Received: 14 June 2013

Maldives Kawakawa Pole and Line Fishery Catch Rate Standardization: 2004-2011

June 2013

Rishi Sharma (rishi.sharma@iotc.org, IOTC Secretariat, Seychelles)

James Geehan (james.geehan@iotc.org, IOTC Secretariat, Seychelles)

M. Shiham Adam (Marine Research Centre, Ministry of Fisheries and Agriculture, Maldives)

Riyaz Jauhary (Marine Research Centre, Ministry of Fisheries and Agriculture, Maldives)

Abstract

A qualitative description and GLM-based standardization of the Maldivian kawakawa (*Euthynnus affinis*, KAW) pole and line fishery catch rate data are presented for the period 2004-2011. The raw data consists of around 124000 records of catch (numbers) and effort (fishing days) by month, atoll and vessel; vessel characteristics were added to the CPUE dataset based on information from the registry of vessels. A subset of 25,762 records were extracted from the dataset, identified as records of fishing activity targeting KAW. FAD data was also incorporated into the analysis using the number of active FADS associated with the nearest atoll that the landing data is collected from. Techniques similar to those used in the standardization of skipjack tuna were used. The distribution of FADs was split into three regions incorporating the North Atolls, Middle Atoll and South Atolls. Vessel specific data including hull-type effects, length of the boat (as a vessel size class) and horse power was also used in the analysis. GLM based models using a log response on CPUE were examined. The final model presented estimated log(CPUE) from independent variables Year, Month, Area (N, S, or M), number of FADs used in the area, and Length of vessel, and interaction effects between the last 3 categories. The data was analysed at a monthly resolution before being was collapsed into quarterly signals for 2004-2011, and finally an annual signal 2004-2011 for analysis in KAW surplus production assessment fit to the CPUE series derived here.

Introduction

Indian Ocean Kawakawa (*Euthynnus affinis*)

Although primarily distributed in the central Pacific, Kawakawa is an important fishery for a number of countries in the Indian Ocean region; namely Iran, Indonesia, India, Malaysia, and Thailand. Numerous other countries also catch the species (Figure 2). The species is primarily caught by Purse Seine and gillnets, but other gears (Figure 2) are also used to catch the species.

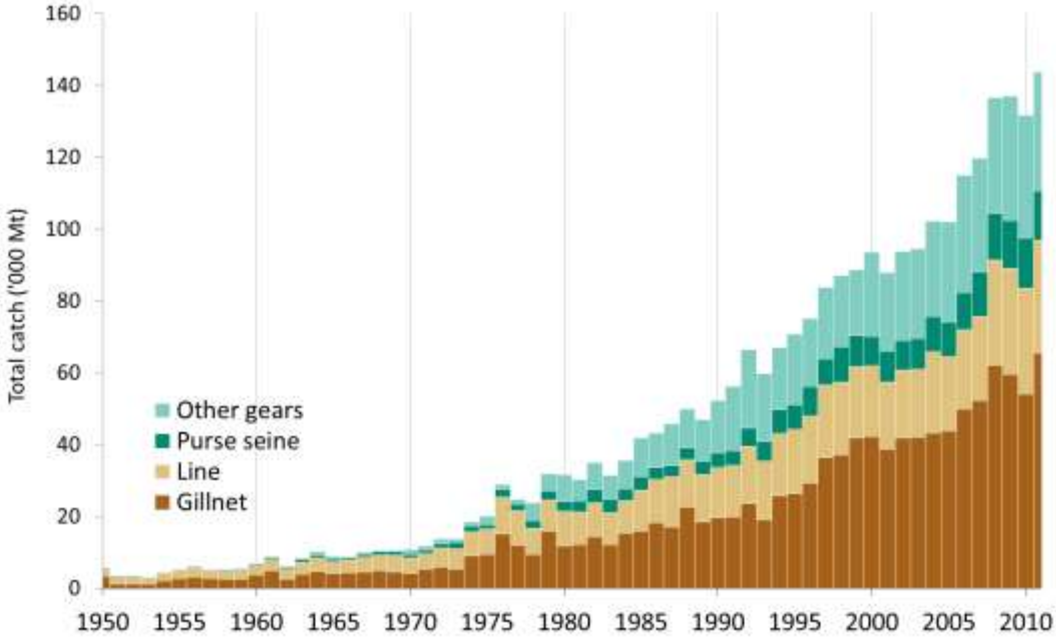


Figure 1. Annual catches of kawakawa by main gear (1950-2011). Source: IOTC database.

The countries that are the primary users of the resource are India, Indonesia and Iran. An attempt to re-estimate the catches across the region[1], is being undertaken in the Indian Ocean region, and it is likely that some of the numbers reported will be revised (Figure 4, Table 1).

[1] Guillermo Moreno, consultant working for IOTC is revising the data with the secretariat

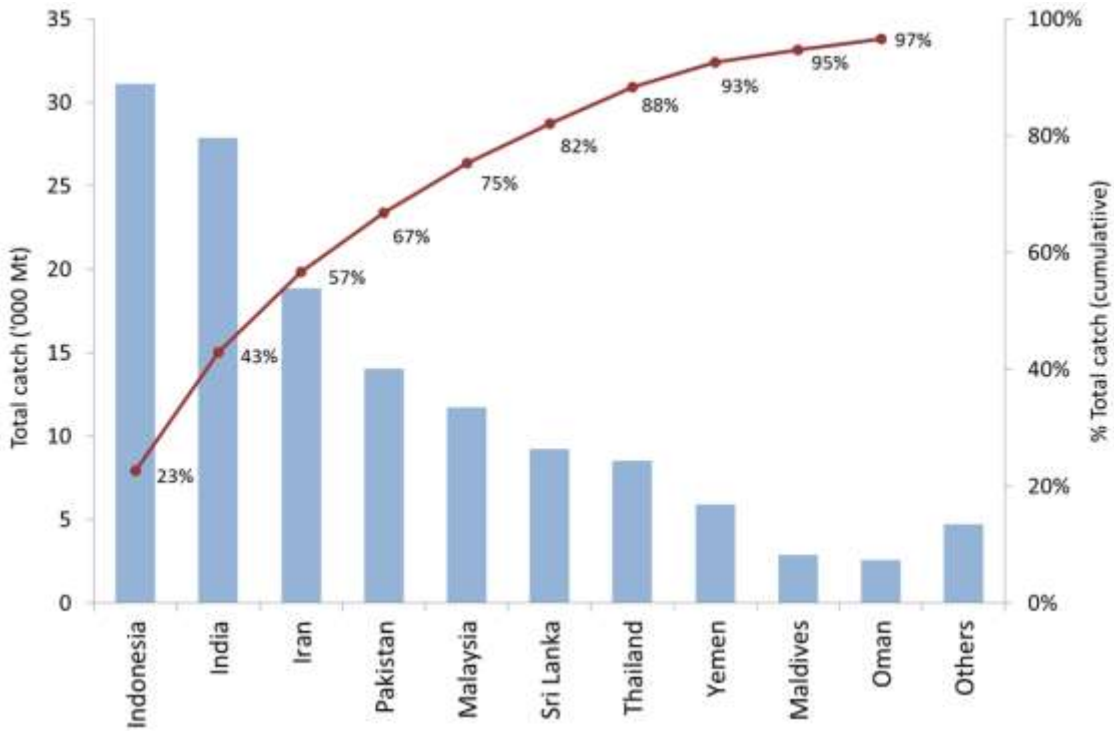


Figure 2: Average catch of Kawakawa (2009-2011) by country (in ranked) order. The red line indicates the cumulative proportion of total kawakawa catch for the countries concerned, over the total combined catch of kawakawa reported from all countries and fisheries. Source: IOTC database.

The trend in the nominal catch of kawakawa has increased in recent years primarily due to increases in effort by Iran and Indonesia, In addition the effects of piracy off the coast of Somalia has redirected fishing effort from Tropical Tunas species to coastal lneritic tuna by countries such as Iran, Pakistan and other Arabian gulf countries.

Although Maldives is not one of the major fleets catching Kawakawa, they consistently account for around 2-5% of the total catch and may still be a useful indicator to use for an index of abundance. This is the first attempt to use the Maldives operational data and estimate CPUE trends correcting for exogenous variables so it is representative of overall abundance.

Methods

Data and Pre-processing

Three data sets were used in the analysis, provided by the Maldives Ministry of Fisheries and Agriculture (MoFA):

i. Monthly catch and effort data 2004-2011, by atoll and vessel.
ii. The registry of vessels 1958-2011, containing vessel dimensions including length and horsepower.
iii. Anchored FAD database from 1981-2012, including the FAD location, nearest atoll, date of deployment and date the FAD was either lost or recovered.

These data remain confidential, however descriptive and graphical summaries of the data are provided below.

Monthly Catch and Effort Data 2004-2011

The CPUE dataset provided by MoFA/MRC[2] consists of monthly observations of catch and effort (days per month) by vessel, for 2004 to 2011, and includes information taken from log-books for 2010 and 2011. The dataset includes the following fields of relevance to the analysis:

- Year, Month, Atoll of fishing activity
- Vessel Identification Number (VIN) (which can be linked to the vessel registry)
- Fishery type (e.g., skipjack, lobster, resort/sport fishing)
- Gear type
- Effort in boat days
- Catch in numbers and mass (Mt), by species
- Hull Type, Vessel length, Vessel Category, and Horsepower

A sub-set of records were extracted for the analysis identified as fishing activity targeting Kawakawa. In the process, a number of issues related to missing information or the quality of the data led to a number of records being omitted from the final analysis.

The data were initially filtered on gear ('pole and line') however it was noted around 61% of selected records reported zero KAW catch (but positive effort) over a number of months. While not uncommon that KAW cannot be located during single trips, it is unlikely vessels targeting KAW would fail to catch any on a regular basis; nor is there evidence of strong enough seasonality in the nominal catch series to suggest long periods of no catch should be expected. Several alternative explanations were proposed:

- Recorded gear and fishery type
  The biggest problem is thought to be misreporting of gear and/or fishery type. Many of the vessels operating as pole and line or handline vessels are actually targeting large yellowfin and thus fail to record this correctly.
- Partial landings
  Some fishing vessels might only be reporting landings made at the home port, and exclude catch unloaded at the canneries, land-based collection facility[3], or transferred to collector vessels. In theory – irrespective of wherever the landing occurred – it is expected that the catch would also be reported at the home port; however this can no longer be guaranteed, particularly as the traditional manner of reporting at the home port has not been followed for vessels participating in the new logbook programme (covering <10% of vessels in 2010). As such, there is the possibility that observed changes (i.e., decline) in the nominal catch may be an artefact of partial unloading in collector vessels or changes to the reporting system.

