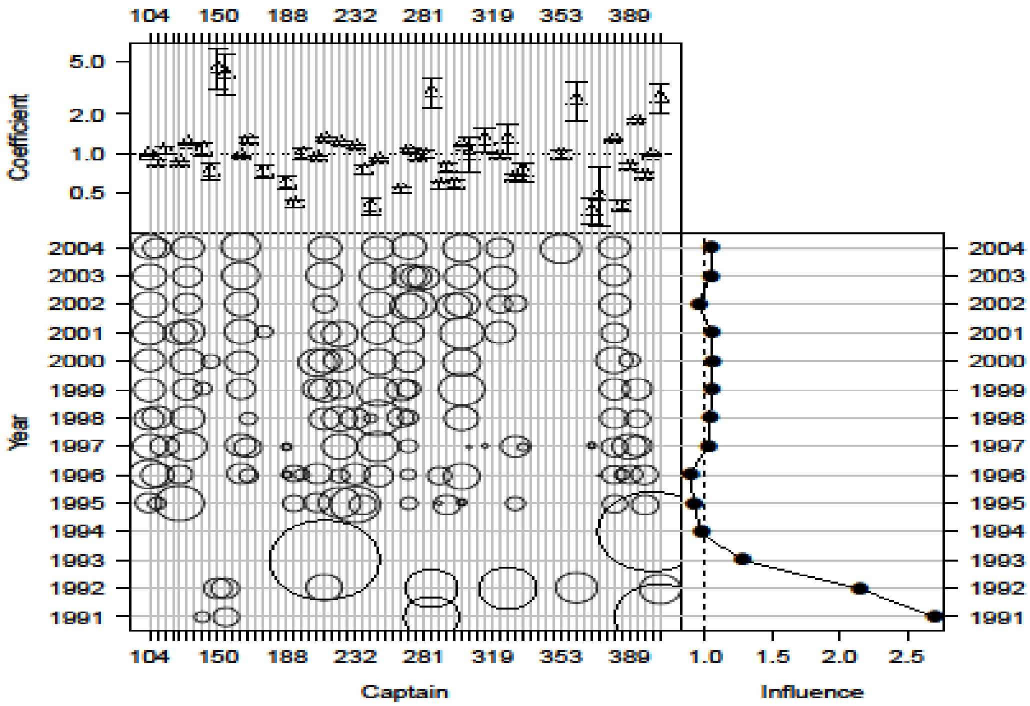


Figure B.6. CDI plot for Captain for the negative binomial fit to 1991/92–2004/05 data for EAG.

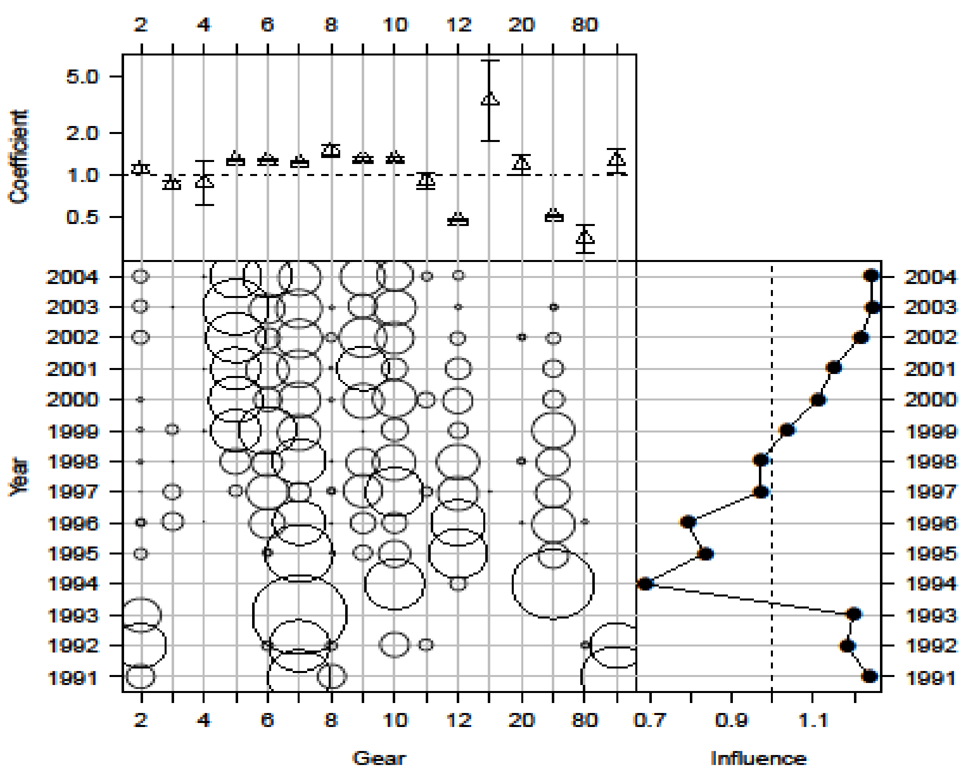


Figure B.7. CDI plot for Gear for the negative binomial fit to 1991/92–2004/05 data for EAG.

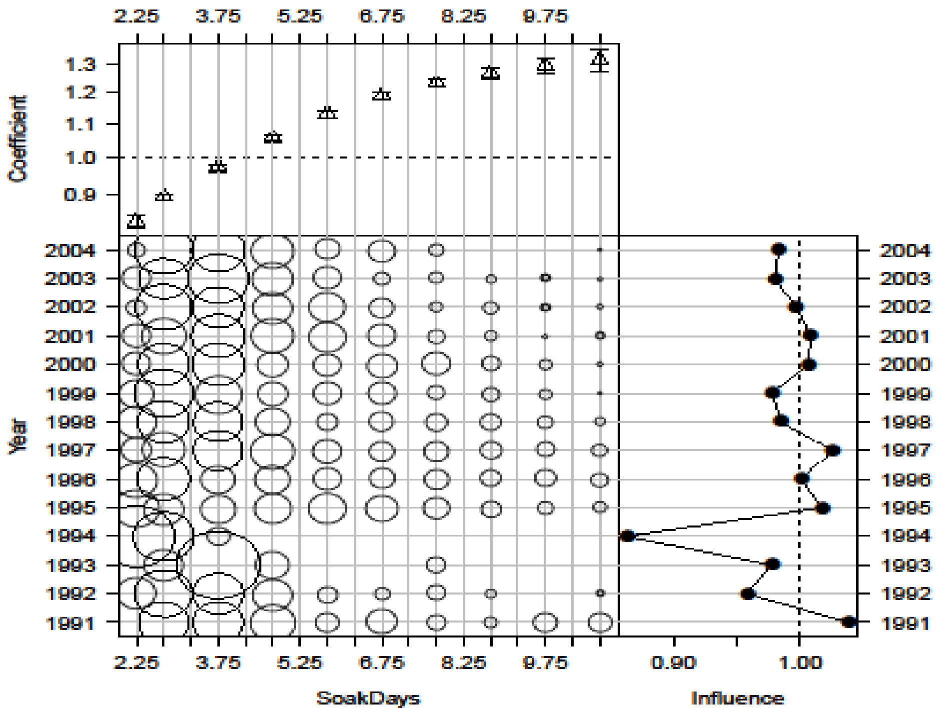


Figure B.8. CDI plot for Soak for the negative binomial fit to 1991/92–2004/05 data for EAG.

