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

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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., 2013). We presented different versions (improvements) of analysis of observer and fish ticket data using generalized linear model (GLM) and generalize additive model (GAM) at the May and September 2012 Crab Plan Team (CPT) meetings. For the February 2013 crab model workshop, we switched back to GLM because it can handle any nonlinear situation either by converting the variables into categorical variables or by using cubic splines. Furthermore, GLM is based on sound statistical principles (Fox and Weisberg, 2011, Zuur et al., 2009).

Following suggestions made at the February 2013 Crab Modeling Workshop, we redid the GLM analysis restricting it to observer pot sample legal size male data and dividing 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 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. Following workshop suggestion, we forced in the *Soak* variable (if not selected) to all final models. We computed yearly CPUE indices with confidence intervals and a number of diagnostic statistics for areas east (EAG) and west (WAG) of 174°W longitude. We presented this analysis at the May 2013 CPT meeting. CPT agreed with the authors that negative binomial family was appropriate for CPUE indices estimation for the given time series of data.

We used the 1995/96-2012/13 observer data for the current CPUE standardization analysis. 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 1995/96–2012/13 data sets. We were unable to use the long-term fish ticket (1985/86–2012/13) data set because it has no soak time information, which played an important role in the post-rationalization period.

Although negative binomial was the preferred family for GLM, we provided results for both delta and negative binomial models. We identified non-interacting explanatory variable sets to standardize observer CPUE data, presented post-fit diagnostic statistics and influence plots and compared standardized CPUE indices between the two error distribution models. Our analysis did not pick up significant interactions. After crab fishery rationalization in 2005, both soak time and CPUE increased markedly, coinciding with a reduction in vessel participation. The CPUE indices from the negative binomial and delta model fits were similar. Trends in standardized and unstandardized CPUE were similar during both pre- and post-rationalization periods, but standardized CPUE values were lower. Residual diagnostic plots for lognormal and negative binomial fits showed no violations of model assumptions, although some residual plots supported negative binomial error distribution over the delta model.

Responses to May 2013 CPT comments

1. Estimate the overdispersion parameter when applying the negative binomial GLM, either using maximum likelihood or by profile likelihood. An initial estimate of the overdisperson parameter can be obtained by applying a GLM with a Poisson error model.

   Response: Following Fox and Weisberg (2011), we employed a grid search method to identify the optimum overdispersion parameter value corresponding to the lowest AIC.

2. The Q-Q plots for all models appear poor. The authors improved the Q-Q plots for the log-normal component of the model by deleting data points with large residuals. This may be acceptable, but further justification is required, and the features of the rejected data points need to be summarized.

Response: We used the two standard error limits from mean of the standardized normal residual errors to remove the outlier records falling outside the limits to get the trimmed data sets.

3. Pearson residuals are hard to interpret for binomial and negative binomial GLMs. Use of deviance residuals should be examined.

   Response: We used deviance residuals for the negative binomial fits. For the binomial component of the delta model, we followed #4 CPT suggestions.

4. The performance of the binomial model can be explored by allocating the predicted positive catch proportions to bins (e.g., in steps of 0.025), and computing the observed proportion of positive catches for each bin. A plot of the average predicted proportion versus observed proportion of positive catches should be linear.

   Response: We included observed versus predicted catch proportion plot to investigate the performance of the binomial model.

5. The influence plots should be provided.

   Response: We included influence plots in this analysis.

6. The negative binomial and delta-lognormal approaches lead to different trends in standardized CPUE for the EAG for 1995/96-2004/05. The reasons for this need to be determined.

   Response: Although the results are not identical the current analysis with the inclusion of 2011/12 and 2012/13 data sets showed closer standardized CPUE trends.

Materials and methods

Preliminary data processing

Observer pot sample data

The data used in the development of CPUE indices were collected by onboard fishery observers during 1995/96–2012/13. Observers collect data from catcher vessels and catcher-processor vessels operating in the Aleutian Islands golden king crab fishery. Observer data collection began in 1988, but 100% observer coverage didn't begin until 1995 and catcher vessel coverage declined to 50% beginning in 2005 (Fitch et al., 2012). The number of sampled pots in EAG and WAG accounted for nearly 4.9% of the total pot lifts in the commercial fishery during the 1995/96–2012/13 fishery period. Although observer coverage is small compared to total effort expended, the nominal CPUEs in observer samples were close to those calculated from the total fishery catch and effort (Gaeuman, 2013). We separated the observer data into EAG (fishing area east of 174°W longitude) and WAG (fishing area west of 174°W longitude) for CPUE standardization. Anecdotal accounts justify the separation of areas and there is hardly any commercial golden king crab abundance (and fishery) 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 101,218 records for 1995/96–2012/13. We considered the 1995/96–2012/13 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 2005/06–2012/13 (post-rationalization) periods for analysis. We used the core vessels' data in the analysis for the legal component.

For EAG, there were 31,663 total records (zero and positive catches), and 28,385 positive catch records for 1995/96–2004/05 and respectively 5,018 and 4,926 for 2005/06–2012/13. For WAG, there were 32,468 total records and 26,820 positive catch records for 1995/96–2004/05 and respectively 7,139 and 6,792 for 2005/06–2012/13.

Observers randomly select a pre-determined number of pots daily and examine the entire pot contents for catch composition and size measurement. They also collect a range of ancillary information on sampled pots such as identity of the vessel, date, location (statistical area and coordinates), depth (fathom), soak time (day), and gear type (different size and rigging of the pot gear). Each observer record for CPUE analysis consists of: year, month, vessel, depth, statistical area, soak time, number of sublegal male crab (< 136 mm carapace length (CL)), number of retained legal male crab (≥ 136 mm CL), and number of non-retained legal male crab. We added the captain identification code and a composite variable,

consisting of the product of number of vessels and average soak time, to each record. The composite variable accounts for the impact of total fishing pressure on CPUE.

The 1995/96–2012/13 observer sampled fisheries took place at depths of 15 to 889 fathoms (one record of 1215 fathoms was ignored), with a soak time of less than 1 to 126 d (records of 306, 360, and 384 d were ignored). The lower- and higher-end values are outliers, due either to unattended or dysfunctional pots or to misrecording of data. Thus, we limited our analyses to the data within the 1–99 percentile range for depth and the 5–95 percentile range for soak time. Because pot gear soak time was an important factor affecting crab catchability, we set its limits for data sub setting to a lower range than those for depth.

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

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

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

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

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

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

Catch = Number of crabs caught. This is the response variable. We considered legal males (retained and non-retained legal-sized crab) catch numbers. 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 longitude. 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, 2013). 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 categorical 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 categorical levels

Year: 1995/96–2012/13 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 2; 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 1985/86–2012/13. The maximum number of vessels dropped to 37 when the period was restricted to 1995/96–2012/13. 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). We considered the shorter data series (1995/96–2012/13) 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. The CPUE trends did not differ significantly for core and total vessels (Figures 3 and 18 for EAG and WAG, respectively).

CPUE standardization

Statistical models

Since 1999, fishermen have continually modified crab pots (e.g., increased the mesh size) to allow sublegal crab to escape (Pengilly, 2013). Increased soak time since 2005 has also reduced sublegal crab catch (Siddeek et al., 2013). Therefore, sublegal crab catchability has changed since 1999. For this reason, we excluded sublegal crab from CPUE analysis and considered the sum of retained and non-retained legal male crab in each record as the nominal CPUE. We treated this CPUE as the response variable for catch rate standardization.

It is important to choose explanatory variables that influence catch rates. Among the explanatory variables, we treated *Soak* time, *Depth*, and product of number of vessels and average soak time as numeric and *Year*, *Month*, *Area*, *Vessel*, and *Captain* as categorical. We gave special significance to the *Year* explanatory variable and considered the estimated canonical coefficients of the *Year* (defined in the subsequent section) as standardized annual CPUE index (Francis, 1999; Starr, 2012).

Observer catch data consist of positive and zero catches and the catch distribution is highly skewed (Figures 4 and 19 for EAG and WAG, respectively). It is important to evaluate the appropriateness of the response variable error distribution in the CPUE standardization model (Ortiz and Arocha, 2004; Punt et al., 2000; Zeileis et al., 2008; Zuur et al., 2009). We examined the suitability of the following alternative error models:

(a) Zero-inflated model is a two-component mixture model combining a point mass at zero with a count distribution such as Poisson or negative binomial (Zeileis et al., 2008). Although observer catch distributions were skewed, there was no evidence of high accumulation of zero catch in every fishery season (Figures 4 and 19 for EAG and WAG, respectively) and the proportion of zero catch was small and dropped dramatically in recent years (Tables 5 and 11 for EAG and WAG, respectively). Therefore, we did not consider this model.

(b) Delta model is a two-stage model that separately models the proportion of positive catch rates by the binomial model and the natural log of positive catch rates by the lognormal model and then combines the two to get a combined CPUE index (Maunder and Punt, 2004; Vignaux, 1994). We considered this model as an alternative for CPUE analysis.

(c) Negative binomial model implicitly estimates the probability of zero and positive catches. The response variable is assumed to be catch rate in number of crab (Punt et al., 2000; Zeileis et al., 2008). We considered this model as another alternative for CPUE analysis. **Based on results from the current observer data analysis, we preferred this model.**

Following Maunder and Punt (2004), the relationship between a function of the expected value of the response variable and the explanatory variables can be written in a linear form as:

$$g(\mu_i) = X_i^T \beta + \epsilon_i. \quad (1)$$

where g is the link function, $\mu_i = E(Y_i)$, Y_i is the ith response variable, X_i is the vector of size p that specifies the explanatory variables for the i-th value of Y, β is a vector of size p parameters, and ϵ_i is the ith residual (Y_i - μ_i), which is assumed to be normally distributed with $E(\epsilon) = 0$ and $Var(\epsilon) = \sigma^2$. The link function used for the lognormal model was identity (observations were already log transformed) and that for binomial was logit, $\ln\left(\frac{\pi_i}{1-\pi_i}\right)$, where π_i is the probability of positive catch, and that for the negative binomial model was $\ln(\mu_i)$.

Following the February 2013 workshop and May 2013 CPT recommendation, we considered the negative binomial distribution to fit the predictor variables to CPUE data (not log transformed). The rationale for considering this 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 Y_i be negative binomial distributed with mean μ_i , parameter (dispersion) θ, and variance of $Y_i = \mu_i + \frac{\mu_i^2}{\theta}$. (Zuur et al., 2009). (1.1)

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

$$\log(\mu_i) = \varphi(X_{i1}, X_{i2}, \ldots, X_{ik}) \text{ or } \mu_i = e^{\varphi(X_{i1}, X_{i2}, \ldots, X_{ik})} \quad (1.2)$$

where φ is the linear predictor function.

We determined the θ value by a grid search method (Fox and Weisberg, 2011) where the optimum value was selected at the minimum AIC value ($AIC = -2\ln(L) + 2p$, where L = maximum likelihood estimate and p = number of parameters (Burnham and Anderson, 2002)).

The model described by equation 1 is over-parameterized. A common remedial solution is to set a categorical coefficient to zero, usually the first, whereupon the remaining coefficients of each categorical represent incremental effects relative to the reference level. In order to make the relative coefficient

values invariant to the choice of base values, following Francis (1999), we scaled the β parameters to canonical coefficients as $\beta_i{}' = \frac{\beta_i}{\bar{\beta}}$, where $\bar{\beta} = \sqrt[n_j]{\prod_{j=1}^{n_j} \beta_{ij}}$.

For the lognormal (and negative binomial) models, the relative year effect on CPUE (i.e. standardized CPUE index for *Year i*) is,

$$Y_i^L = \frac{e^{\mu_i}}{e^{\mu_0}} \tag{2}$$

where *i* is the *i*-th *Year*, 0 is the base *Year*, and *L* refers to either the lognormal or negative binomial model.

For example, consider a fitted lognormal model of the form:

$$y_i = \ln(CPUE_i) = \beta'_0 + \beta'_1 x_1 + \beta'_2 x_2 \,. \tag{2.1}$$

If x_2 is the categorical variable *Year* then β'_2 would take on the values β'_{20} when *Year* is the reference *Year* 0, and β'_{2i} when *Year* is some other *Year i*. So, the *CPUE* index for *Year i* relative to the reference *Year* 0 is estimated as:

$$CPUEindex_i = \frac{e^{y_i}}{e^{y_0}} = \frac{e^{\beta'_0+\beta'_1 x_1+\beta'_{2i} x_2}}{e^{\beta'_0+\beta'_1 x_1+\beta'_{20} x_2}} = e^{\beta'_{2i}-\beta'_{20}}. \tag{2.2}$$

For the binomial model, standardized CPUE index for *Year i* is,

$$Y_i^B = \frac{\frac{\pi_i}{1-\pi_i}}{\frac{\pi_0}{1-\pi_0}} \,. \tag{3}$$

Following Vignaux (1994), the combined CPUE index for *Year i* is

$$Y_i^C = \frac{\pi_i e^{\mu_i}}{\pi_0 e^{\mu_i}} = \frac{Y_i^L}{1-P_0[1-\frac{1}{Y_i^B}]} \,, \tag{4}$$

where Y_i^L = lognormal CPUE index for *Year i* and P_0 = proportion of zero catches for base *Year* 0.

To compare with standardized CPUE indices, we also estimated the nominal CPUE (termed as arithmetic CPUE) from observer samples and scaled it to the level of the standardized CPUE index as follows:

$$A'_i = \frac{A_i}{\bar{A}} \,, \tag{5}$$

where

$$A_i = \frac{\sum_{j=1}^{n_i} C_{ji}}{\sum_{j=1}^{n_i} E_{ji}} \,,$$

$$\bar{A} = \sqrt[k]{\prod_{i=1}^{k} A_{\mathrm{i}}}$$

$\bar{A}$ denotes geometric mean of A_i, C_{ji} represents catch, E_{ji} is effort for each record j in *Year* i (i.e., 1 unit of effort (pot lift) for each record), n_i is the number of records in *Year* i, and k is the number of years.

We applied a forward stepwise selection procedure which generates regression models iteratively, starting with the null model consisting of only the *Year* (for example, $\ln(CPUE_i) = factor\ (Year) + \in_i$) and building in complexity subject to the following stopping rule designed to include only the most important explanatory variables. We stopped addition of new variables when the improvement in R^2 was less than 0.01.

$$R^2 = \frac{(null\ model\ deviance - added\ parameter\ model\ deviance)}{null\ model\ deviance} \quad (6)$$

We first offered all explanatory variables without any interaction terms for selection. Interactions of *Year* with other variables are crucial as significant interactions can cause problems for interpreting *Year* effect. After important variables had been selected, we added the interaction of selected variables with *Year*, singly, to the scope of variables and performed forward selection. Following the February 2013 model workshop recommendation, we forced the soak time variable into all final models, if it was not selected. The reason for this forced inclusion was that soak time increased dramatically after fishery rationalization in 2005/06, confounding it with *Year*.

We used the cubic spline, $ns(X_i, df)$, (R Core Team, 2012), for the continuous variables (X_i) soak time, depth, and the composite variable (product of number of vessels and average soak time). We determined appropriate degrees of freedom (*df*) for cubic splines separately for each error distribution family by the grid search method (on systematically varying *df*) when a single continuous predictor variable was fitted. We selected the optimum *df* at the lowest AIC value (Tables 4 and 10 for EAG and WAG, respectively).

Bootstrap statistics

The standard errors and confidence bounds for the combined CPUE index based on delta model 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 for this calculation and estimated confidence intervals using Efron's method (Efron and Tibshirani, 1986):

97.5 th percentile value of the bootstrapped combined CPUE index distribution – 2.5 th percentile value of the bootstrapped combined CPUE index distribution.

Influence plot

Following Bently et al. (2012), we investigated the influence of each selected predictor variable in the CPUE standardization analysis. The suite of plots developed by Bently et al. included step plot to show progression of standardized *Year* indices that result as each explanatory variable is added; annual influence values for each explanatory variable in the final GLM model; and a plot consisting of a combination of coefficients with standard errors, the distributional changes of the variable, and the annual influence measure (known as coefficient-distribution-influence (CDI) plot). Bently et al.'s R routine is applicable only to log link GLM objects; hence, binomial indices were not considered for influence plots.

Diagnostic statistics

We checked the model assumptions and model fits by various residual plots (Fox and Weisberg, 2011; Maunder and Punt, 2004; Ortiz and Arocha, 2004; Zuur et al., 2009):

(a) The studentized residuals against normal quantiles to check systematic departure from the assumptions underlying the error distribution.

(b) The Pearson residuals (for lognormal fit) or deviance residuals (for negative binomial fit) against final model's predictor variables and predictor function to check whether model misspecification was occurring.

(c) The observed values of the dependent variable against the linear predictor function to assess the validity of the link function.

Diagnostic residual plots for log link function (lognormal component of the delta model and negative binomial model) are easy to implement using the "car" package in R (Fox and Weisberg, 2011). However, diagnostic statistics is not straight forward for the binomial model. For the binomial component of the delta model, following Punt et al. (2000), we plotted observed versus predicted positive catch

success proportions. The points should fall into a 1-1 line. We computed this statistic for the negative binomial family as well although it was not necessary.

We performed all analysis and diagnostic plots in the R platform (version 2.15.2) using its extensive libraries (R Core Team, 2012). R codes for CPUE standardization and bootstrap analyses are listed in Appendixes A and B.

GLM implementation for observer pot sample data analysis

Delta model

For the lognormal component of the delta model (i.e., 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

$$\ln(CPUE_i) = Year_{y_i} + \varepsilon_i \ . \tag{7}$$

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

$$\ln(CPUE_i) = Year_{y_i} + ns(Soak_{si}, df) + Month_{m_i} + Area_{ai} + Vessel_{vi} + Captain_{ci} + Gear_{gi} + ns(Depth_{di}, df) + ns(VesSoak_{vsi}, df) + \varepsilon_i \ , \tag{8}$$

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

We fitted the binomial component of the delta model on catch success (0 or 1) as response variable with the same maximum set of explanatory variables. We used a binomial logit link function in the GLM fitting process.

Negative binomial model

For the negative binomial GLM on positive and zero catches, we assumed the null model to be

$$CPUE_i = Year_{y_i} + \varepsilon_i \ . \tag{9}$$

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

$$CPUE_I = Year_{y_i} + ns(Soak_{si}, df) + Month_{m_i} + Area_{ai} + Vessel_{vi} + Captain_{ci} + Gear_{gi} + ns(Depth_{di}, df) + ns(VesSoak_{vsi}, df) + \varepsilon_i \ , \tag{10}$$

We used a log link function and a dispersion parameter (θ) value in the GLM fitting process.

Results

The distributions of legal crab catch by year in observer data are skewed to the right with small proportions of zero and large proportions of positive catches (Figures 4 and 19 for EAG and WAG, respectively). Thus supporting the families of distributions used in the GLM. The *Year*, *Captain*, *Vessel*, and *Gear* produced low Akaike Information Criterion (*AIC*) values under delta model (combination of lognormal and binomial models) GLMs (Table 3). $AIC = -2\ln(L) + 2k$, where L = maximum likelihood estimate and k=number of parameters (Burnham and Anderson, 2002).

The forward GLM selection procedure produced a suite of final GLM models for the EAG and WAG data for different time periods 1995/04–2004/05 and 2005/06–2012/13 (Tables 6 and 12 for delta model and Tables 7 and 13 for negative binomial model for EAG and WAG, respectively). All final models selected the *Captain* predictor variable.

Tables 8 and 14 provide the analysis of deviance values for delta (lognormal and binomial) and negative 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 R^2 as each selected predictor variable was added. Lognormal and negative binomial GLM fits produced higher R^2 values than the binomial fit for both regions.

We considered *Year*:*Captain*, *Year*:*Gear*, *Year*:*Area*, *Year:Soak*,*Year:Depth*, and *Year*:*Month* interactions one at a time for different subsets of data for EAG and WAG legal size catches (Tables 6,7,12, and 13). The *Year:Captain* and *Year:Gear* interactions were selected by the delta and the negative binomial models for 1995/96–2004/05 data set, but with little improvement in R^2 . Only the *Year:Captain* interaction was selected by the 2005/06–2012/13 data set, but with little improvement in R^2 . Stepwise selection procedure with other interaction terms either did not select the interaction for either model or did not improve R^2.

The yearly CPUE index estimates by the delta (lognormal and binomial) and negative binomial GLM fits were similar for WAG. But the index estimates by the negative binomial fit were slightly low during initial years of 1995/96–2004/05 for EAG(Tables 9 and 15).

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 2005/06–2012/13 periods and for east (EAG) and west (WAG) of 174°W longitude. The parameter estimates are provided in non-log space as well.

The CPUE trends of core vessels and all vessels were very similar largely due to core vessels were almost identical to all vessels during this time period (Figures 3 and 18 for EAG and WAG, respectively).

Significant correlations existed between *Year* versus *VesSoak* and *SoakDays*, and *Month* versus *VesSoak* as depicted in the one-to-one bivariate scatter plot for EAG (Figure 5). On the other hand, *Year* versus *SoakDays* and *VesSoak* scatter plots showed significant correlations for WAG (Figure 20). However, 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, if not selected.

The studentized residual plots for the 1995/96–2004/05 data sets for the two regions appeared satisfactory, but there were systematic departure from the error assumptions for the 2005/06–2012/13 data sets, with studentized residuals deviating grossly from the 1-to-1 lines (Figures 6 and 21 for EAG and WAG, respectively). We considered two possible approaches for addressing that apparent departure from the error assumptions: 1) Use of a different error distribution model; and 2) Trimming the data to satisfy the current error assumptions. For simplicity, we preferred the second option. We trimmed the original 2005/06–2012/13 data sets by excluding records with standardized normal errors falling outside a two-standard-error limit, which we assumed to be outliers. Trimming reduced the core vessel data size from 5,018 to 4,778 records (a 4.8% reduction) for EAG and from 7,453 to 7061 (a 5.3% reduction) for WAG. Trimming the data by removal of outliers improved the residual pattern (Figures 6 and 21) and we used these data subsets in subsequent analysis.

The loess smoother of the Pearson and deviance residuals versus the explanatory variables and linear predictors for the lognormal and negative binomial fits respectively were nearly horizontal for all

predictor variables and the linear predictors for the two data sets (Figures 7, 8 and 22, 23 for EAG and WAG, respectively). The median value for *Gear* categorical level 80 was low for the negative binomial fit deviance residual plot for EAG (Figure 8), but that level represents bottom fish pot gear and its relative contribution to golden king crab bycatch was very low.

The observed versus predicted response variable points in negative binomial models fits plots were more compact (Figures 9 and 24) than those in the lognormal model fit plots although points were widely scattered, which was reflected in low R^2 values.

The observed versus predicted proportion of positive catches by the binomial and negative binomial models fits for the two time series of data were closer to 1-to-1 line supporting the adequacy of those model fits (Figures 10 and 25 for EAG and WAG, respectively).

The *Year* indices were significantly affected only by *Gear* and *Month* categorical variables for the lognormal model and the *Gear* categorical variable for the negative binomial model for the 1995/96–2004/05 data set, but none of the final model explanatory variables had any significant effect on *Year* indices for the 2005/06–2012/13 data set (Figures 11 and 26 for EAG and WAG, respectively). The annual influence values of each final model variables (Figures 12 and 27 for EAG and WAG, respectively) and CDI plots (Figures 13-16 and 28-31 for EAG and WAG, respectively) of final model variables also supported the same conclusion.

The CPUE indices systematically increased from 1995/96 to 2004/05 and leveled off at higher levels during 2005/06–2010/11, slightly increased in 2011/12, and dipped slightly lower in 2012/13 in EAG (Figure 17). The trends in WAG CPUE indices were somewhat different. During the 1995/96–2004/05 period, the CPUE dropped during the first three year, increased in 1998/99, dropped during 1999/00–2001/02 and systematically increased thereafter. The 2005/06–2012/13 CPUE indices were flat (Figure 32). All CPUE indices (combined, negative binomial, lognormal, arithmetic) tracked closely, but not the binomial indices, which fluctuated over the years. The standardized indices closely tracked the nominal

(arithmetic) indices for both data sets, but were slightly lower except for the WAG 2005/06–2012/13 data during 2010//11–2012/13 (Figures 17 and 32 for EAG and WAG, respectively).

Discussion

We compared two statistical models, delta model (consisting of two sub models: lognormal and binomial) and negative binomial model, for the standardization of two sets of observer data from the EAG and WAG golden king crab fishery. The relative merit of fits explained by R^2 did not provide a clear choice of one model over the other for standardization. The trends in estimated CPUE indices by the two models were close, suggesting that the models were robust to mis-specification of error distributions for the current data sets. However, some of the diagnostic plots (e.g., observed response variable versus linear predictor) provided support for the negative binomial over the delta model. The different trends in the binomial CPUE indices also provided less confidence on the use of delta model for CPUE standardization of these data sets. Furthermore, 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 was an alternative to the Poisson distribution when there was overdispersion (i.e., when var > mean) (Zuur et al., 2009) as seen in some of our data sets. The negative binomial distribution only fits into the framework of traditional GLM when the value of dispersion parameter was assumed to be known (Fox and Weisberg, 2011). Although there are other approaches to estimate the dispersion parameter along with the linear predictor model parameters, we used a grid search method to obtain the optimum dispersion parameter value to use it in the framework of traditional GLM. The standardized CPUE trends based on the negative binomial model were similar to those based on delta model (combination of lognormal and binomial families) and R^2 values were also similar. 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. However, we opted for using the CPUE indices based on negative binomial models for reasons provided previously.

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 R^2. The only substantial interaction was for *Year*:*Captain* . However, even for this interaction, the R^2 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 R^2. 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).

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 1995/96–2012/13 data sets. We were unable to use the long-term fish ticket (1985/86–2012/13) 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 EAG and WAG legal male golden king crab. We realized the difficulty in sub setting post-rationalization period data for standardization. In the future, we will evaluate the use of the standardized CPUE data as a relative index of stock abundance for use in stock assessment models. 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).

