Received: 13 June 2014

Maldives Kawakawa Pole and Line Fishery Catch Rate Standardization: 2004-2012

June 2014

IOTC Secretariat, Seychelles[1]

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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 2004-2012. The raw data consists of around 135,645 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 24,566 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 landing data is collected from. Techniques similar to those used in the standardization of skipjack tuna were used [2]. The distribution of FADs was split into three regions incorporating the North Atolls, Middle Atoll and South Atolls. Vessel specific data, including hull-type, length of boat (expressed as a vessel size class) and horse power were 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 in the area, length of vessel, and interaction effects between the 2 categories;number of active FADs within the region and the vessel length operating in that region. The data was analysed at a monthly resolution before being aggregated into quarterly signals for 2004-2012, and finally an annual signal 2004-2012 for analysis in KAW surplus production assessment fit to the CPUE series derived here.The paper updates the analysis and findings of the paper presented at WPNT-03with the addition of 2012 data[3].

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[2] For more details, see paper IOTC-2013-WPTT15-32.

[3] For further details, see paper IOTC-2013-WPNT03-23.

Introduction

Although primarily distributed in the central Pacific, Kawakawa (*Euthynnus affinis*) is an important fishery for a number of countries in the Indian Ocean region, where estimates of annual catches of kawakawa have increased from around 20,000 Mt in the mid-1970's, to 45,000 Mt in the mid-1980's and 156,000 Mt in 2012 – the highest catches ever recorded for this species in the region (Fig. 1).

The increase in the nominal catch of kawakawa in recent years is primarily due to the expansion of fishing effort by Indonesia, India, and Iran. In addition – with the onset of piracy in the late-2000s – the activities of fleets operating in the north-west Indian Ocean targeting tropical tunas have been displaced or reduced, with fishing effort redirected to coastal neritic tuna species by countries such as Iran, Pakistan and other Arabian Gulf countries.

While catches of kawakawa have been recorded at similar levels in in the two Indian Ocean basins (Fig. 2), catches are highly concentrated amongst a small number of coastal states. Between 2010-12 over 70% of the total catches of kawakawa in the Indian Ocean were accounted for by four countries: Indonesia (26%), India (22%), Iran (15%), and Pakistan (9%) (Fig. 3). Most are caught by gillnets, handlines and trolling, or (coastal) purse seines, and may be also an important bycatch of the industrial purse seiners.

Although Maldives is not one of the major fleets catching kawakawa, they account for around 2% of total catches of kawakawa in the Indian Ocean and may still be a useful indicator for estimating an index of abundance. The analysis in this paper attempts to use the Maldives operational data and estimate CPUE trends, while correcting for exogenous variables to ensure estimates are representative of the overall abundance.

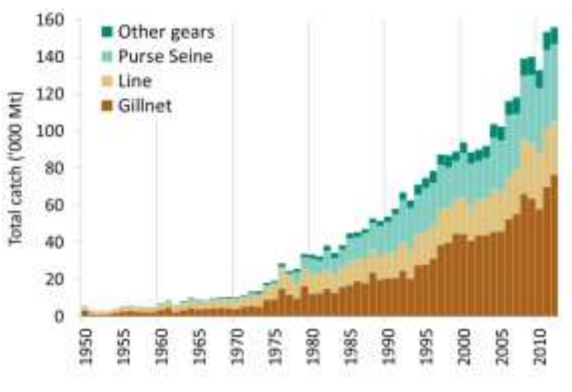


Fig. 1. Annual catches of kawakawa by gear recorded in the IOTC database (1950–2012).

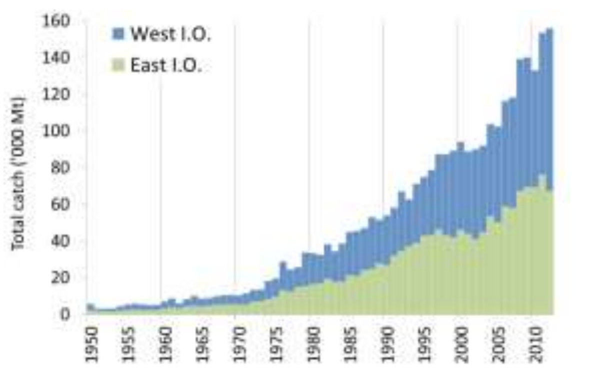


Fig. 2. Annual catches of kawakawa by IOTC area recorded in the IOTC database (1950–2012).

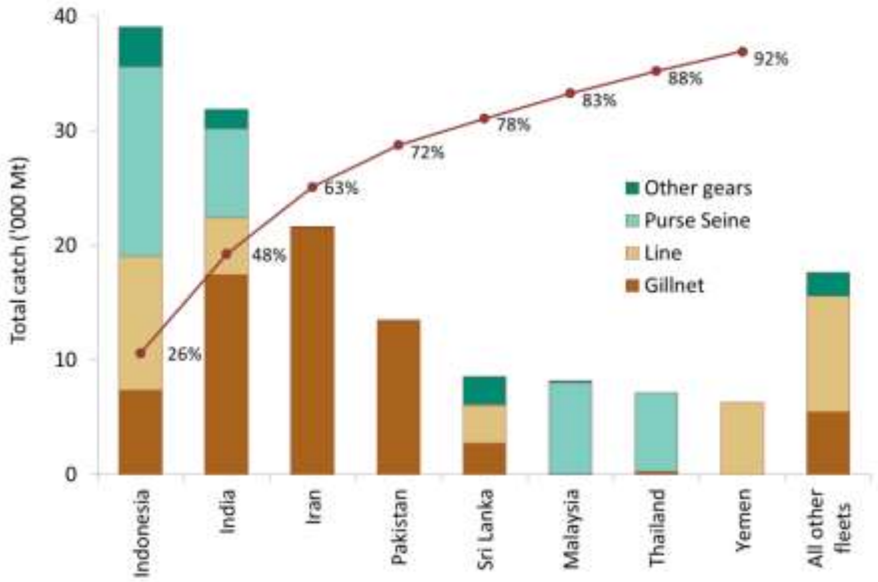


Fig. 3: Average catches of kawakawa in the Indian Ocean over the period 2010–12, by country. Countries are ordered from left to right, according to the importance of catches of kawakawa reported. The red line indicates the (cumulative) proportion of catches of neritic tunas for the countries concerned, over the total combined catches of neritic tunas reported from all countries and fisheries. Source: IOTC database.

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 2004–2012, by individual vessel.
ii. Registry of vessels 1958-2011, containing vessel dimensions (e.g., length and horsepower) of registered vessels.
iii. Anchored FAD (aFAD) database from 1981-2012, including location (longitude-latitude) of aFADs, distance to nearest atoll, date of deployment and current aFAD status (i.e., existing, or date the aFAD was either lost or recovered).

While the data remain confidential, descriptive and graphical summaries of the data are provided below and in the Appendices.

Monthly Catch-and-effort data 2004-2012

The CPUE dataset provided by MoFA/MRC consists of monthly observations of catch-and-effort (days per month) by individual vessel, 2004–2012, taken from self-reported trip reports. The dataset includes the following fields of relevance to the analysis:

- Year, Month, and Atoll of fishing activity
- Vessel Identification Number (VIN) (which can be linked with the vessel dimensions reported in the vessel registry in (ii.) above)
- Fishery type (e.g., skipjack, lobster, resort/sport fishing)
- Gear type (e.g., pole-and-line, hand-line)

- Effort (in trip days)
- Catch in numbers and weight (Mt), by species
- Hull Type, Vessel length, Vessel Category, and Horsepower

Vessel Registry 1958-2010

The Ministry of Transport and Communication maintains the national registry of vessels, including registered fishing vessels, that records key features of vessels over the period 1958-2010, and generally includes most of the vessels in the catch-and-effort database. Vessel characteristics recorded by the vessel registry include length, breadth, depth, gross tonnage and horsepower of newly registered vessels in each year, all of which are strongly correlated and expected to be positively related to fishing efficiency. Previous studies by Mohamed (2007) assumed that total effort of the pole and line fleet was directly proportional to annual average horsepower for the period 1985-2005 but the relationship was not formally defined.

One of the purposes of this paper is to empirically test the assumption of vessel efficiency on CPUE by modelling the average vessel length of vessels as a covariate to reconstruct the CPUE index series to the mid-1980s.

Anchored FADs 1981-2012

A database containing records of anchored FADs was also provided by MoFA/MRC, containing details of the date the aFAD was deployed, current status of the aFAD (i.e., existing, or date the aFAD was either lost or recovered), and nearest Atoll.

