SCIENTIFIC COMMITTEE

NINTH REGULAR SESSION

Pohnpei, Federated States of Micronesia
6-14 August 2013

Analyses of the potential influence of four gear factors (leader type, hook type, “shark” lines and bait type) on shark catch rates in WCPO tuna longline fisheries

WCPFC-SC9-2013/EB-WP-02 rev 1.

(22 July 2013)

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Summary

In reviewing the stock assessments conducted in 2012 for silky and oceanic whitetip sharks, SC8 noted both a) concerns over the status of the stocks, and b) the large impact that non-target longline fisheries are estimated to have. For these reasons, SC8 recommended consideration of mitigation measures as providing the best opportunity to improve their stock status. A number of factors related to longline fishing methods, such as leader type, hook type, shark lines and bait (amongst others) may influence shark catch rates and offer potential for developing mitigation options. This paper represents an extension of work presented in a preliminary analysis of wire trace effects on oceanic whitetip and silky shark provided to WCPFC9 in 2012. The key differences are that this paper, firstly, reviews regional observer data and determines if there is sufficient homogeneity and contrast throughout fishery/area/time strata in the key factors of interest to support integrated regional level analysis of leader, hook, shark line and bait effects. Secondly, it identifies strata within the observer database where data are relatively more concentrated and contain relatively high contrast (heterogeneity) in one or more of these factors through time and space. Finally it describes subregional models to assess the relative effect of wire trace, hook type, shark lines and bait categories (along with other environmental and fishing method) factors upon catches of oceanic whitetip and silky shark in fisheries within the WCPO. Key findings include:

- A significant relationship between shark line use and increased catch of both species was identified in both the RMI/FSM and Fiji based tuna fisheries;
- Wire trace was also estimated to have a positive relationship with silky shark catches in the Fiji fishery, but not in the Hawaii or RMI fisheries;
- Shark bait was not, on its own, estimated to be related to shark catches (although it is uncertain to what degree it may be confounded in models with shark line use); and
- Hook type (interacting with leader type) was assessed in the Hawaii fishery but no substantial difference in effects on catch of either shark species was estimated. However model diagnostics were particularly poor for this fishery, and there is uncertainty over whether some sets in fact constituted “mixed” hook type sets and further work on the models may be required.

This information may, in combination with information on shark condition (See working paper SC9-EB-WP-06) and wire trace usage (WCPFC9-2012-IP-14) assist with the development of models to predict changes in oceanic whitetip and silky shark catch/mortality levels under different potential mitigation scenarios.

To address some specific issues that involve interactions between factors, higher levels of observer coverage plus heterogeneity in fleet practices will be necessary otherwise it might be necessary to undertake specific experiments.

1. Introduction

In reviewing the stock assessments conducted in 2012 for silky and oceanic whitetip sharks, SC8 noted both a) the concerns over the status of the stocks, and b) the large impact that non-target longline fisheries are estimated to have. For these reasons, SC8 recommended consideration of mitigation measures as providing the best opportunity to improve their stock status.

With respect to oceanic whitetip shark SC8 concluded:

> ***Management Advice and Implications***
>
> 50. Despite the data limitations going into the assessment, and the wide range of uncertainties considered, all of the accepted model runs indicate that the WCPO oceanic whitetip shark stock is currently overfished and overfishing is occurring relative to commonly used MSY-based reference points and depletion-based reference points. Management measures to reduce fishing mortality and to rebuild spawning biomass have been agreed to under CMM 2011-04, but mitigation to avoid capture is recommended.
>
> 51. Given the bycatch nature of most of the fishery impacts, mitigation measures provide the best opportunity to improve the status of the WCPO oceanic whitetip shark stock.

Further, for silky shark SC8 concluded:

> ***Management Advice and Implications***
>
> 57. Noting SC8s concerns over the data conflict and potential biases in the silky shark assessment, it is not possible to provide management advice based on the assessment at this time. However, noting that some basic fishery indicators (e.g. mean lengths and some CPUE series) are showing declines in recent years, the SC recommends no increase in fishing mortality on silky sharks.
>
> 58. Further, recognizing that the major fishery impacts relate to non-target fisheries, the SC recommends that the Commission consider mitigation measures to reduce the impact of these non-target fisheries as a precautionary measure. SC8 recommends that the silky shark assessment be updated to incorporate all potentially important data series.

As an immediate step towards further examination of mitigation measures, a preliminary analysis of the impact of wire traces on shark catch rates was presented to WCPFC9 (OFP,2012) which built on that described in Clarke (2011).

While wire traces are not necessarily an indication of shark targeting, the WCPFC9 report along with reports by some other researchers (Ward et al. 2008; Afonso et al. 2012) have suggested that the number of sharks that are on the line when it comes to the side of the boat is higher when wire traces are used[1]. Another report suggests wire trace effects may be shark species specific (Ingram et al. 2012). While the reports of Ward et al. (2008) and Afonso et al. (2012) were based on planned experimental fishing trials that simultaneously tested different hook and/or leader types using an alternating hook or branch line strategy, the WCPFC analysis (OFP, 2012) attempted to estimate coefficients for the relationship between wire trace and catches of shark using a single region wide CPUE model based on grouped regional observer data. It was recognised however, that combining data from many different observer programs that represent many different fleets from different areas with different fishing strategies might lead to significant spatial and temporal confounding between model terms, making model based assessment of the relative effects of different factors (including wire trace) very difficult.

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[1] These studies included Japanese-style and J-style hooks, so these conclusions may not apply to circle hooks.

In addition to that issue, it is also recognised that other fishing method related factors (aside from wire trace use) may influence the catch of sharks by vessels predominantly targeting tuna or swordfish. Like wire trace, some of these factors may be intended to target tuna, but coincidentally are thought to have the potential to increase shark catches also. These include factors such as hook type (e.g., Curran and Bigelow, 2012) and depth of fishing (hooks per basket may be a proxy). However, other fishing methods/strategies are believed to be used to deliberately increase shark catches while mainly targeting tuna.

Longline vessels catching shark can be classified into groups according to whether or not they use none, part or all of their hooks to target sharks. Vessels can be classified as:

1. Those that deliberately and solely target sharks;
2. Those that employ mixed targeting, by targeting tuna or swordfish predominantly but modifying their gear or method to increase the capture of sharks also;
3. Those that target only tuna or swordfish but which as a result of fishing area or method, catch and willingly retain significant numbers of sharks; and
4. Those that target tuna/swordfish but which do not wish to catch sharks and have no desire to retain sharks taken as bycatch.

The strategy of mixed tuna and shark targeting is recognised as occurring in some longline fisheries in the WCPO, although the extent of the practice is somewhat uncertain due to low observer coverage rates on many fleets (similar to the problem associated with estimating wire trace usage). Two key strategies have been noted, the first being to deploy a shallow line off the mainline floats which, regardless of the depth of the tuna hooks in each basket, might increase the probability of taking shark species that frequent surface waters in the area being fished. Secondly, the use of cut up bycatch or tuna as bait on some hooks (either the float line hook or branchline hooks), instead of typical tuna or swordfish baits (mackerel, sardine, squid etc). The use of such baits, as recorded by observers, is believed to represent deliberate baiting for sharks, but typically such baits are only one component of the total bait allocated to a set (e.g. often tuna targeting baits are the predominant bait used). This is not to say that some tuna or swordfish targeting baits might not have higher catch rates relative to others (e.g., Coehlo et al. 2012).

The current paper represents an extension of work undertaken for the WCPFC9 paper that aimed to:

- Examine regional observer data and determine if there is sufficient homogeneity and contrast throughout fishery/area/time strata in the key factors of interest to support integrated regional level analysis of leader, hook, shark line and bait effects;
- If there is not, identify strata within the observer database where observer data is concentrated and contains sufficient contrast (homogeneity) in these factors through time and space; and:
- Develop appropriate models to assess the relative effect of wire trace, hook type, shark lines and bait categories, along with other environmental and fishing method, factors upon catches of oceanic whitetip and silky shark in fisheries within the WCPO.

This information would then be available to combine with information on shark condition at hauling Harley et al. (2013) and wire trace usage (OFP 2012) to develop a future model for predicting potential changes in oceanic whitetip and silky shark catch/mortality levels under different potential mitigation scenarios. Note that this current paper presents key relevant results and discussion up front but is complemented by detailed fishery specific data summaries in the attached appendices.

2. Methods

Database compilation

An operational (set by set) level database of species level observed catch, effort, operational (fishing method) and environmental data was compiled to support the analyses. The database used data extracted from the following sources:

- SPC regional observer database: catch, effort and operational/fishing method data that included key fields such as hooks per basket, hook type, bait type, shark line use, wire trace use;
- NOAA PIROP observer database (provided by US): The catch, effort and fishing method data provided was consistent with that extracted from the SPC database (above); and
- SPC environmental database: data extracted included sea surface temperatures, thermocline depths, moon phase, ocean current direction and speed. Much of the oceanographic data sourced from GODAS (2012).

Identification of strata for modelling

This was conducted in three parts:

a. Observer data were screened to identify fleets for which a minimum level of observer data had been collected (Table A1-1), and then area-fleet-year strata with at least 50 sets per year/area
b. The data were then screened to also identify strata in which there was contrast for the key factors of interest. By “contrast”, we mean that there was more than one level or category of a given factor observed across multiple sets in the strata. For example, a year/area/fleet strata in which some vessels were observed using wire trace and others observed not using wire trace, was considered to have some contrast. The higher the sample sizes (observed effort) for each category of the key factor, the better the contrast.
c. Multiple strata identified with contrast over time (years) from the same fleets and areas were then grouped into “potential” model data sets.
d. Each putative model data set was then examined more closely. Only datasets with sample sizes greater than 1000 sets and with contrast in at least 1 of the key factors (hook, leader, shark line use or bait) throughout the time series were then chosen to develop models on. The 1000 sets level was chosen on the basis that the model type to be used (zero inflated negative binomial) will typically not fit smaller sample sizes while at the same time allowing for a reasonable number of explanatory terms to be included in the models.

This strategy attempts to firstly, isolate observed data in strata where the coverage is relatively higher (and *relatively* more likely to be representative of the fleet observed) and secondly provide the models with datasets in which different levels of the key factors (leader, hook, shark line and bait) are well “mixed” spatially and temporally in the fishery. This may help the models to correctly identify key factor effects and reduce the likelihood of significant collinearity between these and other model terms that would introduce confounding and potentially misleading coefficient estimates. For example, a model which presented data in which for one part of the time series the fishery used J hooks with wire leaders but then later switched to circle hooks without wire leaders, would not be able to differentiate whether one or both factors contributed to any observed change in catch rates over time. However if it was possible to isolate data from a period in which both hook types and both leader types were used simultaneously within the fishery, then the likelihood of the model attributing effects to the correct factors is increased. The final subregional data sets selected for model development are described in the results section.

Model Development

A range of fishing method and environmental factors (terms) were considered for inclusion in the catch models for oceanic whitetip and silky shark. Terms provided in the initial catch models (prior to final model selection) were selected for initial inclusion only if there was *a priori* reason to expect that the term might potentially have a relationship to shark catch rates (i.e. based on existing knowledge or theories relating to species specific habitat preferences and gear interactions).

For the chosen subregional data sets, model development occurred in three phases:

1. **Model database preparation:** Each model area dataset was “trimmed” to exclude outliers and data not representative of the fishery strata being examined, as well as data from fishing operations occurring in areas that are not part of the habitat of the two shark species being assessed. The latter was predominantly achieved by removing sets that occurred in estimated sea surface temperatures of less than 23˚C.

2. **Exploratory modelling:** Collinearity between explanatory variables was assessed using scatter plots as well as Variance Inflation Factor (VIF) analyses using the *corvif* and *myvif* functions sourced from (http://www.highstat.com/BGS/GAM/HighstatLibV4.R) for use in software R 2.12.1, (R Development Core Team, 2011) noting that the standard *vif* function is not supported by the *pscl* package used for the CPUE models. VIF tests were run on the datasets to identify any significant collinear relationships between potential model variables and in particular between key factor variables and temporal (e.g. year) and spatial terms. This approach was useful in identifying appropriate time periods from which to extract fishery data sets and ensuring year terms were not confounded with key factors of interest. Each subregional model data set was then initially explored using Generalised Additive Models (GAMs) for count data (Poisson distribution) and for presence/absence data (binomial distribution) to assess the relationship between catch and potential explanatory variables included in the final models.

3. **Final model development:** Catch data for non-target species (sharks in particular) often contain a large number of sets with zero catch as well as sets with substantial catch, even after attempted exclusion of non-habitat areas from the model data. These phenomena need to be explicitly modelled (Bigelow et al. 2002, Campbell 2004, Ward and Myers 2005,

Minami et al. 2007). Zero inflated Poisson (ZIP) and zero inflated negative binomial (ZINB) (Zuur et al. 2009, Cunningham and Lindenmayer 2005, Welsh et al. 2000) mixture models were tested to determine the final model for each model area and species. These models are useful for modelling counts of rare species when the number of zero observations is larger than expected. Zero inflated models use 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. Zero counts can 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 they deal with over-dispersion better than other models (Zuur et al. 2009).

The following terms were provided to the "starting" models as continuous variables: hooks per basket, time of set, moon phase, latitude, longitude, sea surface temperature and thermocline depth, while fishing effort (number of hooks) was modeled as an offset. Terms provided as factors to the starting models were: year, hook type, wire trace use (yes/no), shark line use (yes/no) and shark bait use (yes/no).

Exploratory GAM modeling assisted in early identification of potential key model terms and the shape of their relationship to shark catch. Final ZINB model selection was undertaken using Akaike information criterion (AIC) based on backwards stepwise selection. Terms were retained in the model if their removal increased the AIC by more than 5 units per degree of freedom (associated with the term removed) with this sequential dropping/testing of terms continued until the AIC was minimized.

Regarding the “leader” factor, it was constructed to refer specifically to the use of wire trace (yes/no) and as such is effectively a factor that compares wire leaders to all other leaders (grouped), noting that they will be dominated by monofilament leaders. Regarding the bait type factor, observers record baits on a species specific basis but do not classify baits directly as being “shark” bait. However it is believed that any use of cutup bycatch or tuna as bait is specifically for the purpose of catching sharks (not tuna), hence the observer database was screened to identify sets which included the use of bycatch species or tunas as bait, and an assumption then made that these baits were being used to target sharks. In some instances, factors were provided to the models that combined hook type and leader type, or leader with shark line and bait use, to assess interacting effects of these factors upon shark catches.

3. Results

Model dataset selection

Putative model region/fleet strata: Initial data screening identified 9 sub-region/fleet strata (Figure 1) in which observer data was concentrated (> 50 sets observed/year) and in which there was some evidence for within year contrast (over multiple years) for at least one of the key factors of interest (hook type, leader type, shark line and bait use).

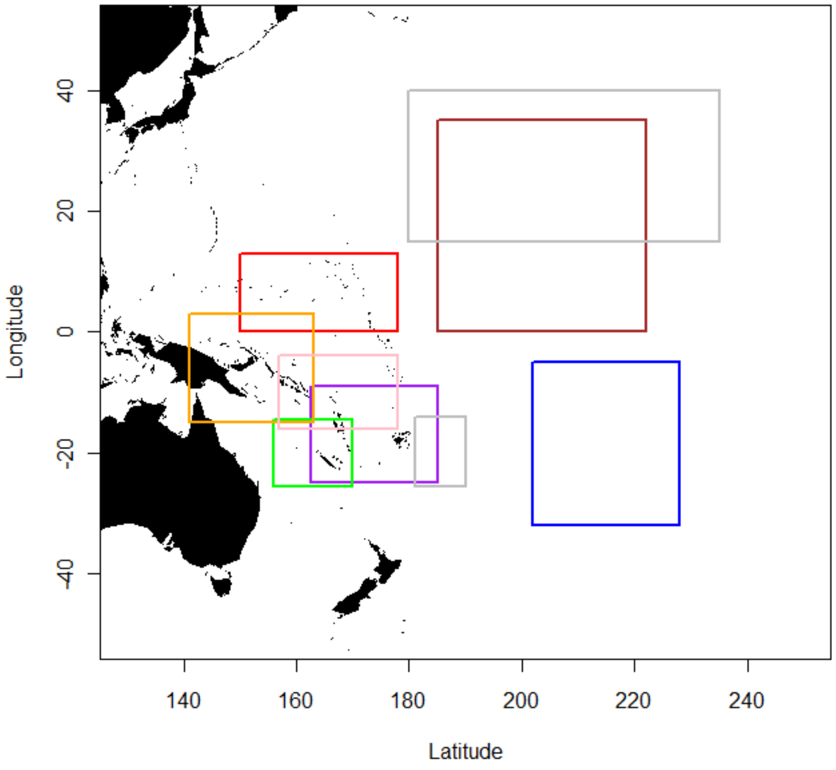


Figure 1: Location of 9 separate putative model regions.

Final Model region/strata: Data from each of these subregions was further assessed to determine if sample sizes (within years numbers of sets observed, and number of sets for each category of the key factors of interest) were sufficient to potentially support model based analyses of key factor effects. Tables detailing the level of contrast in each of the key factors of interest, in each fishery, are provided in Appendices 2-5, along with other fishery specific information for fisheries for which models were developed.

Only 3 of the fishery/regions passed the required criteria for further model development (>1000 sets observed and high contrast in multiple consecutive years for at least one of the key factors), being:

- **Fiji albacore tuna longline fishery** operating in Fiji and Vanuatu (for data spanning 2004 – 2010). The dataset was assessed to have potential for assessing leader, shark line and bait effects upon shark catches.

- **RMI and FSM based tuna longline fishery** operating in RMI and FSM (for data spanning 2004 – 2009). The dataset was assessed to have potential for assessing leader, shark line and bait effects upon shark catches, when restricted to FSM and Chinese flagged fleets operating in the fishery.

- **Hawaii deepset longline tuna fishery** operating in the US/Hawaii EEZ and international waters (for data spanning 2004 – 2011). The dataset was assessed to have potential for assessing leader and hook type effects upon shark catches.

Figure 2 shows how these fisheries overlap with the observed distribution of the key factors of interest, although it cannot be assumed this represents fully the distribution of the use of these fishing methods in the WCPO, given the very low level of observer coverage. Table 1 provides a brief explanation for why some fisheries were excluded from model based analyses.

Final models

Two sets of models were developed.

1. **Primary model set (Table 2)**: These were the main models initially developed for each species and fishery, aimed at assessing the relationship between shark catches and the key factors of interest. For the Hawaii tuna fishery models, hook and leader type were combined into a single factor, with multiple levels describing the different combinations of hook type and leader used through the fishery. In the RMI and Fiji models, key factors of interest were provided individually to the models.

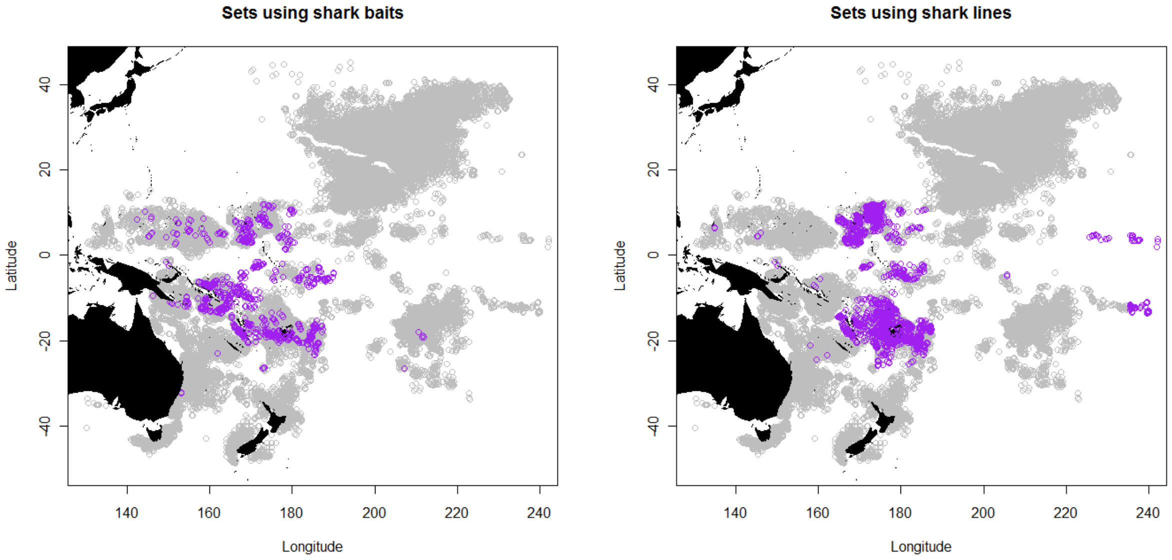
2. **Secondary model set (Table 3)**: . These were an additional set of models developed to help further understand the relationships between shark catches and the key factors of interest. A secondary set of models was developed for the RMI and Fiji fisheries which utilised a single factor that combined information from the leader, shark line and bait terms, to better assess possible “additive” effects of simultaneous use of wire trace, shark lines and bait. Those models include a combined factors term “shkfacs2” which signals for each fishing operation whether wire trace (W) and/or shark lines (L) and/or shark bait (B) were used or not used. For the Hawaii deepset fishery, a secondary model explored the temporal trend in catch by year, using only data from sets utilising tuna hooks with wire trace over the period 2000 to 2007. Details of this model are provided in Appendix 2 only. Confounding between year term and hook/leader factors was identified in the Hawaii data and the purpose of the “Year

effect" model was to assess if the declining trend in oceanic whitetip shark catch evident from an initial full model was still apparent when the data was restricted to a single hook and leader type.

Full summary statistics for all models are provided in appendix 2 (Hawaii), appendix 3 (Fiji) and appendix 4 (RMI/FSM).

Table 1 – Brief outline of reasons for excluding six of the nine fisheries originally identified for model development.

Fishery	Reason for exclusion from modelling
French Polynesia tuna fishery	Proportional hook and leader usage through the fleet had changed substantially over time (Table A5-1) and also spatially (through time), highlighting confounding between temporal and hook x leader factors in model based analyses. GAM based exploratory models indicated that there was likely to be insufficient data (sample sizes) in the primary years with data contrast for key factors, to support ZIP or ZINB GLM based analyses of hook and leader types.
Hawaii shallow set swordfish fishery	The changes in hook and bait types over time as noted by Walsh et al.(2009) suggest that the Hawaii Shallow set fishery observer data might not be suitable for assessing hook type effects upon shark catch rates and closer examination of the temporal trends in the use of hook and leader types in the fishery (Table A5 – 2) confirm that there is insufficient contrast in hook type use within years. Given that this fishery has no recorded use of shark targeting baits nor shark lines, it was determined that models for this fishery would not developed.
Vanuatu tuna fishery	Hook type was related to leader type (fishers used either circle hooks without wire leaders or tuna hooks with wires) so separating hook versus leader effects on shark catches would be difficult. In addition, by itself, sample sizes (number of sets observed) in the Vanuatu fishery would be too small to support ZINB based analyses (Table A5-4), and the fishery operates too differently (setting much shallower and with much shorter sets) to justify grouping with adjacent Fiji data model.
New Caledonia tuna fishery	Some contrast in hook type existed for New Caledonian observer data but closer examination revealed that the level of contrast and sample sizes for hook types within years data was too low (Table A5-3) and data from that fishery was not included in the final model.
Papua New Guinea tuna fishery	Only wire trace had within year contrast in data, and the sample sizes were too small to support model based analyses (Table A5-5).
Solomon Islands tuna fishery	For both the Taiwanese and Solomon Islands fleets, there is no contrast in wire trace or shark line data within years, while there is some contrast for shark baits, but sample sizes are small (Table A5-6 and A5-7).



