SCIENTIFIC COMMITTEE
EIGHTH REGULAR SESSION

7-15 August 2012

Busan, Republic of Korea

Catch per unit effort of silky sharks in the Western and Central Pacific Ocean

WCPFC-SC8-2012/ SA-IP-11 (Rev 1)

Joel Rice[1]

[1] Oceanic Fisheries Programme, Secretariat of the Pacific Community (SPC-OFP), Noumea, New Caledonia.

Catch per unit effort of silky sharks in the Western and Central Pacific Ocean

Summary

This paper follows from the indicator based analysis presented to the Western and Central Pacific Fisheries Commission (WCPFC) Scientific Committee (SC7, Clarke et al. 2011). Following a brief summary of exploratory data analysis this report presents a Catch Per Unit Effort (CPUE) standardization for silky shark (*Carcharhinus falciformis*) taken in longline and purse seine fisheries based on observer data held by the Secretariat of the Pacific - Oceanic Fisheries Program (SPC-OFP).

The objectives were to produce multiple time series of standardized CPUE to be used as indices of abundance for use in the silky shark stock assessment (Rice and Harley 2012). The sections of this report include a) a summary of the exploratory data analysis of silky shark (FAL) CPUE in the WCPO, b) presentation of the final standardized CPUE trends for silky sharks, c) model diagnostics, and d) a discussion of the quality of the available data and the relative strengths and weaknesses of the standardization procedures. This paper is prepared as an information paper along with alternate catch estimates (Rice, 2012) to support the stock assessment of silky sharks presented to the SC (Rice and Harley 2012).

1 Introduction

This paper follows from the indicator based analysis presented to the Western and Central Pacific Fisheries Commission (WCPFC) Scientific Committee (SC7, Clarke et al. 2011). The developments presented here include additional analyses of the Secretariat of the Pacific (SPC) data holdings for silky sharks caught in longline and purse seine fisheries in the Western and Central Pacific Ocean (WCPO).

The framework for the analysis is to construct inputs for stock assessment based on an estimated catch and an index of abundance based on standardized catch per unit of effort (CPUE). The SPC longline observer database contains records from 1985 to recent years, however silky sharks were not routinely identified to species until 1995, hence the dataset used in this analysis spans the years 1995-2009[2]. Recent work by Clarke et al. (2011) noted gaps in observer data in terms of time and space continuity, reporting rate, and identification with respect to sharks. Silky sharks are observed mainly in the equatorial waters in the purse seine fishery (Figure 1), and from about -25˚S to 25˚N in the longline fishery (Figure 1).

CPUE data for species such as sharks often have a large proportion of observations (or sets) with no catch, and also include observations with large catches when areas of higher densities are encountered; this is typical of bycatch species (Ward and Myers 2005). The signals from the nominal[3] CPUE data can be heavily influenced by factors other than abundance and therefore a procedure to standardize CPUE data for changes in factors (e.g. fishing technique, season, bait type) that do not reflect changes in abundance is usually recommended. Nominal CPUE data for bycatch can be more variable than expected (i.e., overdispersed) with many outlying data points from

[2] At the time of this analysis there was insufficient 2010 longline observer records.

[3] The nominal CPUE is based on the observed catch and effort and calculated as catch/effort

uncommonly high catch rates. These outlying data points can sometimes be a function of shark targeting.

2 Methods

This analysis follows the work of Clarke et al., (2011, 2011b) and Walsh and Clarke (2011) however the regions for this study differ slightly. Because silky sharks are tropical species this led to the analysis being considered for one region, from 25˚S to 25˚N and bordered on the east and west by the WCPFC Statistical Area. A comprehensive overview of the observer logsheet data and a characterization of the fisheries in which silky sharks are caught is presented in Clarke et al. (2011), what follows is a summary of the methods used in this analysis.

2.1 Longline data preparation

The data were validated and trimmed (records with missing values for key explanatory variables removed) to include only relevant data from the species 'core' habitat. This was done to reduce the already excessive number of zeros in the data, i.e. zero catch where you would not reasonably expect to catch silky sharks. Environmental data about temperature, salinity, moon phase, and depth of the 27˚C isotherm downloaded from the GODAS database (GODAS 2011) were matched to the observer data on set by set basis.

Because silky sharks are an epi-pelagic tropical species, all sets that occurred in water colder than 25˚C were discarded, this left 95% of the sets with a non-zero catch (Figure 2). The effect of hooks between floats (a proxy for depth) was investigated independently and sets with greater than 30 hooks between floats were discarded, this left 90% of the sets with a non-zero catch (Figure 2). National affiliation of the fishing vessel was included in the data set, and only those nations that had greater than 100 sets since 1995 were used. The last variable that resulted in a culling of the data set was that based on non-zero CPUE for unidentified sets (sets where the target is marked as unidentified) as a function of national affiliation. Flagged vessels where the average positive CPUE was 3 times larger than the mean CPUE for all other nations combined were removed from the bycatch longline data under the premise that these vessels were targeting sharks.

Latitude and longitude were truncated to the nearest 1˚; this location information was used to calculate the set specific association with a 5˚square (referred to hereinafter as cell). Date of set was used to calculate the year, month, quarter and trimester of the set. Set time was used to calculate the time category of the day in sixths starting at midnight. A non-target data set was created as a result of filtering data sets according to the above rules as well as filtering sets where sharks were the intentional target. This was done under the premise that the factors leading to non-zero catch rates when targeting sharks would be different than factors that lead to non-zero catch rates when not targeting sharks.

Although a much smaller proportion of the overall dataset (6.5% of the sets), the targeting sets represent significant shark catch (82% of the total silky shark catch). Therefore the dataset was examined with respect to variables relating to whether sharks were the intentional target of the set. Silky shark CPUE was plotted as a function of the variables sharkline, shark bait, shark target against date of set (Figure 3). Inspection of these covariates led to the separation of shark-targeting sets and non-targeting (bycatch) sets. Shark targeting sets were deemed to be sets where the observer had marked that the set was intentionally targeting sharks of any species, whether shark bait was used, or whether shark lines were used.

The results of these filtering rules are in Table 2.

2.2 Purse Seine data preparation

The only restriction placed on the purse seine observer data was that the set occurred within the rectangle defined by 7˚N and -12˚S Latitude and 139˚W to 192˚E. The purse seine data was separated into two fisheries, one based on associated sets and one based on unassociated sets.

2.3 CPUE methodology

CPUE is commonly used as an index of abundance for marine species. However, it is important that raw nominal catch rates be standardized to remove the effects of factors other than abundance. Further, catch data for non-target species (and sharks in particular) often contain large numbers of observed zeros as well as large catch values which need to be explicitly modelled (Bigelow et al. 2002; Campbell 2004, Ward and Myers 2005; Minami et al. 2007).

Standardized CPUE series for all fisheries (bycatch and target longline; associated and un-associated purse seine fisheries) were developed using generalized linear models. In the longline analyses the number of hooks in a set was the effort measure, whereas for purse seine it was simply the set. It is notoriously difficult to come up with accurate estimates of the true effort that relates to a purse seine set (Punsly, 1987).

2.4 Overview of GLM Analyses

The filtered datasets were standardized using generalized linear models (McCullagh and Nelder 1989) using the software package R (www.r-project.org). Multiple assumed error structures were tested including;

- The delta lognormal approach (DLN) (Lo et al. 1992, Dick 2006, Stefansson 1996, Hoyle and Maunder 2006): this approach is a special case of the more general delta method (Pennington 1996, Ortiz and Arocha 2004), and uses a binomial distribution for the probability *w* of catch being zero and a probability distribution *f(y)*, where y was log(catch/hooks set), for non-zero catches. An index was estimated for each year, which was the product of the year effects for the two model components, $(1-w) * E(y|y \neq 0)$.

$$\Pr(Y=y)=\begin{cases} w, & y=0, \\ (1-w)\,f(y) & \text{otherwise} \end{cases}$$

- The negative binomial (Lawless 1987): is typically more robust to issues of overdispersion (overdispersion can arise due to excess zeros, clustering of observations, or from correlations between observations) was also used. This model has been advocated as a model that is more robust to overdispersion than the Poisson distribution (McCullagh and Nelder 1991), and is appropriate for count data (Ward and Myers 2005), but does not expressly relate covariates to the occurrence of excess zeros (Minami et al. 2007).
- The quasi-Poisson: in which a dispersion parameter ϕ is estimated and corrected for to account for overdispersion, was also used though this tends to produce larger standard

errors and model misspecification when ϕ is large because the standard errors of the covariates are multiplied by $\sqrt{\phi}$.

- Mixture models such the zero inflated Poisson (ZIP) and zero inflated negative binomial (ZINB) (Zuur 2009, Cunningham and Lindenmayer 2005, Welsh et al. 2000): these models are useful for modelling counts of rare species when the number of zero observations is larger than expected. Zero inflated models are a process similar to the delta approach in which the presence or absence of the catch is modelled orthogonally to the size of the catch (Welsh et al 2000), however unlike the delta approach the count data can include zeros. These zeros could result from predator satiation, competition for hooks, or disinterest (called true zeros) as opposed to design errors, sampling errors, observer errors or zeros resulting from sampling outside the habitat range (called false zeros). The total probability of a zero count is then,

  $$\Pr(Y_i = 0) = \Pr(False\ Zeros) + (1 - \Pr(False\ Zeros)) * \Pr(True\ Zeros)$$

  Therefore, the probability distribution for the zero inflated Poisson is equal to:

  $$\Pr(y_i = 0) = \pi_i + (1 - \pi_i) * e^{-\mu_i}$$

  $$\Pr(y_i | y_i > 0) = (1 - \pi_i) * \frac{\mu^{y_i} * e^{-\mu_i}}{y_i!}$$

  Where y_i is the size of the catch of the i^{th} set, and distributed y_i ~ Poisson(μ_i) (μ_i is the mean of the Poisson distribution), and π_i is the probability of a false zero. The probability definition for the zero inflated negative binomial is similar,

  $$\Pr(y_i = 0) = \pi_i + (1 - \pi_i) * \left(\frac{k}{\mu_i + k}\right)^k$$

  $$\Pr(y_i | y_i > 0) = (1 - \pi_i) * \frac{\Gamma(y_i + k)}{\Gamma(k) * \Gamma(y_i + 1)} * \left(\frac{k}{\mu_i + k}\right)^k * \left(1 - \frac{k}{\mu_i + k}\right)^{y_i}$$

  Where y_i is the size of the catch of the i^{th} set, and distributed y_i ~ *Negative Binomial*(μ_i,k), and π_i is the probability of a false zero. Under this parameterization the mean of the negative binomial is μ and the variance is $\mu + \mu^2/k$. The main advantage of the zero inflated approach is that these techniques can model the overdispersion in both the zeros and the counts as opposed to just the counts (negative binomial) and deal with overdispersion better than other models (quasi Poisson).

Each model was fit to the data set independently and all variables used in the models were included as categorical factors except the response variables for catch and the effort (silky and SILKYCPUE) and the offset variable (hook_est); these variables were included in the model as continuous variables (Table 1). Model selection began with regression trees and piecewise ANOVA models for each model (De'ath and Fabricius 2000, Zuur 2009). The Akaike information criterion (AIC) was used as a metric to score the results and determine the final models for each data set. Model specific fitting criteria and model diagnostics resulted in different variables being chosen for different data sets and model types.

Multiple methods of calculating the indices of abundance and confidence intervals exist depending on the model type (Shono H. 2008, Maunder and Punt 2004). In this study estimates were calculated by predicting results based on the fitted model and a training data set that included each year effect and the mean effect for each covariate (Zuur et al 2009). Confidence intervals were calculated as ±1.96* SE, where SE is the standard error associated with the predicted year effect term.

3 Results

For brevity we only describe the model results for the final model chosen for each data set. A comparison of the proportion of zeros, mean non-zero catch and the standardized CPUE for oceanic white tips in the longline and purse seine fleets is presented in Table 3.

3.1 Longline bycatch series

The Zero Inflated Negative Binomial model was the selected model type for the non-target longline dataset. The resulting standardized CPUE trend (Figure 4) contains the combined effects from two models, one that calculates the probability of a zero observation and one that estimates the count per year. The result from the model is the combined predicted level of the response variable, silky shark catch. The resulting standardized CPUE trend was plotted against the mean nominal trend (both relative to their maximum values). The standardized CPUE trend is quite different to the mean nominal trend (Figure 4), mainly since 2004 when the standardized CPUE declines but the nominal increases.

The diagnostic results from the ZINB model (Figure 5) do not show any significant trends in the plots of the residuals against the model covariates (the right hand panel). The left hand panel shows the standard diagnostics of residuals vs. fitted, Pearson residuals vs. fitted, QQ plot and a histogram of the residuals. These model diagnostics plots show the expected departure from normality arising from a mixture model. The partial dependence plots (Figure 6) show the influence of the number of hooks between floats (hk_bt_flt) deceasing at higher numbers of hooks and the influence of the time of day highest during the middle of the day (TIMECAT categories 3 & 4). A deviance table showing the contribution of the model components is presented in Table 4.

