AN ALTERNATIVE INDEX OF ABUNDANCE FOR ATLANTIC SKIPJACK TUNA (*KATSUWONUS PELAMIS*) BASED ON CATCH RATIO AND ABUNDANCE OF A REFERENCE SPECIES

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Summary

Indices of abundance, frequently based on catch rates per unit effort (CPUE), are one of the main inputs to tropical tuna stock assessments. While standardized longline CPUE series are routinely obtained and used in the stock assessments of yellowfin and bigeye tunas, the standardization of the effort in fisheries targeting skipjack tuna is more problematic, due to several factors that are known to affect the efficiency of the fleets but are difficult to quantify. In this scenario, alternative approaches need to be tested. In this document, we propose an alternative approach based on the ratio in the catch of skipjack vs yellowfin tuna, using the abundance of the reference species as an offset in the standardization.

Keywords: Skipjack tuna; Katsuwonus pelamis; CPUE standardization.

Introduction

Catch per unit effort (CPUE) data are one of the main inputs to fish stock assessments, since they are typically the main source of information on relative biomass abundance trends in the populations. CPUE time series are usually standardized to correct for factors, other than abundance, that can affect catch rates.

In the case of Atlantic skipjack, previous approaches for the development of indices of abundance have included the standardization of CPUE from different baitboat (Carneiro et al., 2015; SCRS, 2015), longline (Lauretta and Walter, 2015) and purse seine (Walter et al., 2015) fisheries. A fishery independent index based on larval surveys in the Gulf of Mexico was also included in the latest skipjack stock assessment (Ingram, 2015).

For some species, like bigeye or yellowfin tuna, the longline catch per thousand hooks is used in stock assessments of these species worldwide, including several factors (e.g., hooks between floats, vessel id., sea surface temperature, etc.) that can alter the catchability or the "effective" effort actually exerted. However, in most instances catch rates for skipjack in these fisheries is extremely low.

Pole and line fisheries only operate in some specific regions and their importance have decreased significantly in the latest decades. Moreover, the use of FADs (or vessels acting as them) has extended in the most recent period and also results in difficulties for effort standardization in many of these fisheries.

In the case of the purse seine fishery, particularly since the expansion of fish aggregating devices (FADs) as the main fishing method, the amount of effective effort exerted is difficult to quantify. The number of FADs tracked, the time elapsed since their deployment, the collaboration with other vessels, the assistance from supplies or the incorporation of echosounders in the satellite buoys, among others, are known to affect catch rates, but this information is rarely available and usually difficult to quantify. Nevertheless, significant progress has taken place in the latest years and purse seine indices using more refined approaches are being progressively incorporated in tropical tuna stock assessments (Guéry et al., 2019).

In this context, other approaches are required. Recent studies have developed fishery independent indices based on records from echosounder buoys. It has been successfully applied to bigeye and yellowfin tuna in the Atlantic

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Ocean (Santiago et al., 2020a, 2021) and to skipjack tuna in the Indian (Santiago et al., 2020b) and eastern Pacific (Santiago, Pers. Com.) oceans. Although this approach is promising, there are also some issues to overcome: echosounders are relatively recent and have experienced significant changes since they started being used. Moreover, information from echosounders does not generally serve (progress is taking place in this direction) to differentiate the species and some assumptions need to be made.

In the current study, we explore an alternative approach, inspired by an early study done my Maunder and Hoyle (2007), under the assumption that trends in relative catch rates among species reflect their relative abundance in the population. Therefore, if we are able to model the changes in the catchability ratio between two species and know the variations in stock biomass of one of them, we can infer the variations in biomass of the other.

Methodology

Catch data

Tropical tuna purse seine catch composition data are known to be biased. Due to the similarity of juvenile tuna of the different species (mainly yellowfin and bigeye) and the fact that catches are directly transferred to the wells, without any sorting, the estimates from the skippers and recorded in the logbooks are corrected after a biological sampling, either onboard (e.g. Peatman et al., 2018) or at port (e.g. Duparc et al., 2020).

Back in 1984, the Working Group on Juvenile Tropical Tuna observed biased reports of landings per species provided by vessel fishing logs, which particularly affected young specimens, and a procedure based on multi-species sampling of catches was developed and has been updated and used since then for the correction of size and species composition in purse-seiners and baitboats in the Atlantic and Indian Oceans (Sarralde et al., 2010). This method, known as T3 (see Duparc et al., 2020), aims at obtaining estimates at large spatiotemporal strata, which, although is more robust to characterize the removals by the fisheries, does not allow to use this data with a reasonable spatiotemporal resolution.

The port sampling unit in tropical tuna purse seine fisheries are generally the wells. Ideally, wells containing catch from single sets would provide accurate information on the catch composition at a high spatiotemporal resolution. However, wells generally contain catch from several sets. In this study, we have used the same port sampling data used as input for T3 to inform on catch ratios between species by using the information from wells filled with sets that (i) take place in association with floating objects and (ii) are not split more than a given distance and time between each other.

The selection of the filtering thresholds for the distance and the time between sets needs to balance a good spatio-temporal resolution with an adequate sample size. **Figure 1** shows the rate of samples retained as a function of maximum distance and days between sets contributing to the well sampled.

It was decided to keep samples from well containing sets split less than 3 days and 100 km. This resulted in a retention of c. 69% of the original dataset.