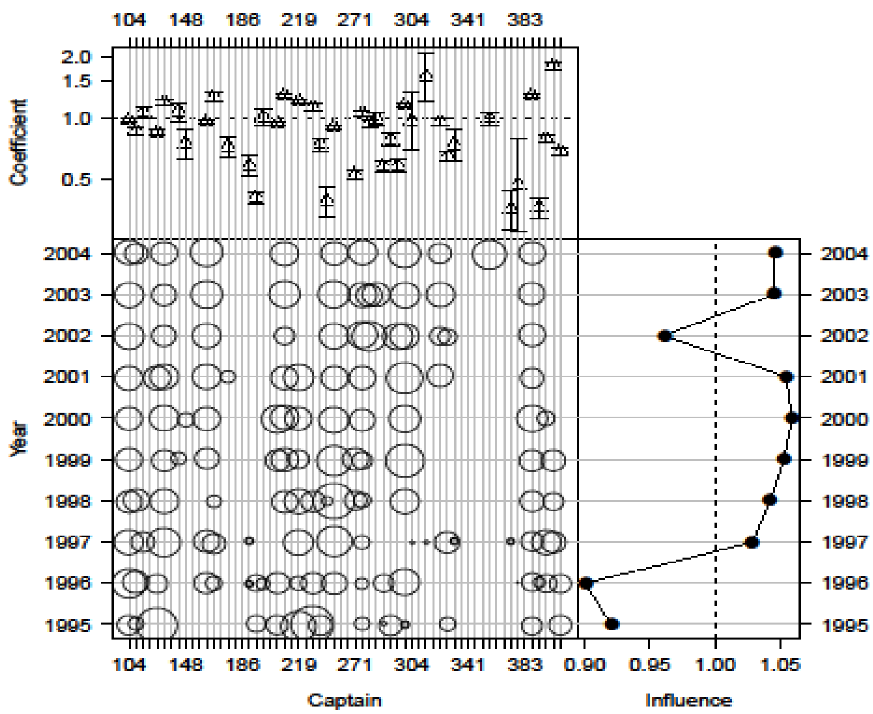


Figure B.9. CDI plot for Captain for the negative binomial fit to 1995/96–2004/05 data for EAG.

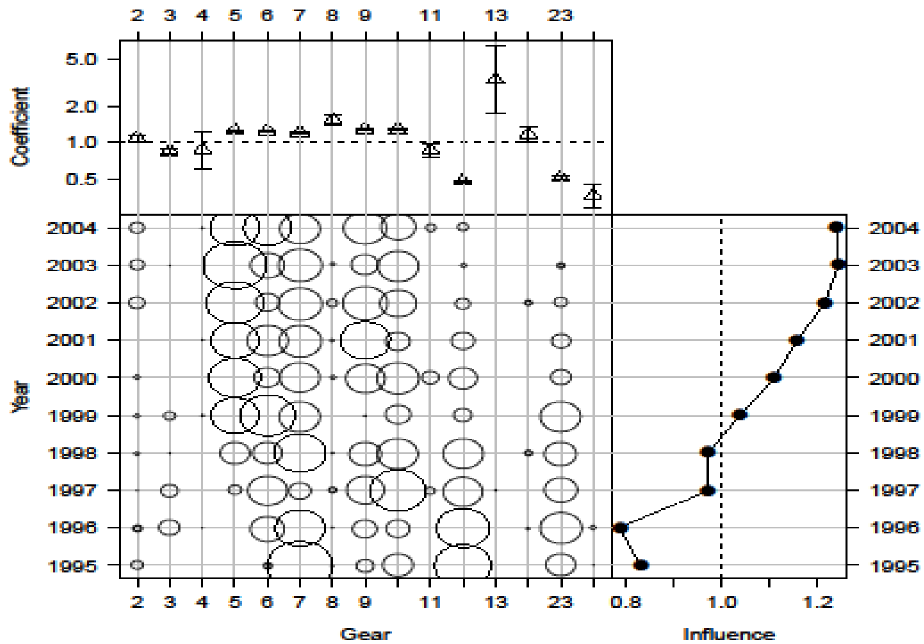


Figure B.10. CDI plot for Gear for the negative binomial fit to 1995/96–2004/05 data for EAG.

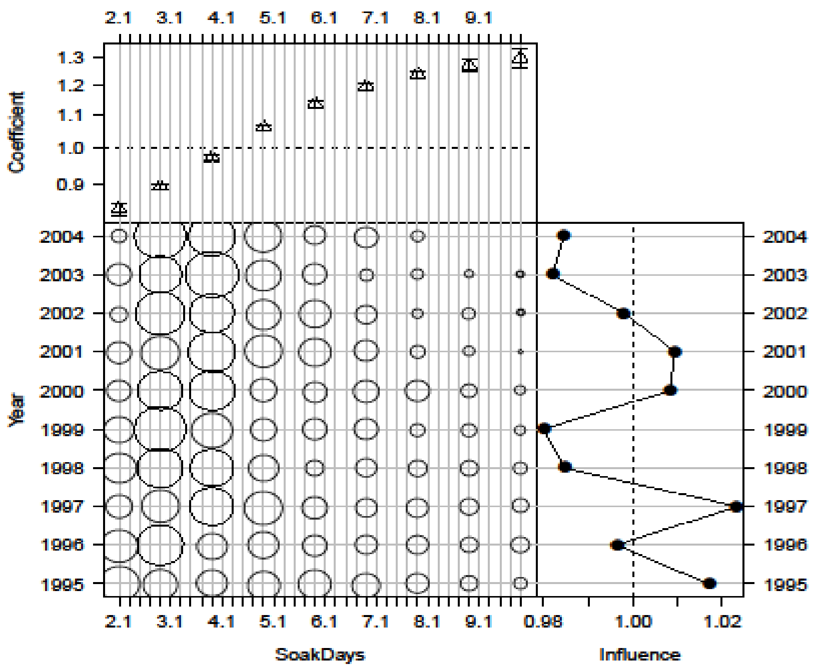


Figure B.11. CDI plot for Soak for the negative binomial fit to 1995/96–2004/05 data for EAG.

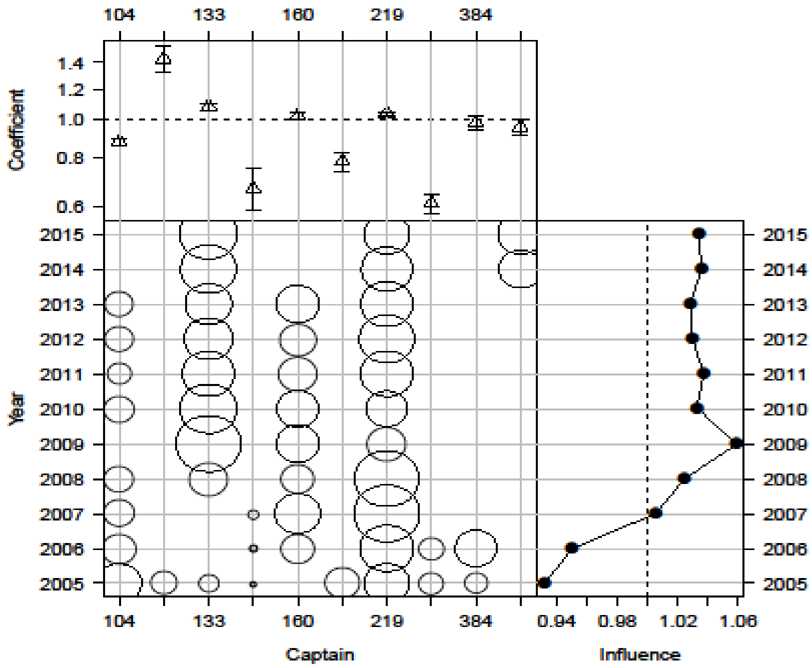


Figure B.12. CDI plot for Captain for the negative binomial fit to 2005/06–2015/16 data for EAG.