Sets using wire trace (purple=YES; red=uncertain; grey=NO)

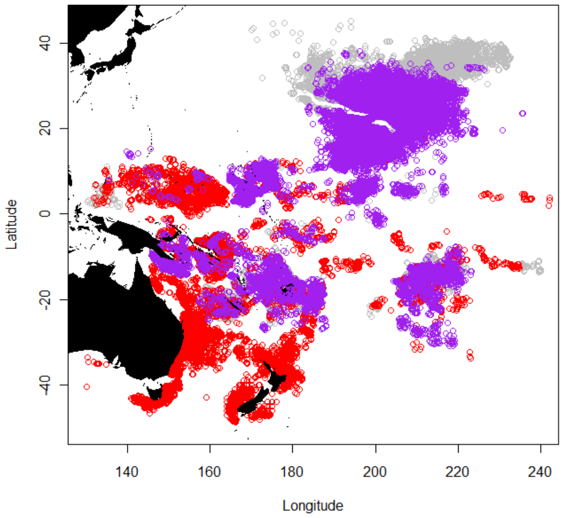
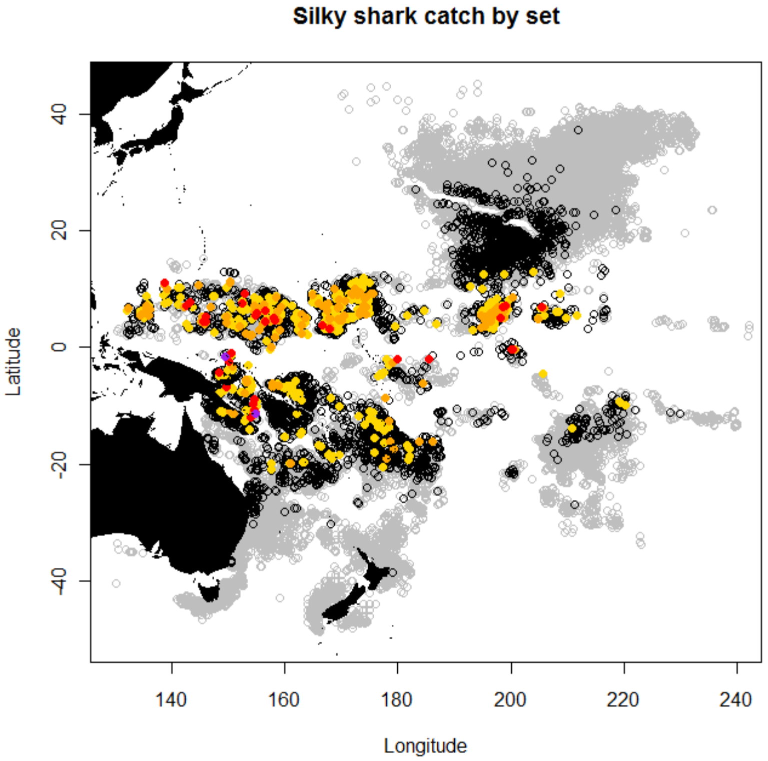


Figure 2: Distribution of observed sets using either shark baits, shark lines or wire trace [Grey = absence of factor, purple = presence; red=uncertain]



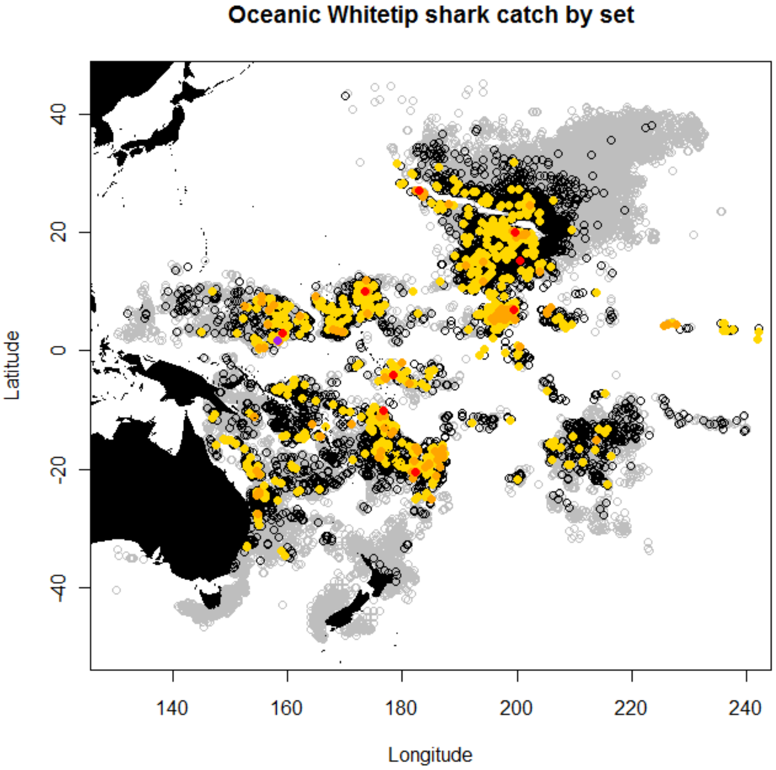


Figure 3: Spatial distribution of observed oceanic whitetip and silky shark catch by set where, for oceanic whitetip, grey is 0 catch, black is 1-2, gold is 3-5, orange is 6-10, red is 11-20 and purple 21+. For silky shark, grey is 0 catch, black is 1-5, gold is 6-10, orange is 11-20, red is 21-40 and purple 41+. Higher catches are overlayed on lesser catches.

Table 2 – Primary models for Fiji, RMI, and Hawaii based fisheries.

Model Fleet/Area	Species	Final Model
Fiji tuna fishery	Oceanic Whitetip Shark	zeroinfl(formula = OCS ~ yy + sst + dnsm + hk_bt_flt + ns(lat, df = 2) + ns(lon, df = 2) + SHKLINE3 | sst + hk_bt_flt, data = dat2, offset = log(hook_est), dist = "negbin")
	Silky Shark	zeroinfl(formula = FAL ~ yy + lat + lon + wire_trace2 + SHKLINE3 | lat + lon + wire_trace2 + SHKLINE3, data = dat2, offset = log(hook_est), dist = "negbin")
RMI based Chinese/FSM tuna fishery	Oceanic Whitetip Shark	zeroinfl(formula = OCS ~ yy + sst + hk_bt_flt + settimed + lat + lon + wire_trace2 + SHKLINE3 | hk_bt_flt + SHKLINE3, data = dat2, offset = log(hook_est), dist = "negbin")
	Silky Shark	zeroinfl(formula = FAL ~ yy + sst + hk_bt_flt + lat + lon + SHKLINE3 | hk_bt_flt + lat + SHKLINE3, data = dat, offset = log(hook_est), dist = "negbin")
Hawaii deepset tuna fishery	Oceanic Whitetip Shark	zeroinfl(formula = OCS ~ yy + sst + hk_bt_flt + ns(lat, df = 2) + lon + hookwire2 | lat + lon, data = dat5, offset = log(hook_est), dist = "negbin")
	Silky Shark	zeroinfl(formula = FAL ~ yy + sst + hk_bt_flt + ns(lat, df = 2) + ns(lon, df = 2) + hookwire2 | lat + lon, data = dat5, offset = log(hook_est), dist = "negbin")

Table 3 – Secondary models for Fiji and RMI based fisheries.

Model Fleet/Area	Species	Final Model
Fiji tuna fishery	Oceanic Whitetip Shark	zeroinfl(formula = OCS ~ yy + sst + dnsm + hk_bt_flt + ns(lat, df = 2) + ns(lon, df = 2) + shkfacs2 | sst + hk_bt_flt, data = dat3, offset = log(hook_est), dist = "negbin")
	Silky Shark	zeroinfl(formula = FAL ~ lat + lon + dnsm + shkfacs2 | lat + lon + dnsm, data = dat3, offset = log(hook_est), dist = "negbin")
RMI based Chinese/FSM tuna fishery	Oceanic Whitetip Shark	zeroinfl(formula = OCS ~ yy + sst + hk_bt_flt + settimed + lat + lon + shkfacs2 | hk_bt_flt, data = dat3, offset = log(hook_est), dist = "negbin")
	Silky Shark	zeroinfl(formula = FAL ~ yy + sst + hk_bt_flt + lat + lon + shkfacs2 | hk_bt_flt + lat, data = dat3, offset = log(hook_est), dist = "negbin")

For brevity, Table 4 provides a summary of the ***main*** model coefficients and significance (p values) for the key factors (leader, hook, shark line and bait) only.

Leader effects

The potential influence leader type (wire or monofilament/other) was assessed in the Fiji and RMI/FSM fishery models. Only one model, silky shark in Fiji fishery, was found to estimate a significant effect in both the count and zero inflation components of the model, with both the occurrence of at least one shark and the number of sharks caught (when at least one is caught) estimated to be significantly higher when wire trace is used in that fishery (Table 4 and Appendix 3).

Table 4 – Key statistics describing estimated effects of wire trace, shark lines, hook type and shark bait generated from ZINB models for both oceanic whitetip and silky sharks caught in either the Hawaii deepset tuna fishery, the Fiji or RMI based tuna fisheries. Only includes estimates for model terms where p<0.05 (for the whole term or at least one factor level). Hook-Leader term levels comprise combinations of hook type (circle=C, circle offset=CO, tuna=T, tuna offset=TO, J hook=JH, J hook offset=JHO) and wire(W) or no wire.

Model Fleet/Area	Species	Model component	Model term	Coefficent	SE	Pr(>|z|)	Delta AIC (df)
Fiji tuna fishery	Oceanic whitetip shark	Count model	Shark line (YES)	1.015	0.11	<< 0.000000	79.31
	Silky shark	Count model	Wire trace (YES)	0.692	0.148	<< 0.000000	22.996
			Shark line (YES)	0.911	0.144	<< 0.000000	23.541
		Presence/Absence model	Wire trace (YES)	2.92	1.052	0.00548	15.208
			Shark line (YES)	-4.389	1.127	< 0.000098	16.809
RMI based Chinese/FSM tuna fishery	Oceanic whitetip shark	Count model	Wire trace (YES)	-0.926	0.458	0.0435	1.919
			Shark line (YES)	0.959	0.2162	<< 0.000000	21.321
		Presence/Absence model	Shark line (YES)	-1.641	0.573	0.00418	0.693
	Silky shark	Count model	Shark line (YES)	0.478	0.144	<< 0.000000	35.601
		Presence/Absence model	Shark line (YES)	-1.402	0.778	0.07166	2.34
Hawaii deepset tuna fishery	Oceanic whitetip shark	Count model	Hook_Leader (CO)	0.285	0.398	0.473	14(8)
			Hook_Leader (COW)	0.085	0.378	0.822	
			Hook_Leader (CW)	0.027	0.414	0.946	
			Hook_Leader (JHOW)	0.852	0.575	0.138	
			Hook_Leader (T)	-1.49	0.815	0.067	
			Hook_Leader (TO)	-0.19	0.4	0.626	
			Hook_Leader (TOW)	-0.17	0.371	0.63	
			Hook_Leader (TW)	-0.07	0.387	0.854	
	Silky shark	Count model	Hook_Leader (CO)	1.708	0.769	0.02646	9(8)
			Hook_Leader (COW)	1.018	0.757	0.17883	
			Hook_Leader (CW)	1.2	0.78	0.12364	
			Hook_Leader (JHOW)	1.219	1.097	0.26657	
			Hook_Leader (T)	0.449	0.885	0.61174	
			Hook_Leader (TO)	1.03	0.772	0.18251	
			Hook_Leader (TOW)	0.831	0.75	0.26781	
			Hook_Leader (TW)	1.123	0.762	0.14088	

The model for oceanic whitetip shark in the RMI/FSM based fishery indicated a weakly significant negative relationship between number of sharks caught (count component) and the use of wire trace but this term had very little effect on AIC when dropped from the model (Table 4 & Appendix 4).

Shark line effects

It is assumed that the use of shallow hooks off the mainline floats are specifically targeted at sharks and that assumption is supported by species composition data for catches on these lines (Figure 4). The majority of the shark observed caught by shark lines in the region are silky shark, followed by oceanic whitetip and blue sharks. Very few tuna are caught on these lines.

The potential influence of shark lines upon overall shark catch per fishing operation was assessed in the Fiji and RMI/FSM fishery models. For both species, in both fisheries, use of shark lines were estimated to be significantly related to a higher catch of sharks (when at least one shark is caught). In contrast, in two of the models (silky shark in Fiji, oceanic whitetip in RMI/FSM), the zero inflation component estimated a significant negative relationship between occurrence of silky shark (or oceanic whitetip) in the catch and the use of shark lines. However, these relationships were less significant in general (compared to the count model effects) and had very low delta AIC scores. Shark lines have not been used in the Hawaii fishery and were not assessed.

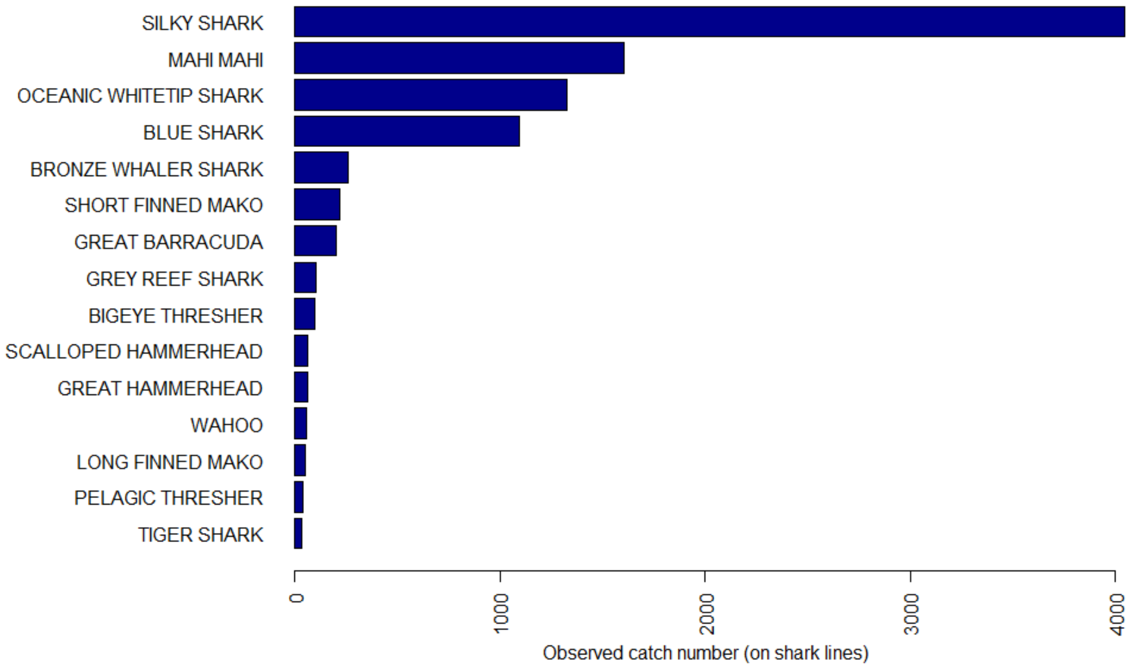


Figure 4. Species composition of observed catch on shark lines in the WCPO, for the top 15 species taken on shark lines (by catch number). Data pertain to 1831 observed sets using shark lines.

To illustrate the influence of leader type (wire versus monofilament/other) and shark line (shark line use = yes, versus shark line use = no) catch rates were predicted for the presence and absence of each factor. This process was bootstrapped (n=100) by running the models with the response variable (catch amount either OCS or FAL) replaced by $\widehat{\Upsilon}$ where $\widehat{\Upsilon} = \vec{\varphi} + \mathrm{f(Resid\_P)} * Var(Resid)$ where $\vec{\varphi}$ is the response vector (OCS or FAL catch) and $\mathrm{f(Resid_P)}$is a random sample of the Pearson residuals from the original model and $Var(Resid)$ is the vector of the approximate variance for the non –parametric residuals from the original models (Zeileis et al 2008, Dudewicz and Mishra 1988). These median estimates (green points) for the components that were statistically significant are plotted in Figure 5 with the and 95% confidence intervals (black lines). These figures show that that for silky sharks the use of shark line and wire trace always had a positive effect (increased the catch), while for oceanic whitetip sharks the median estimates indicated a greater positive effect than silky sharks but also included a wider confidence intervals. The effect of wire trace was significant and positive for silky sharks in the Fiji based fisheries. The use of wire trace had a statistically significant, non-increasing effect on the catch of oceanic whitetip sharks in the RMI based fishery, meaning that while it helped explain the deviance of the model, the use of wire trace alone cannot explain an increase in catch.

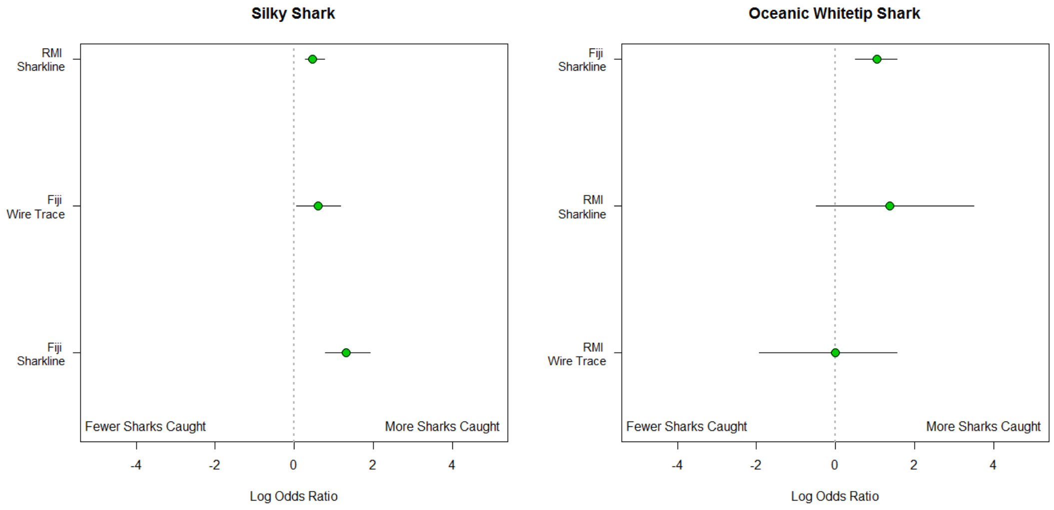


Figure 5: Estimated impacts of wire traces and shark lines on silky shark (left) and oceanic whitetip shark (right) based on data for RMI and Fiji. These median estimates (green points) for the components that were statistically significant with the 95% confidence intervals (black lines)

Shark bait effects

The potential influence of shark bait was assessed in the Fiji and RMI/FSM fishery models. None of the models estimated a significant relationship between use of shark baits and either the presence or number of sharks in the catch.

Alternate models for leader, shark line and bait interactions

An alternate set of models was developed to look at the potential interactive (additive) effect of leader, shark lines and baits on shark catch in the Fiji and RMI fishery models. P values for the ZINB model estimated effect of different combinations of these factors are presented in Table 5. In all models, “shkfacs” was only kept in the presence/absence (count) component of the model after model selection by AIC.

The results from the RMI alternate models confirm the effect of shark lines apparent from the main models (Table 5, Figure 6), and indicate that sets that didn’t use wire trace may have slightly higher catch rate for oceanic whitetip, although this result was only weakly significant.

The Fiji models indicate no difference in catch rate (for either species) for sets using none of the three factors (bait, line, wire) and sets using wire trace only (Table 5, Figure 6). Nearly all categories that use at least shark lines are estimated to have significantly higher catch rates than either sets using none of the factors, or sets using only wire trace. For both oceanic whitetip and silky shark, the category estimated to have the highest catch rate is sets using all three factors.

Combined leader and hook type interactions

The potential influence of different combinations of leader type (wire or monofilament/other) and hook type (circle, circle offset, tuna, tuna offset, J hook, J hook offset) was assessed in the Hawaii deep set tuna fishery. Initial data exploration identified substantial changes in patterns of hook and leader use over time in the fishery (Table A2-1 in Appendix 2), and exploratory GAM analyses suggested that hook/leader type and year terms were confounded (Figure A2-2). VIF analyses suggested the potential for confounding between year and hook/leader terms was minimised during the period 2005-2009, providing a block of data more appropriate for assessing hook/leader effects. However, despite this, the final primary models for both oceanic whitetip and silky shark were on the whole unable to substantially differentiate between effects of each leader-hook category and including this term in the models did not substantially reduce the model AIC per degree of freedom. The models did identify other factors related to oceanic whitetip and silky shark catch (discussed later). However it should be noted that despite using models designed to account for zero inflated data, model diagnostics indicated a poor fit to the data.

It should be noted that exploratory GAM analyses described earlier also raised the question as to whether the substantial decline in GAM predicted catch of oceanic whitetip since the mid-1990s represented a decline in availability (abundance) to the fishery or resulted from temporal trends in the use of different hook and leader types. This led to the running of a secondary ZINB model using only tuna hook and wire leader sets to test if the temporal trend remained when variability in hook/leader types over time was removed. The declining trend was still apparent (Appendix 2, Table A2-4 and Figure A2-7), however, further analyses would be required to confirm this was related only to local abundance.

Other effects

A number of other explanatory variables included in the models were found to be significantly related to both the occurrence of shark in the catch and the number of shark caught when at least one was caught. Full statistical summaries for all model term effects are presented in the appendix for each fishery. In general, the most important factors both in terms of statistical significance and explanatory power were latitude, sea surface temperature, longitude, and hooks per float, often in that order. Latitude and SST were typically somewhat collinear in the models, but where AIC and models indicated significant effects, both were left in the models.

In general, in each fishery and for both species, catches were estimated to be higher in latitudes close to the equator, and typically higher in western areas of each fishery than the eastern area. In the Hawaii deepset fishery, catch was predicted to increase with increasing water temperatures (23c >> 30˚C). The opposite was predicted for the Fijian fishery for oceanic whitetip shark while in RMI where water temperatures are more stable between 27-30˚C, the SST effect was lower and, within that range, predicted to have lower catch at the highest temperatures.

Table 5 – ZINB GLM generated values of Pr(>|z|) to indicate the significance (or otherwise) of differences in estimated coefficients for each level of the model factor "shkfacs" which indicates for each set whether wire trace was used (W) or not (N), then whether shark line was used (L) or not (N), then whether shark bait was used in any part of the set (B) or not (N). Hence each level is a combination of the presence or absence of the three separate factors. Green indicates highly significant differences, and yellow moderately significant differences

		WNN	NNN	WLB	WLN
Oceanic Whitetip in the RMI/FSM fishery	WNN				
	NNN	0.02432			
	WLB	0.00107	0.8607		
	WLN	0.00000	0.4443	0.1264	

		WNN	NNN	WLB	WLN
Silky shark in the RMI/FSM fishery	WNN				
	NNN	0.179213			
	WLB	0.001597	0.731076		
	WLN	0.00000	0.92423	0.607911	

		NNN	NLB	NLN	WLB	WLN	WNN
Oceanic Whitetip in the Fiji fishery	NNN						
	NLB	0.080596					
	NLN	0.00000	0.805125				
	WLB	0.00000	0.436928	0.254677			
	WLN	0.00000	0.562492	0.330997	0.597672		
	WNN	0.745603	0.112505	0.00000	0.00000	0.00000	

		NNN	NLB	NLN	WLB	WLN	WNN
Silky in the Fiji fishery	NNN						
	NLB	0.00262					
	NLN	0.00000	0.93768				
	WLB	0.00000	0.11909	0.0198			
	WLN	0.00000	0.35273	0.0666	0.2228		
	WNN	0.26317	0.01465	0.00000	0.00000	0.00000	

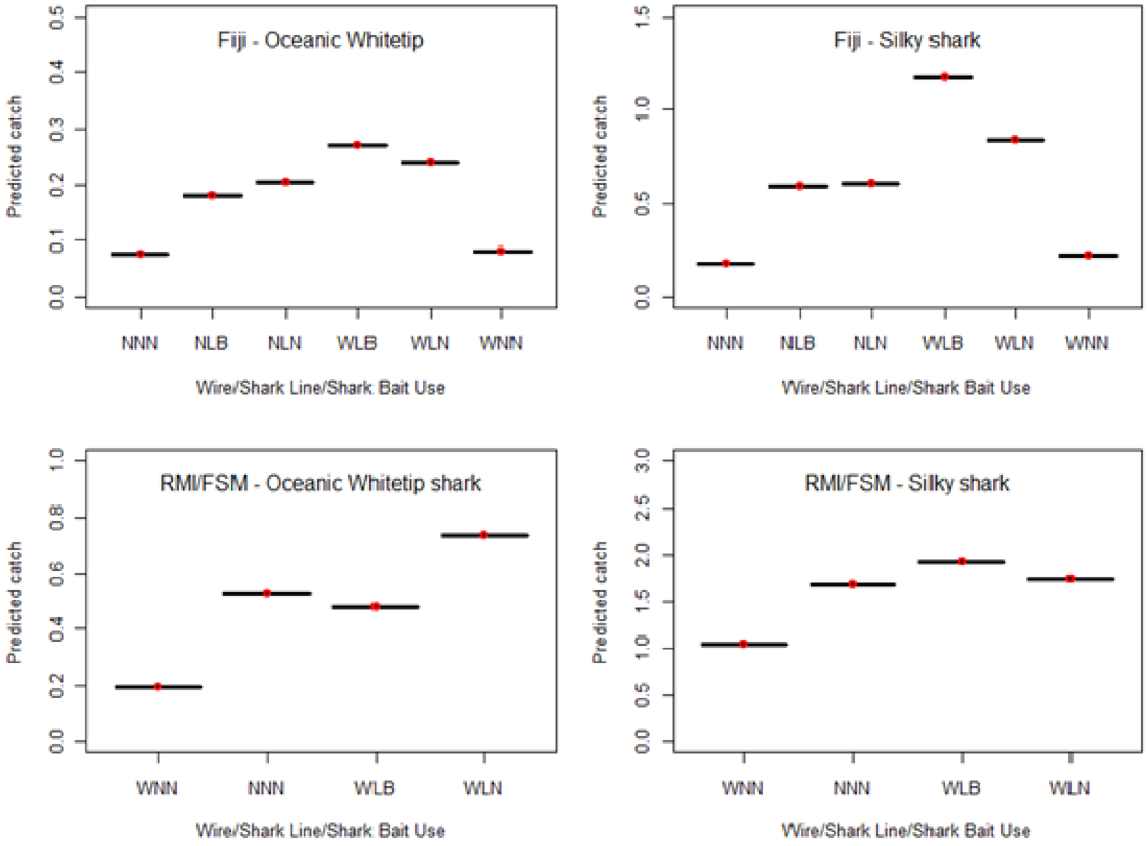


Figure 6. Predicted catch per average set for each level of the combined leader/line/bait factor for silky and oceanic whitetip shark in RMI/FSM and Fiji fisheries. See Table 6 for explanation of codes.