Known-species biomass

It is assumed that the population trends of YFT and BET, as estimated in the latest stock assessments (SCRS 2019, 2021) and used for the provision of management advice are adequately characterized, including numbers at age, weight at age and the selectivity of the purse seine associated fleets. The information from the Stock Synthesis models in the uncertainty grid was used to estimate the vulnerable biomass (as a composite of the numbers at age, the selectivity pattern and the weights at age) to the purse seine associated fishery. In the case of the yellowfin tuna stock assessment, the temporal shifts in selectivity patterns and weight-at-age resulted in dramatic decreases in vulnerable biomass around 2003. Therefore, after different alternatives were explored (original estimates, using the selectivity pattern and W-at-age in the latest period and using only data from 2003), it was decided to use the patterns in the most recent (post-2013) period.

Oceanographic data

Daily fields of surface temperature, salinity, sea surface current, sea surface height, chlorophylle a concentration were obtained from the Copernicus Marine Environmental Monitoring Service https://marine.copernicus.eu/.

Values for each variable were estimated at the weighted sample location and date using bilinear interpolation using the R package ‘fields’ (Nychka et al., 2021).

Model

The development of the model largely follows the methodology of Maunder and Hoyle (2007).

It is considered that the ratio of two species in the catch is proportional to the ratio of both species' biomass, that is:

$$\frac{C_B}{C_A} = \frac{q_B}{q_A}\frac{B_B}{B_A}$$

Expressed in log scale:

$$\ln\left(\frac{C_B}{C_A}\right) = \ln(\frac{q_B}{q_A}) + \ln(B_B) - \ln(B_A)$$

We can model the ratio in catchability using a log-normal approach as follows:

$$\ln\left(\frac{C_B}{C_A}\right) = \beta X + \ln(B_B) - \ln(B_A) + \varepsilon$$

$$\varepsilon \sim N(0, \sigma^2)$$

As in Maunder and Hoyle, the logarithm or the ratio can be modeled using a set of explanatory variables that account for the relative changes in catchability (e.g., longitude and latitude, temperature, etc), an offset equal to the negative of the logarithm of the abundance of species A ('reference species') and a time categorical variable to represent the logarithm of the population of the species B ('species of interest'). To avoid the effect of zeros, a small constant was added to the weight of each species in the sample.

Generalized additive models were run in R using package mgcv (Woods, 2011). All analyses were performed and plot in R (R Core team, 2021)

The method was applied to estimate bigeye and skipjack biomass based on the latest yellowfin tuna stock assessments. Results were compared to the estimates derived from the bigeye and skipjack tuna latest stock assessments.

Results and Discussion

The first analyses, aimed at estimating bigeye tuna using the yellowfin tuna biomass vulnerable to the purse seine fisheries as estimated in the four model runs composing the uncertainty grid as the offset term, predicted a dramatic drop in bigeye vulnerable biomas. This is linked to the estimation of selectivity for the purse seine associated fleet in time-blocks in the case of yellowfin tuna, with a significant shift in 2003. The selection of large individuals only in the early period causes the yellowfin tuna vulnerable biomass to drop after 2003. Since this change is not seen in the bigeye to yellowfin ratio in the catch, it is interpreted as a comparable decrease in bigeye vulnerable biomass (**Figure 2**).

The use of the selectivity pattern in the most recent period (**Figure 3**) improved the estimates of bigeye biomass, as compared to this species' stock assessment results, although some significant deviations were observed, particularly at the end of the time series. It is important to note that the biomass of the cohorts that are vulnerable to the purse seine fishery is mainly informed by the trends in the longline fishery years later. Hence, the biomass of the younger age classes in the most recent period is not generally well informed. Although this exercise was mainly focused at validating the methodology, there are many underlying assumptions that might be violated, notably that the biomass at the younger ages and the selectivity of the purse seine associated fleet is perfectly estimated in both stock assessments.

Therefore, estimates for skipjack tuna based on the yellowfin tuna stock assessment model runs were compared with different abundance indices for this species and with the total biomass as estimated in the lastest skipjack stock assessment (**Figure 4**). The current estimates seem to match well with most of the other indices used in the 2012 skipjack stock assessment. It matched particularly well the estimated total biomass, but for the latest years, where the assessment estimated a significant drop in biomass, but our analyses, as well as some of the other biomass indices used in the 2012 skipjack stock assessment, estimate an increase.

The inclusion of oceanographic variables (**Figure 5**) only resulted in very minor changes and the main term affecting catchability was, by far, the spatial component (**Figure 6**). Due to the exclusion of some years due to the lack of oceanographic data, the little impact over the estimates and the problem of deciding whether some of the covariates can be confounded with abundance, it is considered that the estimates using only a spatial term to account for changes in the ratio of catchability are more convenient.

Table 1 and **Figure 7** show the original estimated coefficients and standard error by year/quarter, as well as the values of the estimates and 95% confidence intervals in linear scale. The deviance explain by the model was *c.* 22%, although this is not unexpected, due to both the small sample sizes (the T3 process is not aimed at estimating set by set or well by well composition accurately, but at large spatiotemporal strata) and the likely real variability between sets. Additional analyses pooling together samples coming from the same 5x5 cell and quarter yielded similar results (**Figure 8**) and improved the percentage of deviance explained (*c.* 44% when observations were unweighted and *c.* 66% if observations were weighted by the total weight in the sample).

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Table 1.- Standardized index of abundance for skipjack for the period 1990-2019. Standard errors and values in the linear scale are also provided.

