Received: 30 September 2014



(Indian Ocean Tuna Commission - Working Party on Tropical Tunas)

# Maldives Skipjack Pole and Line Fishery Catch Rate Standardization 2004-2012: Reconstructing Historic CPUE till 1985

March 2014

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)



## Abstract

A qualitative description and GLM-based standardization of the Maldivian skipjack (*Katsuwona pelamis*, SKJ) 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 55,930 records was extracted from the dataset, identified as records of fishing activity targeting skipjack. In the process, the paper discusses a number of serious issues with the quality of the CPUE dataset, notably records with zero skipjack catch with a directed pole and line (PL) fishery and which were eventually discounted from the final analysis. FAD data was also incorporated into the analysis using the number of active anchored FADS (aFADs) associated with the nearest atoll that the landing data is collected from. In order to do this, the distribution of aFADs 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 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, Region (N, S, or M), number of aFADs associated with each area, length of vessel, and interaction effects between the last 3 categories. The data was analysed at a monthly resolution before being was aggregated into quarterly signals for 2004-2012. Finally, using the average length of vessels (as recorded in the vessel registry and CPUE dataset) as a continuous covariate, the CPUE data was estimated for historic period from 1985 onwards.

## Introduction

The Indian Ocean skipjack tuna (*Katsuwona pelamis*, SKJ) fishery is one of the largest tuna fisheries in the world, with total catches of 400-600 thousand tonnes over the past decade (**Error! Reference ource not found.**). The Maldives standardized CPUE is one of the only reliable sources of information for CPUE for the stock assessment of Skipjack and hence further efforts have been made to use this data, and reconstruct historic series as well. The IOTC Working Party on Tropical Tunas (WPTT 2012) recognized that it was worth further effort to extend the CPUE series of the Maldivian Pole and Line (PL) fishery, and this document describes the continuing effort to do so.

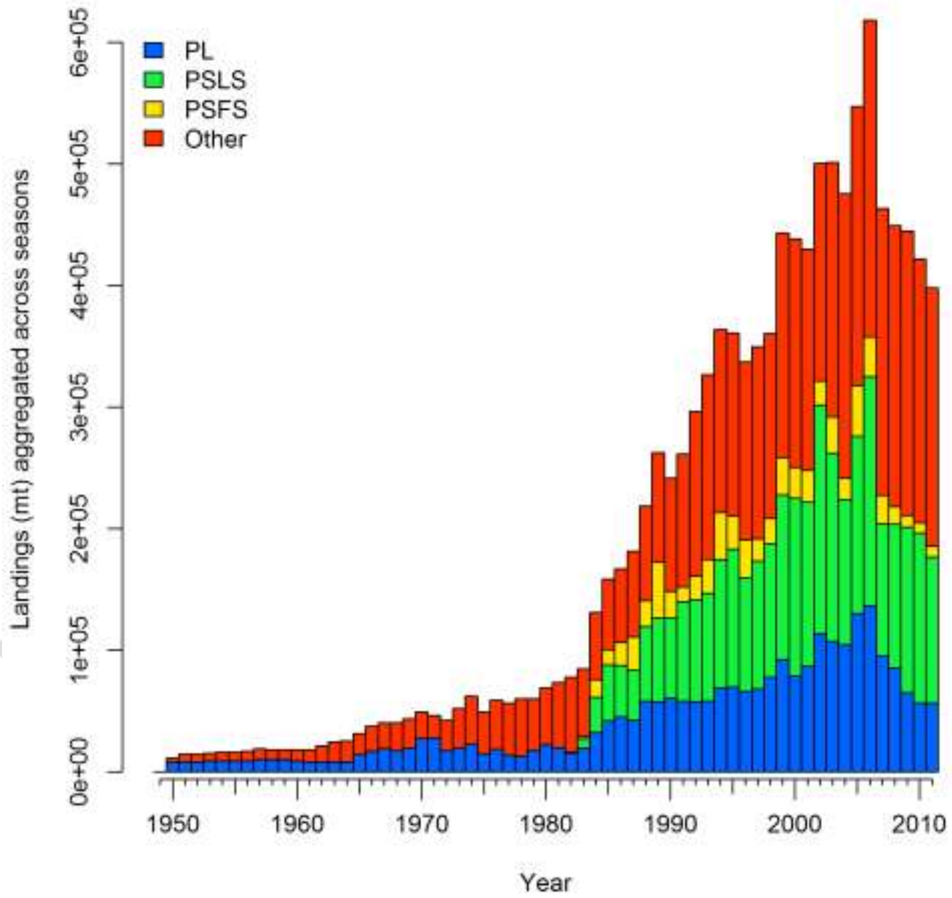



**Figure 1. Aggregate Indian Ocean SKJ catch in mass over time disaggregated by the fleets defined for the assessment.**

Adam (2010) provides a description of the recent Maldives fishery. When nominal effort is defined as a boat day (all fishing vessels assumed to be equally efficient), there appears to be a generally increasing trend in the PL CPUE since the 1970s, with a possible decline in the most recent years (**Error! Reference source not found.**). However, there are a number of features in the fishery which ave changed over time, and which would be expected to change the nature of the relationship between SKJ abundance and CPUE.

In Adam (2012) we realize the difficulty of standardization due to fleet efficiency, inconsistencies between information held in different databases and using different data collection methodologies, and the issue of using anchored FADs (aFADs) to improve catch rates from the mid 1980's.

Most of the changes are expected to increase the catchability of the average vessel (if effort is defined in terms of a daily fishing trip):

- Over the last 30 years, new vessels have tended to be larger and more powerful, with more fishing poles, higher bait holding capacity, more storage space, longer range and presumably improved electronics.
- A network of aFADs was introduced in the 1980s, and most effort has been concentrated near aFADs since then. Deployment of aFADs began in the early 1980's and increased from a relatively small number to over 40 by the early 2000s. Since then the number of aFADs has fluctuated from between 40 to 50 (Appendix 1, figure 3). An attempt to use aFADs to standardize the signal by area is attempted here for the first time.
- Improvements in bait catching techniques. Since around 2000, fishermen began catching bait using lights at night, instead of lift nets during the morning. This has greatly increased the live bait catch and the daily hours available for searching and fishing.
- Use of collector vessels presumably increases the potential range of the vessels from home port.

However, there also appear to be other factors operating in this fishery (or at least in the catch-effort database) which could contribute to an apparent decline in efficiency of the fleet (or change the efficiency in either direction, depending on the trend):

- Limited bait availability is suspected of constraining operations in recent years.
- Fuel subsidies have created incentives to have vessels recognized as fishing vessels, even if that is not their primary purpose. This is thought to have resulted in reporting of fishing effort (and catch) for vessels that were not fishing.
- High fuel costs have likely reduced fishing activity. The total number of fishing days (per month) has fallen from around 8000 in 2004 to around 5000 in 2011. But the number of vessels has also decreased, so actual fishing days per vessel have actually increased (from around 12 days per month in 2004 to 16 days per month in 2011).
- A requirement for license fees to be paid for vessels operating less than 120 days per year created an incentive to over-report effort. The fee was abolished in Jan 2009.
- Many vessels can switch between PL and hand-line (HL) operations within a fishing trip, and there is reason to think that the correct gear type is not always reported. Ultimately, it is possible by focussing on PL, we are missing the true number of boats targeting Skipjack, though is highly unlikely.

Mohamed (2007) proposed a time series of SKJ relative abundance derived from the PL fishery from 1985-2005. That analysis assumed that changes in efficiency over time were adequately explained by, and directly proportional to, mean annual horsepower in the fleet. However, there was no quantitative analysis presented to justify that assumption. Kolody *et al.* (2010) attempted to standardize the PL CPUE series by i) reconstructing the fleet composition from 1958-2007 based on the vessel registry and assumptions about vessel longevity, ii) quantify the relative catchability for different vessel characteristics, based on a partial database of monthly catch-and-effort by vessel from 2004-7, and iii) estimate time series of relative abundance from aggregate catch-and-effort by atoll from 1970-2007, combined with (i) and (ii). However, that attempt was not very successful and was eventually abandoned. Kolody et. al. (2011) used a standardized GLM based method to account for the probability of zero catches (we now know that these records were incorrectly coded at MRC), and catch rate as a function of year, quarter, atoll and vessel-length.

The attempt made here extends Kolody *et. al.* (2011) analysis by adding the effects of anchored FADs, and also estimates the historic CPUE catch rates using vessel length as a covariate (being related to HP and larger boats with higher efficiency, i.e., catchability) to estimate rates to the mid 1980's. Prior to that, the fleet was primarily non-mechanized and the authors felt extending the series beyond the 1980s raised concerns over the reliability of the CPUE estimates.

# 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, as previously stated, 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, figure 3), 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 from the catch-and-effort data were extracted for the analysis, identified as fishing activity targeting skipjack. In the process, a number of issues with the quality of the data were identified – of varying importance – but considered together raise serious questions regarding the reliability of the catch-and-effort data more generally.

Large numbers 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 skipjack catches**

To identify skipjack targeted fishing, the catch-and-effort data were initially filtered on gear ('pole-and-line') and fishery type ('skipjack'). However around 50% of the records selected reported zero skipjack catch – but positive effort – consistently over a number of months. While it is reasonable to assume that skipjack cannot be located during single fishing trips, it is unlikely vessels targeting skipjack 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 skipjack catches were proposed:

- <u>Recorded gear and fishery type</u>
  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 neritic tunas - despite reporting the trip as skipjack fishery type.

- 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[1], 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). There is the possibility that recent declines in the nominal catch discussed in next section (see Appendix 1, figure 4) may be a reflection – in part – of under-reporting of total catches from unloadings prior to arrival at the home port, in addition to changes to the reporting system.

- 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 skipjack catch, but positive effort, was actually higher in 2009 than in earlier years (e.g., around 40% compared to 20-30% for 2004-2008), so this does not seem like an important contributing factor.

**Missing vessel ID and/or vessel dimensions**
Around 3,744 records (2.7% of the total catch-and-effort records) were missing valid vessel identification numbers (VIN) required for linking to the vessel registry and vessel dimensions to model the relationship between CPUE and vessel efficiency.

**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**
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**

[1] 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

The atoll assigned to each vessel's record of catch-and-effort 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 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 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. Vessels targeting skipjack typically fish for 15 days or more each month; however – up to 2009 – a third of vessels reported only a single day of effort per month, which seems highly unusual, particularly when from 2009 onwards the proportion of drops to around 4% (Appendix 1, figure 1). 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 – 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 the data 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 them in the final dataset used in the analysis.

## Selection of CPUE records targeting skipjack

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 skipjack:

- Vessels operating Pole-and-line
- Effort (in days) greater than zero (i.e., including vessels recorded one day effort)
- Total skipjack catch (per month) greater than zero[2]
- Records containing valid vessel identification (VIN) numbers (required to link to information on vessel length recorded in the vessel registry)

Applying the criteria, a subset of 55,930 observations (41% of the total 135,645 catch-and-effort records) were identified as targeting skipjack used in the final analysis. 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

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

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.

### Overview of main trends in skipjack nominal catch and CPUE

- For vessels targeting skipjack – defined according to the criteria above – the nominal catch of skipjack reported by Maldives has declined dramatically over the last decade. Between 2004 Q4 and 2011 Q4, total skipjack catch decreased by 55% from 24,500Mt to 19,600Mt, while effort decreased by 37% from 26,700 to 17,000 fishing days (Appendix 1, figure XX).
- In addition to the overall decline in catch there are large fluctuations in the nominal catch, which suggest some seasonality effects – with most peaks around the first and fourth calendar quarters each year, although the cycles do not strictly follow a regular pattern.
- The nominal CPUE closely follows that of the nominal catch showing an overall decreasing, albeit fluctuating, but trend from a peak of over 1.8 in mid-2006 to below 1.0 since 2009.
- The majority of the nominal skipjack 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, over 55% of skipjack catch between 2004-2012 was concentrated in five atolls (Gaafu Alifu (GA), Gaafu Dhaalu (GN), and Sennu (SE) in the south, Laamu (LA) in the mid atoll area, and Haa Alifu (HA) in the north) (Appendix 1, figure 5).
- The CPUE increases sharply with vessel size. In 2011, a CPUE of 0.31 is reported for vessels 12-17m in length (the common vessel type), 0.84 for vessels 17-22m, 1.25 for vessels 22-27m, and 1.79 for vessels over 27m.
- 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 skipjack (based on the final criteria recommended by MoFA/MRC above), the average size of vessels increased from 16.9m in 2004 to 20.2m by 2011.

## 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 g*lm()*:

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

where:

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

$\beta_T$ = 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 $\sigma^2$.

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), or a continuous variable f(L) (in the latter case, only vessels of >17m were included).

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: Vessel and Atoll effect model (Using main effects, Atoll Area effects, and VIN Numbers with VIN: Atoll interaction).
Model 4: FAD effect model: Accounting for aFAD effects at an aggregated spatial resolution (not Atoll but 3 areas, N, Mid, and S areas).

