An update of Bayesian Skipjack tuna CPUE Standardization for the Maldives Pole and Line Fishery, 1995 – 2024.

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Abstract

The Maldives Pole-and-line CPUE index remains a key input for stock assessment and management procedure of Skipjack tuna. This paper presents an updated Maldives Pole-and-line Skipjack tuna CPUE series for use in the application of the empirical Skipjack tuna Management Procedure (SKJ MP) adopted under the Resolution 24/07. The updated series, incorporating data from 2023 and 2024, follows the methodology as in IOTC-2023-WPTT25(DP)-13 and is required for the first application of SKJ MP. Results indicate a slight decline in skipjack abundance from a 2022/23 peak, with trends consistent with historical cycles observed between 2000 and 2010. The updated index closely matches previous estimates (1995–2022). While future revisions and development could improve the index, this update is submitted for review by the 27th Working Party on Tropical Tuna – Data Preparatory Meeting, ahead of SKJ MP application.

Introduction

The empirical Skipjack tuna Management Procedure (SKJ MP) adopted under the Resolution 24/07 uses the Maldives Pole-and-line Skipjack CPUE series (expert offset excluded, starting from 1995), as described in IOTC-2023-WPTT25(DP)-13 (Medley *et al*. 2023), as one of the standardized CPUE series in its application. The first application of SKJ MP is scheduled for 2025, requiring the updated standardized CPUE series as used in its specification. The Maldives CPUE series is, hence, updated to include new data from 2023 and 2024 (as indicated by WPM15), following the same process as presented in Medley et al. (2023). The standardized CPUE series from Maldives Pole-and-line fishery has been an important data source used for Skipjack stock assessment and is now required as a key data source for application of SKJ MP.

Earlier data exist from 1970 for the Maldives Pole-and-line fishery, but these were compiled into monthly records by atoll and did not record individual trips. In addition, significant corollary information about the fleet operations was missing, making it difficult to use all data in a consistent index. Previous attempts have suggested that there was some potential in earlier data, but abundance indices were not proposed because of the problems encountered (Kolody et al. 2010; Sharma et al. 2013). The primary reason for not using older data is because of the substantial changes in the fleet which have led to significant change in fishing power. While these changes have been identified qualitatively, they were only partially accounted for quantitatively in standardisation process (Medley et al. 2017). Therefore, only the version of this model applied to the 1995-2022 data was used to estimate the standardised CPUE used as an abundance index in the recent skipjack stock assessment.

The process of CPUE development up to Medley et al. (2023) using a Bayesian approach, aimed at combining multiple datasets into a single model, to produce a longer time series of standardized CPUE combinedly for Skipjack and Yellowfin tuna from the Maldives Pole-and-line fishery. The work that concluded from years of work are described in detailed in Medley *et al*. (2020). The objective of this paper is to provide an update of the Skipjack CPUE series from this work, as required for SKJ MP application – for review and consideration by 27th Working Party on Tropical Tuna – Data preparatory meeting, ahead of MP application later in the year.

Methods

The method described below is the model presented in IOTC-2023-WPTT25(DP)-13 that will be used for the Skipjack Management Procedure.

- **Data and model**

For these indices, data were combined from two sources:

1. The vessel specific data 1995-2015 that has been used in previous CPUE indices (Kolody et al. 2010; Sharma et al. 2013; Medley et al. 2017).
2. The 2014-2024 logbook data was processed to be consistent as far as possible with the 2004-2015 trip data and appended to the series.

- **Model structure**

The same model structure was used as for previously presented (Medley *et al.* 2020, Medley *et al.* 2023) implemented in Stan (2025). The model only used the 1995-2024 data, excluding a low number of small vessels (<7.5m length) for which data were believed unreliable. The non vessel-specific 1970-2004 MOFA/IPTP data, which mostly dates from the period prior to the start of this series, has been excluded. The model also does not use the subjective expert information previously considered. This is consistent with instructions received for the skipjack management procedure. It applies the same method as was used for the final index in the previous skipjack stock assessment but has added the additional years 2023 and 2024.

The full method is described in Medley et al. (2020). In summary, the log-linear model has the following components:

1. The model is fitted with a Tweedie likelihood (assuming a sum of Poisson -Gamma variables) to account for zero catches (Dunn and Smyth 2005). Unlike the delta method, the same terms in the linear predictor are fitted to both the zero and non-zero catches. The Tweedie dispersion and power parameters are estimated in the model.
2. Quarterly CPUE is estimated both yellowfin and skipjack simultaneously within the model to help inform on changes in fishing power. Only the skipjack indices are reported here.
3. Vessel length is estimated as a covariate with vessels classified into three size groups. This is has the most important effect for correcting the indices for fishing power.
4. Main effect parameters are included for the atoll chain region (3) and for the data source (older reported data or the new logbooks).

Results

The index implies the skipjack abundance has declined somewhat from a maximum reached in 2022/23, showing potentially cycle observed 2000-2010 (Fig. 1). The updated years appear to be consistent with previous indices showing relatively smooth changes. The indices estimated previously 1995-2022 are nearly identical to updated index for the same period. A small change in offset was corrected using the normalised index (Fig. 2) and the indices have a r-squared value of 0.99989 over this period.

