

An update of Bayesian Skipjack tuna CPUE Standardization for the Maldives Pole and Line Fishery, 1995 – 2025.

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Abstract

The standardized CPUE index for skipjack tuna in the Maldives pole-and-line fishery has been a key input in successive stock assessments since the initial 2011 Indian Ocean skipjack stock assessment conducted using the Stock Synthesis framework. The Maldives skipjack CPUE series that used trip-level and logbook data has been extended using a Bayesian standardization approach that integrates multiple datasets, extending the time series back to 1970. Recent stock assessments (2020, 2023) and the Skipjack Management Procedure have adopted the Bayesian standardized CPUE series from 1995 onwards from the Maldives pole-and-line fishery. The updated CPUE index (1995-2025) demonstrates a declining trend followed by recent increases, approaching peak levels observed between 2000 and 2010. Comparisons with the previous indices (1995–2024) show near-identical results, with a very high correlation (r-squared: 0.9998). Model diagnostics indicate consistency with earlier series and suggest the index remains suitable for stock assessment, though improvements are possible. Better logbook coverage and the availability of vessel-specific data for the period currently in use offer opportunities to refine the model structure, hence alternative models to improve precision are being evaluated to use vessel specific data, to be considered for upcoming Skipjack stock assessments.

Introduction

The standardized CPUE index for skipjack tuna from the Maldives pole-and-line fishery has been used in successive stock assessments since the first skipjack stock assessment conducted by Kolody *et al.* (2011) using the Stock Synthesis framework. Subsequent assessments have incorporated updated CPUE series derived from trip-level data available from 2004 and logbook data collected from 2014 onwards, until the CPUE series was extended with the most recent CPUE standardization methodology. The most recent CPUE standardization, developed using a Bayesian approach (Medley *et al.*, 2017, 2020, 2023), aimed to integrate multiple datasets with varying levels of detail, extending the time series back to 1970. However, for Indian Ocean skipjack tuna stock assessments, the CPUE time series beginning in 1995 has been preferred, as this period was considered more reliable by the WPTT (Fu, 2020). The Skipjack stock assessments conducted in 2020 and 2023, as well as the Management Procedure (Edwards, 2024) and its implementation, have included the CPUE series produced through the Bayesian standardization approach for the Maldives pole-and-line fishery.

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, 2020, 2023). 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.

This paper updates the CPUE from 1995-2025 using exactly the same methodology applied previously (Medley *et al.* 2017, 2020, 2023). The objective is to maintain the consistent index that has been used in previous stock assessment and included in the management procedure.

Methods

The method described below is the model presented in IOTC-2023-WPTT25(DP)-13 that was used in the 2023 stock assessment and in 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 2014-2025 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 1995-2025 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. 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, 2024 and 2025.

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 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 shows a decline, followed by an upward trend from the last index used in the most recent skipjack stock assessment conducted in 2023 (Fig. 1). The upward trend hasn't reached the maximum observed between 2000-2010, though results in almost in the same range in 2nd and 4th quarter of 2025. The indices estimated previously for 1995-2024 (for Skipjack MP application) are nearly identical to updated index for the same period. A small change in offset was corrected using the normalized index (Fig. 2) and the indices have a r-squared value of 0.999845 over this period (Fig. 3).