Based on the deployment and current status for each aFAD, a list of active aFADs was calculated for each month, for each atoll and region (north, middle, and south) (see Appendix 1, Figs. 1a-b), and added to the CPUE dataset according to the month and atoll associated with each record of vessel activity.

Data quality issues

A sub-set of records were extracted for the analysis, identified as fishing activity targeting kawakawa (or 'little tuna') in the catch-and-effort dataset. In the process, a number of data quality issues were identified – of varying importance – but considered together raise serious questions regarding the reliability of the catch-and-effort data.

A number of otherwise valid catch-and-effort records were omitted from the final analysis, in response to the most critical data quality issues discussed below; while other records containing incomplete information, or suspect values considered to have less of an impact on results of the CPUE standardization, were included to preserve as much of the original catch-and-effort information as possible.

Zero kawakawa catches

To identify kawakawa targeted fishing, the catch-and-effort data were initially filtered on gear ('pole-and-line'). However around 60%-75% of records selected reported zero kawakawa catch – but positive effort – consistently over a number of months. While it is reasonable to assume that kawakawa cannot be located during single fishing trips, it is unlikely vessels targeting kawakawa would fail to catch any on a regular basis; nor is there evidence of strong seasonality in the nominal catch series to suggest long periods of low or nil catches. Several alternative explanations for reports of zero kawakawa catches were proposed:

- Recorded gear and fishery type
  One of the major problems with the catch-and-effort data was thought to be the misreporting of gear and/or fishery type. Many of the vessels operating as pole-and-line or hand-line vessels are actually targeting large yellowfin or other species.

- Partial landings
  Reporting of partial landings may also be a contributing factor in the underreporting of total catches, or in some cases, reports of zero catches. It is not uncommon for vessels to offload catches at canneries, land-based collection facilities[4], or transfer catches to collector vessels before landing at the home port. Catches reported at the home port should, in theory, report the total catches for each trip – irrespective of the where the landing actually occurred. However in recent years reporting of total catches can no longer be guaranteed, as the traditional manner of reporting at the home port has not been followed by vessels participating in the new logbook programme (which cover approx. 10% of vessels in 2010).

- Deliberate misreporting of effort
  Prior to 2009, a license fee was levied for boats that operated for less than 120 days within a calendar year. This is thought to have resulted in effort being recorded for boats that remained in port and consequently reported zero catch. The magnitude of the misreporting problem is not known; however, the proportion of records reporting zero kawakawa catch, but positive effort, after 2009 in consistent with earlier years and therefore this does not seem like an important contributing factor.

Missing vessel ID and/or vessel dimensions

14,009 records (10.3% of the total catch-and-effort records) contained either missing vessel identification numbers (VINs), or VINs for which no information on vessel dimensions could be added from the vessel registry – required for modelling the relationship between CPUE, vessel length and vessel efficiency. Records that could not be matched against a valid VIN and details of the vessel dimensions were excluded from the final analysis.

Inconsistencies in reported catch-and-effort

The catch-and-effort data provided MoFA/MRC also appeared to contain a mixture of both unraised and raised data; with unraised data provided for 2004-2009, and 2011, and raised data for 2010 and 2011 (e.g., identified by effort of no. of fishing days reported to seven decimal places). Combining raised and unraised data in the same dataset – with no information on the raising factors in order to convert the catch-and-effort series – is highly likely to distort the nominal CPUE series and CPUE standardization process; however the extent of distortion is unknown until unraised data is provided for the complete time-series.

Invalid monthly effort

[4] There are two major collection centres – in the North Felivaru, operated by MIFCO and the other in the South, Kooddoo Fisheries Maldives Pvt, ltd., previously also operated by MIFCO

A small number of records (350 in total) reported effort greater than 30 days in a month – which is highly unlikely. According to MoFA, 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 vessel's record of catch-and-effort is assumed to relate to area of fishing activity and landing site. Nearly 40% of vessels report activity in only one atoll, while 70% of vessels report activity in either one or two atolls – in many cases over a period of several 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 that catch is unloaded. The issue potentially confounds the analysis of the CPUE detailed below that discusses the possible area effects based on variation between individual atolls or similarly low spatial resolutions. For this reason, the data used in the final analysis were aggregated into larger geographic units (atoll 'regions') which were judged to be a more 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 on-board vessels, but boats may carry ice); although multiday trips are more common in recent years, particularly for larger vessels. However between 2004 and 2009, around 20% to 35% of vessels report only a single day of effort per month, which seems highly improbable – particularly compared to after 2009 when the proportion drops to around 10% or less (Appendix 1, Fig. 2). One suggestion is that these vessels are actually multi-purpose, and report the minimum effort of one day each month in order to claim financial subsidies available to fishing vessels until 2009 – which raises questions on accuracy of reported catches and derived CPUE for such vessels.

To assess the impact on the CPUE standardization, model runs were conducted on a subset of records targeting kawakawa – including and excluding vessels with one day effort. No obvious differences in the nominal CPUE were noted when including the records, and the decision was made to include the records in the final dataset used in the analysis below.

Selection of CPUE records targeting kawakawa

Taking into account all of these considerations of the quality of the catch-and-effort data, the authors followed the recommendation of MoFA/MRC in applying the following criteria in selecting records representing fishing activity targeting kawakawa:

- Vessels operating Pole-and-line;
- Effort (in days) greater than zero (i.e., including vessels recording one day effort);
- Total kawakawa catch (per month) greater than zero[5];

[5] While the criterion excludes a small number of CPUE records that genuinely report actual zero kawakawa catch for a given month, the sub-set of CPUE records was still considered sufficiently representative of kawakawa catch-and-effort to be used in the statistical analysis.

- Records belonging to vessels containing valid VIN numbers (and which can be linked to information on vessel dimensions recorded in the vessel registry).

For the 2014 update to the paper, an additional year – 2012 – was added to the catch-and-effort dataset.

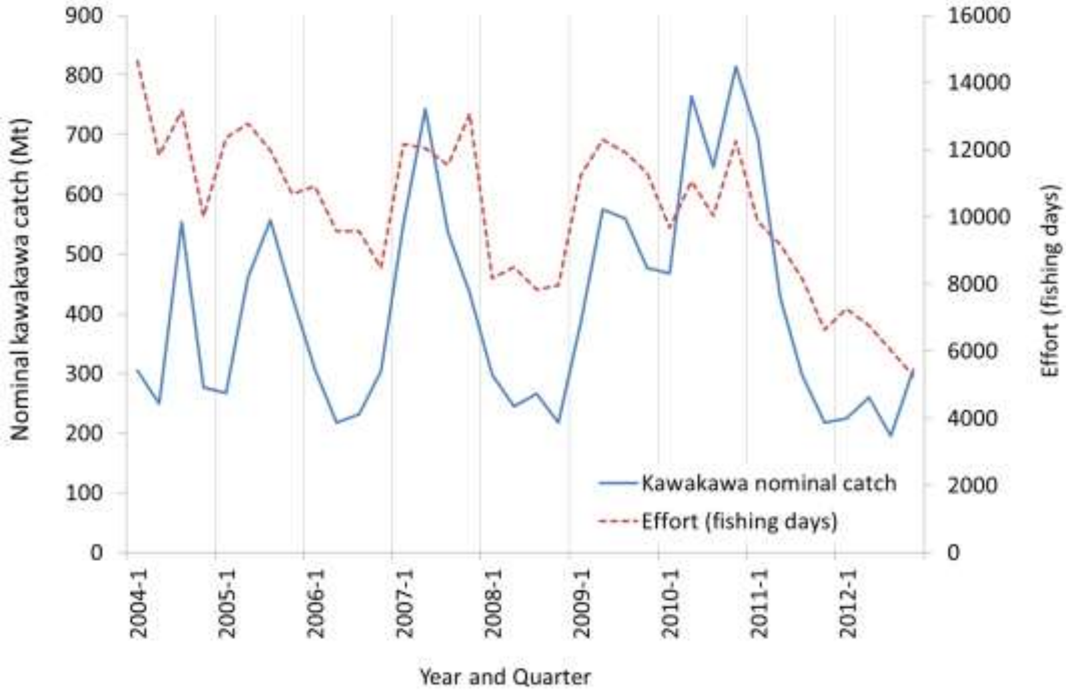
Applying the criteria above, and a subset of 24,566 records (18.1% of the total 135,645 catch-and-effort records for 2004-2012) identified as targeting kawakawa were used in the final analysis. As previously noted above, vessels reporting fishing effort of one day per month – and also targeting kawakawa – were included in the final dataset to maximize the number of catch-and-effort records, and given no apparent bias in the nominal CPUE when including the records.