Table 6 – Number of sets by "shkfacs" factor level, in both the RMI/FSM fishery and the FIJI fishery. Factor levels with less than 15 sets were excluded from data sets prior to modelling. Three letter codes indicate for each set whether wire trace was used (W) or not (N), then whether shark line was used (L) or not (N), then whether shark bait was used in any part of the set (B) or not (N). Hence each level is a combination of the presence or absence of the three separate factors.

	RMI/FSM	**FIJI**
NLB		39
NLN		327
NNB		5
NNN	16	516
WLB	44	57
WLN	333	273
WNB	5	7
WNN	997	359

In all three fisheries catch of oceanic whitetip shark was significantly related to hooks per basket (which is used as a proxy of the depth of fishing) with higher predicted catches on sets with fewer hooks per basket (shallower set hooks). This relationship was also apparent for silky shark in the RMI fishery but not in the other fisheries.

Year terms were included in the models and may potentially provide an indication of changes in local abundance within the fishery over the model periods. In general, there were no consistent temporal trends (increasing or declining catch) in any of the fisheries models except for oceanic whitetip in the Fiji Fishery which had a declining trend. The main Hawaii model did not indicate a strong decline in OCS over the period 2005-2009, however, an alternate model (See Appendix 2, Figure A2-10) which used only sets using tuna hooks with wire (to remove year-hook-wire collinearity issues) over the period 1997 to 2007, indicated an overall declining trend in OCS catch (similar to the trend predicted by GAMs on the full dataset – See Appendix 2). None of the models predicted a trend over time for silky shark, however the time periods examined were typically short (4-5 years).

Model diagnostics

Despite using specialised models for analysing zero inflated data, model diagnostics for all models indicate some significant positive bias in the distribution of residuals, suggesting the count data modelling needs to be improved. ZIP and standard negative binomial GLMs were also tested however the ZINB models provided the best fit. Improved model fits might be gained in future by utilising models that account for random effects (GLMM), for example that might be associated with sets fished within the same trip. This approach was found to provide significant improvement to model fits by Curran and Bigelow (2012). Plots of model fits are provided in each of the fishery specific appendices.

4. Discussion

The analyses in this paper aimed to determine if area and fleet specific observer data sets might provide an indication of the potential effects of wire trace, hook types, shark lines and baits upon catch of silky and oceanic whitetip shark. Of these factors, a significant relationship between shark line use and increased catch of both species was identified in both the RMI/FSM and Fiji based tuna fisheries (shark lines are not used in the Hawaii tuna fishery). Wire trace was also estimated to have a positive relationship with silky shark catches in the Fiji fishery, but not in the Hawaii or RMI fisheries. Shark bait was not, on its own, estimated to be related to shark catches (although it is uncertain to what degree it may be confounded in models with shark line use – this should be looked at further). Hook type (interacting with leader type) was assessed in the Hawaii fishery but no substantial difference in effects on catch of either shark species was estimated. However model diagnostics were particularly poor for this fishery (perhaps due to additional zero inflation, unaccounted for influential factors or interactions between factors) and further work on the models may be required. A key additional uncertainty was the potential inclusion of sets with mixed hooks in the Hawaii dataset but no means to identify these, with only the predominant hook type stated.

The approach used in the current analyses aimed to isolate data that had less complexity to model, more consistency in fishing strategies but also more temporal contrast in the key factors of interest. However it is important to consider these results in the context of:

- Uncertainty associated with using observer data that has low coverage (the exception being the Hawaii with substantial coverage (>20%)). In most Pacific longline fisheries it is highly uncertain as to how representative the observer data is of the fishery as a whole.
- Trade-offs associated with modeling smaller subsets of the overall database. On the one hand there is potential loss of statistical power associated with modeling smaller sample

sizes. However on the other hand, the data are intended to be “better” (less complex and potentially confounded).

That said, even within areas/fisheries there is significant complexity over time and space, the effects of which can be difficult to capture in a model (for example the Hawaii deep set fishery has experienced very large shifts in use of different hook types over time).

While the effect of shark lines, particularly in deep setting fisheries (which otherwise might not frequently capture surface layer sharks like silky and oceanic whitetip), may be relatively easy for models to differentiate, the effects of leader and hook type may be smaller/more subtle on a per set basis and are more likely to be “hidden” amongst the complex effects of many other factors (because hook and leader type doesn’t in theory alter the encounter rate, just the capture likelihood once encountered). However the effects of hook and leader type, through their apparently greater prevalence of use throughout the fishery, may be of significantly greater importance to the overall fishing mortality of the sharks. That said, prevalence of shark line use is also somewhat uncertain.

The substantial difficulties of modeling observer reported catch data to ascertain effects of different gears/fishing methods highlights the fact that the most appropriate means by which to estimate effects of different fishing method factors upon shark catches will be via designed experimental fishing trials which can minimize the confounding influences of other factors upon those of primary interest.

Such trials have already been carried out by various agencies in the past and have made important contributions to our understanding of the effects of key factors such as hook type and leader. But such studies have demonstrated that effects are not simple and factors such as hook type, leader, bait and hook size can have the potential to interact in a potentially complex manner (Afonso et al. 2012) while hook size and level of offset may also be important factors. Teasing apart such relationships will be very difficult using normal observer data in which catchability is influenced by many other additional factors (e.g. environmental).

For example, the experimental fishing trial by Afonso et al. (2012) indicated that hook type and leader type may interact to impact shark mortality. They noted from their experimental field study of two hook types (J and circle) and two leader types (wire and nylon) that while there was no effect of hook type, there was an effect of leader type (wire leaders caught more blue shark) but only within the J hook group. Furthermore, this difference disappeared if all bite offs were assumed to be shark. It is now well recognized that circle hooks reduce gut hooking (increase mouth/jaw hooking) when compared to J hooks (e.g., Epperly et al. 2012, Afonso et al. 2011), but the implications for shark mortality are less clear. Gut hooking may give sharks greater access to the leader and to bite off if its nylon. But subsequent mortality may be high due to internal injury. But if the leader is wire, bite off is less likely, and one might expect CPUE at the boat to be similar between different hook types. Jaw hooking by circle hooks may increase CPUE at the boat if the leader is nylon (compared to J hooks with nylon leaders). It is critical also that post capture condition and survival is also taken into account when considering mitigation options.

It should be noted however that results between experimental trials have varied and this is likely due to a number of factors, including small sample sizes in many studies, variable experimental designs (e.g. using different hook sizes, offsets etc.) and species specific effects. With respect to hook type effects, the most relevant study to date due to its size (2.7 million hooks), design (alternating hooks), and situation in a WCPO fishery (Hawaii) that operates in a similar manner (deep daytime sets for bigeye tuna) to many regional distant water fleets, is that of Curran and Bigelow (2011). The study found reduced catch rates of shark (mainly blue shark) on ***large*** circle hooks (compared to J hooks and tuna hooks), while there was little impact on bigeye tuna catch rates, a finding similar to Korean (Kim et al. 2008), Japanese (Yokota et al. 2006), and Australian studies (Ward et al. 2008). However, it should be noted that the study of Curran and Bigelow (2011) did not assess silky shark and oceanic whitetip shark due to the very low catch rates (a factor which also hindered the current analysis of observer data from the same fishery). It should also be noted that some trials have found increased catch rates of shark on circle hooks (e.g., Ward et al. 2008; Marcias et al. 2012; Afonso et al. 2012; Afonso et al. 2011; Domingo et al. 2012) or no effect (Coechlo et al. 2012), but may not be directly comparable due to differences in hook size, sample sizes and other factors.

The potential importance of hook type effects on shark catch rates, as deduced from experimental fishing trials, also emphasizes further uncertainty in the current observer data based analyses, noting that for the Fiji and FSM/RMI analyses, hook type was not considered, due to such data only being collected from 2008 by observers. Hence any unreported temporal trends in hook type use within these fisheries could influence the modeled results if hook type was confounded with shark line, bait or leader type use over time.

A number of studies have also looked at the effects of wire trace (without hook type), with many finding higher shark CPUEs on wire (versus nylon) leaders (e.g. Ward et al. 2007) but some studies suggesting that such effects are species specific (Ingram et al.2012). The latter study indicated that catch rates were higher on wire leaders for oceanic whitetip shark, and lower for silky shark, results that contradict those of the current observer data based study.

Other factors not considered in this study may also offer potential for mitigation options. Tuna and swordfish bait type (e.g. mackerel, squid etc) has been noted to impact on catch rates of some shark species (Coehlo et al. 2012). In addition, a recent study investigated the potential for the use of “weak” hooks (i.e. hooks that bend and release animals when they are large, like some sharks) (Bigelow et al., 2012) as a mitigation measure.

The current analysis provides sufficiently consistent evidence across fisheries that shark lines can significantly increase silky and oceanic whitetip shark catches by vessels targeting predominantly tuna. The prevalence of shark line use throughout the WCPO is somewhat uncertain, but a ban on the use of this gear/method would undoubtedly contribute to a reduction in silky and oceanic whitetip shark catches in fisheries currently using that method.

The effects of hook type and wire leaders (and their interaction) are perhaps less clear from the current analyses however past research via experimental trials is outlined above. SPC recommends that if the Scientific Committee is of the opinion that information from existing trials (and observer data analyses) is insufficient to parameterize the effects of wire trace and hook types and other fishing method factors (and their interactions e.g. hook type and leader interactions) in shark mortality prediction models, then it should recommend the Commission invest resources into ensuring that such designed experimental trials are undertaken. Such trials are far more likely (if properly designed with large sample sizes and conducted in areas with high abundance of the species of interest) to provide appropriate information on such effects than will analyses of observer data with low coverage and substantial heterogeneity and confounding in key factors across time, areas and fisheries.

It should be noted that SPC has been endeavouring to collect information on prevalence of wire trace usage from industry and has started preliminary analyses on the effects of fishing method and environmental factors upon shark condition and mortality, both of which will contribute to future mortality models to assess mitigation options.

Acknowledgements

The Pacific Islands Regional Observer Programme for provision of the Hawaii deepset observer data and Bill Walsh (JIMAR) and Keith Bigelow (NOAA PIFSC) for advice regarding its use and interpretation, as well as advice on statistical analyses used.

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Appendix 1 – Identification of appropriate data subsets for modelling

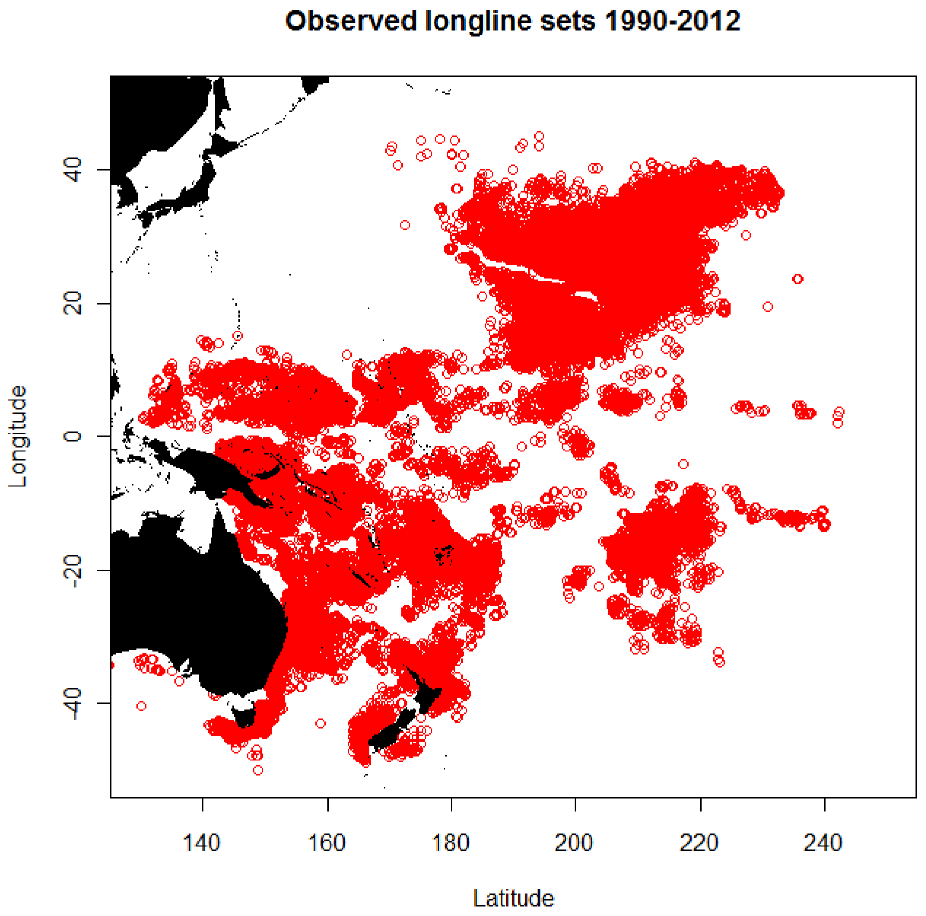


Figure A1.1 – Observed sets since 1990

Table A1.1 – Observed sets by flag and year (grey highlights successive years with > 50 observed sets

Flag	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
AS									2				81										
AU			8									58	422	460	501	614	515	395	431	216	108		
CK						6	6						3	2				12	31	54	7	24	
CN				18	28	105	82	107	88	82	73	118	6	35	206	200	542	566	117	75			
FJ					4	32	12	23		54			40	182	150	419	398	301	314	207	153		
FM					5	3	12	21	28	19	47	27	33	16	67	61	131	62	37				
GU						22	13	7	9														
JP	346	917	1004	1458	910	667	471	714	418	432	301	232	305	324	33	371	217	275	83	244	144	151	
KI																			17		14		
KR		7	8	5					54	55			163			101	216	105					
MH																			22	8			
NC			4				56		27	23		18	56	81	84	35	46	58	84	210	227	170	9
NZ			16		13	80	144	154	142	52	41	304	126	317	549	149	107	182	161	174	175	171	
PF				2				66					66	181	178	141	298	136	190	453	447	320	84
PG							10			46	74	211	212	115	228	338	263	101	164				
PH														37									
PW								13			12												
SB							7	21	41	52	52	60	372	255	159								
TO						17	3		73	18	23				82	11	143	56	107	33	2		
TW				34	92	62	56	117	245	140	117	99	233	107	168		30	58	134	98	58	47	
US					507	549	641	499	591	460	1420	2792	3490	3175	4079	5002	4181	5108	5497	5269	5240	5019	
VU																				50	119	187	4
WS									7	2	6	14					7		1	9	3		

Appendix 2 – Hawaii Deepset Tuna Fishery Models

Hawaii Deepset Tuna Fishery Models

Background

The Hawaii longline fishery can be divided into two parts according to targeting: a deepsetting (>=15 hooks per basket) bigeye tuna targeted fishery and a shallow setting (<15 hooks per basket) swordfish targeting fishery. Observers have collected data from both fisheries under the Pacific Islands Regional Observer Program since 1994, however to different degrees, with 20-26% observer coverage on the deepset fishery since 2004 (Bigelow et al 2012) and almost 100% coverage of the shallow set fishery in the same period. PIROP data represents nearly 60% of total longline observer data in the WCPO. In addition, various regulations have been introduced to the fisheries over time (Walsh et al 2009) which are relevant to the current analyses, including:

- Closure of the shallow set swordfish fishery from 2001-2004, causing a shift to deep set tuna targeting into more southerly areas
- The re-opening of the swordfish fishery was accompanied by 100% observer coverage, use of circle hooks and blue dyed thawed fish baits
- Finning of sharks was banned in most circumstances if carcass not retained, from 2001 (Walsh et al 2009)
- Stricter regulations (in shallow set fishery) in 2004 mandated switch from J to 18/0 circle hooks, and from squid bait to whole fish bait (Bigelow et al 2012). Resulted in 29% reduction in BSH CPUE (Walsh et al. 2009) and increased SWO catches (16%).

Bigelow et al 2012 note that there has been a voluntary progression from using tuna hooks tocircle hooks in the Hawaii-based deep-set fishery. Tuna hooks typically are stronger than circle hooks. The paper states "*The use of tuna hooks in the deep-set tuna longline fishery declined precipitously from 87% in 2004 to 25% in 2010, while circle hooks ranging in size from 14/0 to 16/0 increased from 5% to 43%. The proliferation of the pure circle and mixed hook categories in 2006 suggests that tuna hooks may be entirely replaced in some vessels, while other vessels incrementally replace tuna hooks with circle hooks when gear is lost. The use of 18/0 circle or J-hooks appears to be minimal (0%–6%) in the deep-set fishery*".

Curran and Bigelow (2011) compared CPUE for 16 species for circle hooks v J hooks and circle hooks versus tuna hooks for observed sets using alternating hook types along the length of the gear. Their study did not include silky or oceanic whitetip shark, because these were caught in low numbers, but did find that use of circle hooks did not significantly decrease catch rates of the target species bigeye tuna. Reduced catch rates for many of the bycatch species including shark (blue shark) were found on circle hooks compared to tuna hooks and often also J hooks, and results from the study are considered relevant to other deep setting tuna fisheries in the region that target bigeye tuna. The study represented a proper designed investigation of the effects of hook type which minimises the need to account numerous explanatory variables and simplifies the statistical analyses and interpretation. Unfortunately, this is not the case for using observer data from the deepset tuna longline fleet.

Walsh and colleagues (2009) study of observer data from the Hawaii longline fishery noted that shark catch rates were an order of magnitude higher in the shallow set fishery than in the deep set fishery.

- Finning ban in 2000/01 will have large effect on likely subsequent mortality
- Noted blue shark CPUE decreases may be due to bait switch to Mackerel but also mako CPUE increases might be due to bait preference. Baits may have strong species specific effect on shark bycatch rates

- Note that finning prohibitions are key to reducing shark bycatch

The mean nominal CPUE values for oceanic whitetip sharks and silky sharks were negatively biased, probably to a considerable degree, because these species are not distributed throughout the area exploited by this fishery.

Walsh et al (2009) noted that "nominal CPUE values for five species exhibited significant decreases between 1995–2000 and 2004– 2006. Interpretation of the shallow-set results from the 2004–2006 period is complicated by the fact that the changes in hook and bait types were confounded. The months with the greatest activity and the geographic distribution of sets also differed between time periods. The distributional changes in particular would have introduced sampling variation. Nonetheless, it appears that the switch to mackerel-like fish as bait probably contributed to the reduced blue shark catch rates in this sector". These are key points to be kept in mind when interpreting analyses of the shallow set fishery data, such that these data are probably not be suitable for the current analyses.

Data exploration

The Hawaii longline data set was identified as having the potential to assess hook type and leader type effects upon silky and oceanic whitetip shark catches, due to a long history of recording these factors by observers, and the use of different hook types and leader type throughout the period examined (1994-2011).

Initial data explorations assessed potential for outliers in both response and explanatory variables. The data set was trimmed to reduce extreme variations in other explanatory variables that are not of interest (i.e. sets with outlying or extreme values of set time, hooks per basket, latitude, longitude were removed) but important to account for in the model. In addition, the sets with SST of less than 23C were also removed to reduce the incidence of "false zeros" which can occur as a result of including fishing operations that occur outside species range/habitat. Restricting the data set to latitudes south of 25N also assisted in reducing false zeros, after examination of catch maps.

Collinearity between explanatory variables was also assessed using scatterplotsas well as Variance Inflation Analyses using the *corvif* and *myvif* functions sourced from (http://www.highstat.com/BGS/GAM/HighstatLibV4.R) for use in the in R 2.12.1 (noting that *vif* function is not supported by the pscl package). These indicated significant collinearity between SST, latitude and mm, as well as hook type and year terms when all years were included.

Spatial and temporal variation in the use of different hook types and leader types was examined (Table A2-1). This revealed that proportional hook and leader usage through the fleet had changed substantially over time and also spatially (through time), highlighting likely confounding between temporal and hook x leader factors in analyses. This was confirmed by early GAM based exploratory models (Figure A2-2) which showed that significant hook and leader type effects in models without year terms, were no longer significant when year terms were added in.

Subsequently it was concluded that two main models would be tested (using function zeroinfl from pscl package in R), being:

a. Abundance trend model – this model utilised only data from sets using a single hook type (tuna hook) and leader type (wire trace) combination, for which data existed for a large component of the time series, to examine if the declining catch over time trend (for oceanic whitetip) was apparent outside of the influence of changes in hook and leader types over time.

b. Hook and leader type effect model – This model utilised only data from the period 2005 to 2009 during which there was simultaneous and significant use of many of the different hook and leader types used in the fishery. It was hoped that this contrast in the hook and leader data would allow the model to separate hook, leader and year (abundance) effects. A single explanatory variable was constructed by combining for each set, the hook type and leader type, into a single factor. The intention would be that this factor would allow the assessment of their interaction as well as individual effects

Final Model Results

The function zeroinfl from package pscl was used in R 2.12.1 to run the two models above for both oceanic whitetip and silky shark. For each "main" model and species, 4 test models were run to test firstly, use of linear versus non-linear predictors (which were suggested by some of the exploratory GAM based models), and secondly, the use of poisson versus negative binomial distributions, with Final model selected usedAIC based backwards stepwise process.

Abundance trend model result: There is a clear significant declining trend in catch by year for oceanic whitetip shark for the model based only on sets using tuna hooks and wire trace, which is the predominant gear used in the deepset fishery. The model was not closely examined for spatial shifts over time in fleet operation area etc or other factors that could cause such trends and this should perhaps be assessed further.

Hook and leader effect model:

The potential influence of different combinations of leader type (wire or monofilament/other) and hook type (circle, circle offset, tuna, tuna offset, J hook, J hook offset) was assessed in the Hawaii deep set tuna fishery. Initial data exploration identified substantial changes in patterns of hook and leader use over time in the fishery (Table A2-1), and exploratory GAM analyses suggested that hook/leader type and year terms were confounded (Figure A2-2). VIF analyses suggested the potential for confounding between year and hook/leader terms was minimised during the period 2005-2009, providing a block of data more appropriate for assessing hook/leader effects. However, despite this, the final primary models for both oceanic whitetip and silky shark were on the whole unable to substantially differentiate between effects of each leader-hook category and including this term in the models did not substantially reduce the model AIC per degree of freedom. The models did identify other factors related to oceanic whitetip and silky shark catch (discussed later). However it should be noted that despite using models designed to account for zero inflated data, model diagnostic indicate a poor fit to the data.

Final comments

- There is some uncertainty about the data supplied to SPC, which appeared to indicate entirely "pure" hook sets, when there is likely to have been some sets with mixed hooks. The impacts of this upon the analyses are still to be ascertained. Confirmation has been sought from NOAA.

- Despite measures taken to exclude “false” zeros, the fishery is still on the outer area of these species natural range and further more, catches of these two surface layer species are depressed due to the deep set nature of the hooks. Model predictions and interpretation becomes increasingly difficult with increasing zero inflation. The low encounter/catch level of these species in this fishery combined with the numerous potential explanatory factors mean that separating fishing method effects is more difficult. Latitude and SST effects dominate all the models examined highlighting in particular the higher catches taken in the Palmyra area closer to the equator.
- The spatial and temporal variation in hook and leader type use highlight the need for properly designed experimental studies to examine such effects, for example such as those outlined by Curran and Bigelow (2011) and Bigelow et al (2012) which used alternating hook types on same sets to help simplify the statistical analyses (remove need to worry about other confounding factor effects such as environmental effects).