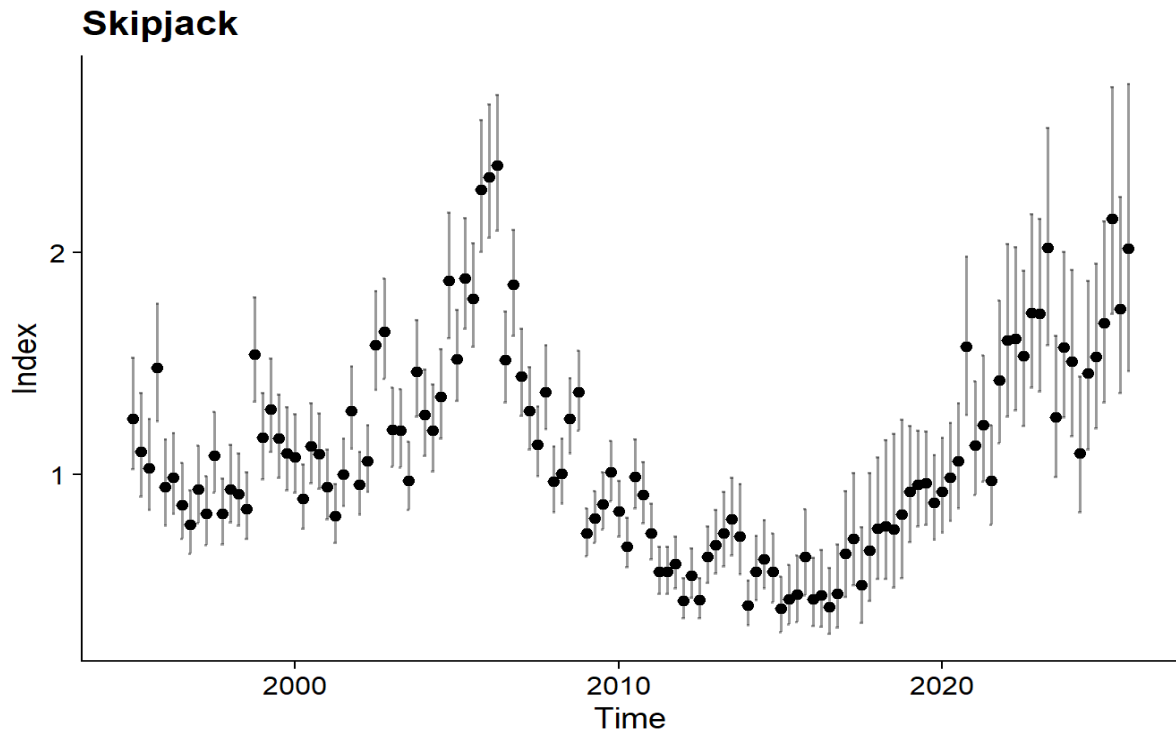


Figure 1. Skipjack final quarterly indices, 1995 – 2025 (Appendix 1).

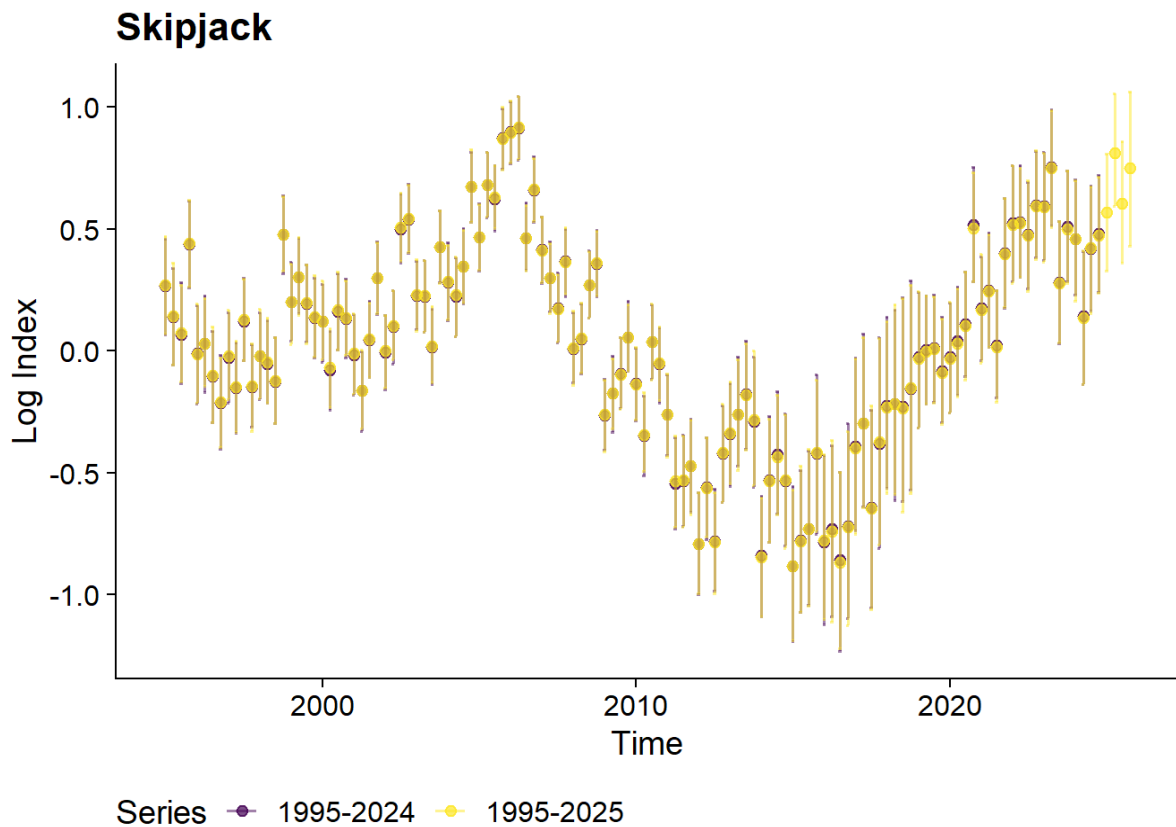


Figure 2. Skipjack normalised log index showing the previous index 1995-2024 plotted over the updated index 1995-2025. Normalisation was carried out by adjusting each series separately by taking away the mean of the log series calculated 1995-2021.