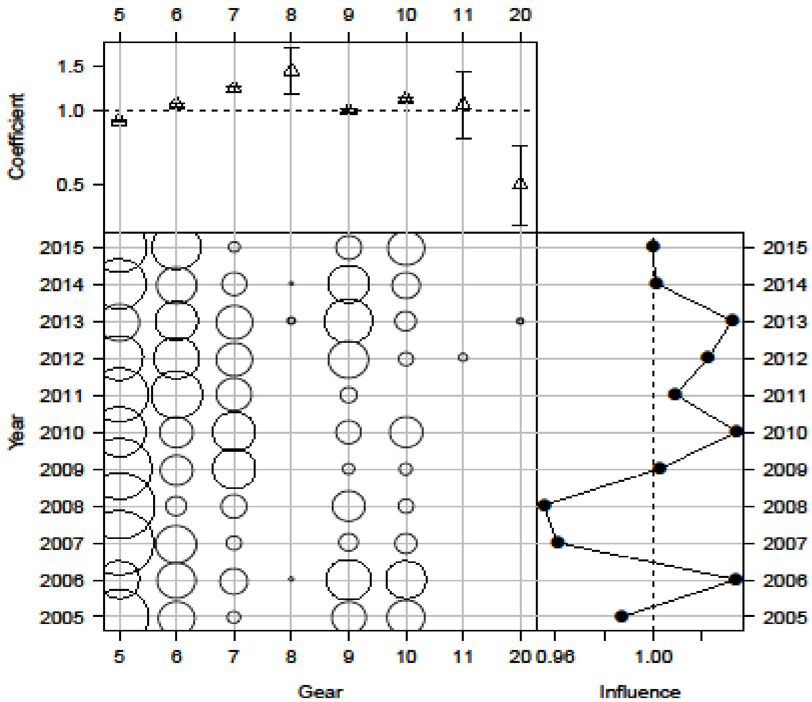


Figure B.13. CDI plot for Gear for the negative binomial fit to 2005/06–2015/16 data for EAG.

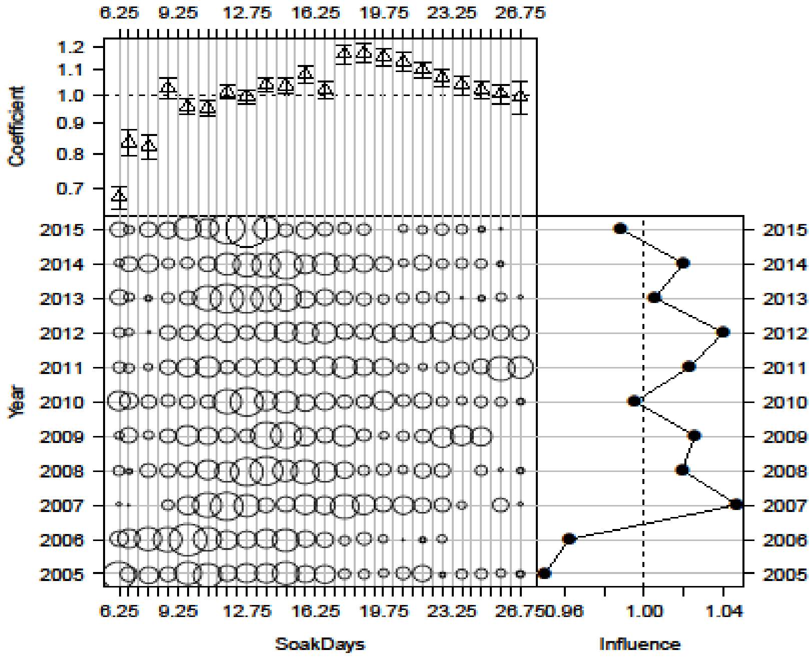


Figure B.14. CDI plot for Soak for the negative binomial fit to 2005/06–2015/16 data for EAG.