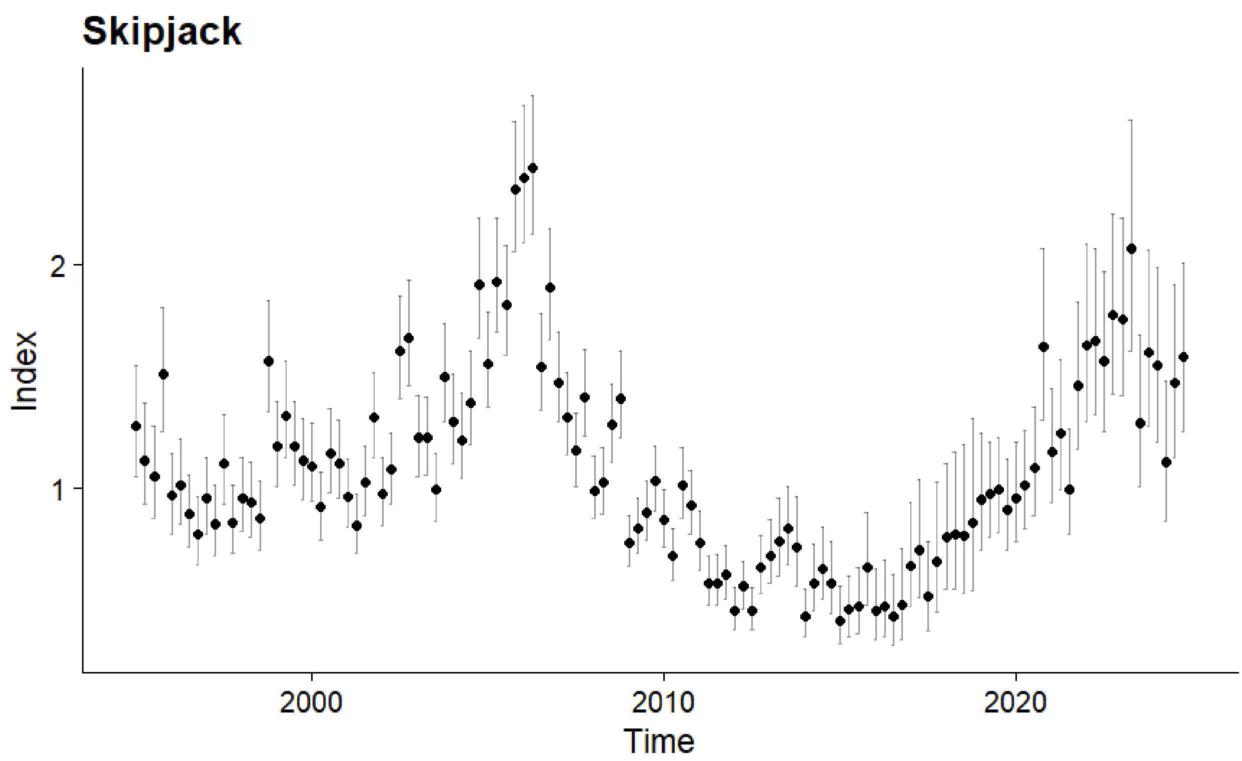

Figure 1. Skipjack final quarterly indices, 1995 – 2024 (Appendix 1).