Year	log(mean)	log(se)	mean	upper	lower
1990.25	-1.1589	0.3469	0.3138	0.6194	0.1590
1990.50	-1.4737	0.3577	0.2291	0.4618	0.1136
1990.75	-0.9070	0.3440	0.4037	0.7923	0.2057
1991.00	-0.5939	0.2979	0.5521	0.9901	0.3079
1991.25	-0.3383	0.3439	0.7130	1.3990	0.3634
1991.50	-1.8634	0.3267	0.1551	0.2943	0.0818
1991.75	-1.6475	0.3012	0.1925	0.3474	0.1067
1992.00	-0.8956	0.3011	0.4084	0.7368	0.2263
1992.25	-1.3932	0.3141	0.2483	0.4595	0.1342
1992.50	-3.2320	0.3311	0.0395	0.0755	0.0206
1992.75	-2.6219	0.3213	0.0727	0.1364	0.0387
1993.00	-1.6366	0.3004	0.1946	0.3507	0.1080
1993.25	-1.9108	0.3049	0.1480	0.2690	0.0814
1993.50	-2.5679	0.3440	0.0767	0.1505	0.0391
1993.75	-2.0196	0.3032	0.1327	0.2404	0.0732
1994.00	-2.0094	0.3185	0.1341	0.2503	0.0718
1994.25	-1.7036	0.3050	0.1820	0.3309	0.1001
1994.50	-3.2298	0.3212	0.0396	0.0742	0.0211
1994.75	-2.9021	0.2944	0.0549	0.0978	0.0308
1995.00	-2.0329	0.2971	0.1310	0.2344	0.0732
1995.25	-2.1873	0.2966	0.1122	0.2007	0.0627
1995.50	-2.4124	0.3314	0.0896	0.1716	0.0468
1995.75	-2.2335	0.2840	0.1072	0.1870	0.0614

1996.00	-1.9458	0.2961	0.1429	0.2553	0.0800
1996.25	-2.4063	0.3081	0.0901	0.1649	0.0493
1996.50	-2.8341	0.3124	0.0588	0.1084	0.0319
1996.75	-1.9520	0.2926	0.1420	0.2519	0.0800
1997.00	-1.3231	0.2944	0.2663	0.4742	0.1495
1997.25	-2.3867	0.3114	0.0919	0.1693	0.0499
1997.50	-2.6345	0.3432	0.0718	0.1406	0.0366
1997.75	-2.1663	0.3448	0.1146	0.2253	0.0583
1998.00	-0.8073	0.5644	0.4461	1.3483	0.1476
1998.25	-2.2151	0.5398	0.1091	0.3144	0.0379
1998.50	-0.8835	0.4868	0.4133	1.0732	0.1592
1998.75	-2.1351	0.4470	0.1182	0.2840	0.0492
1999.00	0.0379	0.4862	1.0386	2.6933	0.4005
1999.25	-0.9468	0.3992	0.3880	0.8485	0.1774
1999.50	-1.4220	0.3781	0.2412	0.5062	0.1150
1999.75	-1.4930	0.5827	0.2247	0.7040	0.0717
2000.00	-0.8299	0.3769	0.4361	0.9129	0.2083
2000.25	-1.2740	0.3531	0.2797	0.5589	0.1400
2000.50	-1.5452	0.4114	0.2133	0.4776	0.0952
2000.75	-1.1336	0.3309	0.3219	0.6157	0.1683
2001.00	-0.7579	0.3634	0.4686	0.9554	0.2299
2001.25	-1.7072	0.3854	0.1814	0.3860	0.0852
2001.50	-0.7083	0.3771	0.4925	1.0313	0.2352
2001.75	-0.9181	0.3958	0.3993	0.8673	0.1838
2002.00	-0.0621	0.3676	0.9398	1.9318	0.4572
2002.25	-0.8663	0.3575	0.4205	0.8474	0.2087
2002.50	-1.4688	0.3714	0.2302	0.4768	0.1112
2002.75	-0.9115	0.3502	0.4019	0.7983	0.2023
2003.00	-0.6802	0.3535	0.5065	1.0126	0.2533
2003.25	-0.5299	0.3586	0.5887	1.1889	0.2915
2003.50	-1.2059	0.3714	0.2994	0.6201	0.1446

2003.75	-0.7595	0.3871	0.4679	0.9993	0.2191
2004.00	-0.9214	0.3690	0.3979	0.8203	0.1931
2004.25	-1.3836	0.3416	0.2507	0.4897	0.1283
2004.50	-0.7937	0.3716	0.4522	0.9368	0.2183
2004.75	-0.6396	0.3391	0.5275	1.0254	0.2714
2005.00	-1.2756	0.3683	0.2793	0.5748	0.1357
2005.25	-0.8598	0.3714	0.4232	0.8765	0.2044
2005.50	-1.1108	0.3201	0.3293	0.6167	0.1758
2005.75	-0.7257	0.3281	0.4840	0.9208	0.2544
2006.00	-0.9505	0.3218	0.3865	0.7264	0.2057
2006.25	-1.0169	0.3381	0.3617	0.7017	0.1865
2006.50	-0.3274	0.3466	0.7208	1.4219	0.3654
2006.75	-0.7625	0.3150	0.4665	0.8649	0.2516
2007.00	-0.4873	0.3697	0.6143	1.2679	0.2976
2007.25	-1.0984	0.3408	0.3334	0.6503	0.1709
2007.50	-0.6063	0.3532	0.5454	1.0899	0.2729
2007.75	-0.5702	0.3285	0.5654	1.0765	0.2970
2008.00	-0.7342	0.3289	0.4799	0.9144	0.2518
2008.25	-1.5309	0.3728	0.2163	0.4492	0.1042
2008.50	-1.5266	0.3643	0.2173	0.4437	0.1064
2008.75	-1.4992	0.3594	0.2233	0.4517	0.1104
2009.00	-1.5191	0.3751	0.2189	0.4566	0.1049
2009.25	-1.2619	0.3754	0.2831	0.5909	0.1357
2009.50	-0.7245	0.3342	0.4846	0.9328	0.2517
2009.75	-0.4677	0.3314	0.6264	1.1995	0.3272
2010.00	-0.5137	0.3523	0.5983	1.1933	0.2999
2010.25	-0.7728	0.3462	0.4617	0.9100	0.2343
2010.50	-1.0878	0.3397	0.3370	0.6558	0.1731
2010.75	-0.6783	0.3392	0.5075	0.9866	0.2610
2011.00	-0.2513	0.4255	0.7778	1.7906	0.3378
2011.25	-0.3330	0.3324	0.7168	1.3749	0.3736