Note, that for all models we examined the effect of one day effort onlu, and repeated the analysis with and without those records.

**Standardized CPUE Series**

The final model recommended was Model 4 as it incorporated vessel effects and aFAD 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,

$\beta_t$ = 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 aFADs 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; or 19.5m X the estimated length co-efficient in the continuous case.

$\sigma^2$ 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).

**Reconstructing Historic Time Series using Vessel Length**

Vessel length is highly correlated with Horse power (Persons r=0.79, Spearmans r=0.87). Hence we chose only vessel length (as a continuous measure) to estimate the historic CPUE to the mid 1980's. Prior to that the vessels were mostly non-mechanized, and the fleet structure was quite different (Anderson 1987), and using the relationship beyond that time maybe spurious.

The model estimated the following (note the CPUE series chosen was the Vessel area FAD, model 4 described above):

$$CPUE_i = \alpha + \beta\overline{Vlen}_i + \varepsilon \qquad (3)$$

Using estimated α and β, and average vessel length (Vlen) at time i, we estimated CPUE from January, 1985 to December, 2003. We then standardized the entire series from January, 1985 to December, 2011, averaging the entire series to 1.

In order to reconstruct the vessel length over time an exponential model fit was developed based on vessel length changing over time. This predicted a vessel length at a particular time, and this was used to estimate the CPUE in year I (eq. 3).

Note, in order to add noise the series, we looked at the ratio of change from year (i-1) to year (i) derived from the entire vessel record archived by MOFA (proprietary information on all vessels, not jus pole and line vessels). If predicted values were too low in value, we had to use average changes to estimate the derived changes in those years to avoid predicting a negative CPUE (shown below).

$$\overline{Vlen_i}_{Noise} = \overline{Vlen_i}\frac{RegisteredVessellen_{i-1}}{RegisteredVessellen_i}$$

## Results and Discussion

### Generalized Linear Models

The covariate factors used in model 1 are as follows:

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

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.

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 and Northern Atoll used (Shaviyanai, SH) and also computed for southern atoll (Gaafu Alifu, GA).

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

The second model examined was:

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

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 aFAD's (FAD variable is the number of active aFADs) at a coarser scale than the atoll levels (Appendix 1, Figure 3, Appendix 2 Figure 3). We now have three areas (LA), (North (N), South(S), and Middle (M)). The model examined was:

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

Diagnostics of each of the 2 main models with ANOVAS (eq. 4 and 6) are in Appendix 2, Figure 1 and Appendix 2, Figure 2 with the parameters as well.

For the FAD effect model we examined the effect of one day only effort that was likely because of the fuel subsidy and performed an analysis with and without it.

Table 1 shows the results of the actual index and standardized index for the main effect model, and the aFAD based models, and compares the results to Kolody et. al. (2011).

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

| Year | Quarter | Model 1 (Vessel:North) | Model 1 (Vessell:South) | Model 3: FAD effects model | | Model 1: Stdized Vessel:Atoll | Model 3: Standardized FAD | Model 3: Without 1 day | PL - preferred | PL - Dale Sensitivity |
|---|---|---|---|---|---|---|---|---|---|---|
| **2004** | 1 | 0.37 | 0.93 | 0.82 | | 1.09 | 1.18 | 1.17 | 1.01 | 1.17 |
| **2004** | 2 | 0.35 | 0.86 | 0.73 | | 1.01 | 1.05 | 1.11 | 0.99 | 0.9 |
| **2004** | 3 | 0.37 | 0.93 | 0.81 | | 1.09 | 1.17 | 1.12 | 1.01 | 1.11 |
| **2004** | 4 | 0.46 | 1.15 | 1.00 | | 1.35 | 1.44 | 1.51 | 1.03 | 1.28 |
| **2005** | 1 | 0.45 | 1.13 | 0.93 | | 1.32 | 1.33 | 1.32 | 0.96 | 1.15 |
| **2005** | 2 | 0.42 | 1.04 | 0.82 | | 1.22 | 1.19 | 1.28 | 1.55 | 1.25 |
| **2005** | 3 | 0.45 | 1.13 | 0.91 | | 1.32 | 1.31 | 1.30 | 1.13 | 1.36 |
| **2005** | 4 | 0.56 | 1.39 | 1.13 | | 1.63 | 1.63 | 1.68 | 1.67 | 1.65 |
| **2006** | 1 | 0.46 | 1.14 | 0.98 | | 1.33 | 1.40 | 1.56 | 1.3 | 1.66 |
| **2006** | 2 | 0.42 | 1.05 | 0.89 | | 1.23 | 1.27 | 1.37 | 1.32 | 1.31 |
| **2006** | 3 | 0.46 | 1.14 | 0.98 | | 1.33 | 1.40 | 1.43 | 1.18 | 1.03 |
| **2006** | 4 | 0.56 | 1.40 | 1.20 | | 1.64 | 1.73 | 1.91 | 1 | 1.25 |
| **2007** | 1 | 0.32 | 0.80 | 0.69 | | 0.93 | 0.99 | 0.98 | 0.77 | 0.81 |
| **2007** | 2 | 0.30 | 0.74 | 0.62 | | 0.86 | 0.89 | 0.87 | 0.91 | 0.77 |
| **2007** | 3 | 0.32 | 0.80 | 0.69 | | 0.94 | 0.99 | 0.89 | 0.83 | 0.79 |
| **2007** | 4 | 0.39 | 0.98 | 0.85 | | 1.15 | 1.22 | 1.17 | 1.33 | 1.07 |
| **2008** | 1 | 0.32 | 0.81 | 0.68 | | 0.95 | 0.98 | 0.94 | 0.66 | 0.62 |
| **2008** | 2 | 0.30 | 0.75 | 0.61 | | 0.88 | 0.88 | 0.87 | 0.72 | 0.76 |
| **2008** | 3 | 0.33 | 0.81 | 0.68 | | 0.95 | 0.98 | 0.87 | 0.91 | 0.92 |
| **2008** | 4 | 0.40 | 1.00 | 0.86 | | 1.17 | 1.23 | 1.03 | 0.93 | 1.05 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **2009** | 1 | 0.31 | 0.77 | 0.64 | | 0.90 | 0.92 | 0.72 | 0.75 | 0.69 |
| **2009** | 2 | 0.28 | 0.71 | 0.57 | | 0.83 | 0.83 | 0.67 | 0.8 | 0.63 |
| **2009** | 3 | 0.31 | 0.77 | 0.64 | | 0.90 | 0.92 | 0.65 | 1.22 | 0.75 |
| **2009** | 4 | 0.38 | 0.95 | 0.78 | | 1.11 | 1.12 | 0.95 | 0.91 | 1.02 |
| **2010** | 1 | 0.27 | 0.69 | 0.52 | | 0.80 | 0.74 | 0.78 | 0.77 | 0.81 |
| **2010** | 2 | 0.25 | 0.63 | 0.46 | | 0.74 | 0.66 | 0.77 | 0.48 | 0.55 |
| **2010** | 3 | 0.27 | 0.69 | 0.51 | | 0.80 | 0.73 | 0.78 | 0.69 | 0.75 |
| **2010** | 4 | 0.34 | 0.85 | 0.63 | | 0.99 | 0.91 | 0.95 | 1.19 | 0.88 |
| **2011** | 1 | 0.22 | 0.55 | 0.40 | | 0.65 | 0.57 | 0.62 | | |
| **2011** | 2 | 0.20 | 0.51 | 0.36 | | 0.60 | 0.52 | 0.54 | | |
| **2011** | 3 | 0.22 | 0.55 | 0.39 | | 0.65 | 0.57 | 0.58 | | |
| **2011** | 4 | 0.27 | 0.68 | 0.49 | | 0.80 | 0.70 | 0.77 | | |
| **2012** | 1 | 0.23 | 0.58 | 0.43 | | 0.68 | 0.62 | 0.72 | | |
| **2012** | 2 | 0.21 | 0.53 | 0.39 | | 0.63 | 0.57 | 0.62 | | |
| **2012** | 3 | 0.23 | 0.58 | 0.43 | | 0.68 | 0.62 | 0.65 | | |
| **2012** | 4 | 0.29 | 0.71 | 0.54 | | 0.83 | 0.77 | 0.85 | | |

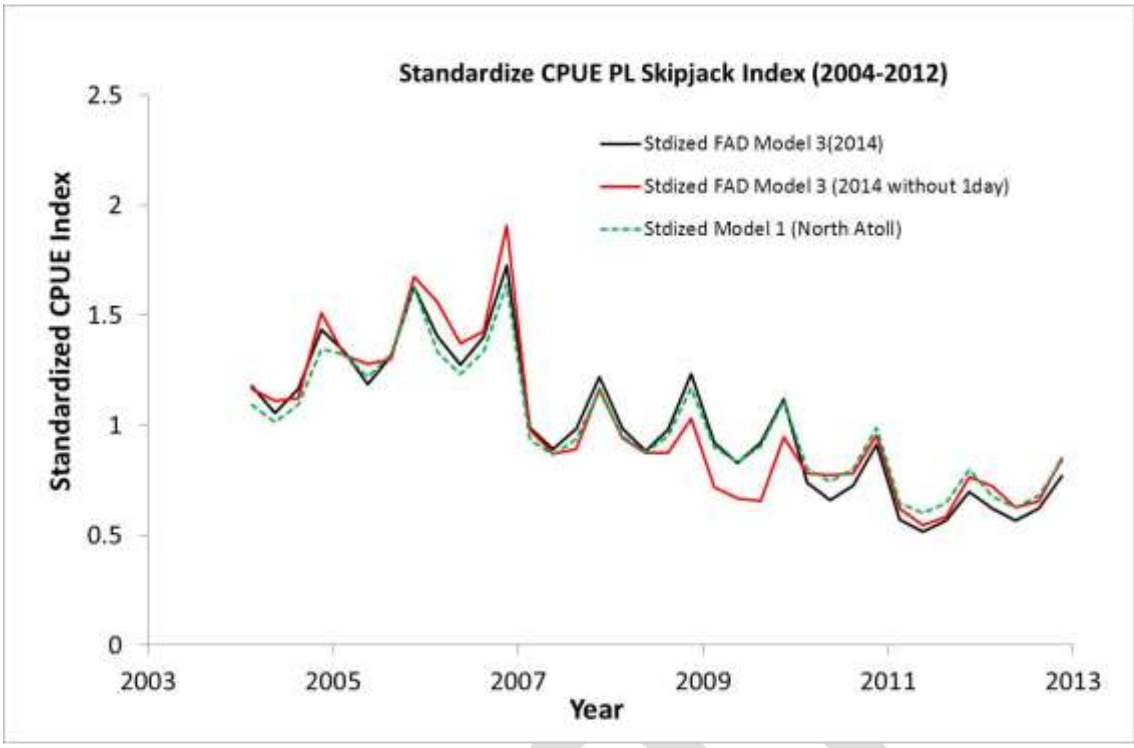



**Figure 1: Standardized Index of the new models (Model 3 FAD is recommended). For Model 3, we show the effect with and without a day.**

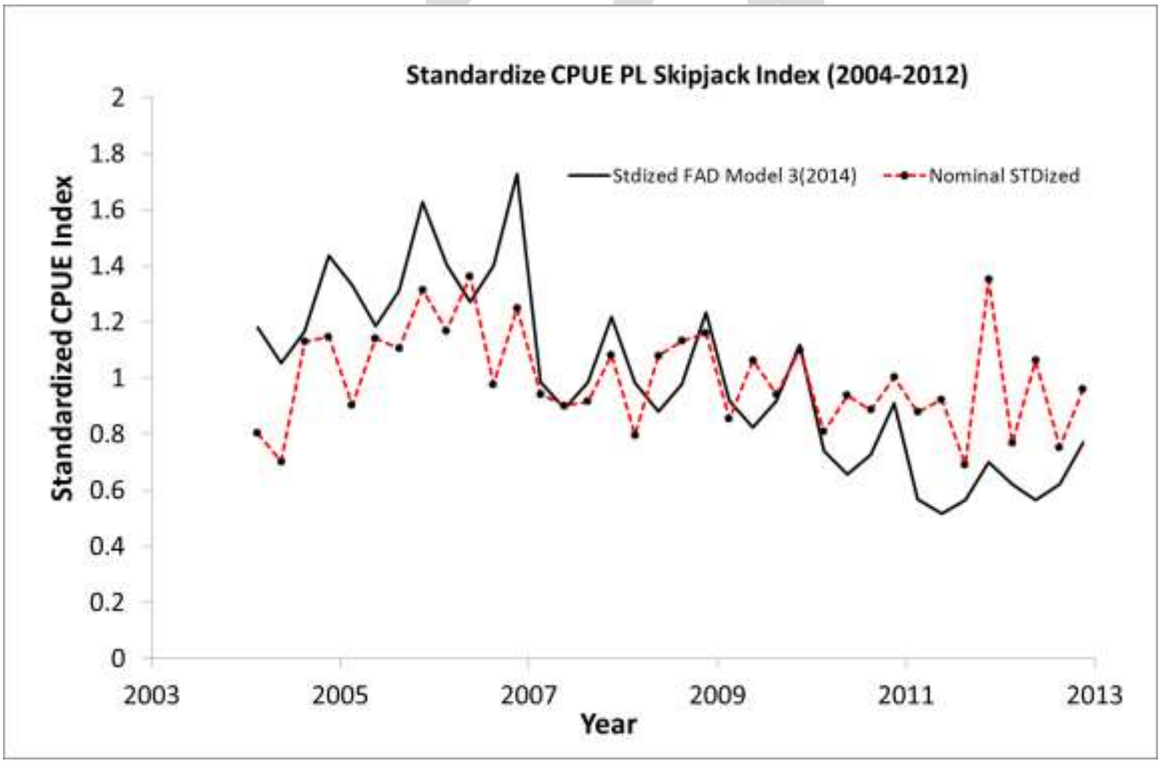



**Figure 2: Standardized Index of the recommended model and the nominal CPUE**

### Reconstructing the Historic Series using the FAD based series.

Table 2: Coefficients of the regression with ANOVA between the standardized CPUE and the average vessel size of the PL fleet.