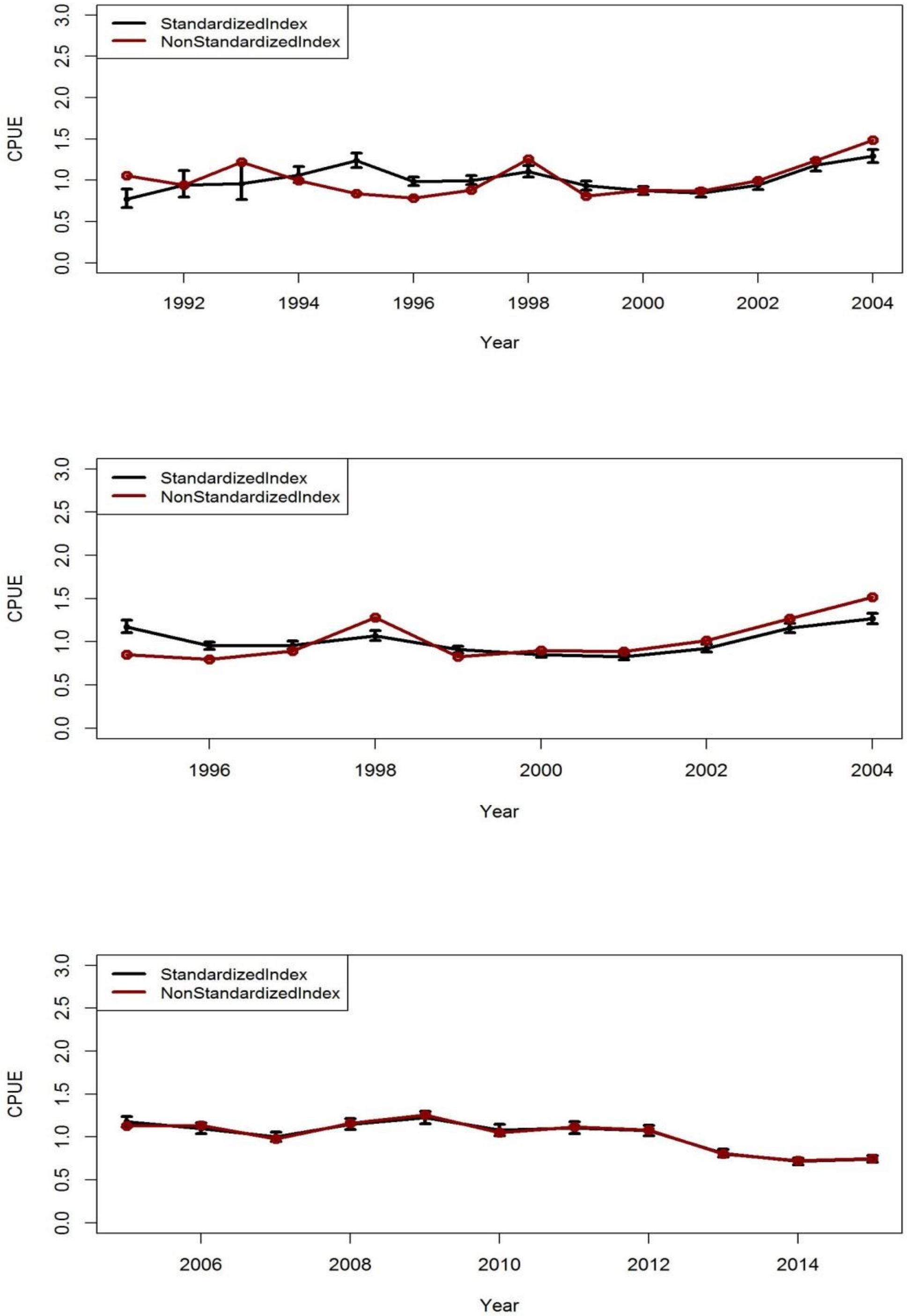


Figure B.15. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from WAG (east of 174 ° W longitude). Top panel: 1991/92–2004/05, middle panel: 1995/96–2004/05, and bottom panel: 2005/06–2015/16. Standardized indices: black line and non-standardized indices: red line.

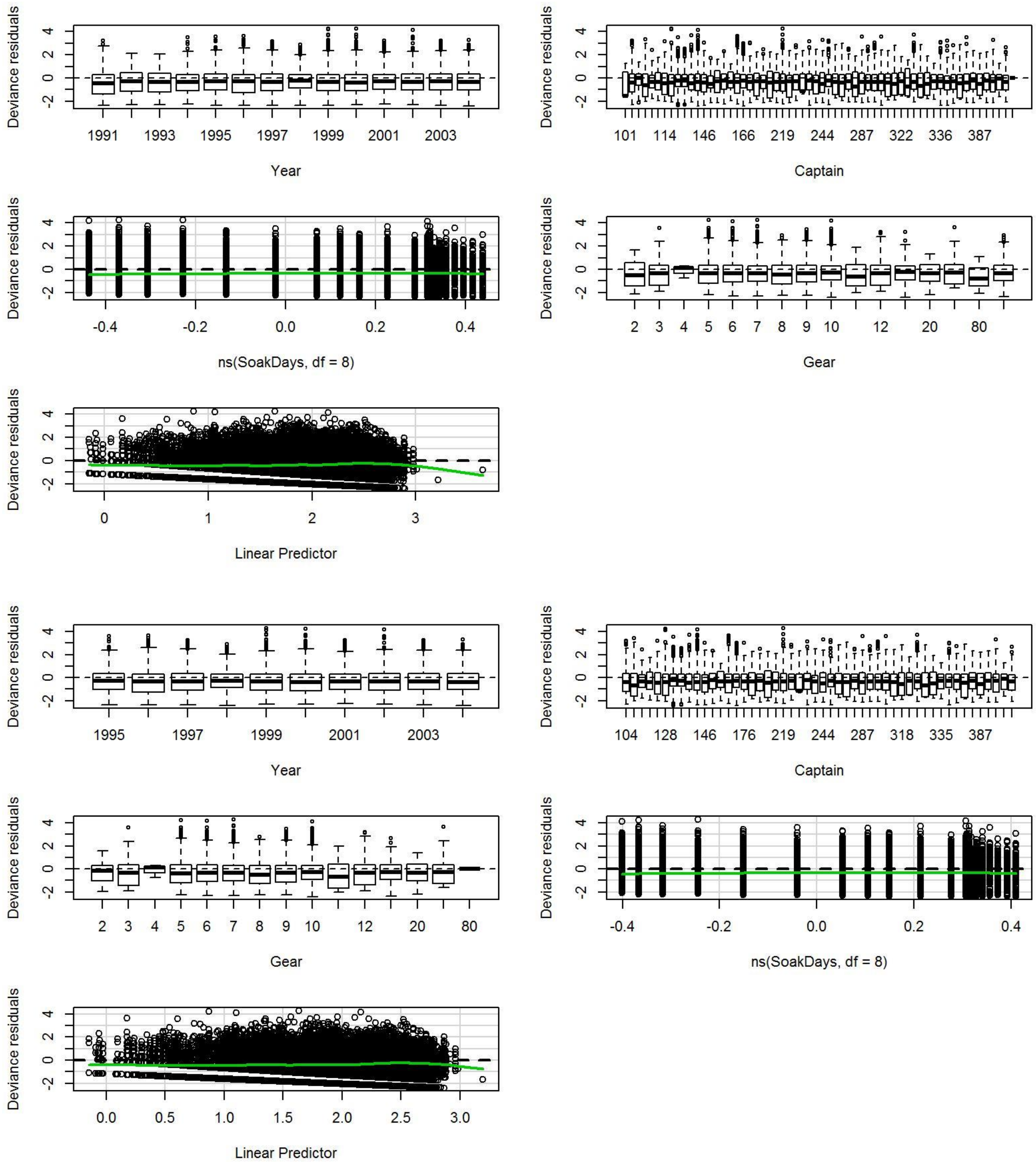


Figure B.16. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from WAG for 1991/92–2004/05 (top) and 1995/96–2005/05 (bottom) periods were used. The solid lines are the loess smoother through the plotted values.

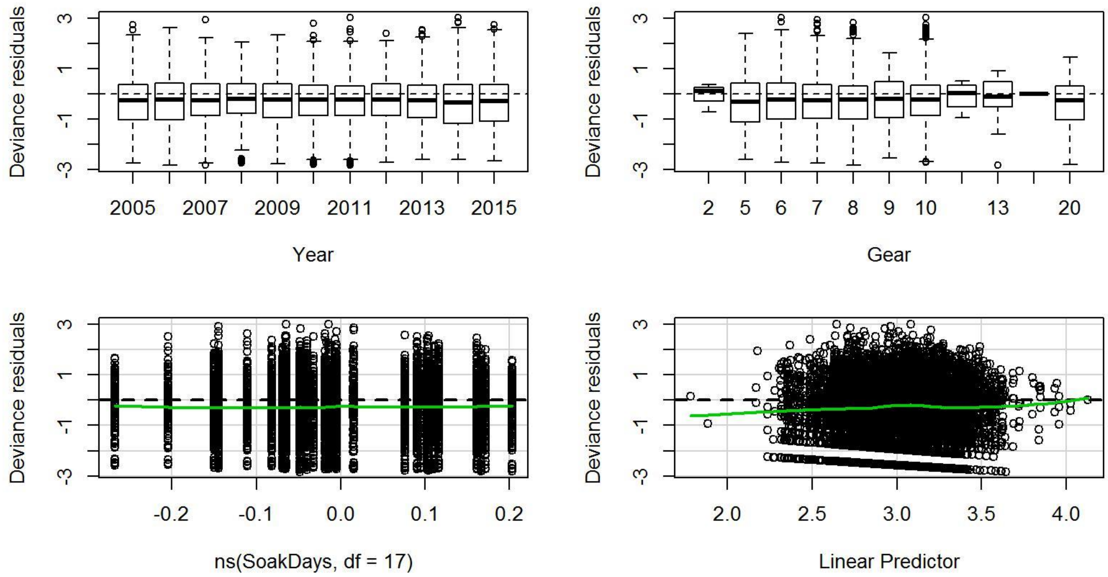


Figure B.17. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from WAG for 2005/06–2015/16 (bottom) periods were used. The solid lines are the loess smoother through the plotted values.