2011.50	-0.0884	0.3224	0.9154	1.7222	0.4866
2011.75	-0.3733	0.3226	0.6885	1.2956	0.3659
2012.00	-0.4109	0.3504	0.6630	1.3176	0.3337
2012.25	-0.2147	0.3616	0.8068	1.6389	0.3972
2012.50	-0.2630	0.3688	0.7687	1.5837	0.3731
2012.75	-1.0479	0.3908	0.3507	0.7544	0.1630
2013.00	-0.3502	0.3743	0.7045	1.4674	0.3383
2013.25	-0.3745	0.3791	0.6877	1.4455	0.3271
2013.50	-0.2241	0.3740	0.7993	1.6635	0.3840
2013.75	-0.4035	0.3235	0.6679	1.2594	0.3543
2014.00	-1.1231	0.4103	0.3253	0.7270	0.1455
2014.25	-0.9678	0.3765	0.3799	0.7947	0.1816
2014.50	-0.7345	0.3395	0.4798	0.9333	0.2466
2014.75	-0.9692	0.3425	0.3794	0.7424	0.1939
2015.00	-0.7112	0.4038	0.4911	1.0836	0.2225
2015.25	-1.0810	0.3535	0.3392	0.6783	0.1697
2015.50	-0.7707	0.3215	0.4627	0.8689	0.2464
2015.75	-0.9751	0.3363	0.3772	0.7291	0.1951
2016.00	-0.6614	0.4521	0.5161	1.2521	0.2128
2016.25	-1.2598	0.3675	0.2837	0.5830	0.1381
2016.50	-0.8518	0.3825	0.4267	0.9029	0.2016
2016.75	-1.3006	0.3481	0.2724	0.5389	0.1377
2017.00	-1.6328	0.4519	0.1954	0.4737	0.0806
2017.25	-0.4377	0.4036	0.6455	1.4238	0.2927
2017.50	-0.6062	0.3747	0.5454	1.1369	0.2617
2017.75	-0.8202	0.3574	0.4403	0.8871	0.2186
2018.00	-0.7060	0.3882	0.4936	1.0564	0.2306
2018.25	-0.1277	0.4113	0.8801	1.9706	0.3931
2018.50	-0.8061	0.4381	0.4466	1.0540	0.1892
2018.75	-0.1487	0.3742	0.8618	1.7944	0.4139

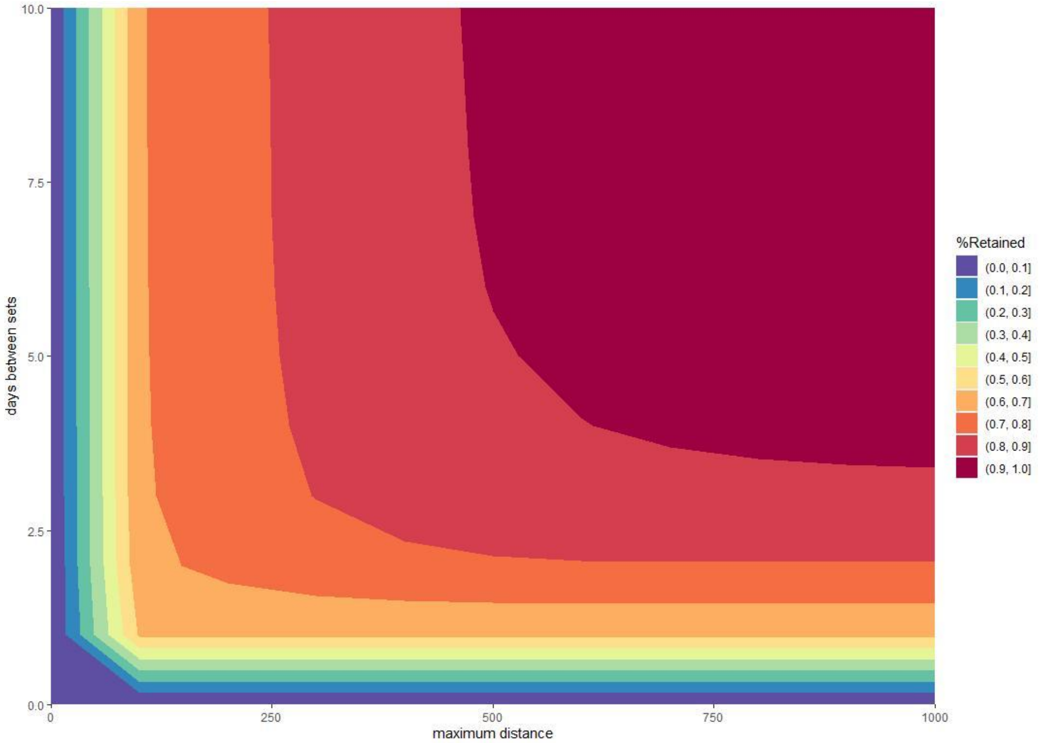

Figure 1.- Percentage of retained samples as a function of the maximum distance and number of days of the sets contributing to the catch in a sample.