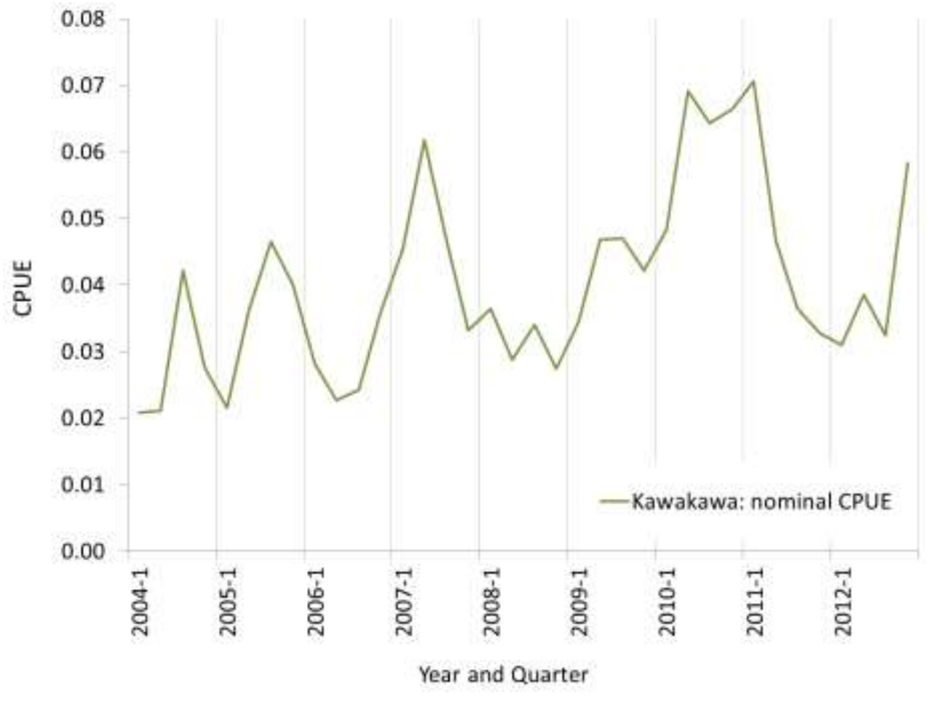
The nominal catch (and CPUE) in numbers were used for all analyses detailed below. Effort used in the calculation of CPUE was taken as the number of trip days; other measures of effort (such as 'Gear quantity' and 'Total fishermen') were available, but not reported consistently for each vessel record to be of use in the analyses.

A second CPUE dataset from 1970 was provided by MoFA, reporting monthly catch-and-effort for from 1970 but at an aggregated level (i.e., total catch-and-effort for all vessels in each month). Information on the vessel size or power, taken from the vessel registry, could not be linked directly to the dataset; therefore the data was not used directly in the analysis below, other than as a historical CPUE series to be compared to the estimated CPUE (see Appendix xx, Fig. xx).

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, when aggregated by calendar quarter, varies from around 200Mt to as high as 800Mt (Figure 3 upper inset). The pattern of fishing effort fluctuates by similar proportions as the nominal catch, but in contrast also indicates an overall decreasing trend 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 (Figure 1 lower inset).
- Catches of kawakawa, and effort to a lesser extent, tends to be concentrated among a small number of atolls – although there are issues regarding the reliability to which atoll is accurately reported for each fishing activity and landing, as discussed above. Of the 26 atolls in total, around 70% of catches of kawakawa between 2004-2012 were concentrated in four atolls: Shaviyani (SH) in the north, and Kaafu (KA), Alifu Alifu (AA), and Alifu Dhaalu (AD) in the mid atoll region (Figure XX below).
- CPUE increases sharply with vessel size. Between 2010-2012 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.





Figs. 4 & 5 (Top): Nominal catch and effort (quarterly), 2004-2012; (Bottom): Nominal CPUE (quarterly), 2004-2012. Source: MFARD catch-and-effort dataset (kawakawa subset).

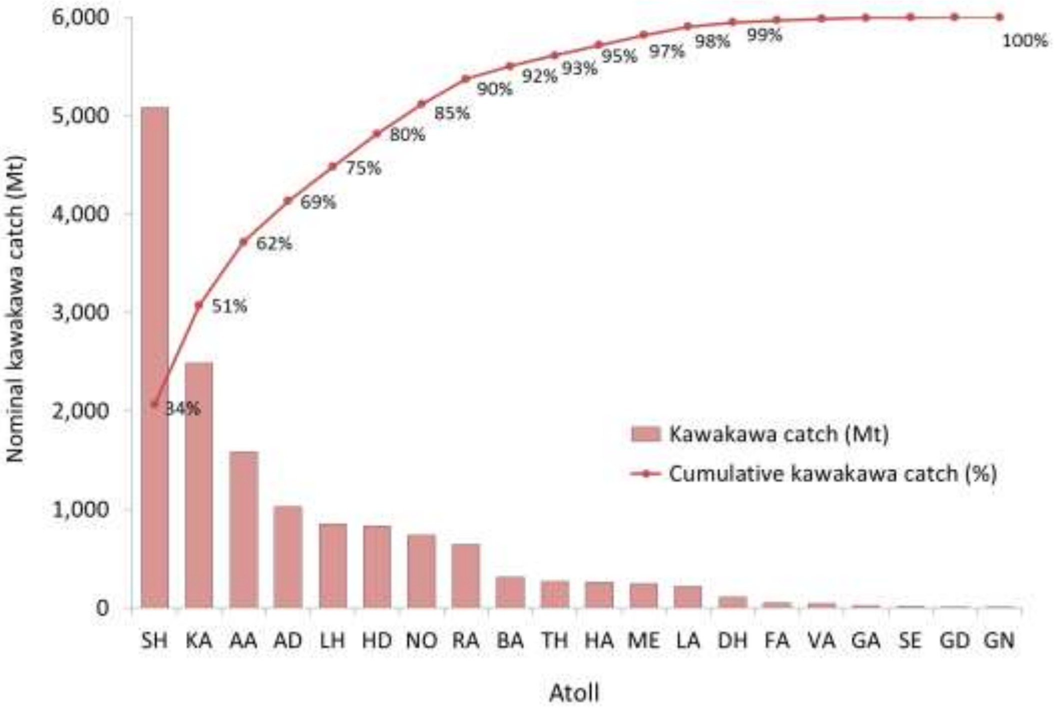


Fig. 6. Distribution of kawakawa catch by Atoll, 2004-2012. The red line indicates the cumulative proportion of total kawakawa catch for each Atoll (in descending order). Source: MFARD catch-and-effort dataset (kawakawa data subset).

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, with explanations of the dependent and independent variables provided below.

Independent Variables

The following independent variables were included in some or all models:

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 (did not converge due to memory limitations in Processor).
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):

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

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. 27,217 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 6 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 7 below) to look at landings rather than over time using the categories shown in Figure 4.