3.2 Target longline data

The longline target data set was fit using the Zero Inflated Poisson with effort included as an offset. Both the nominal CPUE and standardized CPUE based on the ZIP model for silky sharks caught in the longline target fishery (Figure 7) show an increasing trend until the mid 2000’s, after which the two trends diverge with the nominal trending downward.

The diagnostic results from the ZIP model (Figure 8) show residuals vs. covariates on the left hand side and the right hand side panel shows the standard diagnostics of Pearson residual vs. fitted, residuals vs. fitted, QQ plot, and a histogram of the residuals. Partial dependence plots for ZIP model fit of the target longline data (Figure 9) show the influence of the main effects on the overall response. A deviance table showing the contribution of the model components is presented in Table 5.

3.3 Purse seine data associated sets series

The SPC observer data from the purse seine fleet is inherently difficult to standardize because there is no standard metric of effort. Further, silky sharks were only commonly identified to species beginning in the early 2000’s, therefore interpretation of the any standardized time series must be undertaken cautiously. A negative binomial GLM was used to construct a standardized CPUE based on the unassociated purse seine sets (Figure 10). The standardized CPUE is quite similar to the nominal yearly CPUE, which may be due to the fact that the model does not include an offset for effort.

The standardized CPUE shows little departure from the nominal despite departure from normality in the QQ plot (upper right hand panel of Figure 11). The effect of the model covariates is shown in Figure 12 (the partial dependence plots), with vessel name omitted for confidentiality. A deviance table showing the contribution of the model components is presented in Table 6.

3.4 Purse seine data- unassociated sets

A negative binomial GLM was used to construct a standardized CPUE based on the unassociated purse seine sets (Figure 13). The results from this model, as well as the nominal CPUE are similar in trend to the standardized time series for the associated sets, in that they rise throughout the time series (with the exception of the last two years which may be an artifact of the data). Although the standardized CPUE is quite similar to the mean nominal CPUE, it starts higher and ends higher than the nominal CPUE, with the maximum for both occurring in 2007.

The departure from normality shown in the upper right hand panel of Figure 14 (the diagnostic plots) shows the overdispersion of the standardized deviance residuals starting at approximately twice the mean, suggesting it is the larger catch values that are not modelled well by the GLM. An offset such as effort, or potentially catch could help improve this model. Figure 15 shows the partial dependence plots from the standardization model, with vessel name omitted for confidentiality. A deviance table showing the contribution of the model components is presented in Table 7.

4 Discussion

This paper has presented the standardized CPUE series for silky sharks in the western central Pacific based on observer data collected by the SPC over the years 1995- 2009. In late 2011 when the analysis was undertaken, there was insufficient longline observer data for 2010, and these data are critical for both CPUE and catch inputs to the stock assessment therefore our analysis only goes through to 2009. In the analyses described here data was separated into two longline series (bycatch and target) and two purse seine series (unassociated and associated sets) from which a standardized CPUE series was generated for each.

The overall trends are quite different between the bycatch longline and the target longline and purse seine data. The target longline and purse seine standardized CPUE trends reflected the underlying nominal data fairly well, however the longline bycatch standardized CPUE did not. Figure 16 shows the additive effects of the covariates on the longline bycatch standardization model. The most important covariate in the bycatch longline CPUE standardization was vessel name ('vesselname'; Table 4, Figure 16). Introduction of the vessel effect greatly increased the explanatory power of the model and significantly altered the standardized CPUE trend from the nominal. Vessel effects reflect multiple factors that are intrinsic to a fishing operation, including the intention and ability to effectively target a species. The standardization models considered in this study only account for the relative catchability among vessels and make no account for any change in the absolute fishing power over time. Potential changes in vessel characteristics, equipment, crew or captain may alter the vessel effect through time. If a consistent trend in catchability is not accounted for the CPUE index could reflect a change in vessel characteristics, not abundance. Further research on better ways to model vessel catchability through time is recommended (e.g., see Wilberg et al. 2010).

Research into vessel catchability and effort in the purse seine fishery is also recommended. Attempts at including vessel effects in the purse seine CPUE standardization resulted in models that did not converge. The inclusion of a proxy for effort, such as the tonnage of skipjack caught, should also be investigated.

In the early time period, sharks were not commonly identified to species but rather as one 'shark' category. A back extrapolation of the undocumented shark community composition could be undertaken, although it would be inherently uncertain. There are many problems that would have to be overcome to do this including (but not limited to) changes in vessel catchability, targeting, changes in fishing behavior and natural fluctuations in the relative abundance and availability of the individual shark species with respect to each other and to their key prey.

Acknowledgements

This paper benefited from the help of Shelton Harley and Simon Hoyle. Aaron Berger provided valuable comments on drafts of this paper.

5 Figures

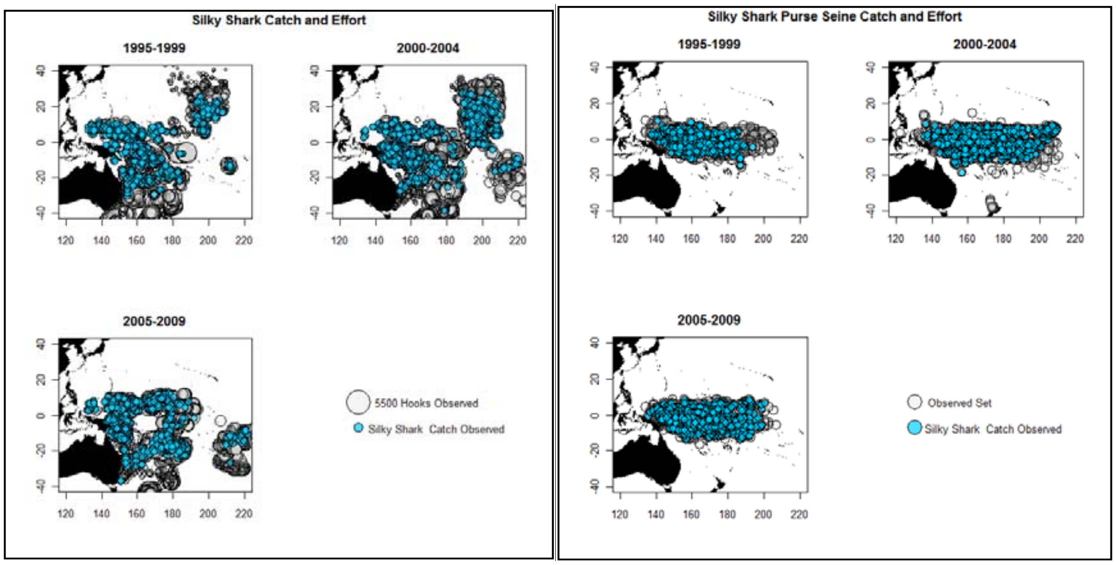

Figure 1: Longline (left panels) and purse seine (right hand side) CPUE for observed silky shark (blue) catch and zero catch events (light grey circles are scaled to the maximum effort is scaled by the number of hooks deployed for longline).

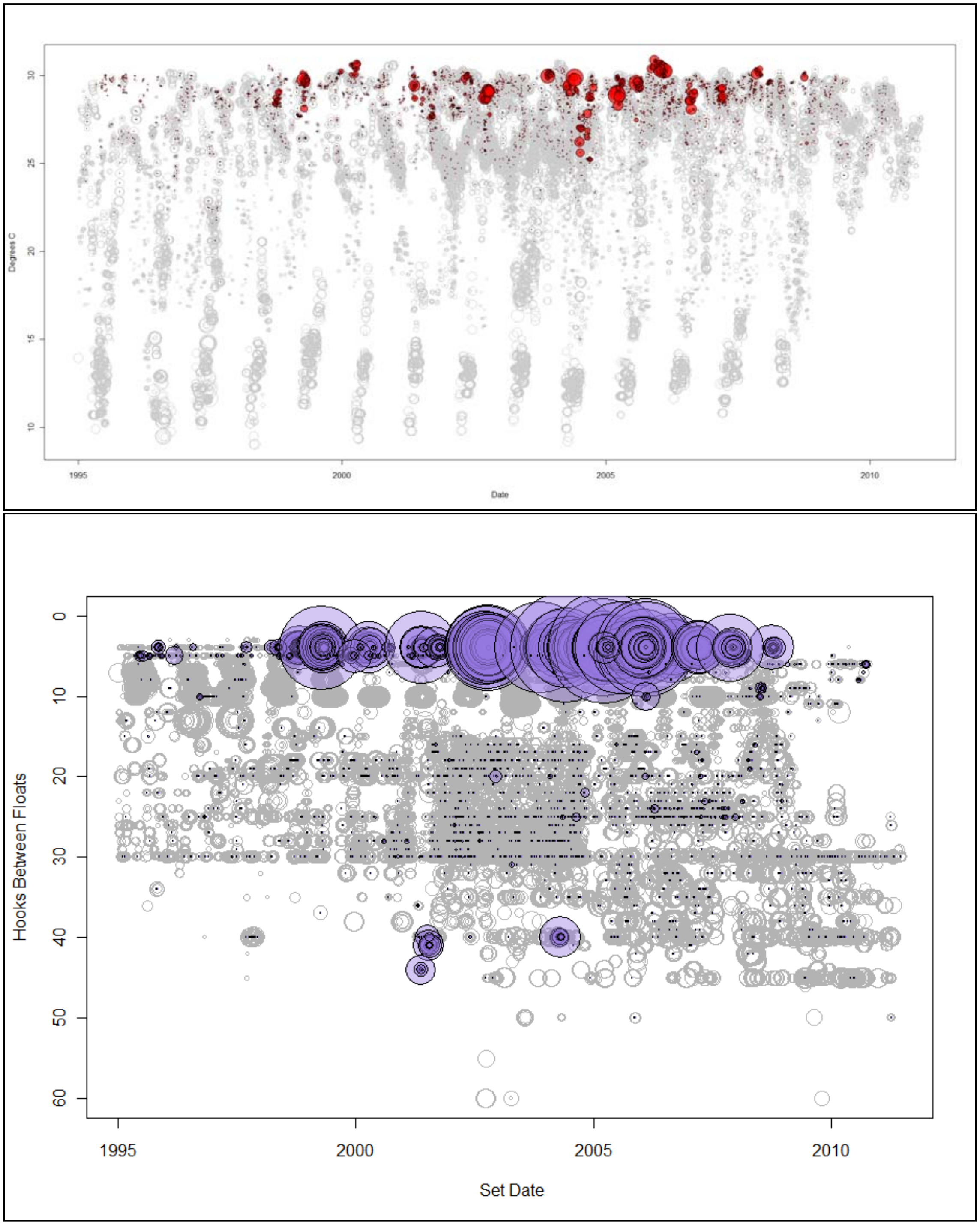

Figure 2: Longline CPUE for silky sharks as a function of time (x-axis both panels) and degrees centigrade (y-axis top panel)or hooks between floats (y-axis bottom panel). Colored circles are scaled proportional to the maximum observed CPUE value. Grey circles are scaled proportional to the maximum number of hooks deployed.

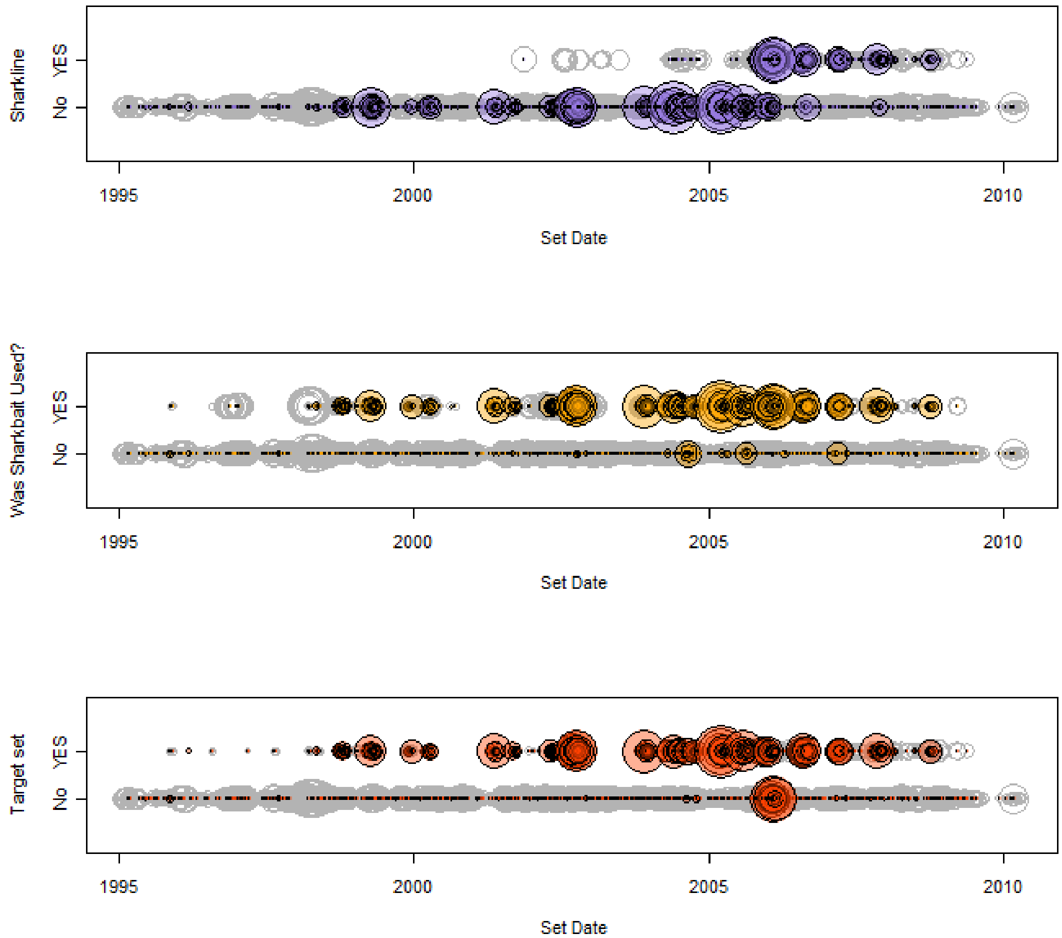

Figure 3: Longline CPUE for silky sharks as a function of time (x-axis) and whether or not a shark line was used (top panel), whether shark bait was used (middle panel), and whether the set intentionally targeted sharks (bottom panel). Colored circles are scaled proportional to the maximum observed CPUE value. Grey circles are scaled proportional to the maximum number of hooks deployed.