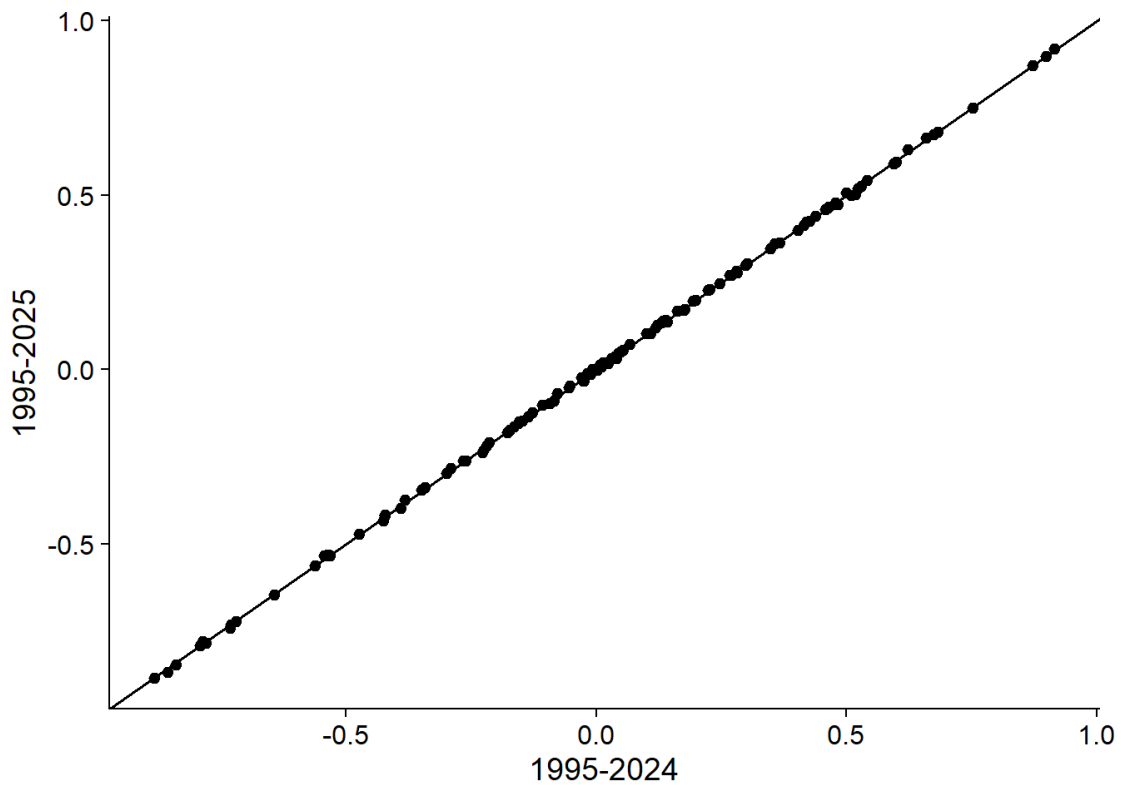


Figure 3. Comparison between 1995-2024 index (provided for MP application) and the current updated 1995-2025 index. R-squared: 0.999845

Conclusion

Diagnostics suggest that in general, there is room for some improvement in the model. The diagnostics follow the same patterns, as was observed for the CPUE used in stock assessment in 2023 and CPUE index used in the Skipjack Management Procedure implementation, suggesting the updated index should continue to be useful to be used in the stock assessment as a consistent time series abundance index. The logbook data are not exhibiting significant problems and now cover most fishing activity replacing previous data sources. The index appeared to be appropriate for use in the Skipjack 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 and alternative models to improve precision are being evaluated that make better use of the logbook data, to be considered for upcoming Skipjack stock assessments.

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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	-2.125255	0.10063620	-2.324244	-2.123827	-1.924557
1995	2	-2.247733	0.10270559	-2.450996	-2.252509	-2.035480
1995	3	-2.320226	0.10252849	-2.520612	-2.321857	-2.124794
1995	4	-1.955329	0.09222469	-2.133545	-1.955089	-1.776307
1996	1	-2.407499	0.10258798	-2.609253	-2.407573	-2.199657
1996	2	-2.361873	0.09377918	-2.541340	-2.363965	-2.177927
1996	3	-2.495666	0.09816804	-2.688934	-2.496811	-2.297308
1996	4	-2.603067	0.09550850	-2.790996	-2.603810	-2.421663
1997	1	-2.417003	0.09372760	-2.594874	-2.417017	-2.225174
1997	2	-2.544389	0.09631950	-2.729335	-2.544248	-2.354380
1997	3	-2.266949	0.08676247	-2.435073	-2.267539	-2.098912
1997	4	-2.543053	0.09196914	-2.724492	-2.541094	-2.366471
1998	1	-2.413547	0.09254109	-2.591652	-2.416272	-2.223862
1998	2	-2.441850	0.09117304	-2.609422	-2.442757	-2.258847
1998	3	-2.516814	0.08921175	-2.693281	-2.517595	-2.338172
1998	4	-1.915796	0.07812734	-2.065415	-1.916516	-1.760474
1999	1	-2.197662	0.08377821	-2.368746	-2.195906	-2.036444
1999	2	-2.090414	0.08258472	-2.250077	-2.090828	-1.928464
1999	3	-2.198166	0.08360077	-2.363359	-2.198543	-2.041094
1999	4	-2.255660	0.08518929	-2.420094	-2.255914	-2.084458
2000	1	-2.274642	0.08305018	-2.431916	-2.274387	-2.108014
2000	2	-2.464679	0.08214458	-2.627977	-2.464356	-2.303408
2000	3	-2.228798	0.08199034	-2.390086	-2.228295	-2.069389
2000	4	-2.262471	0.08009913	-2.413442	-2.261084	-2.105788
2001	1	-2.406539	0.08421522	-2.572771	-2.406516	-2.242710
2001	2	-2.557797	0.08264905	-2.715136	-2.557988	-2.390368
2001	3	-2.346767	0.07809579	-2.501642	-2.347956	-2.196448
2001	4	-2.094427	0.07263429	-2.239731	-2.095863	-1.950597
2002	1	-2.397586	0.07762441	-2.548757	-2.395506	-2.249918
2002	2	-2.291941	0.07524406	-2.431220	-2.290988	-2.146175
2002	3	-1.888134	0.07267828	-2.025598	-1.889486	-1.745522
2002	4	-1.851905	0.07153946	-1.990370	-1.852778	-1.715641
2003	1	-2.165025	0.07614651	-2.314604	-2.164527	-2.017918
2003	2	-2.168046	0.07629287	-2.317463	-2.167244	-2.023585
2003	3	-2.373270	0.07808871	-2.523527	-2.376335	-2.210637
2003	4	-1.969775	0.07494457	-2.116967	-1.968988	-1.820486
2004	1	-2.112816	0.07793791	-2.267894	-2.111962	-1.960527