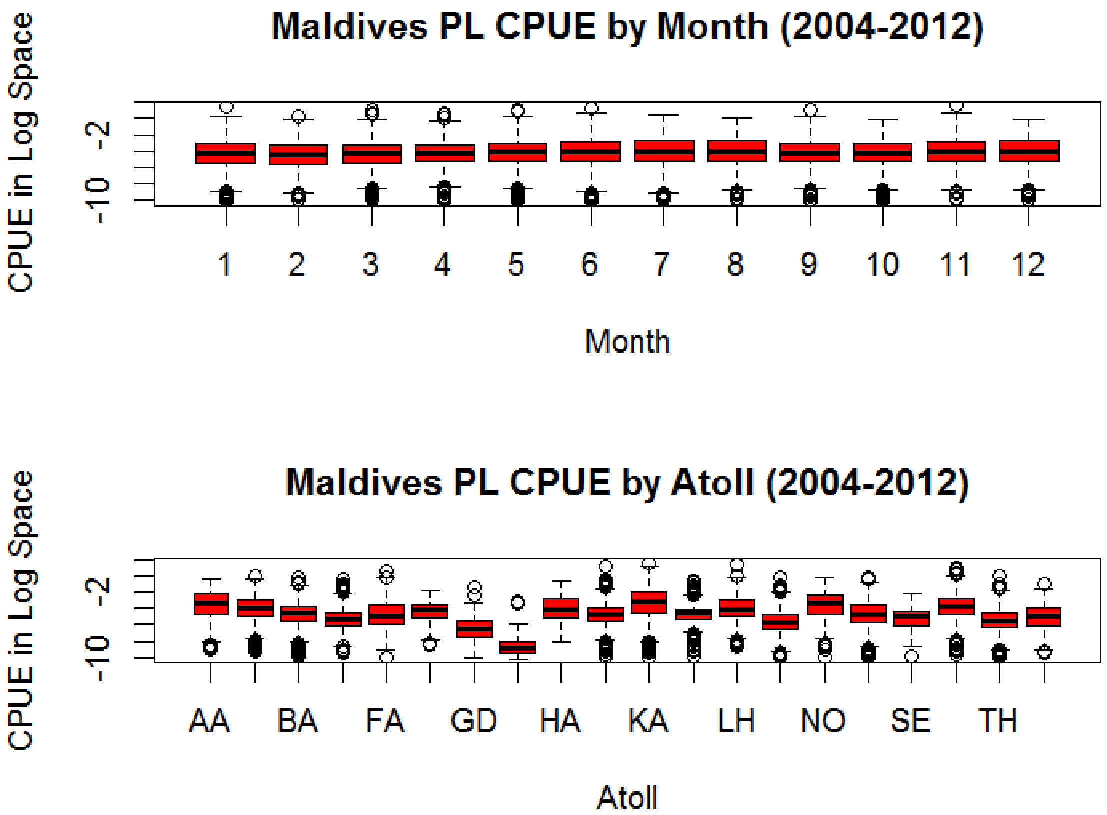


Figure 6: Aggregated nominal CPUE trends over atoll and month for the 8 years examined

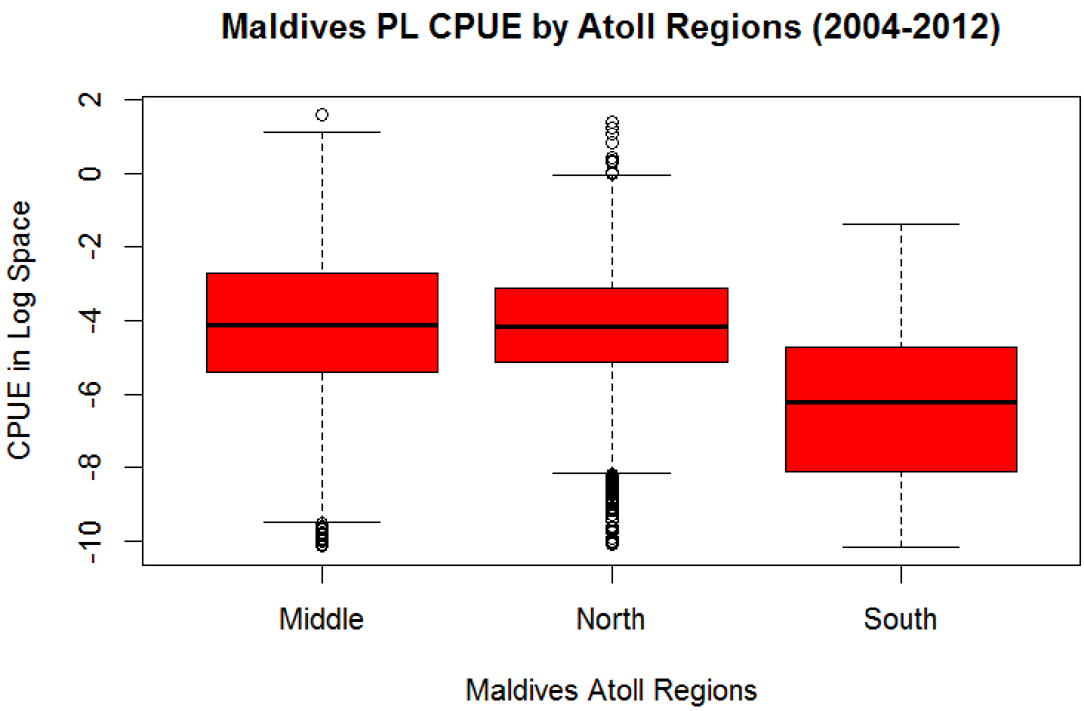


Figure 7: KAW CPUE by broader spatial locations.

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 7, and Figure 8). 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.

Signals obtained from Model 1 and Model 2 are shown in Figure 9 (below).

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.

Year	Quarter	Model 1 (Year and Month Interaction)	Model 1 (Vessel:North)	Model 1 (Vessell:South)	Model 3: FAD effects model	Nominal-Stdized	Stdized Vessel:Atoll	Standardized FAD
2004	1	0.003	0.011	0.018	0.015	0.58	0.67	0.58
2004	2	0.003	0.014	0.021	0.017	0.56	0.79	0.69
2004	3	0.003	0.014	0.021	0.018	1.04	0.80	0.72
2004	4	0.003	0.013	0.020	0.018	0.73	0.73	0.70
2005	1	0.004	0.015	0.023	0.019	0.55	0.87	0.74
2005	2	0.005	0.018	0.028	0.022	0.87	1.03	0.88
2005	3	0.005	0.018	0.028	0.023	1.16	1.04	0.93
2005	4	0.004	0.016	0.026	0.022	0.97	0.96	0.88
2006	1	0.003	0.011	0.018	0.015	0.71	0.66	0.58
2006	2	0.003	0.013	0.021	0.016	0.61	0.78	0.65
2006	3	0.003	0.013	0.021	0.017	0.62	0.79	0.70
2006	4	0.003	0.012	0.019	0.017	0.89	0.72	0.68
2007	1	0.005	0.019	0.030	0.030	1.12	1.14	1.18
2007	2	0.006	0.023	0.036	0.034	1.53	1.35	1.34
2007	3	0.006	0.023	0.036	0.036	1.14	1.36	1.42
2007	4	0.005	0.021	0.033	0.034	0.83	1.24	1.36
2008	1	0.003	0.013	0.020	0.020	0.85	0.75	0.79
2008	2	0.004	0.015	0.024	0.023	0.71	0.89	0.92
2008	3	0.004	0.015	0.024	0.024	0.84	0.89	0.96
2008	4	0.004	0.014	0.022	0.022	0.71	0.82	0.86
2009	1	0.005	0.019	0.030	0.030	0.87	1.10	1.20
2009	2	0.006	0.022	0.035	0.035	1.18	1.31	1.41
2009	3	0.006	0.022	0.035	0.036	1.17	1.31	1.45
2009	4	0.005	0.021	0.032	0.037	1.03	1.21	1.46
2010	1	0.005	0.019	0.030	0.028	1.17	1.14	1.12
2010	2	0.006	0.023	0.036	0.034	1.70	1.35	1.35
2010	3	0.006	0.023	0.036	0.036	1.54	1.36	1.42
2010	4	0.005	0.021	0.033	0.033	1.60	1.24	1.31
2011	1	0.005	0.018	0.028	0.028	1.82	1.04	1.11
2011	2	0.005	0.021	0.033	0.031	1.19	1.23	1.25
2011	3	0.005	0.021	0.033	0.034	0.97	1.24	1.36
2011	4	0.005	0.019	0.030	0.033	0.88	1.14	1.30
2012	1	0.003	0.012	0.018	0.015	0.75	0.68	0.61
2012	2	0.004	0.014	0.022	0.017	0.94	0.81	0.69
2012	3	0.004	0.014	0.022	0.018	0.78	0.81	0.74
2012	4	0.003	0.013	0.020	0.018	1.38	0.74	0.70