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Tables

Aleutian Islands (EAG and WAG)

Table 1. Pre-and post-rationalization periods' percentile cut off *Soak* time (day) and *Depth* (fathom), and trimmed number (n) of observer records for east (EAG) and west (WAG) of 174°W longitude. The 5%–95% percentile range for *Soak* time and 1%–99% percentile range for *Depth* were used on observer data for 1995/96– 2012/13.

Area	Number of records	Variable	Percentile range	
			Pre-rationalization (1995/96– 2004/05)	Post-rationalization (2005/06– 2012/13)
EAG		*Soak* (day)	2–10	5–28
		Depth (fathom)	73–340	83–321
	n		31,663	5,018
WAG		*Soak* (day)	2–24	9–43
		Depth (fathom)	74–310	85–289
	n		32,468	7,453

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 categorical 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 1995/96–2004/05 and 2005/06–2012/13 periods and for east (EAG) and west (WAG) of 174°W longitude.

		AIC			
		EAG		WAG	
Link	**Parameter/Variable**	**1995/06–2004/05**	**2005/06–2012/13**	**1995/06–2004/05**	**2005/06–2012/13**
Lognormal	*Year*	77,154	12,215	75,517	19,370
	Soak	80,015	12,282	74,518	19,331
	Month	77,687	12,378	75,508	19,316
	Captain	77,102	12,185	73,120	19,220
	Vessel	79,069	12,195	73,356	19,226
	Area	80,258	12,412	75,539	19,289
	Gear	76,009	12,365	74,349	19,336
	Depth	80,542	12,419	76,239	19,351
	EastVesSoak	80,245	12,415		
	WestVesSoak			75,944	19,384
Binomial	*Year*	20,512	912	29,675	2,746
	Soak	20.882	917	29,429	2,778
	Month	20,651	913	29,487	2,753
	Captain	20,097	893	28,427	2,727
	Vessel	20,773	891	28,368	2,717
	Area	20,946	922	29,492	2,764
	Gear	20,024	928	29,038	2,780
	Depth	20,887	921	29,887	2,769
	EastVesSoak	21,044	914		
	WestVesSoak			29,951	2,761

EAG

Table 4. Selection of degrees of freedom (*df*) for cubic spline functions of predictor variables for CPUE standardization of the eastern Aleutian Islands (EAG) golden king crab. The *df* values were selected based on minimum AIC. For the negative binomial family, dispersion parameter values of 1.39 and 3.05 for 1995/96-2004/05 and 2005/06-2012/13 fishing periods, respectively were used.

Fishing Period	1995/96–2004/05		2005/06–2012/13	
Predictor Variable	Minimum AIC	df	Minimum AIC	df
		Lognormal		
Soak	79522	5	9377	13
Depth	80409	16	9584	5
VesselSoak	77154	9	9370	6
		Binomial		
Soak	20728	12	907	4
Depth	20874	7	906	37
VesselSoak	20512	9	897	3
		Negative Binomial		
Soak	189430	3	40452	18
Depth	190280	16	40675	5
VesselSoak	187079	9	40463	6

Table 5. Summary of observer data from core vessels used in the standardization of annual CPUE and the zero proportion of catch for eastern Aleutian Islands (EAG) golden king crab.

Fishing season	Vessels	Mean soak time (days)	Mean nominal CPUE (number/pot lift)	Zero catch proportion
1995/96	18	4.76	5.57	0.16
1996/97	14	4.54	5.29	0.19
1997/98	15	4.85	7.65	0.12
1998/99	14	4.33	9.28	0.11
1999/00	15	4.23	9.12	0.11
2000/01	15	4.65	9.73	0.07
2001/02	19	4.54	13.19	0.06
2002/03	19	4.41	13.14	0.06
2003/04	18	4.17	12.21	0.06
2004/05	19	4.19	19.73	0.04
2005/06	7	13.11	29.45	0.04
2006/07	6	11.65	25.00	0.03
2007/08	4	15.91	31.09	0.02
2008/09	3	14.55	29.71	0.01
2009/10	3	15.98	26.58	0.01
2010/11	3	14.28	26.26	0.03
2011/12	3	17.78	39.31	0.008
2012/13	3	17.54	37.84	0.002

Table 6. Step-wise model selection for delta model (lognormal and binomial families) including interactions for the Aleutian Islands golden king crab observer data. Step GLM function was used for selection of variables and final fit. Observer data for EAG (east of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used. Explanatory variables are listed in the order of selection to the model. R^2 determines the relative merit of each fit. The 2005/06–2012/13 data set was trimmed..

Fishing season	**Final model**	**R^2**
1995/96–2004/05	a. *ln(CPUE) = Year+Gear+Captain +ns(Soak, df=5)+Month*	0.25
	Binomial(Success)=Year+Captain +Gear	0.09
	b. *ln(CPUE) = Year+Gear+Captain +ns(Soak, df=5) +Year:Gear*	0.25
	Binomial(Success) =Year+Captain +Gear+Year:Gear	0.10
	c. *ln(CPUE) = Year+Gear+Captain +Year:Captain*	0.26
	Binomial(Success) =Year+Captain +Gear+Year:Captain	0.11
	d. *ln(CPUE) = Year+Gear+Captain +ns(Soak, df=5) +Year:Soak*	0.24
	Binomial(Success): did not pick up Year:Soak	
	e. Did not pick up *Year:Month*	
2005/06–2012/13	a. *ln(CPUE) = Year+Captain+ns(Soak, df=13)+Gear*	0.13
	Binomial(Success) = Year+ns(Depth, df=37)+Captain+Month	0.16
	b. *ln(CPUE) = Year+Captain+ns(Soak, df=13)+Gear +Year:Captain*	0.14
	Binomial(Success): did not pick up Year:Captain	
	c. *Did not pick up Year:Gear*	
	d. *Did not pick up Year:Soak*	
	e. Did not pick up *Year:Month*	
	f. Did not pick up *Year:Depth*	

Table 7. Step-wise model selection for negative binomial family including interactions for the Aleutian Islands golden king crab observer data. Step GLM function was used for selection of variables and final fit. Observer data for EAG (east of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used. Explanatory variables are listed in the order of selection to the model. R^2 determines the relative merit of each fit. The 2005/06–2012/13 data set was trimmed.. θ = dispersion parameter of the negative binomial distribution.

Fishing season	**Final model**	**R^2**
1995/96–2004/05	a. *Negative Binomial: CPUE = Year+Gear+Captain , θ=1.39*	0.23
	b. *Negative Binomial: CPUE = Year+Gear+Captain+Year:Captain , θ=1.39*	0.26
	c. *Negative Binomial: CPUE = Year+Gear+Captain+ns(Soak, df=3)+Year:Gear , θ=1.39*	0.26
	d. *Did not pick up Year:Soak*	
2005/06–2012/13	e. *Negative Binomial: CPUE= Year+Captain +ns(Soak, df=18)+Gear,θ=3.05*	0.13
	f. *Did not pick up Year:Captain*	
	g. *Did not pick up Year:Soak*	
	h. *Did not pick up Year:Gear*	

Table 8. Analysis of deviance for stepwise lognormal, binomial and negative binomial models selection for CPUE standardization. Explanatory variables are listed in the order of acceptance to the model. Acceptance tolerance was set to R^2 difference >= 0.01. Aleutian Islands golden king crab observer data from EAG (east of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used. The 2005/06–2012/13data set was trimmed.. Explanatory variables are listed in the order of selection to the model.R^2 = proportion of deviance explained.

model	Fishing period	Predictor variable	DF	Deviance	R^2
Lognormal	1995/96–2004/05	*Year*	0	19.89	0.11
		Gear	14	27.92	0.20
		Captain	40	79.97	0.23
		Soak	5	9.99	0.24
		Month	11	21.99	0.25
	2005/06–2012/13	*Year*	0	15.95	0.05
		Captain	8	15.95	0.10
		Soak	13	25.98	0.12
		Gear	6	11.99	0.13
Binomial	1995/96-2004/05	*Year*	0	19.97	0.03
		Captain	40	79.96	0.07
		Gear	14	27.98	0.09
	2005/06–2012/13	*Year*	0	15.97	0.03
		Depth	37	73.92	0.11
		Captain	8	15.96	0.15
		Month	7	13.99	0.16
Negative Binomial	1995/96-2004/05	*Year*	0	19.90	0.10
		Gear	14	27.90	0.20
		Captain	40	79.97	0.23
	2005/06–2012/13	*Year*	0	15.96	0.04
		Captain	8	15.95	0.09
		Soak	18	35.98	0.11
		Gear	6	11.98	0.13

Table 9. Time series of standardized CPUE indices with standard errors for delta and negative binomial error models. The combined CPUE indices for delta model were estimated by bootstrap. Aleutian Islands golden king crab observer data from EAG (east of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used. The 2005/06–2012/13 data set was trimmed.

Fishing Season	Combined CPUE Index (Bootstrap mean)	Standard Error (Bootstrap Standard Error)	Negative Binomial CPUE Index	Standard Error
1995/96	0.8649	0.0008	0.7340	0.0224
1996/97	0.8407	0.0005	0.7581	0.0168
1997/98	0.8421	0.0006	0.7907	0.0191
1998/99	0.9715	0.0006	0.9543	0.0175
1999/00	0.9043	0.0005	0.8838	0.0174
2000/01	0.8519	0.0004	0.9065	0.0155
2001/02	1.1237	0.0007	1.1842	0.0180
2002/03	1.1619	0.0009	1.2605	0.0215
2003/04	1.0313	0.0008	1.1054	0.0206
2004/05	1.6249	0.0016	1.8020	0.0270
2005/06	1.1116	0.0011	1.1188	0.0248
2006/07	0.8865	0.0008	0.9122	0.0230
2007/08	1.0086	0.0009	1.0223	0.0215
2008/09	0.9939	0.0009	0.9918	0.0240
2009/10	0.8254	0.0009	0.8247	0.0298
2010//11	0.8000	0.0009	0.8321	0.0285
2011/12	1.2620	0.0013	1.2270	0.0302
2012/13	1.2193	0.0010	1.1476	0.0273

WAG

Table 10. Selection of degrees of freedom (df) for cubic spline functions of predictor variables for CPUE standardization of the western Aleutian Islands (WAG) golden king crab. The df values were selected based on minimum AIC. For the negative binomial family, dispersion parameter values of 0.98 and 1.73 for 1995/96–2004/05 and 2005/06–2012/13 fishing periods, respectively were used.

Fishing Period	1995/96–2004/05		2005/06–2012/13	
Predictor Variable	Minimum AIC	df	Minimum AIC	df
		Lognormal		
Soak	74067	15	16491	9
Depth	76032	10	16565	3
VesselSoak	75516	8	16626	5
		Binomial		
Soak	29165	8	2836	9
Depth	29813	10	2860	3
VesselSoak	29673	8	2836	7
		Negative Binomial		
Soak	170897	16	57656	9
Depth	172530	18	57704	6
VesselSoak	172140	8	57823	7

Table 11. Summary of observer data from core vessels used in the standardization of annual CPUE and the zero proportion of catch for western Aleutian Islands (WAG) golden king crab.

Fishing season	Vessels	Mean soak time (days)	Mean nominal CPUE (number/pot lift)	Zero catch proportion
1995/96	18	6.09	6.26	0.18
1996/97	13	7.09	5.85	0.23
1997/98	9	7.24	6.58	0.19
1998/99	3	8.20	9.42	0.10
1999/00	17	8.09	6.06	0.18
2000/01	12	8.96	6.59	0.20
2001/02	9	10.69	6.51	0.17
2002/03	6	10.25	7.46	0.16
2003/04	6	11.66	9.30	0.12
2004/05	6	11.53	11.14	0.11
2005/06	3	21.34	23.56	0.08
2006/07	3	20.83	23.19	0.08
2007/08	3	22.00	20.67	0.05
2008/09	3	23.13	24.53	0.03
2009/10	3	25.52	26.38	0.03
2010/11	3	23.31	22.20	0.06
2011/12	3	25.47	23.58	0.00
2012/13	4	23.21	22.82	0.03

Table 12. Step-wise model selection for delta model (lognormal and binomial families) including interactions for the Aleutian Islands golden king crab observer data. Step GLM function was used for selection of variables and final fit. Observer data for WAG (west of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used. Explanatory variables are listed in the order of selection to the model. R^2 determines the relative merit of each fit. The 2005/06–2012/13 data set was trimmed.

Fishing season	**Final model**	**R^2**
1995/96–2004/05	a. *ln(CPUE) = Year+Captain +ns(Soak, df=15)+Gear*	0.17
	Binomial(Success)=Year+Captain +Gear	0.07
	b. *ln(CPUE) = Year+Captain +ns(Soak, df=15)+Gear +Year:Gear*	0.18
	Binomial(Success) =did not pick up Year:Gear	
	c. *ln(CPUE) = Year+Captain +ns(Soak, df=15+Gear+Year:Captain*	0.20
	Binomial(Success) =Year+Captain +Year:Captain	0.09
	d. *Did not pick up Year:Soak*	
2005/06–2012/13	a. *ln(CPUE) = Year+Captain*	0.05
	Binomial(Success) = Year+Captain+ns(Soak, df=9)	0.05
	b. *ln(CPUE) = Year+Captain +Year:Captain*	0.06
	Binomial(Success): Year+Captain +ns(Soak,9)+Year:Captain	0.06

Table 13. Step-wise model selection for negative binomial family including interactions for the Aleutian Islands golden king crab observer data. Step GLM function was used for selection of variables and final fit. Observer data for WAG (west of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used. Explanatory variables are listed in the order of selection to the model. R^2 determines the relative merit of each fit. The 2005/06–2012/13 data set was trimmed. θ = dispersion parameter of the negative binomial distribution.

Fishing season	**Final model**	**R^2**
1995/96–2004/05	f. *Negative Binomial: CPUE = Year+Captain+Gear+ ns(Soak, df=14), θ =0.98*	0.18
	b. *Negative Binomial: CPUE = Year+Captain+ ns(Soak, df=14)+Gear+Year:Captain, θ =0.98*	0.20
	c. *Negative Binomial: CPUE = Year+Captain+Gear+ ns(Soak, df=14)+Year:Gear, θ =0.98*	0.19
	d. *Did not pick up Year:Soak*	
2005/06–2012/13	g. *Negative Binomial: CPUE= Year+Captain +ns(Depth, df=6), θ =1.73*	0.06
	f. *Negative Binomial: CPUE= Year+Captain +ns(Depth, df=6)+Year:Captain, θ =1.73*	0.07
	h. *Did not pick up Year:Depth*	

Table 14. Analysis of deviance for stepwise lognormal, binomial and negative binomial models selection for CPUE standardization. Explanatory variables are listed in the order of acceptance to the model. Acceptance tolerance was set to R^2 difference >= 0.01. Aleutian Islands golden king crab observer data from WAG (west of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used. The 2005/06–2012/13data set was trimmed. Explanatory variables are listed in the order of selection to the model. R^2 = proportion of deviance explained.

model	**Fishing period**	**Predictor variable**	**DF**	**Deviance**	**R^2**
Lognormal	1995/96–2004/05	*Year*	0	19.97	0.03
		Captain	49	97.90	0.13
		Soak	15	29.98	0.15
		Gear	14	27.98	0.17
	2005/06–2012/13	*Year*	0	15.99	0.01
		Captain	9	17.95	0.05
Binomial	1995/96-2004/05	*Year*	0	19.99	0.01
		Captain	49	97.95	0.06
		Gear	14	27.99	0.07
	2005/06–2012/13	*Year*	0	15.98	0.02
		Captain	9	17.98	0.04
		Soak	9	17.99	0.05
Negative Binomial	1995/96-2004/05	*Year*	0	19.97	0.03
		Captain	49	97.90	0.13
		Gear	14	27.98	0.15
		Soak	14	27.98	0.18
	2005/06–2012/13	*Year*	0	15.99	0.01
		Captain	9	17.96	0.05
		Depth	6	11.99	0.06

Table 15. Time series of standardized CPUE indices with standard errors for delta and negative binomial error models. The combined CPUE indices for delta model were estimated by bootstrap. Aleutian Islands golden king crab observer data from WAG (west of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used. The 2005/06–2012/13 data set was trimmed.

Fishing Season	Combined CPUE Index (Bootstrap mean)	Standard Error (Bootstrap Standard Error)	Negative Binomial CPUE Index	Standard Error
1995/96	1.17299	0.001218	1.174609	0.031282
1996/97	0.96551	0.000669	0.952877	0.021169
1997/98	0.971748	0.000691	0.962178	0.022336
1998/99	1.131641	0.001	1.069213	0.027692
1999/00	0.903342	0.000626	0.911997	0.022062
2000/01	0.841339	0.000574	0.852623	0.020582
2001/02	0.831457	0.000654	0.826745	0.022521
2002/03	0.919292	0.000791	0.923233	0.024177
2003/04	1.141587	0.000924	1.152868	0.023811
2004/05	1.214662	0.000959	1.269221	0.023865
2005/06	1.006992	0.001002	1.039039	0.025614
2006/07	0.938283	0.001029	0.98602	0.027535
2007/08	0.868497	0.00101	0.897315	0.031904
2008/09	1.07233	0.000922	1.065699	0.024469
2009/10	1.068786	0.00102	1.057438	0.025948
2010//11	0.96407	0.000845	0.939377	0.026564
2011/12	1.019016	0.001027	0.976756	0.027985
2012/13	1.086669	0.001096	1.052016	0.027558

Figures

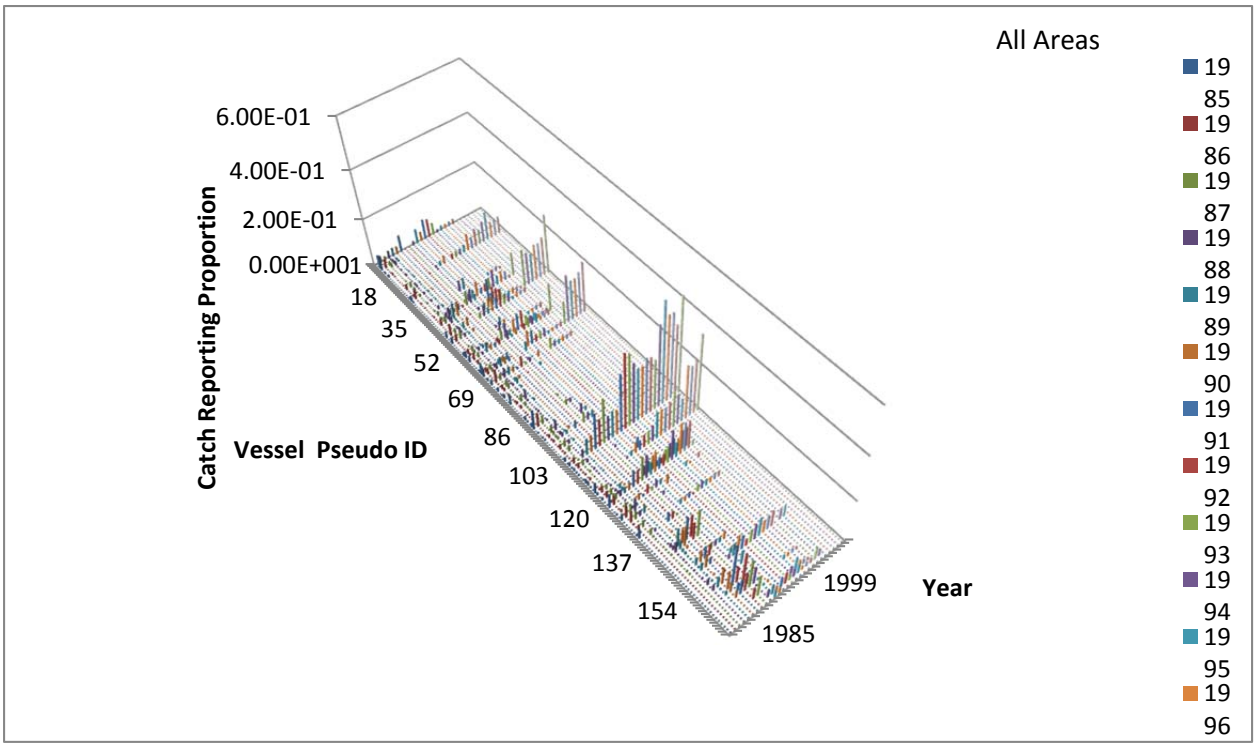

Figure 1. Golden king crab catch reporting frequency by vessel from Aleutian Islands. Fish ticket data from combined east and west of 174°W longitude for 1985/86–2010/11 were used.

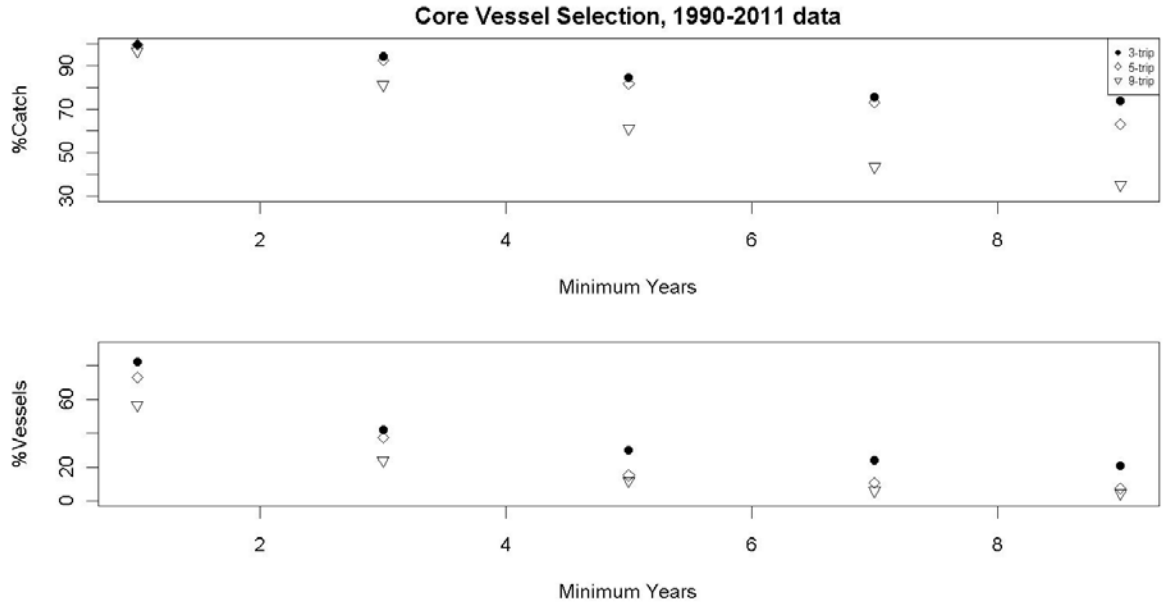

Figure 2. Core vessel selection based for the Aleutian Islands golden king crab fishery. Fish ticket data from combined east and west of 174°W longitude for 1990/91–2010/11 were used. 3-trip = three trips per year; 5-trip = five trips per year; and 9-trip = nine trips per year. The percentage catch and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

EAG

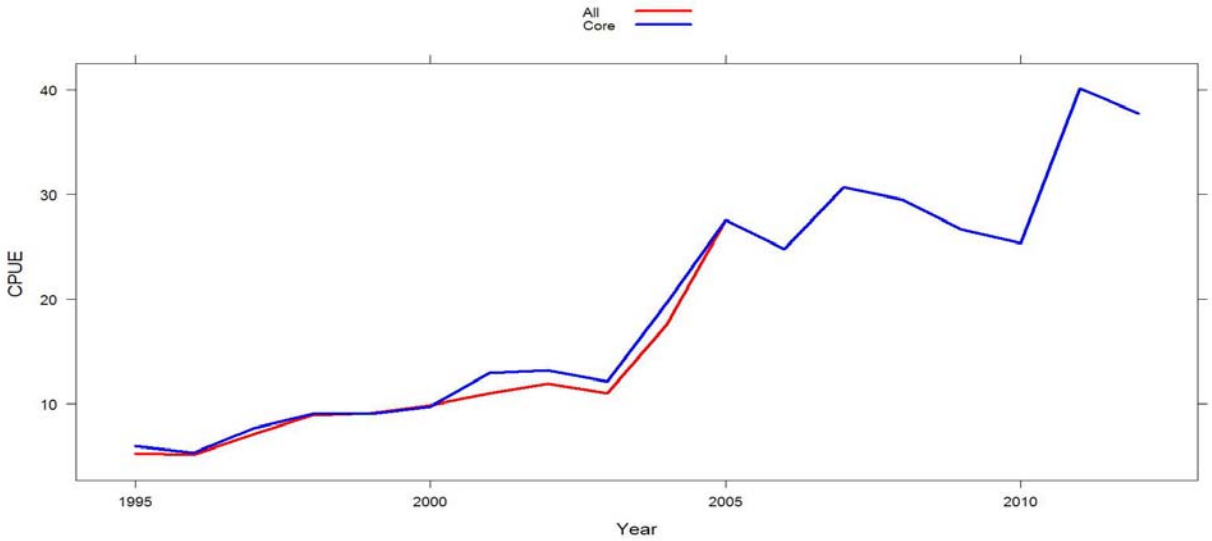

Figure 3. Comparison of legal male CPUE of all and core vessels. Aleutian Islands golden king crab observer data set from EAG (east of 174°W longitude) for 1995/96–2012/13 period was used.