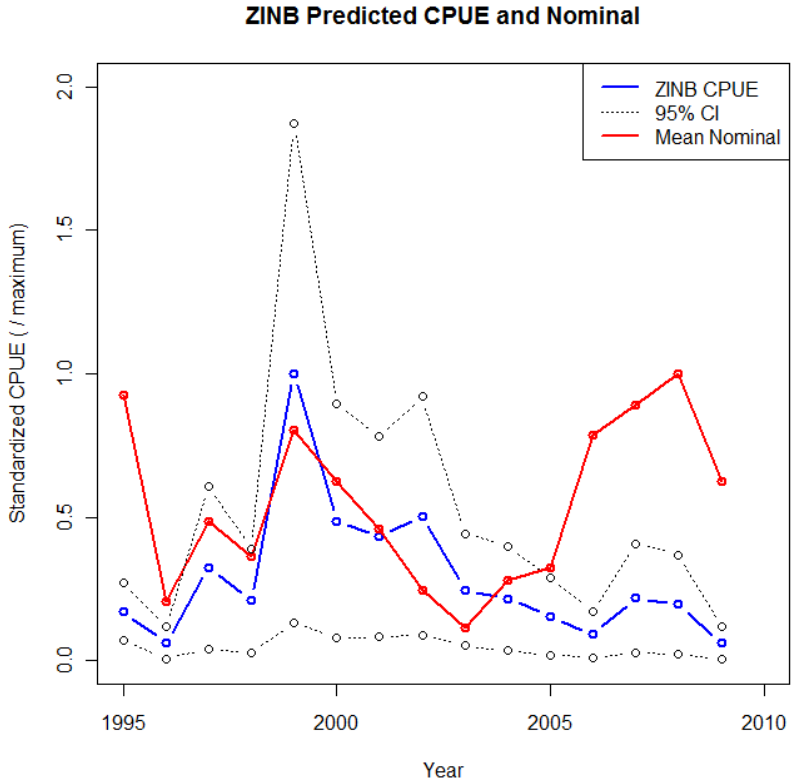

Figure 4. Results from the ZINB model: nominal CPUE (in red), the standardized CPUE time series (in blue), and 95% confidence intervals (in grey).

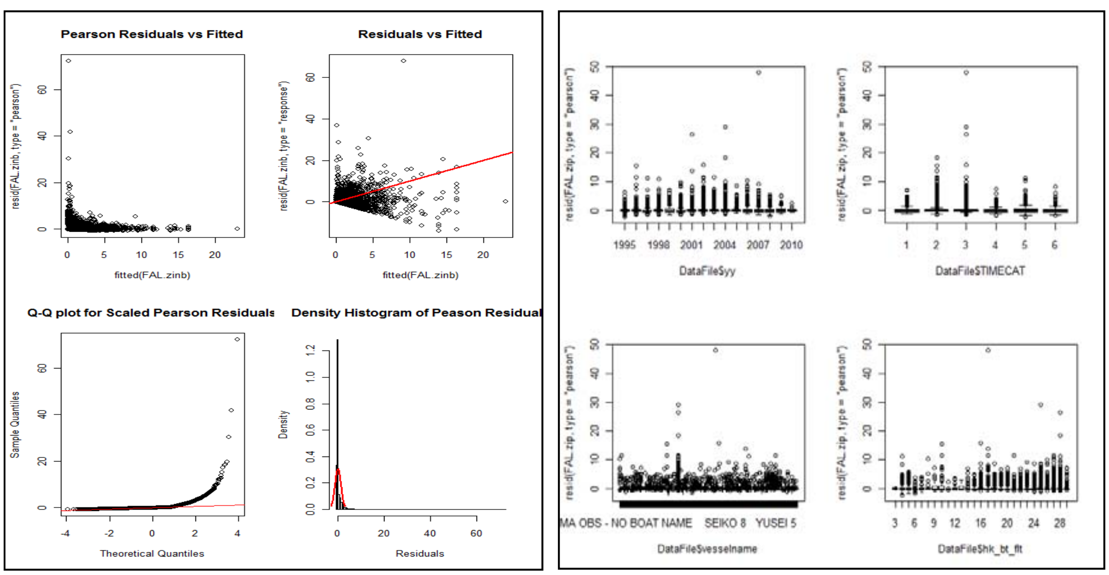

Figure 5. Diagnostic results from the ZINB model fit to the longline bycatch data (on the left hand side) and plots of the Pearson residuals vs. the covariates for the variables Year, TIMECAT, vesselname and hk_bt_flt , on the right hand side. See table 1 for variable descriptions.

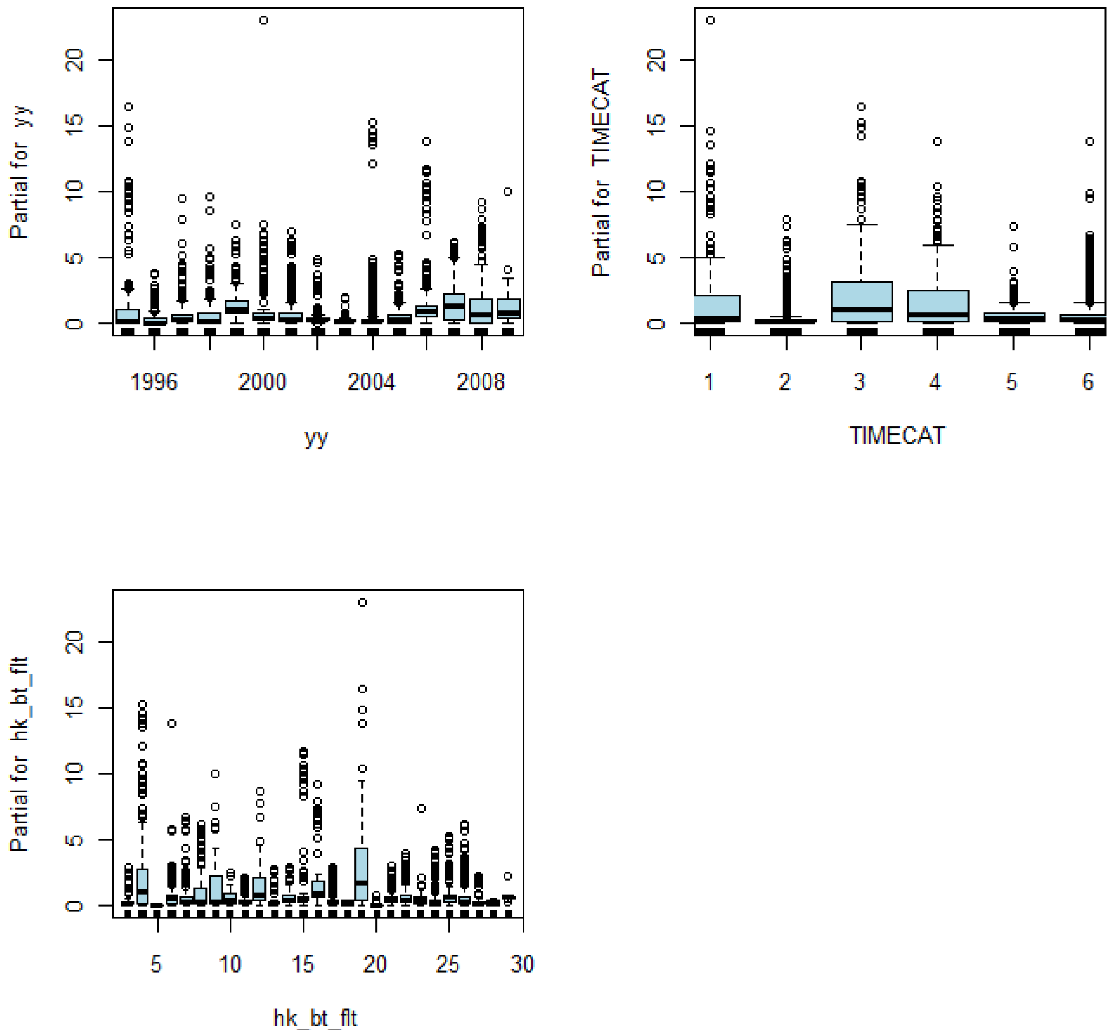

Figure 6. Relative influence of model covariates upon catch rates from the ZINB model fit to the longline bycatch data. See table 1 for variable descriptions.

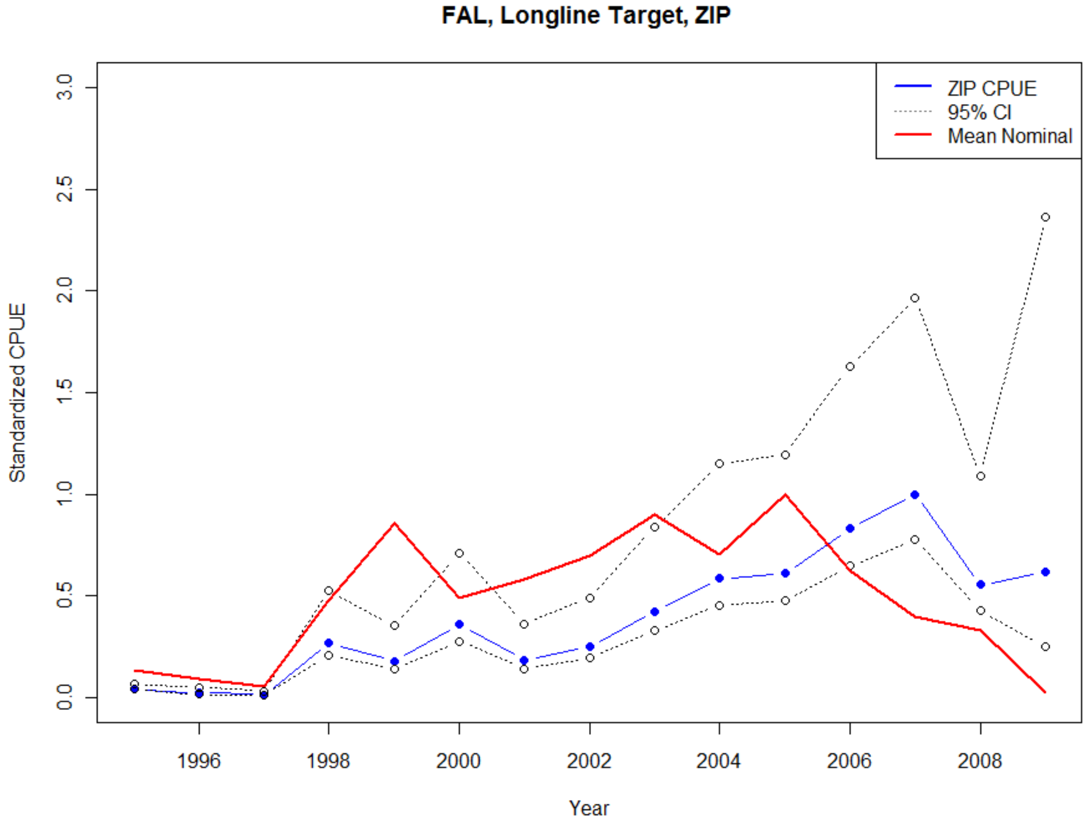

Figure 7. Nominal and standardized (fit to the Zero Inflated -Poisson model) CPUE trends for the "shark targeting" data base.