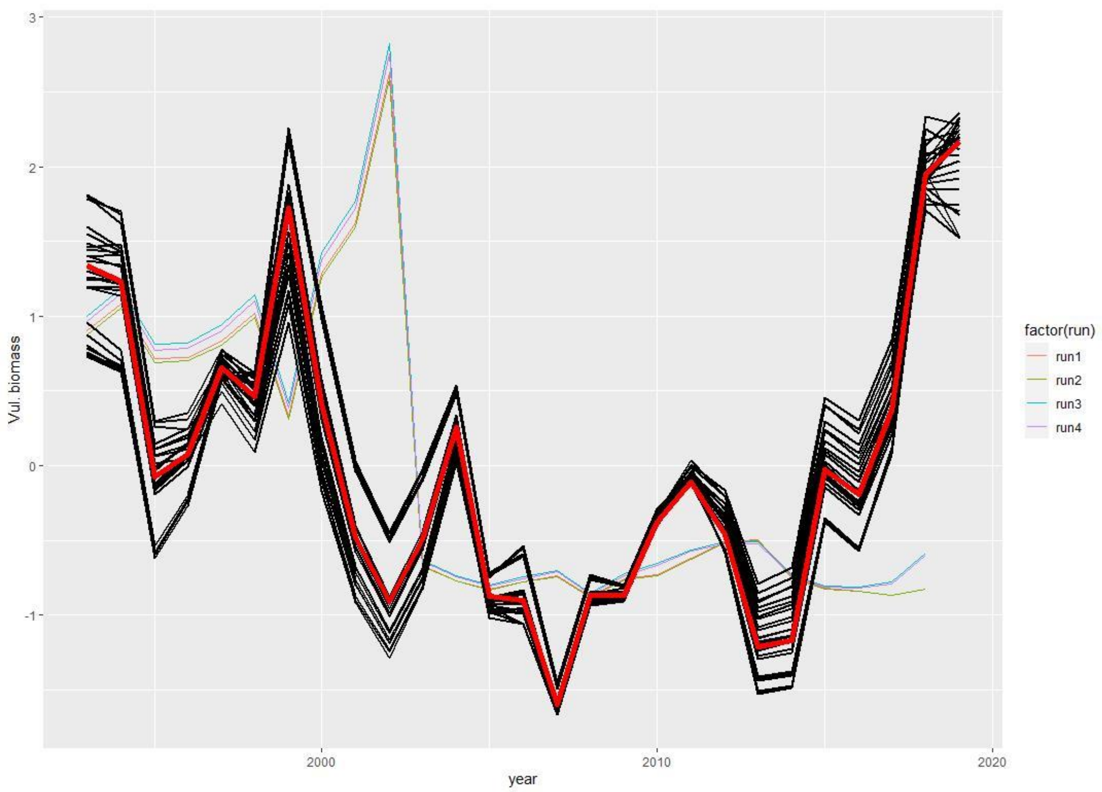

Figure 2.- Estimates of bigeye tuna vulnerable biomass from the 4 runs in the yellowfin tuna stock assessment uncertainty grid using the selectivity by age/year/fishery as estimated in the assessment compared to the estimates derived from the bigeye tuna stock assessment (black lines).