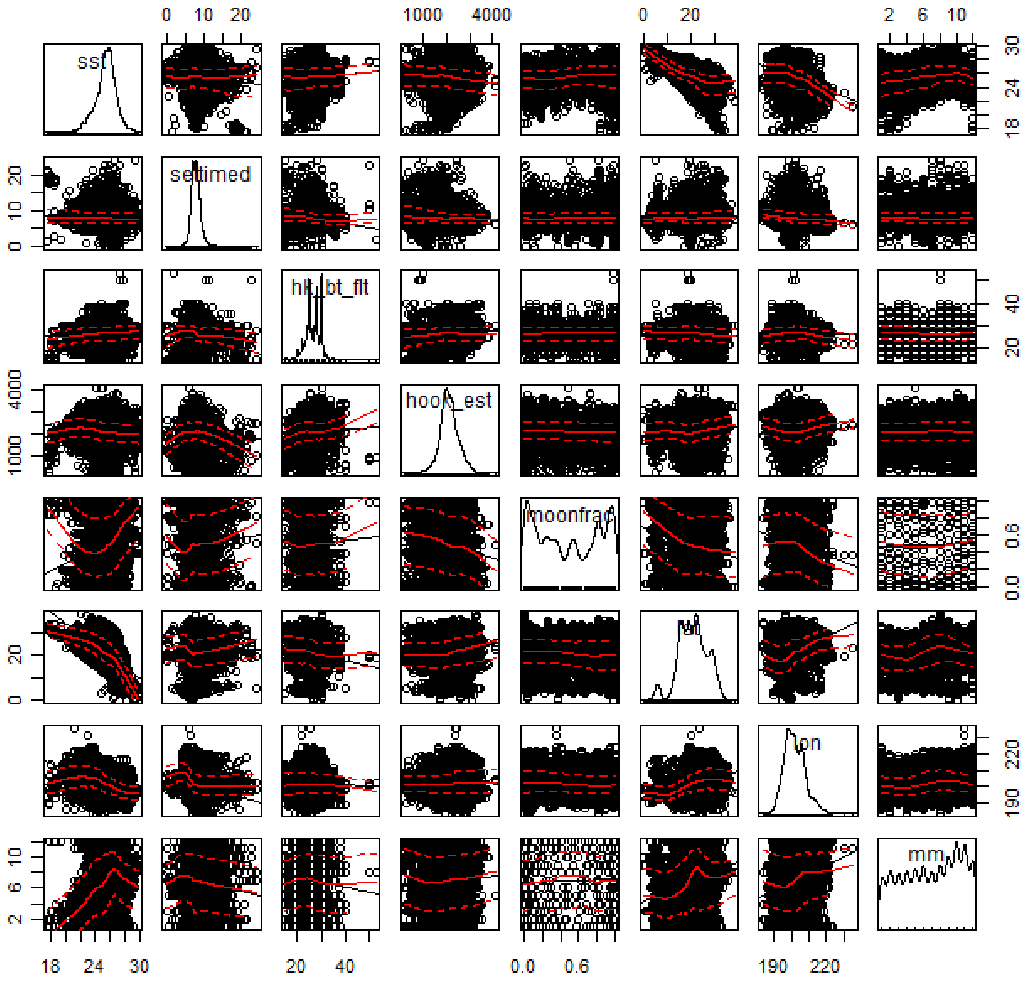
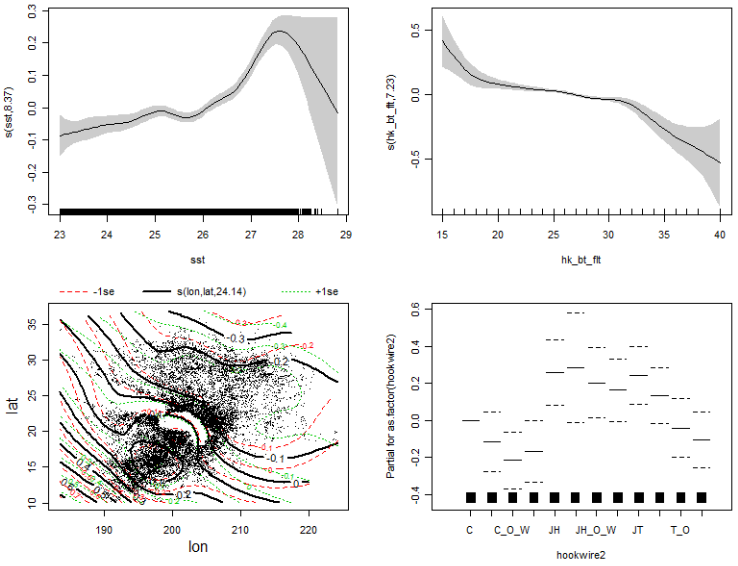


Figure A2-1: Scatterplots for key explanatory variables (to assess potential collinearity).

Table A2-1: Number of observed sets by hook and leader type category (combined) and year in the Hawaii based deep set longline fishery, where: C=Circle hook; JH = J Hook; T = Tuna hook; O = Offset; W = Wire leader used. Where "W" is not included it is assumed a monofilament leader or non wire leader was used. Where "O" is not indicated, the hook is assumed to not be offset.

	C	C_O	C_O_W	C_W	JH	JH_O	JH_O_W	JH_W	T	T_O	T_O_W	T_W
1995	0	0	0	0	12	13	0	0	135	11	0	76
1996	0	0	0	0	32	0	10	0	109	0	0	124
1997	0	0	0	0	0	0	15	0	41	0	0	122
1998	0	0	0	0	0	0	0	0	22	0	0	252
1999	0	0	0	0	0	0	18	15	10	0	0	203
2000	0	0	0	0	9	0	0	1	54	0	0	900
2001	0	0	0	0	172	0	10	27	270	0	11	2067
2002	0	0	0	0	57	4	25	89	190	0	0	2909
2003	0	0	0	0	56	16	13	91	398	0	15	2456
2004	31	0	0	0	11	0	0	136	260	191	1171	1854
2005	50	104	37	39	0	0	40	18	32	248	2296	342
2006	12	156	400	95	0	0	15	0	0	177	2132	191
2007	12	112	856	161	0	0	0	0	45	99	1728	408
2008	0	125	1483	60	0	0	11	13	0	149	1671	42
2009	0	119	1416	42	0	0	14	17	0	43	1223	39
2010	0	70	1686	24	0	0	0	0	0	33	894	7
2011	0	99	2419	15	0	0	0	20	0	0	688	15

GAM model without year term: Significant Hook x Leader effects



GAM model with year term: Hook x Leader effects no longer significant

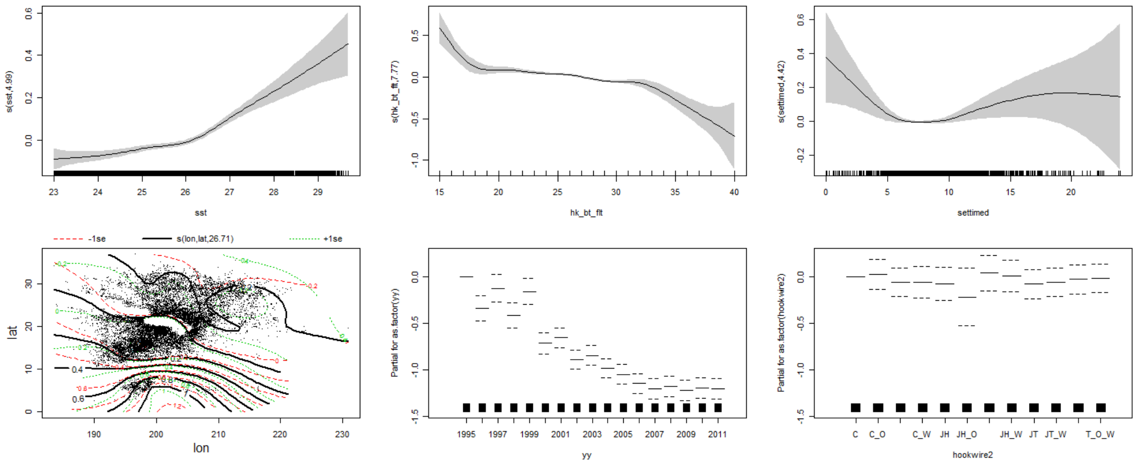
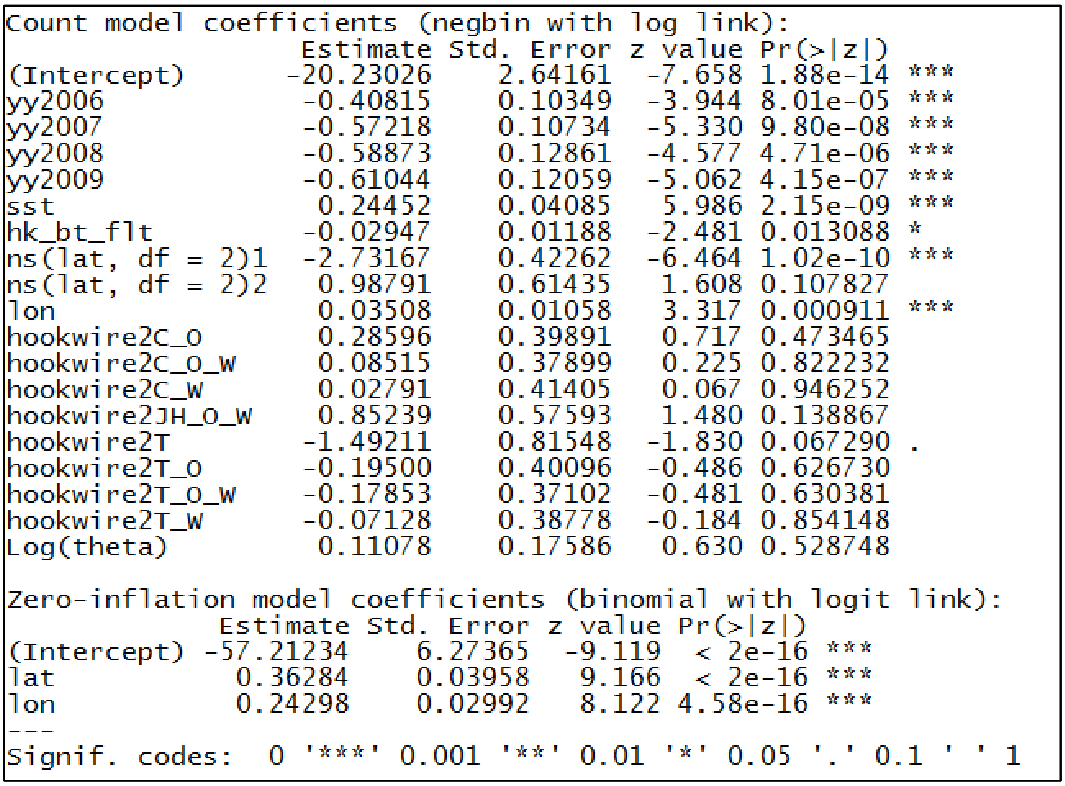


Figure A2-2: Plots of relative effects of explanatory variables upon catches of oceanic whitetip shark in the Hawaii Deepset Fishery, for two example models, one without a year term included in the model (top panel) and one where the year term is included. This demonstrates the confounding between year and hook x leader factors.

*Comment: A range of full (OCS+0.1/hooks*1000) and delta method (separate "presence absence" binomial and count data Poisson models) GAMs were used to explore the OCS and FAL catch relationships. Only a few are presented here to illustrate key points. Overwhelmingly, for models including year terms, regardless of what period they were isolated to, hook and leader effects were not strongly apparent and generally swamped by latitude and SST effects. The latitude effects are dramatically reduced when the Palmyra zone catches are excluded from the analyses (reflecting the fact that that area takes much higher catches per unit effort than areas to the north due to Palmyra being closer to the main habitat area of the two species.)*

Oceanic white tip shark: Primary model

Table A2-2: ZINB model based estimates of model term coefficients, standard errors and significance.



```
Count model coefficients (negbin with log link):
                   Estimate Std. Error z value Pr(>|z|)    
(Intercept)       -20.23026    2.64161  -7.658 1.88e-14 ***
yy2006             -0.40815    0.10349  -3.944 8.01e-05 ***
yy2007             -0.57218    0.10734  -5.330 9.80e-08 ***
yy2008             -0.58873    0.12861  -4.577 4.71e-06 ***
yy2009             -0.61044    0.12059  -5.062 4.15e-07 ***
sst                 0.24452    0.04085   5.986 2.15e-09 ***
hk_bt_flt          -0.02947    0.01188  -2.481 0.013088 *  
ns(lat, df = 2)1   -2.73167    0.42262  -6.464 1.02e-10 ***
ns(lat, df = 2)2    0.98791    0.61435   1.608 0.107827    
lon                 0.03508    0.01058   3.317 0.000911 ***
hookwire2C_O        0.28596    0.39891   0.717 0.473465    
hookwire2C_O_W      0.08515    0.37899   0.225 0.822232    
hookwire2C_W        0.02791    0.41405   0.067 0.946252    
hookwire2JH_O_W     0.85239    0.57593   1.480 0.138867    
hookwire2T         -1.49211    0.81548  -1.830 0.067290 .  
hookwire2T_O       -0.19500    0.40096  -0.486 0.626730    
hookwire2T_O_W     -0.17853    0.37102  -0.481 0.630381    
hookwire2T_W       -0.07128    0.38778  -0.184 0.854148    
Log(theta)          0.11078    0.17586   0.630 0.528748    

Zero-inflation model coefficients (binomial with logit link):
             Estimate Std. Error z value Pr(>|z|)    
(Intercept) -57.21234    6.27365  -9.119  < 2e-16 ***
lat           0.36284    0.03958   9.166  < 2e-16 ***
lon           0.24298    0.02992   8.122 4.58e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

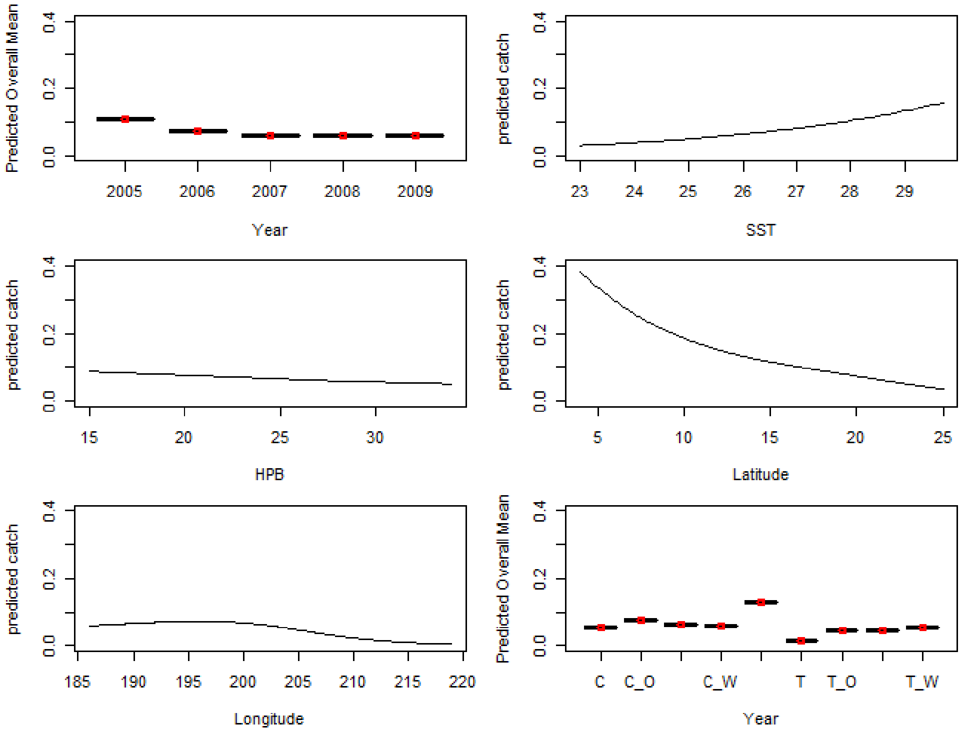


Figure A2-3: Relative influence of different model terms upon the mean predicted catch

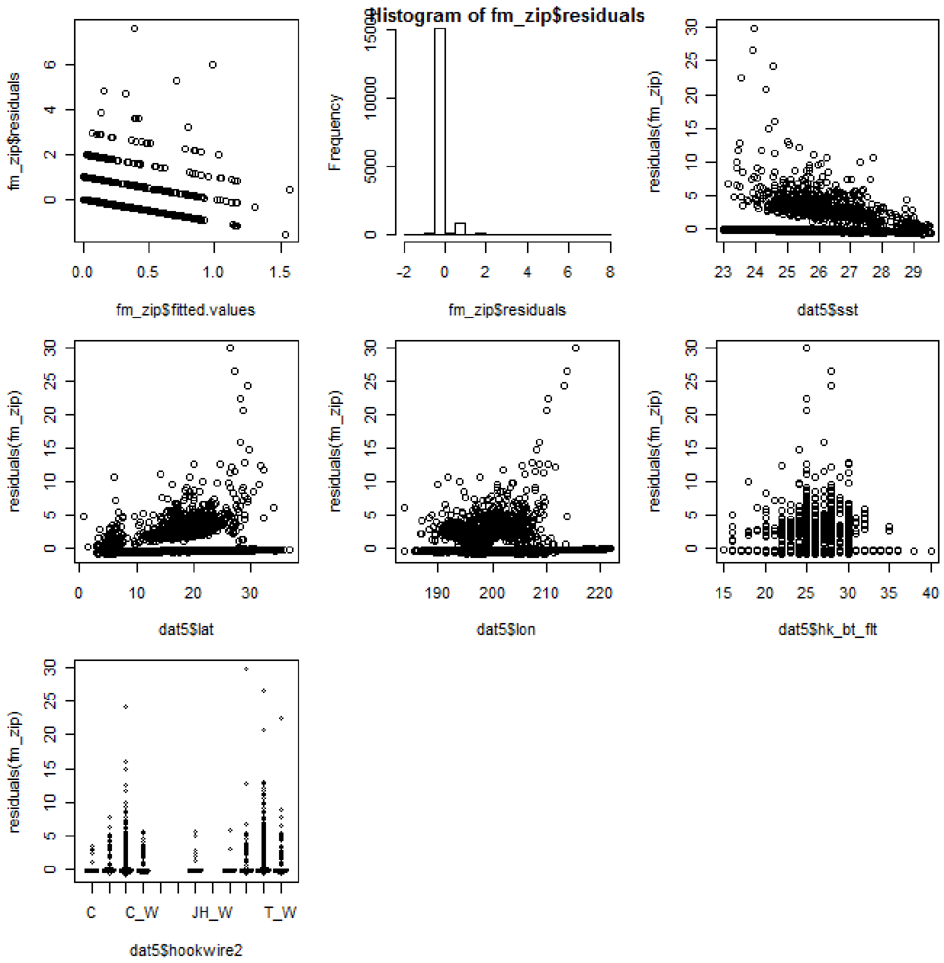
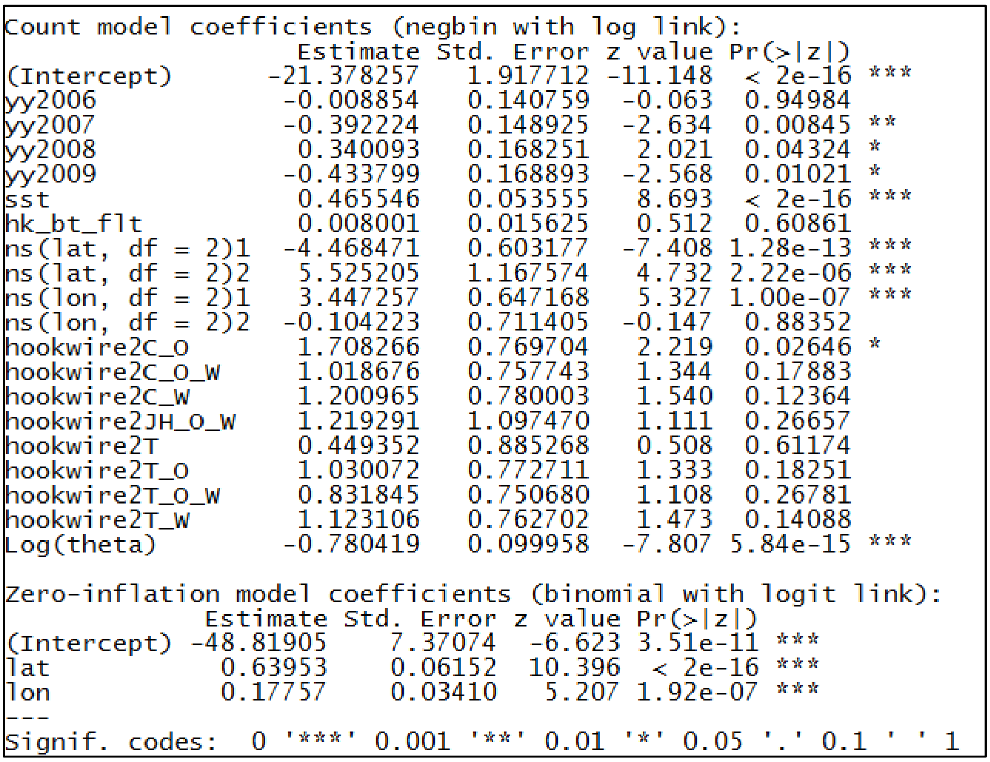


Figure A2-4: Residuals based model diagnostics

Silky shark: Primary model

Table A2-3: ZINB model based estimates of model term coefficients, standard errors and significance.



```
Count model coefficients (negbin with log link):
                     Estimate Std. Error z value Pr(>|z|)    
(Intercept)        -21.378257   1.917712 -11.148  < 2e-16 ***
yy2006              -0.008854   0.140759  -0.063  0.94984    
yy2007              -0.392224   0.148925  -2.634  0.00845 ** 
yy2008               0.340093   0.168251   2.021  0.04324 *  
yy2009              -0.433799   0.168893  -2.568  0.01021 *  
sst                  0.465546   0.053555   8.693  < 2e-16 ***
hk_bt_flt            0.008001   0.015625   0.512  0.60861    
ns(lat, df = 2)1    -4.468471   0.603177  -7.408 1.28e-13 ***
ns(lat, df = 2)2     5.525205   1.167574   4.732 2.22e-06 ***
ns(lon, df = 2)1     3.447257   0.647168   5.327 1.00e-07 ***
ns(lon, df = 2)2    -0.104223   0.711405  -0.147  0.88352    
hookwire2C_O         1.708266   0.769704   2.219  0.02646 *  
hookwire2C_O_W       1.018676   0.757743   1.344  0.17883    
hookwire2C_W         1.200965   0.780003   1.540  0.12364    
hookwire2JH_O_W      1.219291   1.097470   1.111  0.26657    
hookwire2T           0.449352   0.885268   0.508  0.61174    
hookwire2T_O         1.030072   0.772711   1.333  0.18251    
hookwire2T_O_W       0.831845   0.750680   1.108  0.26781    
hookwire2T_W         1.123106   0.762702   1.473  0.14088    
Log(theta)          -0.780419   0.099958  -7.807 5.84e-15 ***

Zero-inflation model coefficients (binomial with logit link):
             Estimate Std. Error z value Pr(>|z|)    
(Intercept) -48.81905    7.37074  -6.623 3.51e-11 ***
lat           0.63953    0.06152  10.396  < 2e-16 ***
lon           0.17757    0.03410   5.207 1.92e-07 ***
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

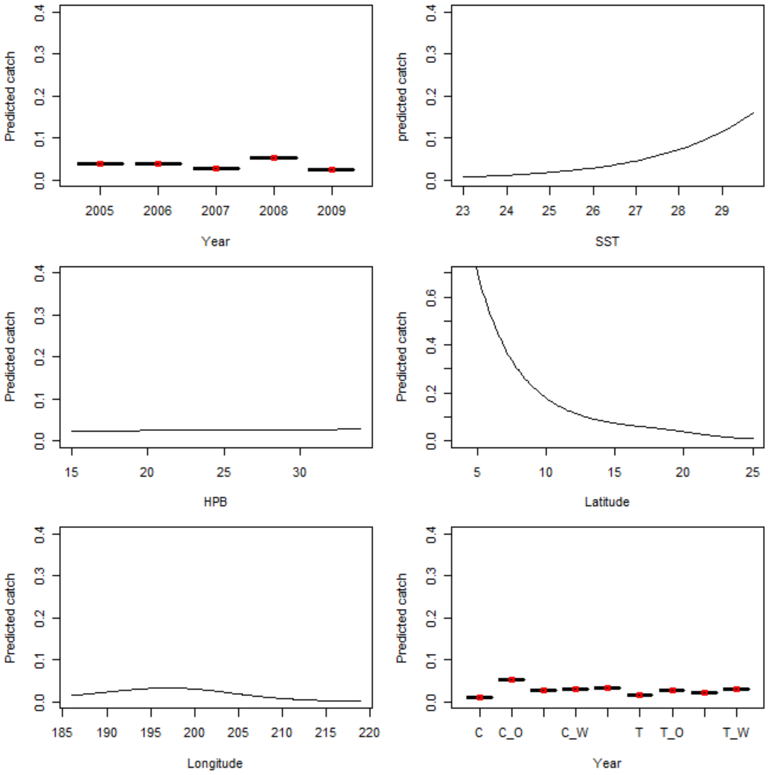


Figure A2-5: Relative influence of different model terms upon the mean predicted catch