2004	2	-2.168648	0.08452020	-2.335041	-2.166689	-2.008197
2004	3	-2.048602	0.07722731	-2.198984	-2.048707	-1.899815
2004	4	-1.720666	0.07288515	-1.868277	-1.720618	-1.569123
2005	1	-1.927885	0.06942577	-2.061393	-1.929332	-1.792820
2005	2	-1.715705	0.06802725	-1.843772	-1.715605	-1.580638
2005	3	-1.766699	0.06593836	-1.893669	-1.765402	-1.633596
2005	4	-1.522696	0.06567675	-1.653170	-1.523148	-1.393826
2006	1	-1.497345	0.06555287	-1.622897	-1.498228	-1.366840
2006	2	-1.476922	0.06583927	-1.606726	-1.475801	-1.351120
2006	3	-1.931815	0.07018268	-2.066947	-1.932089	-1.796999
2006	4	-1.732258	0.06615130	-1.862450	-1.731145	-1.604629
2007	1	-1.981467	0.06963834	-2.113623	-1.982435	-1.843769
2007	2	-2.096782	0.07283595	-2.241939	-2.095940	-1.954401
2007	3	-2.219823	0.07171290	-2.357087	-2.222282	-2.079890
2007	4	-2.029564	0.07031966	-2.162217	-2.032237	-1.888454
2008	1	-2.383379	0.07756780	-2.534811	-2.382703	-2.229470
2008	2	-2.344939	0.07303915	-2.486943	-2.344068	-2.199324
2008	3	-2.124864	0.06923059	-2.257923	-2.125456	-1.987197
2008	4	-2.035284	0.06748667	-2.167622	-2.033963	-1.904422
2009	1	-2.657158	0.07664425	-2.809601	-2.656441	-2.513657
2009	2	-2.569662	0.07395757	-2.714282	-2.568696	-2.425586
2009	3	-2.491018	0.07585940	-2.632880	-2.491496	-2.338551
2009	4	-2.340306	0.07036333	-2.478056	-2.338969	-2.205610
2010	1	-2.531504	0.07519282	-2.678098	-2.530703	-2.378451
2010	2	-2.737329	0.08179260	-2.888526	-2.739721	-2.565774
2010	3	-2.358091	0.07894064	-2.513351	-2.357790	-2.200205
2010	4	-2.447173	0.07605164	-2.598184	-2.446202	-2.295171
2011	1	-2.657079	0.08715497	-2.829497	-2.656651	-2.490155
2011	2	-2.931415	0.09483554	-3.117362	-2.928108	-2.743052
2011	3	-2.928956	0.09559595	-3.118065	-2.927029	-2.743035
2011	4	-2.865943	0.09920146	-3.065601	-2.866328	-2.676683
2012	1	-3.185989	0.10638932	-3.389144	-3.186645	-2.974762
2012	2	-2.958225	0.10378295	-3.156764	-2.958260	-2.750007
2012	3	-3.180110	0.10724378	-3.390585	-3.180134	-2.974505
2012	4	-2.813566	0.10298321	-3.016547	-2.811146	-2.612704
2013	1	-2.731262	0.10661659	-2.938579	-2.734070	-2.523127
2013	2	-2.656005	0.11492997	-2.885168	-2.656493	-2.429576
2013	3	-2.577509	0.11073974	-2.803117	-2.575749	-2.364567
2013	4	-2.677270	0.13881847	-2.946896	-2.678257	-2.393361
2014	1	-3.241026	0.12540683	-3.484606	-3.239896	-2.999531