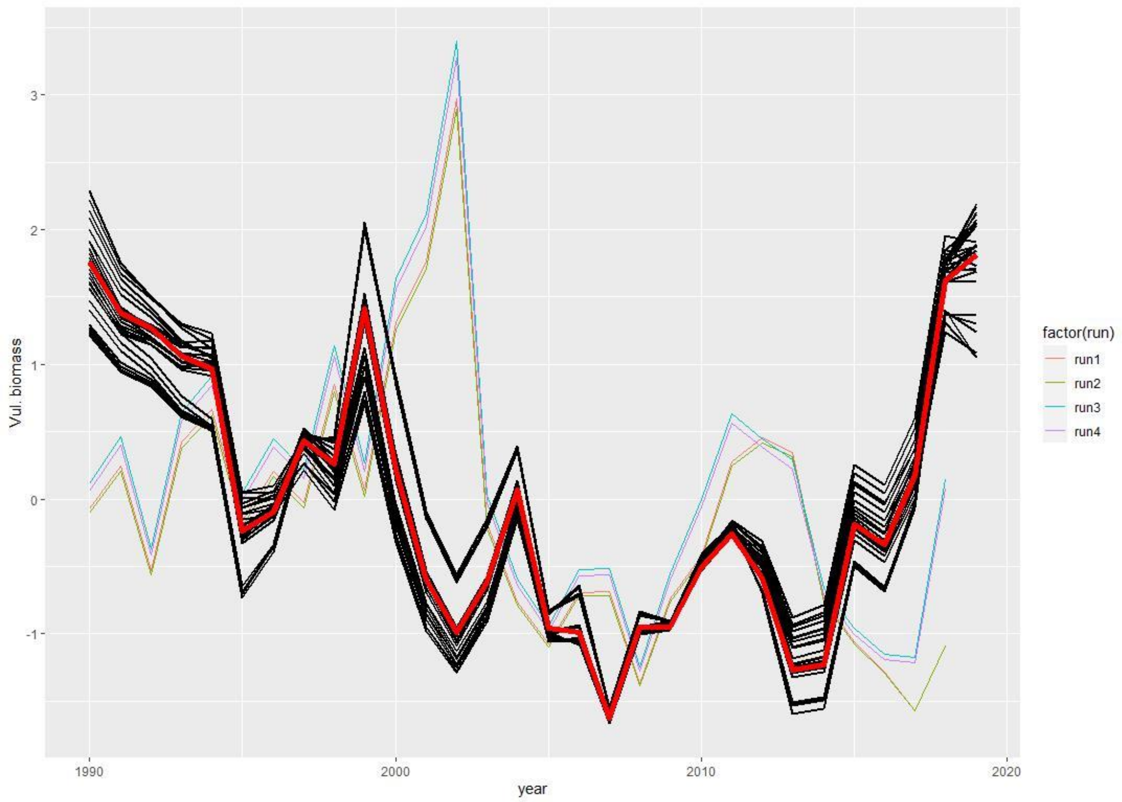

Figure 3.- Estimates of bigeye tuna vulnerable biomass from the 4 runs in the yellowfin tuna stock assessment uncertainty grid using the selectivity by age/year/fishery as estimated in the assessment for the period 2003-2019compared to the estimates derived from the bigeye tuna stock assessment (black lines).

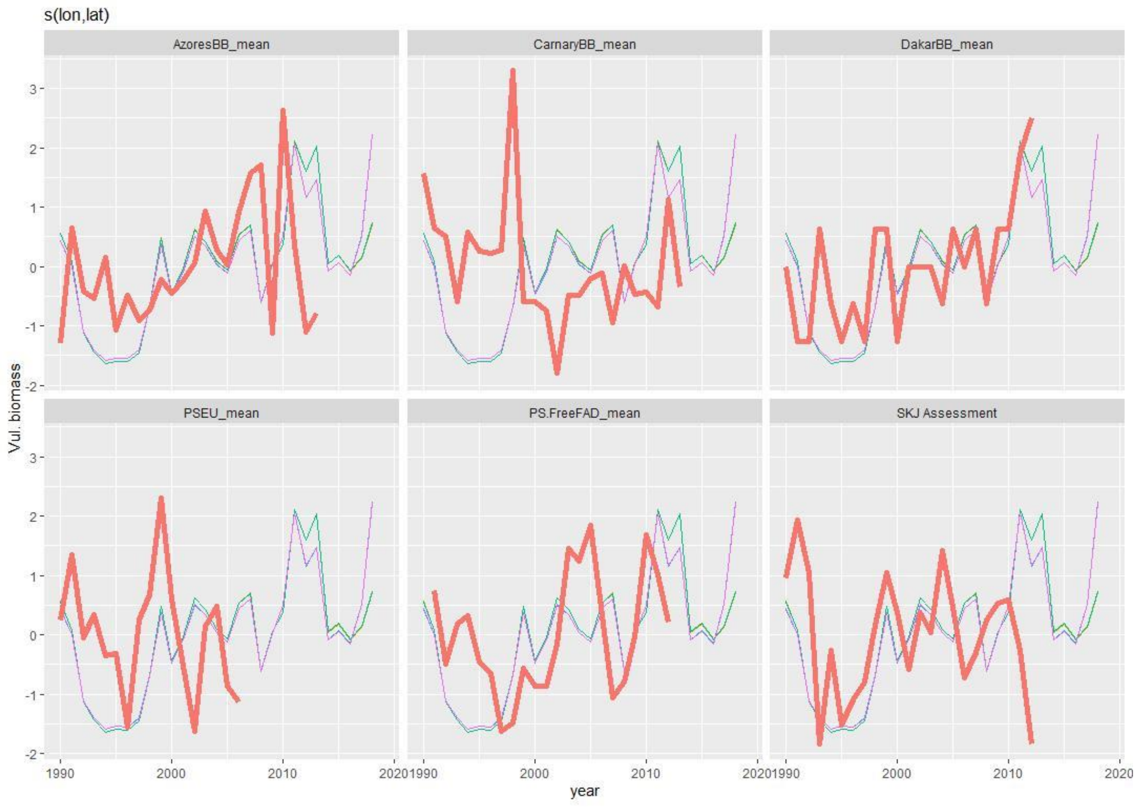

Figure 4.- Current estimates of skipjack abundance vs the indices used in the 2012 stock assessment and the stock assessment biomass estimates. Values are standardized (minus mean and divided by sd) for illustration purposes. Model containing only a spatial term as explanatory term for the relative variation in catchability among the study (skipjack) and reference (yellowfin tuna) species.