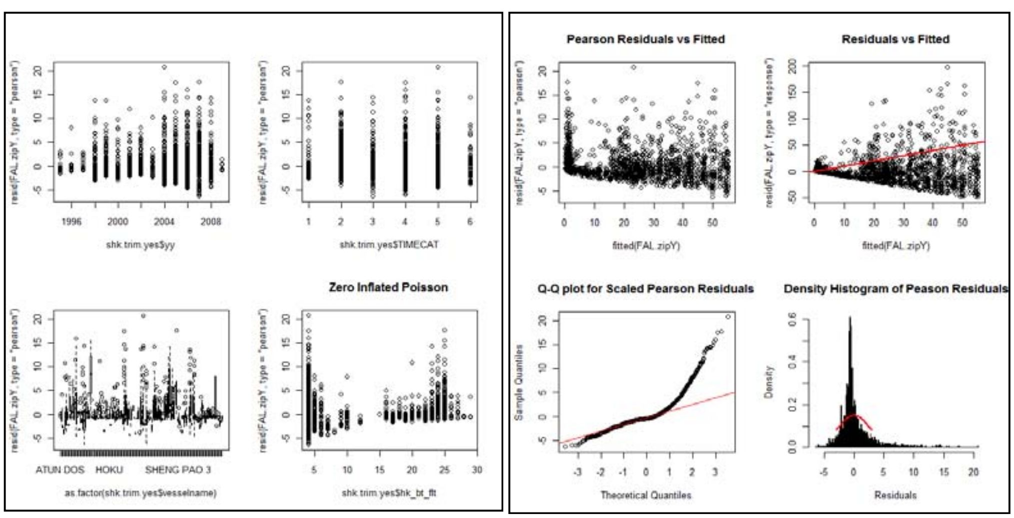

Figure 8. Diagnostic results from the Zero Inflated Poisson model fit to the "shark targeting" data base. (on the right hand side) and plots of the Pearson residuals vs. the covariates for the variables

Year, TIMECAT, vesselname and hk_bt_flt , on the left hand side. See table 1 for variable descriptions.

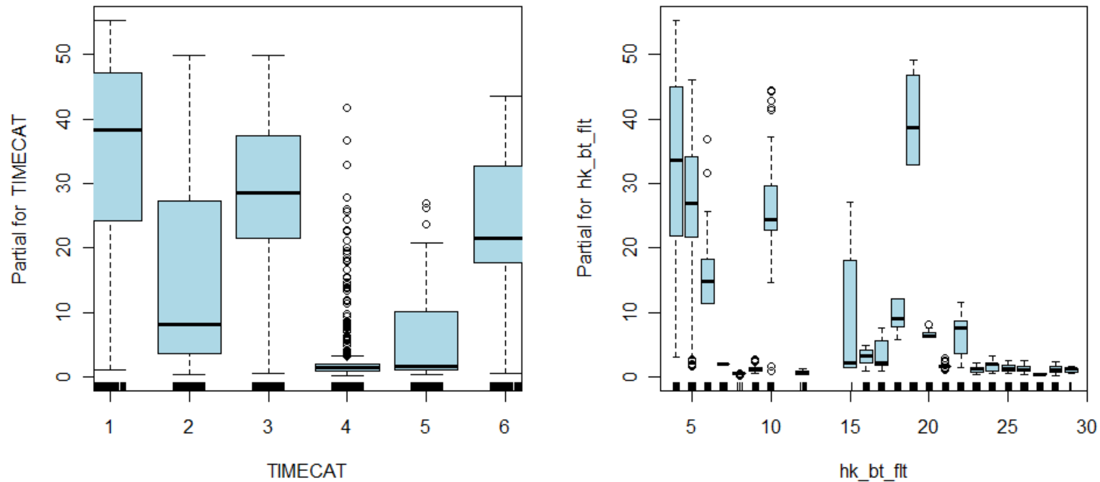

Figure 9. Partial dependence plots for the Zero Inflated -Poisson model fit to the “shark targeting” dataset. See table 1 for variable descriptions.

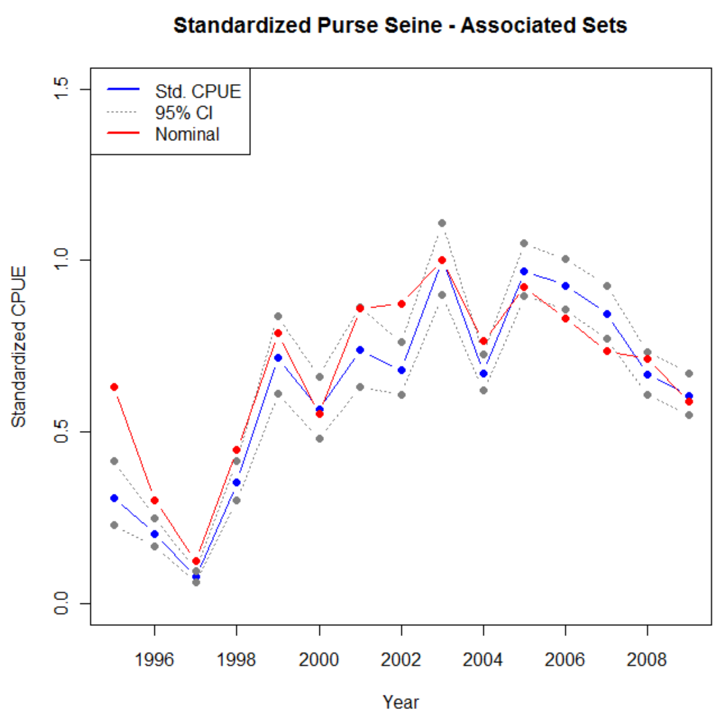

Figure 10. Standardized silky shark CPUE and nominal CPUE from the purse seine fishery, associated sets.

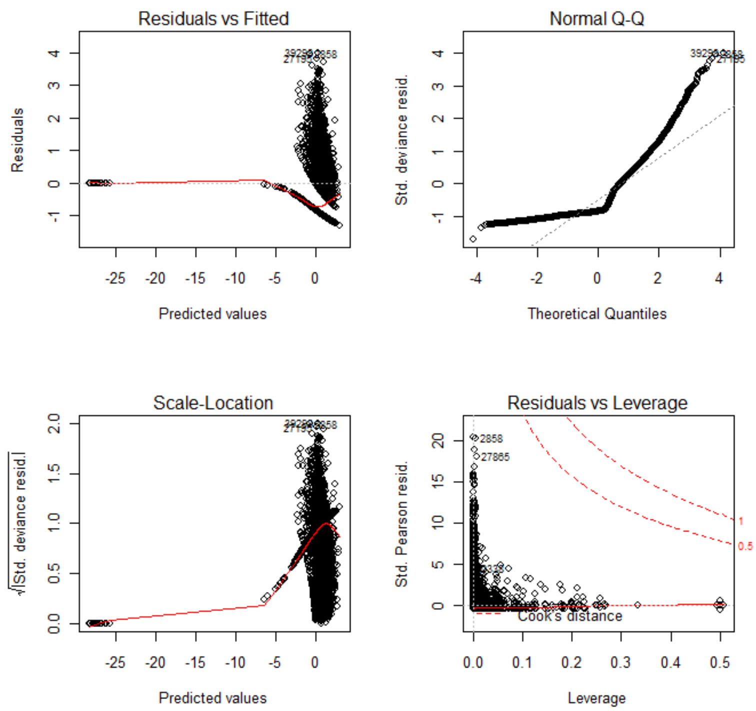

Figure 11. Diagnostic plots from the standardized silky shark CPUE from the purse seine fishery, associated sets.

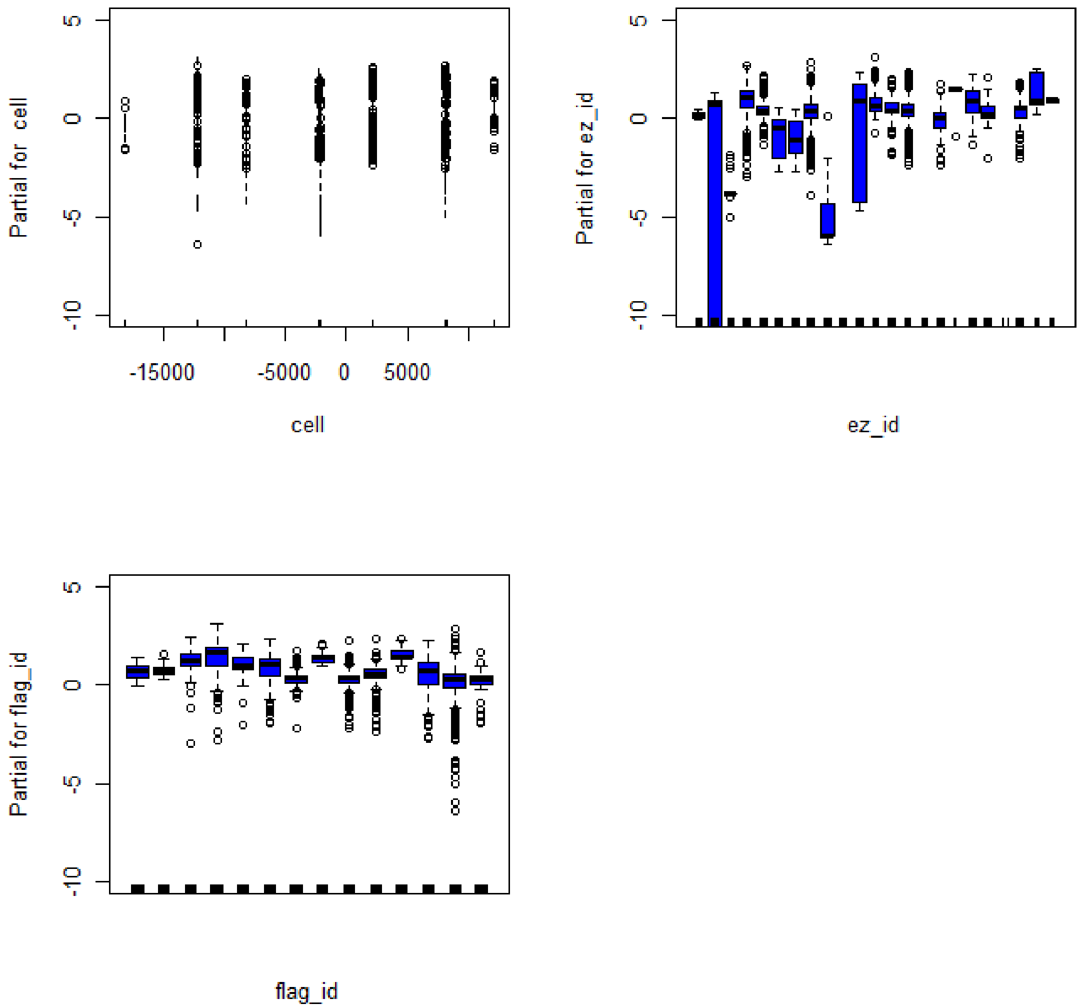

Figure 12. Partial dependence plots from the standardized silky shark CPUE from the purse seine fishery, associated sets. See table 1 for variable descriptions.

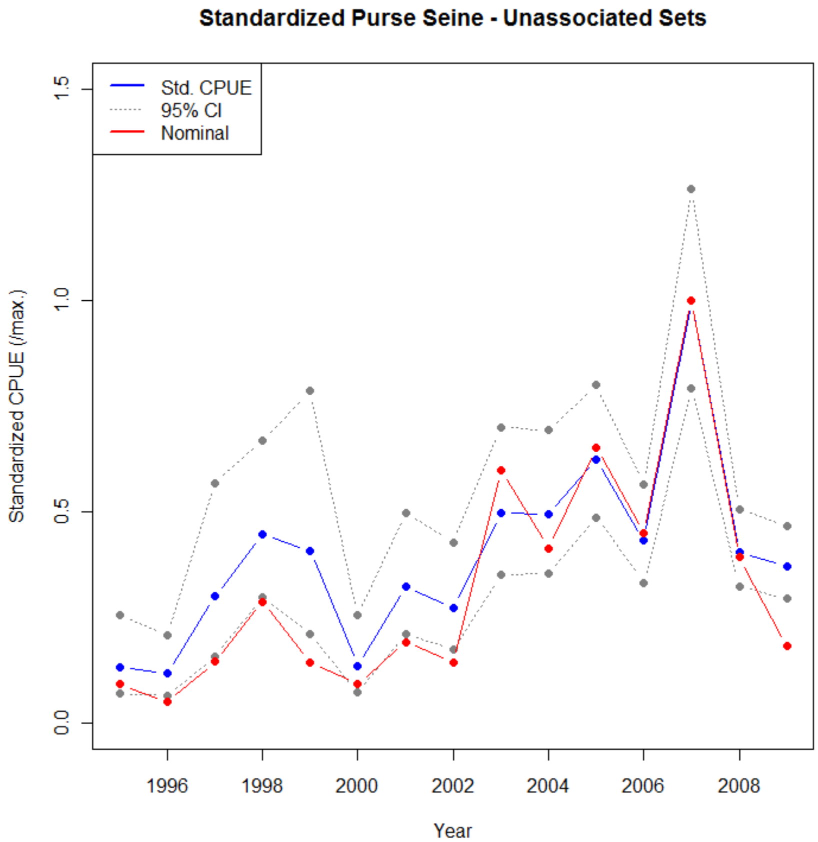

Figure 13. Standardized CPUE and nominal CPUE for silky sharks caught in the unassociated purse seine fleet.