ANOVA

| | *Df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 3.22 | 3.22 | 160.09 | 0.00 |
| Residual | 106 | 2.13 | 0.02 | | |
| Total | 107 | 5.35 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* |
|---|---|---|---|---|---|---|
| Intercept | 2.75 | 0.16 | 16.88 | 0.00 | 2.43 | 3.07 |
| Avg.Vessel | -0.11 | 0.01 | -12.65 | 0.00 | -0.13 | -0.09 |

The relationship between average vessel size and the standardized CPUE (Without averaging it to one is shown in Figure 3).

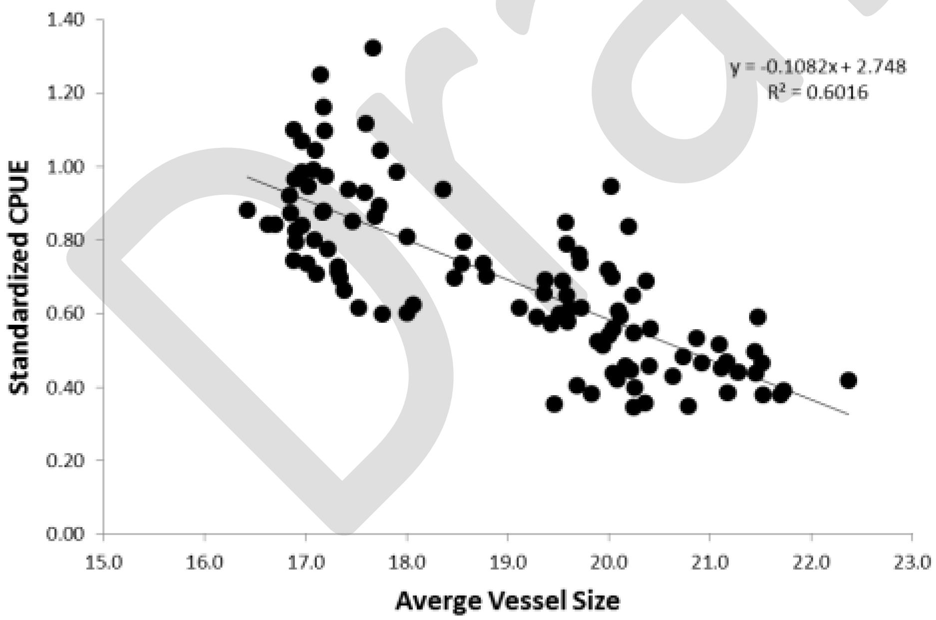



**Figure 3: Relationship between average vessel size and standardized CPUE between 2004-2012.**

The estimate of vessel size changing over time is shown in Figure 4 below. The relationship is derived from the PL fleet changing it average size between 2004-2012, and the non-linear exponential trend is reconstructed back to 1985. This assumes the rate of change began in 1985 and continues to the present date (Figure 4). Inset a shows the series based on the current data (2004-2012) and inset b shows the series estimated back to 1970. As the fleet changed quite dramatically in the mid 1980's (Anderson 1987), we only used the data from mid-1985 to build the relationship with CPUE (Figure

5). To add noise to the smoothed trend, as CPUE data is never this clean, we used the ratio of change in the MRC vessel registry database from one month to the next to derive the index (Figure 6), and then standardized it by quarter (Table 2).

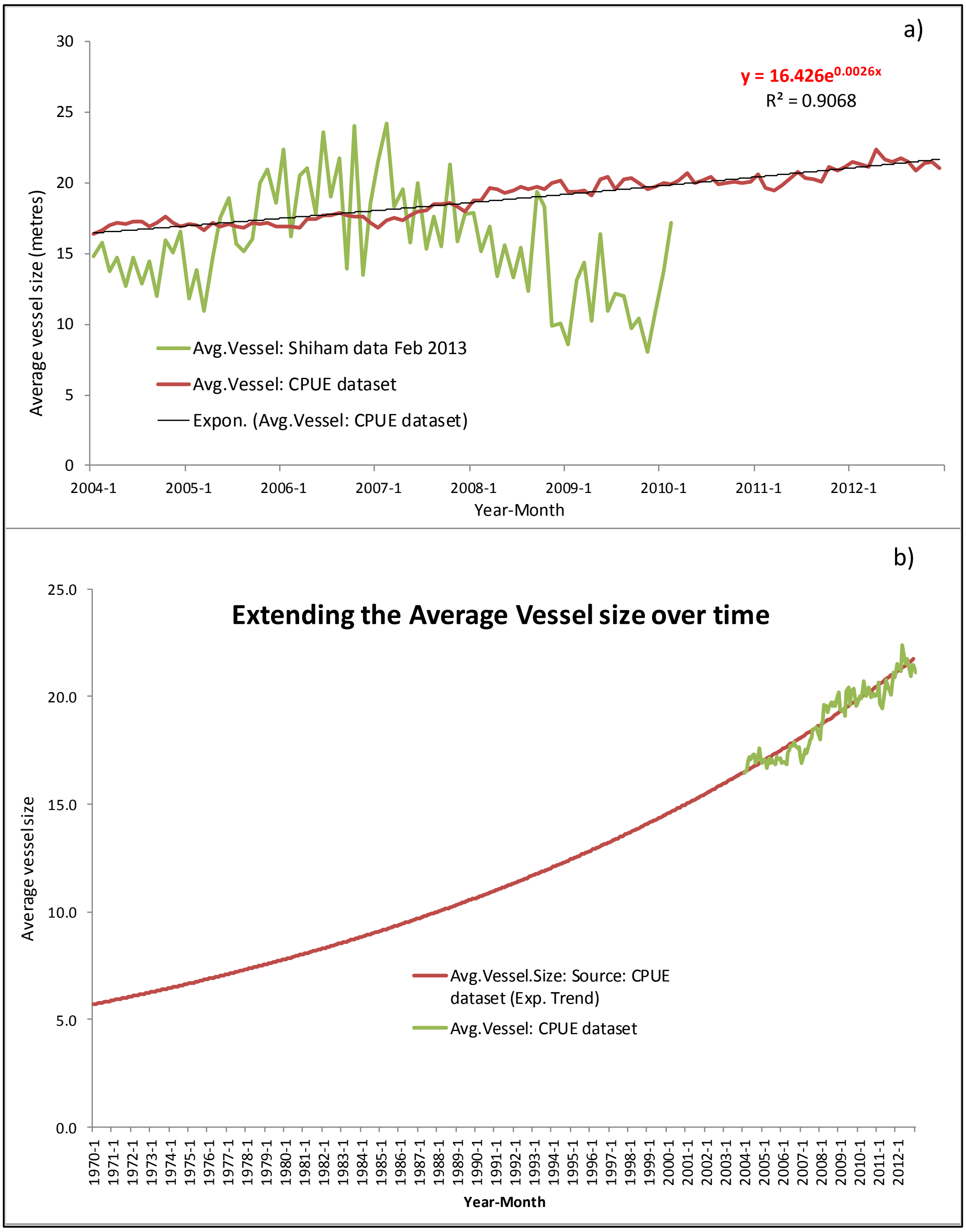



**Figure 4: The relationship between average vessel size over time based on the short time series (inset a) and extended back to 1970 (inset b).**