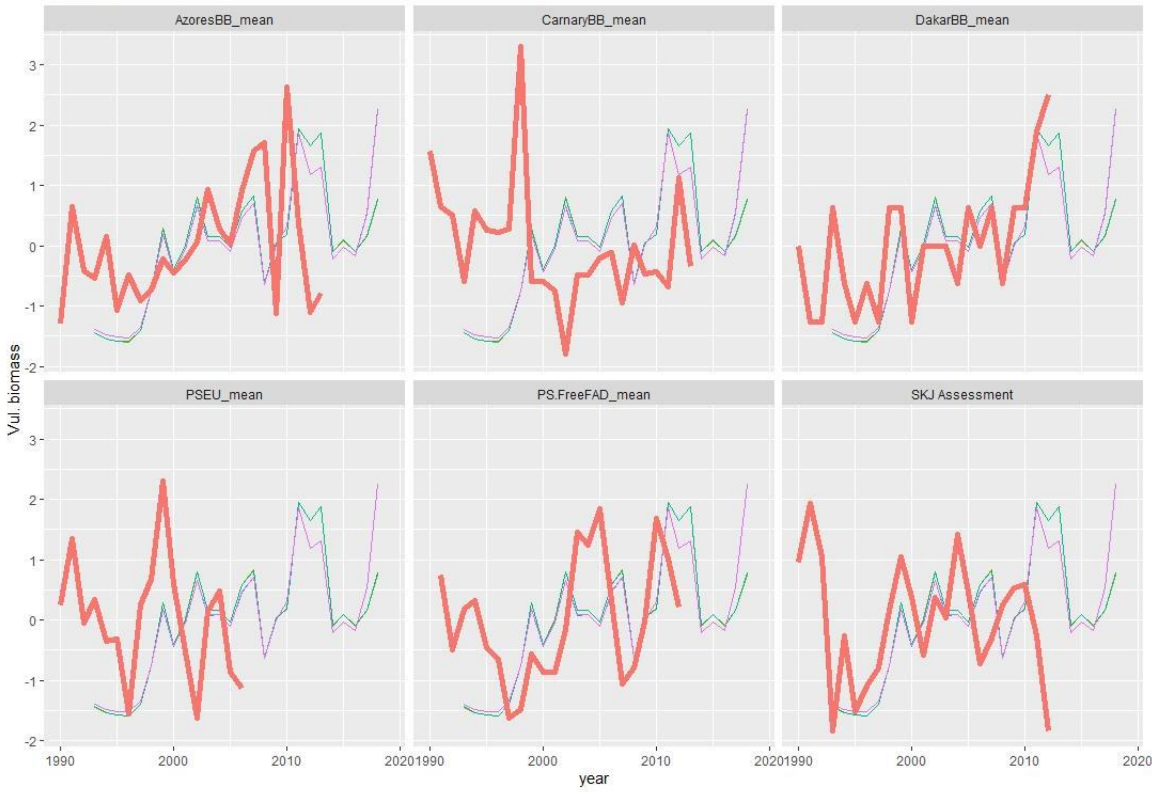

Figure 5.- Current estimates of skipjack abundance vs the indices used in the 2012 stock assessment and the stock assessment biomass estimates. Values are standardized (minus mean and divided by sd) for illustration purposes. Model containing a spatial term and oceanographic variables (sea surface temperature, mixed layer depth, salinity, sea surface height and chlorophyll) as explanatory term for the relative variation in catchability among the study (skipjack) and reference (yellowfin tuna) species.

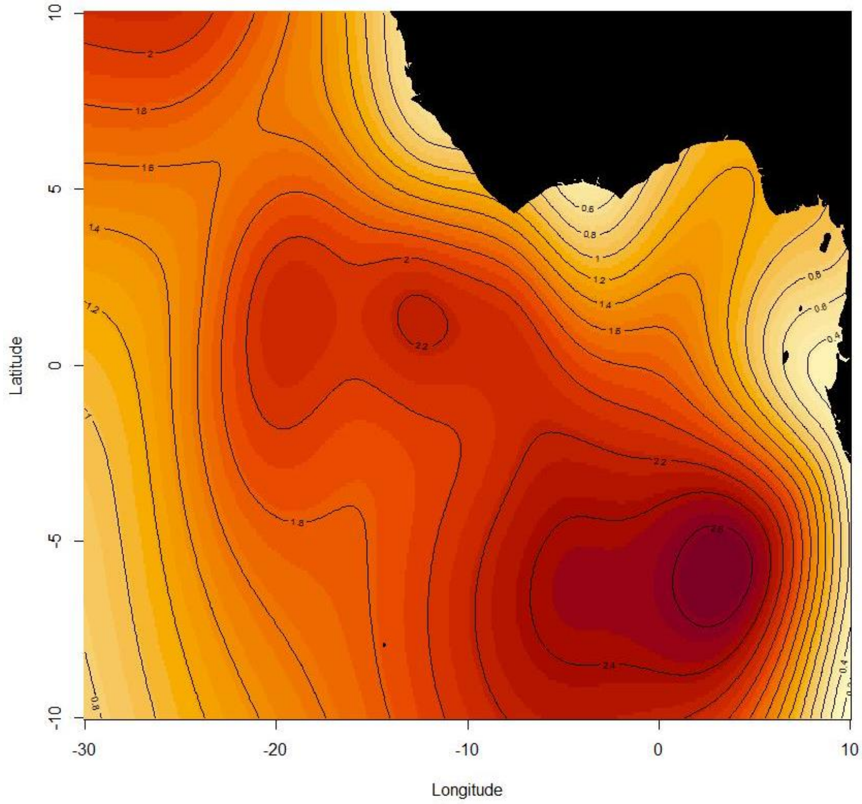

Figure 6.- Estimated effect of longitude and latitude in the skipjack/yellowfin catch ratio (log-scale)