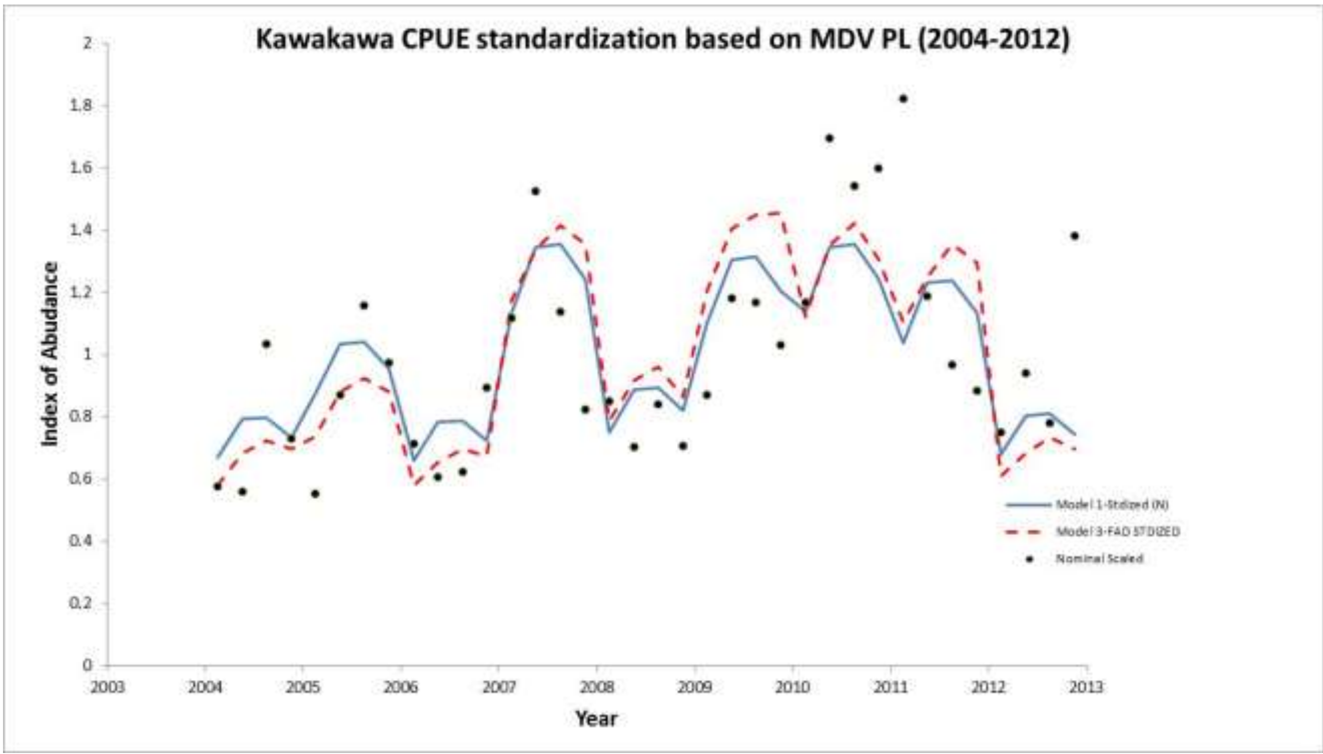


Figure 9: Standardized Index of the KAW CPUE Abundance trends using the 2 models discussed

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 (which account for around 20% to 35% of records between 2004 and 2009, see Appendix 1, Fig. 2) – 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 kawakawa targeted vessels (e.g., reflecting 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 (North, South 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. 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.

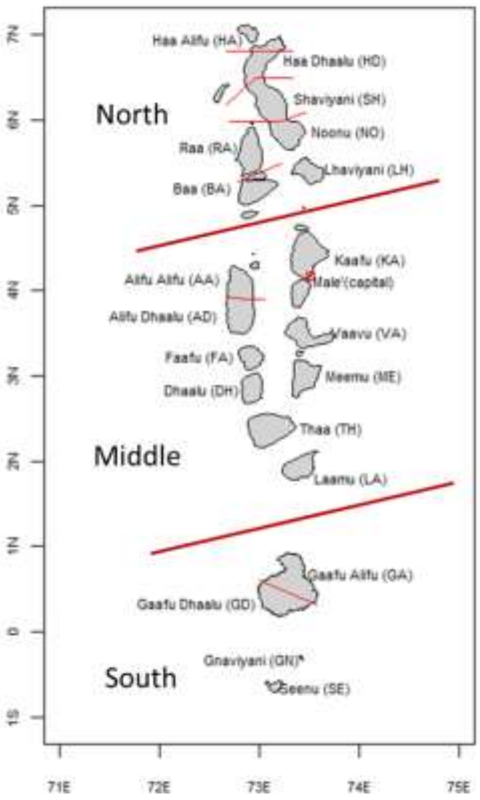
We encourage further investigation of the existing data irregularities, and expansion of the logbook programme to improve these analyses in the future.

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:

Figure 1a-b: Map of Atolls, and number of active aFADs 1994-2012.



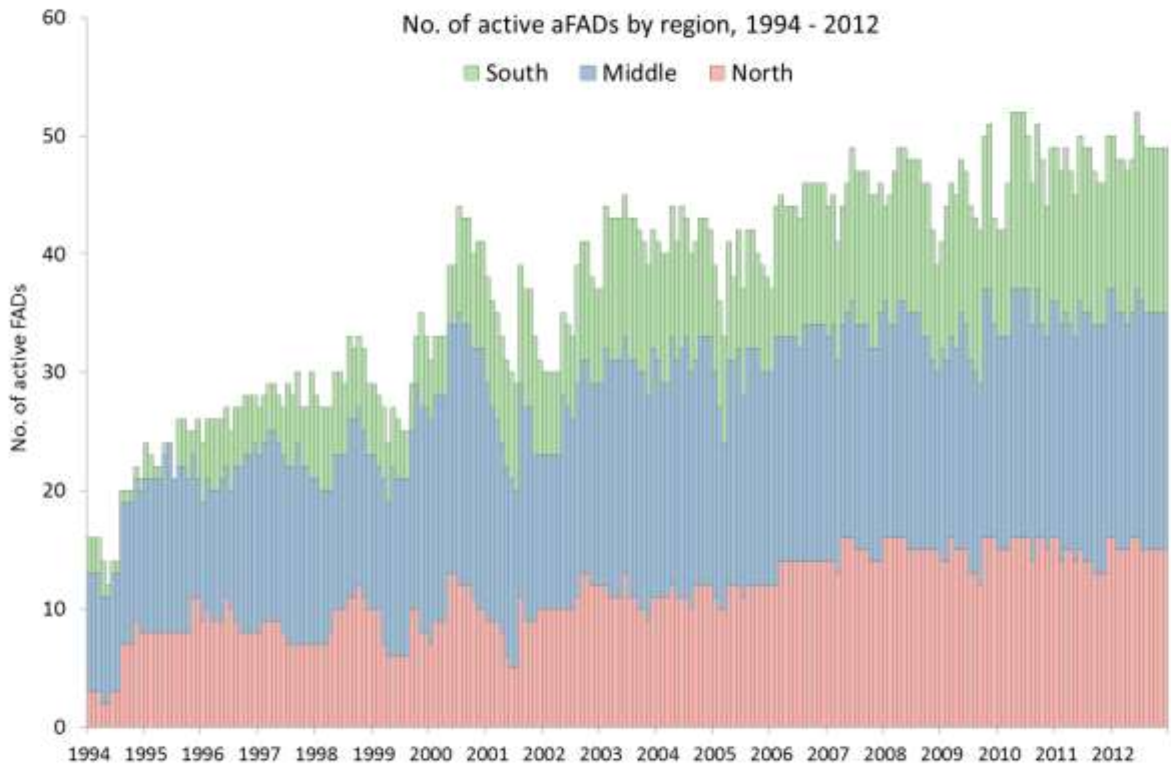
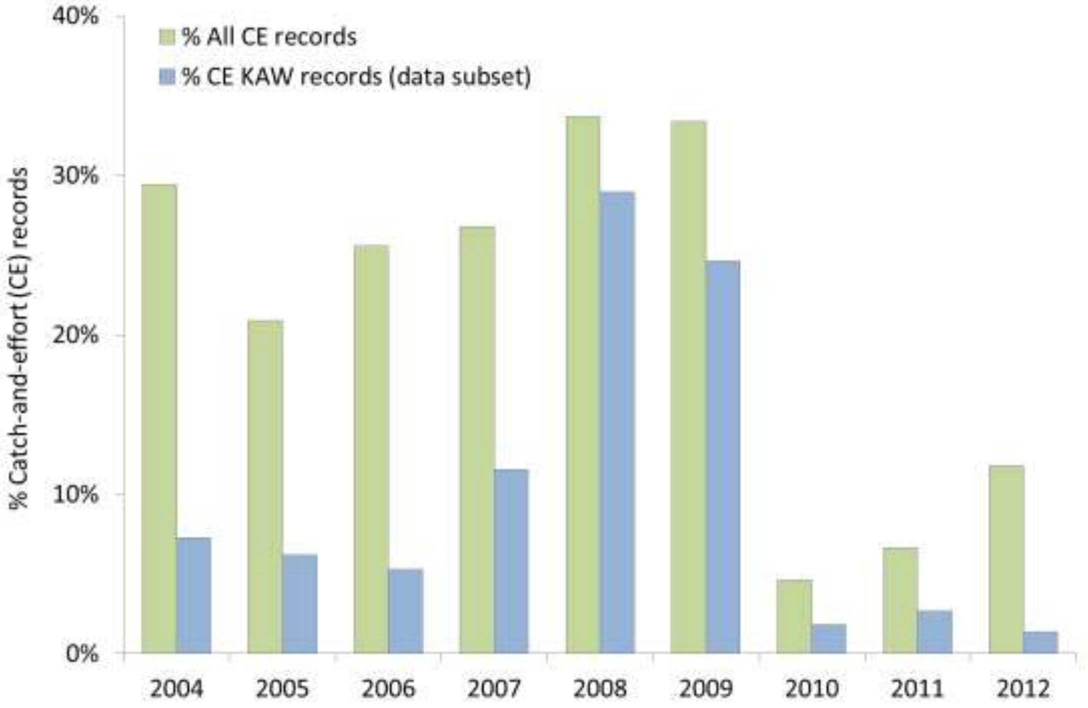


Figure 2. Proportion of records reporting fishing effort of 1 day per month, for all catch-and-effort records, and KAW filtered data subset, 2004-2012. Source: MFARD catch-and-effort data set.