- Deliberate misreporting of effort
  Prior to 2009, a license fee was levied for boats operating for less than 120 days within a calendar year. This is thought to have resulted in effort being recorded for boats that

[2] Data provided in Excel format by MoFA, MRC: 'newdatasetFADS.csv ', with 2011 superseded by 'Catch_Effort_2009.xlsx', 'Catch_Effort_2011.xlsx'.
[3] There are two major collection centres, in the North Felivaru, operated by MIFCO an the other in the South, Kooddoo Fisheries Maldives Pvt, ltd., previously also operated by MIFCO

remained in port and consequently report no catch. The magnitude of the misreporting problem is not known.

A number of other issues with the CPUE data were noted by the authors, but not corrected, for two reasons; either because (i.) they concern a small number of records and were considered to have a negligible impact on the final results, or (ii.) it was unclear how the records should be dealt with, and the preference was to include as many records in calculation of the CPUE as possible. For example:

- Missing vessel ID and/or dimensions
  13,500 records (11% of the total dataset) were missing either vessel identification numbers (VIN), or length and horsepower dimensions, required for modelling the relationship between CPUE and vessel efficiency in calculating the CPUE back-series to the 1970s.

- Invalid monthly effort
  A small number of records (45 in total) reported effort greater than 30 days in a month – which is highly unlikely – including 8 records which reported effort greater than 31 days. The discrepancies were largely attributed to a partial duplication of records due to port sampling activities (primarily in Malé).

- Reliability of atoll reported for fishing activity/landing
  The atoll assigned to each record is assumed to relate to area of fishing activity and landing site. Over two thirds of vessels report activity in only one atoll – in many cases over the course of many months, and even years, which is perhaps surprising. This raises questions on the accuracy of the atoll recorded by each vessel, but also the extent to which the fishing activity takes place in the same atoll as the landing place. The issue may confound analysis of the CPUE that attempts to model area effects based on variation between individual atolls or similarly low spatial resolutions; aggregating the data into larger geographic units (such as atoll region) may be the appropriate scale in studying the extent that variations in the CPUE are related to location.

- Effort of 1 day per month
  Traditionally, vessels have operated single day trips (as there is generally no refrigeration, but the boats may carry ice); multiday trips are more common in recent years, particularly for larger vessels. Around 5-60% of vessels targeting Kawakawa fish for 15 days or more (cumulatively) per month. However a number of vessels report only one day of effort per month (increasing to over a quarter of vessels in 2008 and 2009), which seems highly unusual (Appendix 1, figure 5). One suggestion is that these vessels are actually multi-purpose, and report the minimum effort (of 1 day) each month in order to claim financial subsidies available to fishing vessels.

Taking all of these issues into consideration, the authors followed the recommendation of MoFA/MRC in applying the following conditions in selecting records as representing vessel activity targeting kawakawa:

- Vessels operating Pole and line.

- Effort (in days) greater than zero, and KAW catch greater than zero.
- Records containing valid vessel identification (VIN) number.

Applying the criteria, a subset of 25,672 observations (around 21% from the total 123,792 CPUE records) were identified as targeting KAW and used in the final analysis. The nominal catch (and CPUE) in numbers were used for all analyses detailed below, as mass is calculated as the product of numbers reported. Effort used in the calculation of CPUE was taken as the number of days fishing; other measures of effort ('Gear quantity' and 'Total fishermen') were available, but not consistently reported for each vessel record.

Vessel Registry 1958-2010

The Ministry of Transport and Communication maintains the national registry of vessels, including fishing vessels. The vessel registry records key features of vessels over the period 1958-2010, and includes all of the vessels in the catch and effort database (although not all of the VIN entries were valid). Recorded vessel characteristics include length, breadth, depth, gross tonnage and horsepower, all of which are strongly correlated and expected to be positively related to fishing efficiency. We note that previous studies by Mohamed (2007) assumed that total effective effort of the pole and line fleet was directly proportional to annual average horsepower for the period 1985-2005 but, as previously stated, the relationship was not formally defined.

Vessels around ~12-17m represent the majority of observations in the CPUE dataset, although there is a modest trend in increased use of larger vessels from 2004 to 2011. For vessels identified as targeting KAW (based on the criteria discussed above), the average size of vessels increased from 13.3m in 2004 to 14.4 m by 2011 (vessels that targeted KAW were larger in 2008 and 2009 (15.3 m) though the vessel size decrease after that).

Anchored FADs 1981-2012

A database containing records of anchored FADs was also provided by MoFA/MRC, containing details of the date the FAD was deployed, date of recovery or that the FAD was lost, longitude/latitude, and nearest atoll.

Based on the date of deployment and recovery for each FAD, a list of active FADs was calculated for each month, for each atoll area and region (north, middle, and south), and added to the CPUE dataset by joining on the atoll recorded for each vessel activity.

Overview of main trends in KAW nominal catch and CPUE

- The nominal for kawakawa catch reported by Maldives over the last decade shows a generally stationary – albeit highly fluctuating – trend. The level of catch, even when aggregated by calendar quarter, range from as high as 800Mt to as low as 250Mt (Appendix 1, figure 1). The pattern of fishing effort similarly fluctuates by the similar magnitudes as the nominal catch, but indicates an overall decrease in effort over time.
- The nominal CPUE series shows a clearer trend between catch and effort, indicating an increase in CPUE over time in line with the decreasing effort (Appendix 1, figure 2).
- The majority of the nominal kawakawa catch – and effort to a lesser extent – tends to be concentrated among a small number of atolls (albeit noting the issues regarding the reliability to which atoll is reported for each activity and landing, discussed above). Of the 26 atolls in total, up to 70% of the kawakawa catch each year is concentrated in four atolls (Shaviyani (SH) in the

north, and Kaafu (KA), Alifu Alifu (AA), and Alifu Dhaalu (AD) in the mid atoll region (Appendix 1, figure 4).

- CPUE increases sharply with vessel size. Between 2009-2011 for example, a CPUE of 0.03 is reported for vessels 7-12m in length, 0.05 for vessels 12-17m in length (the most common vessel type), and 0.08 for vessels 17-22m.

Statistical Analysis

The goal of the catch rate standardization is to estimate a time series of catch rates that would be equivalent to what would be observed if the fishery consisted of a single vessel type, fishing in a consistent manner over time. Ideally this time series can be interpreted as being proportional to fishery-selected abundance in the stock assessment. First, the data were filtered in different ways to identify more reliable and/or homogeneous observations (using positive catches, positive efforts, identifiable VINS, and Pole and Line gear). Once this was done, standard GLM methods were employed (e.g. Maunder and Punt 2004) to estimate the effects of different factors in explaining CPUE variability that is not attributable to abundance, e.g. Using R software function *glm()*:

$$\log(CPUE_i) = \beta_T X_{T,i} + \beta_1 X_{1,i} \ldots \beta_n X_{n,i} + e_i \qquad (1)$$

where:

log(CPUE) = monthly CPUE observation *i*, transformed in various ways discussed below,

β_T = the temporal effect that we are interested in extracting as the relative abundance time series (quarterly 2004-2010), and $X_{T,i}$ is the time period of observation *i*,

$\beta_1 \ldots \beta_n$ = coefficients quantifying the effect of the other continuous or categorical explanatory variables ($X_{x,i}$) for observation *i*, and

e = normally distributed error with variance σ^2.

A range of models were examined (**Error! Reference source not found.**), with explanations of the ependent and independent variables provided below.

Independent Variables

The following independent variables were included in some or all models (**Error! Reference source ot found.**):

Y – Year.

M - Month.

A – Atoll, a spatial factor accounting for changes in the spatial distribution of effort. Since this is an indicator of the landing site, it may not always be a very accurate indication of fishing location, particularly now that mechanization allows long distances to be covered, and collector vessels are used.

L, f(L) – vessel length, a general indicator of vessel efficiency, should be correlated with the number of poles, bait capacity, range, hold size, etc. L was treated as either a categorical variable with levels

(<7m, 7 - <12m, 12 – <17m, 17 - <22m, 22 - <27m, 27 - <32m, 32 - <37m, note there was also one value of 58m in the filtered dataset).

V – Vessel Identity Number (VIN). The information contained in the VIN is confounded with L, and A (to the extent that vessels tend to remain around the same home port). But VIN could potentially be useful for identifying catchability effects from other sources (e.g. skipper skill). However, given the large number of vessels, V requires a large number of degrees of freedom. Nonetheless, we did look at a model that accounts for this and have included it as one of our sets for discussion.

Four final set of models are presented:

Model 1: Main effects model (Year and month interaction model)
Model 2: Interaction effects model using Vessel length as a covariate with Atoll area interactions.
Model 3: FAD effect model: Accounting for FAD effects at an aggregated spatial resolution (not Atoll but 3 areas, N, Mid, and S areas).

Standardized CPUE Series

The final model recommended was Model 4 as it incorporated vessel effects and FAD effects at an aggregated spatial resolution. This resolution maybe appropriate as vessels no longer operate in one Atoll, but multiple areas and land at various Atolls. Hence, the atoll effect detected while significant, maybe entirely spurious. The GLM parameter estimates were converted into an overall relative abundance index using a standard approach (e.g. Campbell 2004):

$$I_t = \exp(\beta_t + A \quad + f(L) \quad + FAD + A{:}f(L) + A{:}FAD + \tfrac{1}{2}\sigma^2) - C, \qquad (2)$$

where:

I is the index for time t,

β_t = the estimated time co-efficient,

A = the estimated co-efficient for the standard Area (mid area was chosen as it had the most records)

FAD= the number of active FADs in any given region (average number was used 21.24 across all regions and records)

f(L) is the estimated parameter for a standard vessel: length (17-22m) for the categorical case.

σ^2 is the estimated variance (Mean Squared Error), and

C is the small constant, to account for 0 CPUE's, but in our case we discarded these values due to data collection errors (mis-specified gear and fishery).

Results and Discussion

The data were processed using the filters stated above. 25,962 records were obtained after that. The basic data were plotted to looking at variations in nominal CPUE by month and the variation in catch rate by atoll (Figure 3 below). While there is not much variation in the catch rates by month, there is a substantial amount of variation in landings by ATOLL. For the reasons, stated above, we know that the landings data may not be where they were fishing and hence look at aggregated data in broader spatial locations (Figure 4 below) to look at landings over time using the categories shown in Appendix 1 Figure 3.