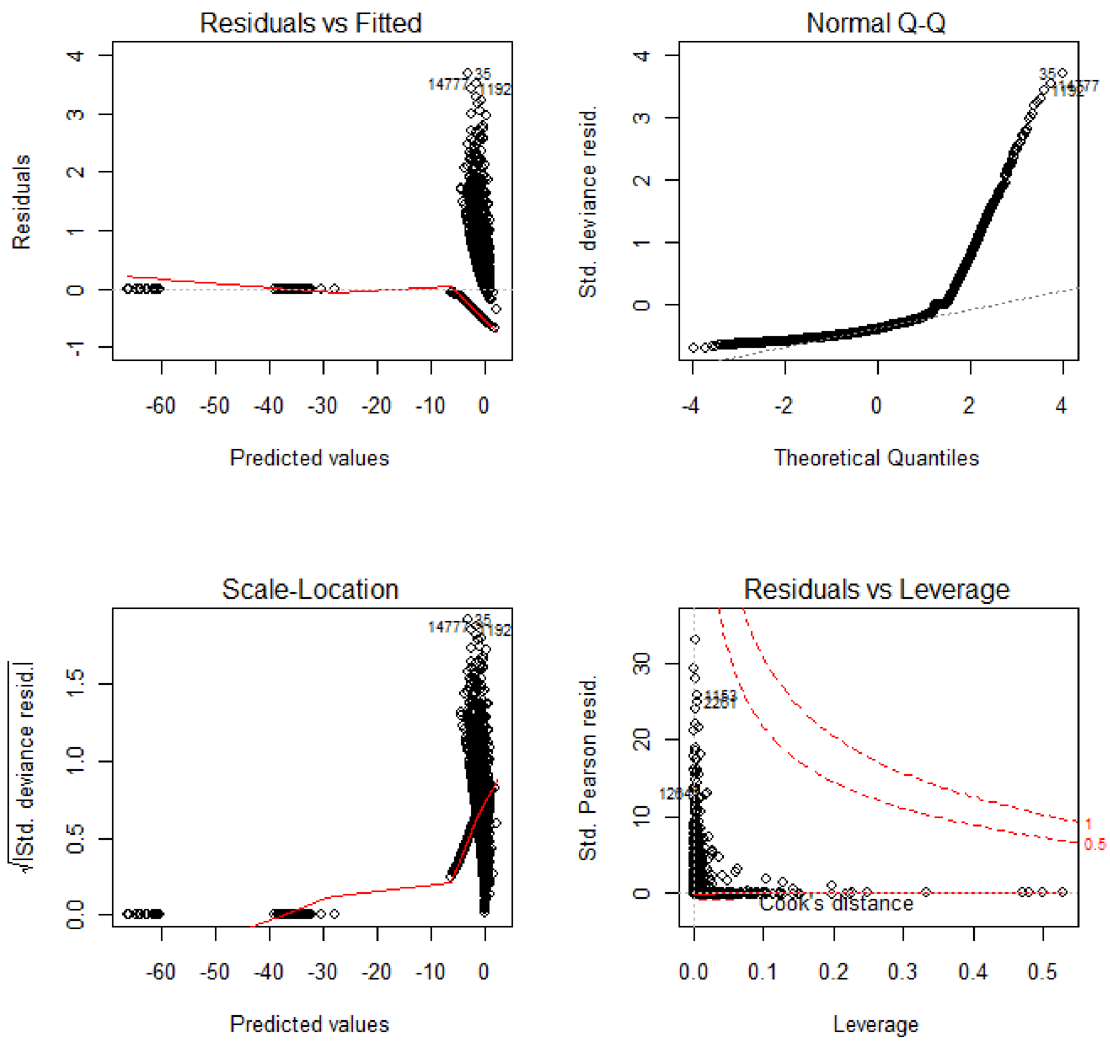

Figure 14. Diagnostic plots from the standardized silky shark CPUE from the purse seine fishery, un-associated sets.

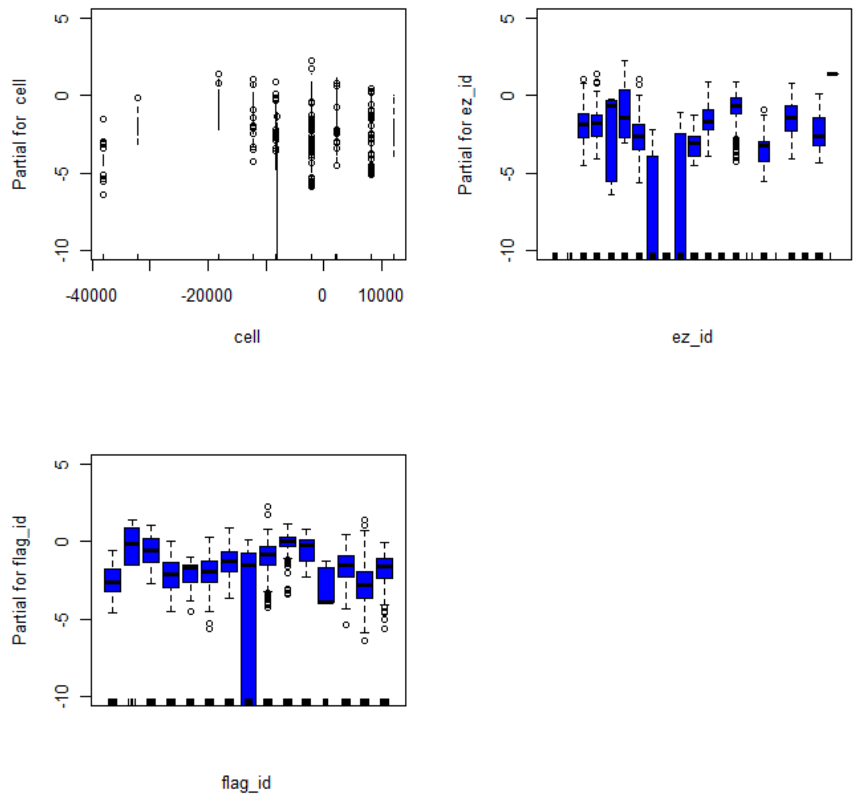

Figure 15. Partial dependence plots from the standardized silky shark CPUE from the purse seine fishery, associated sets. See table 1 for variable descriptions.

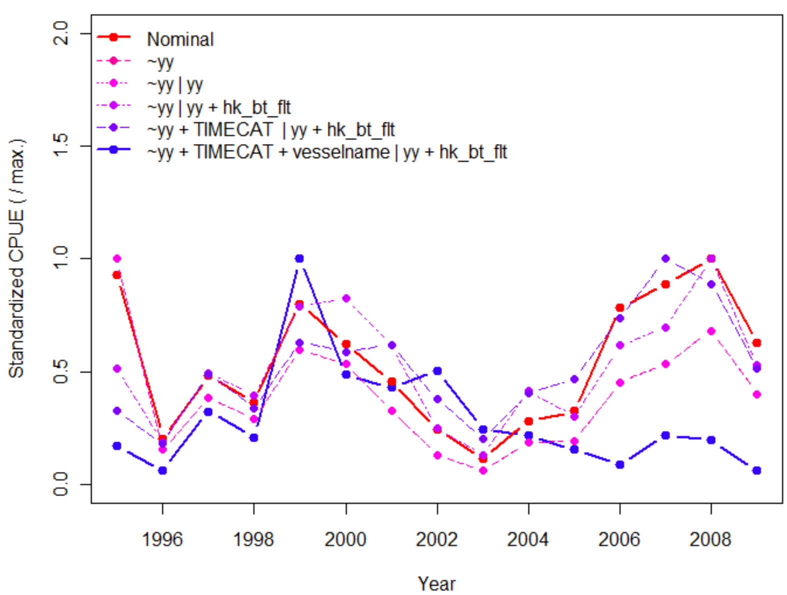

Figure 16. The relative effects of adding in parameters, note that yy and yy|yy are over plotted. See table 1 for variable descriptions.

6 Tables

Table 1. Variables used in the CPUE standardization process

Predictor	Abbreviation	Type	Description
Number of silky sharks caught	silky	Continous	Number of silky sharks caught per set
Silky Shark CPUE	SILKYCPUE	Continous	Set specific catch rate in silky sharks/1000 hooks
Year	yy	Categorical	1995-2010
Month	mm	Categorical	Month of the year (January- December)
Time category	timecat	Categorical	The sixth of the day that the set happened in, beginning at midnight.
Vessel Name	vesselname	Categorical	The name of the fishing vessel
Trip identification number	trip ID	Categorical	The unique trip identification number
Hooks between floats	hk_bt_flt	Categorical	The number of hooks between floats on the longline
Estimated Hooks	hook est	Continous	The total number of estimated hooks fished
Sharkline	shkline	boolean	Were shark lines off the floats used (Y/N)
Shark Bait	Sharkbait	boolean	Was sharkbait used (Y/N)
Exclusive Economic Zone	ez_id	Categorical	Which nations EEZ did the set take place
Vessel Flag	flag_id	Categorical	Which nation is the vessel flagged to
Sea Surface temperature	SST	Categorical	Degrees centigrade

Table 2. Filtering Rules for the longline dataset on silky sharks

Filtering rules for the Bycatch Data

Number of Records	Number removed	Filtering Rule	Number of Silky Sharks
35307	2467	remove sets with marked as target sets	14657
34995	312	remove data from Flags w/ less than 100 sets	14460
19093	15902	remove sets with associated temperatures <=25 degrees	13995
13274	5819	remove sets with >30 hooks between floats	12866
12567	707	remove sets with high CPUE where target is 'unidentified'	9127
12542	25	remove sets in 2010	9123

Filtering Rules for Target data sets.

Number of Records	Number removed	Filtering Rule			Number of Silky Sharks
3775	33999	Keep Shark Bait, shark line or shark target			45752
		of which			
		2467	Marked	*Target*	
		1935	Marked	*Sharkline*	
		1987	Marked	*Sharkbait*	

Table 3. Comparison of the proportion of zeros, mean non-zero catch and the standardized CPUE for silky shark.

Data Source	Bycatch Longline				Target Longline				Associated Purse Seine				Un-Associated Purse Seine			
	% Positive Catch	Mean Annual	Std. Annual	Std. Error	% Positive Catch	Mean Annual	Std. Annual	Std. Error	% Positive Catch	Mean Annual	Std. Annual	Std. Error	% Positive Catch	Mean Annual	Std. Annual	Std. Error
1995	29.82	1.57	0.48	0.12	84.21	3.51	0.22	0.00	17.18	1.55	0.89	1.16	3.68	0.08	0.32	1.39
1996	19.06	0.27	0.18	0.08	45.83	2.55	0.12	0.02	8.59	0.74	0.36	1.11	1.33	0.05	0.28	1.34
1997	27.03	0.62	0.91	0.39	48.28	1.66	0.07	0.01	6.42	0.31	0.14	1.11	0.81	0.13	0.72	1.38
1998	23.04	0.48	0.59	0.25	76.92	11.99	1.37	0.16	15.55	1.10	0.54	1.09	3.45	0.26	1.08	1.23
1999	48.35	0.99	2.79	1.19	83.82	24.39	0.92	0.10	31.88	1.93	1.09	1.08	1.45	0.13	0.98	1.40
2000	31.62	0.86	1.36	0.55	78.12	16.80	1.84	0.21	31.62	1.36	0.87	1.08	1.45	0.08	0.33	1.38
2001	24.71	0.54	1.20	0.47	71.76	14.90	0.94	0.11	35.91	2.11	1.14	1.08	3.91	0.17	0.78	1.24
2002	17.36	0.21	1.41	0.56	50.44	18.65	1.28	0.14	34.06	2.14	1.01	1.06	2.12	0.13	0.66	1.26
2003	11.51	0.10	0.69	0.26	56.41	22.20	2.18	0.25	38.72	2.45	1.49	1.06	4.16	0.54	1.20	1.19
2004	16.58	0.30	0.60	0.25	78.19	19.92	3.00	0.34	36.30	1.87	1.00	1.04	2.33	0.37	1.19	1.19
2005	25.46	0.31	0.43	0.19	78.29	24.39	3.12	0.35	37.68	2.26	1.44	1.04	5.08	0.59	1.50	1.13
2006	41.78	0.71	0.25	0.11	67.80	14.40	4.26	0.48	35.56	2.04	1.39	1.04	3.10	0.41	1.04	1.15
2007	45.41	0.84	0.61	0.26	78.01	8.36	5.12	0.58	35.02	1.81	1.25	1.05	10.63	0.90	2.41	1.13
2008	41.18	1.08	0.54	0.23	70.30	7.43	2.84	0.33	35.01	1.75	0.99	1.05	5.97	0.36	0.97	1.12
2009	42.08	0.63	0.17	0.08	57.14	0.36	3.18	0.97	29.39	1.44	0.91	1.05	4.78	0.17	0.90	1.12

Table 4. Model comparisons for Silky Shark Bycatch CPUE standardization(Longline Zero Inflated Negative Binomial). The model used in the standardization is listed last.