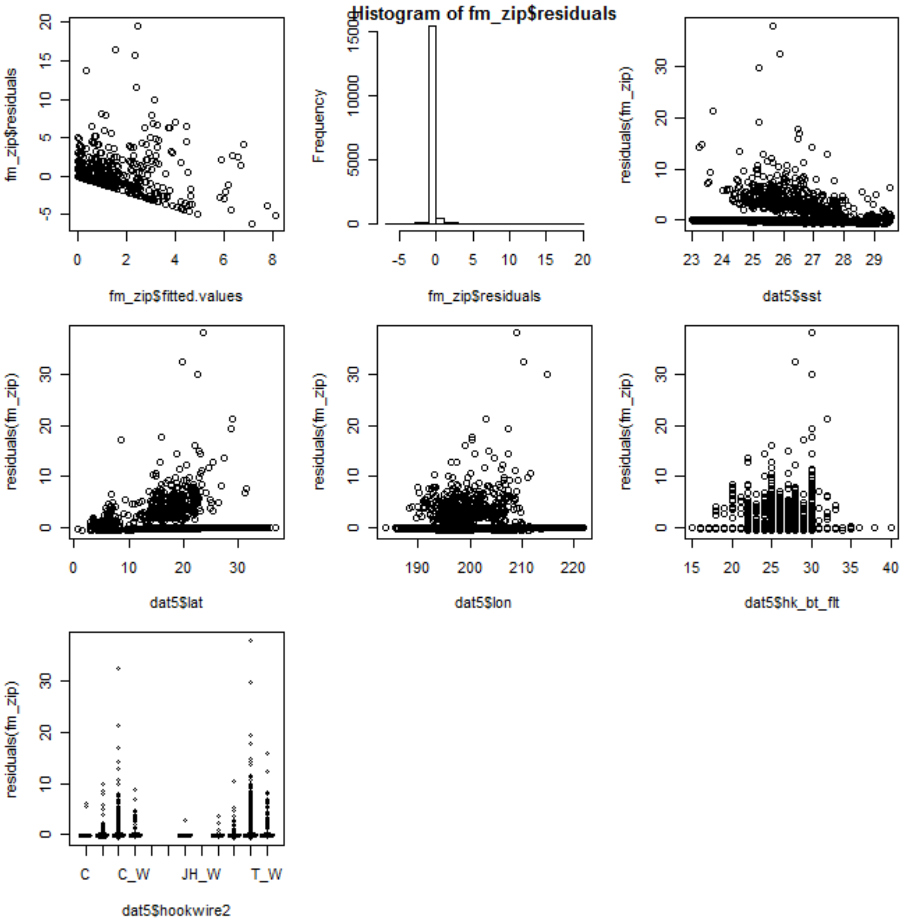
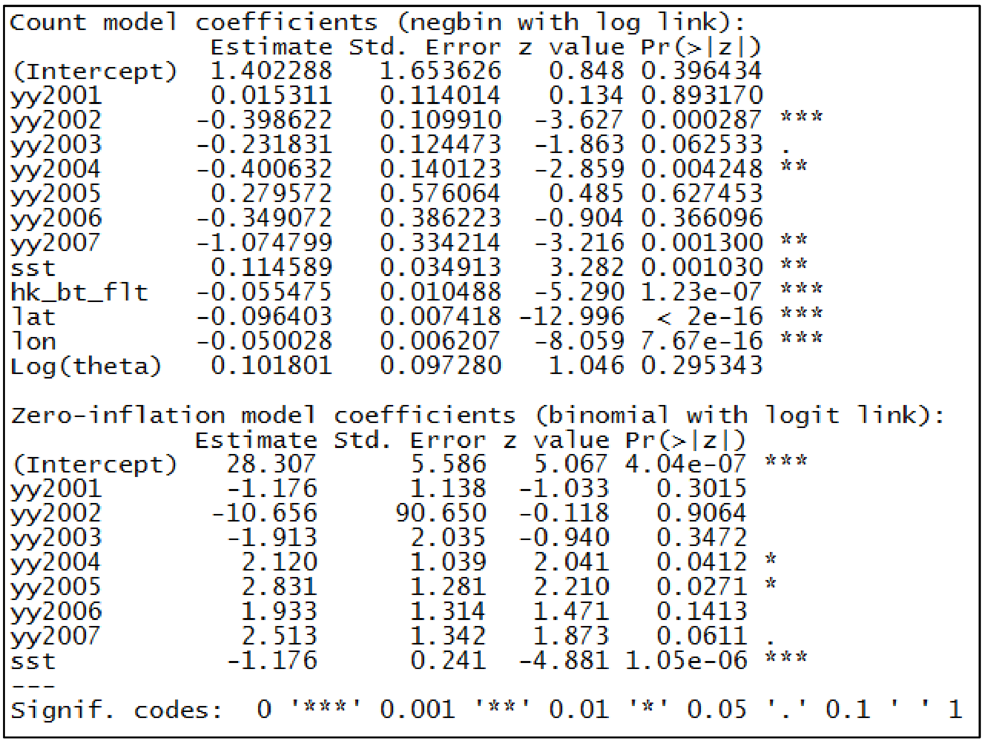


Figure A2-6: Residuals based model diagnostics

Oceanic white tip shark: Secondary model (Tuna hook with wire only)

Table A2-4: ZINB model based estimates of model term coefficients, standard errors and significance.



```
Count model coefficients (negbin with log link):
             Estimate Std. Error z value Pr(>|z|)
(Intercept)  1.402288   1.653626   0.848 0.396434
yy2001       0.015311   0.114014   0.134 0.893170
yy2002      -0.398622   0.109910  -3.627 0.000287 ***
yy2003      -0.231831   0.124473  -1.863 0.062533 .
yy2004      -0.400632   0.140123  -2.859 0.004248 **
yy2005       0.279572   0.576064   0.485 0.627453
yy2006      -0.349072   0.386223  -0.904 0.366096
yy2007      -1.074799   0.334214  -3.216 0.001300 **
sst          0.114589   0.034913   3.282 0.001030 **
hk_bt_flt   -0.055475   0.010488  -5.290 1.23e-07 ***
lat         -0.096403   0.007418 -12.996  < 2e-16 ***
lon         -0.050028   0.006207  -8.059 7.67e-16 ***
Log(theta)   0.101801   0.097280   1.046 0.295343

Zero-inflation model coefficients (binomial with logit link):
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   28.307      5.586   5.067 4.04e-07 ***
yy2001        -1.176      1.138  -1.033   0.3015
yy2002       -10.656     90.650  -0.118   0.9064
yy2003        -1.913      2.035  -0.940   0.3472
yy2004         2.120      1.039   2.041   0.0412 *
yy2005         2.831      1.281   2.210   0.0271 *
yy2006         1.933      1.314   1.471   0.1413
yy2007         2.513      1.342   1.873   0.0611 .
sst           -1.176      0.241  -4.881 1.05e-06 ***
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

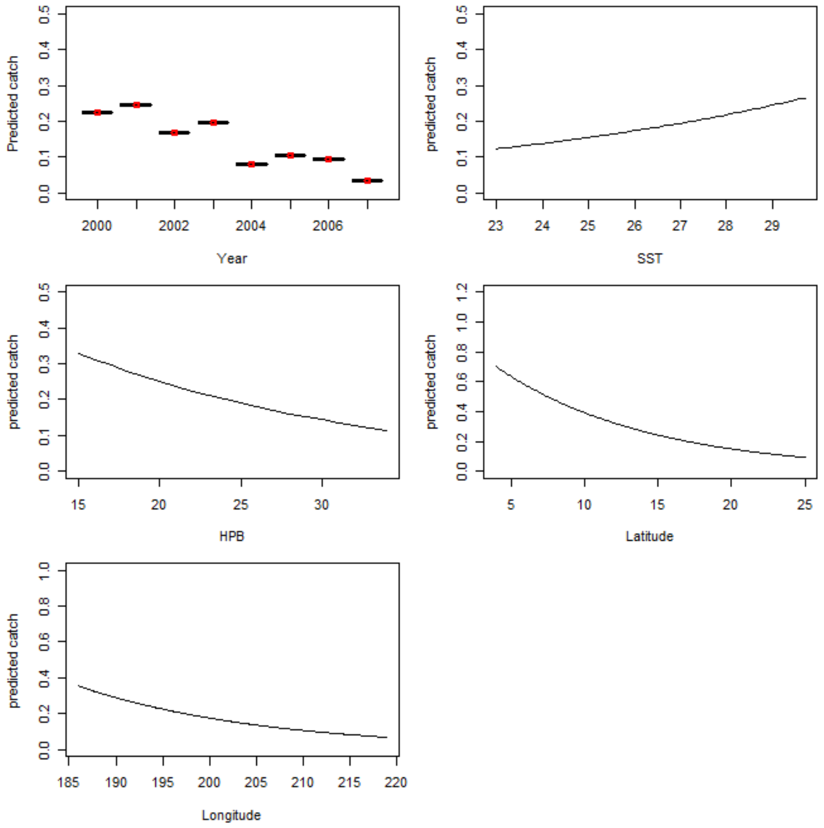


Figure A2-7: Relative influence of different model terms upon the mean predicted catch

Appendix 3 – Fiji Albacore Tuna Fishery Models

Fiji Tuna Fishery Models

Data exploration

The Fiji, Vanuatu and New Caledonian EEZs are adjacent to one another and the longline fisheries in each EEZ target predominantly albacore tuna, hence there was some potential that a combined model could be developed by merging observer data from the three. Species composition data from the observed vessels indicated that albacore was the target for those vessels also.

Initial observer data explorations indicated a high level of within year contrast in leader type, bait type and shark line use in both the Fiji and Vanuatu fisheries, while data on hook types had not been collected until 2008 and little contrast existed for that factor in those two fisheries (Tables A3-1 and A5-4). Closer examination revealed that for the Vanuatu data, hook type was related to leader type (fishers used either circle hooks without wire leaders or tuna hooks with wires) so separating hook versus leader effects on shark catches would be difficult. In addition, while both fisheries apparently target albacore, the Vanuatu fishery appears to operate very differently, setting much shallower and with much shorter sets. Its possible the fishery was targeting yellowfin and albacore together. Inclusion of the Vanuatu data led to some significant collinearity between some model terms and for this and above reasons it was excluded from the Fiji data analysis. By itself the Vanuatu data sample size is too small for model based analyses.

Some contrast in hook type existed for New Caledonian observer data but closer examination revealed that the level of contrast and sample sizes for hook types within years data was too low (Table A5-3) and data from that fishery was not included in the final model. Hence the final model was developed using only the Fiji data.

Initial data explorations assessed potential for outliers in both response and explanatory variables (). Based on these explorations, and noting that the purpose of the analyses is to identify possible differences in catches depending on hook type and leader types, the data set was trimmed to reduce extreme variations in other explanatory variables that are not of interest (i.e. sets with extreme values of set time, hooks per basket, latitude, longitude were removed) but important to account for in the model.

Collinearity between explanatory variables was also assessed using scatterplots as well as Variance Inflation Analyses using the *corvif* and *myvif* functions sourced from (http://www.highstat.com/BGS/GAM/HighstatLibV4.R) for use in the in R 2.12.1 (noting that *vif* function is not supported by the pscl package). Restricting the data to years with good contrast for shark lines, shark baits and wire trace use removed collinearity between these and temporal terms (e.g year) that might have complicated interpretation. Temporal variation in the use of different hook types and leader types was examined, as was the use of shark lines, baits and wire trace over time (Table A3-2). GAM based exploratory models were also used to assist in appropriate modelling by ZINB at the final stage.

Table A3-1 - Number of observed sets by hook and leader type category (combined) and year in the Fijian based albacore longline fishery.

	C	C_MX	C_MX_W	C_W	T_W	UN	UN_UN	UN_W
1994	0	0	0	0	0	0	4	0
1995	0	0	0	0	0	0	32	0
1996	0	0	0	0	0	0	12	0
1997	0	0	0	0	0	0	23	0
1998	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	53	0
2000	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	37	0
2003	0	0	0	0	0	0	133	30
2004	0	0	0	0	0	0	39	109
2005	0	0	0	0	0	155	32	228
2006	0	0	0	0	0	211	36	143
2007	0	0	0	0	0	227	0	72
2008	19	24	0	0	0	182	0	89
2009	10	49	6	7	21	30	0	84
2010	21	0	79	0	0	0	0	7
2011	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0

Table A3-2 - Number of observed sets by with and without wire leaders, by year, in the Fiji based albacore longline fishery. Grey indicates years used for ZINB models

	Wire leader used			Sharklines used			Shark baits used		
Year	**No**	**Uncertain**	**Yes**	**No**	**Uncertain**	**Yes**	**No**	**Uncertain**	**Yes**
1994	0	4	0	0	4	0	4	0	0
1995	0	32	0	0	32	0	32	0	0
1996	0	12	0	0	12	0	12	0	0
1997	0	23	0	0	23	0	23	0	0
1999	0	53	0	1	52	0	53	0	0
2002	0	37	0	37	0	0	37	0	0
2003	0	133	30	151	0	12	163	0	0
2004	0	39	109	112	0	36	148	0	0
2005	155	32	228	285	0	130	410	0	5
2006	211	36	143	247	0	143	360	0	30
2007	227	0	72	191	0	108	294	0	5
2008	225	0	89	120	0	194	286	0	28
2009	89	0	118	98	0	109	188	0	19
2010	21	0	86	62	0	45	86	0	21

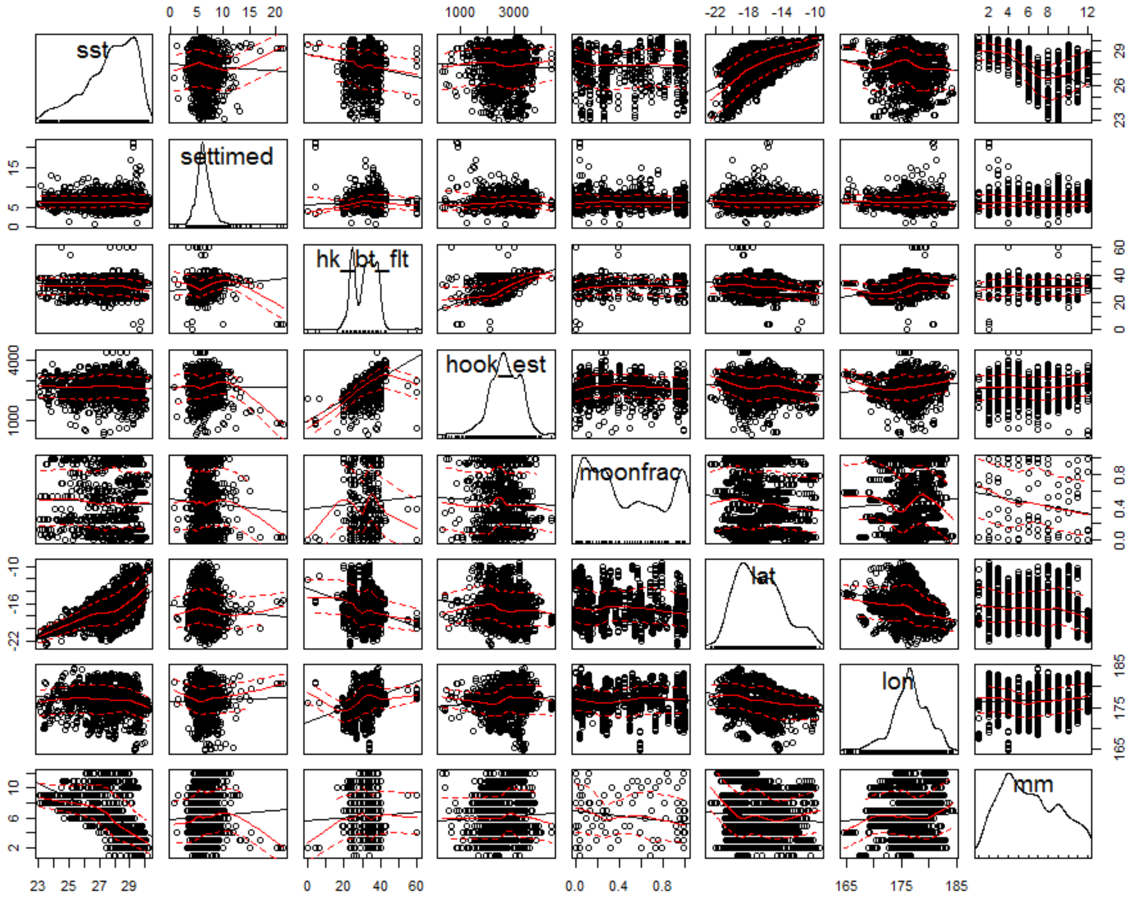
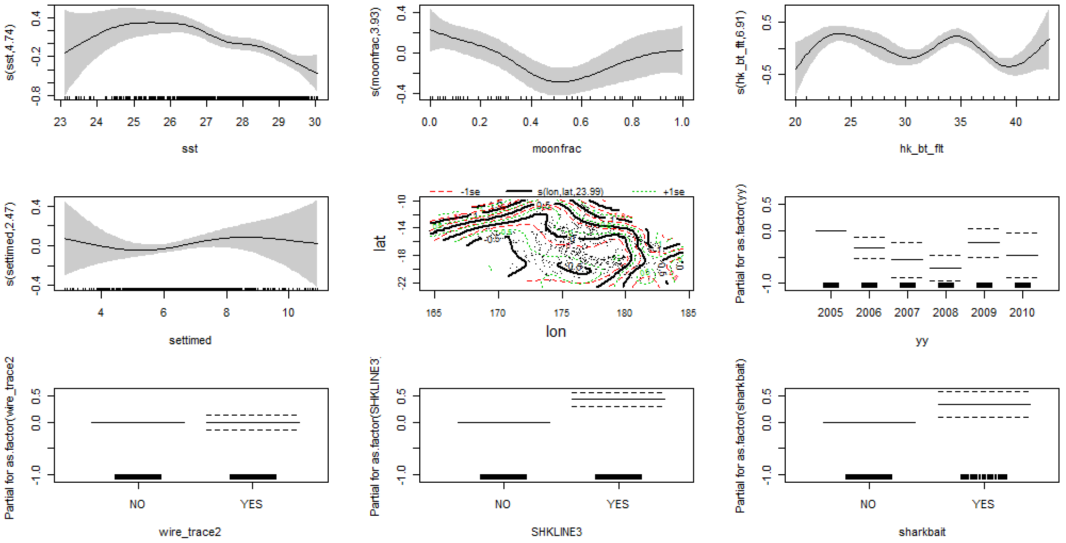
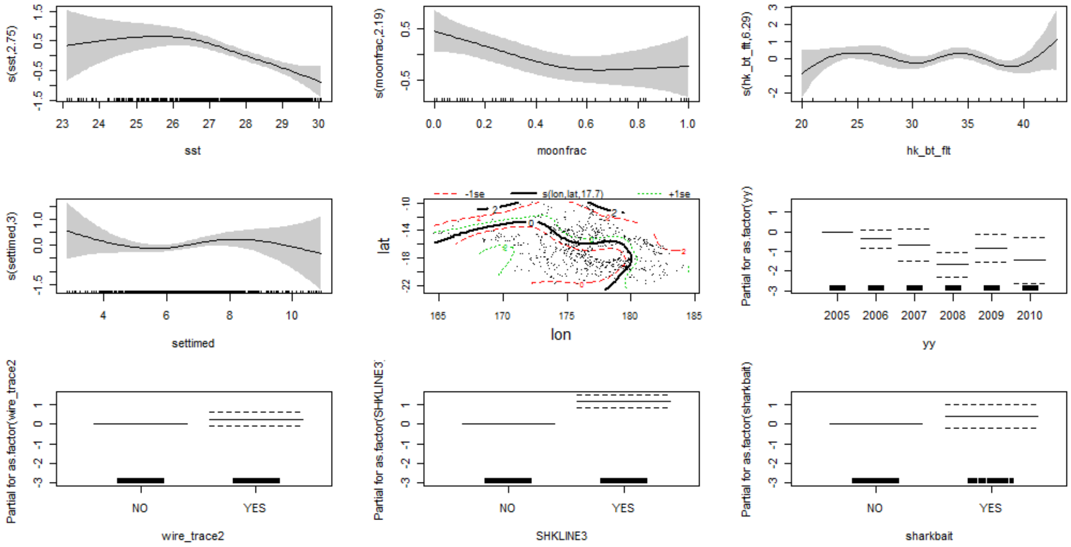


Figure A3-1: Scatterplots for key explanatory variables (to assess potential collinearity).

Oceanic Whitetip Shark – Combined GAM



Oceanic Whitetip – Presence/Absence (Binomial) GAM



Oceanic Whitetip – Count model (Poisson) GAM

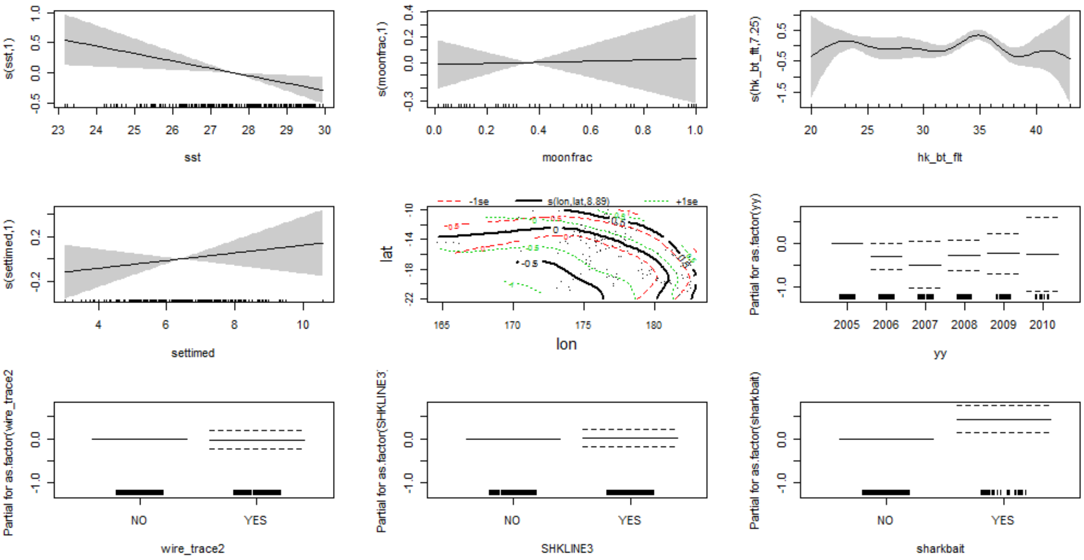
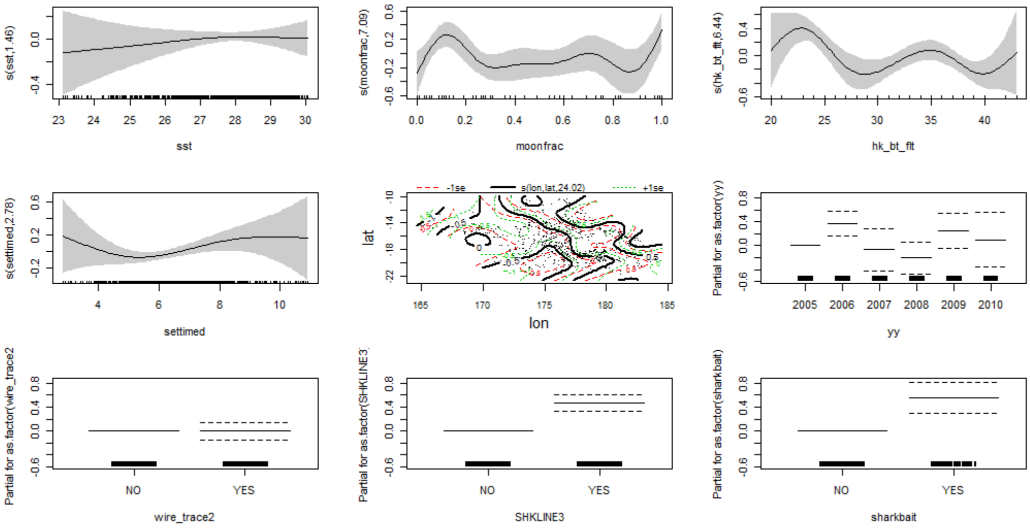
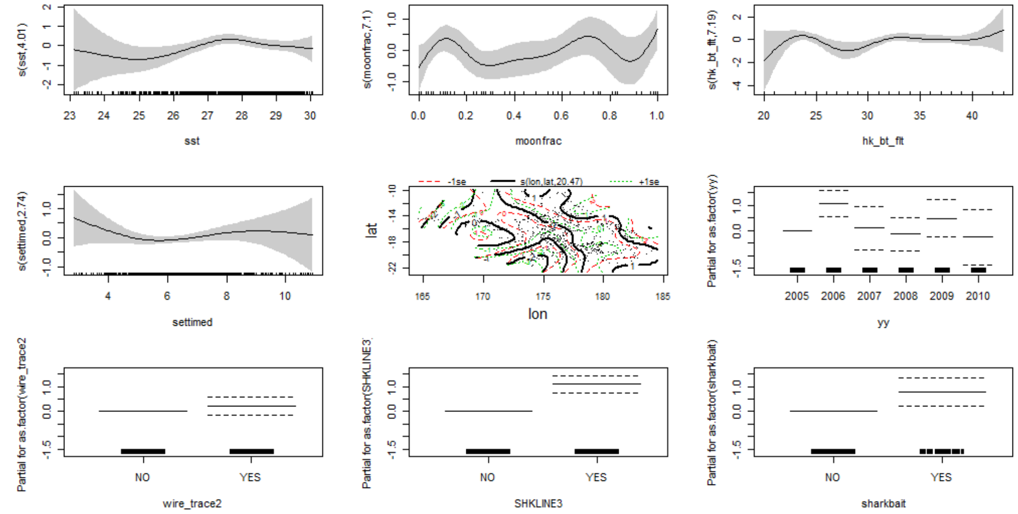


Figure A3-2: Relative effects plots for full, binomial and poisson GAM models for oceanic whitetip shark catch in Fiji longline fishery.

Silky Shark – Combined GAM



Silky Shark – Presence/Absence (Binomial) GAM



Silky Shark – Count model (Poisson) GAM

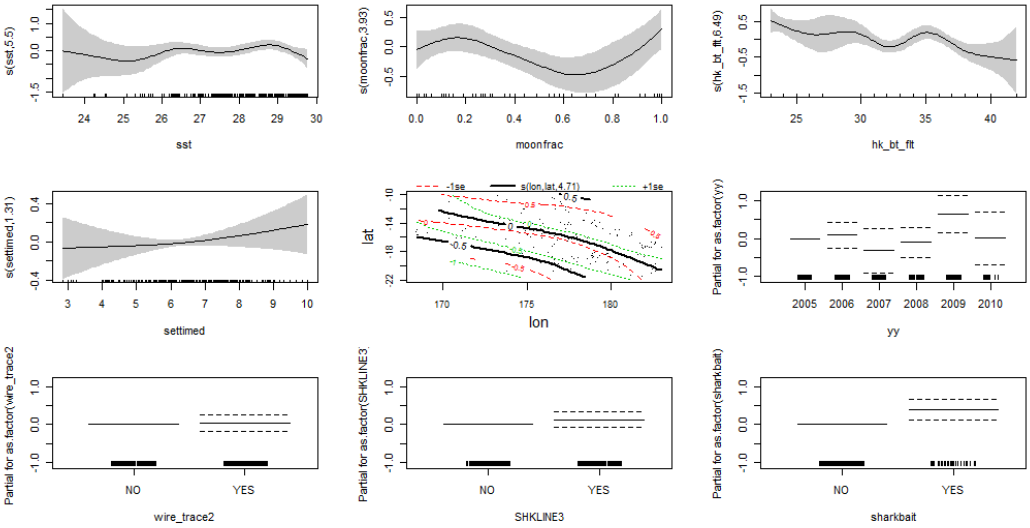
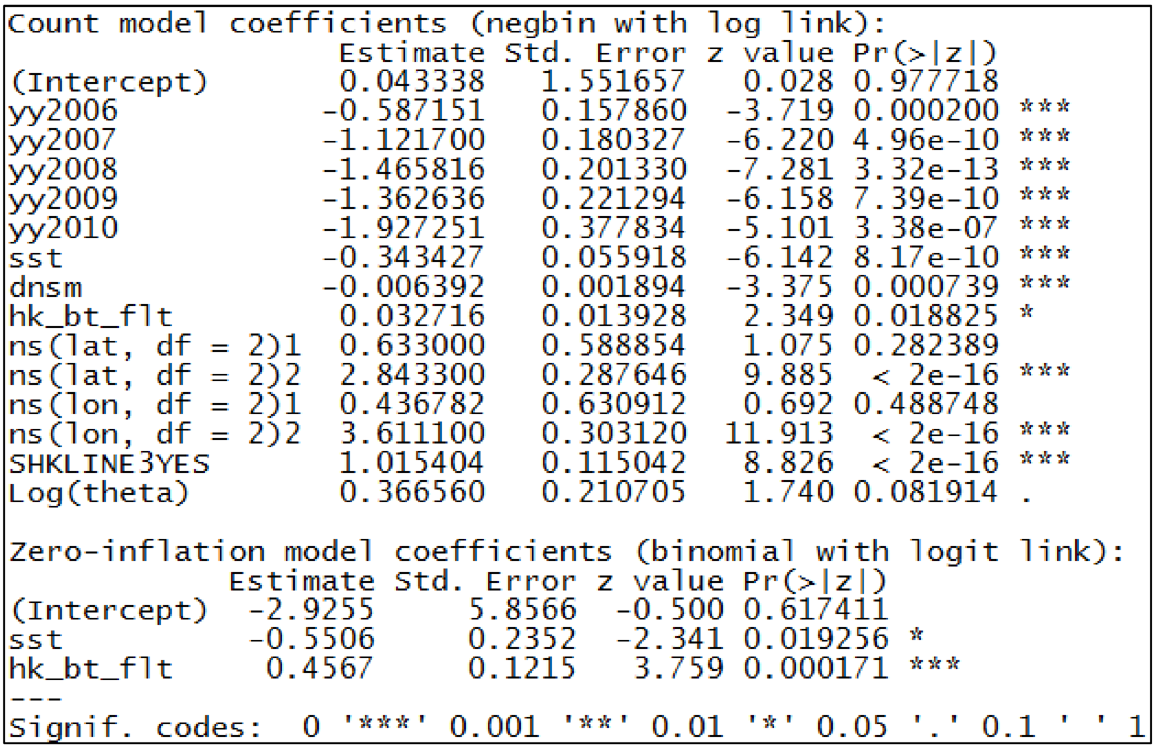


Figure A3-3: Relative effects plots for full, binomial and Poisson GAM models for silky shark catch in Fiji longline fishery.

Oceanic whitetip: Primary model

Table A3-4: ZINB model based estimates of model term coefficients, standard errors and significance.