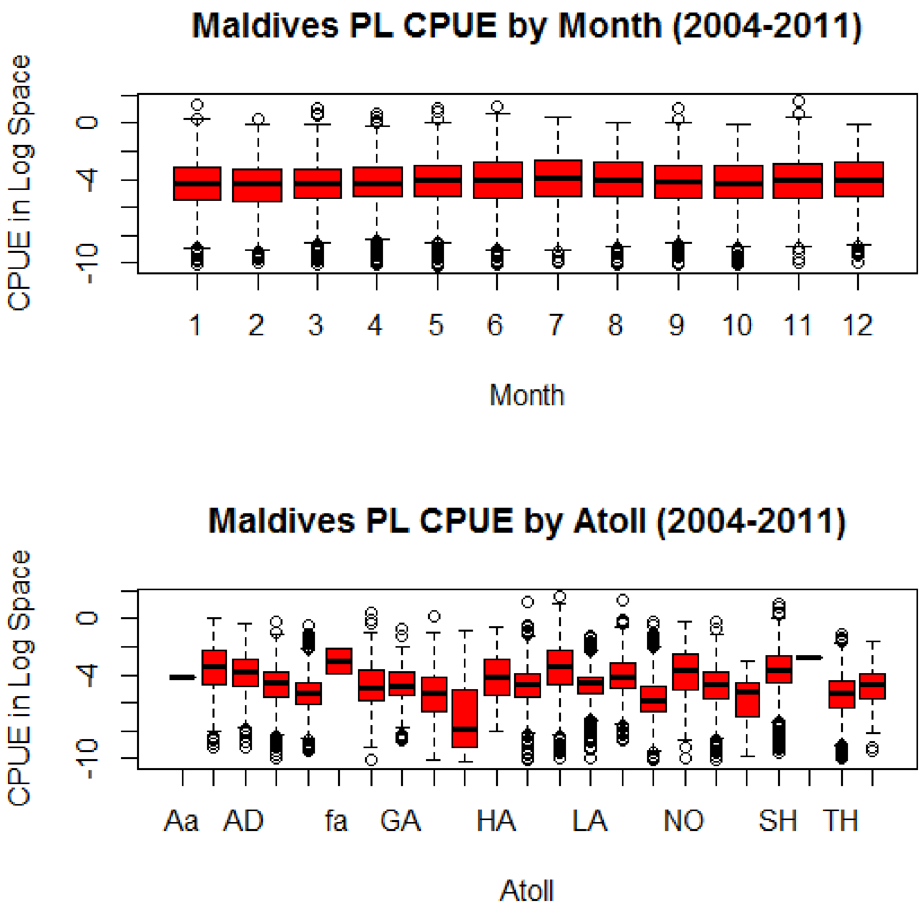


Figure 3: Aggregated nominal CPUE trends over atoll and month for the 8 years examined

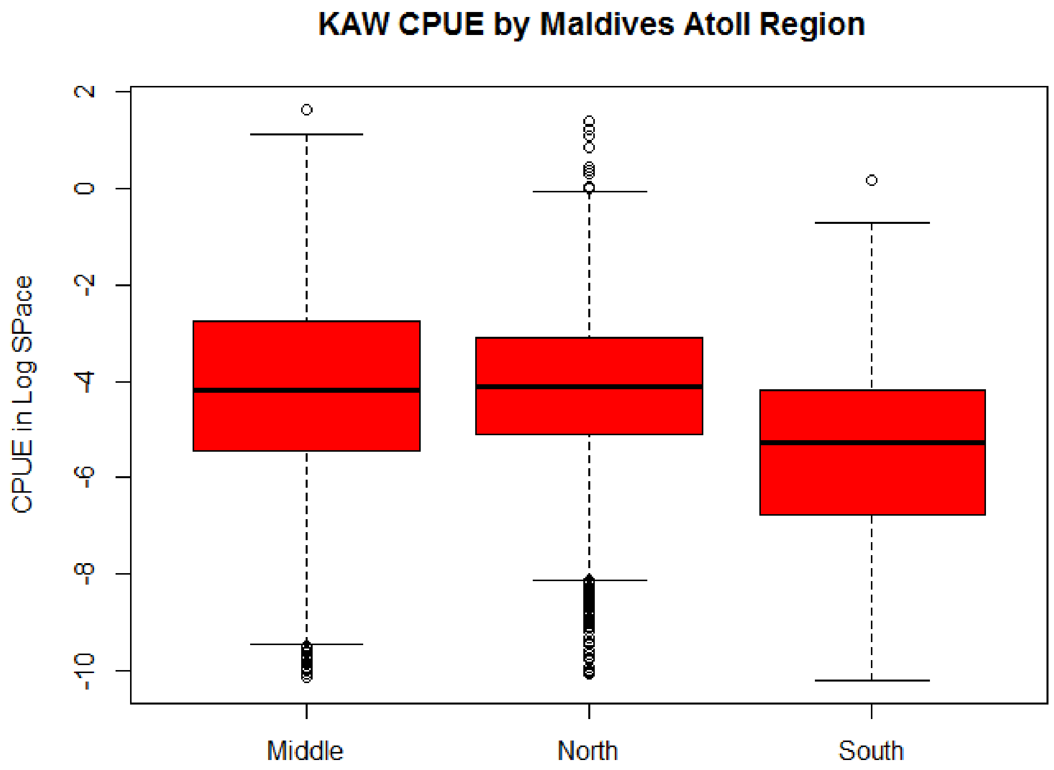


Figure 4: KAW CPUE by broader spatial locations.

Generalized Linear Models

The covariate factors used in model 1 are as follows:

$$\ln(CPUE_{i.m}) = \alpha_i Y_i + \sum_{x=1}^{12} \beta_x M_x + \sum_{y=1}^{n} \gamma_y A_y + \sum_{z=1}^{m} \theta_z V_z + \sum_{y=1}^{n} \sum_{z=1}^{m} \phi_{yz} A_y V_z + \eta G + \varepsilon \quad (4)$$

Where Y is the year effect, M the month effect, A an Atoll effect, V a length category effect for vessel size, and A*V is the Atoll and Vessel Length category interaction, and G is the gear effect.

When looking at an index we only used the Year and Month effects in the standardization.

The second and third index series examined was using the same model with all effects, averaged out for average vessel category (average vessel category was 3, between 12 and 17 m), and Northern Atoll used (Shaviyanai, SH) and also computed for southern atoll (Laamu, LA).

Since, there are no continuous measures used in the standardization, the indices when standardized to 1 are all equivalent.

The second model examined was:

$$\ln(CPUE_{i.m}) = \alpha_i Y_i + \sum_{x=1}^{12} \beta_x M_x + \sum_{y=1}^{n} \gamma_y A_y + \sum_{z=1}^{m} \theta_z VIN_z + \sum_{y=1}^{n} \sum_{z=1}^{m} \phi_{yz} A_y VIN_z + \varepsilon \quad (5)$$

Where all variables are identical to equation 4 except instead of a length category, we now use a VIN as a vessel effect, and due to large number of VINS lose a lot of degrees of freedom. This model had to deal with memory issues in R, and thus was abandoned as the VINs had too many degrees of freedom.

The 3rd model examined was incorporating FAD's (FAD variable is the number of active FADs) at a coarser scale than the atoll levels (Figure yy). We now have three areas (LA), (North (N), South(S), and Middle (M)). The model examined was:

$$\ln(CPUE_{i.m}) = \alpha_i Y_i + \sum_{x=1}^{12} \beta_x M_x + \sum_{y=1}^{n} \gamma_y LA_y + \sum_{z=1}^{m} \theta_z V_z + \lambda FAD + \sum_{y=1}^{n} \sum_{z=1}^{m} \phi_{yz} LA_y V_z + \sum_{y=1}^{n} \kappa_y LA_y + \varepsilon \quad (6)$$

Diagnostics of each of the 2 main model with ANOVAS (eq 4 & 6) are in Appendix 2 and 3 with the parameters as well.

Table 1 shows the results of the actual index and standardized index for the main effect model, the VIN model and the FAD based models.

Table 1: Results of the CPUE standardization (all models) and standardized (2models)

Year	Quarter	Model 1 (Year and Month Interaction)	Model 1 (Vessel:North)	Model 1 (Vessell:South)	Model 3: FAD effects model		Stdized Vessel:Atoll	Standardized FAD
2004	1	0.010	0.031	0.009	0.015		0.74	0.80
2004	2	0.013	0.038	0.011	0.016		0.90	0.86
2004	3	0.012	0.035	0.010	0.018		0.83	0.93
2004	4	0.008	0.025	0.007	0.016		0.60	0.84
2005	1	0.013	0.039	0.011	0.019		0.94	1.01
2005	2	0.016	0.048	0.014	0.021		1.15	1.09
2005	3	0.015	0.044	0.013	0.023		1.06	1.19
2005	4	0.011	0.032	0.009	0.020		0.77	1.07
2006	1	0.010	0.029	0.008	0.013		0.70	0.70
2006	2	0.012	0.036	0.010	0.014		0.86	0.75
2006	3	0.011	0.033	0.010	0.015		0.79	0.82
2006	4	0.008	0.024	0.007	0.014		0.58	0.73
2007	1	0.017	0.049	0.014	0.025		1.19	1.31
2007	2	0.020	0.060	0.017	0.027		1.45	1.41
2007	3	0.019	0.056	0.016	0.029		1.34	1.53
2007	4	0.014	0.040	0.012	0.026		0.97	1.38
2008	1	0.013	0.039	0.011	0.014		0.93	0.76
2008	2	0.016	0.048	0.014	0.016		1.14	0.82
2008	3	0.015	0.044	0.013	0.017		1.05	0.89
2008	4	0.011	0.032	0.009	0.015		0.76	0.80
2009	1	0.018	0.053	0.015	0.020		1.28	1.08
2009	2	0.022	0.065	0.019	0.022		1.56	1.16
2009	3	0.020	0.060	0.017	0.024		1.44	1.26
2009	4	0.015	0.044	0.013	0.022		1.04	1.14
2010	1	0.016	0.049	0.014	0.018		1.17	0.94
2010	2	0.020	0.060	0.017	0.019		1.43	1.01
2010	3	0.019	0.055	0.016	0.021		1.32	1.10
2010	4	0.013	0.040	0.012	0.019		0.96	0.99
2011	1	0.010	0.030	0.009	0.016		0.73	0.85
2011	2	0.013	0.037	0.011	0.017		0.89	0.91
2011	3	0.012	0.034	0.010	0.019		0.82	0.99
2011	4	0.008	0.025	0.007	0.017		0.60	0.89