Appendix 2: Model 1 Results

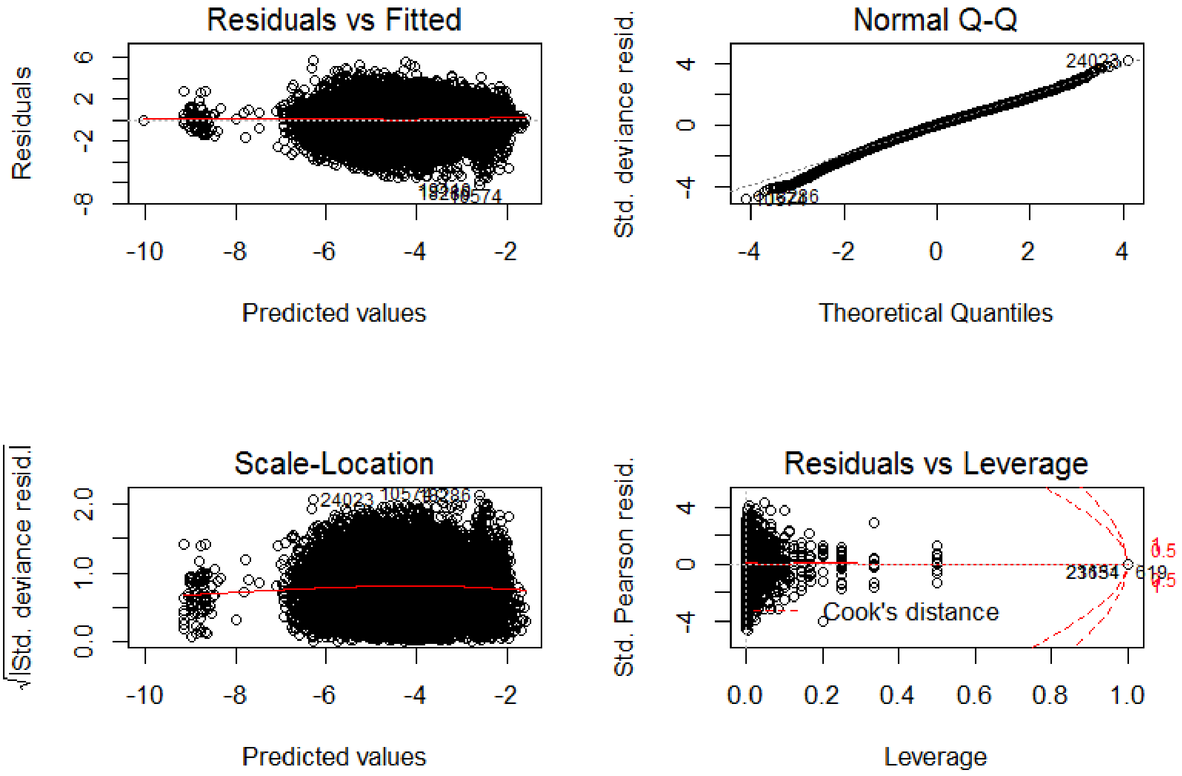


Figure 1: Residual diagnostics of the model using Year, Month, Atoll, Vessel length Category, and Vessel length category (Atoll) Interaction.

```
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                                          24564      71586
factor(Year)                   8   2693.6     24556      68892 173.835 < 2.2e-16 ***
factor(Month)                 11    367.7     24545      68524  17.260 < 2.2e-16 ***
factor(Atoll)                 26  17381.8     24519      51143 345.159 < 2.2e-16 ***
factor(Vessel.Cat)             6   1577.5     24513      49565 135.744 < 2.2e-16 ***
factor(Atoll):factor(Vessel.Cat) 103   2285.9     24410      47279  11.459 < 2.2e-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) + factor(Atoll):factor(Vessel.Cat))

Deviance Residuals:
```

```
    Min       1Q   Median       3Q      Max 
-6.5419  -0.8746   0.0826   0.9358   5.7794 

Coefficients: (53 not defined because of singularities)
                                     Estimate Std. Error t value Pr(>|t|)    
(Intercept)                         -5.853366   1.029713  -5.684 1.33e-08 ***
factor(Year)2005                     0.265194   0.035717   7.425 1.17e-13 ***
factor(Year)2006                    -0.013835   0.037715  -0.367 0.713745    
factor(Year)2007                     0.528566   0.035295  14.975  < 2e-16 ***
factor(Year)2008                     0.113378   0.038617   2.936 0.003329 ** 
factor(Year)2009                     0.498259   0.035024  14.226  < 2e-16 ***
factor(Year)2010                     0.528794   0.038448  13.753  < 2e-16 ***
factor(Year)2011                     0.438688   0.041709  10.518  < 2e-16 ***
factor(Year)2012                     0.015414   0.047031   0.328 0.743105    
factor(Month)2                       0.001831   0.042697   0.043 0.965800    
factor(Month)3                       0.055002   0.042956   1.280 0.200415    
factor(Month)4                       0.125690   0.043825   2.868 0.004135 ** 
factor(Month)5                       0.238818   0.043348   5.509 3.64e-08 ***
factor(Month)6                       0.197695   0.042836   4.615 3.95e-06 ***
factor(Month)7                       0.271582   0.042518   6.388 1.72e-10 ***
factor(Month)8                       0.168635   0.043589   3.869 0.000110 ***
factor(Month)9                       0.139708   0.043886   3.183 0.001457 ** 
factor(Month)10                      0.024844   0.043535   0.571 0.568237    
factor(Month)11                      0.169813   0.043489   3.905 9.46e-05 ***
factor(Month)12                      0.127313   0.043207   2.947 0.003216 ** 
factor(Atoll)AA                      1.849610   1.069873   1.729 0.083855 .  
factor(Atoll)AD                     -0.255592   1.118931  -0.228 0.819318    
factor(Atoll)AN                      0.895574   1.215584   0.737 0.461285    
factor(Atoll)AS                      1.769774   1.203074   1.471 0.141292    
factor(Atoll)BA                      1.249611   1.060115   1.179 0.238509    
factor(Atoll)DH                      0.176931   1.242528   0.142 0.886768    
factor(Atoll)fa                     -0.935483   1.730940  -0.540 0.588893    
factor(Atoll)FA                     -0.259351   1.045726  -0.248 0.804128    
factor(Atoll)GA                      2.117692   2.621662   0.808 0.419233    
factor(Atoll)GD                     -2.791072   1.731355  -1.612 0.106959    
factor(Atoll)GN                     -2.135748   1.242470  -1.719 0.085635 .  
factor(Atoll)HA                      0.101247   1.042969   0.097 0.922667    
factor(Atoll)HD                      0.484865   1.030031   0.471 0.637839    
factor(Atoll)KA                     -1.421730   1.424256  -0.998 0.318180    
factor(Atoll)KM                      2.006378   1.053636   1.904 0.056890 .  
factor(Atoll)La                     -1.930133   1.255050  -1.538 0.124088    
factor(Atoll)LA                      0.884819   1.424493   0.621 0.534509    
factor(Atoll)LH                      2.083379   1.731571   1.203 0.228921    
factor(Atoll)ME                     -1.080677   1.039016  -1.040 0.298305    
factor(Atoll)NO                     -0.072093   1.175973  -0.061 0.951117    
factor(Atoll)RA                      0.564072   1.037771   0.544 0.586762    
factor(Atoll)SE                      0.161495   1.053409   0.153 0.878158    
factor(Atoll)SH                      0.803335   1.031024   0.779 0.435892    
factor(Atoll)Th                      1.390430   1.704632   0.816 0.414693    
factor(Atoll)TH                     -0.928171   1.002603  -0.926 0.354579    
factor(Atoll)VA                     -0.334532   1.024824  -0.326 0.744103    
factor(Vessel.Cat)2                  0.672817   0.540181   1.246 0.212945    
factor(Vessel.Cat)3                  0.513132   0.434828   1.180 0.237979    
factor(Vessel.Cat)4                  1.254963   0.298926   4.198 2.70e-05 ***
factor(Vessel.Cat)5                  1.494783   0.315060   4.744 2.10e-06 ***
factor(Vessel.Cat)6                  1.621239   0.372045   4.358 1.32e-05 ***
factor(Vessel.Cat)7                 -1.940144   1.969004  -0.985 0.324465    
factor(Atoll)AA:factor(Vessel.Cat)2 -1.696471   0.647347  -2.621 0.008782 ** 
factor(Atoll)AD:factor(Vessel.Cat)2  0.911138   0.700840   1.300 0.193590    
factor(Atoll)AN:factor(Vessel.Cat)2  0.329925   0.845693   0.390 0.696448    
factor(Atoll)AS:factor(Vessel.Cat)2 -1.204812   0.828281  -1.455 0.145794    
factor(Atoll)BA:factor(Vessel.Cat)2 -0.861687   0.599939  -1.436 0.150932    
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factor(Atoll)FA:factor(Vessel.Cat)2  0.800900   0.605755   1.322 0.186130    
factor(Atoll)GA:factor(Vessel.Cat)2 -1.348591   2.660264  -0.507 0.612202    
factor(Atoll)GD:factor(Vessel.Cat)2  0.704416   1.572797   0.448 0.654248    
factor(Atoll)GN:factor(Vessel.Cat)2 -1.846173   0.907912  -2.033 0.042020 *  
factor(Atoll)HA:factor(Vessel.Cat)2  0.315675   0.630550   0.501 0.616633    
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factor(Atoll)KM:factor(Vessel.Cat)2 -2.079632   0.603422  -3.446 0.000569 ***
factor(Atoll)La:factor(Vessel.Cat)2        NA         NA      NA       NA    
factor(Atoll)LA:factor(Vessel.Cat)2        NA         NA      NA       NA    
factor(Atoll)LH:factor(Vessel.Cat)2 -2.121274   1.500819  -1.413 0.157548    
factor(Atoll)ME:factor(Vessel.Cat)2 -0.321068   0.564120  -0.569 0.569260    
```

```