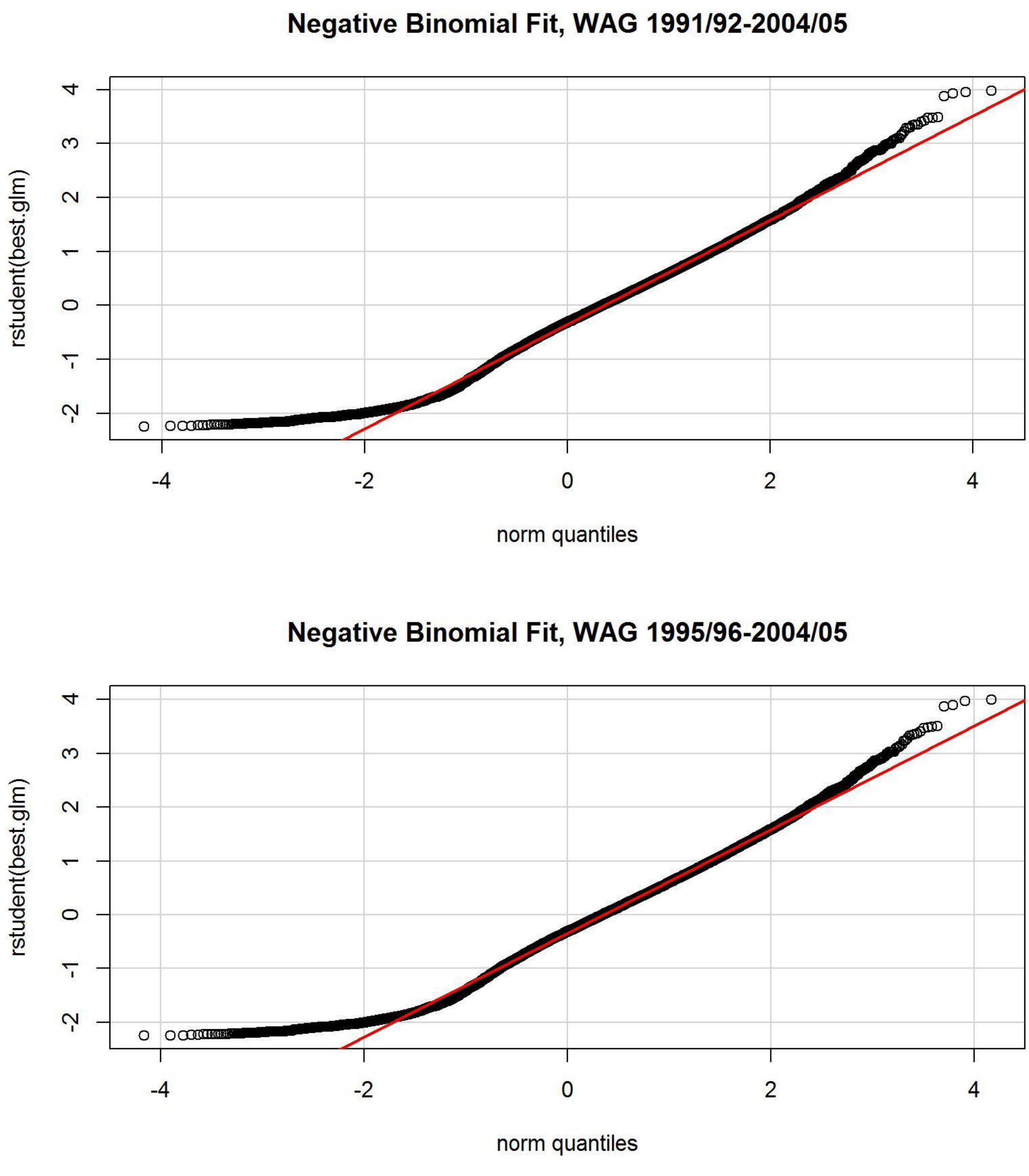


Figure B.18. Studentized residual plots for negative binomial GLM fit to WAG golden king crab observer CPUE data for legal size male crab. Top panel is for 1991/92–2004/05 and bottom panel is for 1995/96–2004/05.

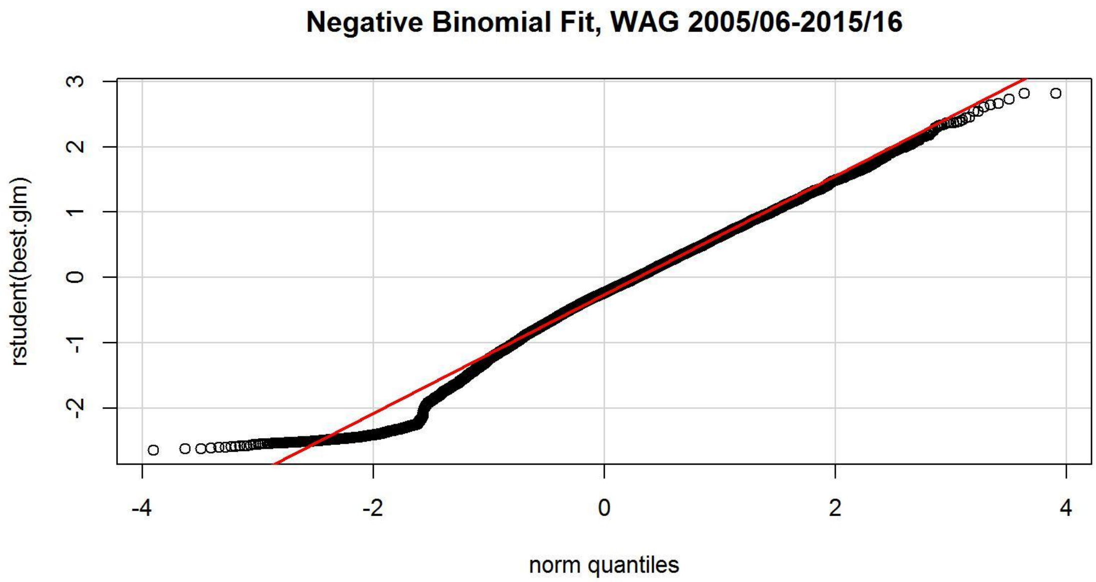


Figure B.19. Studentized residual plots for negative binomial GLM fit to WAG golden king crab observer CPUE data for legal size male crab in 2005/06–2015/16.