```
Count model coefficients (negbin with log link):
                 Estimate Std. Error z value Pr(>|z|)
(Intercept)      0.043338   1.551657   0.028 0.977718
yy2006          -0.587151   0.157860  -3.719 0.000200 ***
yy2007          -1.121700   0.180327  -6.220 4.96e-10 ***
yy2008          -1.465816   0.201330  -7.281 3.32e-13 ***
yy2009          -1.362636   0.221294  -6.158 7.39e-10 ***
yy2010          -1.927251   0.377834  -5.101 3.38e-07 ***
sst             -0.343427   0.055918  -6.142 8.17e-10 ***
dnsm            -0.006392   0.001894  -3.375 0.000739 ***
hk_bt_flt        0.032716   0.013928   2.349 0.018825 *
ns(lat, df = 2)1 0.633000   0.588854   1.075 0.282389
ns(lat, df = 2)2 2.843300   0.287646   9.885  < 2e-16 ***
ns(lon, df = 2)1 0.436782   0.630912   0.692 0.488748
ns(lon, df = 2)2 3.611100   0.303120  11.913  < 2e-16 ***
SHKLINE3YES      1.015404   0.115042   8.826  < 2e-16 ***
Log(theta)       0.366560   0.210705   1.740 0.081914 .

Zero-inflation model coefficients (binomial with logit link):
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -2.9255     5.8566  -0.500 0.617411
sst          -0.5506     0.2352  -2.341 0.019256 *
hk_bt_flt     0.4567     0.1215   3.759 0.000171 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

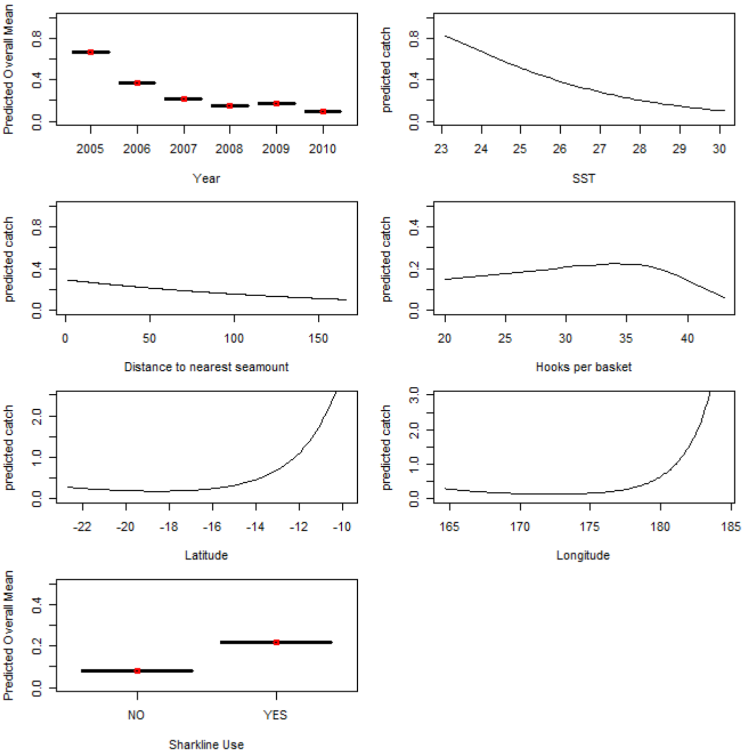


Figure A3-4: Relative influence of different model terms upon the mean predicted catch

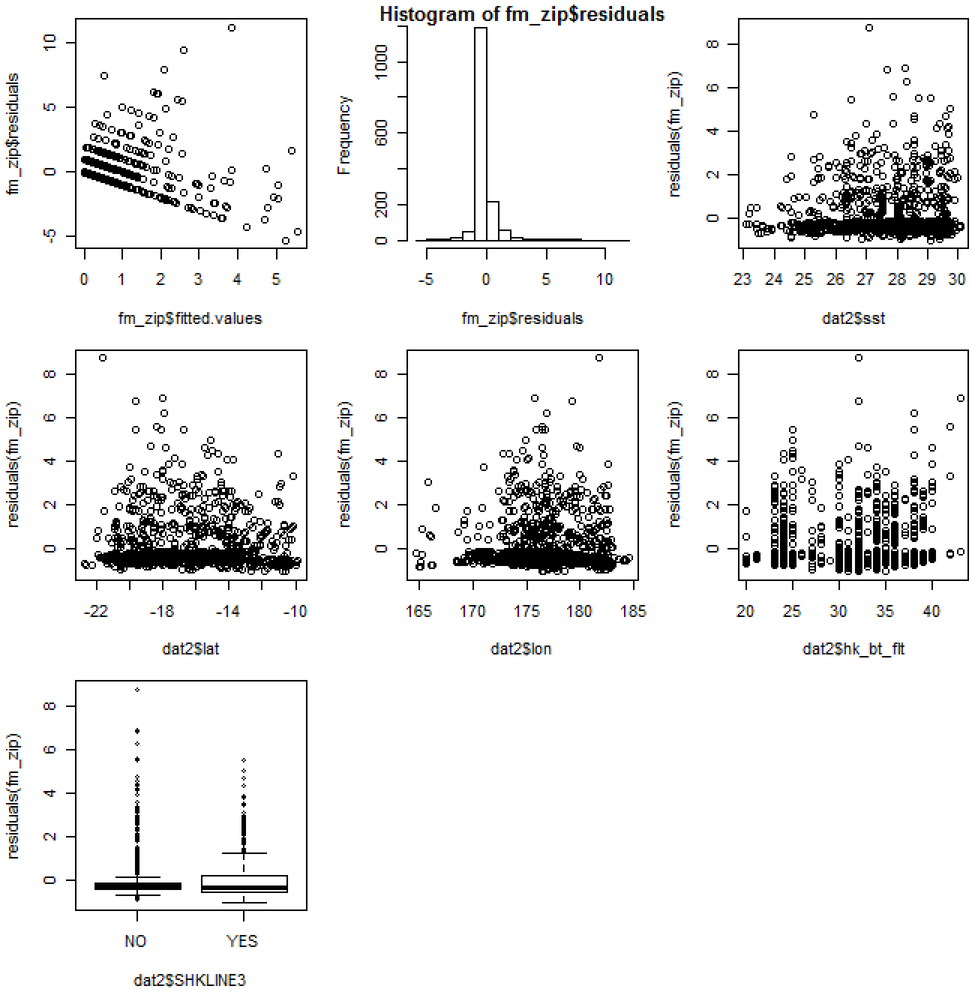
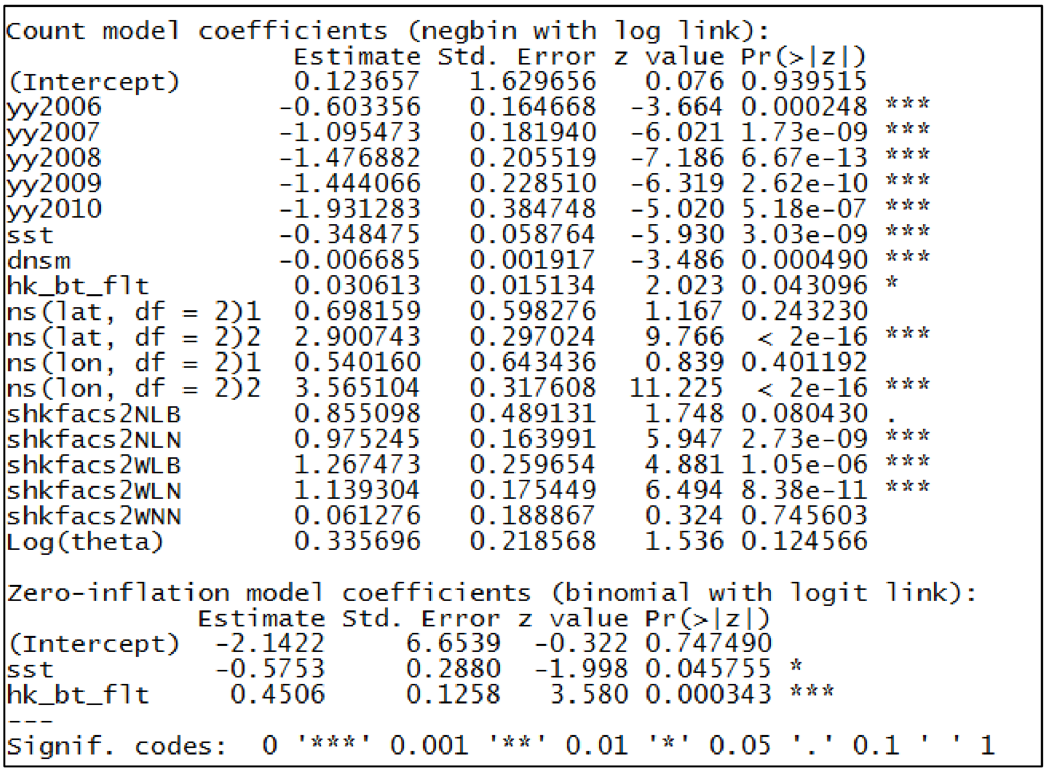


Figure A3-5: Residuals based model diagnostics

Oceanic whitetip: Secondary model (combined shark factor)

Table A3-5: ZINB model based estimates of model term coefficients, standard errors and significance.



```
Count model coefficients (negbin with log link):
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)        0.123657   1.629656   0.076 0.939515
yy2006            -0.603356   0.164668  -3.664 0.000248 ***
yy2007            -1.095473   0.181940  -6.021 1.73e-09 ***
yy2008            -1.476882   0.205519  -7.186 6.67e-13 ***
yy2009            -1.444066   0.228510  -6.319 2.62e-10 ***
yy2010            -1.931283   0.384748  -5.020 5.18e-07 ***
sst               -0.348475   0.058764  -5.930 3.03e-09 ***
dnsm              -0.006685   0.001917  -3.486 0.000490 ***
hk_bt_flt          0.030613   0.015134   2.023 0.043096 *
ns(lat, df = 2)1   0.698159   0.598276   1.167 0.243230
ns(lat, df = 2)2   2.900743   0.297024   9.766  < 2e-16 ***
ns(lon, df = 2)1   0.540160   0.643436   0.839 0.401192
ns(lon, df = 2)2   3.565104   0.317608  11.225  < 2e-16 ***
shkfacs2NLB        0.855098   0.489131   1.748 0.080430 .
shkfacs2NLN        0.975245   0.163991   5.947 2.73e-09 ***
shkfacs2WLB        1.267473   0.259654   4.881 1.05e-06 ***
shkfacs2WLN        1.139304   0.175449   6.494 8.38e-11 ***
shkfacs2WNN        0.061276   0.188867   0.324 0.745603
Log(theta)         0.335696   0.218568   1.536 0.124566

Zero-inflation model coefficients (binomial with logit link):
             Estimate Std. Error z value Pr(>|z|)
(Intercept)   -2.1422     6.6539  -0.322 0.747490
sst           -0.5753     0.2880  -1.998 0.045755 *
hk_bt_flt      0.4506     0.1258   3.580 0.000343 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

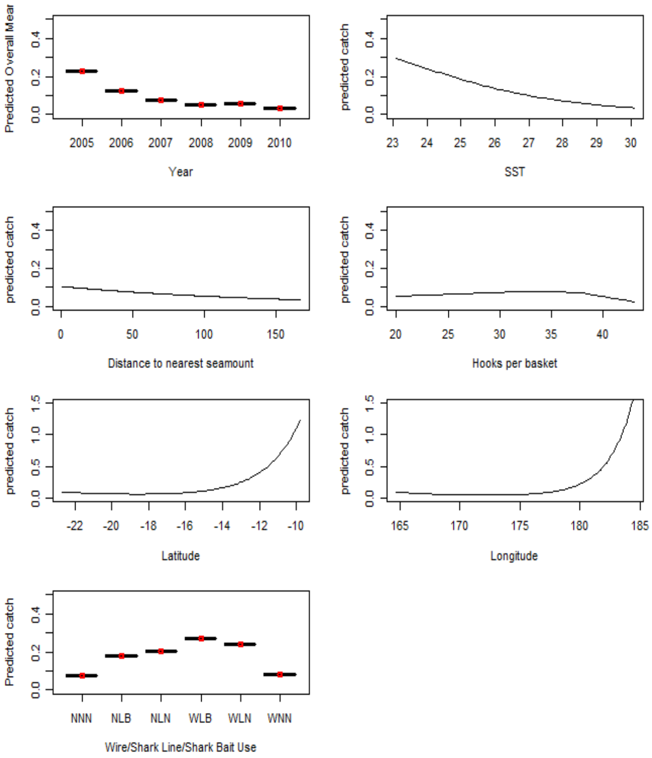


Figure A3-6: Relative influence of different model terms upon the mean predicted catch

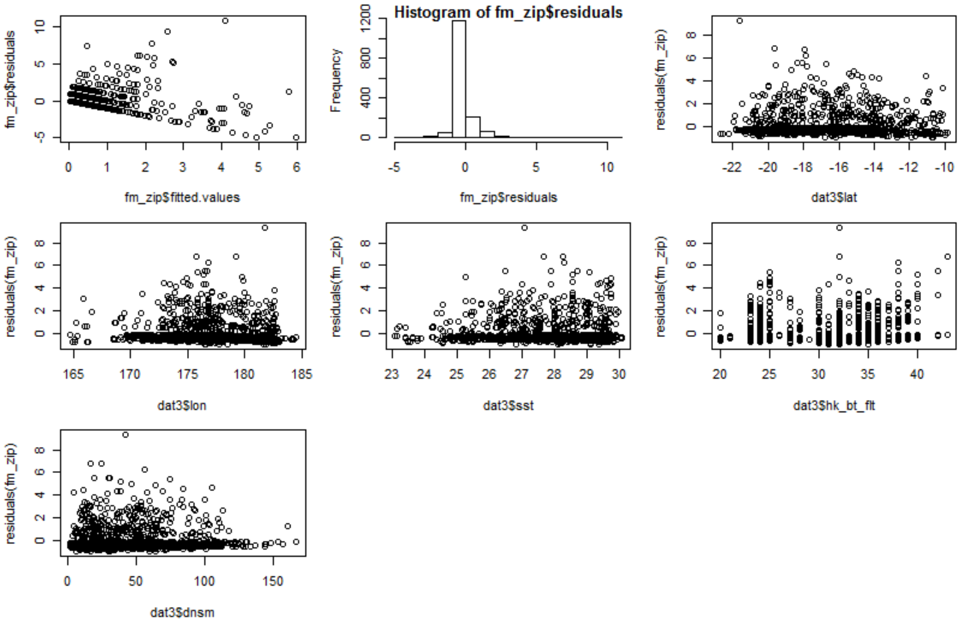
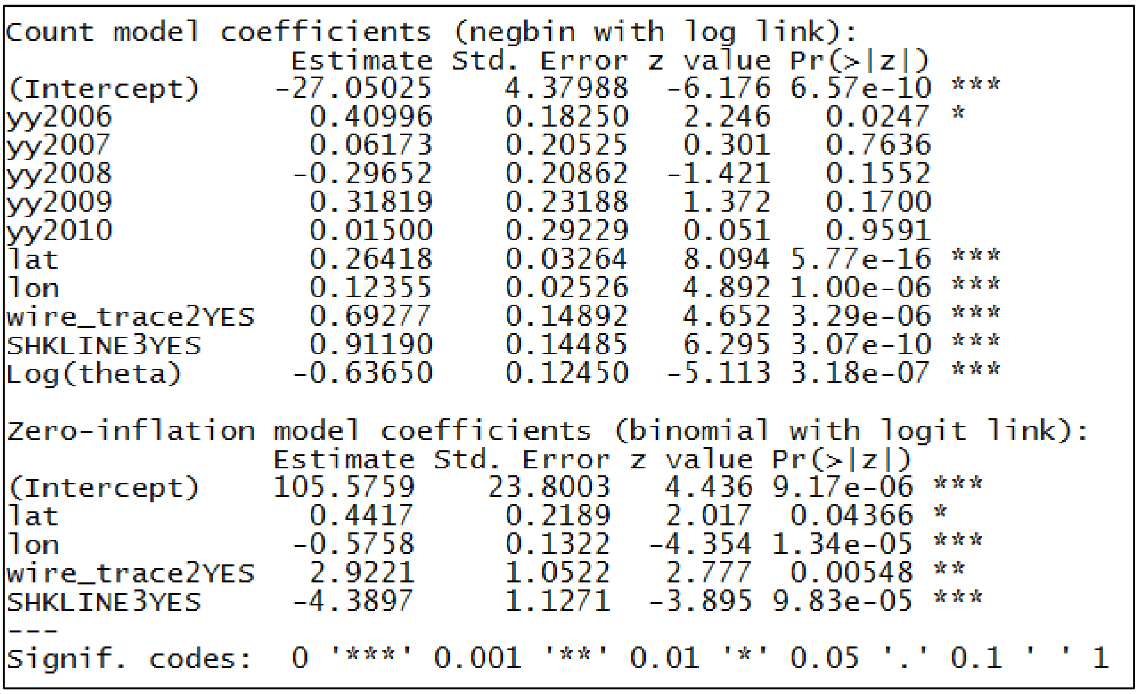


Figure A3-7: Residuals based model diagnostics

Silky shark: Primary model

Table A3-6: ZINB model based estimates of model term coefficients, standard errors and significance.