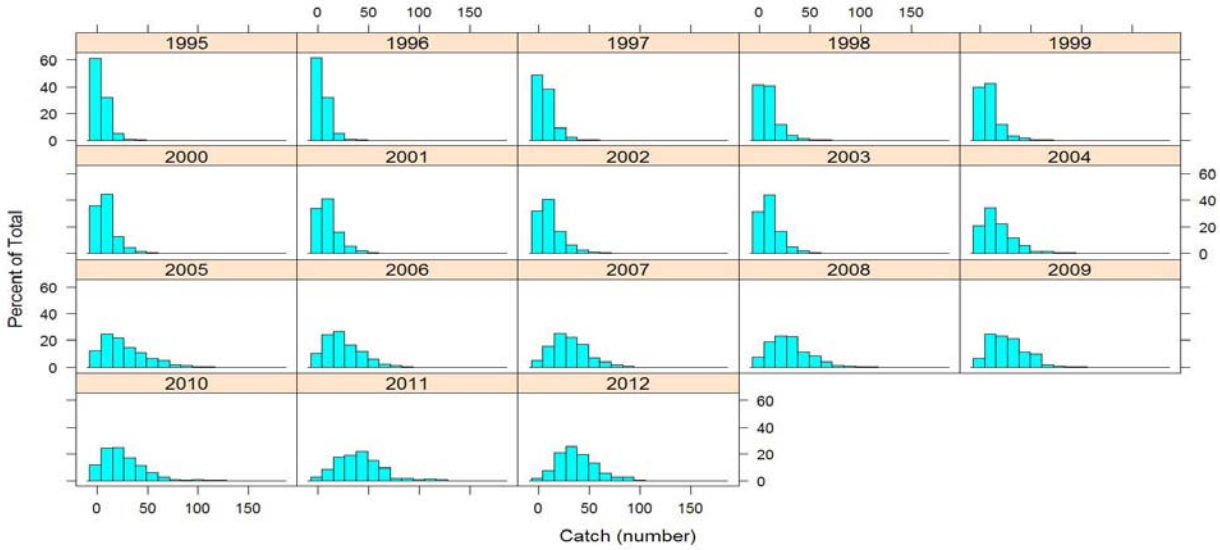

Figure 4. Histograms of observer sample catch by fishing season (1995=1995/96 fishing season) of Aleutian Islands golden king crab from EAG (east of 174°W longitude).

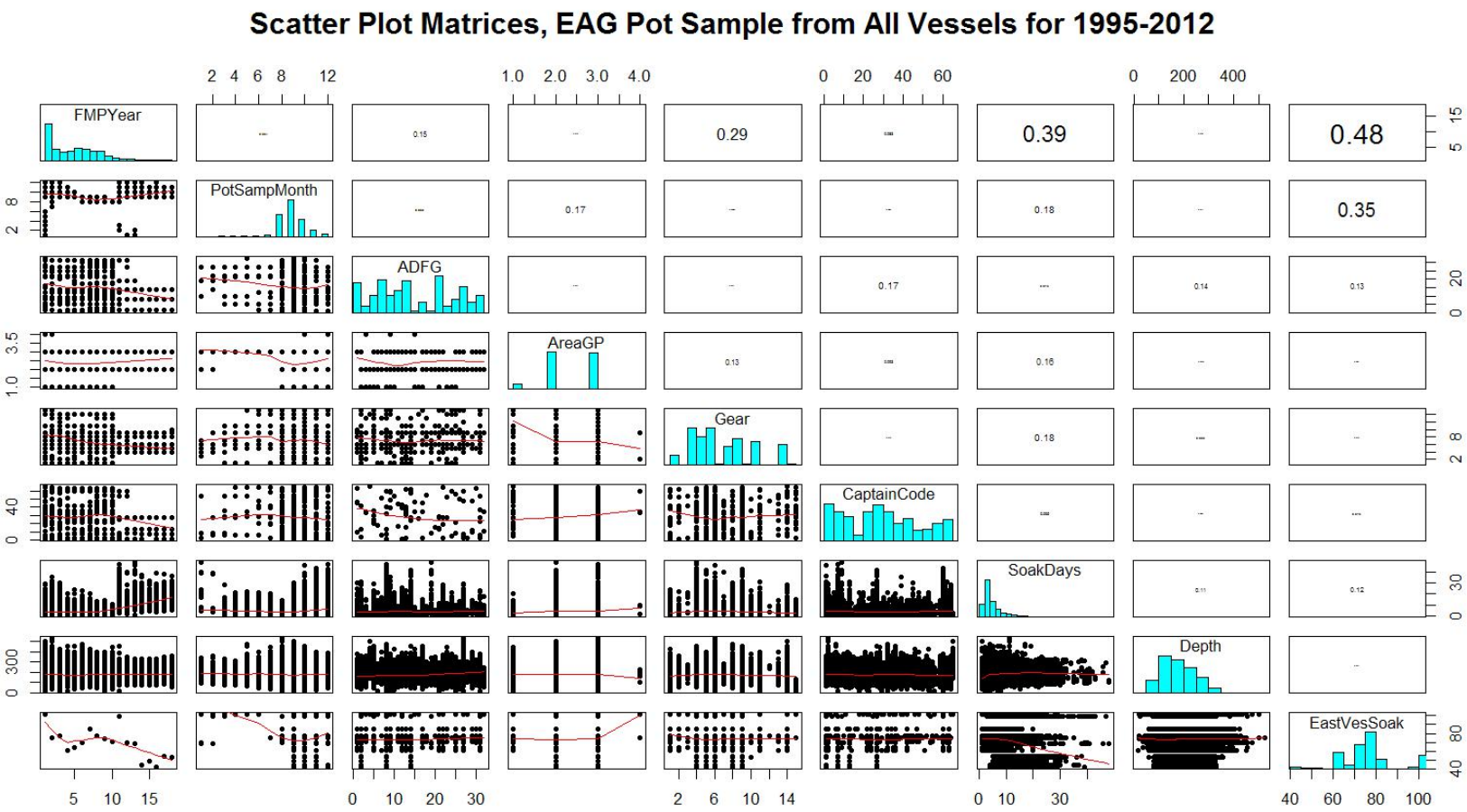

Figure 5. Scatter plot matrices for EAG (east of 174°W longitude) all vessels' observer sample predictor variables. Lowess smooth curves are shown in red. High correlations exist between *Year* versus *EastVesSoak* , *SoakDays*, *Gear*, and *Month* versus *EastVesSoak* .

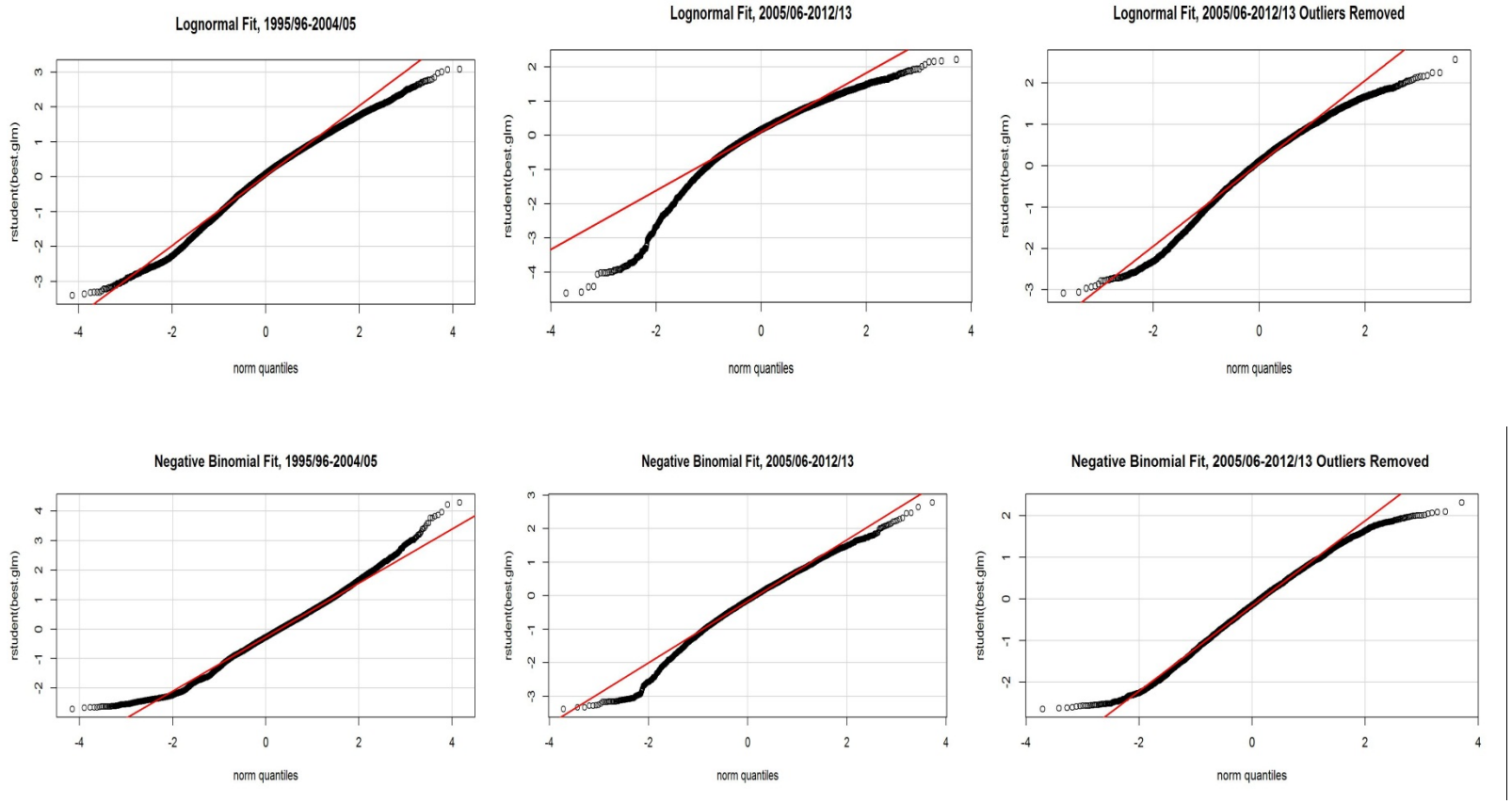

Figure 6. Studentized residual plots after GLM fit for Aleutian Islands golden king crab observer data from EAG (east of 174°W longitude). Top and bottom panels are for lognormal and negative binomial fits, respectively: 1995/96–2004/05 data set (left); 2005/06–2012/13 whole data set (middle); and 2005/06-2012/13 outliers removed (trimmed) data set (right). Outliers= records with standardized normal residuals outside mean residuals ± 2 standard deviations.

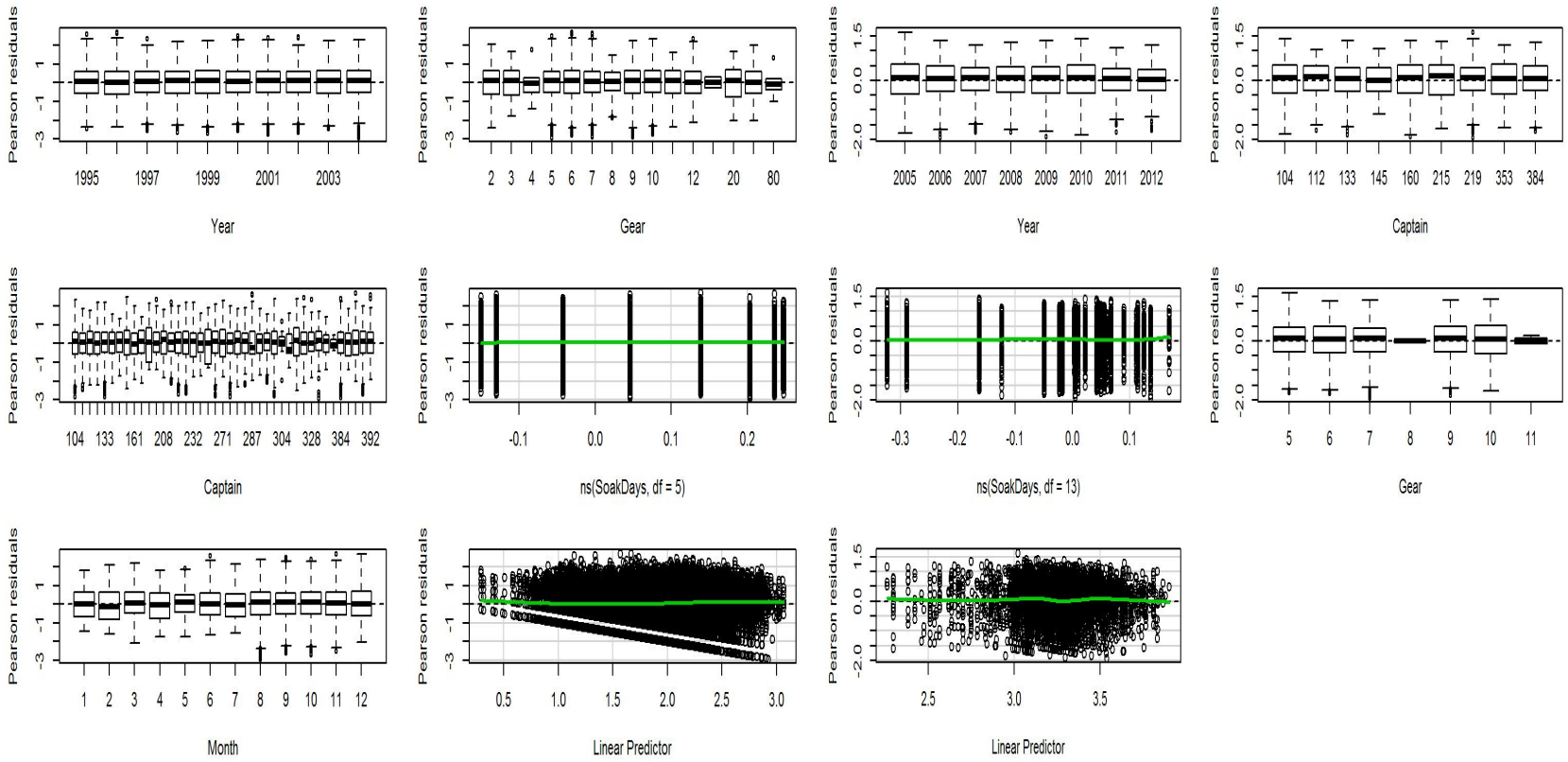

Figure 7. Pearson residuals versus explanatory and response variables of the best lognormal fit model for legal CPUE. Observer data from EAG (east of 174°W longitude) for 1995/96–2004/05 (left) and 2005/06–2012/13 (right) periods were used. The solid lines are the loess smoother through the plotted values.

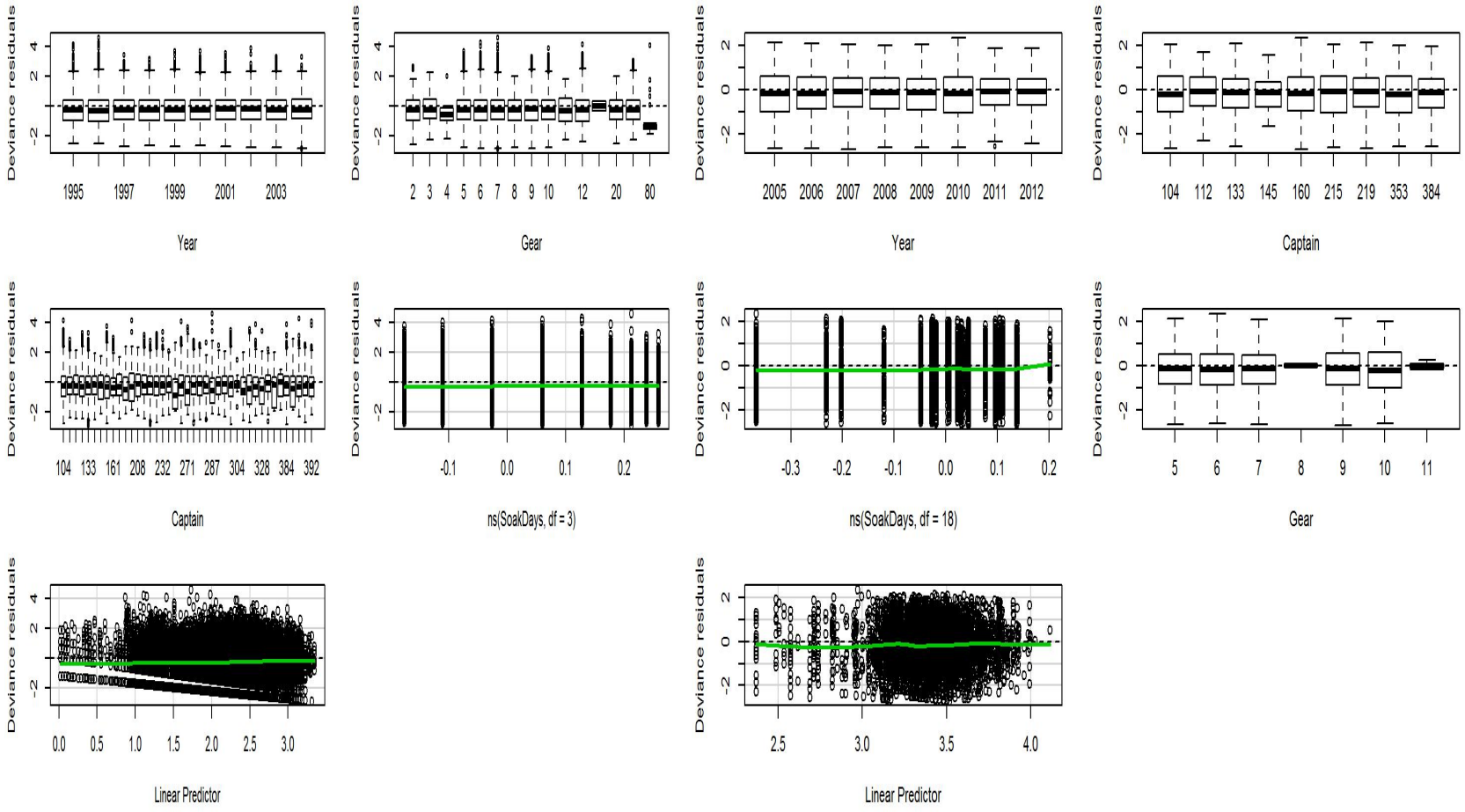

Figure 8. Deviance residuals versus explanatory and response variables of the best negative binomial fit model for legal CPUE. Observer data from EAG (east of 174°W longitude) for 1995/96–2004/05 (left) and 2005/06–2012/13 (right) periods were used. The solid lines are the loess smoother through the plotted values.

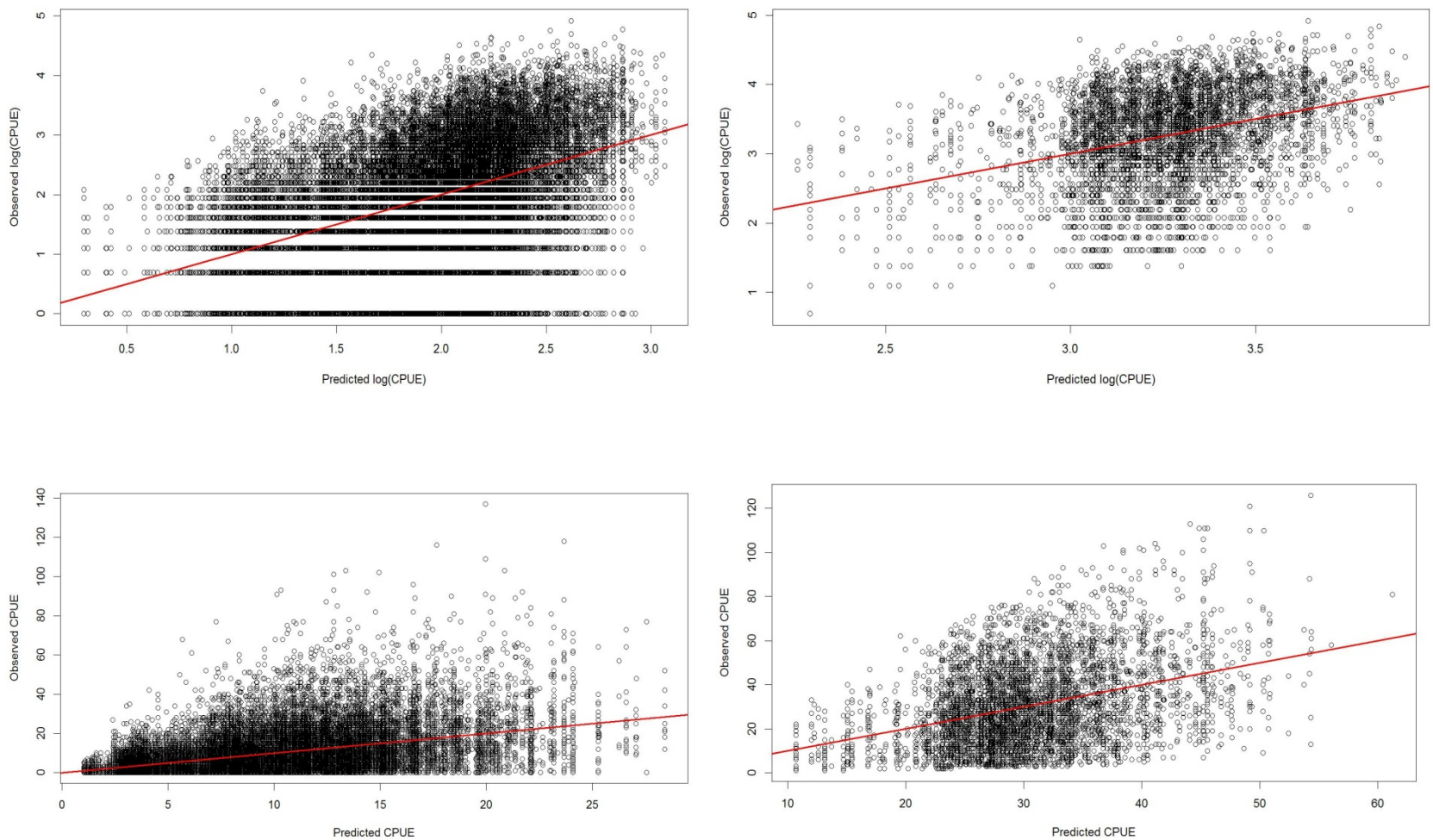

Figure 9. Observed versus predicted response variable of the best fit models for legal CPUE. observer data from EAG (east of 174°W longitude). Top and bottom panels are for lognormal and negative binomial fits, respectively: 1995/96–2004/05 data set (left); 2005/06–2012/13 trimmed data set (right). The solid lines are the 1-1 line.

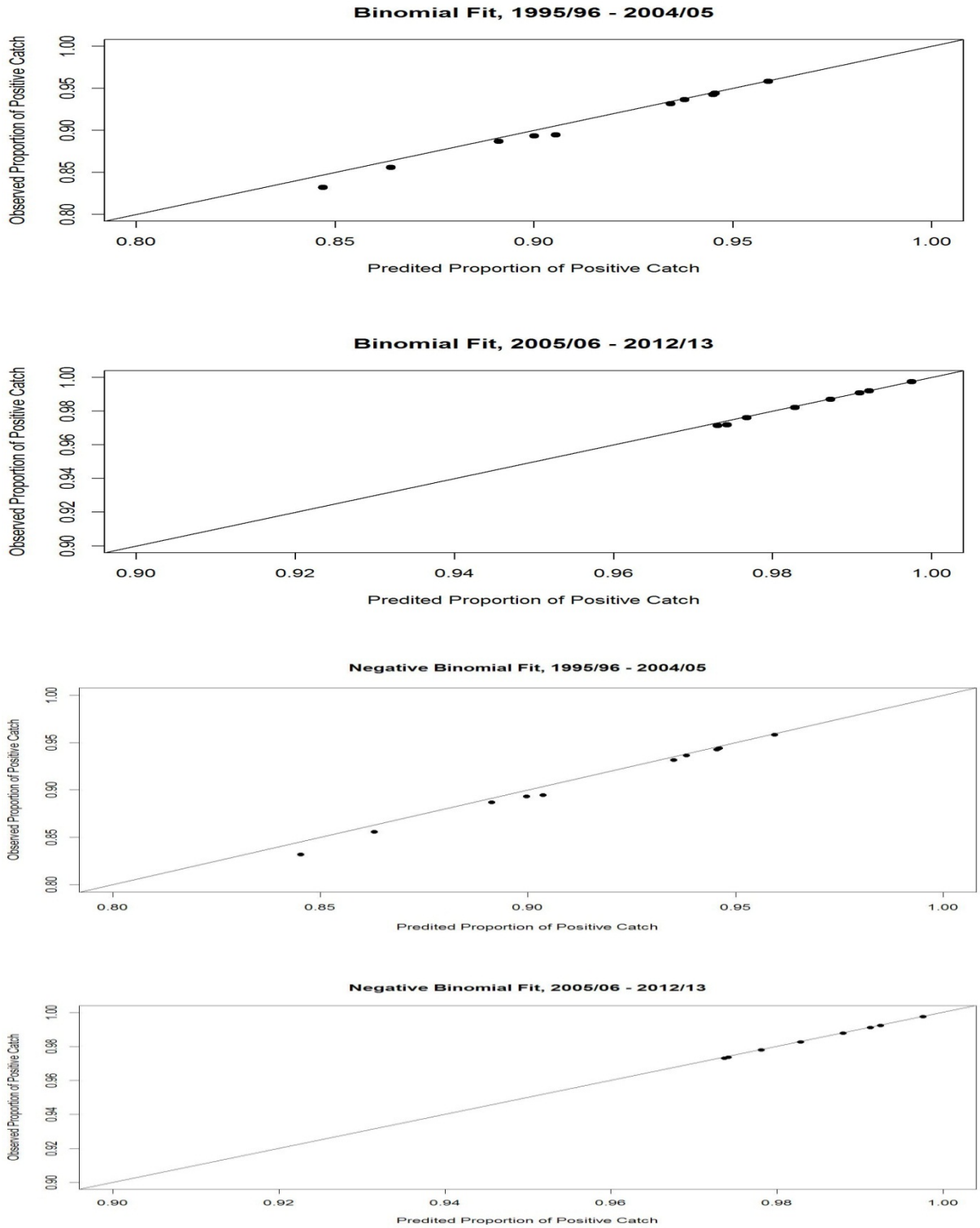

Figure 10. Observed versus predicted positive catch proportions by the binomial and negative binomial models. Aleutian Islands golden king crab observer data from EAG (east of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used.