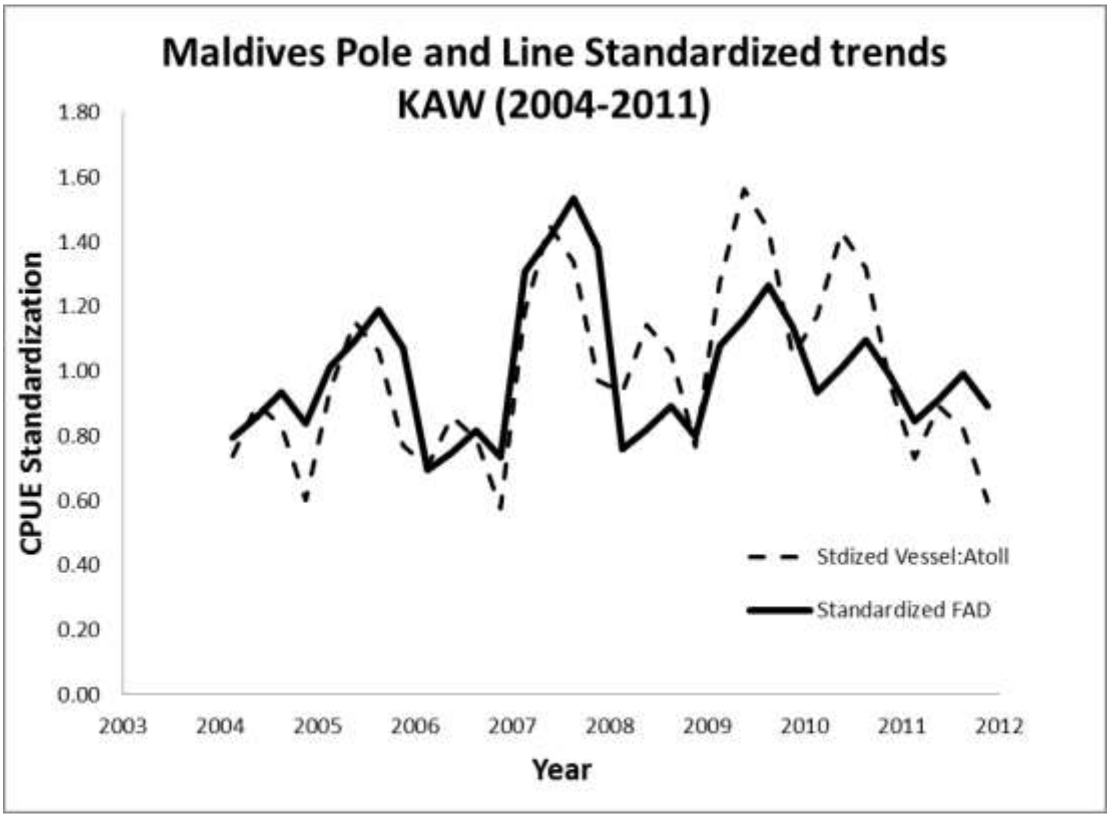


Figure 5: Standardized Index of the KAW CPUE Abundance trends using the 2 models discussed

Final Conclusions and Recommendations

The following caveats are noted with respect to the use of this time series in the context of the next KAW stock assessment:

Several issues remain regarding the quality of CPUE dataset; in many cases invalidating a number of records that could otherwise be useful as data inputs in the stock assessment. Specifically:

i. Large proportions of zero kawakawa catch are recorded in the Pole and line fishery – should they be discounted from the analysis?
ii. Completion of the missing vessel identification numbers or vessel dimensions from the CPUE dataset.
iii. Accuracy of the atoll recorded for fishing activity and landing – to what extent is it reasonable to associate the fishing activity and landing to the same atoll? Our approach of aggregating landings in 3 different regions overcomes – to some extent – uncertainty in associating fishing activity with the nearest landing.
iv. Clarification of the status of vessels reporting effort of 1 day per month (over a third of vessels up to 2009) – how should these be treated in the analysis?
v. Further improvements in the selection criteria for identifying Kawakawa targeted records; should a broader gear definition be used in selection criteria to reflect changes in skipjack targeted vessels (e.g., recent changes from pole and line to handline)?

vi. There are also operational factors that are suspected of being important, but for which there are no data (e.g. bait availability, technological innovation).

vii. An attempt is made to compare the effect of AFADs to the catch rate by aggregating CPUE data on a larger spatial scale (N,S and Mid Atoll). However, the analysis lacks contrast, as the relatively short time period covered corresponds only to recent peak catches in the fishery. In addition, anchored FAD fishing predominates during this period and can be expected to cause hyper-stability in CPUE indices. Our analysis does not account for this effect.

viii. Even if these CPUE series are reliable indicators of abundance for the Maldives region, there are additional concerns about using them as the primary input for a regional stock assessment, as the Maldives represents a very small part of the Indian Ocean KAW range, and abundance may not be representative of the whole population. Overall catches from this region are between 2 and 5% of the Indian Ocean catch.

ix. Genetic analyses should be conducted to examine how many KAW stocks there are in the Indian Ocean region and whether these data can be applied for the whole Indian Ocean or a subset of the landings in the western half.

We encourage further investigation of the existing data irregularities, and expansion of the logbook programme to improve these analyses in the future.

Acknowledgements

The authors are grateful to Ms. Aishat, Ms. Shafana and Ms. Fahmeeda Islam, for their diligent work cleaning up the vessel identity fields, and adding it to the overall database, as well as checking the data from 2010 and 2011. The MOFA is also thanked for sharing their data with us.

Appendix 1: Nominal catch and CPUE

Figure 1: Nominal catch and effort, 2004-2011. Source: MFARD CPUE dataset.

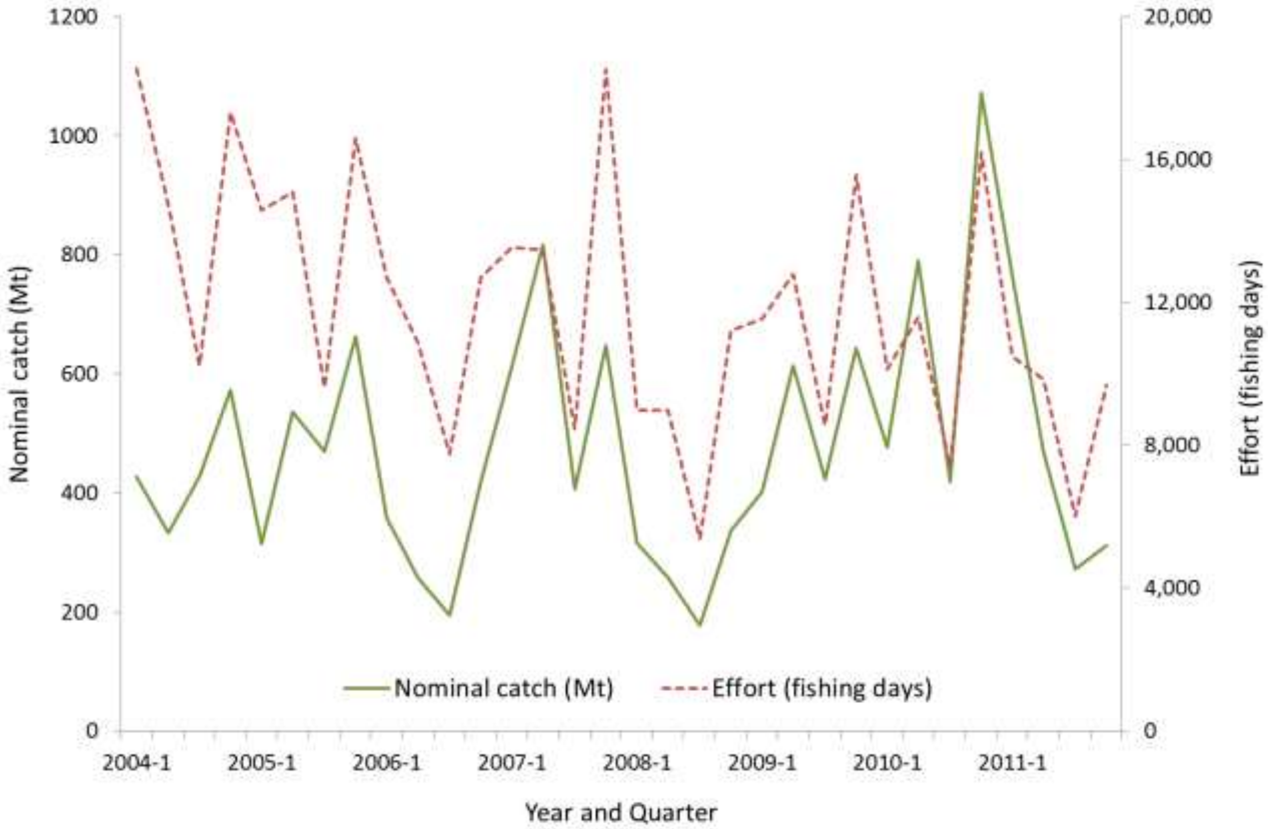


Figure 2: Nominal CPUE, 2004-2011. Source: MFARD CPUE dataset.

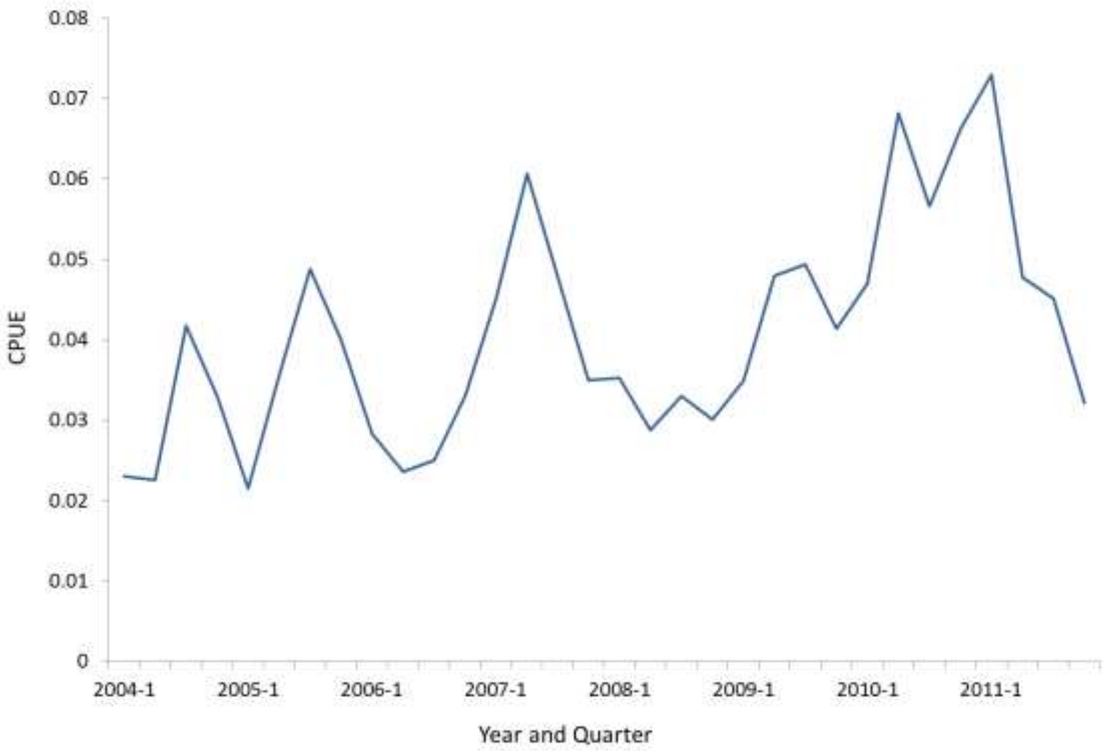


Figure 3. Map of Atolls, and number of active FADs 2001-2013. Source: MFARD FAD database.