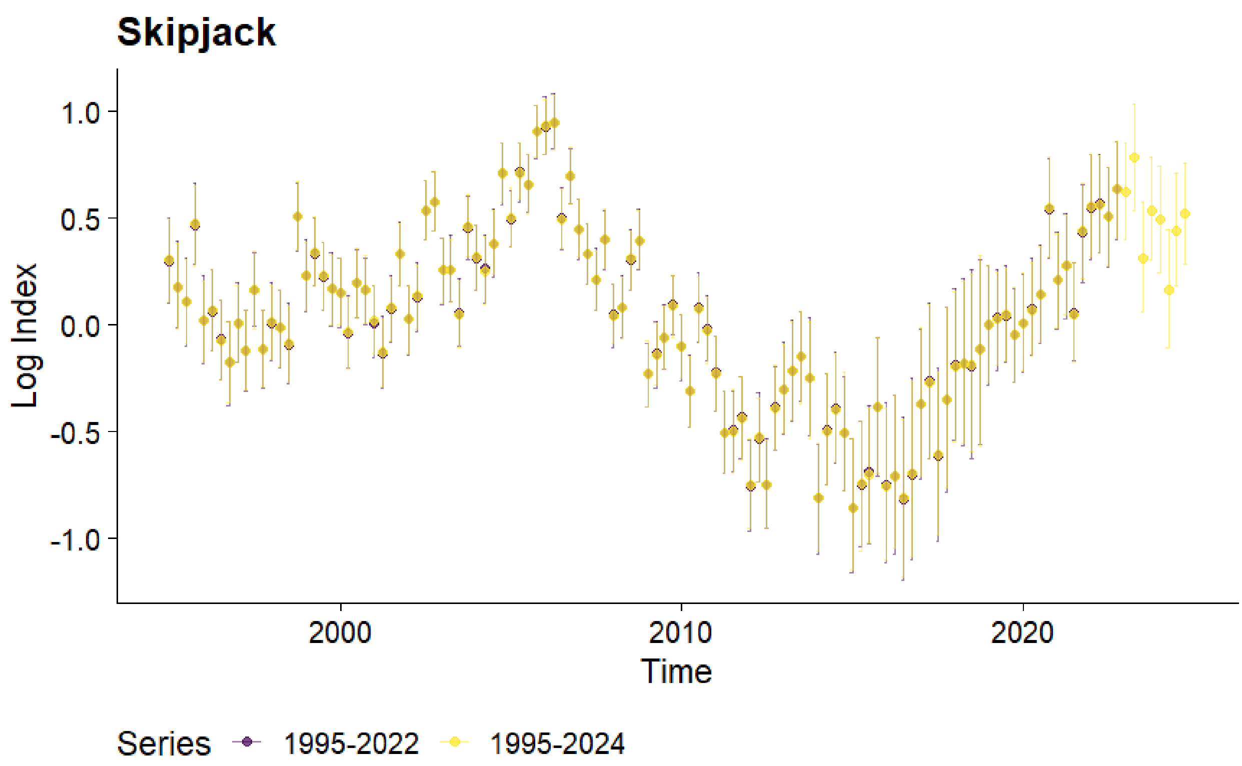

Figure 2. Skipjack normalised log index showing the previous index 1995-2022 plotted over the updated index 1995-2024. Normalisation was carried out by adjusting each series separately by taking away the mean of the log series calculated 1995-2021.

Conclusion

Diagnostics suggest that in general, there is room for improvement in the model, but that the index is useful in stock assessment. The logbook data are not exhibiting significant problems and now cover most fishing activity. They seem consistent with the older data 1995-2015. The index appeared to be appropriate for use in the Skippack Management Procedure.

With the data set having been reduced to the vessel specific data, and with more information in the logbooks, more options will be available to restructure it. The structure can be re-examined, for example adjusting for no observations when both yellowfin and skipjack are absent from the catch and modelling the effect of vessel length in a different way. It is planned to evaluate alternative models to improve precision, but it is not expected that there will be a significant change in index trend.

Acknowledgements

The authors thank the Ministry of Fisheries and Ocean Resources, particularly the Research and Statistics Section, for providing timely data for updating the CPUE series. They also acknowledge the support and constructive feedback from various contributors, including the IOTC Scientific community, during the model's several iterations of development.

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Appendix I: Tables of quarterly log-abundance index for Skipjack tuna

Year	Quarter	Mean	SD	CI 2.5%	Median	CI 97.5
1995	1	-2.124671	0.09827875	-2.317930	-2.123645	-1.931297
1995	2	-2.250551	0.10163411	-2.445835	-2.253215	-2.045136
1995	3	-2.317330	0.10172623	-2.517242	-2.317138	-2.124181
1995	4	-1.956354	0.09378646	-2.146679	-1.955196	-1.773851
1996	1	-2.407419	0.09803035	-2.604436	-2.405367	-2.224458
1996	2	-2.360607	0.09820927	-2.549072	-2.357588	-2.169322
1996	3	-2.498195	0.09647761	-2.684196	-2.498528	-2.313581
1996	4	-2.601351	0.09975399	-2.792614	-2.601557	-2.412196
1997	1	-2.420927	0.09292005	-2.602685	-2.420437	-2.243872
1997	2	-2.548535	0.09647770	-2.731305	-2.548773	-2.359058
1997	3	-2.263669	0.09001334	-2.443754	-2.265474	-2.081686
1997	4	-2.539860	0.09184068	-2.718516	-2.539992	-2.358283
1998	1	-2.414244	0.09082147	-2.587870	-2.415349	-2.243383
1998	2	-2.439937	0.09226995	-2.623552	-2.440819	-2.262508
1998	3	-2.515574	0.09129872	-2.697450	-2.514229	-2.339338
1998	4	-1.915919	0.07971611	-2.072411	-1.916721	-1.758939
1999	1	-2.197697	0.08275503	-2.361022	-2.195383	-2.040649
1999	2	-2.086149	0.08247983	-2.242521	-2.088048	-1.919819
1999	3	-2.198574	0.08078415	-2.356151	-2.198262	-2.040070
1999	4	-2.257130	0.08368151	-2.424460	-2.255012	-2.099839
2000	1	-2.277180	0.08074712	-2.428719	-2.277894	-2.112485
2000	2	-2.462461	0.08539651	-2.633365	-2.462419	-2.300666
2000	3	-2.227484	0.08042913	-2.390816	-2.227535	-2.066616
2000	4	-2.262708	0.08217494	-2.416307	-2.264323	-2.102855
2001	1	-2.408705	0.08108035	-2.564106	-2.407952	-2.245694
2001	2	-2.557808	0.08258826	-2.718756	-2.555873	-2.395997
2001	3	-2.346055	0.07737302	-2.499250	-2.344062	-2.199828
2001	4	-2.095194	0.07352844	-2.245345	-2.095961	-1.950386
2002	1	-2.399322	0.07890033	-2.558327	-2.398857	-2.245316
2002	2	-2.292698	0.07760173	-2.443972	-2.291379	-2.148819
2002	3	-1.889933	0.07166526	-2.029814	-1.888892	-1.747489
2002	4	-1.850538	0.07250114	-1.989163	-1.852607	-1.709370
2003	1	-2.167286	0.07817333	-2.321777	-2.167665	-2.020577
2003	2	-2.168376	0.07507489	-2.316574	-2.166613	-2.026851
2003	3	-2.376234	0.07722128	-2.533231	-2.375719	-2.223754
2003	4	-1.964781	0.07483026	-2.107919	-1.964454	-1.816674
2004	1	-2.111320	0.08194924	-2.265887	-2.110297	-1.957058
2004	2	-2.172669	0.08171255	-2.328605	-2.173591	-2.014293
2004	3	-2.045566	0.07771022	-2.190989	-2.045167	-1.889229
2004	4	-1.717076	0.07186658	-1.853851	-1.718723	-1.575793
2005	1	-1.925079	0.07071232	-2.058940	-1.926969	-1.785767
2005	2	-1.712706	0.06819893	-1.838891	-1.713275	-1.575077
2005	3	-1.768242	0.06849440	-1.902652	-1.768707	-1.631154