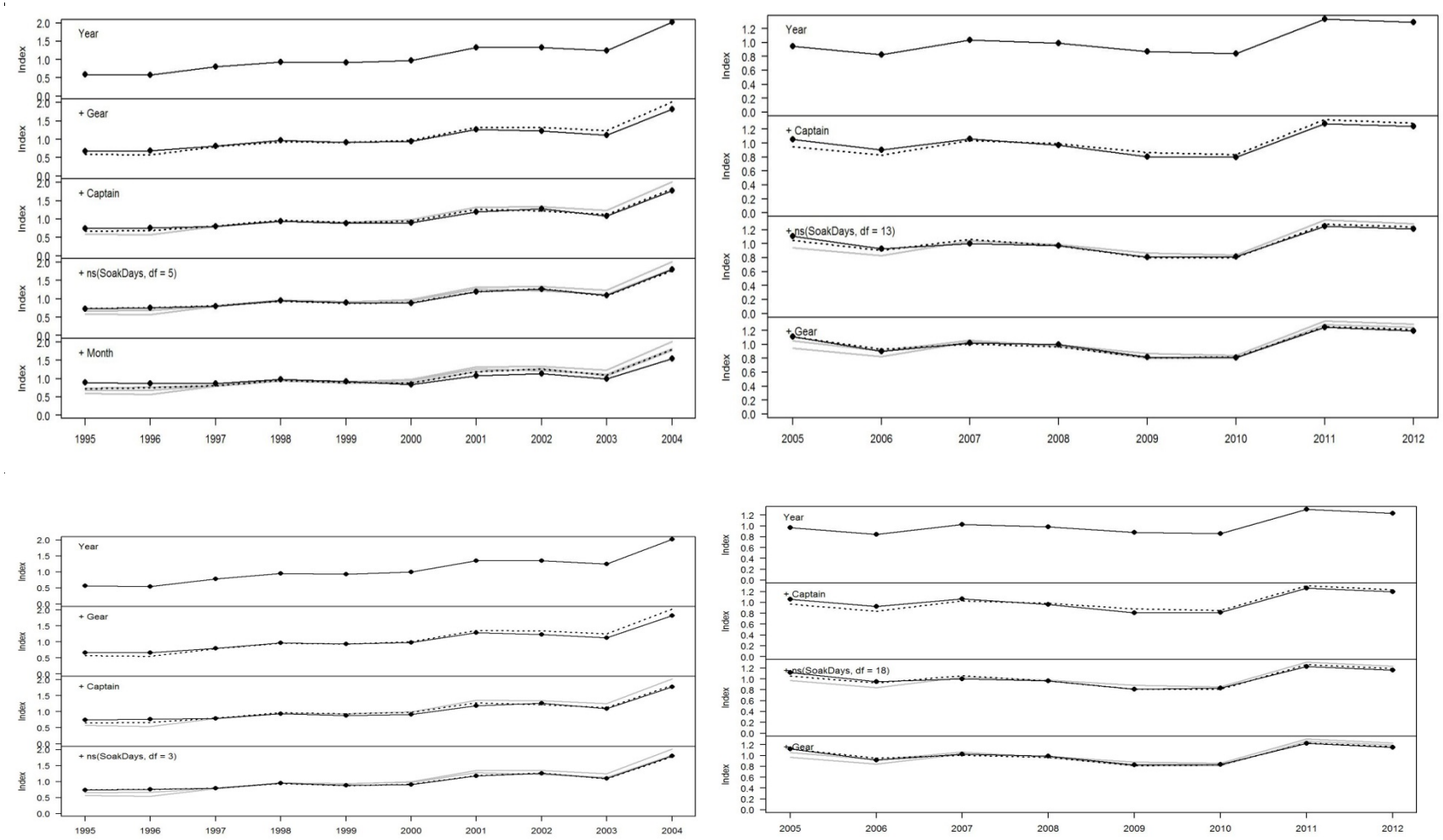

Figure 11. Standardized CPUE index as each explanatory variable is added to the model for Aleutian Islands golden king crab from EAG (east of 174°W longitude). The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. Top row: lognormal error models and bottom row: negative binomial error models. Left column: 1995/96–2004/05 observer data and right column: 2005/06–2012/13 observer trimmed data.

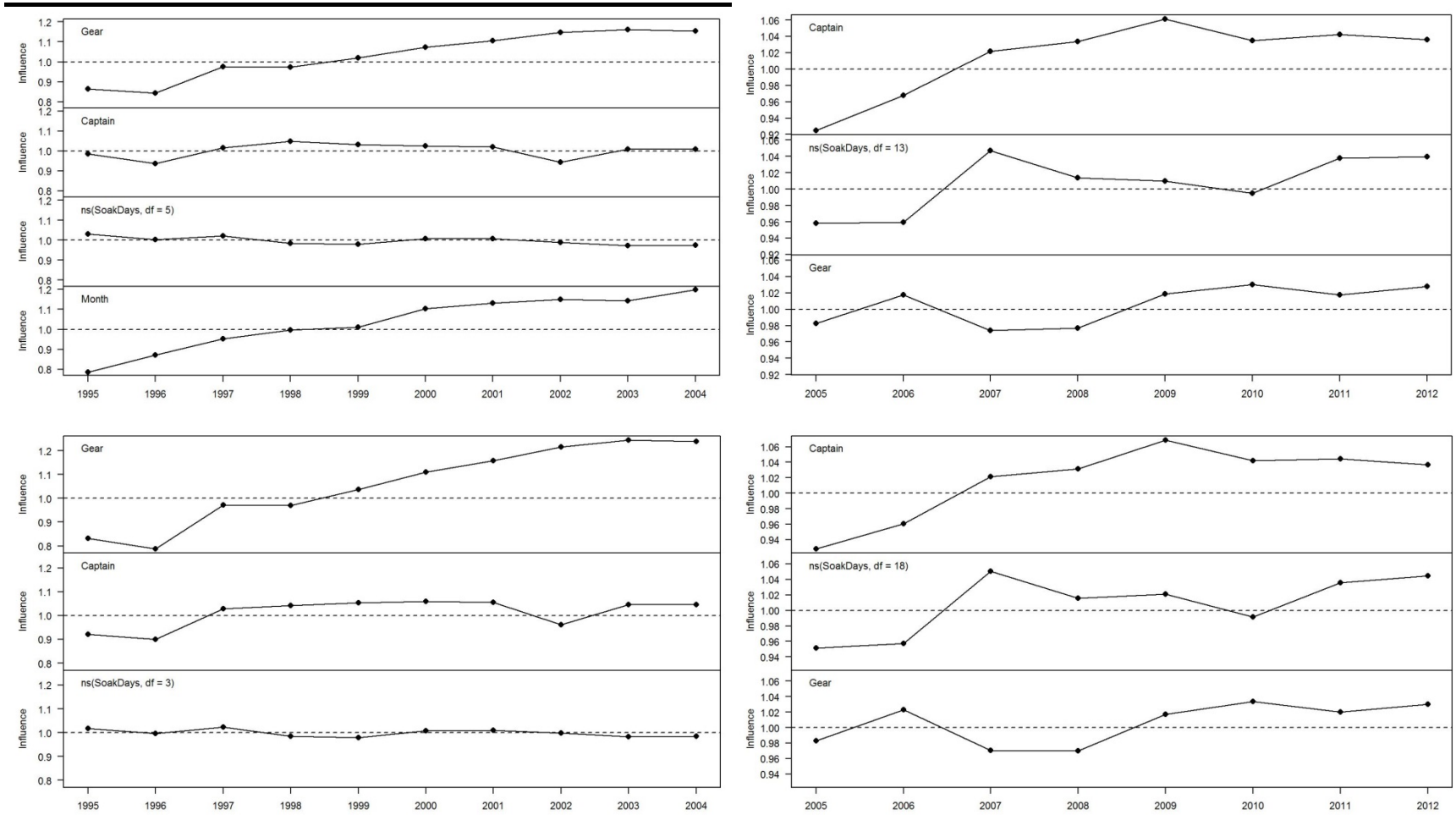

Figure 12. Annual influence values for each explanatory variable in the final GLM model for Aleutian Islands golden king crab from EAG (east of 174°W longitude). Top row: lognormal error models and bottom row: negative binomial error models. Left column: 1995/96–2004/05 observer data and right column: 2005/06–2012/13 observer trimmed data.

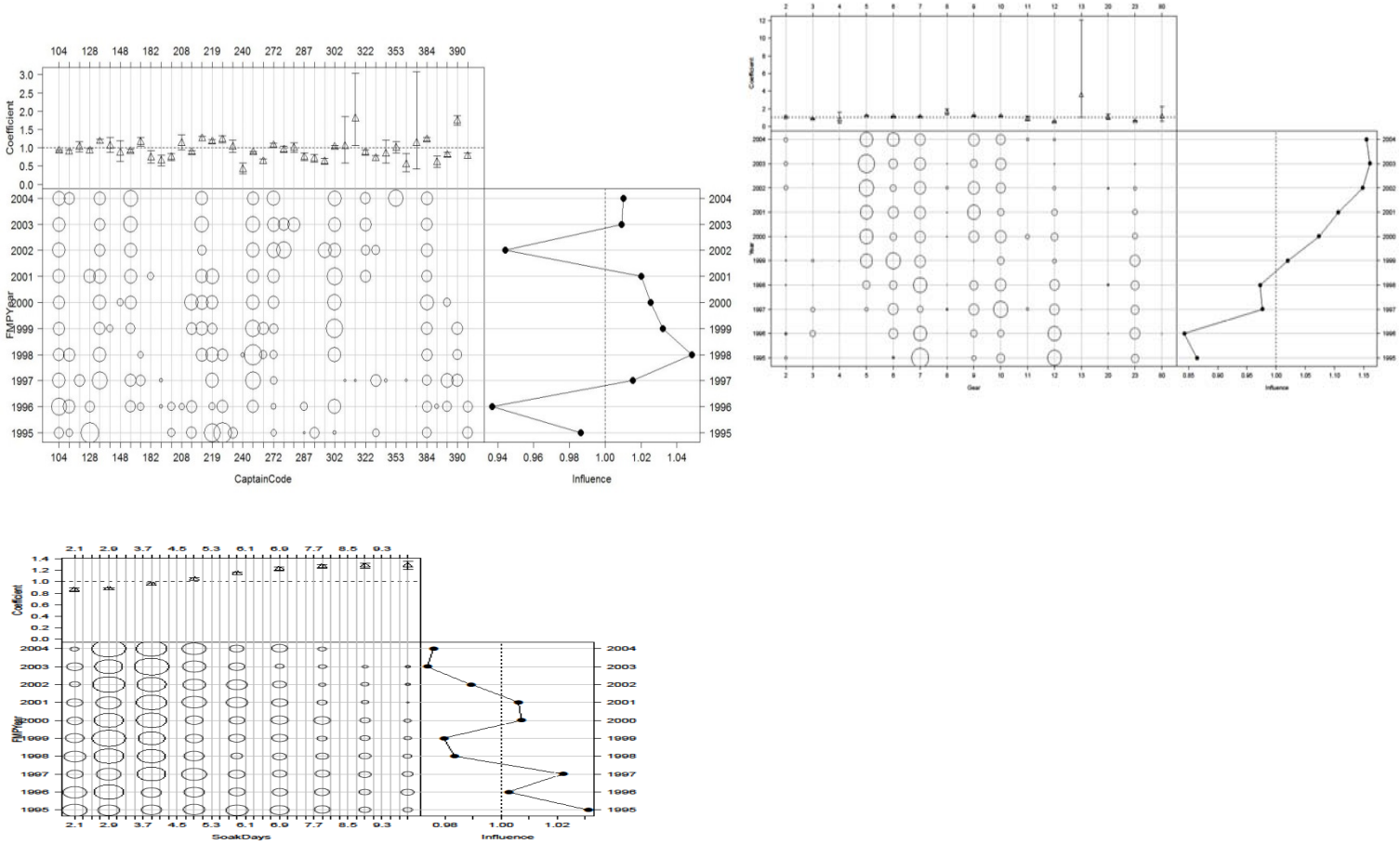

Figure 13. Combination of coefficient values with standard errors, distributional changes of the predictor variable, and its annual influence on the standardized CPUE analysis based on 1995/96–2004/05 observer data for EAG (east of 174°W longitude). Top left panel: *Captain* categorical variable; top right panel: *Gear* categorical variable; and bottom left panel: Soak time continuous variable. Note: Lognormal fit was considered in the analysis.

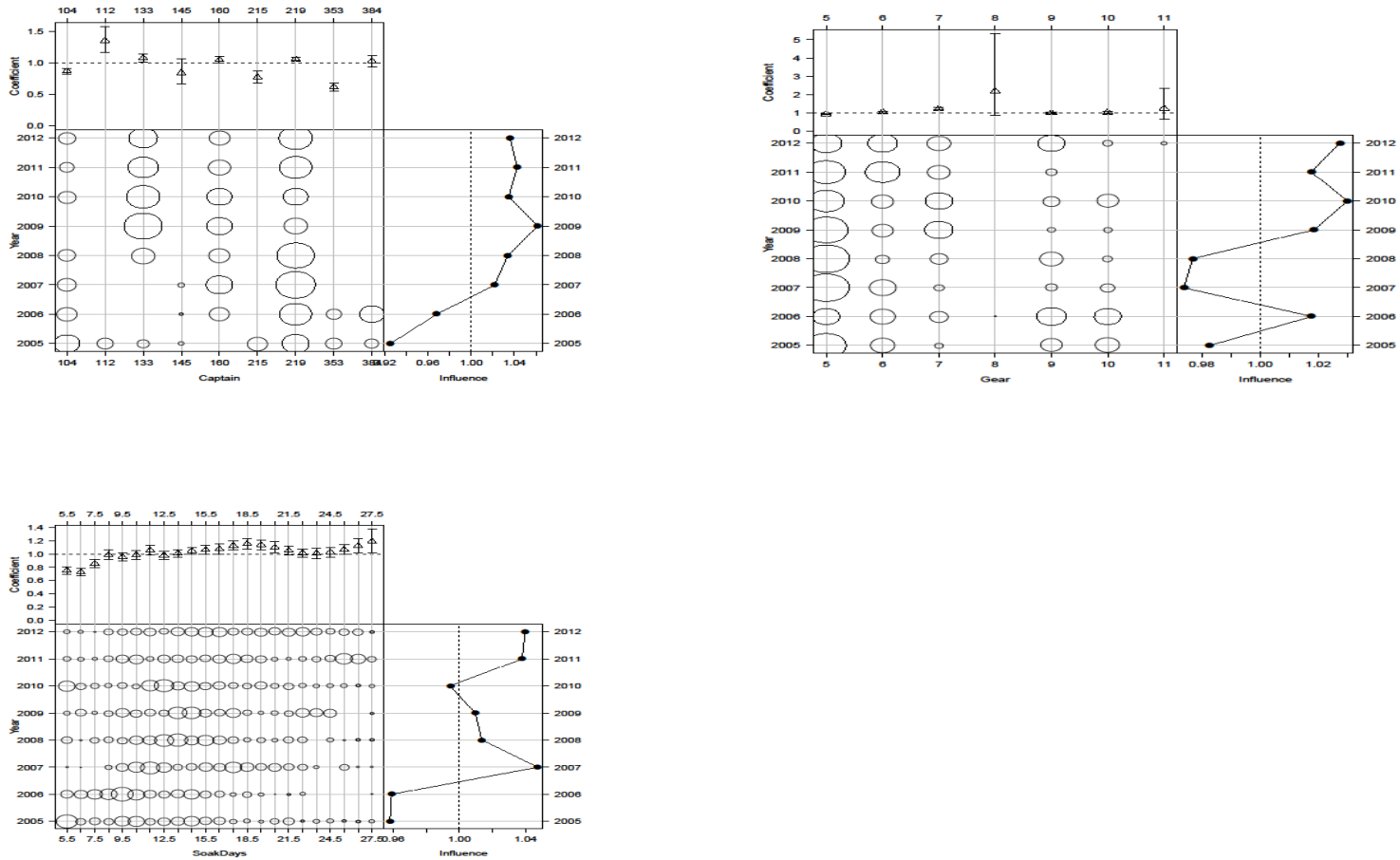

Figure 14. Combination of coefficient values with standard errors, distributional changes of the predictor variable, and its annual influence on the standardized CPUE analysis based on 2005/06–2012/13 observer data for EAG (east of 174°W longitude). Top left panel: *Captain* categorical variable; top right panel: *Gear* categorical variable; and bottom left panel: Soak time continuous variable. Note: Lognormal fit was considered in the analysis.

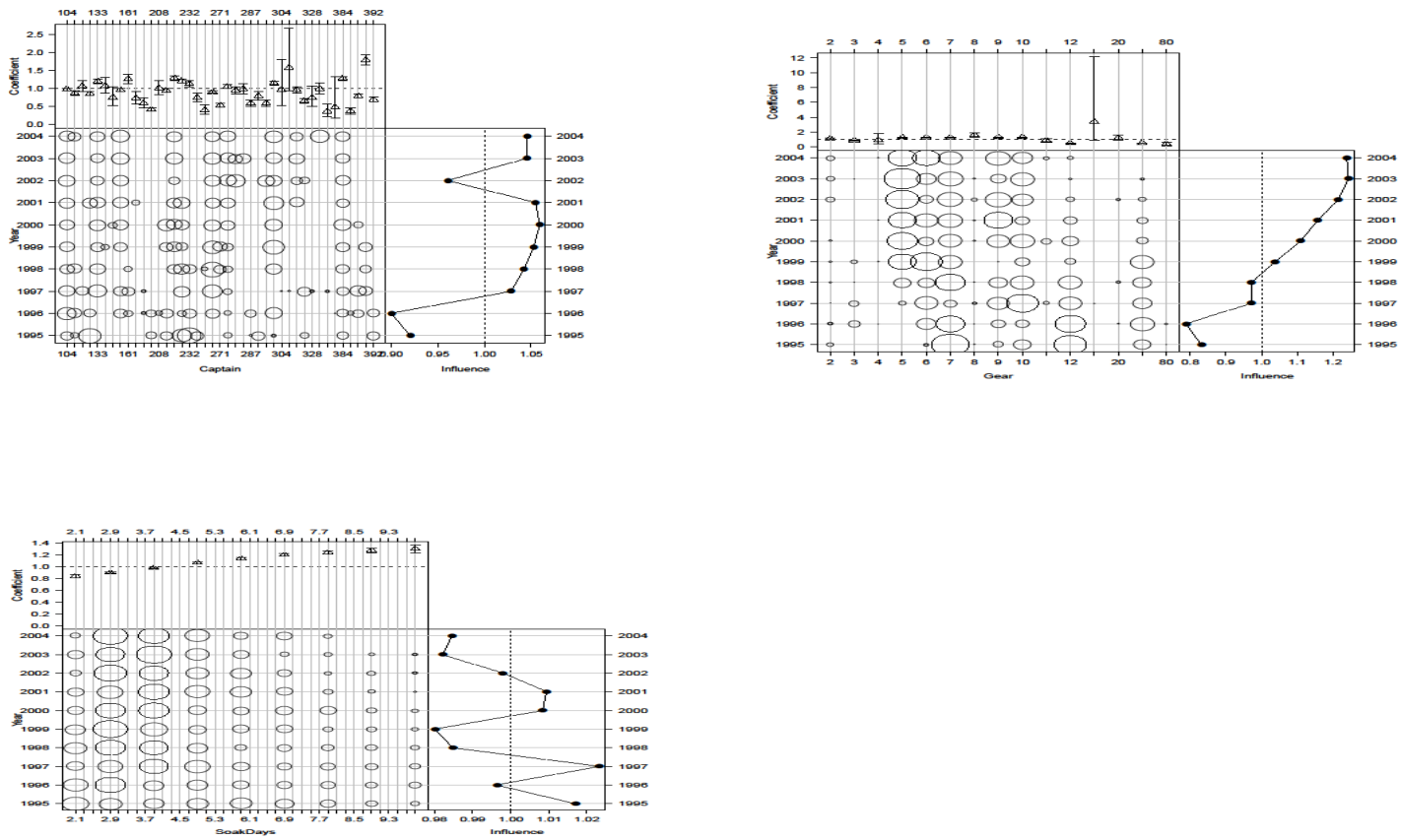

Figure 15. Combination of coefficient values with standard errors, distributional changes of the predictor variable, and its annual influence on the standardized CPUE analysis based on 1995/96–2004/05 observer data for EAG (east of 174°W longitude). Top left panel: *Captain* categorical variable; top right panel: *Gear* categorical variable; and bottom left panel: Soak time continuous variable. Note: Negative binomial fit was considered in the analysis.

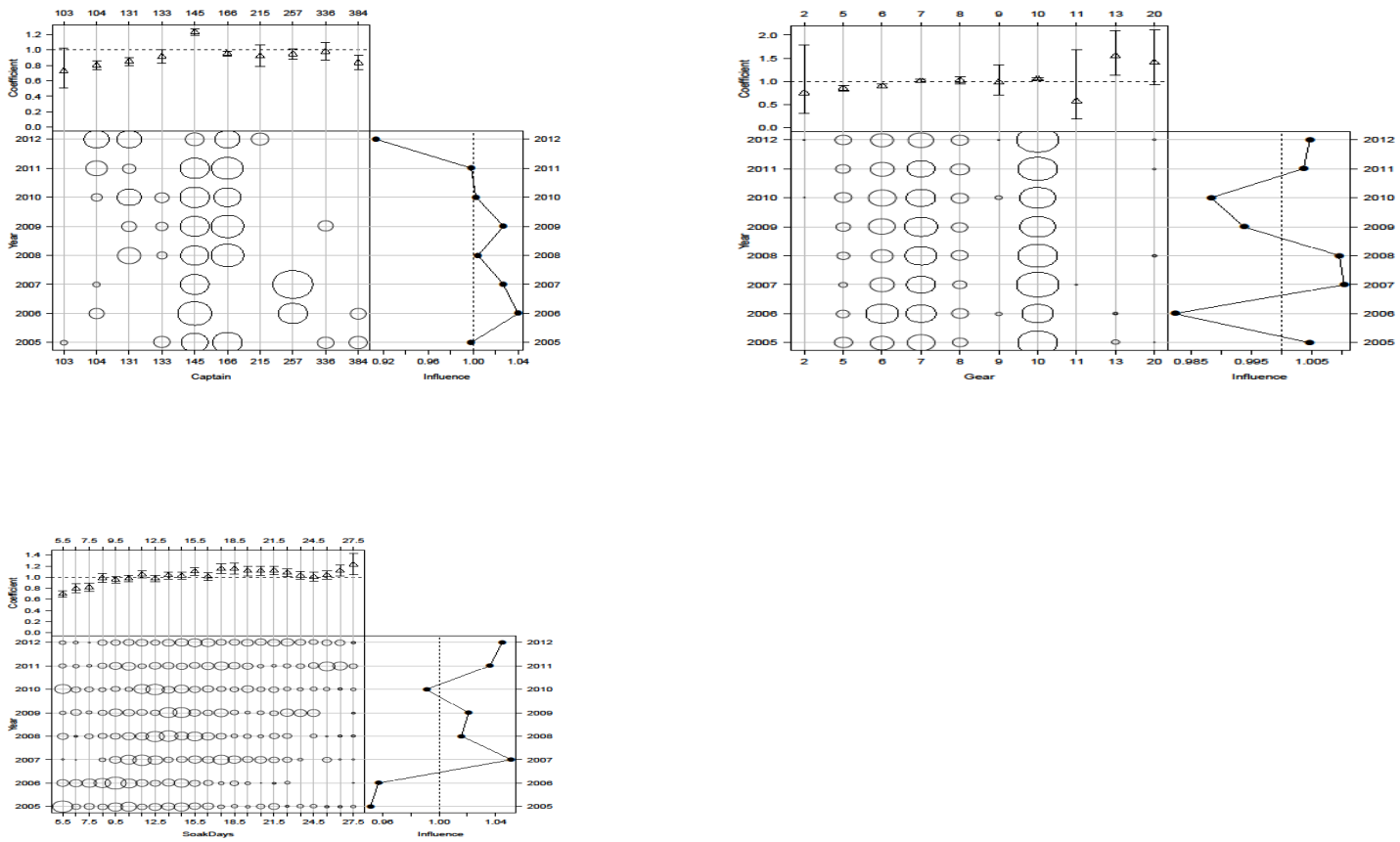

Figure 16. Combination of coefficient values with standard errors, distributional changes of the predictor variable, and its annual influence on the standardized CPUE analysis based on 2005/06–2012/13 observer data for EAG (east of 174°W longitude). Top left panel: *Captain* categorical variable; top right panel: *Gear* categorical variable; and bottom left panel: Soak time continuous variable. Note: Negative binomial fit was considered in the analysis.