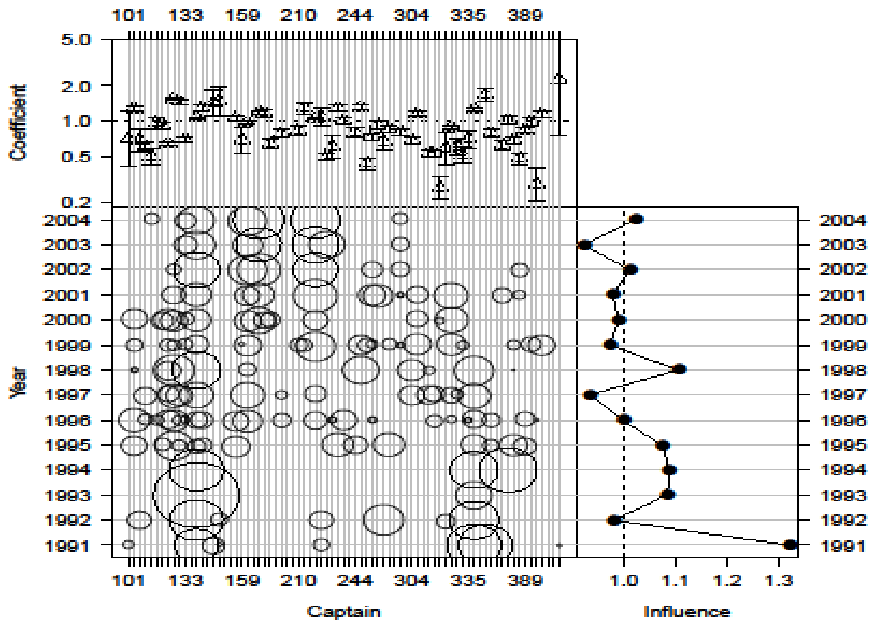


Figure B.20. CDI plot for Captain for the negative binomial fit to 1991/92–2004/05 data for WAG.

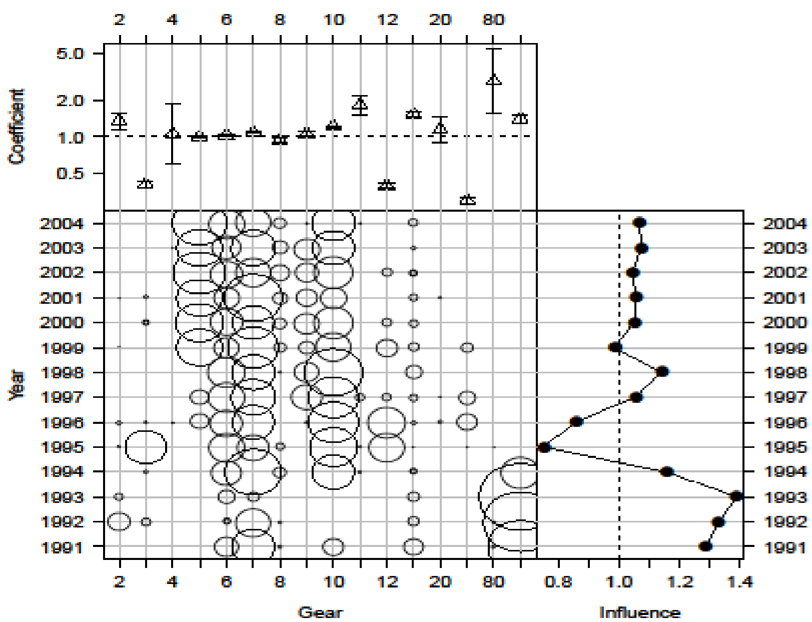


Figure B.21. CDI plot for Gear for the negative binomial fit to 1991/92–2004/05 data for WAG.

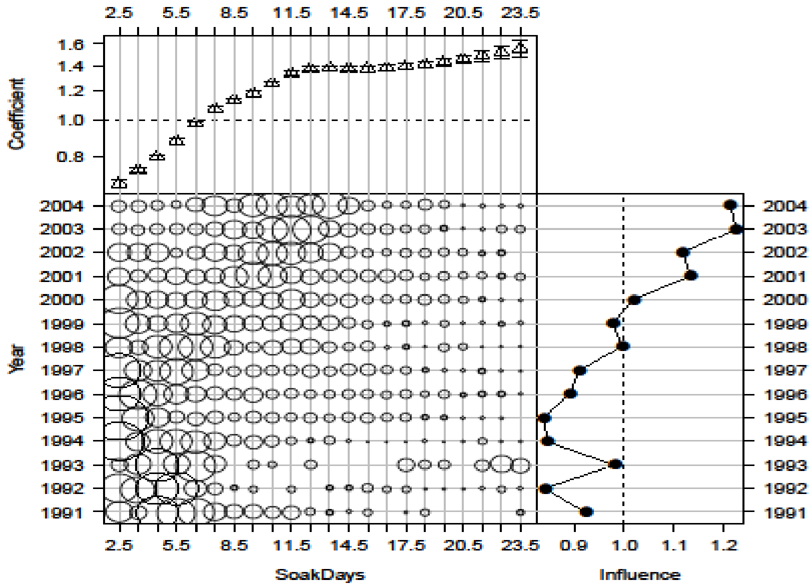


Figure B.22. CDI plot for Soak for the negative binomial fit to 1991/92–2004/05 data for WAG.

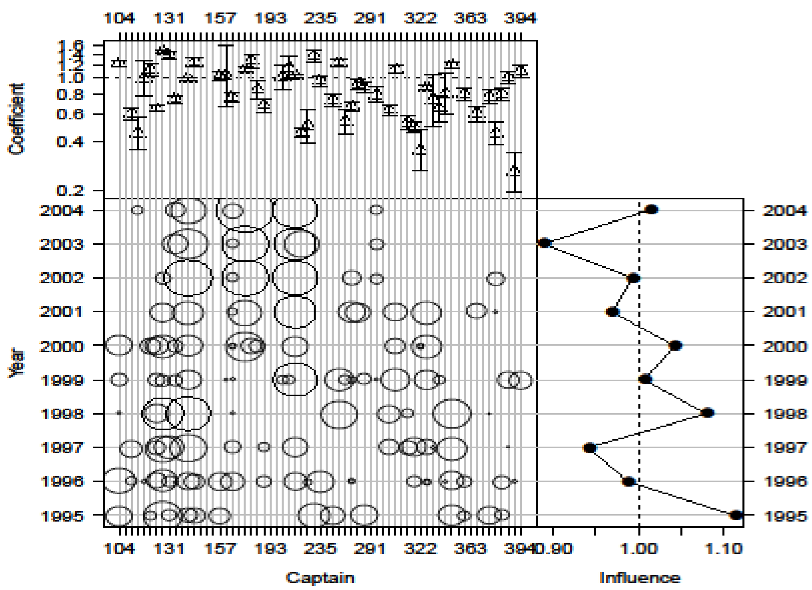


Figure B.23. CDI plot for Captain for the negative binomial fit to 1995/96–2004/05 data for WAG.

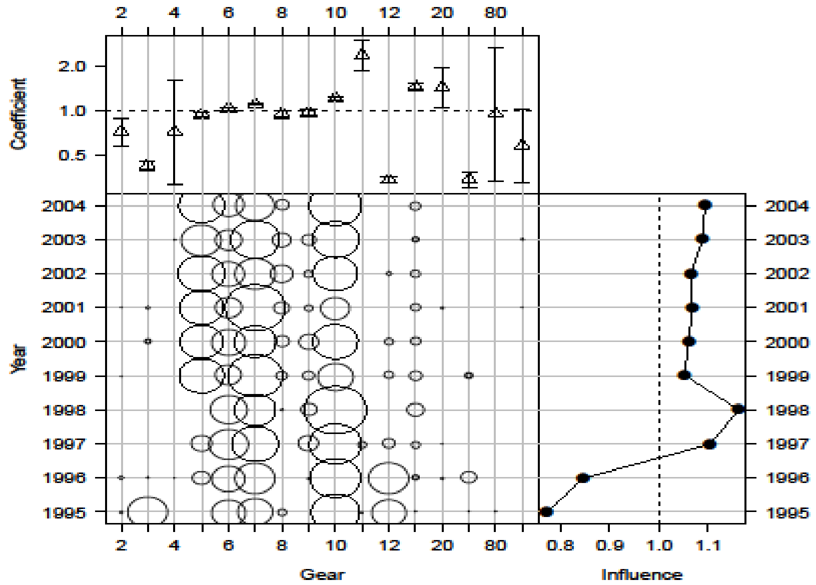


Figure B.24. CDI plot for Gear for the negative binomial fit to 1995/96–2004/05 data for WAG.