2014	2	-2.926039	0.13055827	-3.180066	-2.927792	-2.673563
2014	3	-2.824713	0.12896982	-3.067364	-2.829033	-2.577876
2014	4	-2.927423	0.14155079	-3.203621	-2.926566	-2.657823
2015	1	-3.277620	0.15924692	-3.584862	-3.278109	-2.965230
2015	2	-3.176268	0.15333955	-3.468848	-3.178024	-2.867761
2015	3	-3.125819	0.16575429	-3.440673	-3.125628	-2.799018
2015	4	-2.816623	0.16032816	-3.135928	-2.813543	-2.515936
2016	1	-3.173214	0.17285055	-3.497488	-3.173699	-2.820957
2016	2	-3.138295	0.18885880	-3.508140	-3.136399	-2.762300
2016	3	-3.259423	0.18880430	-3.616431	-3.262150	-2.891725
2016	4	-3.121338	0.20096974	-3.519990	-3.116252	-2.726935
2017	1	-2.790715	0.18425616	-3.147630	-2.792657	-2.427336
2017	2	-2.693394	0.17925017	-3.036856	-2.692246	-2.341322
2017	3	-3.040838	0.21287131	-3.456380	-3.041701	-2.619681
2017	4	-2.772345	0.21958392	-3.192047	-2.768202	-2.342561
2018	1	-2.627943	0.17849218	-2.980813	-2.628718	-2.274216
2018	2	-2.607084	0.20102635	-2.981947	-2.613203	-2.205303
2018	3	-2.631926	0.22051087	-3.057210	-2.631755	-2.179909
2018	4	-2.546905	0.21899867	-2.978265	-2.548482	-2.126125
2019	1	-2.426265	0.14244555	-2.710216	-2.428048	-2.149935
2019	2	-2.394328	0.11511425	-2.613733	-2.396397	-2.168129
2019	3	-2.390054	0.11155579	-2.607024	-2.387569	-2.170769
2019	4	-2.482802	0.111116034	-2.695021	-2.484332	-2.264757
2020	1	-2.428862	0.11737669	-2.650581	-2.428249	-2.194750
2020	2	-2.364448	0.11222392	-2.581889	-2.363289	-2.138942
2020	3	-2.290372	0.11315557	-2.512934	-2.290619	-2.069986
2020	4	-1.891221	0.11601215	-2.111106	-1.892784	-1.663493
2021	1	-2.227295	0.11221252	-2.446270	-2.225915	-1.997855
2021	2	-2.151670	0.11826830	-2.381159	-2.148757	-1.919309
2021	3	-2.378267	0.11834524	-2.606222	-2.378282	-2.146119
2021	4	-1.996482	0.11396243	-2.215986	-1.996149	-1.769196
2022	1	-1.875185	0.12276543	-2.116860	-1.876618	-1.635101
2022	2	-1.868158	0.11635594	-2.093035	-1.870799	-1.643155
2022	3	-1.922274	0.11580506	-2.151717	-1.921627	-1.696280
2022	4	-1.798613	0.11674166	-2.018082	-1.800822	-1.572445
2023	1	-1.805154	0.11510484	-2.030618	-1.804154	-1.582552
2023	2	-1.645154	0.12504184	-1.889073	-1.644283	-1.407176
2023	3	-2.117323	0.13088867	-2.359775	-2.118644	-1.863313
2023	4	-1.893232	0.11900230	-2.117973	-1.895611	-1.654066
2024	1	-1.937218	0.12722825	-2.190164	-1.936245	-1.694033

2024	2	-2.256892	0.14061969	-2.534095	-2.258687	-1.982106
2024	3	-1.975956	0.13459559	-2.241961	-1.972740	-1.721203
2024	4	-1.922769	0.12438928	-2.159390	-1.922097	-1.681008
2025	1	-1.828885	0.12024626	-2.066514	-1.828124	-1.586415
2025	2	-1.581294	0.11917800	-1.803085	-1.581799	-1.338604
2025	3	-1.786060	0.12881919	-2.035511	-1.790823	-1.536457
2025	4	-1.647205	0.16421947	-1.966487	-1.646511	-1.332871

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 (H_0 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.