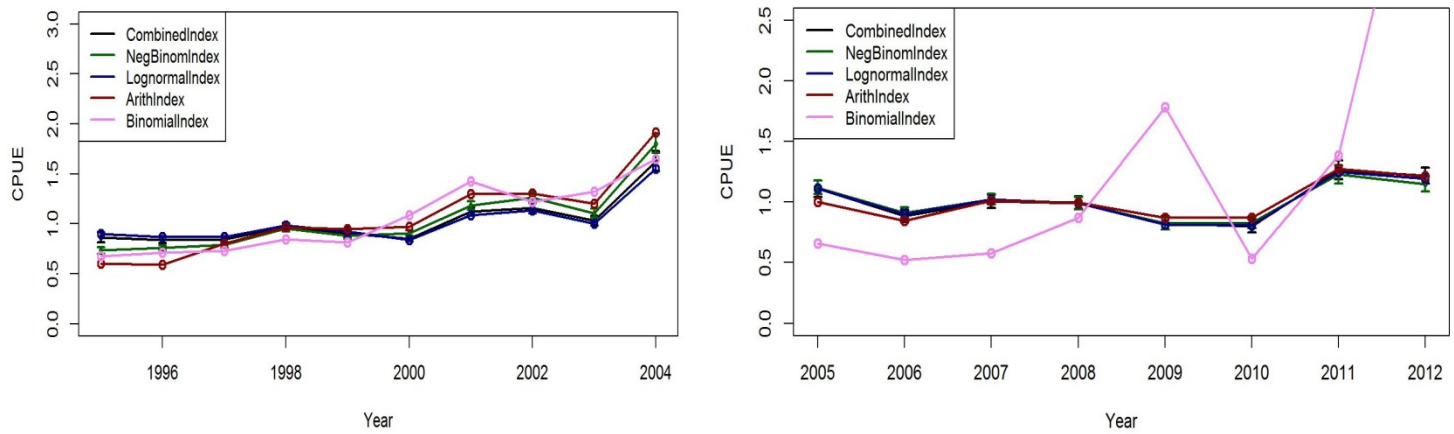

Figure 17. Trends in combined and negative binomial CPUE indices with two standard errors of Aleutian Islands golden king crab from EAG (east of 174°W longitude). Left figure: 1995/96–2004/05 observer data and right figure: 2005/06–2012/13 observer trimmed data. Arithmetic indices are shown on both plots for comparison. Combined indices: black line; Negative binomial indices: green line; Lognormal indices: blue line; Arithmetic indices: red line; and Binomial indices: purple line.

WAG

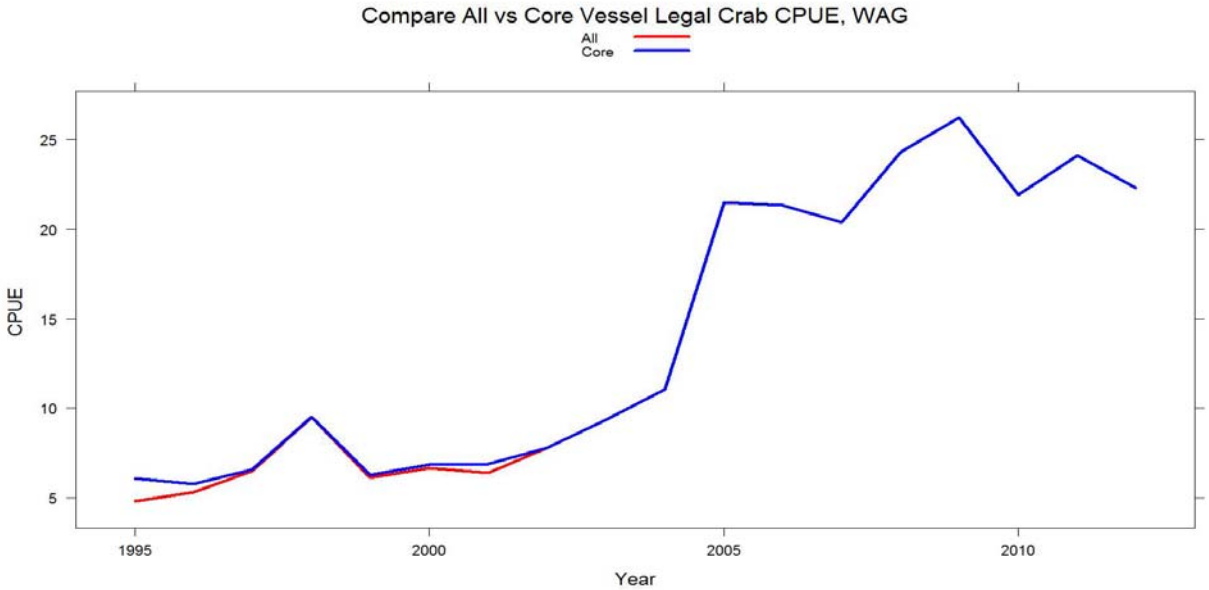

Figure 18. Comparison of legal male CPUE of all and core vessels. Aleutian Islands golden king crab observer data set from WAG (west of 174°W longitude) for 1995/96–2012/13 period was used.

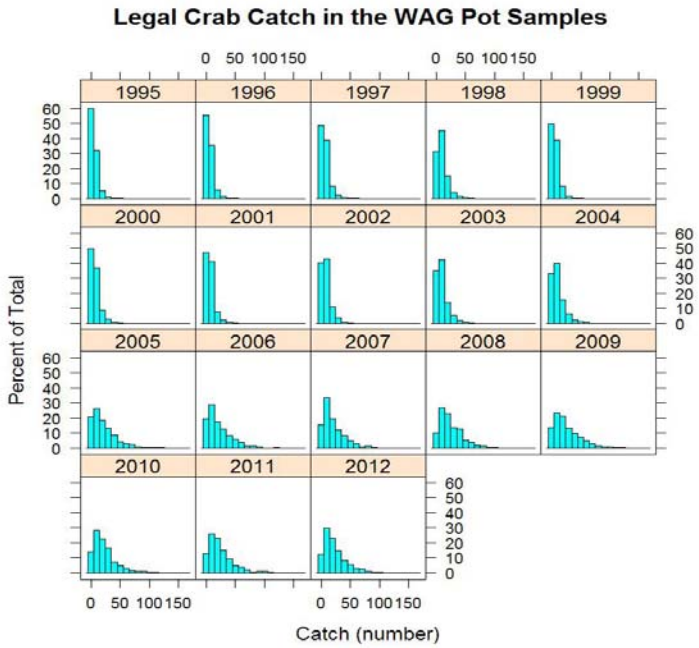

Figure 19. Histograms of observer sample catch by fishing season (1995=1995/96 fishing season) of Aleutian Islands golden king crab from WAG (west of 174°W longitude).

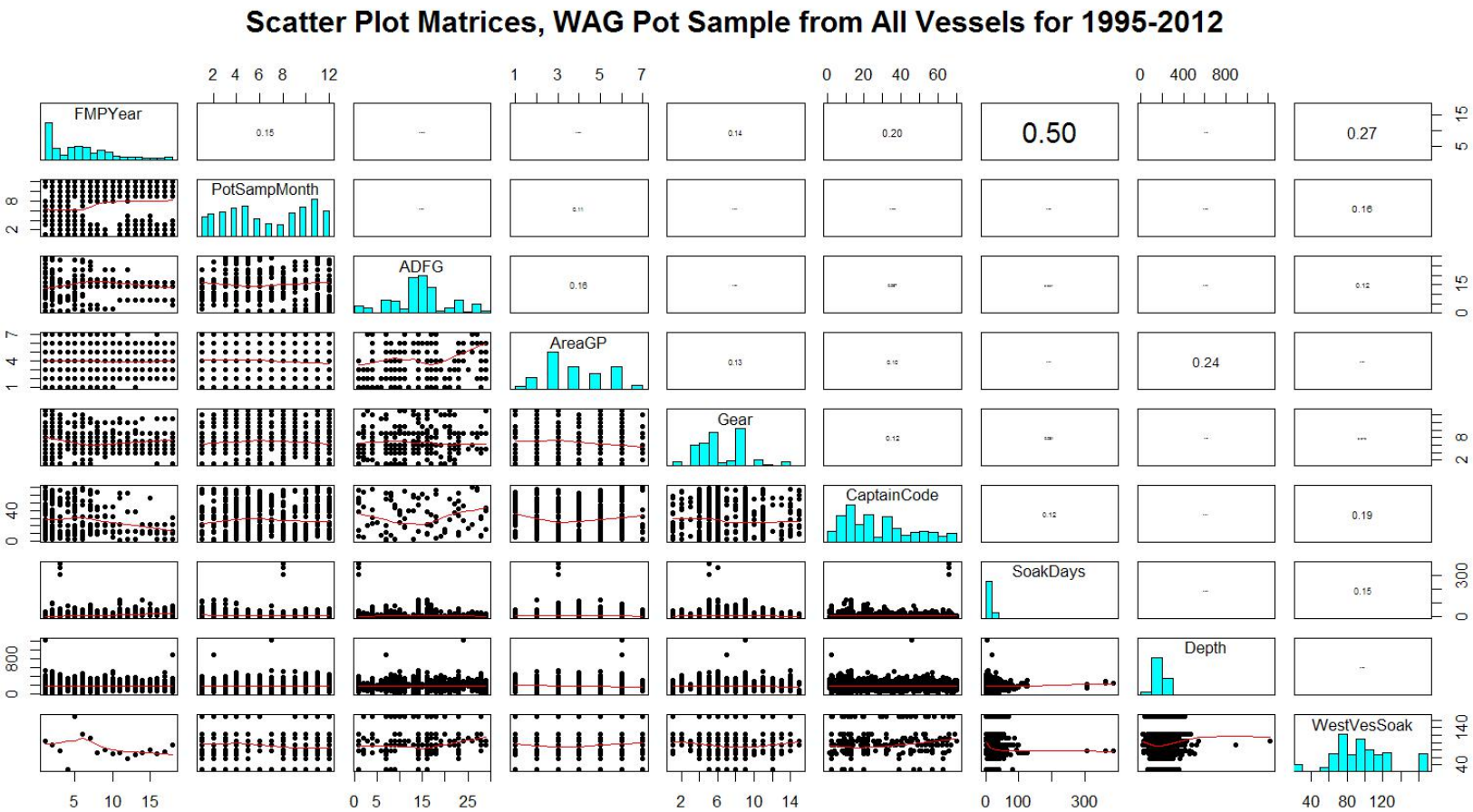

Figure 20. Scatter plot matrices for WAG (west of 174°W longitude) all vessels' observer sample explanatory variables. Lowess smooth curves are shown in red. High correlations exist between *Year* versus *SoakDays* and *WestVesSoak* .

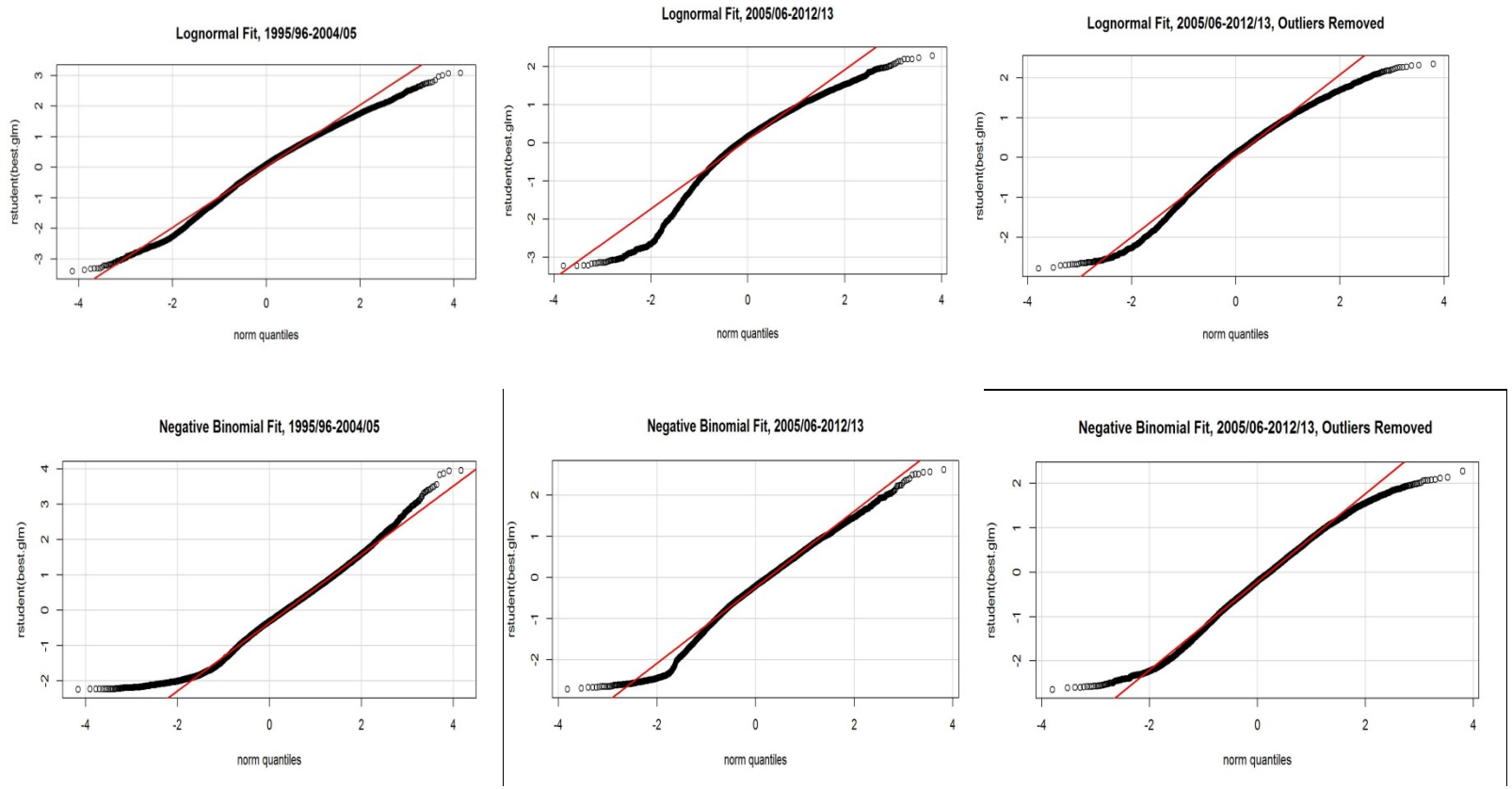

Figure 21. Studentized residual plots after GLM fit for Aleutian Islands golden king crab observer data from WAG (west of 174°W longitude). Top and bottom panels are for lognormal and negative binomial fits, respectively: 1995/96-2004/05 data set (left); 2005/06–2012/13 whole data set (middle); and 2005/06–2012/13 outliers removed (trimmed) data set (right). Outliers= records with standardized normal residuals outside mean residuals ± 2 standard deviations.

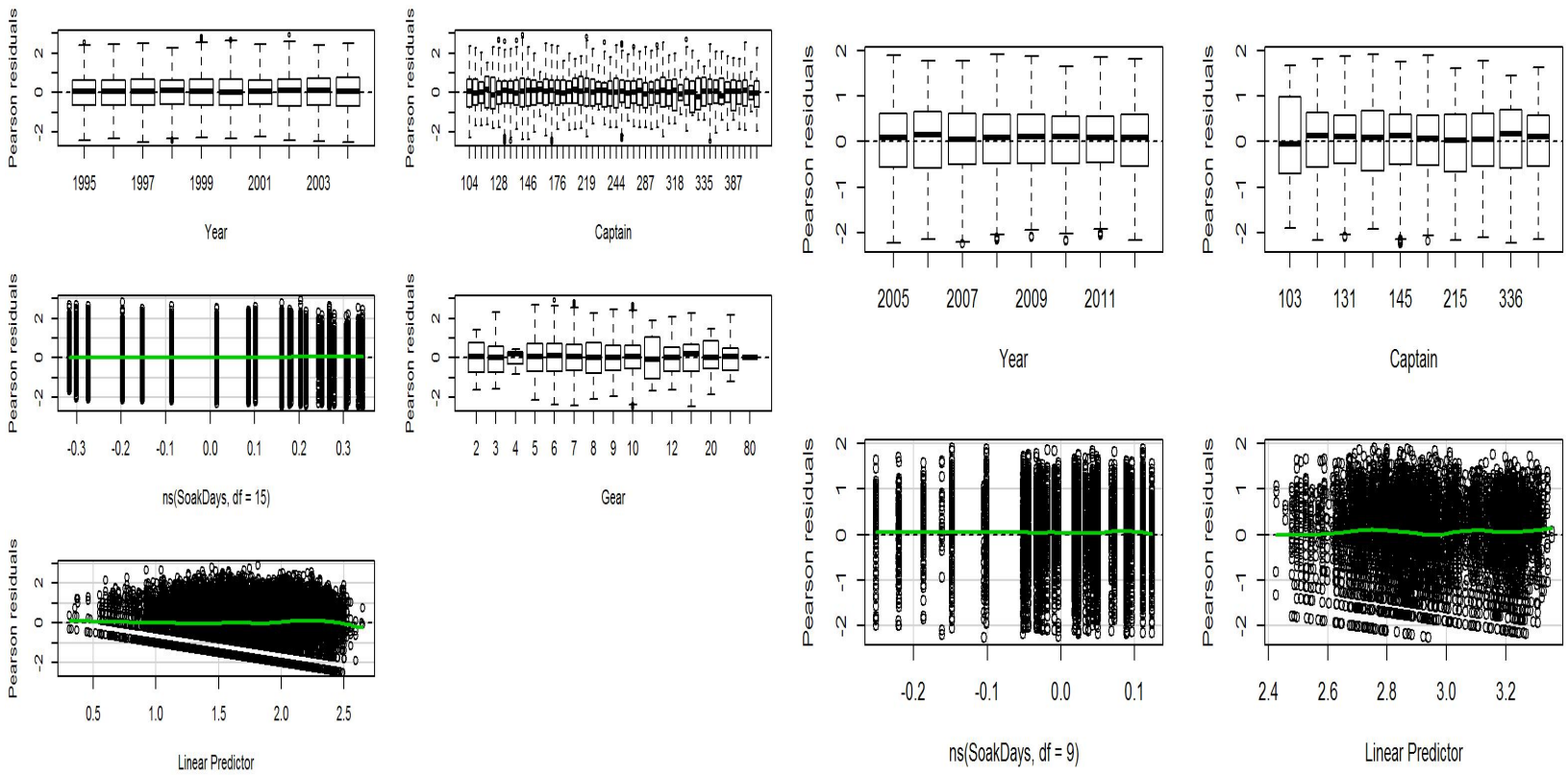

Figure 22. Pearson residuals versus explanatory and response variables of the best lognormal model fit for legal CPUE. Observer data from WAG (west of 174°W longitude) for 1995/96–2004/05 (left) and 2005/06–2012/13 (right) periods were used. The solid lines are the loess smoother through the plotted values.

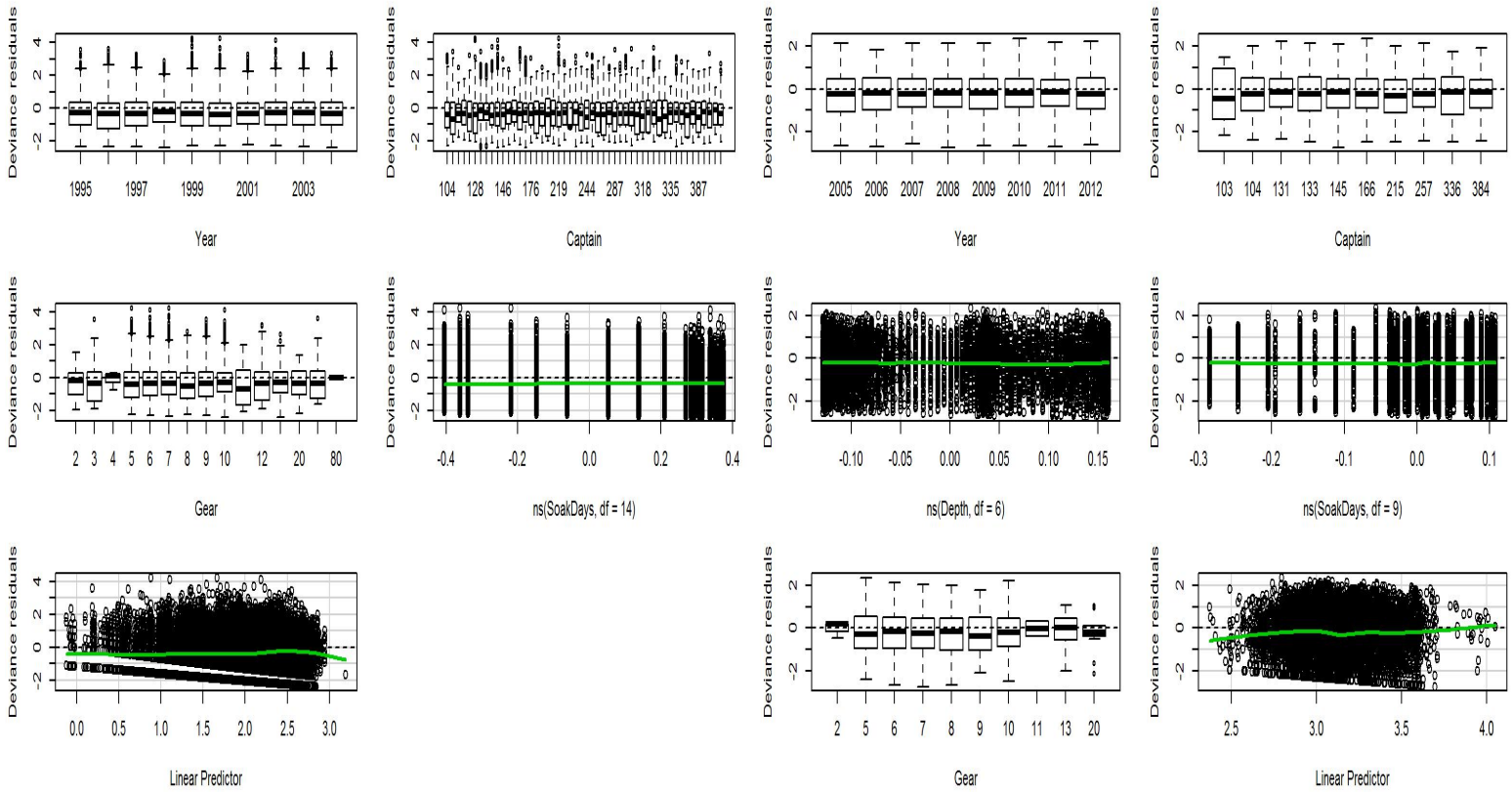

Figure 23. Deviance residuals versus explanatory and response variables of the best negative binomial fit model for legal CPUE. Observer data from WAG (west of 174°W longitude) for 1995/96–2004/05 (left) and 2005/06–2012/13 (right) periods were used. The solid lines are the loess smoother through the plotted values.

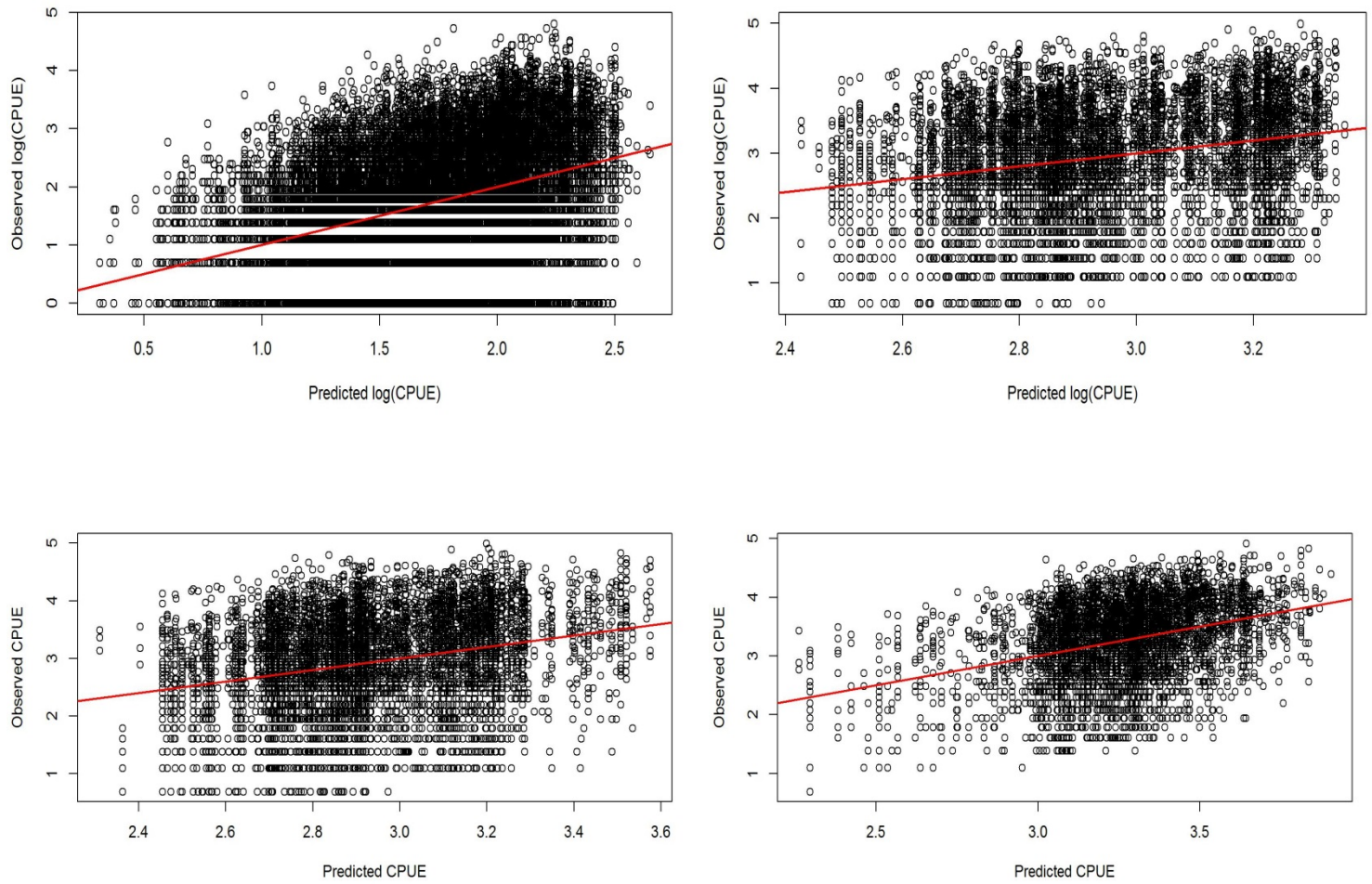

Figure 24. Observed versus predicted response variable of the best fit models for legal CPUE. observer data from WAG (west of 174°W longitude). Top and bottom panels are for lognormal and negative binomial fits, respectively: 1995/96–2004/05 data set (left); 2005/06–2012/13 trimmed data set (right). The solid lines are the 1-1 line.