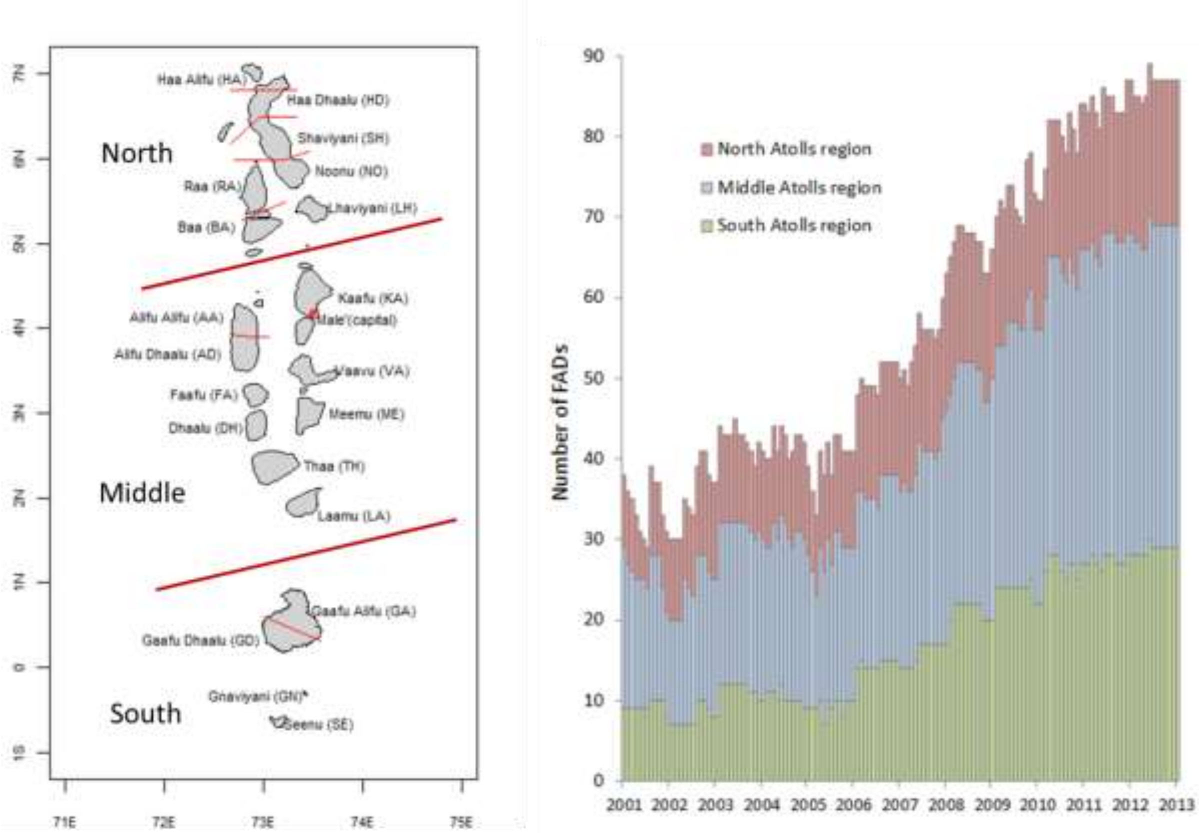


Figure 4. Distribution of kawakawa catch by Atoll, 2004-2011. Source: MFARD CPUE dataset.

The red line indicates the cumulative proportion of total kawakawa catch for each Atoll (in descending order).

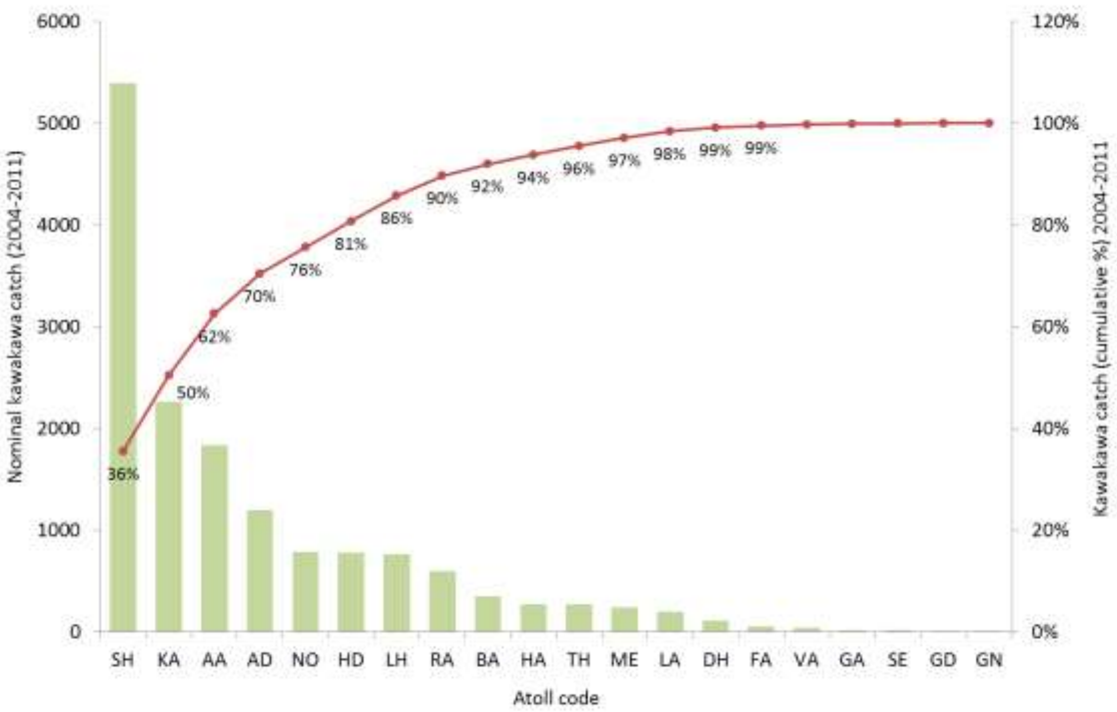
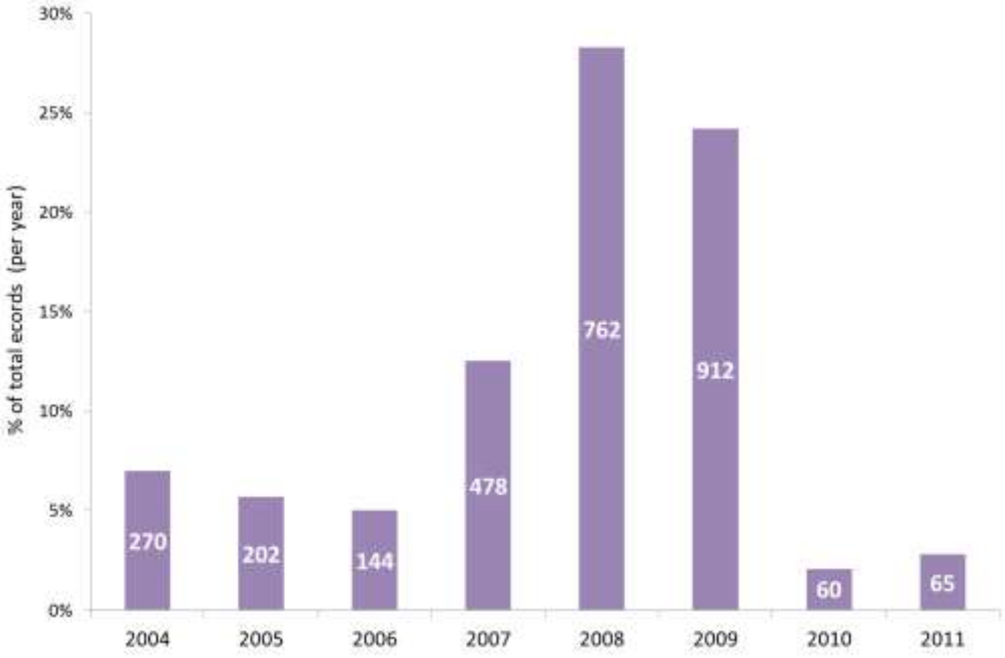


Figure 5. Proportion of records reporting fishing effort of 1 day per month, for KAW filtered dataset 2004-2011 (inset numbers refer to the number of actual records). Source: MFARD CPUE dataset.