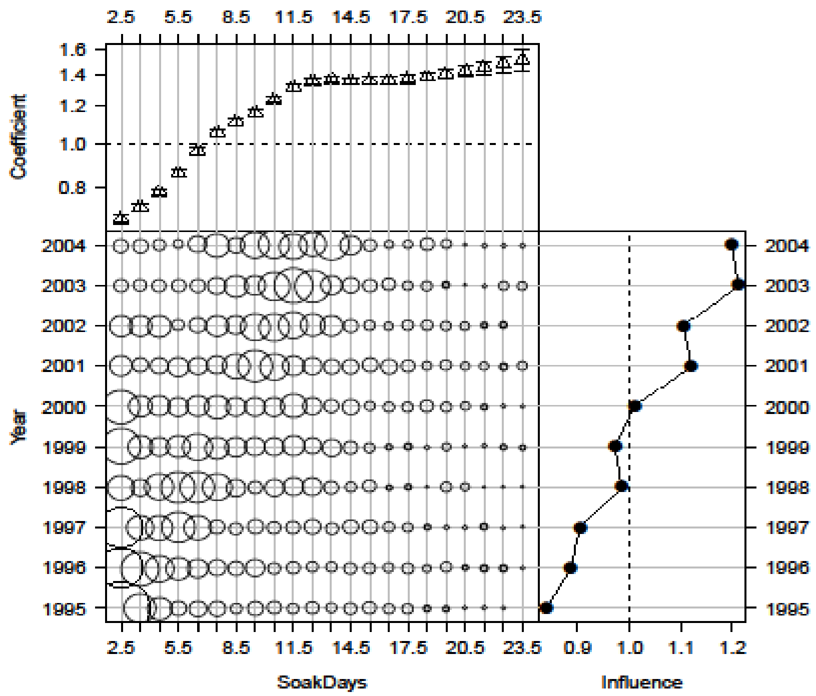


Figure B.25. CDI plot for Soak for the negative binomial fit to 1995/96–2004/05 data for WAG.

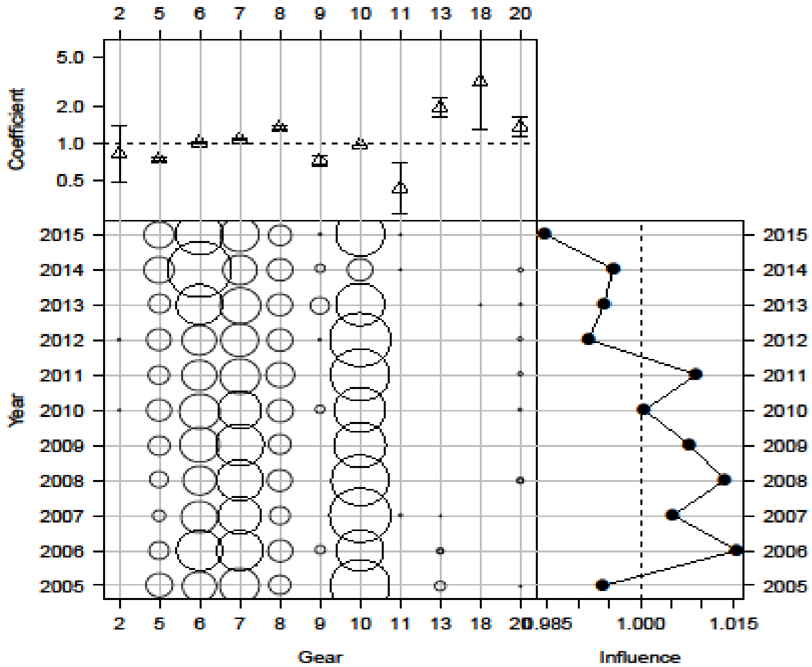


Figure B.26. CDI plot for Gear for the negative binomial fit to 2005/06–2005/15 data for WAG.

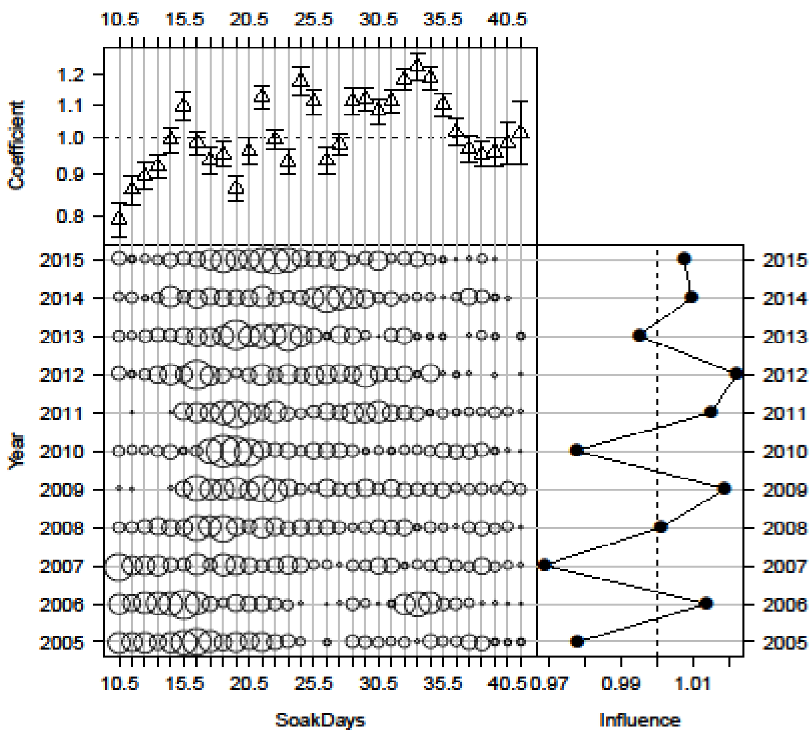


Figure B.27. CDI plot for Soak for the negative binomial fit to 2005/06–2005/15 data for WAG.