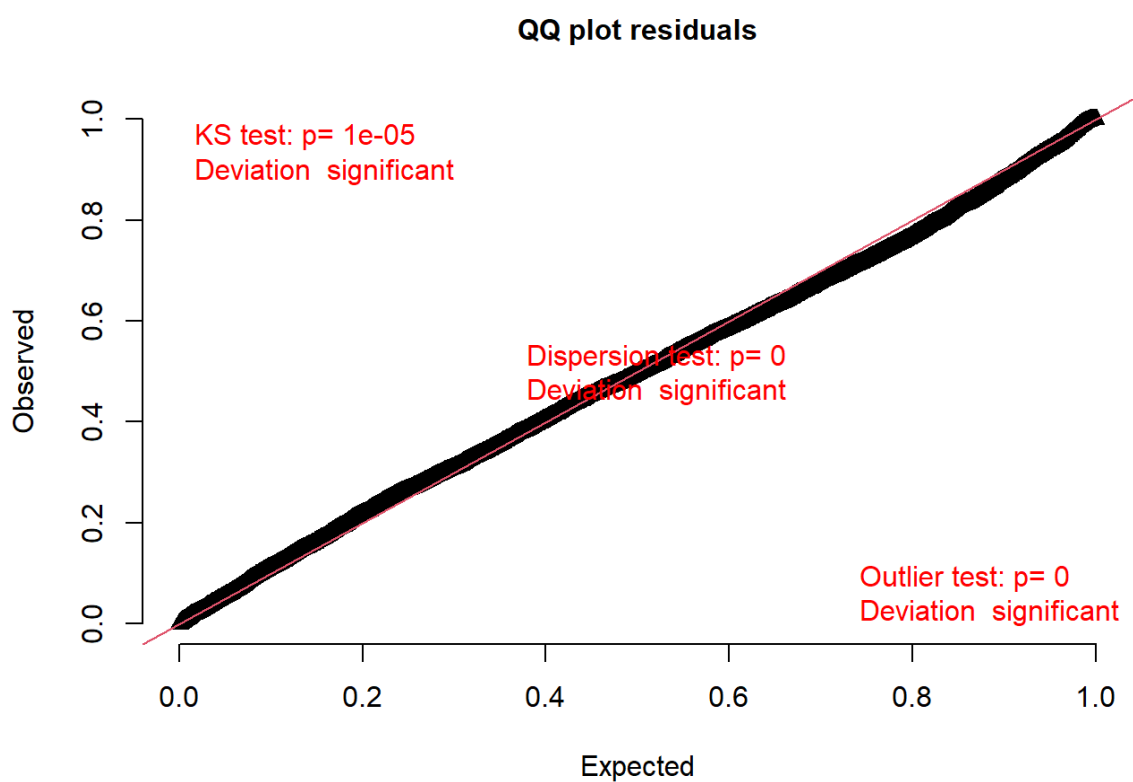


Figure 1: Skipjack: q-q plot for dispersion and to examine the distribution tails.

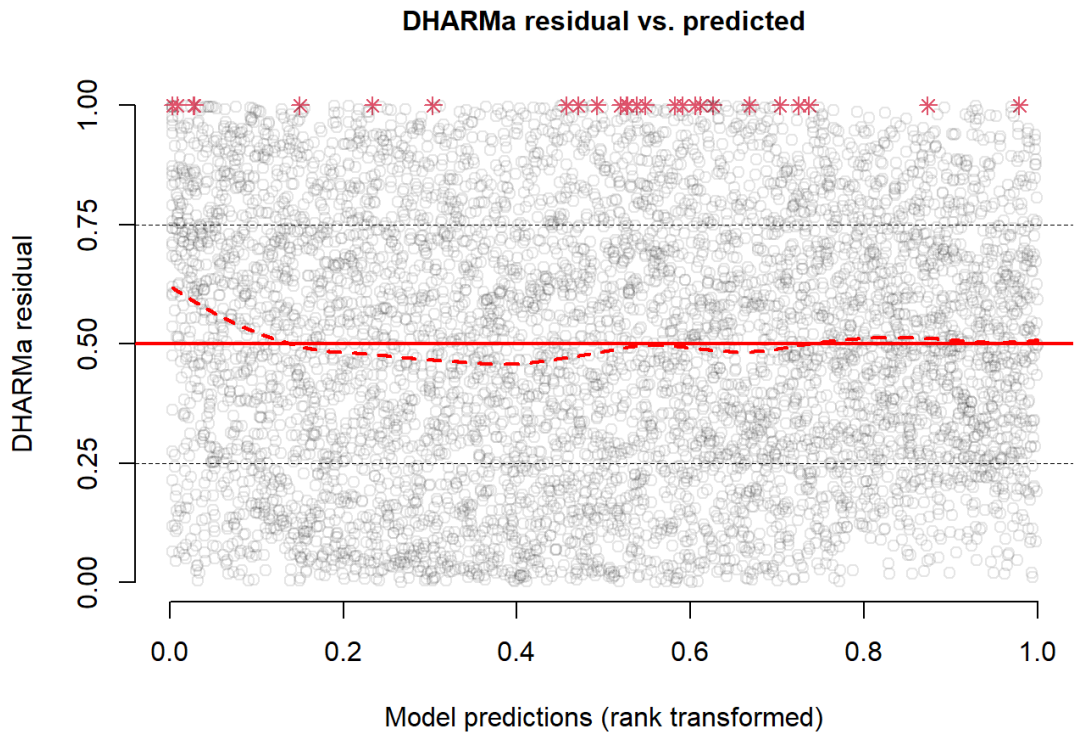


Figure 2: Skipjack: A residual plot against the observed values to look for unexplained patterns.