Appendix 2: Model 1 Results

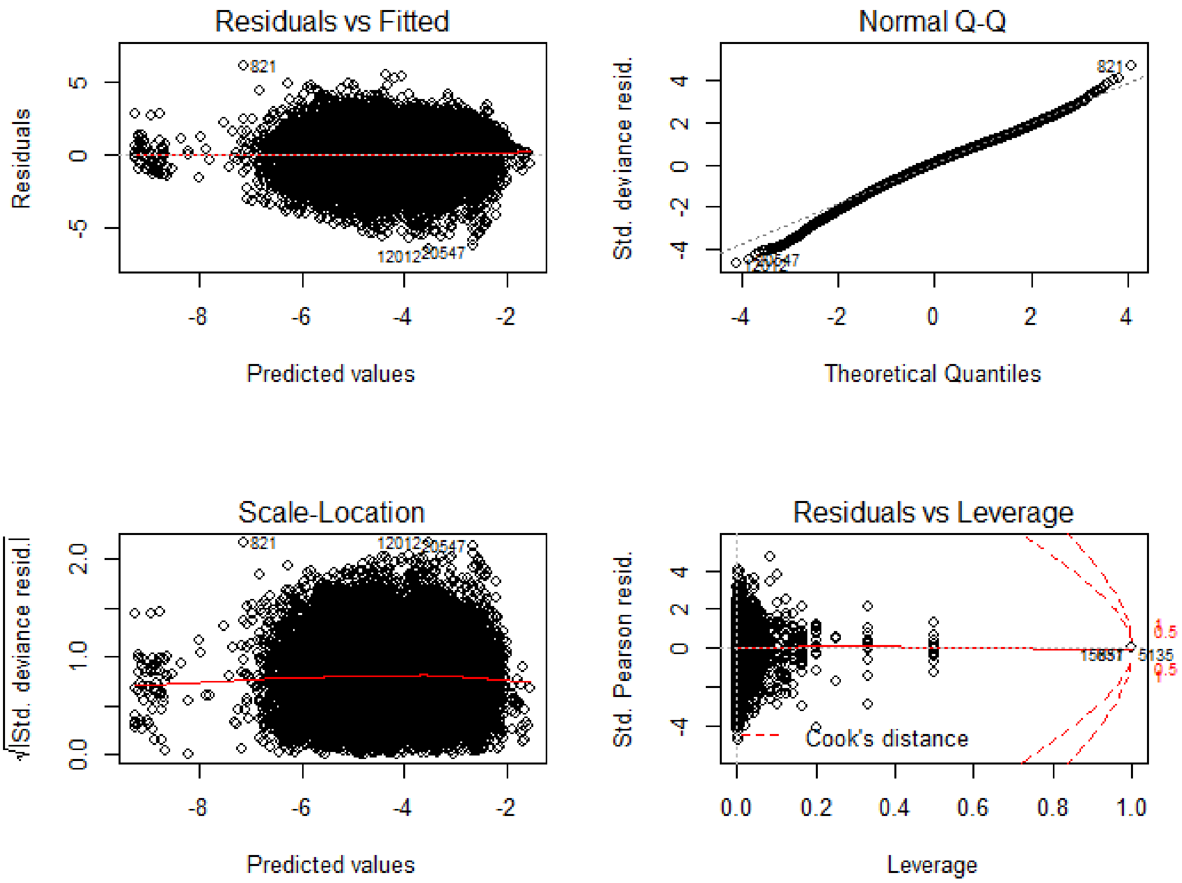


Figure 1: Residual diagnostics of the model using Year, Month, Atoll, Vessel length Category, and Vessel length category (Atoll) Interaction.

Table 1: ANOVA for the Model in equation (1)
Response: log(CPUE)