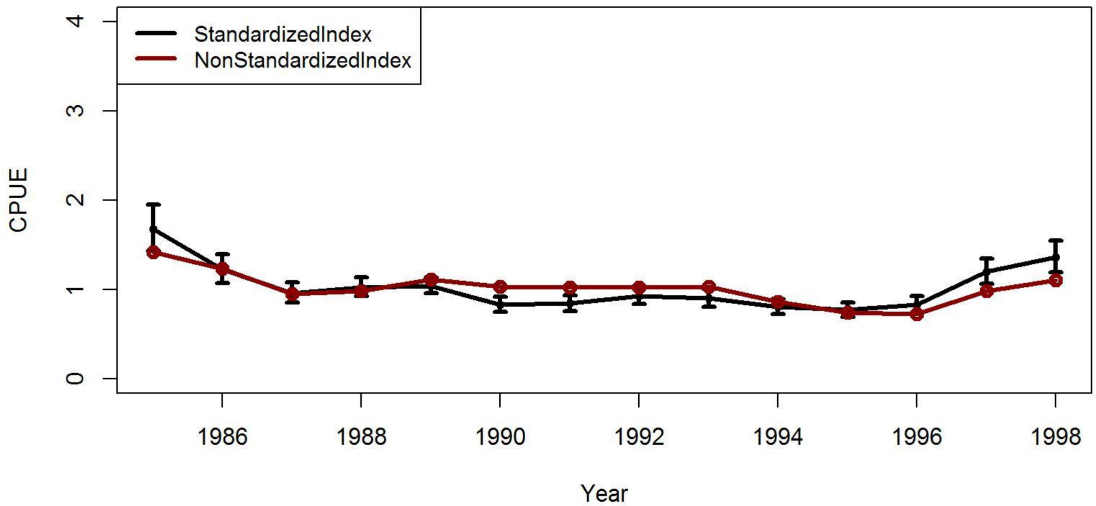


Figure B.28. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

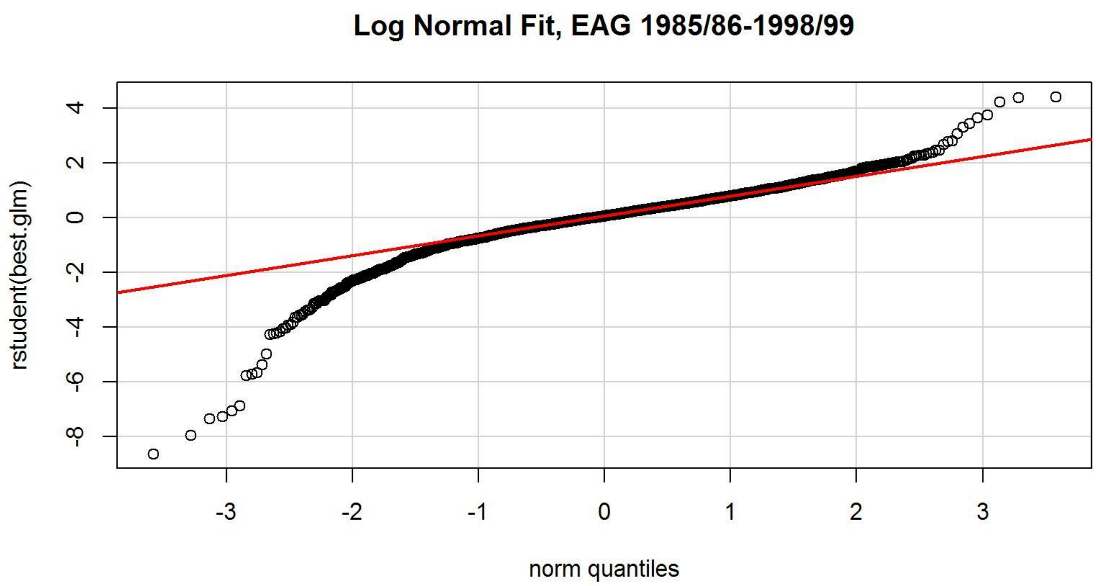


Figure B.29. Studentized residual plots for lognormal GLM fit to EAG golden king crab fish ticket CPUE data, 1985/86–1998/99.

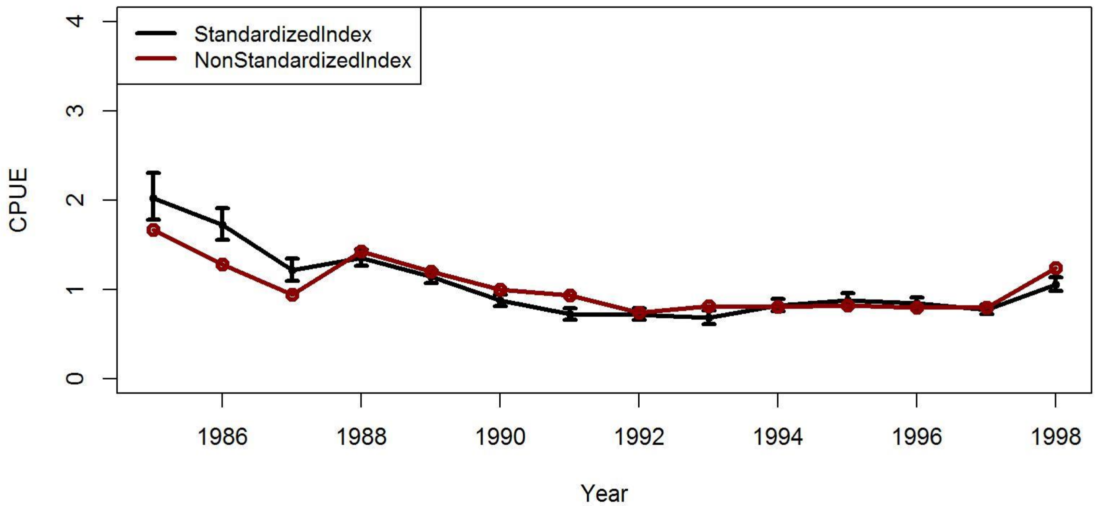


Figure B.30. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG; 1985/86–1998/99 fish ticket data. Standardized indices: black line and non-standardized indices: red line.

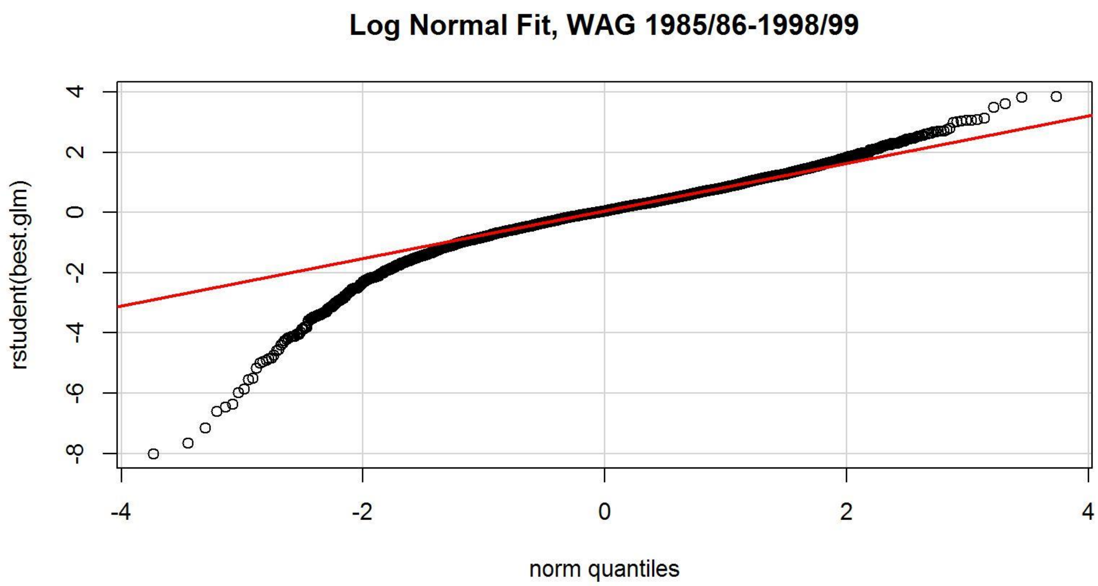


Figure B.31. Studentized residual plots for lognormal GLM fit for WAG golden king crab fish ticket CPUE data, 1985/86–1998/99.