```
Count model coefficients (negbin with log link):
                Estimate Std. Error z value Pr(>|z|)
(Intercept)    -27.05025    4.37988  -6.176 6.57e-10 ***
yy2006           0.40996    0.18250   2.246   0.0247 *
yy2007           0.06173    0.20525   0.301   0.7636
yy2008          -0.29652    0.20862  -1.421   0.1552
yy2009           0.31819    0.23188   1.372   0.1700
yy2010           0.01500    0.29229   0.051   0.9591
lat              0.26418    0.03264   8.094 5.77e-16 ***
lon              0.12355    0.02526   4.892 1.00e-06 ***
wire_trace2YES   0.69277    0.14892   4.652 3.29e-06 ***
SHKLINE3YES      0.91190    0.14485   6.295 3.07e-10 ***
Log(theta)      -0.63650    0.12450  -5.113 3.18e-07 ***

Zero-inflation model coefficients (binomial with logit link):
               Estimate Std. Error z value Pr(>|z|)
(Intercept)    105.5759    23.8003   4.436 9.17e-06 ***
lat              0.4417     0.2189   2.017  0.04366 *
lon             -0.5758     0.1322  -4.354 1.34e-05 ***
wire_trace2YES   2.9221     1.0522   2.777  0.00548 **
SHKLINE3YES     -4.3897     1.1271  -3.895 9.83e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

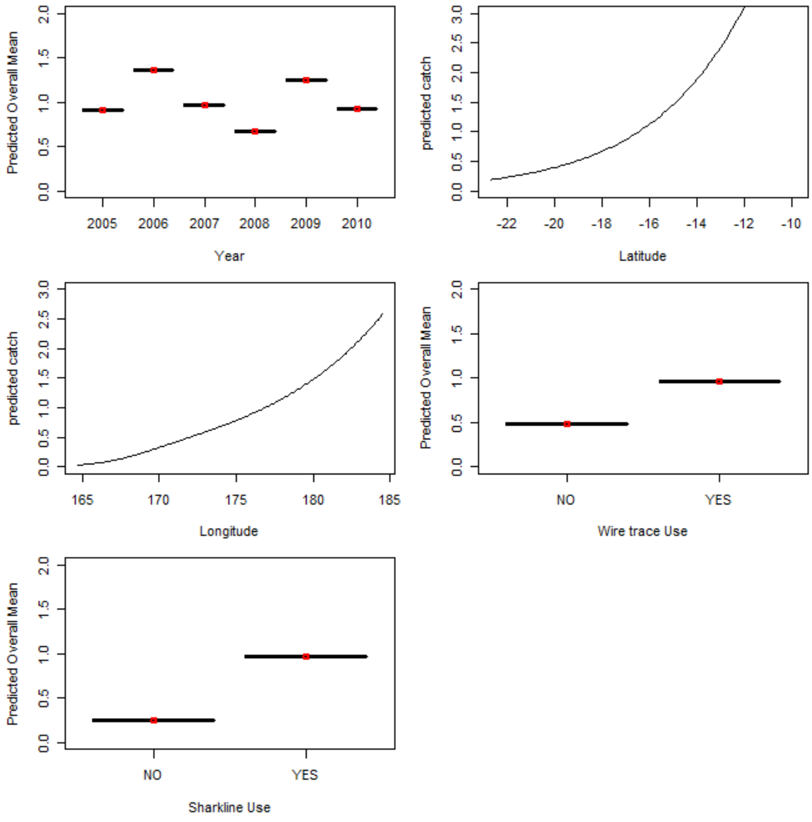


Figure A3-8: Relative influence of different model terms upon the mean predicted catch

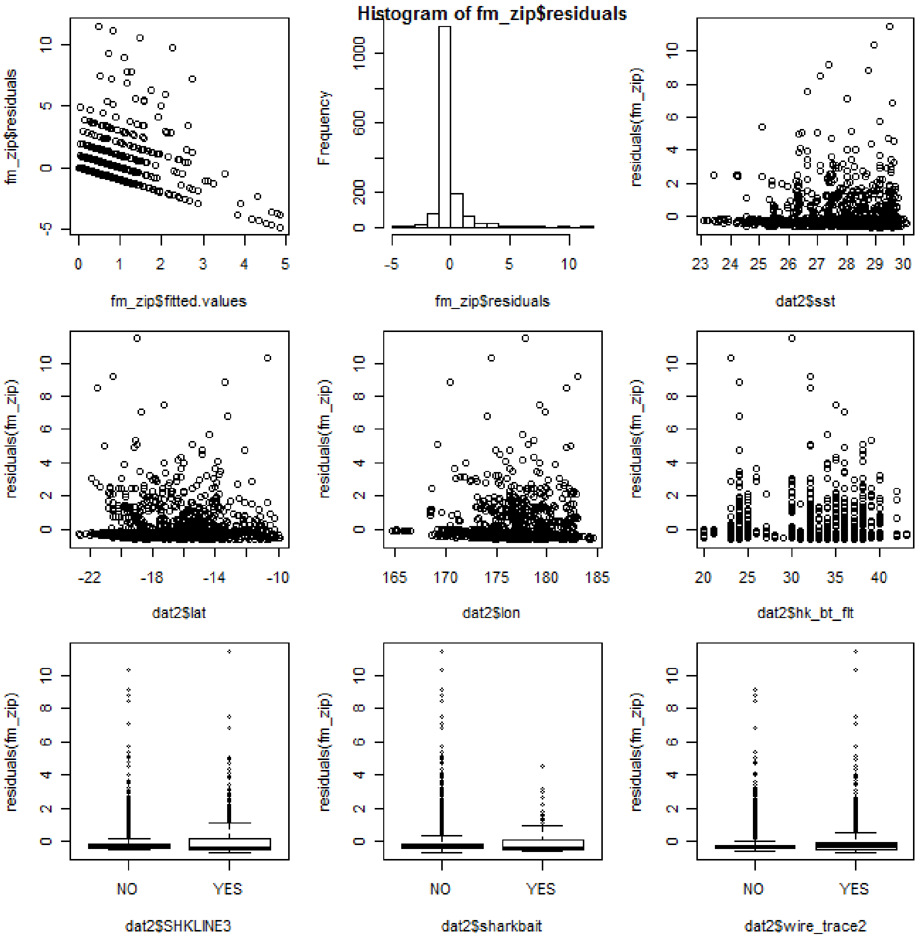
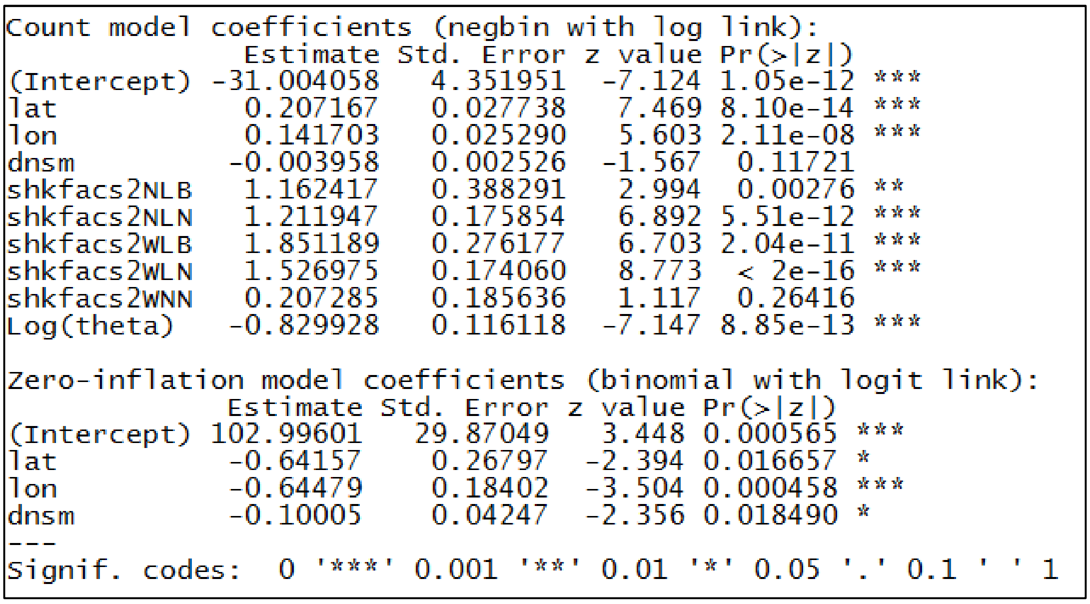


Figure A3-9: Residuals based model diagnostics

Silky shark: Secondary model (combined shark factor)

Table A3-7: ZINB model based estimates of model term coefficients, standard errors and significance.



```
Count model coefficients (negbin with log link):
              Estimate Std. Error z value Pr(>|z|)    
(Intercept) -31.004058   4.351951  -7.124 1.05e-12 ***
lat           0.207167   0.027738   7.469 8.10e-14 ***
lon           0.141703   0.025290   5.603 2.11e-08 ***
dnsm         -0.003958   0.002526  -1.567  0.11721    
shkfacs2NLB   1.162417   0.388291   2.994  0.00276 ** 
shkfacs2NLN   1.211947   0.175854   6.892 5.51e-12 ***
shkfacs2WLB   1.851189   0.276177   6.703 2.04e-11 ***
shkfacs2WLN   1.526975   0.174060   8.773  < 2e-16 ***
shkfacs2WNN   0.207285   0.185636   1.117  0.26416    
Log(theta)   -0.829928   0.116118  -7.147 8.85e-13 ***

Zero-inflation model coefficients (binomial with logit link):
             Estimate Std. Error z value Pr(>|z|)    
(Intercept) 102.99601   29.87049   3.448 0.000565 ***
lat          -0.64157    0.26797  -2.394 0.016657 *  
lon          -0.64479    0.18402  -3.504 0.000458 ***
dnsm         -0.10005    0.04247  -2.356 0.018490 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

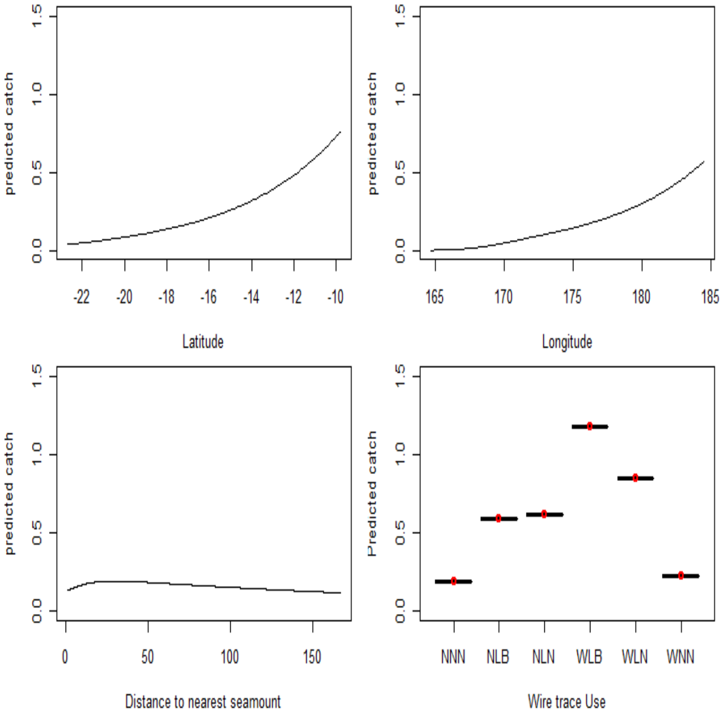


Figure A3-10: Relative influence of different model terms upon the mean predicted catch

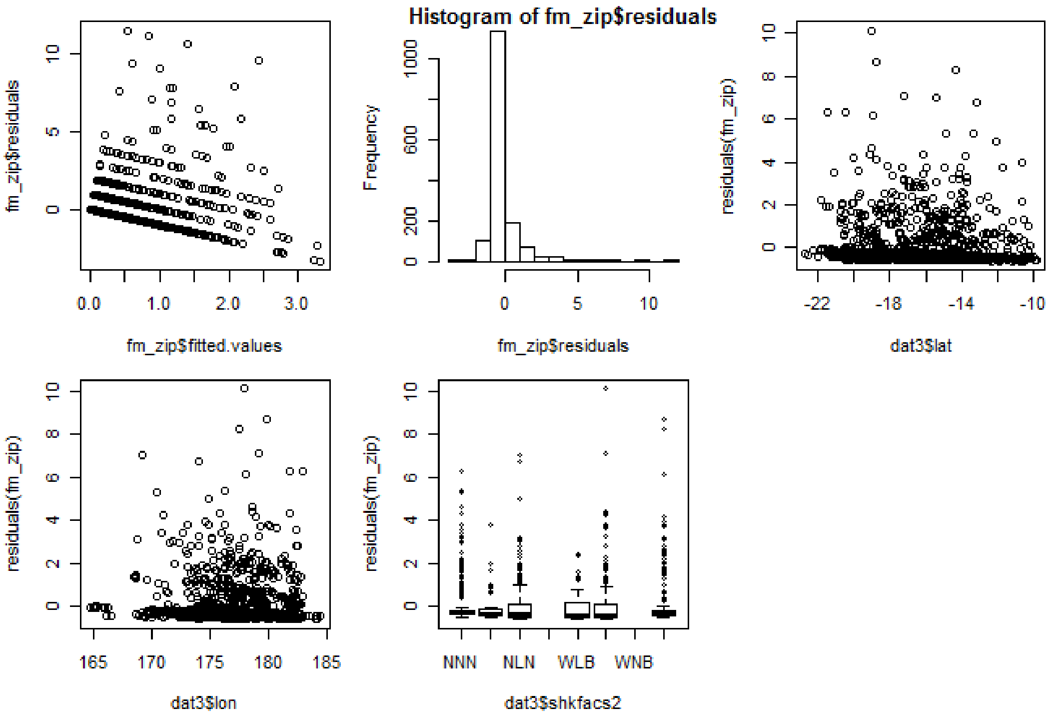


Figure A3-11: Various residuals based model diagnostics

Appendix 4 – FSM and Marshall Islands Tuna Fishery

FSM and Marshall Islands Tuna Fishery Models

Data exploration

The FSM and Marshall Islands EEZs are adjacent to one another and the longline fisheries in each EEZ target predominantly bigeye and yellowfin tuna (with main target species changing over time). There has been some crossover over time by some fleets fishing in one or other EEZ, and a significant amount of observer data has been collected since the early 1990s (although at low coverage rates). Data exploration was undertaken to determine if a combined model could be developed by merging observer data from the two EEZs.

Initial observer data explorations indicated a reasonable level of within year contrast in leader type, bait type and shark line use in both the FSM and Chinese flagged fleets, while there was little data on hook types across any fleets (Table A4-1). Observer data collected from Taiwanese and Japanese fleets had little contrast in any of these factors and given that too few sets had been observed in either fleet to support a standalone analysis, and the fleets operate quite differently to the FSM and Chinese flagged fleets (which have operated in a very similar manner) these data were excluded from model based analyses.

Hence the final model was developed using only the FSM and Chinese flagged observer data combined.

Initial data explorations assessed potential for outliers in both response and explanatory variables. Based on these explorations, and noting that the purpose of the analyses is to identify possible differences in catches depending on hook type and leader types, the data set was trimmed to reduce extreme variations in other explanatory variables that are not of interest (i.e. sets with extreme values of set time, hooks per basket, latitude, longitude were removed) but important to account for in the model.

Collinearity between explanatory variables was also assessed using scatterplots as well as Variance Inflation Analyses using the *corvif* and *myvif* functions sourced from (http://www.highstat.com/BGS/GAM/HighstatLibV4.R) for use in the in R 2.12.1 (noting that *vif* function is not supported by the pscl package). Restricting the data to 2004-2009 resulted in a data set exhibiting very little collinearity between the key explanatory factors, except for sst and latitude (as expected and seen in all other datasets).

Table A4-1: Number of observed sets by with and without wire leaders, shark lines or shark baits, by year, for the FSM fleet.

	Shark line			Wire trace			Shark bait		
	NO	UNCERTAIN	YES	NO	UNCERTAIN	YES	NO	UNKNOWN	YES
1994	0	5	0	0	5	0	5	0	0
1995	0	3	0	0	3	0	1	0	2
1996	0	12	0	0	12	0	12	0	0
1997	0	19	0	0	19	0	19	0	0
1998	0	23	0	0	23	0	23	0	0
1999	0	19	0	0	19	0	19	0	0
2000	0	47	0	0	47	0	47	0	0
2001	0	27	0	0	27	0	27	0	0
2002	18	0	0	0	18	0	18	0	0
2003	16	0	0	0	5	11	16	0	0
2004	55	0	12	0	17	50	63	0	4
2005	41	0	11	7	12	33	41	0	11
2006	110	0	0	13	14	83	110	0	0
2007	47	0	15	0	0	62	53	0	9
2008	11	0	9	0	0	20	20	0	0

Table A4 –2: Number of observed sets by with and without wire leaders, shark lines or shark baits, by year, for the Chinese fleet.

	Shark line			Wire trace			Shark bait		
	NO	UNCERTAIN	YES	NO	UNCERTAIN	YES	NO	UNKNOWN	YES
1993	0	17	0	0	17	0	17	0	0
1994	0	28	0	0	28	0	28	0	0
1995	0	87	0	0	87	0	79	0	8
1996	0	69	0	0	69	0	69	0	0
1997	0	89	0	0	89	0	89	0	0
1998	0	81	0	0	81	0	74	0	7
1999	0	64	0	0	64	0	64	0	0
2000	0	69	0	0	69	0	68	0	1
2001	0	52	0	0	52	0	52	0	0
2002	6	0	0	0	6	0	6	0	0
2003	5	0	0	0	5	0	5	0	0
2004	113	0	41	10	60	84	121	0	33
2005	177	0	10	0	50	137	179	0	8
2006	410	0	113	7	43	473	508	0	15
2007	298	0	207	56	0	449	480	0	25
2008	49	0	35	12	9	63	84	0	0
2009	67	0	0	0	0	67	67	0	0

Oceanic whitetip shark: Primary model

Table A4-3: ZINB model based estimates of model term coefficients, standard errors and significance.

```
Count model coefficients (negbin with log link):
               Estimate Std. Error z value Pr(>|z|)    
(Intercept)    12.36984    7.27491   1.700   0.0891 .  
yy2005         -0.28697    0.36133  -0.794   0.4271    
yy2006         -0.55448    0.28633  -1.937   0.0528 .  
yy2007         -0.02747    0.28414  -0.097   0.9230    
yy2008         -0.51742    0.37417  -1.383   0.1667    
yy2009         -0.18517    0.41657  -0.445   0.6567    
sst            -0.22484    0.14713  -1.528   0.1265    
hk_bt_flt      -0.20065    0.03246  -6.182 6.35e-10 ***
settimed       -0.14812    0.05822  -2.544   0.0110 *  
lat             0.03259    0.02493   1.307   0.1911    
lon            -0.04499    0.02491  -1.806   0.0709 .  
wire_trace2YES -0.92601    0.45862  -2.019   0.0435 *  
SHKLINE3YES     0.95970    0.21627   4.437 9.10e-06 ***
Log(theta)      0.34237    0.29882   1.146   0.2519    

Zero-inflation model coefficients (binomial with logit link):
            Estimate Std. Error z value Pr(>|z|)   
(Intercept)  3.32939    1.24533   2.674  0.00751 **
hk_bt_flt   -0.16835    0.07369  -2.285  0.02233 * 
SHKLINE3YES -1.64138    0.57310  -2.864  0.00418 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

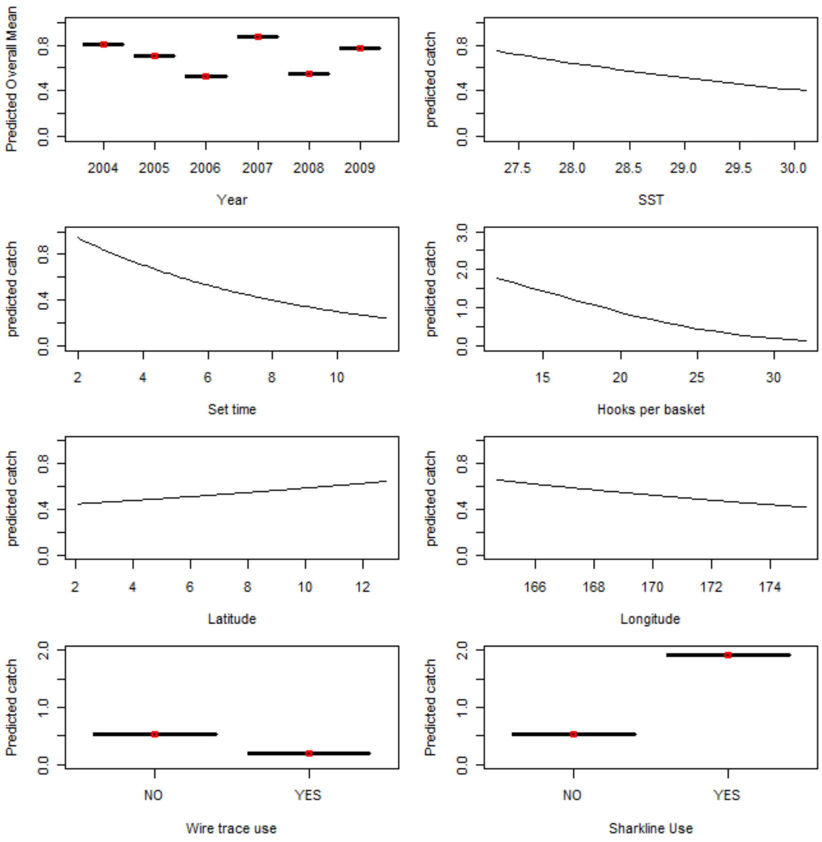


Figure A4-1: Relative influence of different model terms upon the mean predicted catch per thousand hooks

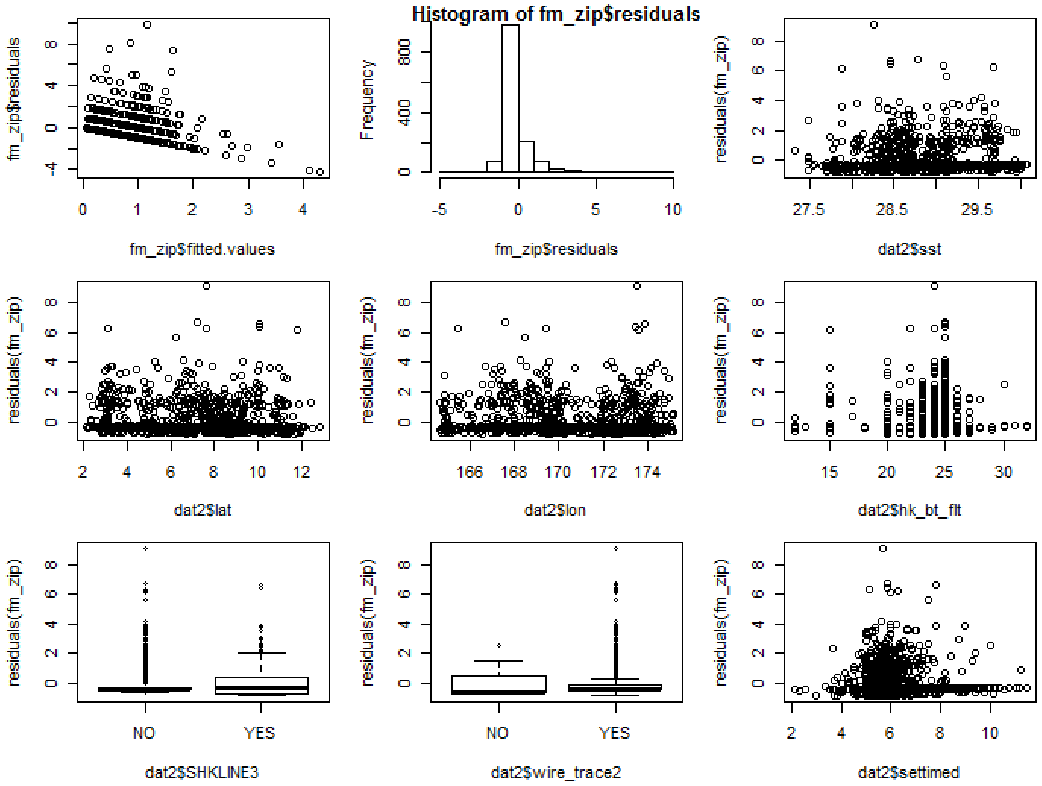


Figure A4-2: Various residuals based model diagnostics

Oceanic Whitetip Shark – Seondary model

Table A4-4: ZINB model based estimates of model term coefficients, standard errors and significance.

```
Count model coefficients (negbin with log link):
              Estimate Std. Error z value Pr(>|z|)    
(Intercept) 10.467010   7.145973   1.465  0.14299    
yy2005      -0.319297   0.372381  -0.857  0.39120    
yy2006      -0.519231   0.301697  -1.721  0.08524 .  
yy2007       0.007836   0.299820   0.026  0.97915    
yy2008      -0.386605   0.386258  -1.001  0.31688    
yy2009      -0.067035   0.428377  -0.156  0.87565    
sst         -0.210656   0.148075  -1.423  0.15484    
hk_bt_flt   -0.179321   0.027964  -6.413 1.43e-10 ***
settimed    -0.126390   0.057856  -2.185  0.02892 *  
lat          0.030560   0.025603   1.194  0.23262    
lon         -0.048031   0.024356  -1.972  0.04860 *  
shkfacs2NNN  0.996403   0.442433   2.252  0.02432 *  
shkfacs2WLB  0.906595   0.277023   3.273  0.00107 ** 
shkfacs2WLN  1.334999   0.120983  11.035  < 2e-16 ***
Log(theta)  -0.080403   0.148708  -0.541  0.58873    

Zero-inflation model coefficients (binomial with logit link):
            Estimate Std. Error z value Pr(>|z|)  
(Intercept)  13.0622     6.2628   2.086   0.0370 *
hk_bt_flt    -0.9665     0.4925  -1.962   0.0497 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 

Theta = 0.9227 
Number of iterations in BFGS optimization: 64 
Log-likelihood: -1141 on 17 Df
```