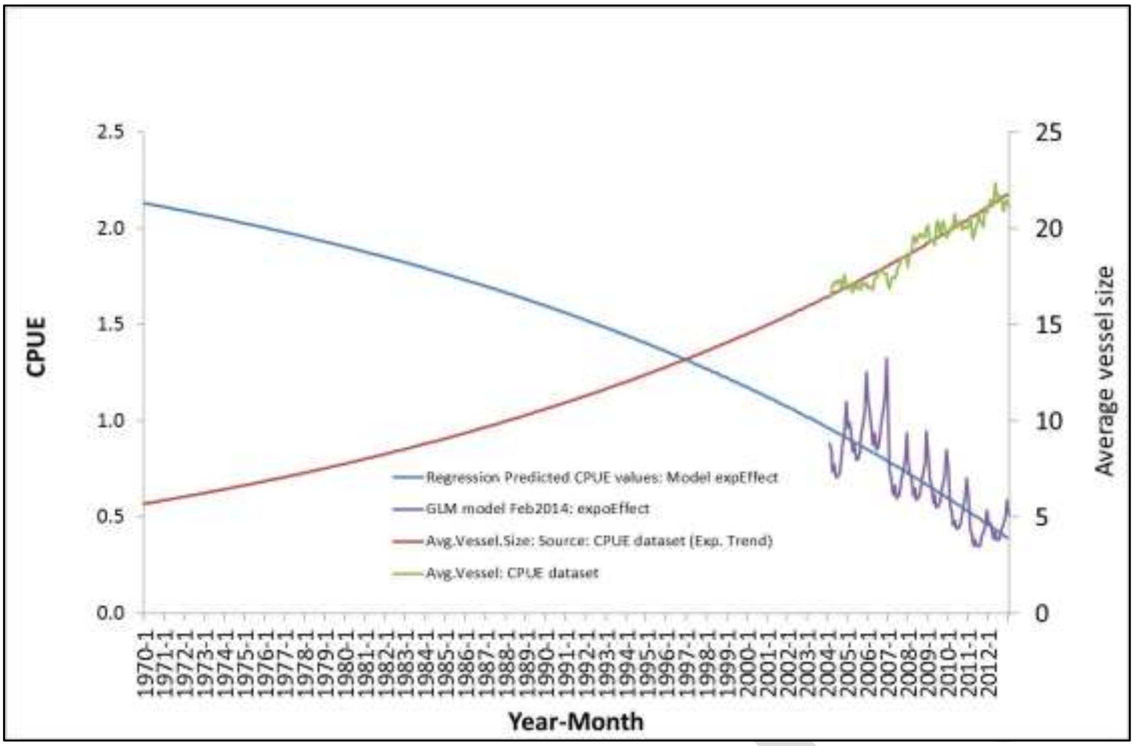



**Figure 5: The historic series (CPUE estimated from 1970-2012) based on estimated vessel length.**

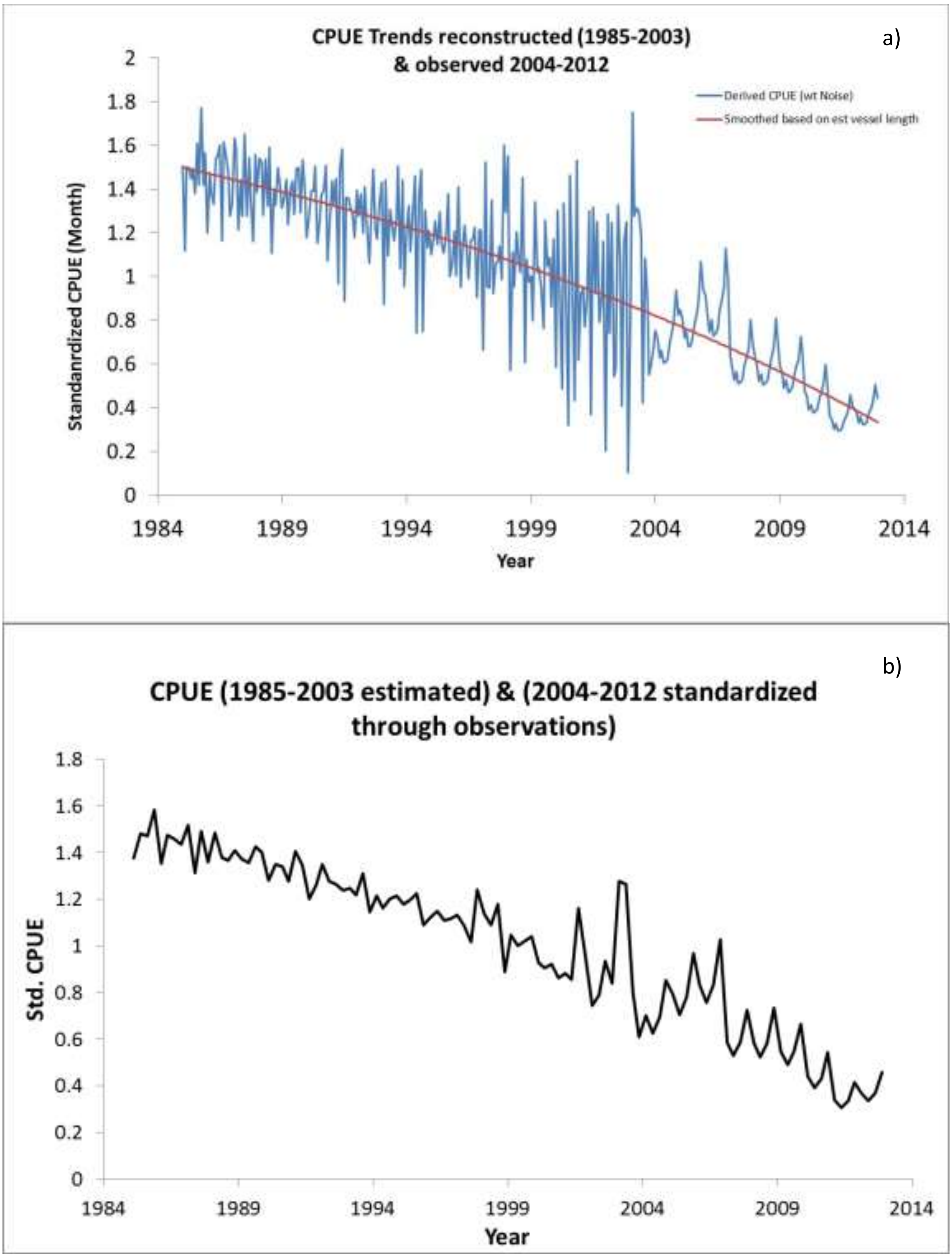



**Figure 6 : The historic standardized to one, series with noise based on the ratio of change from one time step to the next based on the vessel registry record in the Maldives by month, 6a and quarter, 6b (CPUE estimated from 1985-2012).**

Table 3: Values of the standardized CPUE for Maldives PL fisheries from 1985-2012 by quarter.

| Year | Quarter | CPUE-STD | | Year | Quarter | CPUE-STD | | Year | Quarter | CPUE-STD |
|---|---|---|---|---|---|---|---|---|---|---|
| **1985** | 1 | 1.38 | | **1996** | 1 | 1.12 | | **2007** | 1 | 0.59 |
| **1985** | 2 | 1.48 | | **1996** | 2 | 1.15 | | **2007** | 2 | 0.53 |
| **1985** | 3 | 1.47 | | **1996** | 3 | 1.11 | | **2007** | 3 | 0.59 |
| **1985** | 4 | 1.58 | | **1996** | 4 | 1.12 | | **2007** | 4 | 0.72 |
| **1986** | 1 | 1.35 | | **1997** | 1 | 1.13 | | **2008** | 1 | 0.58 |
| **1986** | 2 | 1.47 | | **1997** | 2 | 1.09 | | **2008** | 2 | 0.52 |
| **1986** | 3 | 1.46 | | **1997** | 3 | 1.02 | | **2008** | 3 | 0.58 |
| **1986** | 4 | 1.43 | | **1997** | 4 | 1.24 | | **2008** | 4 | 0.73 |
| **1987** | 1 | 1.52 | | **1998** | 1 | 1.14 | | **2009** | 1 | 0.55 |
| **1987** | 2 | 1.31 | | **1998** | 2 | 1.09 | | **2009** | 2 | 0.49 |
| **1987** | 3 | 1.49 | | **1998** | 3 | 1.18 | | **2009** | 3 | 0.55 |
| **1987** | 4 | 1.36 | | **1998** | 4 | 0.89 | | **2009** | 4 | 0.66 |
| **1988** | 1 | 1.48 | | **1999** | 1 | 1.05 | | **2010** | 1 | 0.44 |
| **1988** | 2 | 1.38 | | **1999** | 2 | 1.00 | | **2010** | 2 | 0.39 |
| **1988** | 3 | 1.36 | | **1999** | 3 | 1.02 | | **2010** | 3 | 0.43 |
| **1988** | 4 | 1.41 | | **1999** | 4 | 1.04 | | **2010** | 4 | 0.54 |
| **1989** | 1 | 1.37 | | **2000** | 1 | 0.93 | | **2011** | 1 | 0.34 |
| **1989** | 2 | 1.36 | | **2000** | 2 | 0.91 | | **2011** | 2 | 0.31 |
| **1989** | 3 | 1.43 | | **2000** | 3 | 0.92 | | **2011** | 3 | 0.34 |
| **1989** | 4 | 1.40 | | **2000** | 4 | 0.86 | | **2011** | 4 | 0.42 |
| **1990** | 1 | 1.28 | | **2001** | 1 | 0.88 | | 2012 | 1 | 0.37 |
| **1990** | 2 | 1.35 | | **2001** | 2 | 0.85 | | 2012 | 2 | 0.34 |
| **1990** | 3 | 1.34 | | **2001** | 3 | 1.16 | | 2012 | 3 | 0.37 |
| **1990** | 4 | 1.28 | | **2001** | 4 | 0.96 | | 2012 | 4 | 0.46 |
| **1991** | 1 | 1.41 | | **2002** | 1 | 0.74 | | | | |
| **1991** | 2 | 1.35 | | **2002** | 2 | 0.79 | | | | |
| **1991** | 3 | 1.20 | | **2002** | 3 | 0.93 | | | | |
| **1991** | 4 | 1.26 | | **2002** | 4 | 0.84 | | | | |
| **1992** | 1 | 1.35 | | **2003** | 1 | 1.28 | | | | |
| **1992** | 2 | 1.28 | | **2003** | 2 | 1.26 | | | | |
| **1992** | 3 | 1.26 | | **2003** | 3 | 0.80 | | | | |
| **1992** | 4 | 1.24 | | **2003** | 4 | 0.61 | | | | |
| **1993** | 1 | 1.25 | | **2004** | 1 | 0.70 | | | | |
| **1993** | 2 | 1.22 | | **2004** | 2 | 0.63 | | | | |
| **1993** | 3 | 1.31 | | **2004** | 3 | 0.69 | | | | |
| **1993** | 4 | 1.14 | | **2004** | 4 | 0.85 | | | | |
| **1994** | 1 | 1.21 | | **2005** | 1 | 0.79 | | | | |
| **1994** | 2 | 1.16 | | **2005** | 2 | 0.70 | | | | |
| **1994** | 3 | 1.20 | | **2005** | 3 | 0.78 | | | | |
| **1994** | 4 | 1.22 | | **2005** | 4 | 0.97 | | | | |
| **1995** | 1 | 1.18 | | **2006** | 1 | 0.83 | | | | |
| **1995** | 2 | 1.20 | | **2006** | 2 | 0.76 | | | | |
| **1995** | 3 | 1.22 | | **2006** | 3 | 0.83 | | | | |
| **1995** | 4 | 1.09 | | **2006** | 4 | 1.03 | | | | |



## Final Conclusions and Recommendations

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

- Several fundamental issues remain outstanding regarding the general quality of CPUE dataset; in many cases invalidating significant numbers of records that could otherwise be useful as data for the stock assessment. Specifically:

    i. large numbers of records with zero skipjack catch recorded as skipjack fishery – how should these be treated in future analyses?;
    ii. data cleaning of missing vessel identification numbers from the catch-and-effort 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?
    iv. clarification of the status of vessels reporting effort of 1 day per month (which account for over a third of vessels up to 2009);
    v. improvements in the selection criteria for identifying skipjack 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 hand-line)?
    vi. there are also other 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 comparing a larger spatial scale. However, the analysis lacks contrast, as the relatively short time period covered corresponds only to recent peak catches. Furthermore, anchored FAD fishing is thought to predominate during this period (which can be expected to cause hyper-stability in CPUE indices). The 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, given the Maldives represents a very small part of the Indian Ocean SKJ range, and abundance may not be representative of the whole population.
    ix. genetic analyses have suggested that there might be (at least) two SKJ populations in the Indian Ocean (Dammannagoda *et al*. 2011). The relative abundance of the two may differ, and the Maldives fishery would presumably not index both of them accurately.

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.

# References


Anderson, R.C and Hafiz, A. 1985. Problems of Tuna Stock Assessment in the Maldives. BOBP News 20:12-13

Anderson, C. 1987. Tuna Catches by Masdhonis in the first years of Mechanization. MRC Fisheries Research Journal 157-167

Campbell, R.A. 2004. CPUE standardization and the construction of indices of stock abundance in a spatially varying fishery using general linear models. Fish. Res. 70: 209-227.

Dammannagoda, S.T., Hurwood, D.A., and Mather, P.B. 2011. Genetic analysis reveals two stocks of skipjack tuna (*Katsuwonas pelamis*) in the northwestern Indian Ocean. Can. J. Fish. Aquat. Sci. 68: 210-223.

Kolody, D., M. S. Adam, C. Anderson. 2010. Catch rate standardization for the Maldivian skipjack pole and line fishery 1970-2007. IOTC-2010-WPTT-05.

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

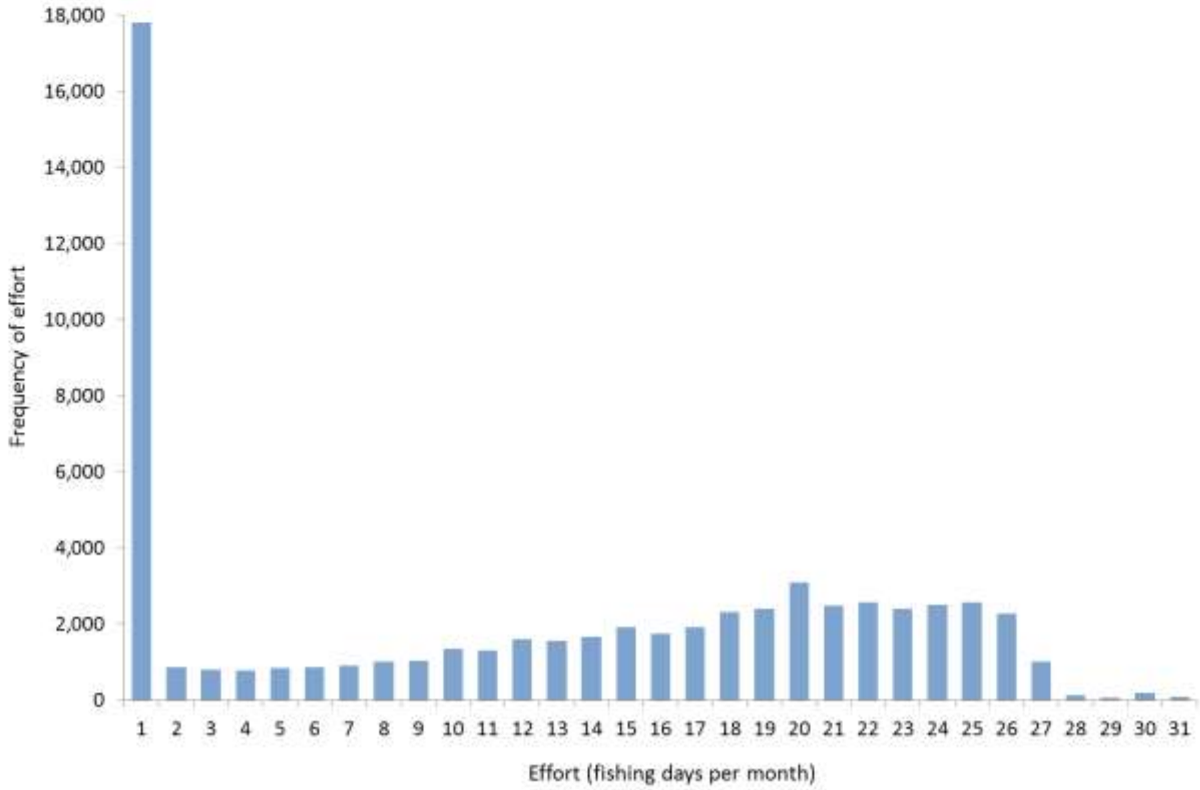
Mohamed, S. 2007. A bioeconomic analysis of Maldivian skipjack tuna fishery. M.Sc. thesis, University of Tromso. 39 pp.