2005	4	-1.519885	0.06385642	-1.643652	-1.518945	-1.394747
2006	1	-1.496225	0.06632091	-1.627374	-1.495418	-1.368804
2006	2	-1.478146	0.06698062	-1.607423	-1.477077	-1.351490
2006	3	-1.931532	0.07172988	-2.069907	-1.932844	-1.788867
2006	4	-1.727422	0.06649585	-1.858162	-1.726877	-1.595333
2007	1	-1.979333	0.06987779	-2.110577	-1.980239	-1.837411
2007	2	-2.096365	0.07332617	-2.233305	-2.096141	-1.953238
2007	3	-2.217512	0.07214604	-2.361541	-2.216805	-2.079073
2007	4	-2.027450	0.06905670	-2.160911	-2.028778	-1.886345
2008	1	-2.379969	0.07432777	-2.516022	-2.383196	-2.236307
2008	2	-2.345773	0.07520130	-2.495254	-2.346228	-2.200758
2008	3	-2.119707	0.07088275	-2.260390	-2.117438	-1.986533
2008	4	-2.030607	0.06821171	-2.165011	-2.031260	-1.891226
2009	1	-2.656759	0.07573326	-2.808419	-2.656866	-2.502810
2009	2	-2.567678	0.07593228	-2.712872	-2.568112	-2.416557
2009	3	-2.486776	0.07506704	-2.633989	-2.488466	-2.337216
2009	4	-2.338070	0.07388199	-2.483445	-2.338876	-2.199350
2010	1	-2.527736	0.07776870	-2.678673	-2.528427	-2.379237
2010	2	-2.738447	0.08347167	-2.908412	-2.738586	-2.573487
2010	3	-2.355170	0.07877507	-2.513981	-2.354683	-2.205121
2010	4	-2.449587	0.07877060	-2.607031	-2.451181	-2.294378
2011	1	-2.655088	0.08812518	-2.832247	-2.655268	-2.481412
2011	2	-2.930895	0.09712562	-3.121071	-2.931103	-2.735487
2011	3	-2.929888	0.09852792	-3.123652	-2.929363	-2.729121
2011	4	-2.866323	0.10028410	-3.064137	-2.866611	-2.667728
2012	1	-3.176722	0.10841949	-3.382565	-3.177894	-2.961875
2012	2	-2.958236	0.10286097	-3.161242	-2.956105	-2.770615
2012	3	-3.172021	0.10444698	-3.381327	-3.174843	-2.964627
2012	4	-2.815269	0.10147369	-3.013391	-2.815536	-2.614495
2013	1	-2.731402	0.10589980	-2.930110	-2.733349	-2.522413
2013	2	-2.645881	0.11646974	-2.871389	-2.645654	-2.414100
2013	3	-2.575548	0.10932483	-2.794766	-2.575541	-2.363968
2013	4	-2.679311	0.14202667	-2.957685	-2.678923	-2.410439
2014	1	-3.236135	0.12915550	-3.488482	-3.234939	-2.979407
2014	2	-2.922838	0.13198299	-3.177393	-2.927681	-2.659108
2014	3	-2.820075	0.12983254	-3.066482	-2.823257	-2.562933
2014	4	-2.928988	0.13862595	-3.204161	-2.931682	-2.648217
2015	1	-3.280083	0.15937973	-3.575606	-3.283627	-2.957575
2015	2	-3.170791	0.15262822	-3.485473	-3.167792	-2.879814
2015	3	-3.126186	0.15843605	-3.447421	-3.126362	-2.816898
2015	4	-2.811122	0.16529976	-3.120751	-2.810217	-2.486827
2016	1	-3.180372	0.17884048	-3.528274	-3.181669	-2.821137
2016	2	-3.121367	0.18650315	-3.476717	-3.133223	-2.760214
2016	3	-3.241700	0.18905233	-3.610076	-3.240605	-2.870124
2016	4	-3.117564	0.20761776	-3.515664	-3.122311	-2.691482
2017	1	-2.795376	0.18516289	-3.137476	-2.799432	-2.441244