Predictor	Offset	Df	Deviance	Residual DF	Res. Deviance	Chisq	Pr(>Chisq)	Model
intercept only	log(Hook_Est)			12539	25775.32			
yy | yy	log(Hook_Est)	28	1107.32	12511	24668	1108.2	<2e-16	ZINB
yy | yy + hk_bt_flt	log(Hook_Est)	26	754	12485	23914	753	<2e-16	ZINB
yy + TIMECAT | yy + hk_bt_flt	log(Hook_Est)	31	522	12480	23392	1276	<2e-16	ZINB
yy + TIMECAT + vesselname | yy + hk_bt_flt	log(Hook_Est)	421	2488	12090	20904	3763	<2e-16	ZINB

Table 5. Model comparisons for Silky Shark Target CPUE standardization (Longline Zero Inflated Poisson). The model used in the standardization is listed last.

Predictor	Offset	Df	Deviance	Residual DF	Res. Deviance	Chisq	Pr(>Chisq)	Model
intercept only	log(Hook_Est)			2568	92118			
yy	log(Hook_Est)	31	10982	2540	81136	10983		
yy+hk_bt+flt	log(Hook_Est)	2	41968	2538	39168	41966	<2.02E-15	ZIP
yy+hk_bt+flt | yy	log(Hook_Est)	1	-544	2539	39712	41424	<2.02E-15	ZIP
yy+hk_bt_flt | yy + hk+_bt_flt	log(Hook_Est)	2	544	2538	39168	41966	<2.02E-15	ZIP
yy+hk_bt_flt +TIMECAT| yy + hk+_bt_flt	log(Hook_Est)	7	548	2533	38620	42515	<2.02E-15	ZIP

Table 6. Model comparison for Silky Shark CPUE standardization from the Associated Purse Seine Fleet. The model used in the standardization is listed last.

Predictor	Df	Deviance Explained	Resid. DF	Resid. Dev	P(>|Chi|)
NULL			28790	21355	
+ yy	14	550	28776	20805	<2.20E-16
+ cell	83	688	28693	20117	<2.20E-16
+ ez_id	24	162	28669	19955	<2.20E-16
+ flag_id	13	378	28656	19577	<2.20E-16

Table 7. Model comparison for Silky Shark CPUE standardization from the Un-associated Purse Seine Fleet. The model used in the standardization is listed last.

	Df	Deviance Explained	Resid. DF	Resid. Dev	P(>|Chi|)
NULL			15434	4025	
+ yy	14	321	15420	3704	<2.20E-16
+ cell	67	434	15353	3269	<2.20E-16
+ ez_id	17	51	15336	3218	0.00002842
+ flag_id	14	53	15322	3165	0.000001716

7 References

Bigelow K. A., Hampton J., & Miyabe N. (2002) Application of a habitat-based model to estimate effective longline fishing effort and relative abundance of Pacific bigeye tuna (*Thunnus obesus*). Fisheries Oceanography 11: 143-155.

Clarke, S. Harley, S. Hoyle, S. and Rice J. (2011) An Indicator-based Analysis of Key Shark Species based on Data held by SPC-OFP. http://www.wcpfc.int/doc/eb-wp-01/indicator-based-analysis-key-shark-species-based-data-held-spc-ofp

Clarke, S., Yokawa, K. Matsunaga, H., Nakano, H. (2011b) Analysis of North Pacific Shark Data from Japanese Commercial Longline and Research/Training Vessel Records. WCPFC-SC7-EB-WP-04. Accessed online at http://www.wcpfc.int/doc/eb-wp-02/analysis-north-pacific-shark-data-japanese-commercial-longline-and-researchtraining-ves

Campbell R. A. (2004) CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. Fisheries Research 70: 209-227.

Cunningham, R.B., Lindenmayer, D.B. (2005). Modeling count data of rare species: some statistical issues. Ecology 86, 1135–1142.

De'ath G. & Fabricius K. E. (2000) Classification and regression trees: a powerful yet simple technique for ecological data analysis. Ecology 81: 3178-3192.

Dick E. J. Delta_glm. [1.7.2]. (2006) Santa Cruz, CA, USA, NOAA.

GODAS (2011) Data provided by the NOAA-ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/, data accessed November 2011.

Hoyle S. D. & Maunder M. N. (2006) Standardisation of yellowfin and bigeye CPUE data from Japanese longliners, 1975-2004. IATTC Working Group on Stock Assessments. 6th Meeting, SAR-7-07.http://www.iattc.org/PDFFiles2/SAR-7-07-LL-CPUE-standardization.pdf. 2006.

Lawless, J.F. (1987) Negative binomial and mixed Poisson regression. Can. J. Stat. 15, 209–225.

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

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

McCullagh P. & Nelder J. A. (1989) Generalized Linear Models. Chapman & Hall.

Minami, M. Lennert-Cody, C.E., Gao, W. , Román-Verdesoto, M. (2007) Modeling shark bycatch: the zero-inflated negative binomial regression model with smoothing. Fisheries Research 84: 210-221.

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

Pennington, M. (1996) Estimating the mean and variance from highly skewed marine data. Fish. Bull. 94, 498–505

Punsly R. (1987) Estimation of the relative annual abundance of yellowfin tuna, Thunnus albacares , in the eastern Pacific Ocean during 1970-1985. I-ATTC, LA JOLLA, CA.

Rice, J. (2012) Alternative catch time series for oceanic whitetip and silky sharks in the Western and Central Pacific Ocean. WCPFC-SC8-SA-IP-12.

Rice, J., and Harley, S. J. (2012) Stock assessment of silky sharks in the Western and Central Pacific Ocean. WCPFC-SC8-SA-WP-07.

Shono H. (2008) Confidence interval estimation of CPUE year trend in delta-type two-step model. Fisheries Science 74: 712-717.

Stefansson G. (1996) Analysis of groundfish survey abundance data: Combining the GLM and delta approaches. Ices Journal of Marine Science 53: 577-588.

Wilberg, M.J., Thorson, J.T., Linton, B.C., Berkson, J. (2010) Incorporating time-varying catchability into population dynamic stock assessment models. Rev. Fish. Sci. 19(1): 7-24

Walsh, W. A., and S. C. Clarke. (2011) Analyses of catch data for oceanic whitetip and silky sharks reported by fishery observers in the Hawaii-based longline fishery in 1995−2010. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-11-10, 43 p. + Appendices.

Ward, P., Myers, R.A., (2005), Shifts in open –ocean fish communities coinciding with the commencement of commercial fishing. Ecology 86, 835-847.

Welsh, A.H., Cunningham, R.B., Chambers, R.L., 2000. Methodology for estimating the abundance of rare animals: seabird nesting on North East Herald Cay. Biometrics 56, 22–30.

Zurr, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, Graham, M.S. (2009) Mixed effects models and extensions in ecology with R. Springer, NY, NY.

8 APPENDIX 2 Deviance tables for the zero Inflated negative binomial model (ZINB)

Call:

```
zeroinfl(formula = silky ~ yy + TIMECAT + vesselname | yy + hk_bt_flt, data = DataFile,
   offset = log(hook_est), dist = "negbin")
```

Pearson residuals:

Min	1Q	Median	3Q	Max
-0.89775	-0.41531	-0.28670	-0.01595	72.50433

Count model coefficients (negbin with log link):

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-8.983e+00	5.359e-01	-16.763	< 2e-16	***
yy1996	-1.379e+00	4.494e-01	-3.068	0.002158	**
yy1997	2.976e-01	4.226e-01	0.704	0.481279	
yy1998	-9.388e-02	4.140e-01	-0.227	0.820601	
yy1999	1.399e+00	3.991e-01	3.505	0.000457	***
yy2000	8.853e-01	3.898e-01	2.271	0.023154	*
yy2001	9.458e-01	4.040e-01	2.341	0.019216	*
yy2002	9.727e-01	3.790e-01	2.566	0.010277	*
yy2003	4.622e-01	3.963e-01	1.166	0.243460	
yy2004	5.300e-02	3.916e-01	0.135	0.892343	
yy2005	-4.482e-01	4.393e-01	-1.020	0.307586	
yy2006	-1.004e+00	4.235e-01	-2.371	0.017751	*
yy2007	-1.365e-01	4.214e-01	-0.324	0.746033	
yy2008	-2.424e-01	4.527e-01	-0.535	0.592436	
yy2009	-1.393e+00	5.034e-01	-2.767	0.005665	**
TIMECAT2	1.504e-01	1.082e-01	1.390	0.164508	
TIMECAT3	-2.018e-02	1.223e-01	-0.165	0.868927	
TIMECAT4	3.142e-01	1.857e-01	1.692	0.090711	.
TIMECAT5	4.297e-01	1.433e-01	2.998	0.002721	**
TIMECAT6	2.615e-01	1.694e-01	1.544	0.122622	
Vesselname ...391 record eliminated					
Log(theta)	-1.426e-01	5.338e-02	-2.672	0.007542	**

Zero-inflation model coefficients (binomial with logit link):

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	9.16104	16.75570	0.547	0.58456	
yy1996	-16.59925	329.94647	-0.050	0.95988	
yy1997	-2.60315	1.06873	-2.436	0.01486	*
yy1998	-1.71489	0.97622	-1.757	0.07897	.
yy1999	-3.99750	2.20384	-1.814	0.06970	.
yy2000	-0.63351	0.76920	-0.824	0.41017	
yy2001	0.07115	0.78256	0.091	0.92756	
yy2002	-0.39438	0.74941	-0.526	0.59871	
yy2003	0.27688	0.76603	0.361	0.71777	
yy2004	-0.75383	0.76019	-0.992	0.32138	
yy2005	-2.83995	0.96094	-2.955	0.00312	**
yy2006	-4.54235	1.42883	-3.179	0.00148	**
yy2007	-11.55041	43.45384	-0.266	0.79039	
yy2008	-13.86074	81.60807	-0.170	0.86513	
yy2009	-17.88761	1715.81085	-0.010	0.99168	

```
hk_bt_flt4   -21.89448   89.29831  -0.245  0.80631
hk_bt_flt5   -22.70632  111.37187  -0.204  0.83845
hk_bt_flt6   -13.01636   28.69203  -0.454  0.65008
hk_bt_flt7   -21.29395  193.11226  -0.110  0.91220
hk_bt_flt8    -7.55539   16.77224  -0.450  0.65237
hk_bt_flt9    -9.79005   16.82152  -0.582  0.56057
hk_bt_flt10   -5.81624   16.73385  -0.348  0.72816
hk_bt_flt11  -25.91863 4986.55937  -0.005  0.99585
hk_bt_flt12   -9.35639   16.76432  -0.558  0.57677
hk_bt_flt13  -22.38725  461.51264  -0.049  0.96131
hk_bt_flt14  -24.95409 1088.55091  -0.023  0.98171
hk_bt_flt15  -11.01236   16.90555  -0.651  0.51479
hk_bt_flt16  -11.70836   16.83274  -0.696  0.48670
hk_bt_flt17  -10.41576   16.75055  -0.622  0.53406
hk_bt_flt18   -9.95019   16.74356  -0.594  0.55233
hk_bt_flt19   -9.13371   16.74314  -0.546  0.58540
hk_bt_flt20   -9.58129   16.74333  -0.572  0.56716
hk_bt_flt21   -8.41232   16.74447  -0.502  0.61539
hk_bt_flt22   -9.24505   16.74166  -0.552  0.58080
hk_bt_flt23   -9.30088   16.74550  -0.555  0.57860
hk_bt_flt24   -7.22413   16.73912  -0.432  0.66605
hk_bt_flt25   -7.87944   16.73999  -0.471  0.63786
hk_bt_flt26   -8.09169   16.74105  -0.483  0.62885
hk_bt_flt27   -7.79043   16.74076  -0.465  0.64168
hk_bt_flt28   -7.64648   16.74031  -0.457  0.64784
hk_bt_flt29   -7.75087   16.74339  -0.463  0.64342
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Theta = 0.8671
Number of iterations in BFGS optimization: 169
Log-likelihood: -1.045e+04 on 452 Df
```