Terms added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			22718	65474			
factor(Year)	6	2845.1	22712	62629	252.5169	< 2e-16	***
factor(Month)	11	451.5	22701	62178	21.8588	< 2e-16	***
factor(Atoll)	22	16610.6	22679	45567	402.0789	< 2e-16	***
factor(Vessel.Cat)	6	1042.8	22673	44524	92.5578	< 2e-16	***
GearQty	1	10.2	22672	44514	5.4055	0.02008	*
factor(Atoll):factor(Vessel.Cat)	116	2158.5	22556	42356	9.9093	< 2e-16	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 2: Summary Results for Model 1

```
Call:
glm(formula = log(CPUE) ~ factor(Year) + factor(Month) + factor(Atoll) +
    factor(Vessel.Cat) + GearQty + factor(Atoll):factor(Vessel.Cat))
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-6.4563  -0.8435   0.0900   0.9255   6.1623

Coefficients: (16 not defined because of singularities)
                                     Estimate Std. Error t value Pr(>|t|)
(Intercept)                        -4.6263191  0.6026582  -7.677 1.70e-14 ***
factor(Year)2005                    0.2463849  0.0322671   7.636 2.33e-14 ***
factor(Year)2006                   -0.0454767  0.0343246  -1.325 0.185217
factor(Year)2007                    0.4771234  0.0323828  14.734  < 2e-16 ***
factor(Year)2008                    0.2385282  0.0375425   6.354 2.14e-10 ***
factor(Year)2009                    0.5503196  0.0339654  16.202  < 2e-16 ***
factor(Year)2010                    0.4631244  0.0373403  12.403  < 2e-16 ***
factor(Month)2                     -0.0092345  0.0440251  -0.210 0.833860
factor(Month)3                      0.0633693  0.0442076   1.433 0.151744
factor(Month)4                      0.1079720  0.0453113   2.383 0.017186 *
factor(Month)5                      0.2471149  0.0446729   5.532 3.21e-08 ***
factor(Month)6                      0.2064999  0.0440955   4.683 2.84e-06 ***
factor(Month)7                      0.3213596  0.0436331   7.365 1.83e-13 ***
factor(Month)8                      0.2321960  0.0448554   5.177 2.28e-07 ***
factor(Month)9                      0.2105783  0.0452563   4.653 3.29e-06 ***
factor(Month)10                     0.0810756  0.0446309   1.817 0.069295 .
factor(Month)11                     0.1853122  0.0446850   4.147 3.38e-05 ***
factor(Month)12                     0.1504358  0.0441556   3.407 0.000658 ***
factor(Atoll)AD                    -1.4444123  1.1399089  -1.267 0.205122
factor(Atoll)AN                    -0.2845796  0.5373114  -0.530 0.596369
factor(Atoll)AS                     1.2626848  0.9940770   1.270 0.204024
factor(Atoll)BA                     0.0278321  0.6562482   0.042 0.966172
factor(Atoll)DH                    -1.0333492  0.9118521  -1.133 0.257125
factor(Atoll)FA                    -1.4993878  0.6301817  -2.379 0.017354 *
factor(Atoll)GA                    -2.7811382  0.9534521  -2.917 0.003539 **
factor(Atoll)GD                    -4.0070851  1.4971780  -2.676 0.007447 **
factor(Atoll)GN                    -3.5789033  0.9942369  -3.600 0.000319 ***
factor(Atoll)HA                    -1.1324508  0.6242259  -1.814 0.069665 .
factor(Atoll)HD                    -0.7900753  0.6029028  -1.310 0.190056
factor(Atoll)KA                    -2.6563389  1.1408604  -2.328 0.019902 *
factor(Atoll)KM                     0.6389121  0.6531181   0.978 0.327962
factor(Atoll)LA                    -0.4692697  1.1410957  -0.411 0.680897
factor(Atoll)LH                     0.8165659  1.4973242   0.545 0.585518
factor(Atoll)ME                    -2.2044498  0.6197404  -3.557 0.000376 ***
factor(Atoll)NO                    -1.2889099  0.8219062  -1.568 0.116849
factor(Atoll)RA                    -0.5446951  0.6172930  -0.882 0.377574
factor(Atoll)SE                    -1.6415603  0.6817847  -2.408 0.016060 *
factor(Atoll)SH                    -0.3334203  0.6049067  -0.551 0.581507
factor(Atoll)TH                    -2.7059752  0.5119000  -5.286 1.26e-07 ***
factor(Atoll)VA                    -2.4584549  1.4696811  -1.673 0.094384 .
factor(Vessel.Cat)2                -0.6893817  0.6776956  -1.017 0.309048
factor(Vessel.Cat)3                 1.1426199  0.6738378   1.696 0.089958 .
factor(Vessel.Cat)4                 1.7375930  0.6705335   2.591 0.009566 **
factor(Vessel.Cat)5                 2.2245924  0.6967137   3.193 0.001410 **
factor(Vessel.Cat)6                 2.2218119  0.4513347   4.923 8.59e-07 ***
factor(Vessel.Cat)7                 1.0985532  0.3453868   3.181 0.001471 **
GearQty                             0.0010846  0.0002633   4.120 3.81e-05 ***
factor(Atoll)AD:factor(Vessel.Cat)2  2.5030510  1.1876387   2.108 0.035078 *
factor(Atoll)AN:factor(Vessel.Cat)2  1.6100117  0.6270932   2.567 0.010252 *
factor(Atoll)AS:factor(Vessel.Cat)2 -0.4507560  1.0451553  -0.431 0.666268
factor(Atoll)BA:factor(Vessel.Cat)2  0.4249739  0.7295345   0.583 0.560217
factor(Atoll)DH:factor(Vessel.Cat)2  0.8648378  0.9678102   0.894 0.371544
factor(Atoll)FA:factor(Vessel.Cat)2  2.1003992  0.7343112   2.860 0.004235 **
factor(Atoll)GA:factor(Vessel.Cat)2  3.6595251  1.3952918   2.623 0.008728 **
factor(Atoll)GD:factor(Vessel.Cat)2  2.1021875  1.6046717   1.310 0.190195
factor(Atoll)GN:factor(Vessel.Cat)2 -0.3406882  1.0679949  -0.319 0.749731
factor(Atoll)HA:factor(Vessel.Cat)2  2.2343869  0.7823371   2.856 0.004294 **
factor(Atoll)HD:factor(Vessel.Cat)2  1.2051074  0.6824020   1.766 0.077413 .
factor(Atoll)KA:factor(Vessel.Cat)2  3.0966807  1.1850916   2.613 0.008980 **
factor(Atoll)KM:factor(Vessel.Cat)2 -0.6320002  0.7404728  -0.854 0.393386
factor(Atoll)LA:factor(Vessel.Cat)2         NA         NA      NA       NA
factor(Atoll)LH:factor(Vessel.Cat)2 -0.8775867  1.5370733  -0.571 0.568042
factor(Atoll)ME:factor(Vessel.Cat)2  0.8779535  0.6994268   1.255 0.209402
factor(Atoll)NO:factor(Vessel.Cat)2  1.7888514  0.8924449   2.004 0.045035 *
factor(Atoll)RA:factor(Vessel.Cat)2  0.4148833  0.6940250   0.598 0.549984
factor(Atoll)SE:factor(Vessel.Cat)2  0.2194187  0.8787903   0.250 0.802835
```

```
factor(Atoll)SH:factor(Vessel.Cat)2  1.3528315  0.6821730   1.983 0.047366 *
factor(Atoll)TH:factor(Vessel.Cat)2  1.7568899  0.6032774   2.912 0.003592 **
factor(Atoll)VA:factor(Vessel.Cat)2  2.6635360  1.6232024   1.641 0.100829
factor(Atoll)AD:factor(Vessel.Cat)3  0.8702260  1.1978377   0.726 0.467541
factor(Atoll)AN:factor(Vessel.Cat)3 -0.3475139  0.6250498  -0.556 0.578231
factor(Atoll)AS:factor(Vessel.Cat)3 -2.0338552  1.0540840  -1.930 0.053681 .
factor(Atoll)BA:factor(Vessel.Cat)3 -2.1933578  0.7269688  -3.017 0.002555 **
factor(Atoll)DH:factor(Vessel.Cat)3 -1.2853138  0.9690278  -1.326 0.184722
factor(Atoll)FA:factor(Vessel.Cat)3  0.5991903  0.7288447   0.822 0.411023
factor(Atoll)GA:factor(Vessel.Cat)3  1.9443203  1.6975940   1.145 0.252081
factor(Atoll)GD:factor(Vessel.Cat)3  0.7120594  1.5376854   0.463 0.643317
factor(Atoll)GN:factor(Vessel.Cat)3 -2.0858709  1.0723162  -1.945 0.051763 .
factor(Atoll)HA:factor(Vessel.Cat)3  0.6724341  0.7037712   0.955 0.339349
factor(Atoll)HD:factor(Vessel.Cat)3 -0.7683393  0.6780792  -1.133 0.257180
factor(Atoll)KA:factor(Vessel.Cat)3  1.0576881  1.1816658   0.895 0.370753
factor(Atoll)KM:factor(Vessel.Cat)3 -0.3993625  0.7212668  -0.554 0.579792
factor(Atoll)LA:factor(Vessel.Cat)3 -1.3006304  1.1822476  -1.100 0.271286
factor(Atoll)LH:factor(Vessel.Cat)3 -1.8366889  1.5301491  -1.200 0.230023
factor(Atoll)ME:factor(Vessel.Cat)3 -0.6468073  0.6944255  -0.931 0.351642
factor(Atoll)NO:factor(Vessel.Cat)3  0.7482304  0.8788179   0.851 0.394553
factor(Atoll)RA:factor(Vessel.Cat)3 -0.8888253  0.6903432  -1.288 0.197929
factor(Atoll)SE:factor(Vessel.Cat)3 -1.0832640  0.8904375  -1.217 0.223787
factor(Atoll)SH:factor(Vessel.Cat)3 -0.0584281  0.6776145  -0.086 0.931287
factor(Atoll)TH:factor(Vessel.Cat)3  0.6143008  0.5980850   1.027 0.304378
factor(Atoll)VA:factor(Vessel.Cat)3  0.6493925  1.5176539   0.428 0.668734
factor(Atoll)AD:factor(Vessel.Cat)4  0.1698936  1.2086890   0.141 0.888219
factor(Atoll)AN:factor(Vessel.Cat)4 -0.6729308  0.6216005  -1.083 0.279007
factor(Atoll)AS:factor(Vessel.Cat)4 -4.3735169  1.0700922  -4.087 4.38e-05 ***
factor(Atoll)BA:factor(Vessel.Cat)4 -2.4303153  0.7567711  -3.211 0.001323 **
factor(Atoll)DH:factor(Vessel.Cat)4 -2.0567862  0.9703573  -2.120 0.034049 *
factor(Atoll)FA:factor(Vessel.Cat)4 -0.0818878  0.7505664  -0.109 0.913123
factor(Atoll)GA:factor(Vessel.Cat)4  0.1411789  1.2743219   0.111 0.911786
factor(Atoll)GD:factor(Vessel.Cat)4  0.5373603  1.5581815   0.345 0.730200
factor(Atoll)GN:factor(Vessel.Cat)4         NA         NA      NA       NA
factor(Atoll)HA:factor(Vessel.Cat)4 -0.2852055  0.7350292  -0.388 0.698005
factor(Atoll)HD:factor(Vessel.Cat)4 -1.8073620  0.6995051  -2.584 0.009779 **
factor(Atoll)KA:factor(Vessel.Cat)4  0.6797507  1.1806592   0.576 0.564798
factor(Atoll)KM:factor(Vessel.Cat)4 -0.9509566  0.7188570  -1.323 0.185891
factor(Atoll)LA:factor(Vessel.Cat)4 -2.4558989  1.1865398  -2.070 0.038483 *
factor(Atoll)LH:factor(Vessel.Cat)4 -2.3710030  1.5292508  -1.550 0.121051
factor(Atoll)ME:factor(Vessel.Cat)4 -1.0737157  0.6955974  -1.544 0.122702
factor(Atoll)NO:factor(Vessel.Cat)4 -0.1219360  0.8885770  -0.137 0.890853
factor(Atoll)RA:factor(Vessel.Cat)4 -2.2690805  0.7228455  -3.139 0.001697 **
factor(Atoll)SE:factor(Vessel.Cat)4 -0.1644595  1.2220718  -0.135 0.892950
factor(Atoll)SH:factor(Vessel.Cat)4 -0.5869373  0.6761651  -0.868 0.385383
factor(Atoll)TH:factor(Vessel.Cat)4 -0.0829689  0.6234859  -0.133 0.894137
factor(Atoll)VA:factor(Vessel.Cat)4  0.7054177  1.5760894   0.448 0.654464
factor(Atoll)AD:factor(Vessel.Cat)5  0.0289327  1.2416983   0.023 0.981410
factor(Atoll)AN:factor(Vessel.Cat)5 -0.4448892  0.6819752  -0.652 0.514180
factor(Atoll)AS:factor(Vessel.Cat)5 -2.4362849  1.1747244  -2.074 0.038098 *
factor(Atoll)BA:factor(Vessel.Cat)5 -2.8133552  0.9317602  -3.019 0.002536 **
factor(Atoll)DH:factor(Vessel.Cat)5 -3.2580883  1.0246055  -3.180 0.001476 **
factor(Atoll)FA:factor(Vessel.Cat)5 -3.8414347  0.7990557  -4.807 1.54e-06 ***
factor(Atoll)GA:factor(Vessel.Cat)5 -0.8470622  1.0762825  -0.787 0.431275
factor(Atoll)GD:factor(Vessel.Cat)5 -0.4958534  1.5977757  -0.310 0.756305
factor(Atoll)GN:factor(Vessel.Cat)5 -2.4086764  1.7294304  -1.393 0.163707
factor(Atoll)HA:factor(Vessel.Cat)5 -0.8955123  0.7398738  -1.210 0.226154
factor(Atoll)HD:factor(Vessel.Cat)5 -1.7758509  0.8701892  -2.041 0.041286 *
factor(Atoll)KA:factor(Vessel.Cat)5  0.0768978  1.1965769   0.064 0.948760
factor(Atoll)KM:factor(Vessel.Cat)5 -1.1809376  0.7463006  -1.582 0.113575
factor(Atoll)LA:factor(Vessel.Cat)5 -4.0709107  1.2705114  -3.204 0.001356 **
factor(Atoll)LH:factor(Vessel.Cat)5 -2.7321536  1.5416901  -1.772 0.076378 .
factor(Atoll)ME:factor(Vessel.Cat)5  0.3794556  0.7261575   0.523 0.601291
factor(Atoll)NO:factor(Vessel.Cat)5         NA         NA      NA       NA
factor(Atoll)RA:factor(Vessel.Cat)5 -1.7938579  0.7217167  -2.486 0.012943 *
factor(Atoll)SE:factor(Vessel.Cat)5 -4.2139202  1.2367865  -3.407 0.000658 ***
factor(Atoll)SH:factor(Vessel.Cat)5 -1.2801147  0.7091760  -1.805 0.071077 .
factor(Atoll)TH:factor(Vessel.Cat)5 -0.3939589  0.6601247  -0.597 0.550650
factor(Atoll)VA:factor(Vessel.Cat)5         NA         NA      NA       NA
factor(Atoll)AD:factor(Vessel.Cat)6         NA         NA      NA       NA
factor(Atoll)AN:factor(Vessel.Cat)6 -0.7751256  0.7121646  -1.088 0.276427
factor(Atoll)AS:factor(Vessel.Cat)6 -5.2635373  1.6458537  -3.198 0.001385 **
factor(Atoll)BA:factor(Vessel.Cat)6         NA         NA      NA       NA
factor(Atoll)DH:factor(Vessel.Cat)6 -3.5007958  0.8992538  -3.893 9.93e-05 ***
factor(Atoll)FA:factor(Vessel.Cat)6         NA         NA      NA       NA
factor(Atoll)GA:factor(Vessel.Cat)6 -0.4944926  1.0096985  -0.490 0.624321
factor(Atoll)GD:factor(Vessel.Cat)6 -0.8677766  1.4891891  -0.583 0.560089
```

```
factor(Atoll)GN:factor(Vessel.Cat)6         NA         NA      NA       NA
factor(Atoll)HA:factor(Vessel.Cat)6 -0.2039066  0.6233321  -0.327 0.743578
factor(Atoll)HD:factor(Vessel.Cat)6 -1.6447715  0.5247348  -3.134 0.001724 **
factor(Atoll)KA:factor(Vessel.Cat)6  0.8530594  1.0910990   0.782 0.434320
factor(Atoll)KM:factor(Vessel.Cat)6 -1.1301205  0.5328720  -2.121 0.033949 *
factor(Atoll)LA:factor(Vessel.Cat)6 -2.2728949  1.1174254  -2.034 0.041959 *
factor(Atoll)LH:factor(Vessel.Cat)6 -3.6946110  1.5070927  -2.451 0.014234 *
factor(Atoll)ME:factor(Vessel.Cat)6  0.2823363  1.0797534   0.261 0.793723
factor(Atoll)NO:factor(Vessel.Cat)6         NA         NA      NA       NA
factor(Atoll)RA:factor(Vessel.Cat)6 -2.1814000  0.7324961  -2.978 0.002904 **
factor(Atoll)SE:factor(Vessel.Cat)6 -3.5362487  1.4786353  -2.392 0.016785 *
factor(Atoll)SH:factor(Vessel.Cat)6 -1.1572645  0.7640183  -1.515 0.129860
factor(Atoll)TH:factor(Vessel.Cat)6         NA         NA      NA       NA
factor(Atoll)VA:factor(Vessel.Cat)6         NA         NA      NA       NA
factor(Atoll)AD:factor(Vessel.Cat)7  1.7030972  1.1712857   1.454 0.145949
factor(Atoll)AN:factor(Vessel.Cat)7         NA         NA      NA       NA
factor(Atoll)AS:factor(Vessel.Cat)7 -1.8039802  0.8803580  -2.049 0.040460 *
factor(Atoll)BA:factor(Vessel.Cat)7 -1.2480159  0.4497697  -2.775 0.005528 **
factor(Atoll)DH:factor(Vessel.Cat)7 -1.3980858  0.7956016  -1.757 0.078886 .
factor(Atoll)FA:factor(Vessel.Cat)7 -0.7769190  0.4296196  -1.808 0.070559 .
factor(Atoll)GA:factor(Vessel.Cat)7         NA         NA      NA       NA
factor(Atoll)GD:factor(Vessel.Cat)7  0.3079475  1.4680107   0.210 0.833848
factor(Atoll)GN:factor(Vessel.Cat)7         NA         NA      NA       NA
factor(Atoll)HA:factor(Vessel.Cat)7 -0.1322394  0.4204426  -0.315 0.753126
factor(Atoll)HD:factor(Vessel.Cat)7 -1.0676164  0.3635766  -2.936 0.003324 **
factor(Atoll)KA:factor(Vessel.Cat)7  0.8267570  1.0325806   0.801 0.423331
factor(Atoll)KM:factor(Vessel.Cat)7 -0.7792884  0.4411366  -1.767 0.077318 .
factor(Atoll)LA:factor(Vessel.Cat)7 -1.4725768  1.0491056  -1.404 0.160437
factor(Atoll)LH:factor(Vessel.Cat)7 -1.3358197  1.4548459  -0.918 0.358531
factor(Atoll)ME:factor(Vessel.Cat)7 -0.7354902  0.4038986  -1.821 0.068624 .
factor(Atoll)NO:factor(Vessel.Cat)7 -0.2293622  0.6677416  -0.343 0.731233
factor(Atoll)RA:factor(Vessel.Cat)7 -1.4388396  0.3857016  -3.730 0.000192 ***
factor(Atoll)SE:factor(Vessel.Cat)7  0.5710947  1.4500894   0.394 0.693707
factor(Atoll)SH:factor(Vessel.Cat)7 -0.4326247  0.3563677  -1.214 0.224767
factor(Atoll)TH:factor(Vessel.Cat)7         NA         NA      NA       NA
factor(Atoll)VA:factor(Vessel.Cat)7         NA         NA      NA       NA
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 1.877803)

    Null deviance: 65474  on 22718  degrees of freedom
Residual deviance: 42356  on 22556  degrees of freedom
  (3039 observations deleted due to missingness)
AIC: 78953


Number of Fisher Scoring iterations: 2
```