2017	2	-2.692571	0.18542341	-3.052191	-2.694955	-2.329704
2017	3	-3.034201	0.20203163	-3.410789	-3.036575	-2.646462
2017	4	-2.773035	0.21400783	-3.193343	-2.774829	-2.343678
2018	1	-2.622114	0.18155881	-2.972517	-2.621829	-2.267506
2018	2	-2.610641	0.19633103	-2.983312	-2.607356	-2.221073
2018	3	-2.615920	0.21364676	-3.020299	-2.613138	-2.191025
2018	4	-2.541801	0.22402454	-2.993087	-2.539090	-2.101208
2019	1	-2.423671	0.14043044	-2.696745	-2.425680	-2.147964
2019	2	-2.397731	0.11327180	-2.616963	-2.399809	-2.181062
2019	3	-2.381490	0.11211038	-2.596503	-2.380287	-2.165314
2019	4	-2.474738	0.11503585	-2.696165	-2.476264	-2.250752
2020	1	-2.419614	0.11603107	-2.644706	-2.418743	-2.181059
2020	2	-2.357031	0.11336720	-2.572417	-2.355320	-2.137467
2020	3	-2.283515	0.11475385	-2.505674	-2.283046	-2.061094
2020	4	-1.877534	0.12108950	-2.105697	-1.877860	-1.638985
2021	1	-2.216936	0.11310117	-2.437945	-2.217593	-1.998702
2021	2	-2.147874	0.11733693	-2.375497	-2.151582	-1.913636
2021	3	-2.375115	0.11815769	-2.603897	-2.377146	-2.132800
2021	4	-1.988205	0.11515310	-2.207990	-1.988989	-1.762837
2022	1	-1.871704	0.12229041	-2.106338	-1.873384	-1.627803
2022	2	-1.860919	0.11871344	-2.086176	-1.862325	-1.636936
2022	3	-1.917677	0.11645352	-2.145996	-1.918932	-1.689842
2022	4	-1.794821	0.11755233	-2.017927	-1.793611	-1.566412
2023	1	-1.801782	0.11370077	-2.023935	-1.805333	-1.574581
2023	2	-1.639639	0.12503850	-1.890024	-1.639235	-1.393695
2023	3	-2.113888	0.13149377	-2.362782	-2.112344	-1.847826
2023	4	-1.888496	0.11989556	-2.121747	-1.891707	-1.640930
2024	1	-1.928965	0.12667878	-2.179799	-1.929796	-1.678950
2024	2	-2.258380	0.14113459	-2.535174	-2.261376	-1.978228
2024	3	-1.982759	0.13313965	-2.242390	-1.984035	-1.719244
2024	4	-1.908176	0.12023577	-2.142451	-1.906916	-1.671266

Appendix II: Residual diagnostics

Residuals are compared to simulated residuals from the Tweedie distribution using the DHARMa package (Hartig 2024). The package converts all residuals to an expected uniform distribution for easy comparison. Standard residual plots help identify problems in the model and possible ways to improve it.

All show a statistically significant (H0 true p < 5%) departure from the assumed residual distribution (plots in red) for skipjack. This is perhaps not surprising given the large sample size. However, departures are relatively small.