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factor(Atoll)SE:factor(Vessel.Cat)2 -1.088096   0.670719  -1.622 0.104756
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factor(Atoll)Th:factor(Vessel.Cat)2        NA         NA      NA       NA
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factor(Atoll)VA:factor(Vessel.Cat)2        NA         NA      NA       NA
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factor(Atoll)SE:factor(Vessel.Cat)3 -0.376728   0.623541  -0.604 0.545733
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factor(Atoll)VA:factor(Vessel.Cat)3        NA         NA      NA       NA
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factor(Atoll)SE:factor(Vessel.Cat)4 -0.340473   0.790402  -0.431 0.666647
factor(Atoll)SH:factor(Vessel.Cat)4 -0.243435   0.309349  -0.787 0.431333
factor(Atoll)Th:factor(Vessel.Cat)4        NA         NA      NA       NA
factor(Atoll)TH:factor(Vessel.Cat)4        NA         NA      NA       NA
factor(Atoll)VA:factor(Vessel.Cat)4        NA         NA      NA       NA
factor(Atoll)AA:factor(Vessel.Cat)5 -0.081880   0.469698  -0.174 0.861612
factor(Atoll)AD:factor(Vessel.Cat)5  0.585666   0.577445   1.014 0.310479
factor(Atoll)AN:factor(Vessel.Cat)5  0.455162   0.755550   0.602 0.546897
factor(Atoll)AS:factor(Vessel.Cat)5 -0.910827   0.873990  -1.042 0.297353
factor(Atoll)BA:factor(Vessel.Cat)5 -2.072090   0.697880  -2.969 0.002989 **
factor(Atoll)DH:factor(Vessel.Cat)5 -2.020494   0.805792  -2.507 0.012167 *
factor(Atoll)fa:factor(Vessel.Cat)5  0.822002   1.993787   0.412 0.680137
factor(Atoll)FA:factor(Vessel.Cat)5 -1.876801   0.475072  -3.951 7.82e-05 ***
factor(Atoll)GA:factor(Vessel.Cat)5 -2.869741   2.446061  -1.173 0.240723
factor(Atoll)GD:factor(Vessel.Cat)5  0.317060   1.493870   0.212 0.831921
factor(Atoll)GN:factor(Vessel.Cat)5 -1.121712   1.246482  -0.900 0.368181
factor(Atoll)HA:factor(Vessel.Cat)5 -0.191978   0.400434  -0.479 0.631640
factor(Atoll)HD:factor(Vessel.Cat)5 -1.277910   0.451278  -2.832 0.004633 **
factor(Atoll)KA:factor(Vessel.Cat)5  1.316040   1.036432   1.270 0.204175
factor(Atoll)KM:factor(Vessel.Cat)5 -0.380717   0.394764  -0.964 0.334846
factor(Atoll)La:factor(Vessel.Cat)5        NA         NA      NA       NA
factor(Atoll)LA:factor(Vessel.Cat)5 -2.097339   1.091254  -1.922 0.054623 .
```

```
factor(Atoll)LH:factor(Vessel.Cat)5 -2.058478   1.431089  -1.438 0.150334    
factor(Atoll)ME:factor(Vessel.Cat)5  1.098982   0.364124   3.018 0.002546 ** 
factor(Atoll)NO:factor(Vessel.Cat)5        NA         NA      NA       NA    
factor(Atoll)RA:factor(Vessel.Cat)5 -0.527460   0.361262  -1.460 0.144290    
factor(Atoll)SE:factor(Vessel.Cat)5 -2.773410   0.796587  -3.482 0.000499 ***
factor(Atoll)SH:factor(Vessel.Cat)5 -0.862275   0.334269  -2.580 0.009898 ** 
factor(Atoll)Th:factor(Vessel.Cat)5        NA         NA      NA       NA    
factor(Atoll)TH:factor(Vessel.Cat)5        NA         NA      NA       NA    
factor(Atoll)VA:factor(Vessel.Cat)5        NA         NA      NA       NA    
factor(Atoll)AA:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)AD:factor(Vessel.Cat)6  0.616554   1.506662   0.409 0.682383    
factor(Atoll)AN:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)AS:factor(Vessel.Cat)6 -3.839000   1.569723  -2.446 0.014466 *  
factor(Atoll)BA:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)DH:factor(Vessel.Cat)6 -2.678712   0.872997  -3.068 0.002154 ** 
factor(Atoll)fa:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)FA:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)GA:factor(Vessel.Cat)6 -3.033751   2.479240  -1.224 0.221092    
factor(Atoll)GD:factor(Vessel.Cat)6 -0.181523   1.488527  -0.122 0.902941    
factor(Atoll)GN:factor(Vessel.Cat)6  2.975285   1.126838   2.640 0.008286 ** 
factor(Atoll)HA:factor(Vessel.Cat)6  0.587473   0.562242   1.045 0.296090    
factor(Atoll)HD:factor(Vessel.Cat)6 -0.936046   0.448082  -2.089 0.036717 *  
factor(Atoll)KA:factor(Vessel.Cat)6  1.899544   1.069838   1.776 0.075821 .  
factor(Atoll)KM:factor(Vessel.Cat)6 -0.468696   0.447954  -1.046 0.295431    
factor(Atoll)La:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)LA:factor(Vessel.Cat)6 -0.571026   1.078736  -0.529 0.596569    
factor(Atoll)LH:factor(Vessel.Cat)6 -3.202232   1.480155  -2.163 0.030517 *  
factor(Atoll)ME:factor(Vessel.Cat)6  1.092138   1.061972   1.028 0.303769    
factor(Atoll)NO:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)RA:factor(Vessel.Cat)6 -0.101757   0.609753  -0.167 0.867464    
factor(Atoll)SE:factor(Vessel.Cat)6 -1.639529   0.913983  -1.794 0.072853 .  
factor(Atoll)SH:factor(Vessel.Cat)6 -1.007571   0.647460  -1.556 0.119676    
factor(Atoll)Th:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)TH:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)VA:factor(Vessel.Cat)6        NA         NA      NA       NA    
factor(Atoll)AA:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)AD:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)AN:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)AS:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)BA:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)DH:factor(Vessel.Cat)7  1.367159   2.126783   0.643 0.520341    
factor(Atoll)fa:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)FA:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)GA:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)GD:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)GN:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)HA:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)HD:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)KA:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)KM:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)La:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)LA:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)LH:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)ME:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)NO:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)RA:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)SE:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)SH:factor(Vessel.Cat)7        NA         NA      NA       NA    
factor(Atoll)Th:factor(Vessel.Cat)7        NA         NA      NA       NA    
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 1.936875)

    Null deviance: 71586  on 24564  degrees of freedom
Residual deviance: 47279  on 24410  degrees of freedom
AIC: 86108

Number of Fisher Scoring iterations: 2
```