Worm, B. and Tittensor, D. P. 2011. Range contraction in large pelagic predators. Proc. Natl Acad. Sci. USA 108: doi:10.1073/pnas.1102353108.

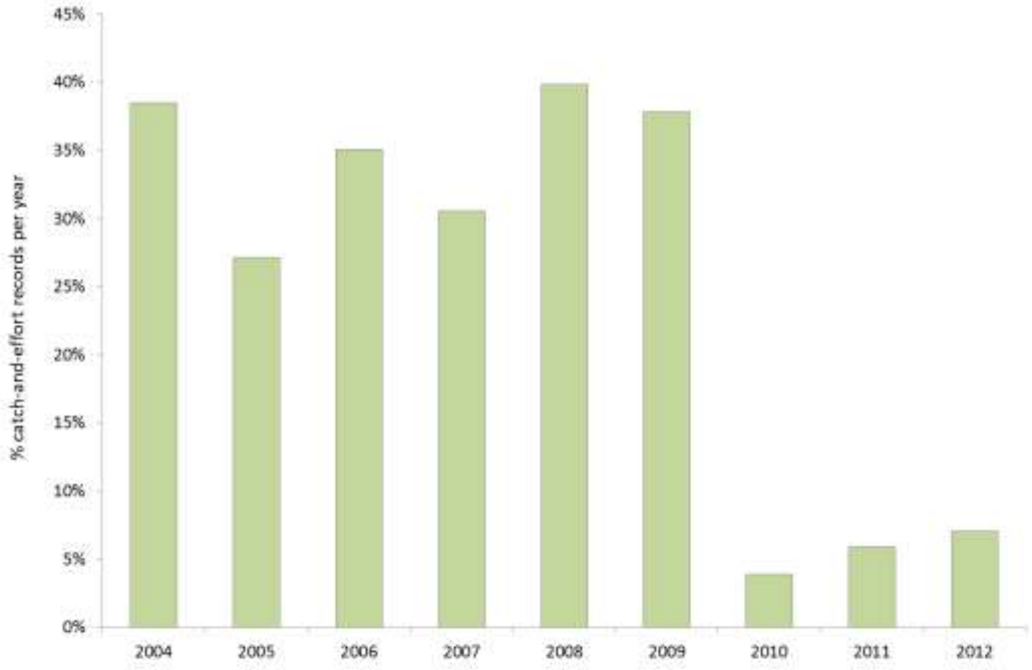
WPTT 2010. Report of the 12th session of the IOTC working party on tropical tunas. Victoria, Seychelles 18-25 Oct 2010.

# Appendix 1: Nominal catch and CPUE

**Appendix 1 Figure 1. Distribution of fishing days per month, for skipjack targeted vessels[3] 2004-2012.**

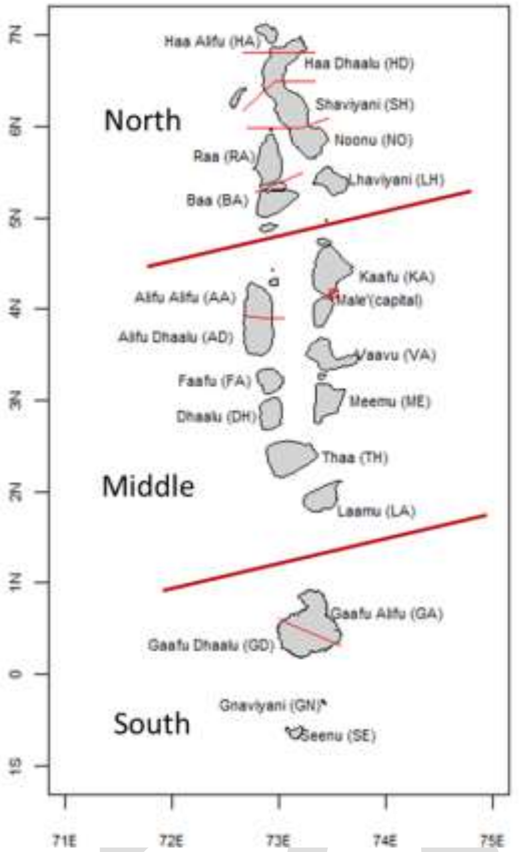


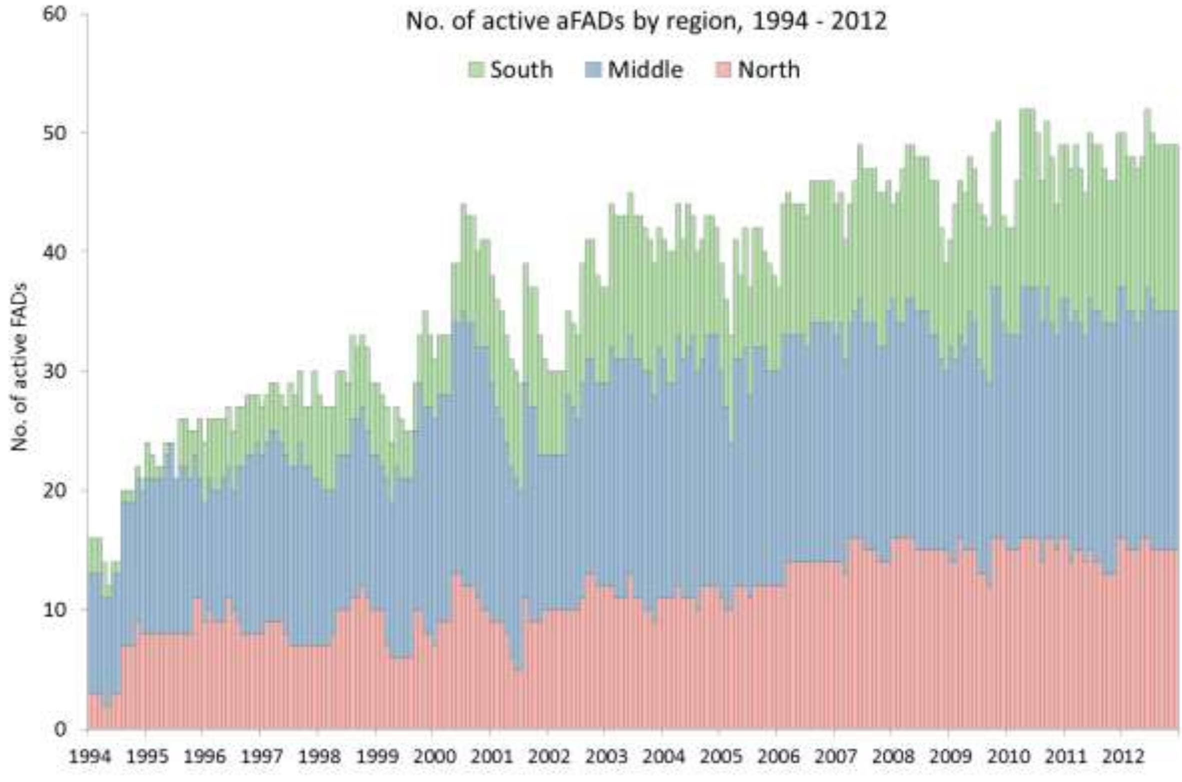

**Appendix 1 Figure 2. Proportion of records reporting effort of 1 day per month, for skipjack targeted vessels[3] 2004-2012.**



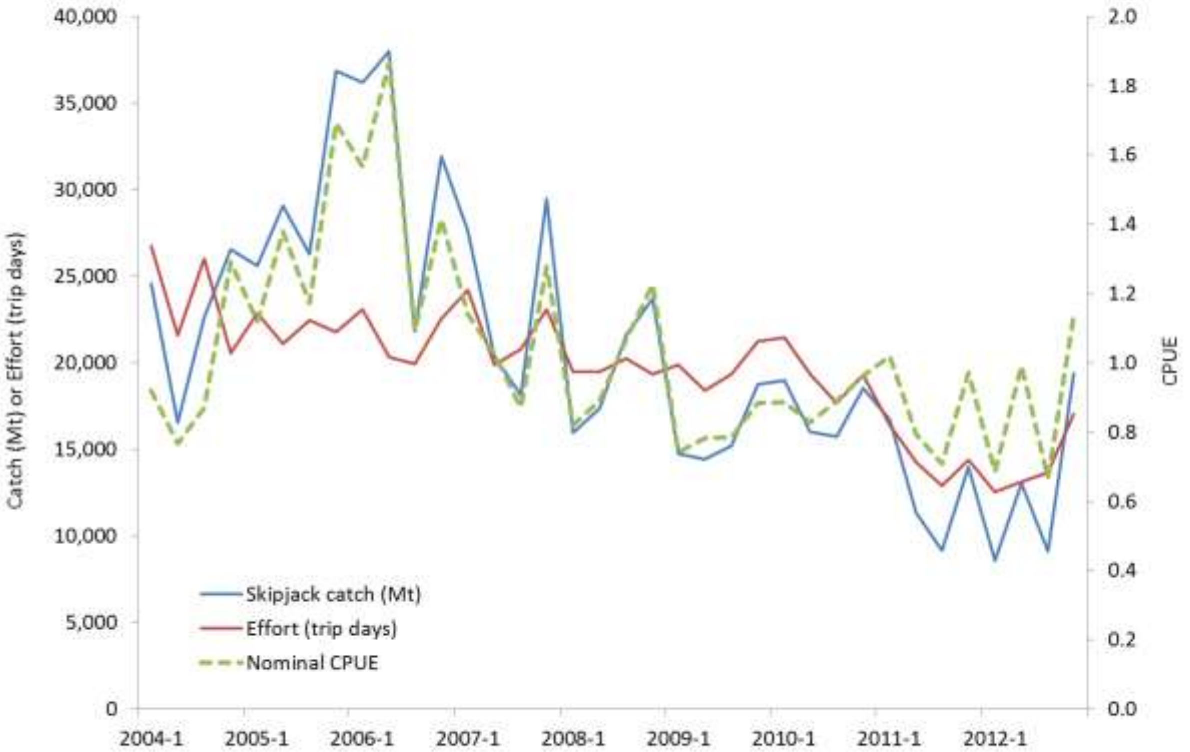

[3] Based on catch-and-effort records included in the final analysis. Selection criteria, gear: pole-and-line, effort: >0, skipjack catch >0, as well as records containing valid VIN numbers (required for matching to vessel length).