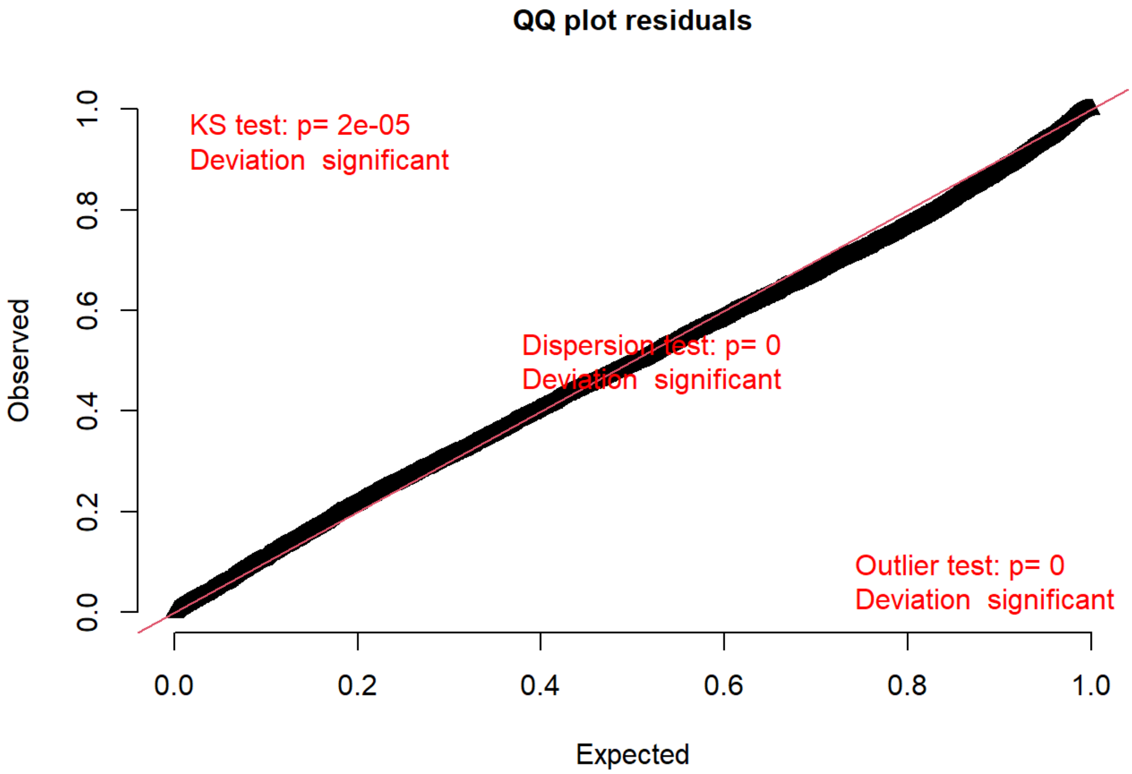

Figure 3: Skipjack: q-q plot for dispersion and to examine the distribution tails.

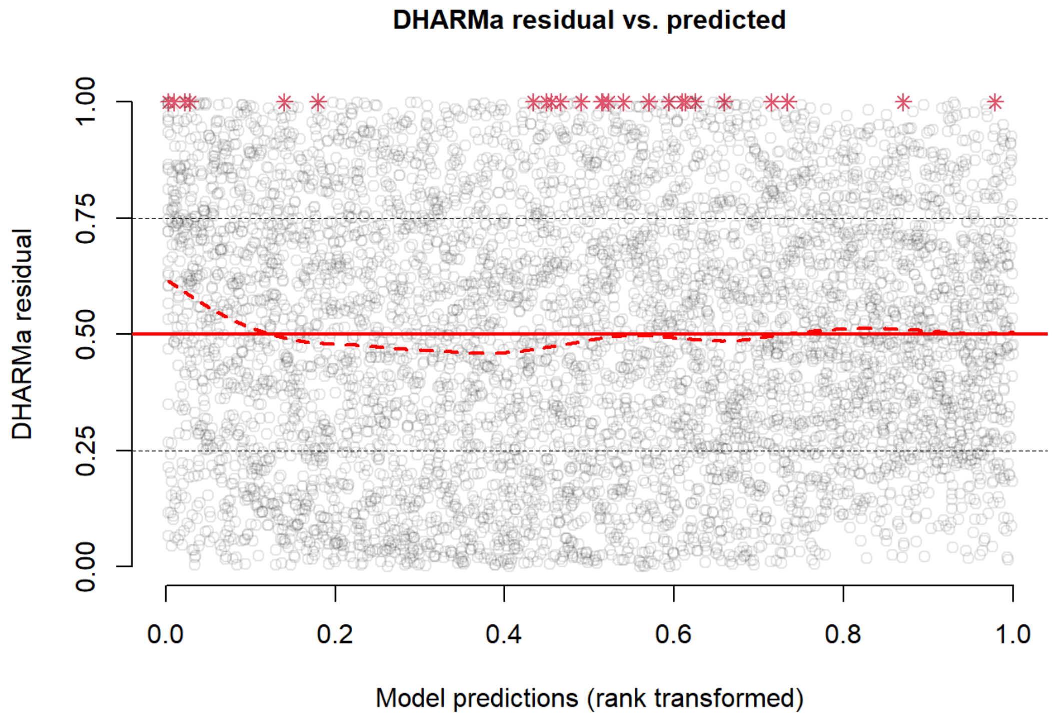

Figure 4: Skipjack: A residual plot against the observed values to look for unexplained patterns.