Appendix 3: Model 3 Results (FAD Effects)

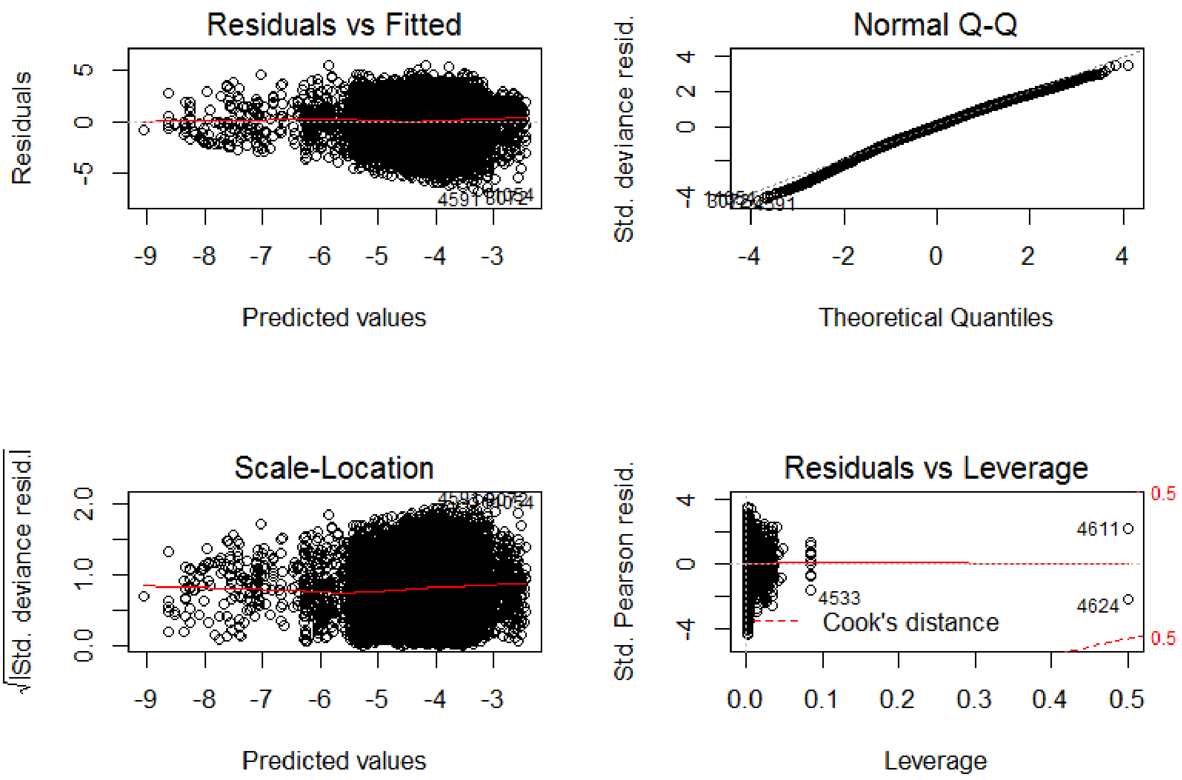

Figure 1: Residual Diagnostics of the FAD effects model on broader spatial resolution

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			24564	71586			
factor(Year)	8	2693.6	24556	68892	134.029	< 2.2e-16	***
factor(Month)	11	367.7	24545	68524	13.308	< 2.2e-16	***
factor(Vessel.Cat)	6	4139.8	24539	64385	274.657	< 2.2e-16	***
factor(FAD_Region)	2	1816.5	24537	62568	361.542	< 2.2e-16	***
Region_FAD	1	9.1	24536	62559	3.623	0.057	.
factor(Vessel.Cat):factor(FAD_Region)	11	890.7	24525	61668	32.233	< 2.2e-16	***
factor(FAD_Region):Region_FAD	2	63.5	24523	61605	12.648	3.236e-06	***

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  
-6.9888  -0.9834   0.0341   1.1135   5.5533  

Coefficients: (1 not defined because of singularities)
                                            Estimate Std. Error t value Pr(>|t|)    
(Intercept)                                 -6.58213    0.23767 -27.694  < 2e-16 ***
factor(Year)2005                             0.27689    0.04115   6.728 1.75e-11 ***
factor(Year)2006                            -0.01420    0.04470  -0.318 0.750688    
factor(Year)2007                             0.70049    0.04437  15.788  < 2e-16 ***
factor(Year)2008                             0.30404    0.04840   6.283 3.39e-10 ***
factor(Year)2009                             0.75531    0.04417  17.101  < 2e-16 ***
factor(Year)2010                             0.67168    0.04824  13.925  < 2e-16 ***
factor(Year)2011                             0.61887    0.04796  12.905  < 2e-16 ***
factor(Year)2012                             0.01817    0.05726   0.317 0.751041    
factor(Month)2                              -0.05655    0.04866  -1.162 0.245234    
factor(Month)3                              -0.01487    0.04927  -0.302 0.762808    
factor(Month)4                               0.02403    0.05000   0.480 0.630877    
factor(Month)5                               0.14298    0.04944   2.892 0.003829 ** 
factor(Month)6                               0.14075    0.04907   2.868 0.004132 ** 
factor(Month)7                               0.28970    0.04834   5.993 2.09e-09 ***
factor(Month)8                               0.14360    0.04953   2.899 0.003741 ** 
factor(Month)9                               0.03334    0.04983   0.669 0.503515    
factor(Month)10                              0.01742    0.04955   0.351 0.725223    
factor(Month)11                              0.15908    0.04938   3.221 0.001278 ** 
factor(Month)12                              0.16584    0.04915   3.374 0.000742 ***
factor(Vessel.Cat)2                          0.85984    0.10437   8.238  < 2e-16 ***
factor(Vessel.Cat)3                          1.62204    0.10252  15.822  < 2e-16 ***
factor(Vessel.Cat)4                          2.01486    0.10548  19.102  < 2e-16 ***
factor(Vessel.Cat)5                          2.21328    0.11096  19.946  < 2e-16 ***
factor(Vessel.Cat)6                          2.73716    0.13150  20.814  < 2e-16 ***
factor(Vessel.Cat)7                         -0.23101    0.46883  -0.493 0.622201    
factor(FAD_Region)North                      1.00609    0.27481   3.661 0.000252 ***
factor(FAD_Region)South                     -2.40639    0.63248  -3.805 0.000142 ***
Region_FAD                                   0.01944    0.01076   1.807 0.070830 .  
factor(Vessel.Cat)2:factor(FAD_Region)North -0.33240    0.11402  -2.915 0.003558 ** 
factor(Vessel.Cat)3:factor(FAD_Region)North -0.62606    0.11081  -5.650 1.62e-08 ***
factor(Vessel.Cat)4:factor(FAD_Region)North -0.98693    0.12001  -8.224  < 2e-16 ***
factor(Vessel.Cat)5:factor(FAD_Region)North -1.34892    0.13220 -10.204  < 2e-16 ***
factor(Vessel.Cat)6:factor(FAD_Region)North -2.03806    0.22546  -9.040  < 2e-16 ***
factor(Vessel.Cat)7:factor(FAD_Region)North       NA         NA      NA       NA    
factor(Vessel.Cat)2:factor(FAD_Region)South -2.53012    0.33089  -7.646 2.14e-14 ***
factor(Vessel.Cat)3:factor(FAD_Region)South -2.50757    0.31161  -8.047 8.85e-16 ***
factor(Vessel.Cat)4:factor(FAD_Region)South -1.60819    0.36634  -4.390 1.14e-05 ***
factor(Vessel.Cat)5:factor(FAD_Region)South -1.95320    0.35815  -5.454 4.98e-08 ***
factor(Vessel.Cat)6:factor(FAD_Region)South -2.76094    0.39988  -6.904 5.16e-12 ***
factor(Vessel.Cat)7:factor(FAD_Region)South -2.10904    1.23898  -1.702 0.088723 .  
factor(FAD_Region)North:Region_FAD          -0.00480    0.01508  -0.318 0.750315    
factor(FAD_Region)South:Region_FAD           0.21169    0.04371   4.843 1.28e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 2.51212)

    Null deviance: 71586  on 24564  degrees of freedom
Residual deviance: 61605  on 24523  degrees of freedom
AIC: 92384

Number of Fisher Scoring iterations: 2
```