Deviance table for the TARGET LONGLINE

```
summary(FAL.zipY)

Call:
zeroinfl(formula = silky ~ as.factor(yy) + as.factor(TIMECAT) + hk_bt_flt | as.factor(yy) +
    hk_bt_flt, data = shk.trim.yes, offset = log(hook_est), dist = "poisson")

Pearson residuals:
    Min      1Q  Median      3Q     Max
-6.4291 -1.1519 -0.5251  0.7283 20.7199

Count model coefficients (poisson with log link):
                  Estimate Std. Error z value Pr(>|z|)
(Intercept)      -5.173278   0.134553 -38.448  < 2e-16 ***
as.factor(yy)1996   0.375535   0.185862   2.021 0.043331 *
as.factor(yy)1997  -0.184176   0.207330  -0.888 0.374366
as.factor(yy)1998   1.354589   0.129233  10.482  < 2e-16 ***
as.factor(yy)1999   1.618015   0.128410  12.600  < 2e-16 ***
as.factor(yy)2000   1.558886   0.131745  11.833  < 2e-16 ***
```

```
as.factor(yy)2001    1.630902   0.129134  12.630  < 2e-16 ***
as.factor(yy)2002    2.106194   0.127818  16.478  < 2e-16 ***
as.factor(yy)2003    2.138045   0.129309  16.534  < 2e-16 ***
as.factor(yy)2004    1.895517   0.127967  14.813  < 2e-16 ***
as.factor(yy)2005    2.030443   0.127658  15.905  < 2e-16 ***
as.factor(yy)2006    2.130788   0.127836  16.668  < 2e-16 ***
as.factor(yy)2007    2.097988   0.128364  16.344  < 2e-16 ***
as.factor(yy)2008    1.571055   0.129936  12.091  < 2e-16 ***
as.factor(yy)2009    1.573527   0.466420   3.374 0.000742 ***
as.factor(TIMECAT)2  0.288378   0.048429   5.955 2.61e-09 ***
as.factor(TIMECAT)3  0.594506   0.044835  13.260  < 2e-16 ***
as.factor(TIMECAT)4  0.689897   0.042772  16.129  < 2e-16 ***
as.factor(TIMECAT)5  0.586315   0.043196  13.573  < 2e-16 ***
as.factor(TIMECAT)6  0.469846   0.047659   9.858  < 2e-16 ***
hk_bt_flt           -0.171236   0.001844 -92.846  < 2e-16 ***

Zero-inflation model coefficients (binomial with logit link):
                Estimate Std. Error z value Pr(>|z|)
(Intercept)        -2.773985   0.718096  -3.863 0.000112 ***
as.factor(yy)1996   1.276942   0.833126   1.533 0.125347
as.factor(yy)1997   1.211168   0.822859   1.472 0.141047
as.factor(yy)1998  -0.836222   0.755300  -1.107 0.268234
as.factor(yy)1999   0.276411   0.753745   0.367 0.713830
as.factor(yy)2000  -1.034359   0.816253  -1.267 0.205083
as.factor(yy)2001   0.258620   0.753038   0.343 0.731271
as.factor(yy)2002   0.483912   0.732162   0.661 0.508653
as.factor(yy)2003  -0.236868   0.788109  -0.301 0.763756
as.factor(yy)2004  -1.457141   0.759294  -1.919 0.054975 .
as.factor(yy)2005  -1.186004   0.747588  -1.586 0.112640
as.factor(yy)2006  -1.879408   0.745428  -2.521 0.011694 *
as.factor(yy)2007  -3.734488   0.784111  -4.763 1.91e-06 ***
as.factor(yy)2008  -2.837529   0.807078  -3.516 0.000438 ***
as.factor(yy)2009 -13.606724 480.788852  -0.028 0.977422
hk_bt_flt           0.192233   0.009907  19.404  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Number of iterations in BFGS optimization: 58
Log-likelihood: -1.931e+04 on 37 Df
```

Deviance table for Purse Seine Fishery – Associated sets

```
Call:
glm.nb(formula = silky ~ as.factor(yy) + as.factor(cell) + as.factor(ez_id) +
    as.factor(flag_id), data = psA.dat, maxit = 2500, init.theta = 0.1815410529,
    link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.3183  -0.9131  -0.8360  -0.0463   3.9925

Coefficients: (2 not defined because of singularities)
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)          -1.396e+00  2.139e+00  -0.653 0.513964
as.factor(yy)1996     -4.137e-01  1.805e-01  -2.292 0.021910 *
as.factor(yy)1997     -1.372e+00  1.882e-01  -7.292 3.05e-13 ***
as.factor(yy)1998      1.377e-01  1.749e-01   0.788 0.430918
as.factor(yy)1999      8.420e-01  1.722e-01   4.889 1.01e-06 ***
```

as.factor(yy)2000	6.044e-01	1.744e-01	3.466	0.000528	***
as.factor(yy)2001	8.715e-01	1.737e-01	5.018	5.22e-07	***
as.factor(yy)2002	7.911e-01	1.663e-01	4.757	1.96e-06	***
as.factor(yy)2003	1.175e+00	1.641e-01	7.158	8.20e-13	***
as.factor(yy)2004	7.771e-01	1.602e-01	4.850	1.23e-06	***
as.factor(yy)2005	1.144e+00	1.609e-01	7.110	1.16e-12	***
as.factor(yy)2006	1.100e+00	1.609e-01	6.835	8.21e-12	***
as.factor(yy)2007	1.007e+00	1.626e-01	6.194	5.86e-10	***
as.factor(yy)2008	7.724e-01	1.622e-01	4.763	1.91e-06	***
as.factor(yy)2009	6.756e-01	1.627e-01	4.152	3.29e-05	***
as.factor(cell)-02142	-2.662e-01	1.783e+00	-0.149	0.881318	
as.factor(cell)-02148	-4.040e-01	1.783e+00	-0.227	0.820786	
as.factor(cell)-02152	9.882e-02	1.784e+00	0.055	0.955824	
as.factor(cell)-02158	3.280e-01	1.784e+00	0.184	0.854131	
as.factor(cell)-02162	2.262e-01	1.785e+00	0.127	0.899155	
as.factor(cell)-02168	1.188e-01	1.787e+00	0.067	0.946980	
as.factor(cell)-02172	9.781e-02	1.788e+00	0.055	0.956369	
as.factor(cell)-02178	-7.415e-02	1.789e+00	-0.041	0.966937	
as.factor(cell)-02182	1.708e-01	1.789e+00	0.095	0.923951	
as.factor(cell)-02188	1.016e-02	1.796e+00	0.006	0.995488	
as.factor(cell)-02192	-1.674e-01	1.803e+00	-0.093	0.926012	
as.factor(cell)-02198	9.087e-03	1.821e+00	0.005	0.996018	
as.factor(cell)-02202	-1.558e+00	2.200e+00	-0.708	0.478811	
as.factor(cell)-08142	1.660e+00	2.447e+00	0.679	0.497386	
as.factor(cell)-08148	-2.609e-01	1.788e+00	-0.146	0.884028	
as.factor(cell)-08152	1.424e-01	1.786e+00	0.080	0.936444	
as.factor(cell)-08158	-2.719e-02	1.789e+00	-0.015	0.987870	
as.factor(cell)-08162	-2.442e-02	1.791e+00	-0.014	0.989122	
as.factor(cell)-08168	2.377e-01	1.788e+00	0.133	0.894253	
as.factor(cell)-08172	3.372e-01	1.788e+00	0.189	0.850384	
as.factor(cell)-08178	3.123e-01	1.792e+00	0.174	0.861628	
as.factor(cell)-08182	4.700e-01	1.790e+00	0.263	0.792810	
as.factor(cell)-08188	-1.613e-02	1.803e+00	-0.009	0.992861	
as.factor(cell)-08192	5.562e-01	1.809e+00	0.307	0.758563	
as.factor(cell)-08198	-2.835e-02	1.863e+00	-0.015	0.987862	
as.factor(cell)-08202	-2.756e+01	2.678e+05	0.000	0.999918	
as.factor(cell)-08208	-2.797e+01	4.648e+05	0.000	0.999952	
as.factor(cell)-12152	-8.744e-01	1.937e+00	-0.451	0.651701	
as.factor(cell)-12158	1.986e-01	1.821e+00	0.109	0.913136	
as.factor(cell)-12162	3.648e-01	1.864e+00	0.196	0.844816	
as.factor(cell)-12168	2.833e-01	1.950e+00	0.145	0.884478	
as.factor(cell)-12172	9.645e-01	1.844e+00	0.523	0.600987	
as.factor(cell)-12178	-4.317e-01	1.919e+00	-0.225	0.822037	
as.factor(cell)-12182	-5.899e-01	1.959e+00	-0.301	0.763294	
as.factor(cell)-12188	1.073e+00	1.890e+00	0.567	0.570416	
as.factor(cell)-12192	6.863e-01	2.102e+00	0.326	0.744066	
as.factor(cell)-12198	-2.800e+01	2.858e+05	0.000	0.999922	
as.factor(cell)-12202	-2.804e+01	3.286e+05	0.000	0.999932	
as.factor(cell)-18188	-2.719e+01	4.584e+05	0.000	0.999953	
as.factor(cell)02132	-2.783e+01	4.648e+05	0.000	0.999952	
as.factor(cell)02138	-1.111e+00	1.788e+00	-0.621	0.534578	
as.factor(cell)02142	-5.451e-01	1.783e+00	-0.306	0.759861	
as.factor(cell)02148	-1.854e-01	1.785e+00	-0.104	0.917294	
as.factor(cell)02152	-2.971e-01	1.786e+00	-0.166	0.867883	
as.factor(cell)02158	-1.966e-01	1.787e+00	-0.110	0.912391	
as.factor(cell)02162	5.522e-03	1.787e+00	0.003	0.997535	
as.factor(cell)02168	1.192e-01	1.791e+00	0.067	0.946938	
as.factor(cell)02172	7.571e-02	1.791e+00	0.042	0.966286	
as.factor(cell)02178	5.522e-01	1.790e+00	0.309	0.757673	
as.factor(cell)02182	5.467e-01	1.806e+00	0.303	0.762124	
as.factor(cell)02188	-2.075e-01	1.808e+00	-0.115	0.908637	
as.factor(cell)02192	3.041e-01	1.825e+00	0.167	0.867690	

```
as.factor(cell)02198  -1.983e+00  2.184e+00  -0.908 0.364025
as.factor(cell)02202   2.296e+00  2.032e+00   1.130 0.258456
as.factor(cell)02208   1.433e+00  2.007e+00   0.714 0.475105
as.factor(cell)08138  -3.714e+00  1.960e+00  -1.895 0.058072 .
as.factor(cell)08142  -1.557e+00  1.826e+00  -0.853 0.393681
as.factor(cell)08148   2.582e-01  1.812e+00   0.143 0.886678
as.factor(cell)08152   5.384e-03  1.849e+00   0.003 0.997677
as.factor(cell)08158  -8.446e-02  1.824e+00  -0.046 0.963071
as.factor(cell)08162  -9.083e-01  1.871e+00  -0.485 0.627341
as.factor(cell)08168   1.233e+00  1.865e+00   0.661 0.508770
as.factor(cell)08172   6.915e-01  1.832e+00   0.377 0.705853
as.factor(cell)08178   4.449e-01  1.808e+00   0.246 0.805640
as.factor(cell)08182   1.163e+00  2.081e+00   0.559 0.576253
as.factor(cell)08188   8.012e-01  1.862e+00   0.430 0.667006
as.factor(cell)08192   1.022e+00  1.861e+00   0.549 0.582902
as.factor(cell)08198   1.868e+00  2.396e+00   0.780 0.435516
as.factor(cell)08202   2.665e+00  2.150e+00   1.240 0.215044
as.factor(cell)08208   1.999e+00  1.912e+00   1.046 0.295603
as.factor(cell)12138  -2.879e+01  2.922e+05   0.000 0.999921
as.factor(cell)12142  -1.538e+00  1.994e+00  -0.772 0.440394
as.factor(ez_id)CK     8.911e-01  1.145e+00   0.778 0.436402
as.factor(ez_id)FJ    -2.711e+00  1.802e+00  -1.504 0.132539
as.factor(ez_id)FM     1.477e+00  1.160e+00   1.274 0.202761
as.factor(ez_id)GL     9.557e-01  1.159e+00   0.824 0.409713
as.factor(ez_id)HB     2.569e-01  1.177e+00   0.218 0.827271
as.factor(ez_id)ID     7.825e-01  1.194e+00   0.655 0.512339
as.factor(ez_id)IW     8.508e-01  1.156e+00   0.736 0.461533
as.factor(ez_id)JV    -1.562e+00  1.690e+00  -0.924 0.355233
as.factor(ez_id)KI    -2.487e+01  2.778e+04  -0.001 0.999286
as.factor(ez_id)LN     1.067e-01  1.489e+00   0.072 0.942904
as.factor(ez_id)MH     1.007e+00  1.176e+00   0.856 0.391792
as.factor(ez_id)NR     9.011e-01  1.161e+00   0.776 0.437773
as.factor(ez_id)PG     1.140e+00  1.158e+00   0.984 0.325264
as.factor(ez_id)PW     3.699e-01  5.278e+05   0.000 0.999999
as.factor(ez_id)PX     6.388e-01  1.155e+00   0.553 0.580182
as.factor(ez_id)PY            NA         NA      NA       NA
as.factor(ez_id)SB     9.112e-01  1.163e+00   0.783 0.433500
as.factor(ez_id)TK     8.015e-01  1.148e+00   0.698 0.484935
as.factor(ez_id)TO            NA         NA      NA       NA
as.factor(ez_id)TV     8.744e-01  1.159e+00   0.755 0.450439
as.factor(ez_id)WF     2.049e+00  1.610e+00   1.273 0.203162
as.factor(ez_id)WS     5.086e-01  1.414e+00   0.360 0.719026
as.factor(flag_id)ES   2.749e-01  3.929e-01   0.700 0.484109
as.factor(flag_id)FM   6.884e-01  2.155e-01   3.195 0.001400 **
as.factor(flag_id)JP   1.221e+00  2.192e-01   5.571 2.53e-08 ***
as.factor(flag_id)KI   5.313e-01  2.786e-01   1.907 0.056538 .
as.factor(flag_id)KR   5.214e-01  2.131e-01   2.447 0.014424 *
as.factor(flag_id)MH  -3.835e-01  2.105e-01  -1.822 0.068448 .
as.factor(flag_id)NZ   9.044e-01  3.226e-01   2.803 0.005060 **
as.factor(flag_id)PG  -1.246e-01  2.004e-01  -0.622 0.534199
as.factor(flag_id)PH   1.221e-01  2.042e-01   0.598 0.549780
as.factor(flag_id)SB   1.144e+00  2.284e-01   5.006 5.55e-07 ***
as.factor(flag_id)TW   4.082e-01  2.058e-01   1.983 0.047334 *
as.factor(flag_id)US  -3.386e-02  2.041e-01  -0.166 0.868219
as.factor(flag_id)VU  -3.166e-01  2.257e-01  -1.403 0.160682
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(0.1815) family taken to be 1)

    Null deviance: 21444  on 28770  degrees of freedom
Residual deviance: 19575  on 28651  degrees of freedom
```

```
AIC: 83285
Number of Fisher Scoring iterations: 1
          Theta:  0.18154
       Std. Err.:  0.00256
 2 x log-likelihood:  -83042.55900
```