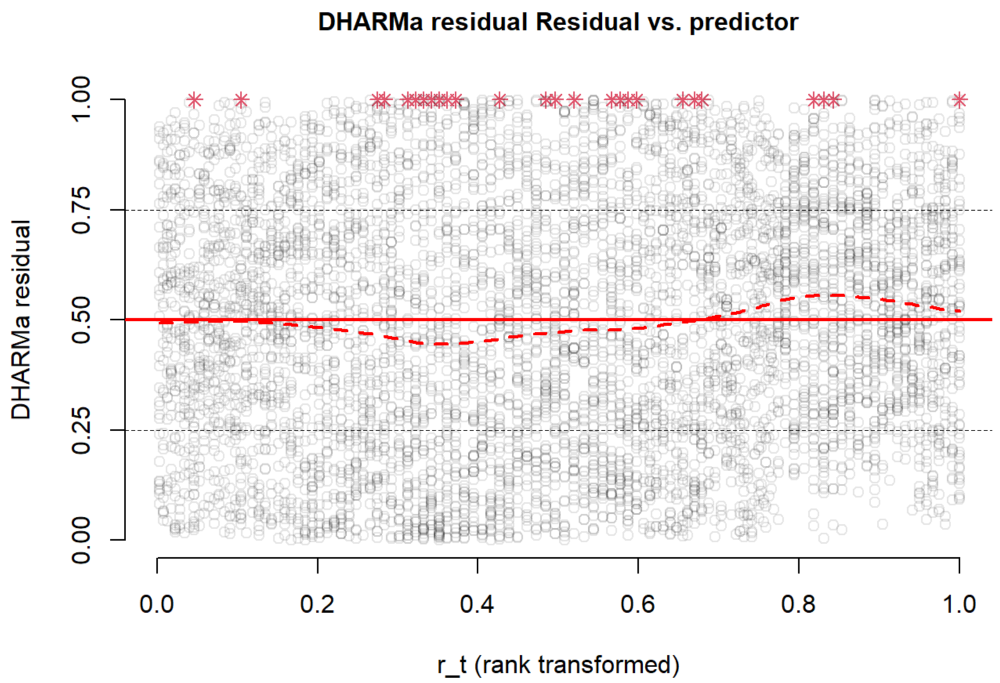

Figure 5: Skipjack: A residual plot against time.

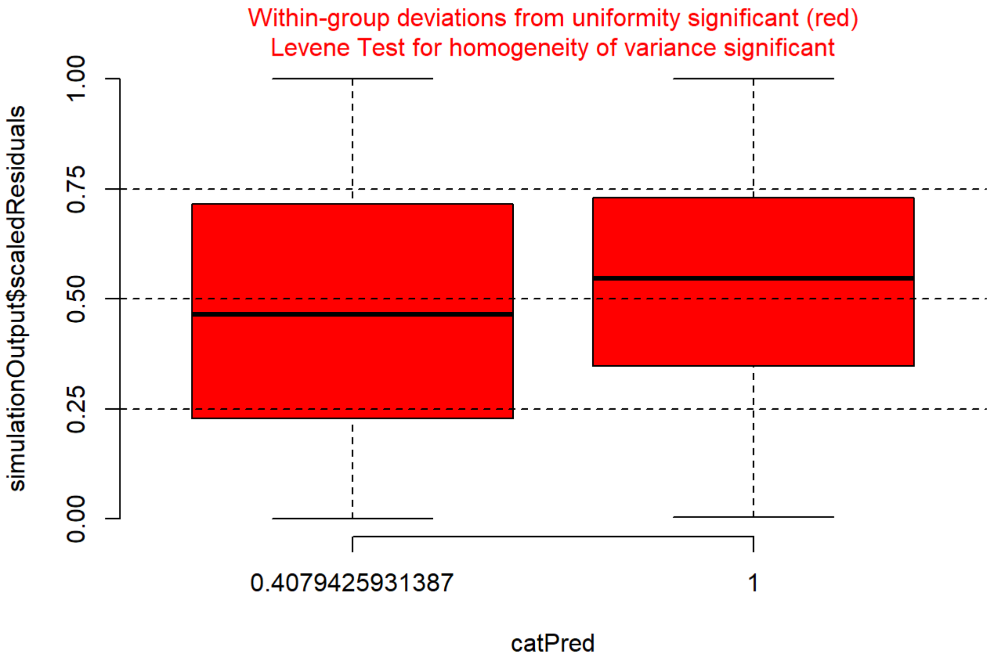

Figure 6: Skipjack: Residual distribution plot by the data source (old reporting system vs logbooks).

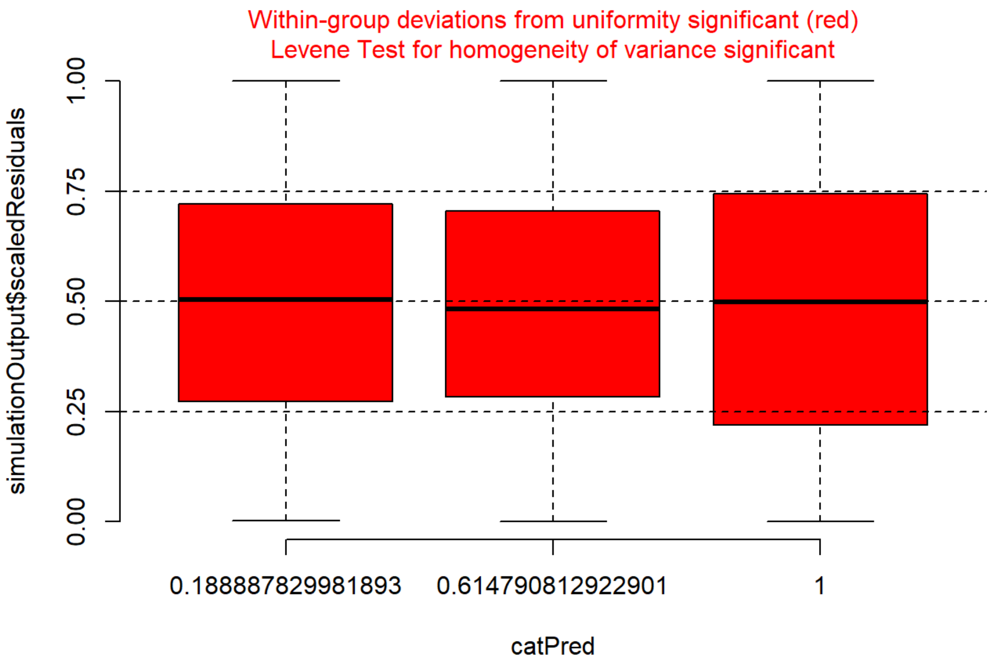

Figure 7: Skipjack: Residual distribution plot by atoll chain.