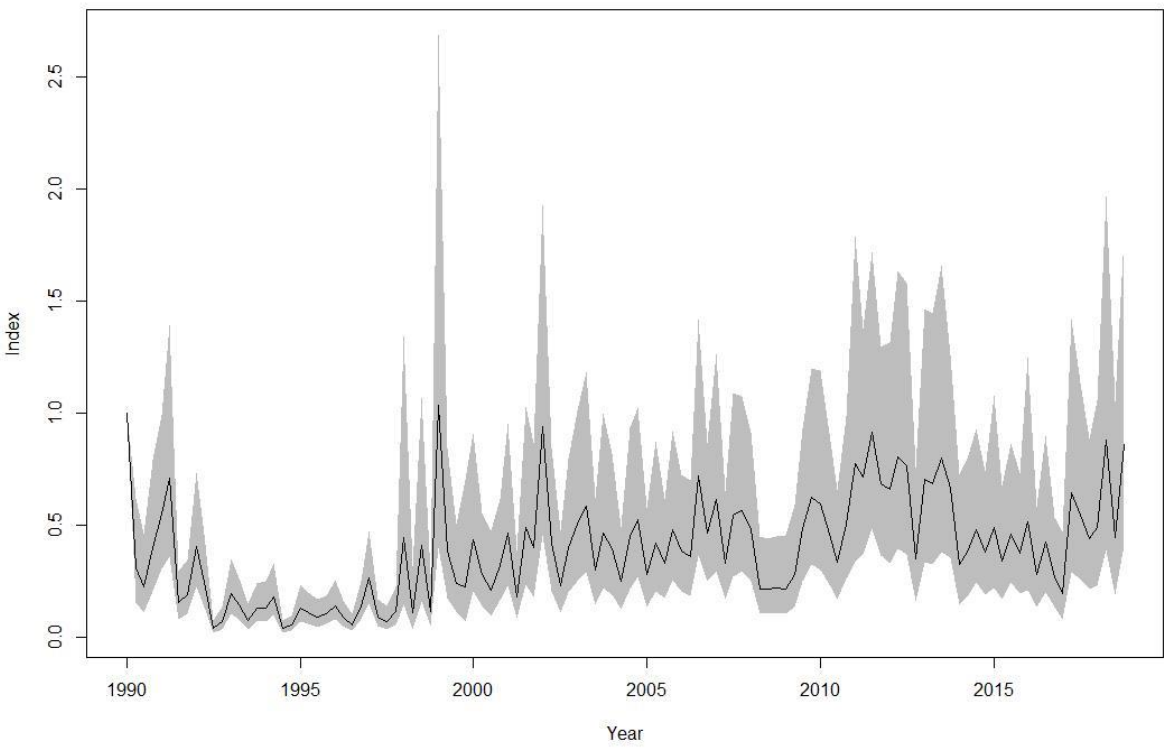

Figure 7.- Estimated index of abundance for skipjack (linear scale) and 95% confidence intervals (shaded area).

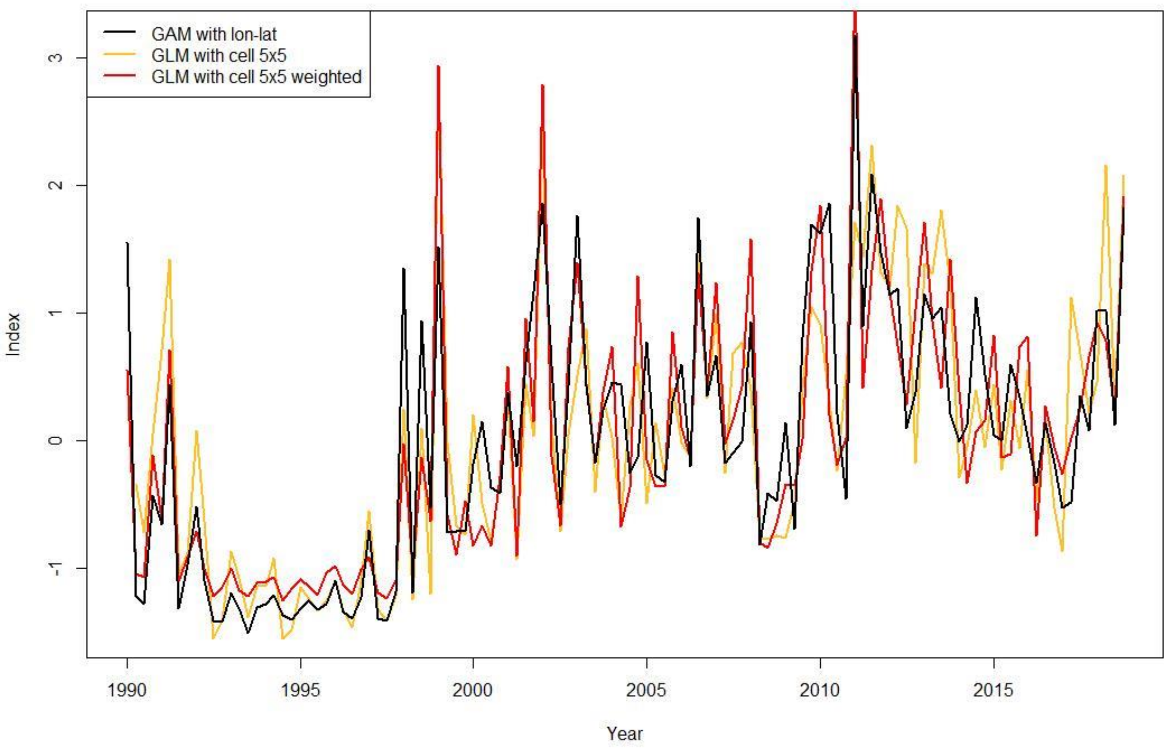

Figure8.- Estimated indices of abundance for skipjack (log scale) using a GAM, with a thin plate spline on the mean longitude and latitude of each sample as the term accounting for relative variations in catchability, and GLMs (unweighted and weighted by sample weight), with the 5ºx5º cell as a categorical term.