Deviance Table for Purse Seine – Unassociated Sets

```
Call:
glm.nb(formula = silky ~ as.factor(yy) + as.factor(cell) + as.factor(ez_id) +
   as.factor(flag_id), data = psU.dat, maxit = 2500, init.theta = 0.04812851732,
   link = log)

Deviance Residuals:
   Min      1Q   Median      3Q     Max
-0.6781  -0.4674  -0.3832  -0.2644   3.7530

Coefficients: (3 not defined because of singularities)
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)          -1.411e+01  4.063e+02  -0.035 0.972297
as.factor(yy)1996     -1.959e-01  4.449e-01  -0.440 0.659713
as.factor(yy)1997      8.129e-01  4.725e-01   1.720 0.085342 .
as.factor(yy)1998      1.230e+00  4.000e-01   3.076 0.002099 **
as.factor(yy)1999      1.116e+00  4.687e-01   2.381 0.017244 *
as.factor(yy)2000      1.931e-02  4.675e-01   0.041 0.967050
as.factor(yy)2001      9.001e-01  4.011e-01   2.244 0.024841 *
as.factor(yy)2002      7.306e-01  4.117e-01   1.774 0.076012 .
as.factor(yy)2003      1.291e+00  3.795e-01   3.403 0.000667 ***
as.factor(yy)2004      1.397e+00  3.803e-01   3.673 0.000240 ***
as.factor(yy)2005      1.543e+00  3.645e-01   4.233 2.31e-05 ***
as.factor(yy)2006      1.184e+00  3.676e-01   3.222 0.001272 **
as.factor(yy)2007      2.024e+00  3.639e-01   5.561 2.68e-08 ***
as.factor(yy)2008      1.130e+00  3.584e-01   3.152 0.001621 **
as.factor(yy)2009      1.027e+00  3.597e-01   2.855 0.004304 **
as.factor(cell)-02148  1.680e-02  2.245e-01   0.075 0.940340
as.factor(cell)-02152 -1.260e-01  2.453e-01  -0.513 0.607635
as.factor(cell)-02158 -5.362e-01  2.414e-01  -2.221 0.026363 *
as.factor(cell)-02162 -2.917e-01  3.071e-01  -0.950 0.342180
as.factor(cell)-02168 -1.159e+00  4.045e-01  -2.865 0.004167 **
as.factor(cell)-02172 -1.699e+00  4.479e-01  -3.793 0.000149 ***
as.factor(cell)-02178 -4.783e-01  4.500e-01  -1.063 0.287838
as.factor(cell)-02182 -2.333e+00  6.419e-01  -3.634 0.000279 ***
as.factor(cell)-02188 -7.623e-01  8.134e-01  -0.937 0.348632
as.factor(cell)-02192 -1.078e+00  7.954e-01  -1.356 0.175186
as.factor(cell)-02198 -2.539e+00  1.154e+00  -2.200 0.027817 *
as.factor(cell)-02202 -2.648e+01  8.434e+06   0.000 0.999997
as.factor(cell)-02208 -5.853e+01  1.682e+07   0.000 0.999997
as.factor(cell)-08142 -3.655e+01  4.745e+07   0.000 0.999999
as.factor(cell)-08148 -5.713e-01  4.661e-01  -1.226 0.220290
as.factor(cell)-08152 -4.280e-01  2.566e-01  -1.668 0.095335 .
as.factor(cell)-08158 -2.313e-01  4.486e-01  -0.516 0.606131
as.factor(cell)-08162 -1.926e+00  5.495e-01  -3.504 0.000458 ***
as.factor(cell)-08168 -1.808e+00  5.829e-01  -3.102 0.001923 **
as.factor(cell)-08172 -7.124e-01  4.996e-01  -1.426 0.153925
as.factor(cell)-08178 -2.194e+00  7.104e-01  -3.089 0.002012 **
as.factor(cell)-08182 -1.238e+00  6.961e-01  -1.778 0.075330 .
as.factor(cell)-08188 -3.146e+01  9.428e+06   0.000 0.999997
as.factor(cell)-08192 -1.255e+00  8.884e-01  -1.412 0.157813
as.factor(cell)-08198 -2.816e+01  3.335e+05   0.000 0.999933
```

as.factor(cell)-08202	-5.975e+01	1.529e+07	0.000	0.999997	
as.factor(cell)-08208	-6.131e+01	2.192e+07	0.000	0.999998	
as.factor(cell)-12152	-3.431e+00	1.287e+00	-2.666	0.007674	**
as.factor(cell)-12158	-2.089e+00	6.486e-01	-3.221	0.001279	**
as.factor(cell)-12162	-2.451e+00	1.211e+00	-2.024	0.042931	*
as.factor(cell)-12168	-1.789e+00	1.581e+00	-1.132	0.257675	
as.factor(cell)-12172	-3.598e+01	3.189e+07	0.000	0.999999	
as.factor(cell)-12178	-3.653e+01	5.254e+07	0.000	0.999999	
as.factor(cell)-12188	1.395e+01	4.063e+02	0.034	0.972615	
as.factor(cell)-18172	-3.617e+01	8.608e+07	0.000	1.000000	
as.factor(cell)-18198	-2.419e+01	6.711e+07	0.000	1.000000	
as.factor(cell)-32172	-2.347e+01	2.373e+07	0.000	0.999999	
as.factor(cell)-38172	-2.420e+01	1.628e+07	0.000	0.999999	
as.factor(cell)02132	-2.625e+01	4.745e+07	0.000	1.000000	
as.factor(cell)02138	-2.621e+00	8.270e-01	-3.169	0.001530	**
as.factor(cell)02142	-7.008e-01	2.730e-01	-2.567	0.010259	*
as.factor(cell)02148	-7.975e-01	2.789e-01	-2.859	0.004248	**
as.factor(cell)02152	-1.167e+00	3.207e-01	-3.640	0.000273	***
as.factor(cell)02158	-8.937e-01	3.380e-01	-2.644	0.008183	**
as.factor(cell)02162	-1.374e+00	3.684e-01	-3.730	0.000191	***
as.factor(cell)02168	-2.160e+00	5.008e-01	-4.312	1.62e-05	***
as.factor(cell)02172	-1.507e+00	5.165e-01	-2.918	0.003521	**
as.factor(cell)02178	3.490e-02	4.516e-01	0.077	0.938400	
as.factor(cell)02182	2.785e+00	1.407e+00	1.979	0.047792	*
as.factor(cell)02188	-2.078e+00	1.127e+00	-1.845	0.065108	.
as.factor(cell)02192	-2.587e-02	9.341e-01	-0.028	0.977903	
as.factor(cell)02198	-3.697e+01	1.227e+07	0.000	0.999998	
as.factor(cell)02202	-5.005e+01	1.119e+07	0.000	0.999996	
as.factor(cell)08138	-3.630e+01	1.012e+07	0.000	0.999997	
as.factor(cell)08142	1.020e-01	7.410e-01	0.138	0.890529	
as.factor(cell)08148	-3.566e+01	1.061e+07	0.000	0.999997	
as.factor(cell)08152	4.235e-01	1.214e+00	0.349	0.727278	
as.factor(cell)08158	-9.724e-01	1.339e+00	-0.726	0.467649	
as.factor(cell)08162	-1.552e+00	1.768e+00	-0.878	0.379900	
as.factor(cell)08168	-3.545e+01	1.134e+07	0.000	0.999998	
as.factor(cell)08172	-3.668e+01	1.268e+07	0.000	0.999998	
as.factor(cell)08178	-2.097e+00	1.169e+00	-1.795	0.072727	.
as.factor(cell)08182	8.074e-01	4.684e+00	0.172	0.863140	
as.factor(cell)08192	-3.610e+01	6.711e+07	0.000	1.000000	
as.factor(cell)12138	-3.687e+01	6.711e+07	0.000	1.000000	
as.factor(cell)12142	-3.495e+01	4.745e+07	0.000	0.999999	
as.factor(cell)12162	-3.610e+01	6.711e+07	0.000	1.000000	
as.factor(ez_id)FJ	1.269e+01	5.390e+07	0.000	1.000000	
as.factor(ez_id)FM	1.127e+01	4.063e+02	0.028	0.977863	
as.factor(ez_id)GL	1.142e+01	4.063e+02	0.028	0.977570	
as.factor(ez_id)HB	9.294e+00	4.063e+02	0.023	0.981748	
as.factor(ez_id)ID	1.324e+01	4.063e+02	0.033	0.974011	
as.factor(ez_id)IW	1.062e+01	4.063e+02	0.026	0.979144	
as.factor(ez_id)JV	1.116e+01	4.063e+02	0.027	0.978091	
as.factor(ez_id)KI	-2.312e+01	6.711e+06	0.000	0.999997	
as.factor(ez_id)LN	3.690e+01	8.434e+06	0.000	0.999997	
as.factor(ez_id)MH	1.143e+01	4.063e+02	0.028	0.977549	
as.factor(ez_id)NR	1.186e+01	4.063e+02	0.029	0.976702	
as.factor(ez_id)NZ	NA	NA	NA	NA	
as.factor(ez_id)PG	1.153e+01	4.063e+02	0.028	0.977358	
as.factor(ez_id)PW	NA	NA	NA	NA	
as.factor(ez_id)PX	1.036e+01	4.063e+02	0.025	0.979665	
as.factor(ez_id)PY	1.270e+01	6.822e+07	0.000	1.000000	
as.factor(ez_id)SB	1.154e+01	4.063e+02	0.028	0.977348	
as.factor(ez_id)TK	-6.585e+00	1.394e+07	0.000	1.000000	
as.factor(ez_id)TV	1.165e+01	4.063e+02	0.029	0.977128	
as.factor(ez_id)WS	NA	NA	NA	NA	

```
as.factor(flag_id)ES   2.899e+00  2.218e+00   1.307 0.191172
as.factor(flag_id)FM   1.916e+00  4.757e-01   4.027 5.66e-05 ***
as.factor(flag_id)JP   8.354e-01  4.902e-01   1.704 0.088330 .
as.factor(flag_id)KI   3.879e-01  6.171e-01   0.629 0.529598
as.factor(flag_id)KR   6.471e-01  4.266e-01   1.517 0.129326
as.factor(flag_id)MH   1.389e+00  4.686e-01   2.965 0.003028 **
as.factor(flag_id)NZ   2.030e+00  8.144e-01   2.493 0.012672 *
as.factor(flag_id)PG   1.065e+00  4.105e-01   2.595 0.009452 **
as.factor(flag_id)PH   1.439e+00  4.370e-01   3.292 0.000993 ***
as.factor(flag_id)SB   1.612e+00  7.177e-01   2.247 0.024662 *
as.factor(flag_id)TV   8.507e-01  1.953e+00   0.435 0.663217
as.factor(flag_id)TW   9.490e-01  4.207e-01   2.256 0.024082 *
as.factor(flag_id)US   5.204e-01  4.246e-01   1.225 0.220389
as.factor(flag_id)VU   5.081e-01  4.644e-01   1.094 0.273873
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(0.0481) family taken to be 1)
  Null deviance: 4024.6  on 15434  degrees of freedom
Residual deviance: 3164.7  on 15322  degrees of freedom
AIC: 13290
Number of Fisher Scoring iterations: 1
          Theta:  0.04813
      Std. Err.:  0.00187
2 x log-likelihood:  -13061.83800
```