**Appendix 1 Figure 3. Map of Atolls, and number of active aFADs 1994-2012**

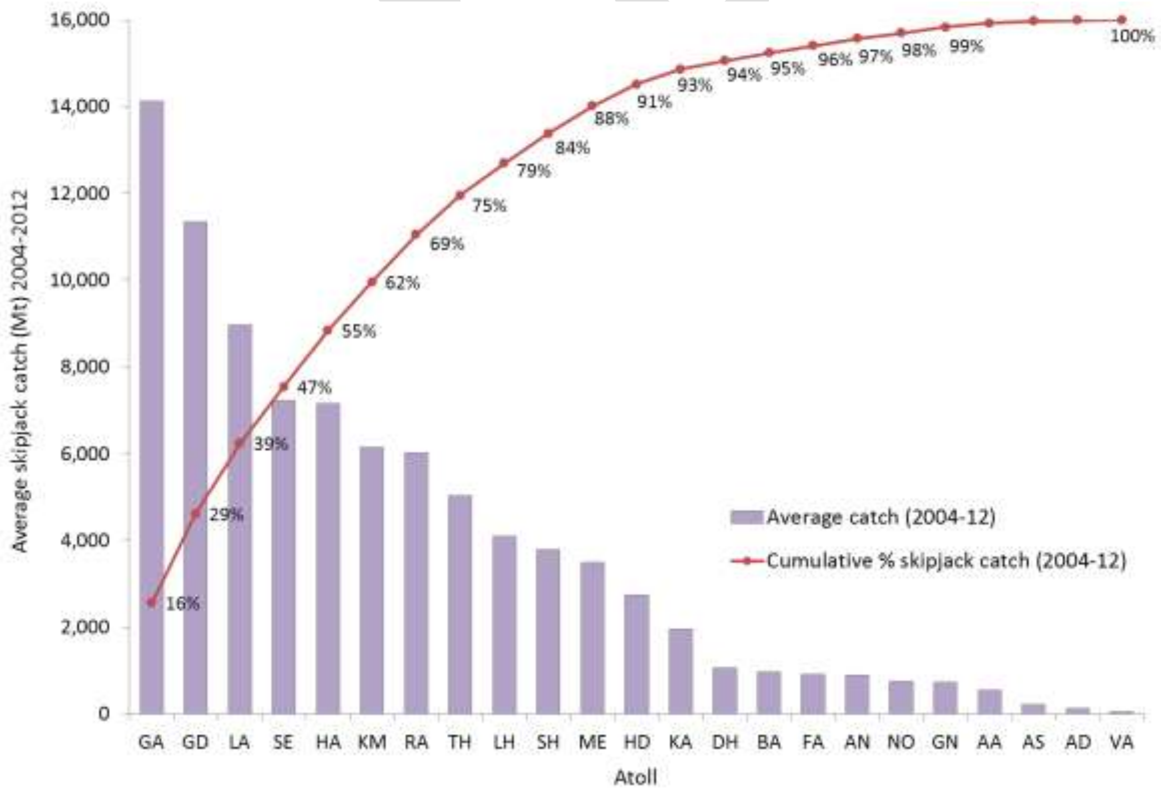


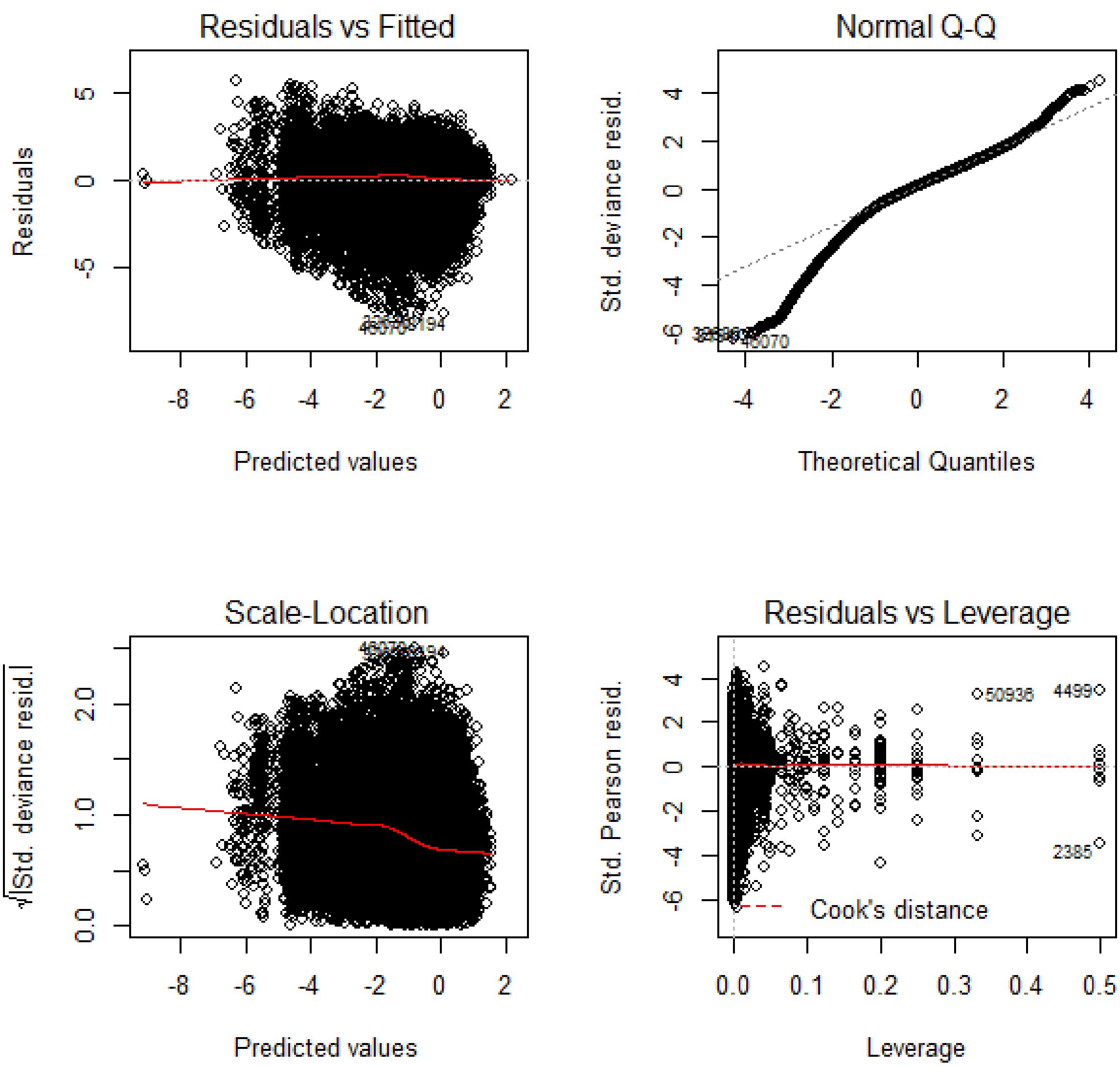
**Appendix 1 Figure 4: Nominal catch-and-effort and CPUE of skipjack targeted vessels, 2004-2012.**




**Appendix 1 Figure 5. Distribution of nominal skipjack catch by Atoll, 2004-2012 (for skipjack targeted vessels).**



## Appendix 2: Model 1 Results




**Appendix 2 Figure 1: Residual diagnostics of the model using Year, Month, Atoll, Vessel length Category, and Vessel length-Atoll Interactions**

```
Response: log(CPUE)

Terms added sequentially (first to last)
```

| | Df | Deviance | Resid. Df | Resid. Dev | F | Pr(>F) | |
|---|---|---|---|---|---|---|---|
| NULL | | | 55928 | 170518 | | | |
| factor(Year) | 8 | 2696 | 55920 | 167822 | 200.708 | < 2.2e-16 | *** |
| factor(Month) | 11 | 1135 | 55909 | 166687 | 61.441 | < 2.2e-16 | *** |
| factor(Atoll) | 27 | 45604 | 55882 | 121083 | 1006.072 | < 2.2e-16 | *** |
| factor(Vessel.lenv2) | 6 | 19819 | 55876 | 101264 | 1967.505 | < 2.2e-16 | *** |
| factor(Atoll):factor(Vessel.lenv2) | 113 | 7646 | 55763 | 93618 | 40.306 | < 2.2e-16 | *** |