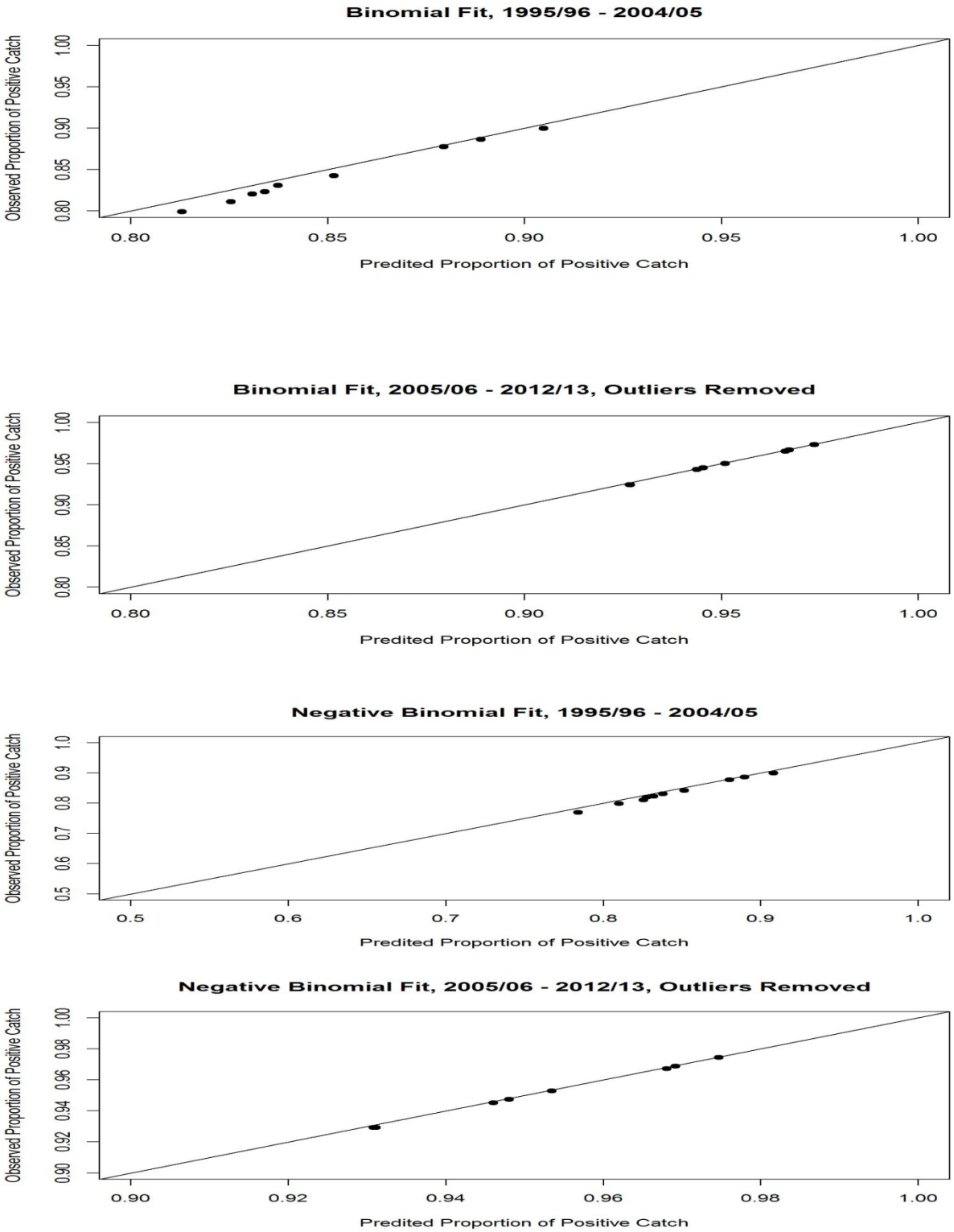

Figure 25. Observed versus predicted positive catch proportions by the binomial and negative binomial models. Aleutian Islands golden king crab observer data from WAG (west of 174°W longitude) for 1995/96–2004/05 and 2005/06–2012/13 periods were used.

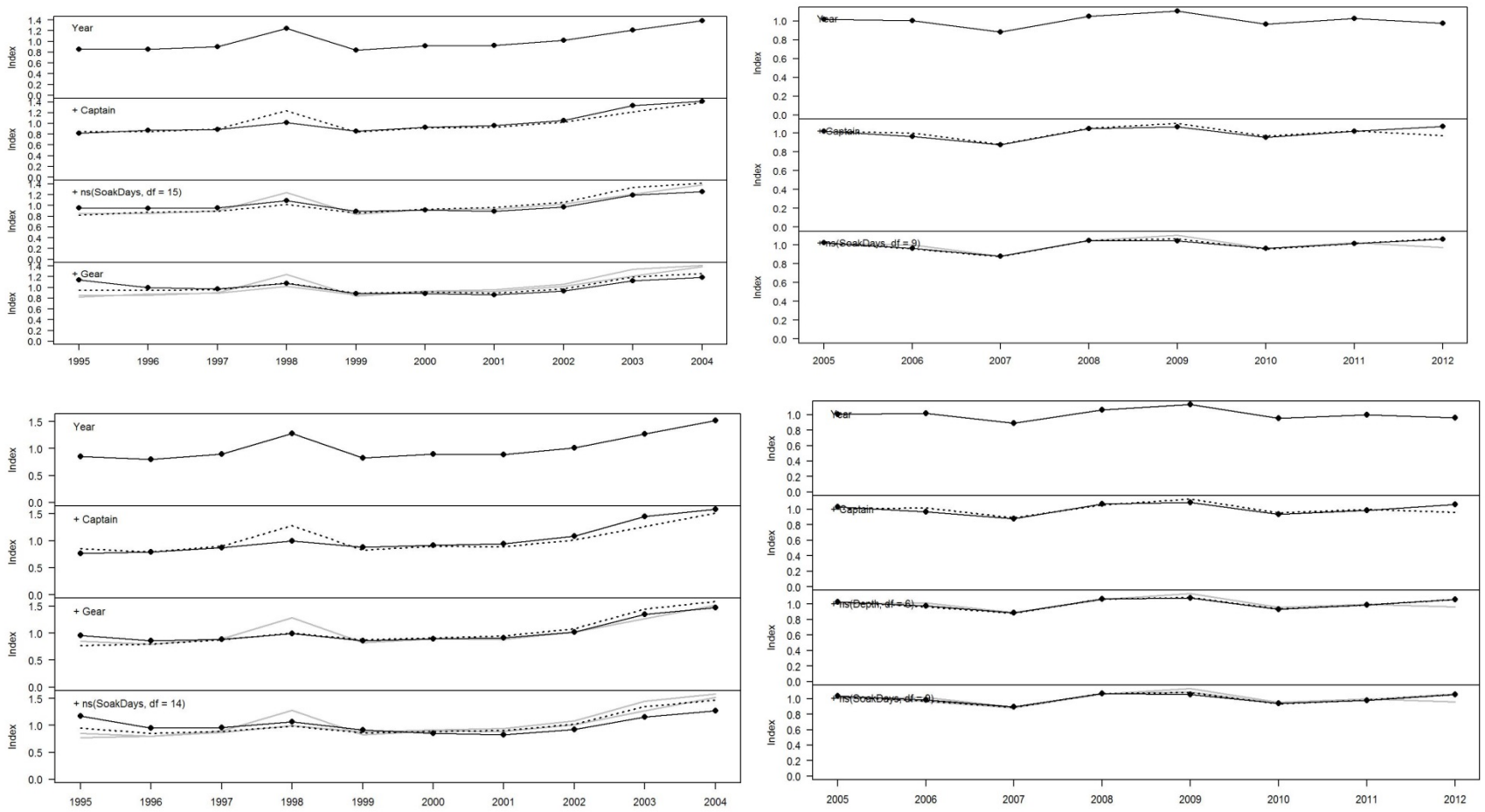

Figure 26. Standardized CPUE index as each explanatory variable is added to the model for Aleutian Islands golden king crab from WAG (west of 174°W longitude). The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. Top row: lognormal error models and bottom row: negative binomial error models. Left column: 1995/96–2004/05 observer data and right column: 2005/06–2012/13 observer trimmed data**.**

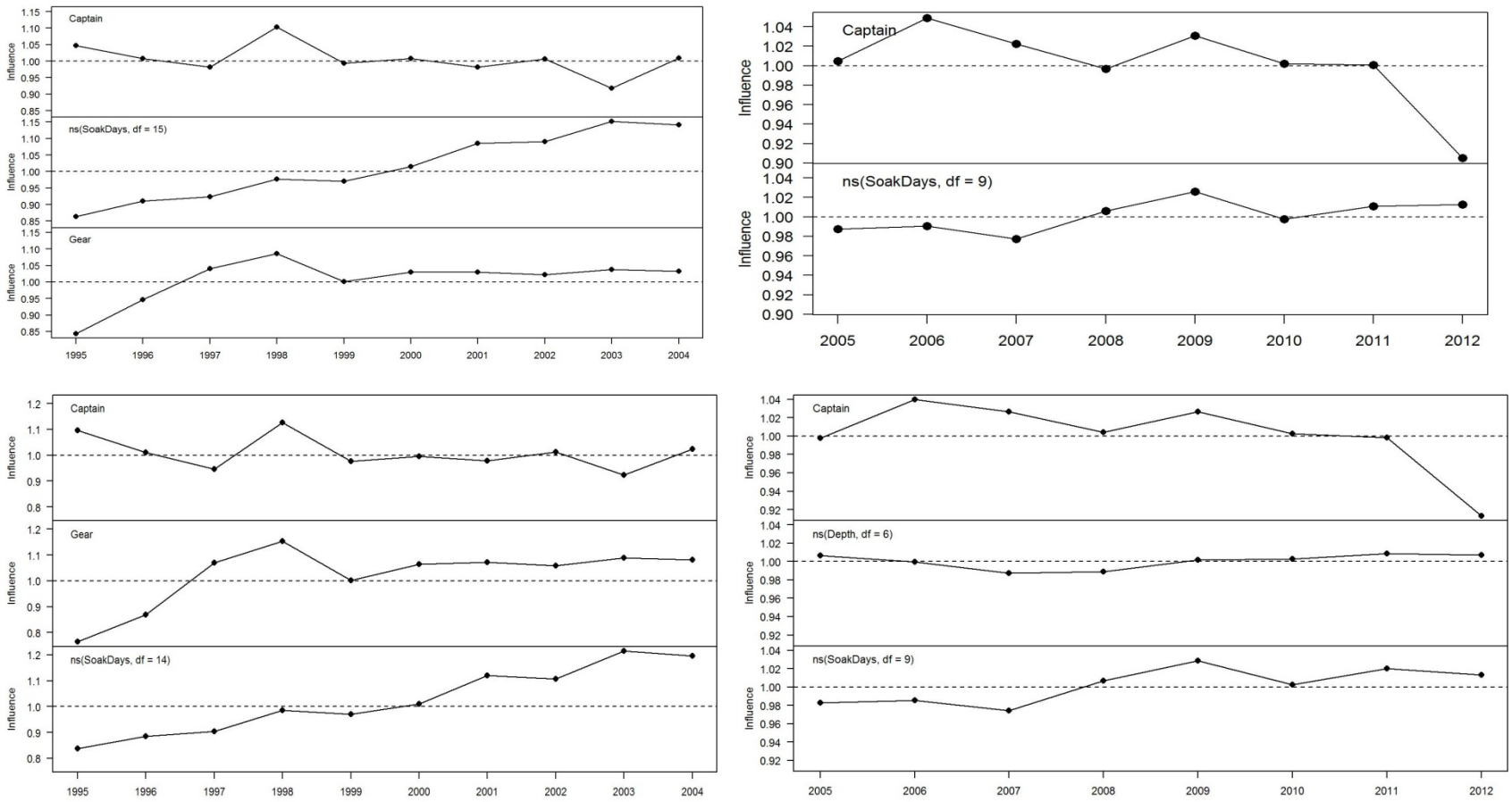

Figure 27. Annual influence values for each explanatory variable in the final GLM model for Aleutian Islands golden king crab from WAG west of 174°W longitude). Top row: lognormal error models and bottom row: negative binomial error models. Left column: 1995/96–2004/05 observer data and right column: 2005/06–2012/13 observer trimmed data.

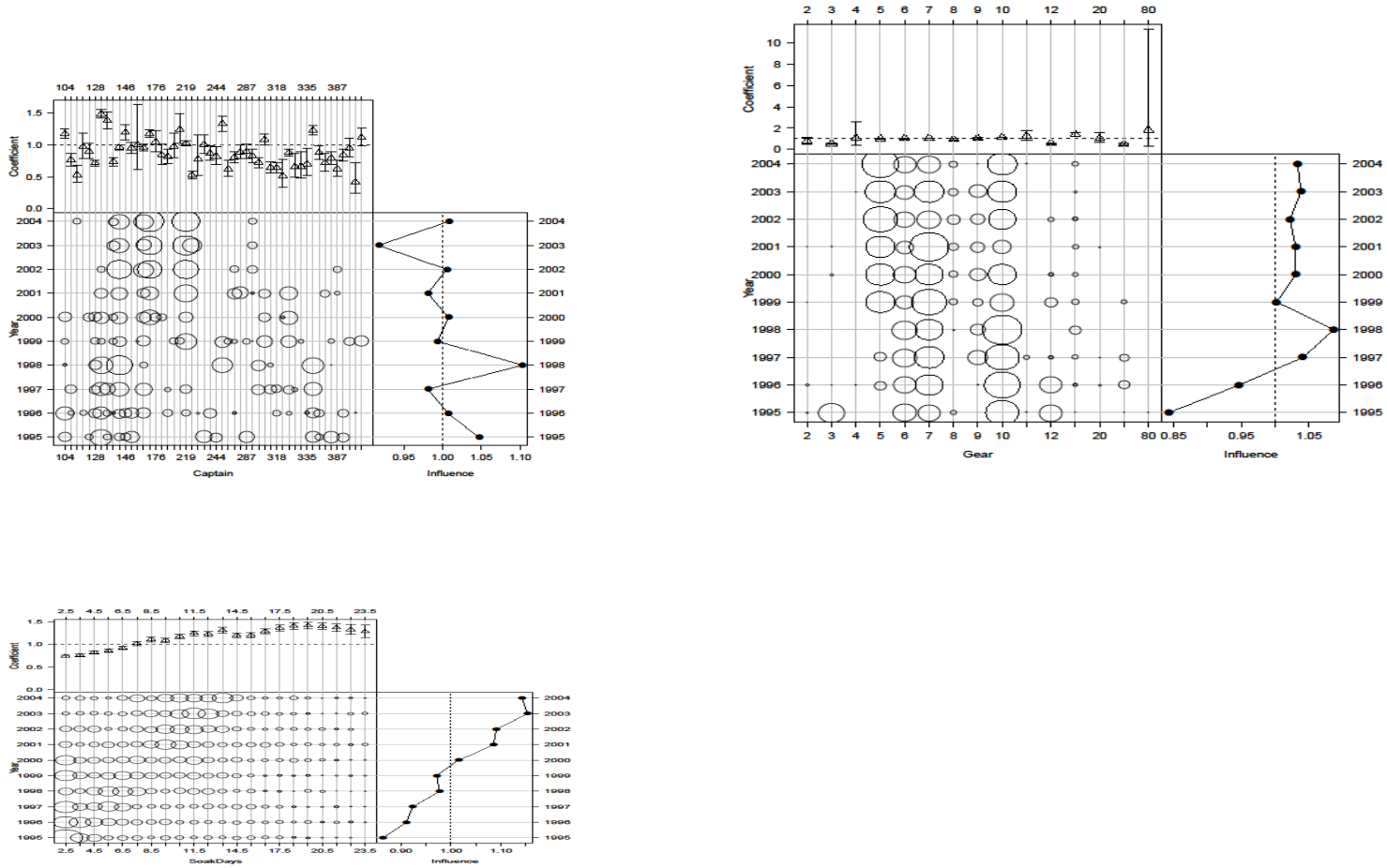

Figure 28. Combination of coefficient values with standard errors, distributional changes of the predictor variable, and its annual influence on the standardized CPUE analysis based on 1995/96–2004/05 observer data for WAG (west of 174°W longitude). Top left panel: *Captain* categorical variable; top right panel: *Gear* categorical variable; and bottom left panel: Soak time continuous variable. Note: Lognormal fit was considered in the analysis.

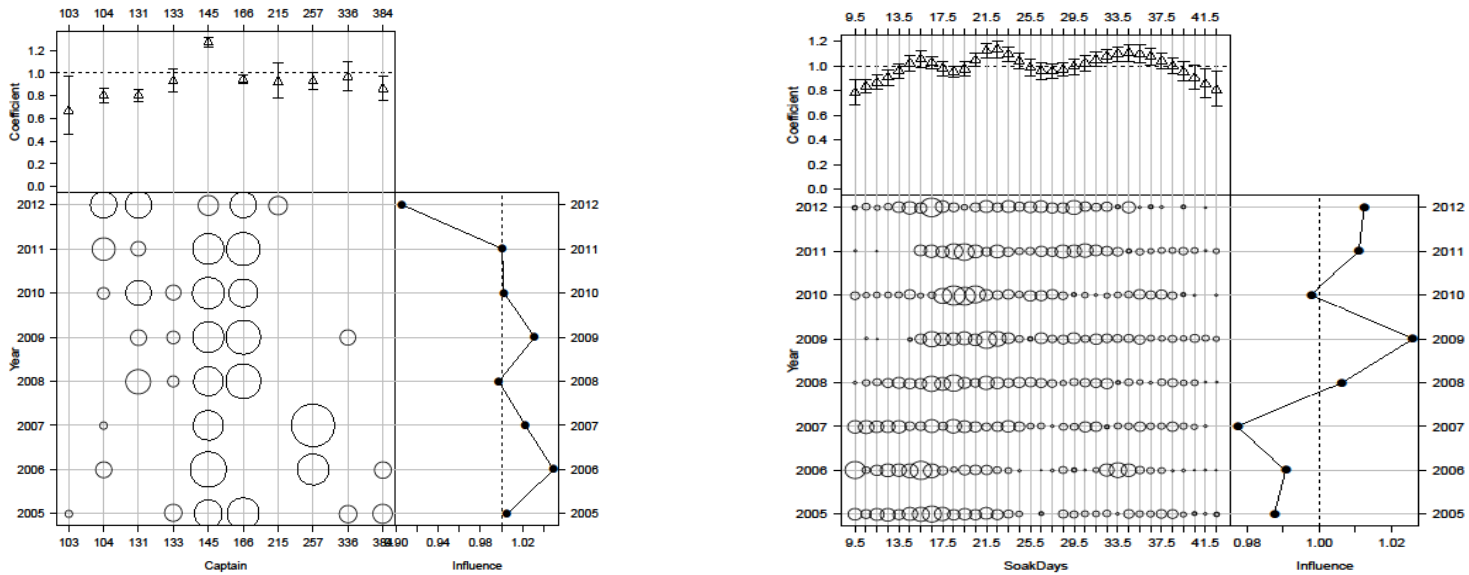

Figure 29. Combination of coefficient values with standard errors, distributional changes of the predictor variable, and its annual influence on the standardized CPUE analysis based on 2005/06–2012/13 observer data for WAG (west of 174°W longitude). Top left panel: *Captain* categorical variable; top right panel: *Soak* time continuous variable. Note: Lognormal fit was considered in the analysis.

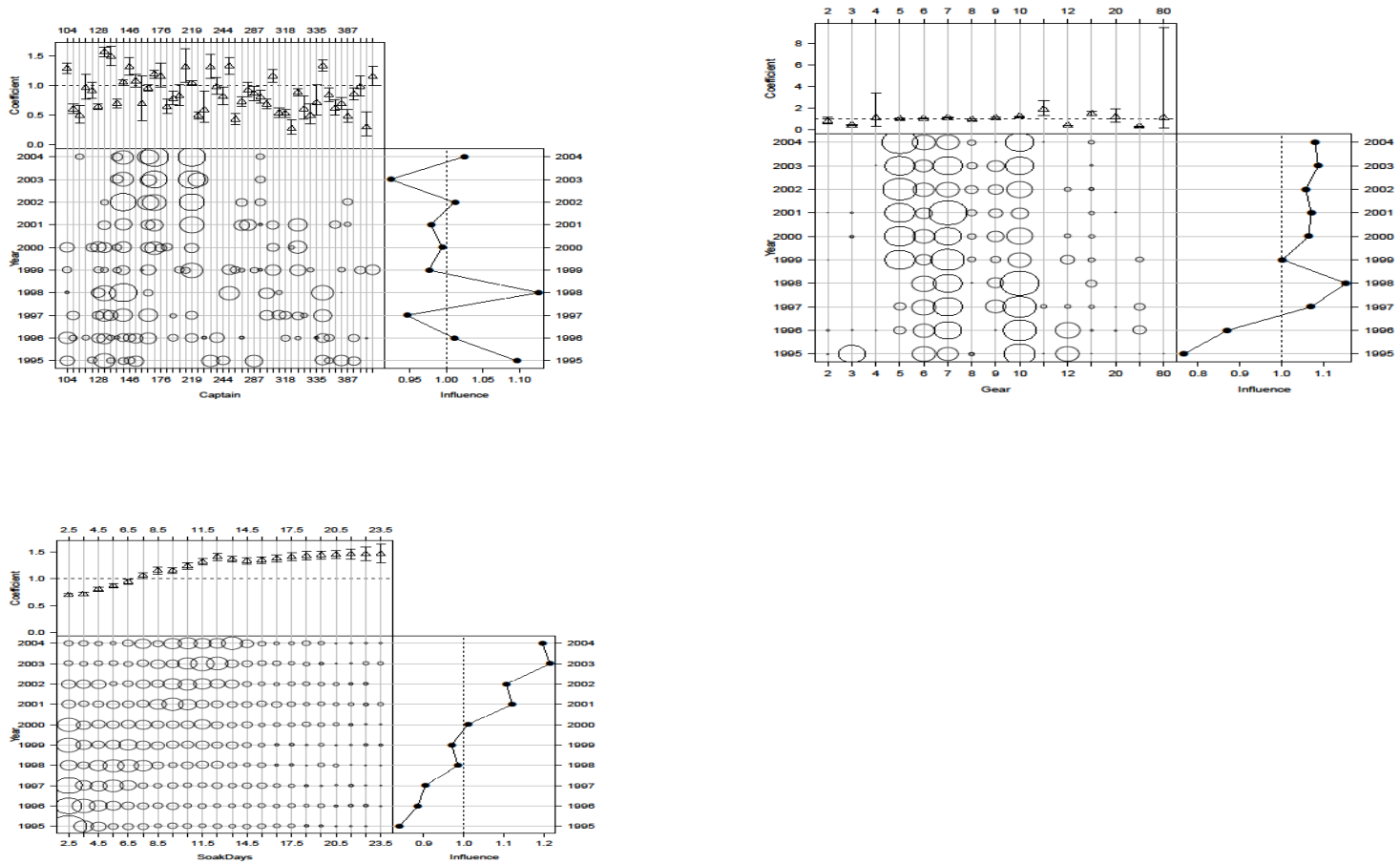

Figure 30. Combination of coefficient values with standard errors, distributional changes of the predictor variable, and its annual influence on the standardized CPUE analysis based on 1995/96–2004/05 observer data for WAG (west of 174°W longitude). Top left panel: *Captain* categorical variable; top right panel: *Gear* categorical variable; and bottom left panel: Soak time continuous variable. Note: Negative binomial fit was considered in the analysis.

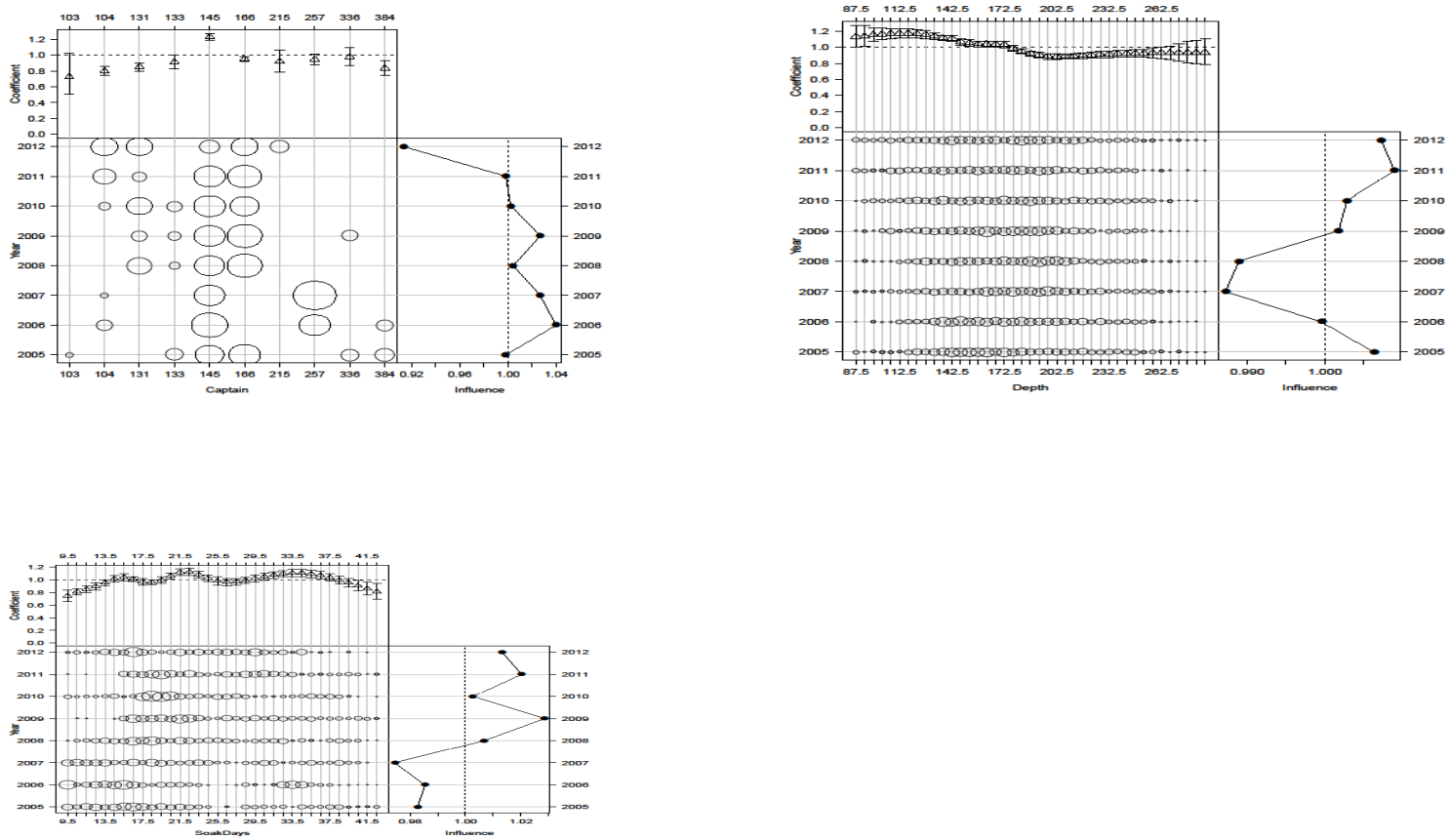

Figure 31. Combination of coefficient values with standard errors, distributional changes of the predictor variable, and its annual influence on the standardized CPUE analysis based on 2005/06–2012/13 observer data for WAG (west of 174°W longitude). Top left panel: *Captain* categorical variable; top right panel: *Depth* numerical variable; and bottom left panel: Soak time numerical variable. Note: Negative binomial fit was considered in the analysis.