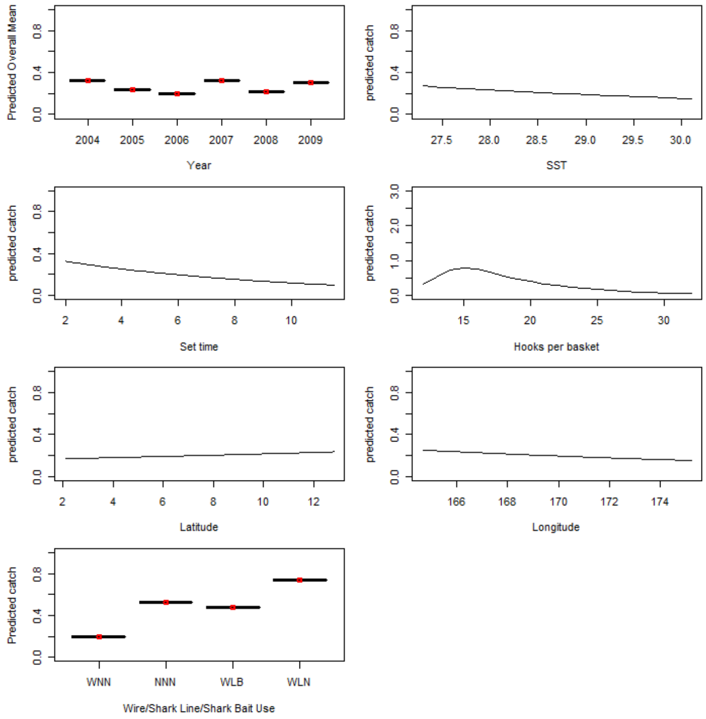


Figure A4-3: Relative influence of different model terms upon the mean predicted catch per thousand hooks

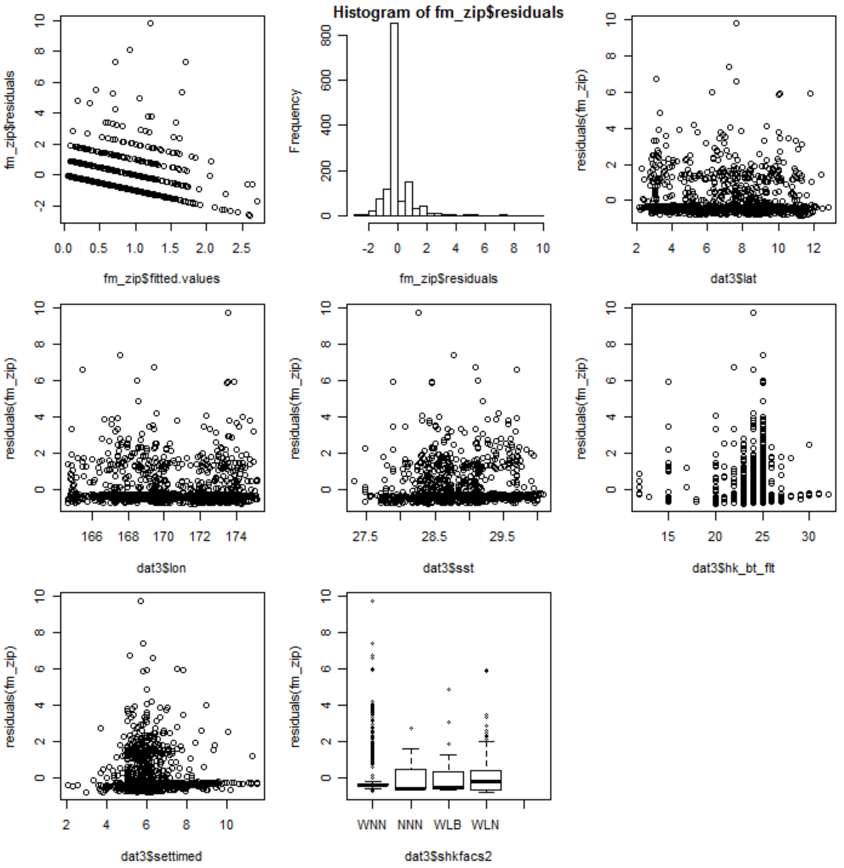


Figure A4-4 Various residuals based model diagnostics

Silky shark: Primary model

Table A4-5: ZINB model based estimates of model term coefficients, standard errors and significance.

```
Count model coefficients (negbin with log link):
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  0.81566    4.84159   0.168 0.866213
yy2005      -0.41186    0.22671  -1.817 0.069271 .
yy2006      -0.50204    0.20170  -2.489 0.012810 *
yy2007       0.28656    0.19562   1.465 0.142952
yy2008       0.07356    0.26990   0.273 0.785196
yy2009      -0.87148    0.29268  -2.978 0.002905 **
sst         -0.02752    0.09575  -0.287 0.773772
hk_bt_flt   -0.05941    0.01824  -3.256 0.001129 **
lat         -0.07569    0.01986  -3.811 0.000138 ***
lon         -0.02962    0.01731  -1.711 0.087144 .
SHKLINE3YES  0.47887    0.08513   5.625 1.85e-08 ***
Log(theta)  -0.05856    0.08262  -0.709 0.478464

Zero-inflation model coefficients (binomial with logit link):
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  9.10742    2.20707   4.126 3.68e-05 ***
hk_bt_flt   -0.33936    0.07942  -4.273 1.93e-05 ***
lat         -0.80253    0.23369  -3.434 0.000595 ***
SHKLINE3YES -1.40241    0.77857  -1.801 0.071662 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

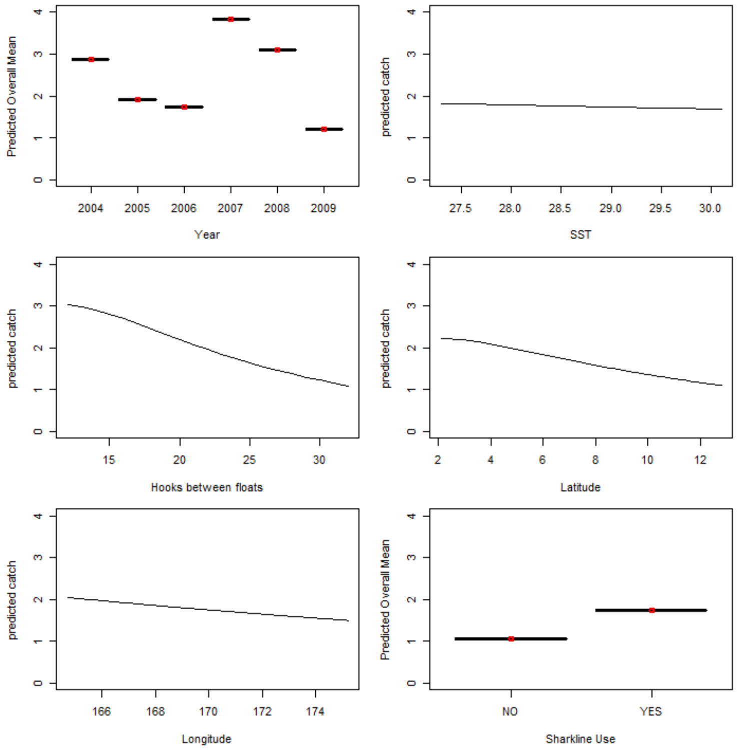


Figure A4-5: Relative influence of different model terms upon the mean predicted catch per thousand hooks

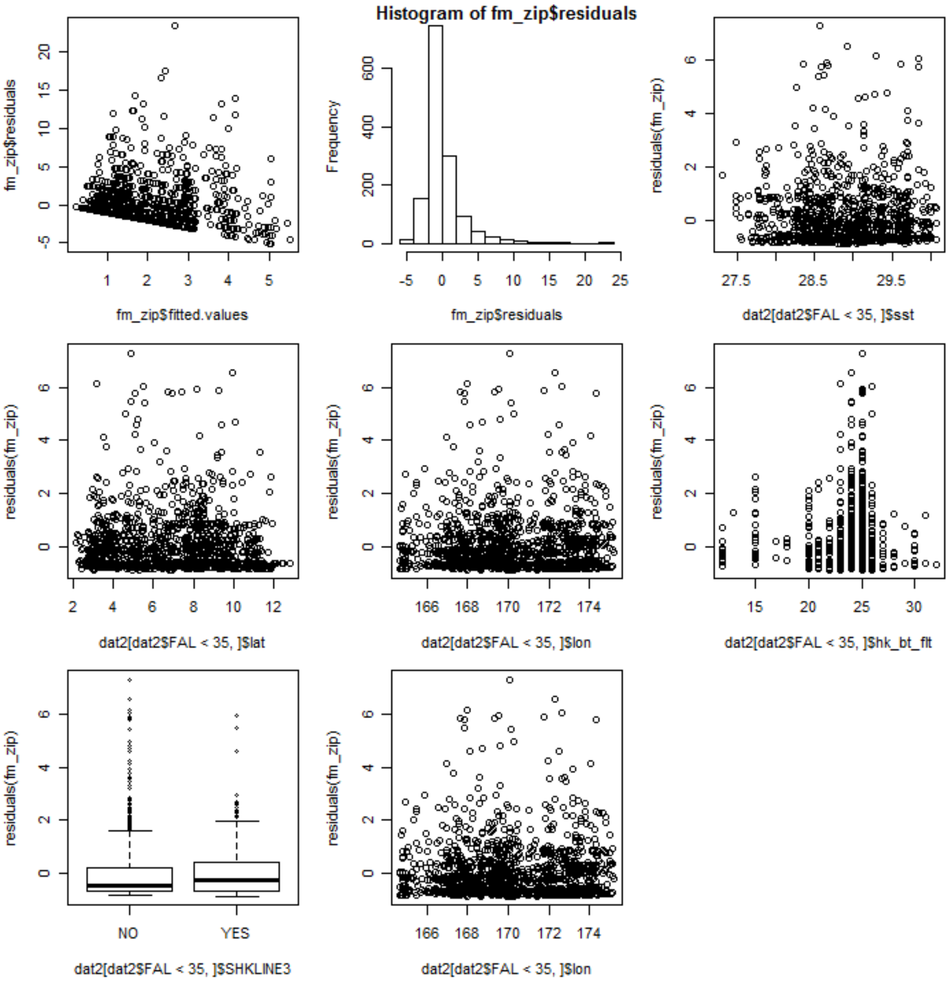


Figure A4-6: Various residuals based model diagnostics

Silky Shark – Secondary model

Table A4-6: ZINB model based estimates of model term coefficients, standard errors and significance.

```
Count model coefficients (negbin with log link):
             Estimate Std. Error z value Pr(>|z|)
(Intercept)   1.54904    4.90416   0.316 0.752107
yy2005       -0.28666    0.24629  -1.164 0.244459
yy2006       -0.38454    0.22245  -1.729 0.083869 .
yy2007        0.39726    0.21816   1.821 0.068614 .
yy2008        0.19735    0.28599   0.690 0.490147
yy2009       -0.75866    0.30847  -2.459 0.013916 *
sst          -0.05135    0.09691  -0.530 0.596198
hk_bt_flt    -0.05678    0.01867  -3.041 0.002361 **
lat          -0.07348    0.01986  -3.700 0.000216 ***
lon          -0.03120    0.01752  -1.781 0.074960 .
shkfacs2NNN   0.47454    0.35330   1.343 0.179213
shkfacs2WLB   0.61172    0.19380   3.156 0.001597 **
shkfacs2WLN   0.50827    0.08977   5.662 1.49e-08 ***
Log(theta)   -0.08069    0.08031  -1.005 0.315064

Zero-inflation model coefficients (binomial with logit link):
             Estimate Std. Error z value Pr(>|z|)
(Intercept)   8.98364    2.07538   4.329 1.50e-05 ***
hk_bt_flt    -0.34169    0.07701  -4.437 9.13e-06 ***
lat          -0.87219    0.25588  -3.409 0.000653 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

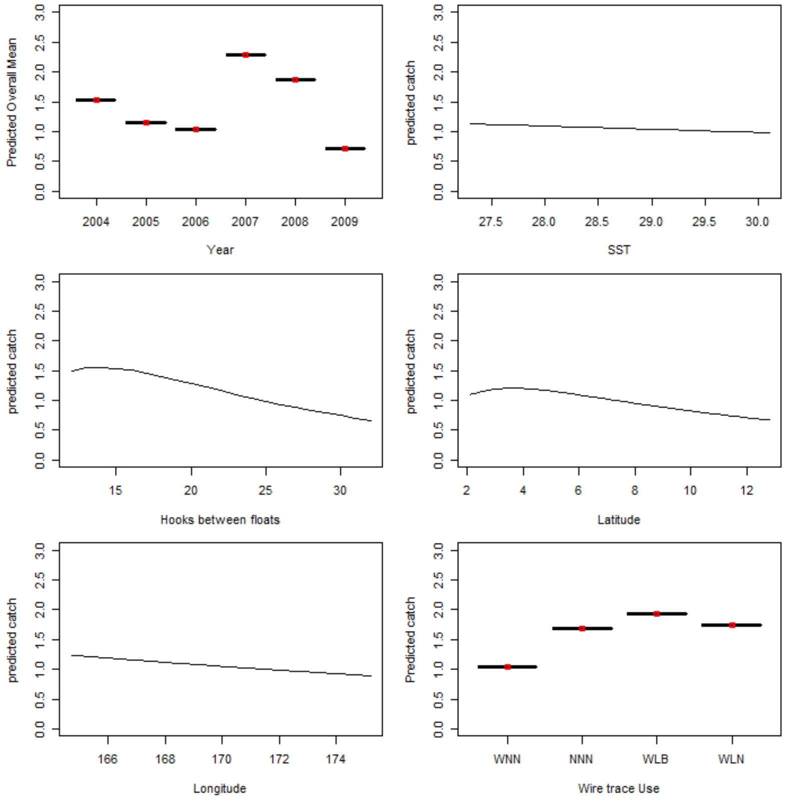


Figure A4-8: Relative influence of different model terms upon the mean predicted catch per thousand hooks

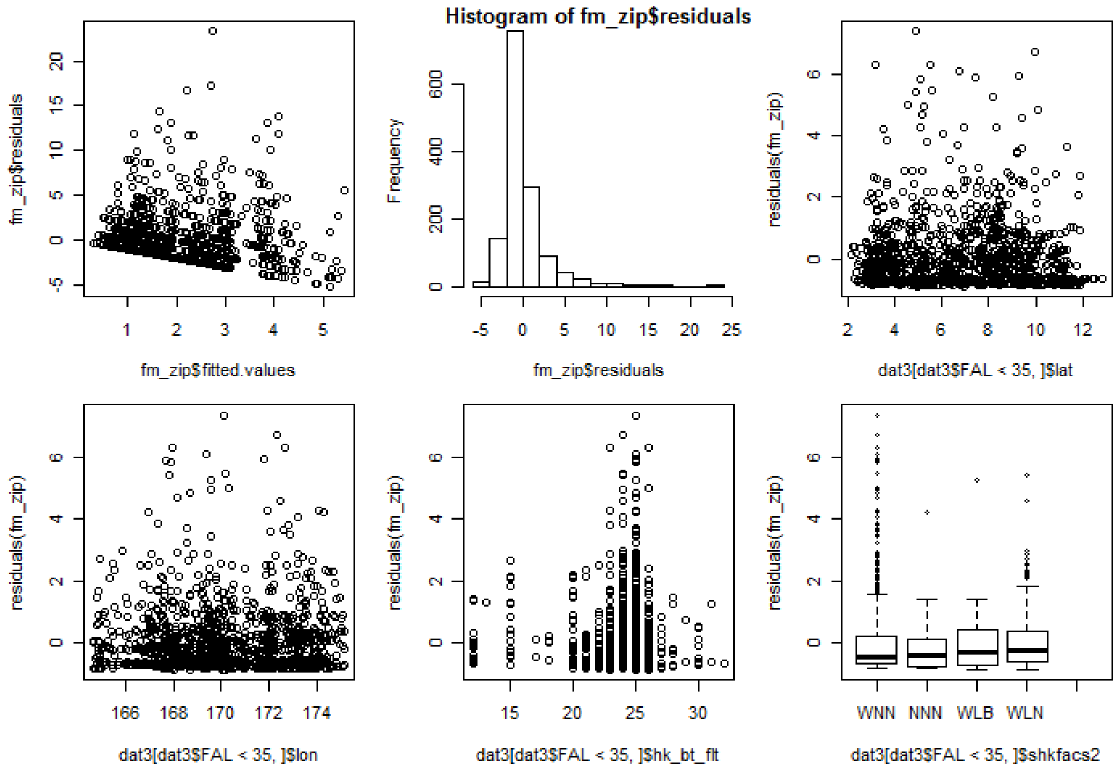


Figure A4-6: Various residuals based model diagnostics

Appendix 5 – Tables of fishery specific key factors for fisheries not included in model based analyses

French Polynesia

Table A5-1: Number of observed sets by hook and leader type category (combined) and year in the French Polynesia longline fishery, where: C=Circle hook; JH = J Hook; T = Tuna hook; O = Offset; W = Wire leader used, UN= Unknown/Uncertain. MX = mixed hook types. Where "W" is not included it is assumed a monofilament leader or non wire leader was used. Where "O" is not indicated, the hook is assumed to not be offset.

	C	C_W	JH	JH_W	MX	T	T_W	UN	UN_W
1990	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	2	0
1994	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	66	0
1998	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	66	0
2003	0	0	0	0	0	0	0	177	0
2004	0	0	0	0	0	0	0	173	5
2005	0	0	0	0	0	0	0	90	51
2006	0	0	0	0	0	0	0	93	204
2007	0	0	0	0	0	0	0	22	114
2008	0	0	0	0	0	33	0	59	97
2009	0	8	0	12	30	48	176	45	120
2010	6	41	4	26	39	83	175	30	30
2011	17	20	0	0	88	104	61	18	0
2012	35	9	0	0	24	16	0	0	0

Hawaii shallow set longline fishery

Table A5-2: Number of observed sets by hook and leader type category (combined) and year in the Hawaii based shallow-set longline fishery, where: C=Circle hook; JH = J Hook; T = Tuna hook; O = Offset; W = Wire leader used; X=unknown. Where "W" is not included it is assumed a monofilament leader or non wire leader was used. Where "O" is not indicated, the hook is assumed to not be offset.

	C	C_O	C_O_W	JH	JH_O	JH_W	T_O	X
1990	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0
1994	0	0	0	209	98	0	9	15
1995	0	0	0	228	17	0	37	16
1996	0	0	0	276	21	14	45	8
1997	0	0	0	288	0	0	33	0
1998	0	0	0	300	0	15	0	2
1999	0	0	0	193	0	0	0	0
2000	0	0	0	431	0	0	0	1
2001	0	0	0	144	0	0	0	29
2002	0	0	0	2	0	0	0	22
2003	0	0	0	0	0	0	0	17
2004	59	23	0	0	8	0	0	50
2005	107	1017	57	0	7	0	0	449
2006	0	828	0	0	0	0	0	19
2007	28	1540	0	0	0	0	0	0
2008	0	1583	17	0	0	0	0	0
2009	0	1748	11	0	0	0	0	0
2010	0	1873	0	0	0	0	0	0
2011	0	1460	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0

New Caledonia albacore fishery

Table A5-3 - Number of observed sets by hook and leader type category (combined) and year in the New Caledonian based albacore longline fishery, where: C=Circle hook; JH = J Hook; T = Tuna hook; O = Offset; W = Wire leader used; UN=unknown; MX=mix of hooks. Where "W" is not included it is assumed a monofilament leader or non wire leader was used. Where "O" is not indicated, the hook is assumed to not be offset.

	C	C_MX	C_MX_UN	C_MX_W	C_W	MX	T	T_UN	T_W	UN	UN_UN	UN_W
1990	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	4	0
1993	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	48	7
1997	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	6	21
1999	0	0	0	0	0	0	0	0	0	0	6	17
2000	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	18	0
2002	0	0	0	0	0	0	0	0	0	0	56	0
2003	0	0	0	0	0	0	0	0	0	0	81	0
2004	0	0	0	0	0	0	0	0	0	0	56	28
2005	0	0	0	0	0	0	0	0	0	0	7	28
2006	0	0	0	0	0	0	0	0	0	29	0	17
2007	0	0	0	0	0	0	0	0	0	57	0	1
2008	0	0	0	0	0	0	0	0	0	76	0	8
2009	129	26	0	0	10	0	0	0	0	45	0	0
2010	152	19	0	0	0	9	8	0	0	0	37	0
2011	64	0	17	0	0	8	0	9	0	57	15	0
2012	0	0	0	0	0	0	0	0	0	0	0	0

Vanuatu

Table A5-4 - Number of observed sets by hook and leader type category (combined) and year in the Vanuatu based albacore longline fishery where: C=Circle hook; JH = J Hook; T = Tuna hook; O = Offset; W = Wire leader used; UN=unknown; MX=mix of hooks. Where "W" is not included it is assumed a monofilament leader or non wire leader was used. Where "O" is not indicated, the hook is assumed to not be offset.

	C_MX	C_MX_UN	C_MX_W	T_UN	T_W	UN_W
2009	9	0	3	9	14	4
2010	67	16	9	0	26	0

Papua New Guinea

Table A5-5 - Number of observed sets by leader, shark line and bait type category and year in the Papua New Guinea tuna longline fishery

	Wire trace use			Sharkline use			Sharkbait use		
	No_Wire	Unknown	Wire	No_Sharkline	Unknown	Sharkline	No_Sharkbait	Unknown	Sharkbait
1990	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0
1996	0	9	0	0	9	0	9	0	0
1997	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0
2000	0	10	0	0	10	0	10	0	0
2001	0	41	0	0	41	0	41	0	0
2002	0	84	0	84	0	0	84	0	0
2003	0	70	30	100	0	0	100	0	0
2004	0	60	77	137	0	0	137	0	0
2005	23	26	72	121	0	0	121	0	0
2006	35	0	85	118	0	2	118	0	2
2007	29	0	0	29	0	0	29	0	0
2008	0	0	111	111	0	0	111	0	0
2009	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0

Solomon Islands tuna fishery

Solomon Islands fleet

Table A5-6 - Number of observed sets by leader, shark line and bait type category and year in the Solomon Islands flagged tuna longline fleet

	No_Wire	Unknown	Wire	No_Sharkline	Unknown	Sharkline	No_Sharkbait	Unknown	Sharkbait
1996	0	7	0	0	7	0	7	0	0
1997	0	21	0	0	21	0	21	0	0
1998	0	9	17	0	26	0	26	0	0
1999	0	27	11	2	36	0	37	0	1
2000	0	51	0	1	50	0	51	0	0
2001	0	60	0	1	58	1	59	0	1
2002	0	361	7	368	0	0	310	0	58
2003	0	229	25	253	0	1	235	0	19
2004	0	54	105	159	0	0	149	0	10

Taiwan fleet

Table A5-7 - Number of observed sets by leader, shark line and bait type category and year in the Taiwan flagged tuna longline fleet

	No_Wire	Unknown	Wire	No_Sharkline	Unknown	Sharkline	No_Sharkbait	Unknown	Sharkbait
1997	0	45	0	0	45	0	45	0	0
1998	0	23	43	0	66	0	23	0	43
1999	0	18	20	0	38	0	38	0	0
2000	0	50	0	3	47	0	32	0	18
2001	0	25	0	0	25	0	17	0	8
2002	0	150	0	150	0	0	118	0	32
2003	0	105	0	104	0	1	96	0	9
2004	0	28	30	58	0	0	58	0	0

RMI/FSM Fishery

Table A5-8 Taiwan excluded fleet

	Shark line			Wire trace			Shark bait		
	NO	UNCERTAIN	YES	NO	UNCERTAIN	YES	NO	UNKNOWN	YES
1993	0	34	0	0	34	0	34	0	0
1994	0	91	0	0	91	0	90	0	1
1995	0	62	0	0	62	0	55	0	7
1996	0	0	0	0	0	0	0	0	0
1997	0	50	0	0	50	0	50	0	0
1998	0	69	0	0	54	15	68	0	1
1999	0	30	0	0	30	0	30	0	0
2000	0	67	0	0	67	0	62	0	5
2001	0	17	0	0	17	0	17	0	0
2002	15	0	0	0	15	0	15	0	0
2003	0	0	0	0	0	0	0	0	0
2004	8	0	0	0	0	8	6	0	2
2005	0	0	0	0	0	0	0	0	0
2006	6	0	0	0	4	2	5	0	1
2007	8	0	0	8	0	0	8	0	0
2008	43	0	4	40	0	7	33	0	14
2009	53	0	0	42	0	11	53	0	0
2010	1	0	0	1	0	0	1	0	0

Table A5-9 – Japan excluded fleet

	Shark line			Wire trace			Shark bait		
	NO	UNCERTAIN	YES	NO	UNCERTAIN	YES	NO	UNKNOWN	YES
1990	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	23	0	0	23	0	23	0	0
1994	0	38	0	0	38	0	38	0	0
1995	0	40	0	0	40	0	40	0	0
1996	0	33	0	0	33	0	33	0	0
1997	0	90	0	0	90	0	90	0	0
1998	0	33	0	0	33	0	33	0	0
1999	0	36	0	0	36	0	36	0	0
2000	0	16	0	0	16	0	16	0	0
2001	0	1	0	0	1	0	1	0	0
2002	38	0	0	0	38	0	38	0	0
2003	0	0	0	0	0	0	0	0	0
2004	20	0	0	0	20	0	20	0	0
2005	79	0	0	38	41	0	79	0	0
2006	26	0	0	26	0	0	26	0	0
2007	28	0	0	28	0	0	28	0	0
2008	0	0	0	0	0	0	0	0	0
2009	4	0	0	4	0	0	4	0	0
2010	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0