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

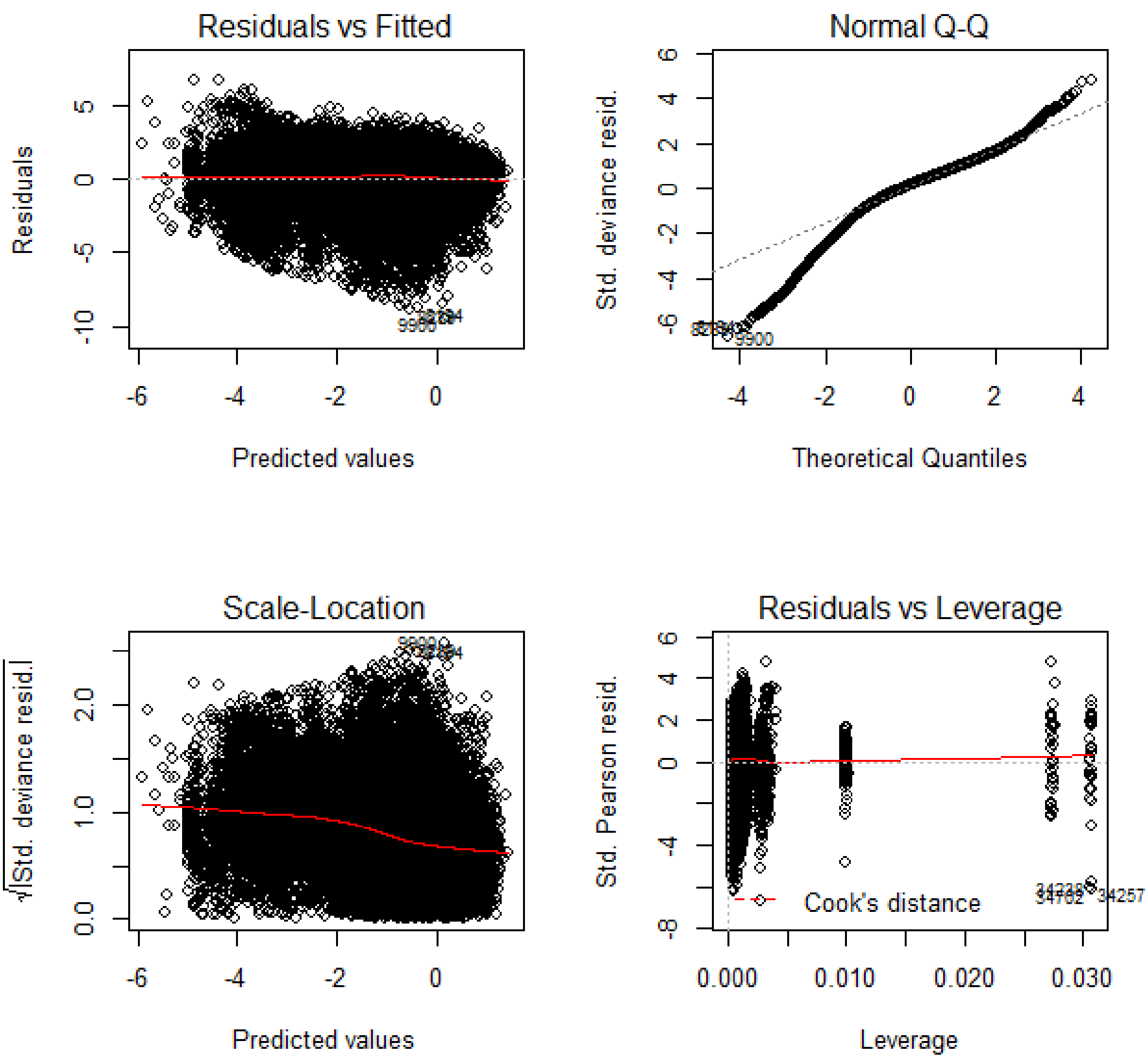
```
Table 2: Summary Results for Model 1

Call:
glm(formula = log(CPUE) ~ factor(Year) + factor(Month) + factor(Atoll) +
    factor(Vessel.lenv2) + factor(Atoll):factor(Vessel.lenv2))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-8.1299  -0.6209   0.1331   0.8174   5.7365

Coefficients: (49 not defined because of singularities)
                                       Estimate Std. Error t value Pr(>|t|)
(Intercept)                            0.615424   1.402414   0.439 0.660785
factor(Year)2005                       0.188400   0.021330   8.832  < 2e-16 ***
factor(Year)2006                       0.197749   0.020922   9.452  < 2e-16 ***
factor(Year)2007                      -0.156556   0.021293  -7.353 1.97e-13 ***
factor(Year)2008                      -0.140264   0.021486  -6.528 6.72e-11 ***
factor(Year)2009                      -0.193371   0.021553  -8.972  < 2e-16 ***
factor(Year)2010                      -0.308241   0.024855 -12.402  < 2e-16 ***
factor(Year)2011                      -0.524716   0.028027 -18.722  < 2e-16 ***
factor(Year)2012                      -0.478657   0.026304 -18.197  < 2e-16 ***
factor(Month)2                        -0.048824   0.025588  -1.908 0.056390 .
factor(Month)3                        -0.177756   0.025852  -6.876 6.22e-12 ***
factor(Month)4                        -0.086566   0.026877  -3.221 0.001279 **
factor(Month)5                        -0.172602   0.027261  -6.332 2.45e-10 ***
factor(Month)6                        -0.195844   0.027161  -7.210 5.65e-13 ***
factor(Month)7                        -0.167696   0.026346  -6.365 1.97e-10 ***
factor(Month)8                        -0.054099   0.026071  -2.075 0.037984 *
factor(Month)9                         0.000744   0.026032   0.029 0.977198
factor(Month)10                        0.071614   0.026138   2.740 0.006148 **
factor(Month)11                        0.231264   0.025971   8.905  < 2e-16 ***
factor(Month)12                        0.098464   0.025790   3.818 0.000135 ***
factor(Atoll)AA                       -2.268022   1.307499  -1.735 0.082813 .
factor(Atoll)AD                       -2.374667   1.832582  -1.296 0.195048
factor(Atoll)AN                       -4.235666   1.314450  -3.222 0.001272 **
factor(Atoll)AS                       -5.019628   1.378894  -3.640 0.000273 ***
factor(Atoll)BA                       -5.680072   1.674914  -3.391 0.000696 ***
factor(Atoll)Dh                       -8.530221   1.531448  -5.570 2.56e-08 ***
factor(Atoll)DH                       -7.322878   1.443076  -5.074 3.90e-07 ***
factor(Atoll)fa                       -1.376873   1.452740  -0.948 0.343247
factor(Atoll)FA                       -1.828005   1.309284  -1.396 0.162664
factor(Atoll)GA                       -0.413550   1.675015  -0.247 0.804992
factor(Atoll)GD                       -0.952739   1.431875  -0.665 0.505811
factor(Atoll)GN                       -4.723242   1.404474  -3.363 0.000772 ***
factor(Atoll)HA                        1.144529   1.909157   0.599 0.548846
factor(Atoll)HD                       -5.885377   1.517222  -3.879 0.000105 ***
factor(Atoll)KA                       -3.730057   1.303399  -2.862 0.004214 **
factor(Atoll)KM                        0.282328   1.426932   0.198 0.843158
factor(Atoll)La                       -1.045483   1.374738  -0.760 0.446961
factor(Atoll)LA                       -6.260587   1.437145  -4.356 1.33e-05 ***
factor(Atoll)LH                       -2.938142   1.311735  -2.240 0.025102 *
factor(Atoll)ME                       -9.422982   1.589364  -5.929 3.07e-09 ***
factor(Atoll)NO                       -2.752598   1.909157  -1.442 0.149368
factor(Atoll)RA                       -3.564246   1.544662  -2.307 0.021033 *
factor(Atoll)SE                       -6.353984   1.410726  -4.504 6.68e-06 ***
factor(Atoll)SH                       -6.480386   1.426971  -4.541 5.60e-06 ***
factor(Atoll)Th                       -3.466742   1.587132  -2.184 0.028946 *
factor(Atoll)TH                       -2.352947   1.298518  -1.812 0.069988 .
factor(Atoll)VA                       -0.631789   1.314313  -0.481 0.630733
factor(Vessel.lenv2)2                 -2.682168   2.062092  -1.301 0.193366
factor(Vessel.lenv2)3                 -2.574060   1.927847  -1.335 0.181816
factor(Vessel.lenv2)4                 -0.916727   1.909002  -0.480 0.631078
factor(Vessel.lenv2)5                  1.965145   0.533829   3.681 0.000232 ***
factor(Vessel.lenv2)6                  2.135793   0.535339   3.990 6.63e-05 ***
factor(Vessel.lenv2)7                  6.569496   0.207591  31.646  < 2e-16 ***
factor(Atoll)AA:factor(Vessel.lenv2)2  0.568145   2.045092   0.278 0.781160
factor(Atoll)AD:factor(Vessel.lenv2)2 -0.535940   2.378909  -0.225 0.821756
factor(Atoll)AN:factor(Vessel.lenv2)2  2.311542   2.009506   1.150 0.250024
factor(Atoll)AS:factor(Vessel.lenv2)2  2.819156   2.049374   1.376 0.168945
factor(Atoll)BA:factor(Vessel.lenv2)2  4.677045   2.258415   2.071 0.038369 *
factor(Atoll)Dh:factor(Vessel.lenv2)2        NA         NA      NA       NA
factor(Atoll)DH:factor(Vessel.lenv2)2  5.855202   2.098737   2.790 0.005275 **
factor(Atoll)fa:factor(Vessel.lenv2)2        NA         NA      NA       NA
factor(Atoll)FA:factor(Vessel.lenv2)2  1.839878   2.032159   0.905 0.365267
factor(Atoll)GA:factor(Vessel.lenv2)2  2.512261   2.293506   1.095 0.273355
factor(Atoll)GD:factor(Vessel.lenv2)2 -0.466640   2.109089  -0.221 0.824897
```

```
factor(Atoll)GN:factor(Vessel.lenv2)2  3.189213   2.064324   1.545 0.122372
factor(Atoll)HA:factor(Vessel.lenv2)2 -0.188163   2.484270  -0.076 0.939625
factor(Atoll)HD:factor(Vessel.lenv2)2  5.683681   2.143081   2.652 0.008001 **
factor(Atoll)KA:factor(Vessel.lenv2)2  2.574298   1.997746   1.289 0.197542
factor(Atoll)KM:factor(Vessel.lenv2)2  1.334955   2.080846   0.642 0.521172
factor(Atoll)La:factor(Vessel.lenv2)2        NA         NA      NA       NA
factor(Atoll)LA:factor(Vessel.lenv2)2  7.781126   2.105972   3.695 0.000220 ***
factor(Atoll)LH:factor(Vessel.lenv2)2  3.412070   2.011395   1.696 0.089821 .
factor(Atoll)ME:factor(Vessel.lenv2)2  7.136130   2.200855   3.242 0.001186 **
factor(Atoll)NO:factor(Vessel.lenv2)2  2.134163   2.440008   0.875 0.381766
factor(Atoll)RA:factor(Vessel.lenv2)2  2.239090   2.163287   1.035 0.300654
factor(Atoll)SE:factor(Vessel.lenv2)2  4.493720   2.069588   2.171 0.029912 *
factor(Atoll)SH:factor(Vessel.lenv2)2  5.918535   2.079713   2.846 0.004431 **
factor(Atoll)Th:factor(Vessel.lenv2)2        NA         NA      NA       NA
factor(Atoll)TH:factor(Vessel.lenv2)2  0.167707   1.994758   0.084 0.932998
factor(Atoll)VA:factor(Vessel.lenv2)2        NA         NA      NA       NA
factor(Atoll)AA:factor(Vessel.lenv2)3  4.009004   1.867272   2.147 0.031799 *
factor(Atoll)AD:factor(Vessel.lenv2)3  2.022146   2.264131   0.893 0.371796
factor(Atoll)AN:factor(Vessel.lenv2)3  4.071083   1.868281   2.179 0.029332 *
factor(Atoll)AS:factor(Vessel.lenv2)3  5.864156   1.914603   3.063 0.002193 **
factor(Atoll)BA:factor(Vessel.lenv2)3  6.304354   2.134954   2.953 0.003149 **
factor(Atoll)Dh:factor(Vessel.lenv2)3 10.743275   2.061092   5.212 1.87e-07 ***
factor(Atoll)DH:factor(Vessel.lenv2)3  8.162976   1.960382   4.164 3.13e-05 ***
factor(Atoll)fa:factor(Vessel.lenv2)3  1.609268   2.048694   0.786 0.432159
factor(Atoll)FA:factor(Vessel.lenv2)3  2.603405   1.863643   1.397 0.162436
factor(Atoll)GA:factor(Vessel.lenv2)3  2.048898   2.136037   0.959 0.337459
factor(Atoll)GD:factor(Vessel.lenv2)3  2.488931   1.950196   1.276 0.201874
factor(Atoll)GN:factor(Vessel.lenv2)3  3.728304   1.929960   1.932 0.053389 .
factor(Atoll)HA:factor(Vessel.lenv2)3  0.211202   2.323546   0.091 0.927575
factor(Atoll)HD:factor(Vessel.lenv2)3  6.513847   2.013299   3.235 0.001215 **
factor(Atoll)KA:factor(Vessel.lenv2)3  3.556745   1.857649   1.915 0.055543 .
factor(Atoll)KM:factor(Vessel.lenv2)3  1.388912   1.946026   0.714 0.475405
factor(Atoll)La:factor(Vessel.lenv2)3  2.892194   1.929728   1.499 0.133942
factor(Atoll)LA:factor(Vessel.lenv2)3  7.555138   1.953545   3.867 0.000110 ***
factor(Atoll)LH:factor(Vessel.lenv2)3  3.958099   1.863836   2.124 0.033705 *
factor(Atoll)ME:factor(Vessel.lenv2)3 10.554462   2.068486   5.103 3.36e-07 ***
factor(Atoll)NO:factor(Vessel.lenv2)3  2.738256   2.323429   1.179 0.238586
factor(Atoll)RA:factor(Vessel.lenv2)3  4.365081   2.034127   2.146 0.031883 *
factor(Atoll)SE:factor(Vessel.lenv2)3  7.932915   1.934960   4.100 4.14e-05 ***
factor(Atoll)SH:factor(Vessel.lenv2)3  6.850602   1.946149   3.520 0.000432 ***
factor(Atoll)Th:factor(Vessel.lenv2)3        NA         NA      NA       NA
factor(Atoll)TH:factor(Vessel.lenv2)3  3.583121   1.854174   1.932 0.053308 .
factor(Atoll)VA:factor(Vessel.lenv2)3        NA         NA      NA       NA
factor(Atoll)AA:factor(Vessel.lenv2)4  2.835050   1.851937   1.531 0.125810
factor(Atoll)AD:factor(Vessel.lenv2)4  1.342574   2.250883   0.596 0.550867
factor(Atoll)AN:factor(Vessel.lenv2)4  3.474773   1.846950   1.881 0.059928 .
factor(Atoll)AS:factor(Vessel.lenv2)4  3.620733   1.906659   1.899 0.057570 .
factor(Atoll)BA:factor(Vessel.lenv2)4  5.198967   2.119592   2.453 0.014177 *
factor(Atoll)Dh:factor(Vessel.lenv2)4  6.812531   2.074377   3.284 0.001024 **
factor(Atoll)DH:factor(Vessel.lenv2)4  7.364058   1.940664   3.795 0.000148 ***
factor(Atoll)fa:factor(Vessel.lenv2)4  1.791280   2.030969   0.882 0.377790
factor(Atoll)FA:factor(Vessel.lenv2)4  1.649574   1.844102   0.895 0.371051
factor(Atoll)GA:factor(Vessel.lenv2)4  0.718486   2.118100   0.339 0.734451
factor(Atoll)GD:factor(Vessel.lenv2)4  1.513610   1.931563   0.784 0.433267
factor(Atoll)GN:factor(Vessel.lenv2)4  5.086795   2.052061   2.479 0.013183 *
factor(Atoll)HA:factor(Vessel.lenv2)4 -0.765055   2.308080  -0.331 0.740292
factor(Atoll)HD:factor(Vessel.lenv2)4  4.909122   1.996543   2.459 0.013943 *
factor(Atoll)KA:factor(Vessel.lenv2)4  2.430350   1.838392   1.322 0.186174
factor(Atoll)KM:factor(Vessel.lenv2)4  0.076100   1.927361   0.039 0.968505
factor(Atoll)La:factor(Vessel.lenv2)4  1.750641   1.975717   0.886 0.375579
factor(Atoll)LA:factor(Vessel.lenv2)4  6.455919   1.935397   3.336 0.000851 ***
factor(Atoll)LH:factor(Vessel.lenv2)4  3.044961   1.844712   1.651 0.098817 .
factor(Atoll)ME:factor(Vessel.lenv2)4  9.011026   2.051262   4.393 1.12e-05 ***
factor(Atoll)NO:factor(Vessel.lenv2)4  1.375007   2.311027   0.595 0.551861
factor(Atoll)RA:factor(Vessel.lenv2)4  3.506666   2.017086   1.738 0.082132 .
factor(Atoll)SE:factor(Vessel.lenv2)4  6.948661   1.916468   3.626 0.000288 ***
factor(Atoll)SH:factor(Vessel.lenv2)4  5.869588   1.927909   3.045 0.002331 **
factor(Atoll)Th:factor(Vessel.lenv2)4  2.707958   2.099330   1.290 0.197085
factor(Atoll)TH:factor(Vessel.lenv2)4  2.542255   1.835733   1.385 0.166097
factor(Atoll)VA:factor(Vessel.lenv2)4        NA         NA      NA       NA
factor(Atoll)AA:factor(Vessel.lenv2)5  0.041834   0.241670   0.173 0.862569
factor(Atoll)AD:factor(Vessel.lenv2)5 -1.792497   1.311080  -1.367 0.171571
factor(Atoll)AN:factor(Vessel.lenv2)5  0.890410   0.285328   3.121 0.001805 **
factor(Atoll)AS:factor(Vessel.lenv2)5        NA         NA      NA       NA
factor(Atoll)BA:factor(Vessel.lenv2)5  1.690364   1.085772   1.557 0.119516
factor(Atoll)Dh:factor(Vessel.lenv2)5  4.881614   1.040975   4.689 2.75e-06 ***
factor(Atoll)DH:factor(Vessel.lenv2)5  2.630507   0.654320   4.020 5.82e-05 ***
```