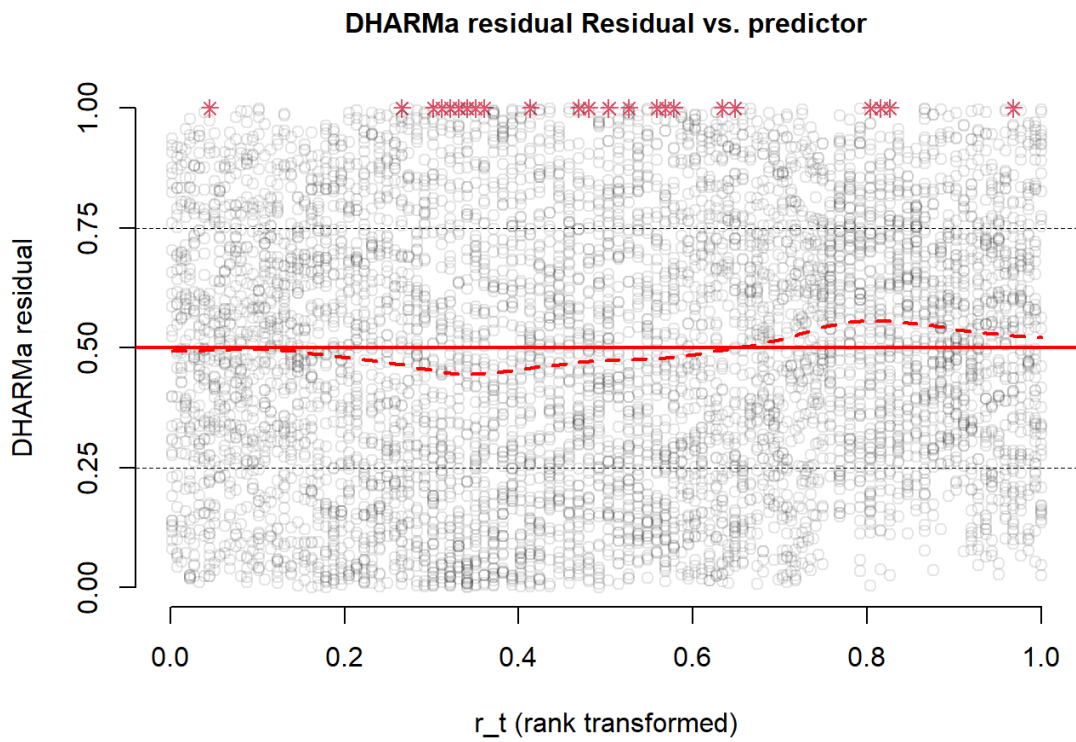


Figure 3: Skipjack: A residual plot against time.

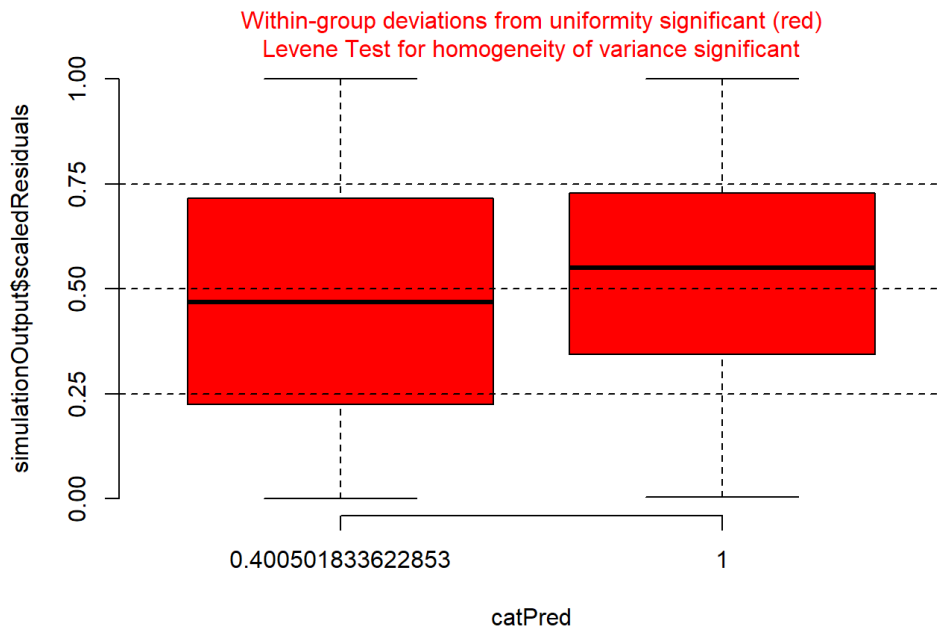


Figure 4: Skipjack: Residual distribution plot by the data source (old reporting system vs logbooks).

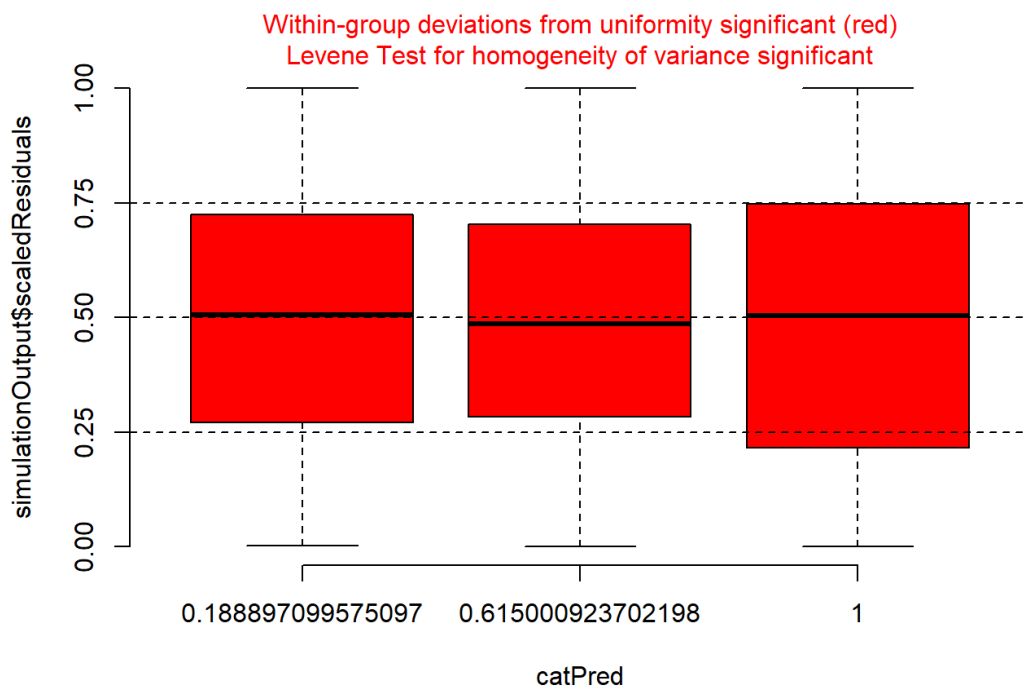


Figure 5: Skipjack: Residual distribution plot by atoll chain.