Appendix 3: Model 3 Results (FAD Effects)

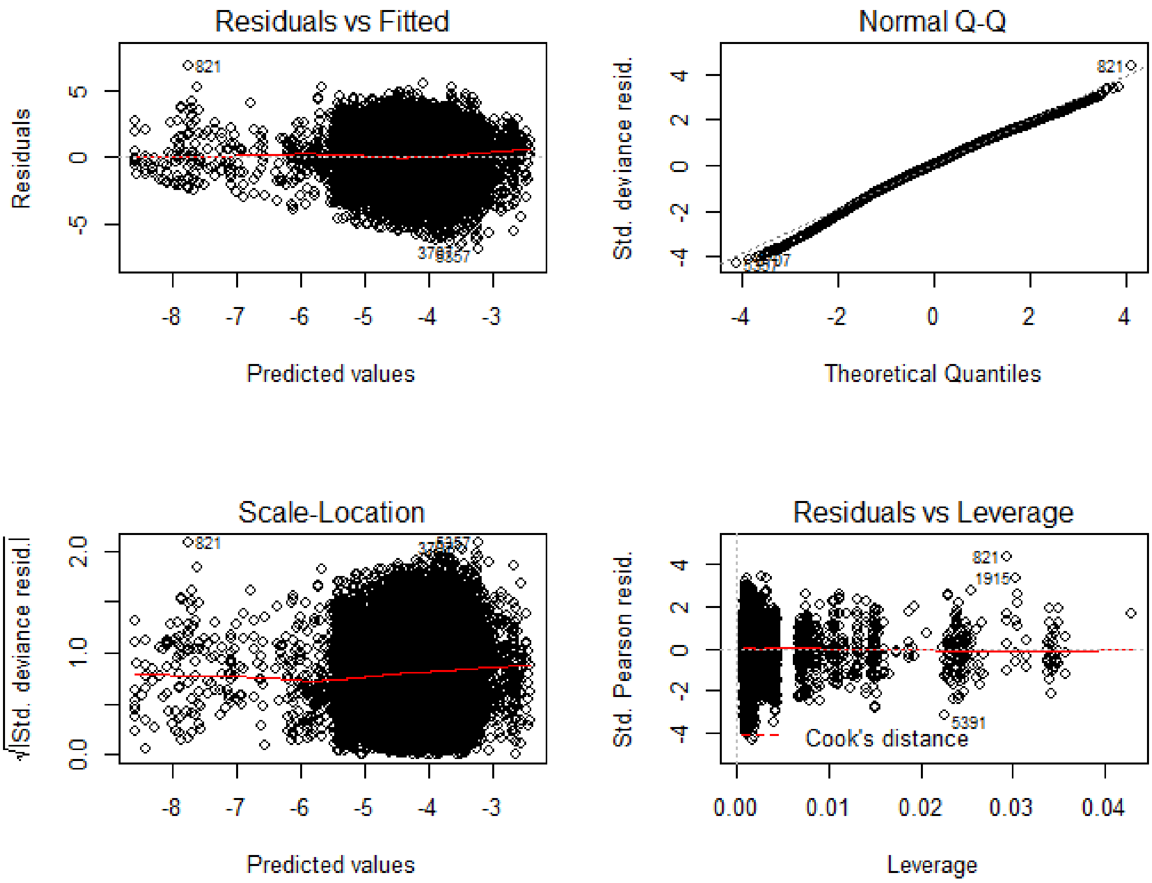


Figure 1: Residual Diagnostics of the FAD effects model on broader spatial resolution

Table 1: ANOVA on the model with FAD and broader spatial Area effects

Response: log(CPUE)

Terms added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			25757	74077			
factor(Year)	7	2788.5	25750	71289	159.002	< 2.2e-16	***
factor(Month)	11	371.4	25739	70917	13.478	< 2.2e-16	***
factor(Vessel.Cat)	6	3654.7	25733	67263	243.126	< 2.2e-16	***
factor(FAD_Region)	2	1274.9	25731	65988	254.434	< 2.2e-16	***
Region_FAD	1	388.7	25730	65599	155.139	< 2.2e-16	***
factor(Vessel.Cat):factor(FAD_Region)	12	779.8	25718	64819	25.938	< 2.2e-16	***
factor(FAD_Region):Region_FAD	2	390.9	25716	64428	78.022	< 2.2e-16	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 4: Summary of Model Parameter values

```
Call:
glm(formula = log(CPUE) ~ factor(Year) + factor(Month) + factor(Vessel.Cat) +
    factor(FAD_Region) + Region_FAD + factor(FAD_Region):factor(Vessel.Cat) +
    factor(FAD_Region):Region_FAD)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-6.8604  -0.9787   0.0376   1.1010   6.8186

Coefficients:
                                             Estimate Std. Error t value Pr(>|t|)
(Intercept)                                 -6.866666   0.128270 -53.533  < 2e-16 ***
factor(Year)2005                             0.242427   0.036963   6.559 5.53e-11 ***
factor(Year)2006                            -0.135686   0.043143  -3.145  0.00166 **
factor(Year)2007                             0.496600   0.048156  10.312  < 2e-16 ***
factor(Year)2008                            -0.047641   0.062088  -0.767  0.44290
factor(Year)2009                             0.302645   0.066034   4.583 4.60e-06 ***
factor(Year)2010                             0.161185   0.079155   2.036  0.04173 *
factor(Year)2011                             0.061315   0.088901   0.690  0.49039
factor(Month)2                              -0.056391   0.047305  -1.192  0.23324
factor(Month)3                              -0.004723   0.047482  -0.099  0.92077
factor(Month)4                              -0.029260   0.048990  -0.597  0.55034
factor(Month)5                               0.109044   0.048505   2.248  0.02458 *
factor(Month)6                               0.079703   0.048206   1.653  0.09826 .
factor(Month)7                               0.270661   0.047220   5.732 1.00e-08 ***
factor(Month)8                               0.122037   0.048485   2.517  0.01184 *
factor(Month)9                               0.006749   0.048950   0.138  0.89034
factor(Month)10                             -0.056824   0.049021  -1.159  0.24640
factor(Month)11                              0.077892   0.048767   1.597  0.11023
factor(Month)12                              0.070506   0.048826   1.444  0.14874
factor(Vessel.Cat)2                          0.724820   0.083028   8.730  < 2e-16 ***
factor(Vessel.Cat)3                          1.420185   0.080677  17.603  < 2e-16 ***
factor(Vessel.Cat)4                          1.786487   0.084787  21.070  < 2e-16 ***
factor(Vessel.Cat)5                          1.840537   0.092350  19.930  < 2e-16 ***
factor(Vessel.Cat)6                          2.410346   0.120409  20.018  < 2e-16 ***
factor(Vessel.Cat)7                          1.272483   0.090558  14.052  < 2e-16 ***
factor(FAD_Region)North                      0.861016   0.151256   5.692 1.27e-08 ***
factor(FAD_Region)South                     -2.915725   0.326696  -8.925  < 2e-16 ***
Region_FAD                                   0.042549   0.004488   9.480  < 2e-16 ***
factor(Vessel.Cat)2:factor(FAD_Region)North -0.213289   0.097141  -2.196  0.02812 *
factor(Vessel.Cat)3:factor(FAD_Region)North -0.425080   0.093334  -4.554 5.28e-06 ***
factor(Vessel.Cat)4:factor(FAD_Region)North -0.667891   0.105262  -6.345 2.26e-10 ***
factor(Vessel.Cat)5:factor(FAD_Region)North -0.956154   0.120795  -7.916 2.56e-15 ***
factor(Vessel.Cat)6:factor(FAD_Region)North -1.739017   0.228250  -7.619 2.65e-14 ***
factor(Vessel.Cat)7:factor(FAD_Region)North -0.687105   0.108860  -6.312 2.80e-10 ***
factor(Vessel.Cat)2:factor(FAD_Region)South -1.133303   0.198614  -5.706 1.17e-08 ***
factor(Vessel.Cat)3:factor(FAD_Region)South -1.176491   0.230058  -5.114 3.18e-07 ***
factor(Vessel.Cat)4:factor(FAD_Region)South -0.860740   0.285959  -3.010  0.00261 **
factor(Vessel.Cat)5:factor(FAD_Region)South -1.309920   0.291484  -4.494 7.02e-06 ***
factor(Vessel.Cat)6:factor(FAD_Region)South -2.775320   0.339416  -8.177 3.05e-16 ***
factor(Vessel.Cat)7:factor(FAD_Region)South -1.175813   0.282052  -4.169 3.07e-05 ***
factor(FAD_Region)North:Region_FAD           0.021487   0.009645   2.228  0.02591 *
factor(FAD_Region)South:Region_FAD           0.133982   0.010796  12.411  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 2.505375)

    Null deviance: 74077  on 25757  degrees of freedom
Residual deviance: 64428  on 25716  degrees of freedom
AIC: 96799

Number of Fisher Scoring iterations: 2
```