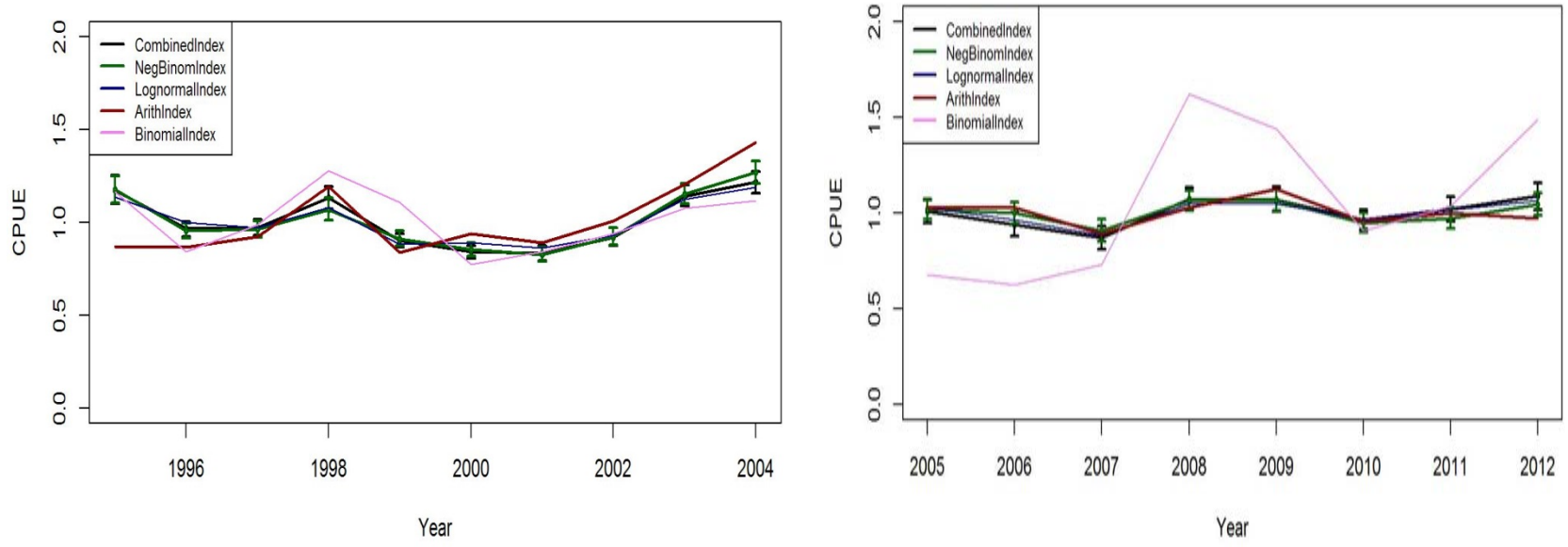

Figure 32. Trends in combined and negative binomial CPUE indices with two standard errors of Aleutian Islands golden king crab from WAG (west of 174°W longitude). Left figure: 1995/96–2004/05 observer data and right figure: 2005/06–2012/13 observer trimmed data. Arithmetic indices are shown on both plots for comparison. Combined indices: black line; Negative binomial indices: green line; Lognormal indices: blue line; Arithmetic indices: red line; and Binomial indices: purple line.

Appendix A

R script used in CPUE standardization.

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/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/allpotsampleAddAreaTripVesSoak95_12.csv", header=TRUE)
```

#Create a data frame with selected variables

```
allpotsampleSub<-
as.data.frame(list(allpotsample$Year,allpotsample$Month,allpotsample$FTPotLifts,allpotsample$ADFG,allpotsample$EastWest,


allpotsample$StatArea,allpotsample$Depth,allpotsample$SoakDays,allpotsample$Gear,allpotsample$Sublegal,allpotsample$LegalRet,

allpotsample$LegalNR,allpotsample$Captain,allpotsample$AreaGP,allpotsample$Yrsof5Tr,allpotsample$EastVess,
allpotsample$WestVess,allpotsample$TotalVess,   allpotsample$EastVesSoak,allpotsample$WestVesSoak))

   names(allpotsampleSub)<-
c("Year","Month","FTPotLifts","ADFG","EastWest","StatArea","Depth","SoakDays","Gear","Sublegal",


"LegalRet","LegalNR","Captain","AreaGP","Yrsof5Tr","EastVess","WestVess","TotalVess","EastVesSoak","WestVesSoak")
```

Restrict the data set to 1995 -2004

```
  allpotsampleSub<- allpotsampleSub[allpotsampleSub$Year < 2005,]
```

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$Year != -9,]
allpotsampleSub<- allpotsampleSub[allpotsampleSub$Month != -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$EastWest==1,]
# Subset pre rationalization years for EAG
eprepotsampleSub<- epotsampleSub[epotsampleSub$Year<2005,]
# 5% and 95% trimmed by pre and post rationalization, and data combined for EAG
eprepotsampleSubcut <- eprepotsampleSub[eprepotsampleSub$SoakDays>1 & eprepotsampleSub$SoakDays<11,]
epotsampleSubtrim<- eprepotsampleSubcut
# 1% and 99% trimmed on depth
epotsampleSubtrim <- epotsampleSubtrim[epotsampleSubtrim$Depth>72 & epotsampleSubtrim$Depth<341,]
# Change some data frame variables to categorical for EAG
epotsampleSubtrim$Year<- as.factor(epotsampleSubtrim$Year)
```

```
epotsampleSubtrim$Month<- as.factor(epotsampleSubtrim$Month)

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

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

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

epotsampleSubtrim$Captain<- as.factor(epotsampleSubtrim$Captain)
```

 # 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$Year)-table(datacore$Year[datacore$success==1]))/table(datacore$Year)
```

 # Subset core data by positive catch values

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

 # Find the best model from negative binomial fit

```
library(MASS)

library(splines)

glm.object<- glm(Legals~Year,family = negative.binomial(1.39),data=datacore)

epotsampleout1<- stepCPUE(glm.object, scope=list(upper=
~(Year+ns(SoakDays,df=3)+Month+ADFG+Captain+AreaGP+Gear+ns(Depth,df=16)+ns(EastVesSoak,df=9)),low
er= ~Year),family = negative.binomial(1.39),direction="forward",trace=9,r2.change=0.01)
```

 # Get results from negative binomial fit of the best model

```
best.glm<- glm(Legals~ Year+Gear+Captain+ns(SoakDays,df=3),family = negative.binomial(1.39),y=TRUE,
data=datacore)
```

 # 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 relative indices (with the base year =1)

```
sumglm<-summary(best.glm)

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

Get canonical negative binomial indices

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

 # Write the output to a file

```
write.csv(cpue1.glm,"C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/epotsample
NoInteractNegBinomYearlyCPUE95_04LDifferDF.csv",row.names=F)
```

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

```
base.glm<-glm(Legals~ Year,family = negative.binomial(1.39),y=TRUE, data=datacore)

sumglm1<-summary(base.glm)

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

Get canonical indices for the base negative binomial index

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

Write the output to a file

```
write.csv(cpue2.glm,"C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/epotsample
NoInteractNegBinomBaseYearCPUE95_04LDifferDF.csv",row.names=F)
```

Positive observed CPUE from core data

```
write.csv(datacore1,"C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/epotsampleN
oInteractNegBinomCatches95_04LDifferDF.csv",row.names=F)
```

Arithmetic CPUE index

```
RCPUE<- tapply(datacore1$Legals,datacore1$Year,mean)

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

RCPUEdash<- RCPUE/GMRCPUE
```

Write the output to a file

```
write.csv(RCPUEdash,"C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/epotsampl
eNoInteractNegBinomScaledArithCPUE95_04LDifferDF.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/epotsampleNoInteract
parameters.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))

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

write.csv(allpotsample.cpue,"C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/epots
ampleNoInteractNegBinomVariouscpue95_04LDifferDF.csv",row.names=F)
```

Plot various CPUE

 # Read the file

```
epotsample.CPUE<- read.csv("C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/

 epotsampleNoInteractNegBinomVariouscpue95_04LDifferDF.csv",header=T)
```

 # Set the plotting parameters

 # Load the gplots package

```
   library(gplots)

   attach(epotsample.CPUE)

jpeg(file="C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/epotsampleNoInteractN
egBinomCPUE95_04LDifferDFFig1.jpg",width=1600,height=900,res=200)

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

plotCI(x=Year,y=ArithInd,ui=NULL,li=NULL,cex=1,type="o",col="darkred",lwd=3,add=TRUE)


legend("topleft",c("NegativeBinomIndex","ArithIndex"),lty=c("solid","solid"),col=c("black","darkred"),lwd=3,cex=
0.9)
```

```
dev.off()

detach(epotsample.CPUE)

detach(package:gplots
```

Collect model fit diagnostic values

```
Yhat<- best.glm$fitted.values

Ytemp<- datacore$Legals

Yobs<- Ytemp
```

Make scatter plot of Yobs versus Yhat

```
jpeg(file="C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/epotsampleNoInteractNegBinomObsYPredY95_04LDifferDFFig2.jpg",width=1600,height=900,res=200)

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

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

dev.off()
```

Plot residuals

```
library(car)

jpeg(file="C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/epotsampleNoInteractNegBinomCPUEManyRes95_04LDifferDFFig3.jpg",width=1600,height=900,res=200)

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

dev.off()

detach(package:car)
```

Make qqPlot of studentized residuals from the car package

```
library(car)

jpeg(file="C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPTWorkRSplineDifferDF/epotsampleNoInteractNegBinomCPUEStudentRes95_04LDifferDFFig4.jpg",width=1600,height=900,res=200)

qqPlot(rstudent(best.glm),main="Negative Binomial Fit, 1995/96-2004/05",envelope=FALSE)

dev.off()

detach(package:car)
```

 # Test for collinearity

```
library(car)

epotsampleNoInteract95_04LDifferDFmod.vif<- vif(best.glm)
```

 # Write the output to a file

```
write.csv(epotsampleNoInteract95_04LDifferDFmod.vif,"C:/Users/ssiddeek/Documents/Sep2013CPT/Sep2013CPT
WorkRSplineDifferDF/epotsampleNoInteractNegativeBinomial95_04LDifferDFVIF.csv",row.names=T)

detach(package:car)