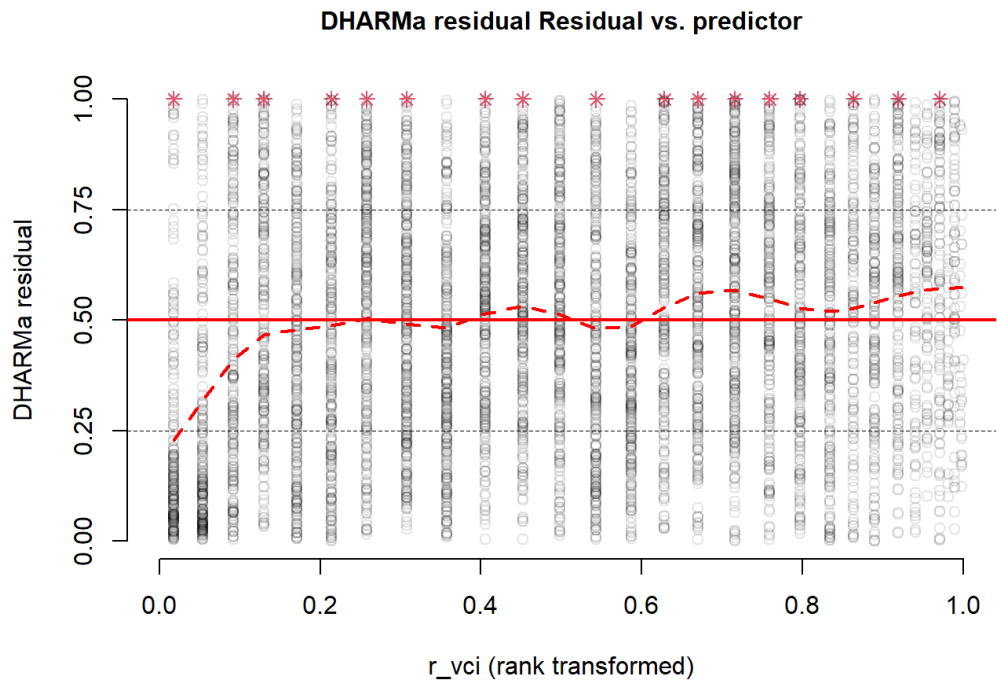


Figure 6: Skipjack: A residual plot against vessel length.

DHARMa zero-inflation test via comparison to expected zeros with simulation under H_0 = fitted model

```
data: simulationOutput
ratioObsSim = 0.69587, p-value < 2.2e-16
alternative hypothesis: two.sided
```

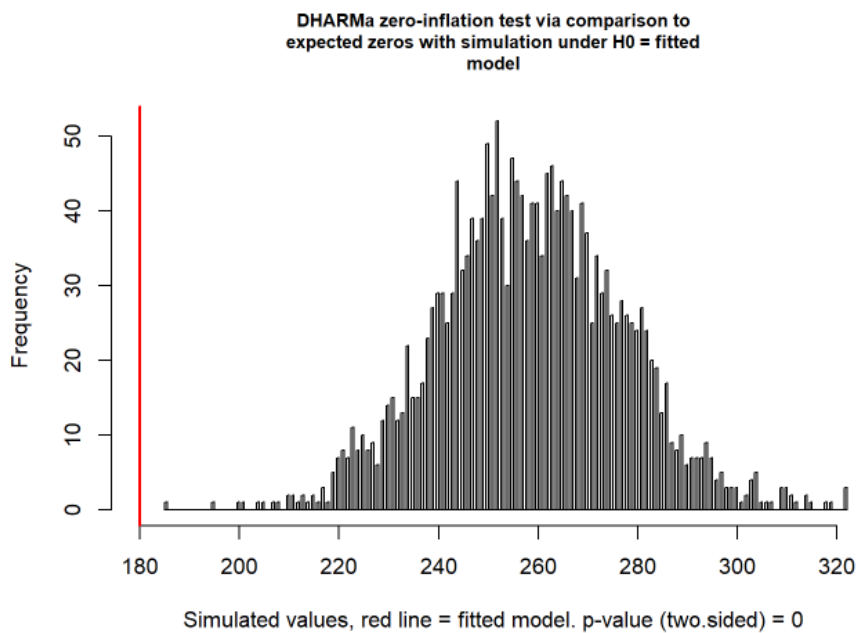


Figure 7: Skipjack: An examination of the estimated zero catches compared to the observed number showing clear positive bias.