9.2 BET – BIGEYE TUNA

The last stock assessment for bigeye tuna was conducted in 2018 (Anon. 2018b) through a process that included a data preparatory meeting in April and an assessment meeting in July. The stock assessment used fishery data from the period 1950-2017 and all indices of relative abundance used in the assessment were constructed through 2017. This Executive Summary reports stock status and management advice for bigeye in 2019 but it is mostly based on the 2018 assessment results. Only a few fishery indicators have been updated (catch and a new index of relative abundance for juveniles from acoustic buoys). The complete description of the stock assessment process and the development of management advice is found in the Report of the 2018 ICCAT Bigeye Tuna Data Preparatory Meeting (Anon. 2018a) and the Report of the 2018 ICCAT Bigeye Tuna Stock Assessment Meeting (Anon. 2018b) as well as in Walter *et al*., 2018 where stock projections and Kobe 2 Strategic Matrix are described.

BET-1. Biology

Bigeye tunas are distributed throughout the Atlantic Ocean between 50ºN and 45ºS, but not in the Mediterranean Sea. This species swims at deeper depths than other tropical tuna species and exhibits extensive vertical movements. Similar to the results obtained in other oceans, pop-up tagging and archival acoustic tracking studies conducted on adult fish in the Atlantic have revealed that they exhibit clear diurnal patterns: they are found much deeper during the daytime than at night. In the eastern tropical Pacific, this diurnal pattern is exhibited equally by juveniles and adults. In the western Pacific these daily patterns have been associated with feeding and are synchronized with depth changes in the deep scattering layer. Spawning takes place in tropical waters when the environment is favorable. From nursery areas in tropical waters, juvenile fish tend to diffuse into temperate waters as they grow. Catch information from surface gears indicate that the Gulf of Guinea is a major nursery ground for this species. Dietary habits of bigeye tuna are varied and prey organisms like fish, mollusks, and crustaceans are found in their stomach contents. Bigeye tuna exhibit relatively fast growth: about 110 cm fork length at age three, 145 cm at age five and 163 cm at age seven. Recently, however, reports from other oceans suggest that growth rates of juvenile bigeye are lower than those estimated in the Atlantic. The growth rates of bigeye tuna differ between sexes based on Indian Ocean tagging data, males reaching around 10 cm larger L_{INF} than females. Bigeye tuna become mature around 100 cm at around 3 years old. Young fish form schools mixed with other tunas such as young yellowfin tuna and skipjack. These schools are often associated with drifting objects, whale sharks and sea mounts. This association weakens as bigeye tuna grow. Indian and Pacific Oceans tagging data showed that bigeye longevity is over 10 years, which may imply lower natural mortality rates than previously being assumed for the Atlantic Ocean. Therefore, the Committee adopted a new natural mortality vector in the 2015 assessment which has also been used in 2018 (but using the Richards growth curve of Hallier *et al.* 2005 in the Lorenzen natural mortality estimation as this is the growth curve used in the assessment). Various pieces of evidence, such as a lack of identified genetic heterogeneity, the time-area distribution of fish and movements of tagged fish (**BET-Figure 1**), suggest an Atlantic-wide single stock for this species. However, the possibility of other more complex scenarios of stock structure should not be disregarded. These uncertainties in stock structure, natural mortality, and growth could have important implications for the stock assessment. The ongoing Atlantic Ocean Tropical tuna Tagging Programme (AOTTP) is contributing to reduce some of these uncertainties.

BET-2. Fisheries indicators

The stock has been exploited by three major gears (longline, baitboat and purse seine fisheries) and by many countries throughout its range, ICCAT has detailed data on the fishery for this stock since the 1950s. Scientific sampling at landing ports for purse seine vessels from the EU and other fleets has been conducted since 1980 to estimate bigeye tuna catches (**BET-Figure 2, BET-Table 1**). The size of fish caught varies among fisheries: medium to large fish for the longline fishery and purse seine free school sets, small to large for subtropical baitboat fishery, and small for tropical baitboat and for purse seine FAD fisheries.