###########
```

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$Year)),ncol=BootSize))

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

     {

       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)	1.03095	0.152273	6.770399	1.31E-11	2.803727
Year1996	-0.03315	0.032166	-1.03052	0.302775	0.967396
Year1997	-0.03483	0.035158	-0.99069	0.321843	0.965769
Year1998	0.089771	0.034244	2.621498	0.008759	1.093923
Year1999	0.024705	0.034834	0.709235	0.478184	1.025013
Year2000	-0.06811	0.034634	-1.96658	0.049241	0.934158
Year2001	0.187378	0.037247	5.030677	4.92E-07	1.206083
Year2002	0.233178	0.040642	5.737347	9.72E-09	1.262606
Year2003	0.106979	0.03998	2.675804	0.007459	1.112911
Year2004	0.545821	0.045985	11.8696	2.03E-32	1.726025
Gear3	-0.15026	0.082129	-1.82952	0.067333	0.860487
Gear4	-0.26802	0.359263	-0.74602	0.45566	0.764894
Gear5	0.156331	0.060953	2.564776	0.010329	1.169213
Gear6	0.118013	0.062327	1.893467	0.058306	1.125259
Gear7	0.089356	0.061803	1.445817	0.14824	1.093469
Gear8	0.470388	0.119768	3.927502	8.60E-05	1.600616
Gear9	0.185606	0.062636	2.96324	0.003047	1.203947
Gear10	0.143657	0.062159	2.311109	0.020834	1.154488
Gear11	-0.14868	0.150013	-0.99111	0.321643	0.861846
Gear12	-0.60618	0.062832	-9.64761	5.44E-22	0.545429
Gear13	1.242986	0.617994	2.011324	0.044301	3.465946
Gear20	0.045364	0.153846	0.29487	0.768095	1.046409
Gear23	-0.5263	0.06315	-8.33411	8.16E-17	0.590786
Gear80	0.104398	0.35978	0.290172	0.771686	1.110042
Captain105	-0.03345	0.040253	-0.83095	0.40601	0.967105
Captain108	0.106447	0.070368	1.512714	0.130364	1.112319
Captain128	-0.00105	0.038059	-0.02767	0.977927	0.998948
Captain133	0.248875	0.032252	7.716558	1.23E-14	1.282582
Captain145	0.140667	0.100519	1.399403	0.161703	1.151041
Captain148	-0.06219	0.162747	-0.38211	0.702381	0.939707
Captain160	-0.00666	0.028852	-0.23089	0.817405	0.993361
Captain161	0.230099	0.053369	4.311506	1.63E-05	1.258725
Captain182	-0.23007	0.113539	-2.02633	0.04274	0.79448
Captain188	-0.36432	0.111577	-3.26522	0.001095	0.694666
Captain204	-0.20679	0.065942	-3.13592	0.001715	0.813192
Captain208	0.207955	0.091706	2.267632	0.023359	1.231158
Captain210	-0.0498	0.032968	-1.51051	0.130925	0.951421
Captain213	0.310805	0.031868	9.752957	1.94E-22	1.364524
Captain219	0.240103	0.029389	8.169735	3.22E-16	1.271381
Captain232	0.285772	0.042271	6.760423	1.40E-11	1.330788

Table C.12 continued.

Captain233	0.113498	0.081938	1.385159	0.166015	1.120189
Captain240	-0.80356	0.16985	-4.73096	2.25E-06	0.447734
Captain247	-0.05221	0.025015	-2.08726	0.036874	0.949127
Captain271	-0.38548	0.055152	-6.98941	2.82E-12	0.680122
Captain272	0.147889	0.031877	4.639296	3.51E-06	1.159384
Captain276	0.040198	0.049139	0.818044	0.413339	1.041016
Captain281	0.075359	0.068928	1.093294	0.274274	1.078271
Captain287	-0.20643	0.073077	-2.82484	0.004734	0.813483
Captain291	-0.26229	0.075238	-3.48616	0.000491	0.769287
Captain300	-0.37916	0.068737	-5.51609	3.50E-08	0.684437
Captain302	0.109698	0.028082	3.906309	9.39E-05	1.115941
Captain304	0.120897	0.291573	0.414637	0.678411	1.128509
Captain315	0.67226	0.264086	2.545613	0.010914	1.958659
Captain322	-0.05111	0.046664	-1.09522	0.273429	0.950177
Captain326	-0.24793	0.052847	-4.69152	2.72E-06	0.780414
Captain328	-0.09548	0.188723	-0.50591	0.612924	0.908939
Captain353	0.086289	0.080407	1.073155	0.283211	1.090121
Captain358	-0.52614	0.220293	-2.38837	0.01693	0.59088
Captain359	0.205988	0.502615	0.409833	0.681932	1.228739
Captain384	0.292336	0.029672	9.852329	7.29E-23	1.339552
Captain388	-0.42543	0.126997	-3.34994	0.000809	0.653488
Captain389	-0.12711	0.041084	-3.09398	0.001977	0.880634
Captain390	0.640261	0.042878	14.93227	3.16E-50	1.896977
Captain392	-0.16115	0.050784	-3.17333	0.001509	0.851161
ns(SoakDays, df = 5)1	0.112519	0.02731	4.120039	3.80E-05	1.119093
ns(SoakDays, df = 5)2	0.190852	0.028601	6.672868	2.55E-11	1.210281
ns(SoakDays, df = 5)3	0.399674	0.030823	12.96656	2.44E-38	1.491338
ns(SoakDays, df = 5)4	0.400103	0.043857	9.122932	7.78E-20	1.491978
ns(SoakDays, df = 5)5	0.39647	0.031369	12.63898	1.62E-36	1.486568
Month2	-0.04737	0.212042	-0.2234	0.823228	0.953735
Month3	0.255277	0.14643	1.743337	0.081286	1.290818
Month4	0.08559	0.148371	0.576864	0.564036	1.089359
Month5	0.216957	0.14541	1.492032	0.135702	1.24229
Month6	0.185227	0.143632	1.289598	0.197201	1.203492
Month7	0.109601	0.143226	0.765225	0.444144	1.115832
Month8	0.754977	0.140572	5.370754	7.90E-08	2.127564
Month9	0.627476	0.139906	4.484984	7.32E-06	1.872878
Month10	0.497325	0.140254	3.545899	0.000392	1.644317
Month11	0.391004	0.141204	2.769065	0.005625	1.478465
Month12	0.303139	0.144106	2.10359	0.035423	1.354103

Table C.13. Parameter estimates for the lognormal GLM fit. EAG trimmed observer data for 2005/06–2012/13 were used. The parameter values in the last column are in normal space.

Parameter	Estimate	Std. Error	t value	Pr(>|t|)	Exp(Estimate)
(Intercept)	3.024428	0.079153	38.2099	4.51E-278	20.58222
Year2006	-0.21423	0.034268	-6.25162	4.43E-10	0.807164
Year2007	-0.08583	0.037964	-2.26096	0.023807953	0.917746
Year2008	-0.1135	0.040651	-2.79207	0.005258529	0.892705
Year2009	-0.31156	0.047803	-6.51759	7.90E-11	0.732302
Year2010	-0.31646	0.045161	-7.00738	2.78E-12	0.728725
Year2011	0.113612	0.047638	2.384931	0.01712213	1.120318
Year2012	0.070059	0.044376	1.578763	0.114458435	1.072572
Captain112	0.444636	0.080984	5.490387	4.22E-08	1.559922
Captain133	0.213594	0.039762	5.371824	8.17E-08	1.238119
Captain145	-0.03293	0.119394	-0.27582	0.782699169	0.967605
Captain160	0.188537	0.038867	4.850868	1.27E-06	1.207482
Captain215	-0.12047	0.067101	-1.79542	0.072651006	0.8865
Captain219	0.19955	0.031449	6.34523	2.43E-10	1.220853
Captain353	-0.34938	0.063454	-5.50608	3.87E-08	0.705124
Captain384	0.16808	0.05024	3.345552	0.000827698	1.183032
ns(SoakDays, df = 13)1	0.18956	0.089933	2.107782	0.035103182	1.208718
ns(SoakDays, df = 13)2	0.049677	0.094431	0.526071	0.598863643	1.050932
ns(SoakDays, df = 13)3	0.090189	0.089298	1.009973	0.312560549	1.094381
ns(SoakDays, df = 13)4	0.221928	0.096709	2.294811	0.021788266	1.248481
ns(SoakDays, df = 13)5	0.061335	0.092181	0.665376	0.50584323	1.063255
ns(SoakDays, df = 13)6	0.15879	0.100373	1.582	0.113717574	1.172092
ns(SoakDays, df = 13)7	0.181332	0.100725	1.800267	0.071883304	1.198813
ns(SoakDays, df = 13)8	0.179175	0.092936	1.92793	0.053924598	1.19623
ns(SoakDays, df = 13)9	0.289242	0.104665	2.7635	0.00574101	1.335415
ns(SoakDays, df = 13)10	0.238907	0.102523	2.330292	0.019833254	1.269861
ns(SoakDays, df = 13)11	0.191715	0.088611	2.163548	0.030549827	1.211325
ns(SoakDays, df = 13)12	-0.12717	0.178613	-0.712	0.476500384	0.880582
ns(SoakDays, df = 13)13	0.480008	0.085609	5.606962	2.18E-08	1.616088
Gear6	0.110819	0.027201	4.074131	4.70E-05	1.117192
Gear7	0.269906	0.036574	7.379794	1.87E-13	1.309841
Gear8	0.84008	0.449045	1.870816	0.06143337	2.316552
Gear9	0.054198	0.032169	1.684794	0.092095419	1.055693
Gear10	0.086923	0.034725	2.503163	0.012342889	1.090813
Gear11	0.271233	0.319021	0.850205	0.395254832	1.311581

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)	1.391432	0.190128	7.318413	2.58E-13	4.020603674
Year1996	-0.1288	0.031345	-4.10905	3.98E-05	0.879152798
Year1997	-0.15595	0.034525	-4.51707	6.30E-06	0.855601209
Year1998	-0.05136	0.038006	-1.35141	0.176577	0.949934911
Year1999	-0.25165	0.036358	-6.92133	4.58E-12	0.777517537
Year2000	-0.24631	0.036187	-6.8067	1.02E-11	0.781676236
Year2001	-0.27741	0.038296	-7.24381	4.48E-13	0.757745062
Year2002	-0.19938	0.039843	-5.00427	5.64E-07	0.819235097
Year2003	-0.01205	0.040091	-0.3005	0.763799	0.988025079
Year2004	0.043298	0.040073	1.080475	0.27994	1.044249
Captain108	-0.43169	0.075552	-5.71381	1.12E-08	0.649412759
Captain112	-0.79735	0.131128	-6.08071	1.21E-09	0.450520073
Captain113	-0.19209	0.104289	-1.8419	0.0655	0.825232874
Captain114	-0.27234	0.074266	-3.66704	0.000246	0.761598903
Captain128	-0.49319	0.045319	-10.8826	1.59E-27	0.610678262
Captain130	0.235211	0.039128	6.011262	1.86E-09	1.265175555
Captain131	0.161143	0.055826	2.886519	0.003898	1.174852821
Captain133	-0.47059	0.057825	-8.13807	4.19E-16	0.624636464
Captain145	-0.19764	0.04103	-4.81699	1.47E-06	0.820662899
Captain146	0.016648	0.059527	0.279672	0.779731	1.016787297
Captain157	-0.21111	0.05062	-4.17044	3.05E-05	0.809685721
Captain159	-0.16016	0.247812	-0.6463	0.518092	0.852007491
Captain160	-0.20725	0.04156	-4.98686	6.18E-07	0.812813437
Captain166	0.00061	0.0421	0.014485	0.988443	1.000609998
Captain176	-0.1149	0.083648	-1.37365	0.169562	0.891452198
Captain182	-0.3361	0.097413	-3.4502	0.000561	0.714554634
Captain188	-0.36472	0.073381	-4.97017	6.73E-07	0.694392682
Captain210	-0.1877	0.102108	-1.83824	0.066038	0.828864302
Captain213	0.054451	0.098722	0.551558	0.581256	1.055960722
Captain219	-0.13751	0.040617	-3.38548	0.000712	0.871526135
Captain230	-0.80447	0.065399	-12.3009	1.11E-34	0.447323698
Captain232	-0.41403	0.200306	-2.06701	0.038742	0.660977922
Captain234	-0.15615	0.076542	-2.04005	0.041355	0.855430679
Captain235	-0.30386	0.070292	-4.32287	1.55E-05	0.737961308
Captain244	-0.35865	0.089345	-4.01425	5.98E-05	0.698615397
Captain257	0.126317	0.055934	2.258341	0.023932	1.134642083
Captain271	-0.6435	0.108576	-5.92673	3.13E-09	0.525451341
Captain272	-0.38084	0.061273	-6.21539	5.20E-10	0.683290519
Captain277	-0.2825	0.068805	-4.10576	4.04E-05	0.753899621
Captain287	-0.27536	0.066816	-4.12112	3.78E-05	0.759302059

Table C.14 continued.

Captain302	-0.35726	0.070225	-5.08741	3.65E-07	0.69958761
Captain304	-0.48707	0.062917	-7.74153	1.02E-14	0.61442404
Captain308	-0.0815	0.053646	-1.51928	0.128704	0.921730025
Captain315	-0.60276	0.076793	-7.84916	4.34E-15	0.547299411
Captain318	-0.60915	0.072165	-8.44103	3.30E-17	0.543813824
Captain322	-0.83634	0.213423	-3.91869	8.93E-05	0.433294259
Captain326	-0.28968	0.045693	-6.33962	2.34E-10	0.74850472
Captain328	-0.58415	0.146699	-3.98198	6.85E-05	0.557578186
Captain332	-0.5791	0.152618	-3.79446	0.000148	0.560400396
Captain335	-0.51769	0.154834	-3.34351	0.000828	0.5958954
Captain336	0.043206	0.046306	0.933067	0.350794	1.044153396
Captain359	-0.29412	0.069048	-4.25961	2.05E-05	0.745188455
Captain369	-0.49351	0.100878	-4.89219	1.00E-06	0.610478928
Captain384	-0.3973	0.068475	-5.80215	6.62E-09	0.672129558
Captain387	-0.63633	0.107581	-5.91493	3.36E-09	0.529229767
Captain389	-0.33695	0.06029	-5.5889	2.31E-08	0.713941734
Captain390	-0.21433	0.08623	-2.48561	0.012939	0.807078119
Captain392	-1.03874	0.27877	-3.72616	0.000195	0.353900558
Captain394	-0.0524	0.070521	-0.7431	0.457426	0.948945108
ns(SoakDays, df = 15)1	35709.89	13151.12	2.71535	0.006625	
ns(SoakDays, df = 15)2	-16573	6103.456	-2.71534	0.006625	0
ns(SoakDays, df = 15)3	4440.858	1635.416	2.71543	0.006623	
ns(SoakDays, df = 15)4	-1189.73	438.2088	-2.71499	0.006632	0
ns(SoakDays, df = 15)5	319.0537	117.4175	2.717258	0.006587	
ns(SoakDays, df = 15)6	-85.1032	31.46156	-2.70499	0.006835	0
ns(SoakDays, df = 15)7	23.34414	8.429514	2.769334	0.005621	13747750676
ns(SoakDays, df = 15)8	-5.76363	2.256926	-2.55375	0.010662	0.003139699
ns(SoakDays, df = 15)9	2.12796	0.600842	3.54163	0.000398	8.397716628
ns(SoakDays, df = 15)10	0.116437	0.152935	0.761348	0.446456	1.123486167
ns(SoakDays, df = 15)11	0.759233	0.080647	9.414314	5.13E-21	2.136636299
ns(SoakDays, df = 15)12	0.3886	0.055751	6.970345	3.24E-12	1.474914895
ns(SoakDays, df = 15)13	14225.6	5238.701	2.715482	0.006622	
ns(SoakDays, df = 15)14	-32513.3	11974.13	-2.71529	0.006626	0
ns(SoakDays, df = 15)15	18289.65	6735.443	2.715433	0.006623	
Gear3	-0.36171	0.191913	-1.88478	0.059471	0.696481803
Gear4	0.318156	0.49638	0.640953	0.521559	1.374590566
Gear5	0.258012	0.185093	1.393959	0.163341	1.294354314
Gear6	0.299052	0.18412	1.624221	0.10434	1.348579484
Gear7	0.325648	0.183767	1.77207	0.076394	1.384928135
Gear8	0.186017	0.18914	0.98349	0.325375	1.204443186
Gear9	0.313289	0.187232	1.673264	0.094287	1.367917255
Gear10	0.394768	0.183386	2.152663	0.031354	1.48404058
Gear11	0.493568	0.251547	1.962134	0.049757	1.638151494

Table C.14 continued.

Gear12	-0.29754	0.187055	-1.59066	0.111698	0.742642827
Gear13	0.605959	0.191861	3.15832	0.001589	1.833009956
Gear20	0.28656	0.283769	1.009833	0.312584	1.331837584
Gear23	-0.47149	0.193842	-2.43235	0.015008	0.624070333
Gear80	0.871736	0.934264	0.933072	0.350791	2.391057092

Table C.15. Parameter estimates for the lognormal GLM fit. WAG trimmed observer data for 2005/06–2012/13 were used. The parameter values in the last column are in normal space.

Parameter	Estimate	Std. Error	t value	Pr(>|t|)	Exp(Estimate)
(Intercept)	2.301439	0.199821	11.51749	2.09E-30	9.988549
Year2006	-0.06311	0.044665	-1.41288	0.157737	0.938843
Year2007	-0.15248	0.050913	-2.99494	0.002755	0.858575
Year2008	0.020119	0.04125	0.487738	0.625752	1.020323
Year2009	0.018265	0.04195	0.435396	0.663289	1.018433
Year2010	-0.06032	0.043685	-1.38089	0.167358	0.941459
Year2011	-0.01239	0.046049	-0.26898	0.787953	0.98769
Year2012	0.034872	0.045515	0.766167	0.443604	1.035487
Captain104	0.185066	0.195718	0.945573	0.344401	1.203298
Captain131	0.185559	0.194449	0.954284	0.339974	1.203892
Captain133	0.331977	0.196032	1.693482	0.09041	1.39372
Captain145	0.64468	0.190524	3.383727	0.000719	1.905377
Captain166	0.347486	0.191826	1.811469	0.070113	1.415505
Captain215	0.325347	0.209132	1.555706	0.119826	1.384512
Captain257	0.330325	0.196956	1.677152	0.09356	1.39142
Captain336	0.372993	0.198195	1.881948	0.059887	1.452075
Captain384	0.257392	0.198529	1.296496	0.194849	1.293552
ns(SoakDays, df = 9)1	0.350485	0.07564	4.633577	3.66E-06	1.419755
ns(SoakDays, df = 9)2	0.206905	0.095485	2.166886	0.030279	1.229866
ns(SoakDays, df = 9)3	0.177075	0.084301	2.100496	0.035723	1.19372
ns(SoakDays, df = 9)4	0.489101	0.093684	5.220767	1.84E-07	1.630849
ns(SoakDays, df = 9)5	0.151424	0.100371	1.508646	0.131437	1.16349
ns(SoakDays, df = 9)6	0.239738	0.093413	2.566414	0.010297	1.270915
ns(SoakDays, df = 9)7	0.403781	0.08273	4.880714	1.08E-06	1.497476
ns(SoakDays, df = 9)8	0.295055	0.166735	1.769612	0.076837	1.343201
ns(SoakDays, df = 9)9	-0.03581	0.096871	-0.36963	0.711673	0.964827

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)	1.721271	0.068756	25.0344	5.60E-137	5.591629
Year1996	0.032316	0.025413	1.271648	0.203507692	1.032844
Year1997	0.07448	0.03055	2.437935	0.014776883	1.077323
Year1998	0.262511	0.028701	9.146282	6.24E-20	1.300191
Year1999	0.185736	0.030187	6.152805	7.70E-10	1.204104
Year2000	0.211121	0.029001	7.279895	3.42E-13	1.235062
Year2001	0.478358	0.030762	15.55034	2.52E-54	1.613423
Year2002	0.540845	0.034196	15.81602	3.96E-56	1.717457
Year2003	0.409519	0.033933	12.06841	1.84E-33	1.506093
Year2004	0.898212	0.038834	23.12973	2.20E-117	2.455209
Gear3	-0.25538	0.084136	-3.03532	0.002404797	0.774622
Gear4	-0.22541	0.365064	-0.61744	0.536946296	0.798192
Gear5	0.147367	0.06301	2.338808	0.019351587	1.15878
Gear6	0.136253	0.064087	2.126081	0.03350426	1.145972
Gear7	0.104233	0.063523	1.640884	0.100831348	1.109859
Gear8	0.35542	0.120304	2.954353	0.003135561	1.42678
Gear9	0.165076	0.064578	2.556234	0.010585839	1.179483
Gear10	0.160079	0.063725	2.512016	0.012009298	1.173604
Gear11	-0.2385	0.156902	-1.52004	0.128510558	0.787811
Gear12	-0.83642	0.064797	-12.9082	5.05E-38	0.43326
Gear13	1.115976	0.648472	1.720931	0.085273213	3.052545
Gear20	0.064888	0.162536	0.399221	0.689733392	1.067039
Gear23	-0.76197	0.065326	-11.664	2.26E-31	0.466748
Gear80	-1.10508	0.239619	-4.6118	4.01E-06	0.331186
Captain105	-0.11977	0.041206	-2.90654	0.003657012	0.887128
Captain108	0.084246	0.073924	1.139626	0.254450643	1.087896
Captain128	-0.13886	0.038664	-3.59147	0.000329317	0.870348
Captain133	0.203691	0.033319	6.113393	9.87E-10	1.225919
Captain145	0.088732	0.104576	0.84849	0.396171557	1.092788
Captain148	-0.27063	0.169451	-1.59712	0.110249385	0.762897
Captain160	-0.02326	0.029485	-0.78898	0.430129722	0.977005
Captain161	0.254688	0.056084	4.54122	5.61E-06	1.290059
Captain182	-0.2991	0.118315	-2.52801	0.011475974	0.741484
Captain188	-0.51164	0.117553	-4.35244	1.35E-05	0.599511
Captain204	-0.86369	0.063834	-13.5303	1.35E-41	0.421603
Captain208	0.030011	0.095867	0.313046	0.754247901	1.030466
Captain210	-0.04132	0.035054	-1.1787	0.238525121	0.959524
Captain213	0.276127	0.033146	8.330675	8.36E-17	1.318015
Captain219	0.214357	0.030339	7.065385	1.63E-12	1.239065
Captain232	0.143607	0.041305	3.476779	0.000508158	1.15443

Table C.16 continued.

Captain233	-0.27411	0.077947	-3.51659	0.00043774	0.760251
Captain240	-0.91145	0.163301	-5.5814	2.41E-08	0.401942
Captain247	-0.08268	0.026063	-3.17231	0.001513737	0.920645
Captain271	-0.60992	0.054074	-11.2795	1.89E-29	0.543392
Captain272	0.078646	0.033009	2.382591	0.01719717	1.081822
Captain276	-0.03444	0.050608	-0.68062	0.496119917	0.966142
Captain281	0.008428	0.072561	0.116144	0.907539241	1.008463
Captain287	-0.51253	0.071903	-7.12805	1.04E-12	0.59898
Captain291	-0.22082	0.07742	-2.85222	0.004344376	0.801861
Captain300	-0.51241	0.072215	-7.09565	1.31E-12	0.599049
Captain302	0.160776	0.029017	5.540663	3.04E-08	1.174422
Captain304	-0.01133	0.315069	-0.03596	0.971315699	0.988735
Captain315	0.479032	0.265277	1.80578	0.070962248	1.614511
Captain322	-0.022	0.046412	-0.47401	0.635494692	0.97824
Captain326	-0.4042	0.054176	-7.46087	8.82E-14	0.667512
Captain328	-0.27833	0.184686	-1.50707	0.131801941	0.757043
Captain353	0.014938	0.082747	0.180531	0.856737045	1.01505
Captain358	-1.00245	0.222831	-4.49872	6.86E-06	0.366978
Captain359	-0.72631	0.517126	-1.40451	0.160177546	0.483692
Captain384	0.26983	0.030557	8.830336	1.10E-18	1.309742
Captain388	-0.97808	0.117615	-8.31596	9.46E-17	0.376033
Captain389	-0.2115	0.042706	-4.95244	7.37E-07	0.809369
Captain390	0.605771	0.04386	13.8116	2.90E-43	1.832665
Captain392	-0.35081	0.051533	-6.80744	1.01E-11	0.70412
ns(SoakDays, df = 3)1	0.32594	0.026959	12.09039	1.41E-33	1.385332
ns(SoakDays, df = 3)2	0.469227	0.042611	11.01198	3.76E-28	1.598758
ns(SoakDays, df = 3)3	0.395398	0.026933	14.68063	1.24E-48	1.484975

Table C.17. Parameter estimates for the negative binomial GLM fit. EAG trimmed observer data for 2005/06–2012/13 were used. The parameter values in the last column are in normal space.

Parameter	Estimate	Std. Error	t value	Pr(>|t|)	Exp(Estimate)
(Intercept)	3.165215	0.078374	40.38615	9.09E-307	23.69384
Year2006	-0.20408	0.03121	-6.53909	6.84E-11	0.815393
Year2007	-0.09017	0.03424	-2.63341	0.0084806	0.913778
Year2008	-0.12048	0.036579	-3.29361	0.00099634	0.886498
Year2009	-0.30493	0.04334	-7.03591	2.26E-12	0.737172
Year2010	-0.29598	0.040905	-7.23574	5.37E-13	0.743804
Year2011	0.092375	0.042837	2.156458	0.03109807	1.096776
Year2012	0.025476	0.039853	0.639251	0.52269076	1.025803
Captain112	0.503715	0.073498	6.853441	8.13E-12	1.654857
Captain133	0.207776	0.035996	5.772195	8.32E-09	1.230937
Captain145	-0.06698	0.111684	-0.59969	0.54874103	0.935218
Captain160	0.209249	0.035076	5.965522	2.62E-09	1.232751
Captain215	-0.12067	0.061007	-1.9779	0.04799786	0.886331
Captain219	0.171071	0.028513	5.999729	2.12E-09	1.186575
Captain353	-0.34305	0.05876	-5.83821	5.63E-09	0.709601
Captain384	0.12346	0.045958	2.686365	0.0072486	1.131405
ns(SoakDays, df = 18)1	0.274219	0.194739	1.408137	0.15915609	1.315503
ns(SoakDays, df = 18)2	-0.61302	0.381057	-1.60874	0.10774031	0.541712
ns(SoakDays, df = 18)3	3.007473	1.433084	2.098602	0.03590479	20.2362
ns(SoakDays, df = 18)4	-10.988	5.409714	-2.03116	0.0422947	1.69E-05
ns(SoakDays, df = 18)5	24.0135	11.63326	2.06421	0.03905204	2.68E+10
ns(SoakDays, df = 18)6	-23.6846	11.64969	-2.03307	0.04210101	5.17E-11
ns(SoakDays, df = 18)7	11.02367	5.434685	2.028392	0.042576	61308.46
ns(SoakDays, df = 18)8	-2.49597	1.893686	-1.31805	0.18755054	0.082416
ns(SoakDays, df = 18)9	-0.92405	2.279962	-0.40529	0.68527993	0.396907
ns(SoakDays, df = 18)10	1.209147	2.27855	0.530665	0.5956756	3.350626
ns(SoakDays, df = 18)11	-0.19645	1.049991	-0.1871	0.85159375	0.821643
ns(SoakDays, df = 18)12	0.168824	0.271691	0.621383	0.53437734	1.183912
ns(SoakDays, df = 18)13	0.316596	0.15134	2.091946	0.03649636	1.372448
ns(SoakDays, df = 18)14	0.184159	0.118441	1.554858	0.12004671	1.202207
ns(SoakDays, df = 18)15	0.281066	0.105927	2.653394	0.00799525	1.324542
ns(SoakDays, df = 18)16	0.15437	0.098156	1.572693	0.11585657	1.166922
ns(SoakDays, df = 18)17	-0.1586	0.182585	-0.86866	0.38507647	0.853333
ns(SoakDays, df = 18)18	0.577066	0.093994	6.139417	8.96E-10	1.780806
Gear6	0.141175	0.024585	5.742389	9.92E-09	1.151626
Gear7	0.303446	0.033138	9.157081	7.76E-20	1.354518
Gear8	0.630359	0.406155	1.552014	0.1207255	1.878284
Gear9	0.069438	0.028994	2.394919	0.01666261	1.071905
Gear10	0.117535	0.031494	3.732019	0.00019217	1.124722
Gear11	0.153811	0.286931	0.536056	0.59194507	1.16627

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)	1.60164	0.216148	7.409908	1.29E-13	4.961164
Year1996	-0.2092	0.035001	-5.97714	2.29E-09	0.811229
Year1997	-0.19949	0.038628	-5.16446	2.43E-07	0.819148
Year1998	-0.09401	0.042869	-2.19305	0.028311	0.910271
Year1999	-0.25305	0.040698	-6.21791	5.10E-10	0.776426
Year2000	-0.32037	0.040311	-7.94748	1.96E-15	0.725878
Year2001	-0.35119	0.042743	-8.21636	2.17E-16	0.703847
Year2002	-0.24081	0.044414	-5.4219	5.94E-08	0.785992
Year2003	-0.01868	0.044647	-0.41846	0.675613	0.981491
Year2004	0.077468	0.04458	1.73772	0.08227	1.080547
Captain108	-0.75659	0.07883	-9.5978	8.73E-22	0.469263
Captain112	-0.95328	0.153545	-6.20847	5.42E-10	0.385475
Captain113	-0.29452	0.115218	-2.55621	0.010586	0.744888
Captain114	-0.34566	0.080114	-4.31459	1.60E-05	0.707752
Captain128	-0.69376	0.049329	-14.0641	8.56E-45	0.499692
Captain130	0.198398	0.043622	4.548084	5.43E-06	1.219448
Captain131	0.151046	0.063461	2.380128	0.017312	1.16305
Captain133	-0.61527	0.063192	-9.7365	2.26E-22	0.540495
Captain145	-0.20128	0.044907	-4.48218	7.41E-06	0.817681
Captain146	0.021886	0.065141	0.335978	0.73689	1.022127
Captain157	-0.17816	0.05687	-3.13278	0.001733	0.836807
Captain159	-0.62405	0.26639	-2.34263	0.019155	0.535769
Captain160	-0.29747	0.044837	-6.63447	3.31E-11	0.742695
Captain166	-0.07525	0.046406	-1.62154	0.104912	0.927512
Captain176	-0.10677	0.092903	-1.14927	0.250452	0.898732
Captain182	-0.70444	0.101946	-6.90994	4.94E-12	0.494384
Captain188	-0.50157	0.080812	-6.20661	5.48E-10	0.605579
Captain210	-0.44861	0.108868	-4.12073	3.79E-05	0.638512
Captain213	0.018655	0.11139	0.167475	0.866998	1.01883
Captain219	-0.21113	0.043601	-4.84233	1.29E-06	0.809668
Captain230	-0.96207	0.073111	-13.1591	1.91E-39	0.382102
Captain232	-0.78116	0.215704	-3.62145	0.000293	0.457874
Captain234	0.018935	0.086283	0.219446	0.826304	1.019115
Captain235	-0.26996	0.078319	-3.44698	0.000568	0.763407
Captain244	-0.45915	0.096618	-4.75224	2.02E-06	0.63182
Captain257	0.032735	0.062927	0.520206	0.602923	1.033277
Captain271	-1.10027	0.113475	-9.69615	3.36E-22	0.332782
Captain272	-0.5721	0.066586	-8.59187	8.93E-18	0.56434
Captain277	-0.33428	0.077303	-4.32421	1.54E-05	0.715857
Captain287	-0.39958	0.074319	-5.37657	7.64E-08	0.670599

Table C.18 continued.

Captain302	-0.47064	0.078823	-5.97081	2.39E-09	0.624605
Captain304	-0.63246	0.069461	-9.10528	9.08E-20	0.531284
Captain308	-0.10524	0.058929	-1.78589	0.074127	0.900108
Captain315	-0.87983	0.083121	-10.585	3.86E-26	0.414852
Captain318	-0.89827	0.078566	-11.4332	3.26E-30	0.407274
Captain322	-1.56758	0.222855	-7.03407	2.05E-12	0.20855
Captain326	-0.37668	0.050139	-7.51262	5.94E-14	0.686138
Captain328	-0.76053	0.159742	-4.76101	1.93E-06	0.467417
Captain332	-0.95232	0.16485	-5.77692	7.68E-09	0.385843
Captain335	-0.59193	0.180911	-3.27191	0.001069	0.553261
Captain336	0.035533	0.051468	0.690403	0.489946	1.036172
Captain359	-0.42948	0.077364	-5.55135	2.86E-08	0.650849
Captain369	-0.7334	0.106969	-6.85618	7.20E-12	0.480275
Captain384	-0.61995	0.076405	-8.11399	5.07E-16	0.537972
Captain387	-0.99126	0.116116	-8.53678	1.44E-17	0.371111
Captain389	-0.41187	0.067919	-6.06417	1.34E-09	0.66241
Captain390	-0.27362	0.095112	-2.87682	0.00402	0.760622
Captain392	-1.47156	0.317352	-4.637	3.55E-06	0.229567
Captain394	-0.11193	0.078343	-1.42869	0.153102	0.894109
Gear3	-0.63408	0.218027	-2.90825	0.003637	0.530425
Gear4	0.315751	0.612969	0.515118	0.606474	1.371289
Gear5	0.249929	0.210623	1.186618	0.235387	1.283934
Gear6	0.285151	0.209717	1.359694	0.173936	1.329963
Gear7	0.341882	0.209338	1.633159	0.102445	1.407595
Gear8	0.17759	0.215081	0.82569	0.408986	1.194336
Gear9	0.322179	0.212924	1.513118	0.13026	1.380131
Gear10	0.449059	0.20883	2.150359	0.031534	1.566837
Gear11	0.873897	0.278857	3.13385	0.001727	2.39623
Gear12	-0.67784	0.212376	-3.19169	0.001416	0.507713
Gear13	0.62363	0.218414	2.855263	0.004303	1.865687
Gear20	0.394443	0.320677	1.230031	0.218694	1.483557
Gear23	-0.95472	0.219684	-4.34586	1.39E-05	0.384921
Gear80	0.344035	1.092098	0.315022	0.752747	1.410628
ns(SoakDays, df = 14)1	-96.4514	88.12093	-1.09453	0.273729	1.29E-42
ns(SoakDays, df = 14)2	44.81752	40.89649	1.095877	0.273141	2.91E+19
ns(SoakDays, df = 14)3	-11.7919	10.95765	-1.07613	0.281875	7.57E-06
ns(SoakDays, df = 14)4	3.464361	2.934199	1.180684	0.237737	31.95604
ns(SoakDays, df = 14)5	-0.52422	0.781326	-0.67094	0.502267	0.592018
ns(SoakDays, df = 14)6	0.690603	0.199579	3.460303	0.00054	1.994917
ns(SoakDays, df = 14)7	0.449207	0.108782	4.129441	3.65E-05	1.56707
ns(SoakDays, df = 14)8	0.61216	0.072182	8.480765	2.33E-17	1.84441
ns(SoakDays, df = 14)9	0.662278	0.054095	12.24279	2.19E-34	1.939204
ns(SoakDays, df = 14)10	0.772886	0.052282	14.78295	2.73E-49	2.166009

Table C.18 continued.

ns(SoakDays, df = 14)11	0.655161	0.053801	12.17757	4.86E-34	1.925452
ns(SoakDays, df = 14)12	-35.3267	32.95133	-1.07209	0.283689	4.55E-16
ns(SoakDays, df = 14)13	88.44989	80.02874	1.105227	0.26907	2.59E+38
ns(SoakDays, df = 14)14	-50.7919	47.07601	-1.07893	0.280626	8.74E-23

Table C.19. Parameter estimates for the Negative binomial GLM fit. WAG trimmed observer data for 2005/06–2012/13 were used. The parameter values in the last column are in normal space.

Parameter	Estimate	Std. Error	t value	Pr(>|t|)	Exp(Estimate)
(Intercept)	2.656909	0.194139	13.68562	4.32E-42	14.25217
Year2006	-0.05237	0.039608	-1.3223	0.18611	0.948973
Year2007	-0.14664	0.045031	-3.25652	0.001133	0.863601
Year2008	0.025335	0.036793	0.688574	0.491114	1.025658
Year2009	0.017553	0.037223	0.471571	0.637247	1.017708
Year2010	-0.10083	0.039057	-2.58169	0.009852	0.904083
Year2011	-0.06181	0.041084	-1.50459	0.132475	0.940058
Year2012	0.012412	0.040644	0.305393	0.760076	1.01249
Captain104	0.097889	0.176799	0.553672	0.579821	1.10284
Captain131	0.16333	0.175635	0.929941	0.352434	1.177425
Captain133	0.230304	0.177074	1.300615	0.193433	1.258983
Captain145	0.530999	0.172075	3.085867	0.002038	1.700631
Captain166	0.273196	0.173299	1.576443	0.114969	1.314158
Captain215	0.237726	0.188614	1.260385	0.207573	1.268361
Captain257	0.266844	0.177614	1.502382	0.133044	1.305836
Captain336	0.301111	0.178888	1.683244	0.092373	1.35136
Captain384	0.140935	0.179314	0.785968	0.431913	1.15135
ns(Depth, df = 6)1	-0.09305	0.068973	-1.34907	0.177359	0.911148
ns(Depth, df = 6)2	-0.05438	0.086216	-0.63077	0.528212	0.94707
ns(Depth, df = 6)3	-0.25935	0.077506	-3.34624	0.000823	0.77155
ns(Depth, df = 6)4	-0.22469	0.068938	-3.25925	0.001122	0.798766
ns(Depth, df = 6)5	-0.1009	0.165459	-0.60979	0.542021	0.904028
ns(Depth, df = 6)6	-0.2282	0.096332	-2.36892	0.017867	0.795964
ns(SoakDays, df = 9)1	0.388483	0.068551	5.667083	1.51E-08	1.474741
ns(SoakDays, df = 9)2	0.235446	0.08609	2.734887	0.006256	1.265473
ns(SoakDays, df = 9)3	0.268291	0.075969	3.53161	0.000416	1.307728
ns(SoakDays, df = 9)4	0.517309	0.084265	6.139067	8.76E-10	1.677507
ns(SoakDays, df = 9)5	0.191792	0.090161	2.127214	0.033437	1.211419
ns(SoakDays, df = 9)6	0.333117	0.083782	3.97602	7.08E-05	1.395311
ns(SoakDays, df = 9)7	0.419381	0.073216	5.728007	1.06E-08	1.52102
ns(SoakDays, df = 9)8	0.385379	0.150657	2.557994	0.010549	1.470171
ns(SoakDays, df = 9)9	-0.00397	0.084128	-0.04719	0.962362	0.996038

Table C.19 continued.

(Intercept)	2.782401	0.224934	12.36988	1.06E-34	16.15777
Year2006	-0.09448	0.044854	-2.1064	0.035213	0.909845
Year2007	-0.18366	0.050846	-3.61204	0.000306	0.83222
Year2008	0.021105	0.040756	0.517831	0.604596	1.021329
Year2009	0.012897	0.041287	0.312384	0.75476	1.012981
Year2010	-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
Captain104	0.140728	0.189637	0.742091	0.458063	1.151112
Captain131	0.116178	0.177929	0.652945	0.513818	1.123195
Captain133	0.228867	0.177162	1.291853	0.19646	1.257175
Captain145	0.581111	0.171784	3.38279	0.000722	1.788023
Captain166	0.353586	0.1737	2.03561	0.041836	1.424165
Captain257	0.364926	0.179465	2.033407	0.042058	1.440407
Captain336	0.321389	0.179846	1.787021	0.073987	1.379042
Captain384	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