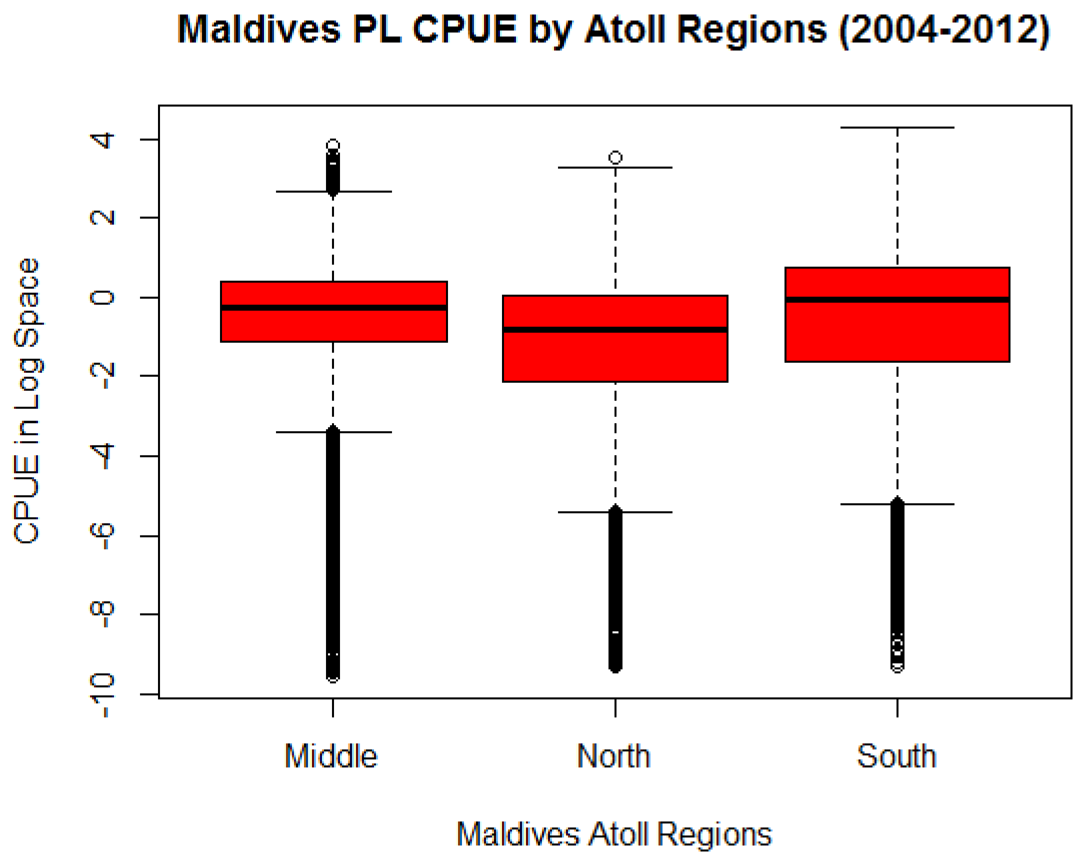
```
factor(Atoll)fa:factor(Vessel.lenv2)5        NA         NA      NA       NA    
factor(Atoll)FA:factor(Vessel.lenv2)5        NA         NA      NA       NA    
factor(Atoll)GA:factor(Vessel.lenv2)5 -1.635766   1.060990  -1.542 0.123144    
factor(Atoll)GD:factor(Vessel.lenv2)5 -0.975890   0.609889  -1.600 0.109580    
factor(Atoll)GN:factor(Vessel.lenv2)5  2.434579   0.572687   4.251 2.13e-05 ***
factor(Atoll)HA:factor(Vessel.lenv2)5 -3.412854   1.402158  -2.434 0.014936 *  
factor(Atoll)HD:factor(Vessel.lenv2)5  0.605511   0.833028   0.727 0.467302    
factor(Atoll)KA:factor(Vessel.lenv2)5 -1.167150   0.187211  -6.234 4.57e-10 ***
factor(Atoll)KM:factor(Vessel.lenv2)5 -2.370909   0.596401  -3.975 7.04e-05 ***
factor(Atoll)La:factor(Vessel.lenv2)5 -0.997894   0.511340  -1.952 0.051000 .  
factor(Atoll)LA:factor(Vessel.lenv2)5  3.735305   0.624844   5.978 2.27e-09 ***
factor(Atoll)LH:factor(Vessel.lenv2)5  0.595697   0.239477   2.487 0.012868 *  
factor(Atoll)ME:factor(Vessel.lenv2)5  7.348716   0.921156   7.978 1.52e-15 ***
factor(Atoll)NO:factor(Vessel.lenv2)5 -0.167195   1.423568  -0.117 0.906506    
factor(Atoll)RA:factor(Vessel.lenv2)5  0.888604   0.840797   1.057 0.290581    
factor(Atoll)SE:factor(Vessel.lenv2)5  4.366458   0.559195   7.808 5.89e-15 ***
factor(Atoll)SH:factor(Vessel.lenv2)5  3.004130   0.603356   4.979 6.41e-07 ***
factor(Atoll)Th:factor(Vessel.lenv2)5  0.367258   0.959785   0.383 0.701984    
factor(Atoll)TH:factor(Vessel.lenv2)5        NA         NA      NA       NA    
factor(Atoll)VA:factor(Vessel.lenv2)5        NA         NA      NA       NA    
factor(Atoll)AA:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)AD:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)AN:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)AS:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)BA:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)Dh:factor(Vessel.lenv2)6  5.485473   1.226747   4.472 7.78e-06 ***
factor(Atoll)DH:factor(Vessel.lenv2)6  3.838252   0.671309   5.718 1.09e-08 ***
factor(Atoll)fa:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)FA:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)GA:factor(Vessel.lenv2)6 -1.761230   1.061962  -1.658 0.097229 .  
factor(Atoll)GD:factor(Vessel.lenv2)6 -0.693058   0.611418  -1.134 0.256998    
factor(Atoll)GN:factor(Vessel.lenv2)6  2.610406   0.554228   4.710 2.48e-06 ***
factor(Atoll)HA:factor(Vessel.lenv2)6 -3.659121   1.405106  -2.604 0.009212 ** 
factor(Atoll)HD:factor(Vessel.lenv2)6 -3.412384   1.020904  -3.343 0.000831 ***
factor(Atoll)KA:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)KM:factor(Vessel.lenv2)6 -2.233162   0.598507  -3.731 0.000191 ***
factor(Atoll)La:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)LA:factor(Vessel.lenv2)6  3.908453   0.623359   6.270 3.64e-10 ***
factor(Atoll)LH:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)ME:factor(Vessel.lenv2)6  7.816130   1.087317   7.188 6.63e-13 ***
factor(Atoll)NO:factor(Vessel.lenv2)6  0.571642   1.427929   0.400 0.688916    
factor(Atoll)RA:factor(Vessel.lenv2)6  1.157797   0.847005   1.367 0.171653    
factor(Atoll)SE:factor(Vessel.lenv2)6  4.259284   0.559715   7.610 2.79e-14 ***
factor(Atoll)SH:factor(Vessel.lenv2)6 -0.285429   1.426921  -0.200 0.841457    
factor(Atoll)Th:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)TH:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)VA:factor(Vessel.lenv2)6        NA         NA      NA       NA    
factor(Atoll)AA:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)AD:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)AN:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)AS:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)BA:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)Dh:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)DH:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)fa:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)FA:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)GA:factor(Vessel.lenv2)7 -6.041679   0.948772  -6.368 1.93e-10 ***
factor(Atoll)GD:factor(Vessel.lenv2)7 -5.160230   0.367616 -14.037  < 2e-16 ***
factor(Atoll)GN:factor(Vessel.lenv2)7 -5.523037   0.435874 -12.671  < 2e-16 ***
factor(Atoll)HA:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)HD:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)KA:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)KM:factor(Vessel.lenv2)7 -6.483837   0.386748 -16.765  < 2e-16 ***
factor(Atoll)La:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)LA:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)LH:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)ME:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)NO:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)RA:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)SE:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)SH:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)Th:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)TH:factor(Vessel.lenv2)7        NA         NA      NA       NA    
factor(Atoll)VA:factor(Vessel.lenv2)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 1.678851)

    Null deviance: 170518  on 55928  degrees of freedom
Residual deviance:  93618  on 55763  degrees of freedom
AIC: 187865


Number of Fisher Scoring iterations: 2
```

## Model 3 Results (FAD Effects)




**Appendix 2 Figure 2: Residual Diagnostics of the FAD effects model on broader spatial resolution**




**Appendix 2 Figure 3: Log CPUE rates by different regions**

Table 3: 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 | | | 55928 | 170518 | | | |
| factor(Year) | 8 | 2696 | 55920 | 167822 | 165.352 | < 2.2e-16 | *** |
| factor(Month) | 11 | 1135 | 55909 | 166687 | 50.618 | < 2.2e-16 | *** |
| factor(Vessel.lenv2) | 6 | 47541 | 55903 | 119147 | 3888.195 | < 2.2e-16 | *** |
| factor(FAD_Region) | 2 | 1482 | 55901 | 117664 | 363.728 | < 2.2e-16 | *** |
| Region_FAD | 1 | 42 | 55900 | 117622 | 20.767 | 5.198e-06 | *** |
| factor(Vessel.lenv2):factor(FAD_Region) | 11 | 3684 | 55889 | 113938 | 164.357 | < 2.2e-16 | *** |
| factor(FAD_Region):Region_FAD | 2 | 49 | 55887 | 113888 | 12.123 | 5.447e-06 | *** |

---

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

Table 4: Summary of Model Parameter values

Coefficients: (1 not defined because of singularities)

| | Estimate | Std. Error | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| (Intercept) | -0.221014 | 0.277749 | -0.796 | 0.426190 | |
| factor(Year)2005 | 0.109818 | 0.024262 | 4.526 | 6.01e-06 | *** |
| factor(Year)2006 | 0.178190 | 0.023538 | 7.570 | 3.78e-14 | *** |
| factor(Year)2007 | -0.176743 | 0.024648 | -7.171 | 7.56e-13 | *** |
| factor(Year)2008 | -0.182539 | 0.025665 | -7.112 | 1.15e-12 | *** |
| factor(Year)2009 | -0.257183 | 0.025512 | -10.081 | < 2e-16 | *** |
| factor(Year)2010 | -0.469784 | 0.028644 | -16.401 | < 2e-16 | *** |
| factor(Year)2011 | -0.719635 | 0.031148 | -23.104 | < 2e-16 | *** |
| factor(Year)2012 | -0.629497 | 0.030273 | -20.794 | < 2e-16 | *** |
| factor(Month)2 | -0.060383 | 0.028279 | -2.135 | 0.032742 | * |
| factor(Month)3 | -0.195612 | 0.029008 | -6.743 | 1.56e-11 | *** |
| factor(Month)4 | -0.123466 | 0.029815 | -4.141 | 3.46e-05 | *** |
| factor(Month)5 | -0.219677 | 0.030165 | -7.283 | 3.32e-13 | *** |

```
factor(Month)6                                 -0.205572   0.030557  -6.728 1.74e-11 ***
factor(Month)7                                 -0.178062   0.029213  -6.095 1.10e-09 ***
factor(Month)8                                 -0.067639   0.028924  -2.338 0.019366 *
factor(Month)9                                 -0.009498   0.028889  -0.329 0.742321
factor(Month)10                                 0.058476   0.029054   2.013 0.044155 *
factor(Month)11                                 0.225781   0.028735   7.857 3.99e-15 ***
factor(Month)12                                 0.097100   0.028460   3.412 0.000646 ***
factor(Vessel.lenv2)2                          -2.840398   0.251963 -11.273  < 2e-16 ***
factor(Vessel.lenv2)3                          -0.240689   0.248961  -0.967 0.333661
factor(Vessel.lenv2)4                           0.227032   0.249087   0.911 0.362059
factor(Vessel.lenv2)5                           0.556321   0.249446   2.230 0.025736 *
factor(Vessel.lenv2)6                           0.964839   0.250471   3.852 0.000117 ***
factor(Vessel.lenv2)7                           1.111031   0.285318   3.894 9.87e-05 ***
factor(FAD_Region)North                        -4.131717   0.376450 -10.975  < 2e-16 ***
factor(FAD_Region)South                        -3.335132   0.301637 -11.057  < 2e-16 ***
Region_FAD                                     -0.006532   0.006123  -1.067 0.286098
factor(Vessel.lenv2)2:factor(FAD_Region)North  5.302734   0.346360  15.310  < 2e-16 ***
factor(Vessel.lenv2)3:factor(FAD_Region)North  4.059291   0.342551  11.850  < 2e-16 ***
factor(Vessel.lenv2)4:factor(FAD_Region)North  4.355273   0.343492  12.679  < 2e-16 ***
factor(Vessel.lenv2)5:factor(FAD_Region)North  4.682056   0.343887  13.615  < 2e-16 ***
factor(Vessel.lenv2)6:factor(FAD_Region)North  4.503279   0.350541  12.847  < 2e-16 ***
factor(Vessel.lenv2)7:factor(FAD_Region)North        NA         NA      NA       NA
factor(Vessel.lenv2)2:factor(FAD_Region)South  3.317925   0.267238  12.416  < 2e-16 ***
factor(Vessel.lenv2)3:factor(FAD_Region)South  2.787934   0.262045  10.639  < 2e-16 ***
factor(Vessel.lenv2)4:factor(FAD_Region)South  3.996747   0.262893  15.203  < 2e-16 ***
factor(Vessel.lenv2)5:factor(FAD_Region)South  4.088908   0.262397  15.583  < 2e-16 ***
factor(Vessel.lenv2)6:factor(FAD_Region)South  3.891303   0.263471  14.769  < 2e-16 ***
factor(Vessel.lenv2)7:factor(FAD_Region)South  3.882805   0.303744  12.783  < 2e-16 ***
factor(FAD_Region)North:Region_FAD             -0.047893   0.009946  -4.815 1.48e-06 ***
factor(FAD_Region)South:Region_FAD             -0.030619   0.009886  -3.097 0.001955 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 2.037828)

    Null deviance: 170518  on 55928  degrees of freedom
Residual deviance: 113888  on 55887  degrees of freedom
AIC: 198579

Number of Fisher Scoring iterations: 2
```