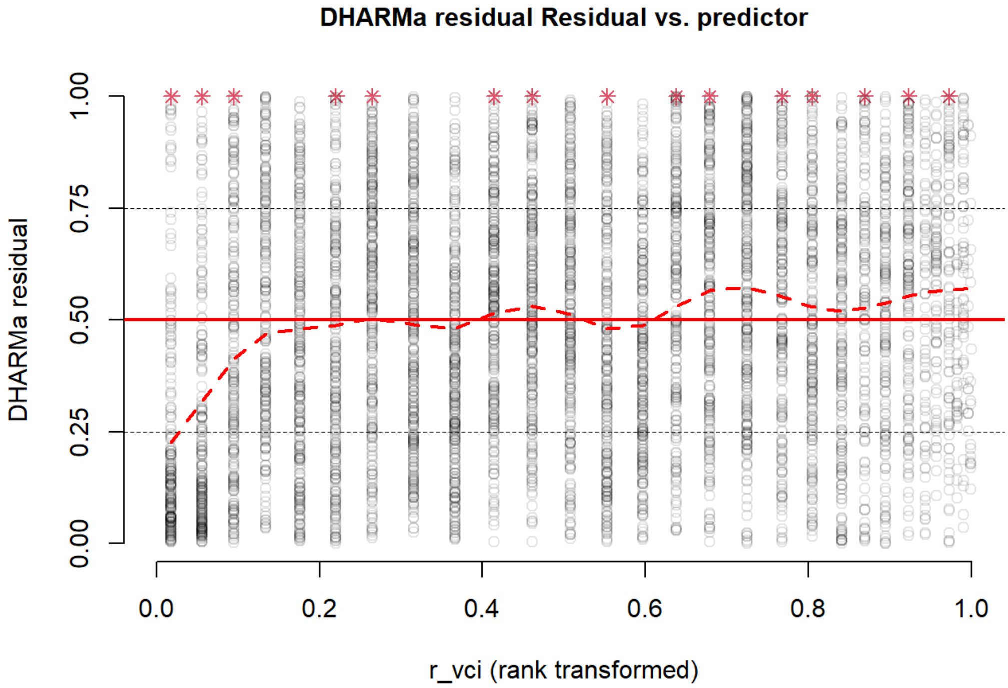

Figure 8: Skipjack: A residual plot against vessel length.

```
    DHARMa zero-inflation test via comparison to expected zeros with
    simulation under H0 = fitted model

data:  simulationOutput
ratioObsSim = 0.7006, p-value < 2.2e-16
alternative hypothesis: two.sided
```

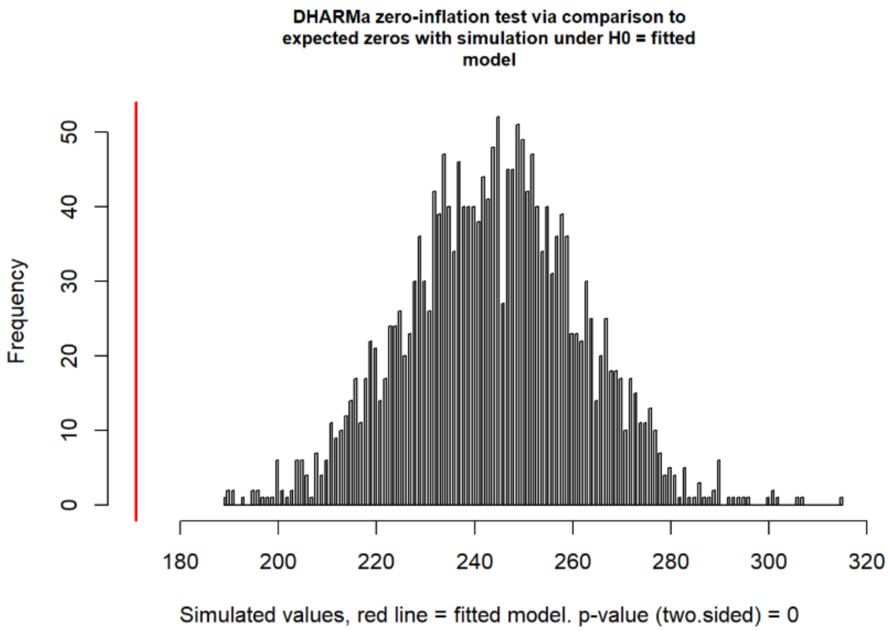

Figure 9: Skipjack: An examination of the estimated zero catches compared to the observed number showing clear positive bias.