The major historical baitboat fisheries are located in Ghana, Senegal, the Canary Islands, Madeira and the Azores. Since 2013, a new "vessel associated-school" fishing method using handline, where the vessels acts as a fish aggregating device developed in the western equatorial area, with bigeye catches increasing from 555 t in 2012 to 2,012 t in 2013 and further to around 5,000 t in 2015-2017. The tropical purse seine fleets operate in the Gulf of Guinea in the East Atlantic with these fleets are comprised of vessels flying the flags of Ghana, EU-France, EU-Spain and others. The longline fleets operate across a broader geographic range, covering tropical and temperate regions (**BET-Figure 2**). While bigeye tuna is a primary target species for most of the longline and some baitboat fisheries, this species has always been of secondary importance for the other surface fisheries. In the purse seine fishery, unlike yellowfin tuna, bigeye tunas are mostly caught while fishing on floating objects such as logs or manmade fish aggregating devices (FADs). The estimated total numbers of FADs released yearly has increased since the beginning of the FAD fishery, especially in recent years. During 2013-2017, landings of bigeye in weight caught by longline fleets represent 48%, while purse seine fleets represent 34% and baitboat and other surface fleets represent 18% of the total (**BET-Table 1**). In 2018, landings of bigeye in weight caught by longline represent 44%, purse seiner and baitboat 39% and other surface fleets 17%.

The total annual Task I catch (**BET-Table 1**, **BET-Figure 3**) increased continuously up to the mid-1970s reaching 60,000 t and fluctuated over the next 15 years. In 1992, catch reached 100,000 t and continued to increase, reaching a historic high of about 135,000 t in 1994. Since then, reported and estimated catch continuously declined and fell to 59,192 t by 2006. From the low level of 2006, catches have increased again and reached 79,524 t in 2015. Catches have averaged since then 77,646 t in the period 2015-2018. The preliminary catch estimated for 2018 was 73,366 t (there still remains an estimate 2.4% non-reported catch, for which in general the average of the last three years has been assumed). The agreed TAC of 65,000 t imposed since 2016 has been exceeded every year.

After the historic high catch in 1994, all major fisheries exhibited a decline in catch while the relative share of each fishery in total catch remained relatively constant until 2008. These reductions in catch were related to declines in fishing fleet size (longline) as well as decline in CPUE (longline and baitboat). Although the general trend of decreasing catches continued for longline and baitboat, the purse seiner catches increased, as did the relative contribution of purse seine in the total catches in the period 2010-2017. Other surface fisheries, from CPCs with no specific catch limits under Rec. 16-01, also have increased the catches in recent years from around 1,000 t in 2011 to around 7,000 t in 2017, mainly due to the development of the new handline vessel associated-school fishery in the equatorial western Atlantic.

Nominal purse seine effort, expressed in terms of carrying capacity, has decreased regularly since the mid-1990s up to 2006. However, after this date, several European Union purse seiners have transferred their effort to the East Atlantic, due to piracy in the Indian Ocean, and a fleet of new purse seiners have started operating from Tema (Ghana), whose catches are probably underestimated. All this has contributed to the growth in carrying capacity of the purse seiners, which is gradually nearing the level observed in the early 1990s (**SKJ-Figure 9, SKJ-Table 2**). The nominal effort of baitboats has remained stable for over 20 years. By 2010, overall carrying capacity of the purse seine fleet had increased significantly, to about the same level as in the 1990s, and has increased by nearly 50% since. The above number do not include all purse seine vessels currently fishing for tropical tunas in the Atlantic. The total number of purse seine vessels (estimated by the Committee) targeting tropical tunas in the eastern Atlantic has increased in the last five years by 18%, from 49 in 2014 to 58 in 2018. FOB based fishing has accelerated even more rapidly than free school fishing.

Species composition and catch at size from the Ghanaian fleet of baitboats and purse seiners, has been thoroughly reviewed during the past few years. This review has led to new estimates of Task I, and partially Task II catch and effort and size, for these fleets for the period 1973-2013. This revision has shown that catches of bigeye tuna by Ghanaian fleets over the period 1996-2005 were significantly lower than previously estimated by an average of 2,500 t, whereas catches were larger for yellowfin tuna. The Task II estimations for the period 2006 to 2014 (made by the Secretariat during 2016, Ortiz and Palma, 2017) were updated in order to include the last three years (2015 to 2017) using the same methodology as in 2016. The updated Ghanaian bigeye catch estimates done in 2018 were significantly lower than previously estimated because a different area stratification for species composition was used, which is believed to be more accurately represent Ghanaian catches.

Significant catches of small bigeye tuna continue to be diverted to local West African markets, predominantly in Abidjan, and sold as *faux poissons* in ways that make their monitoring and official reporting challenging. Monitoring of such catches has recently progressed through a coordinated approach that allows ICCAT to properly account for these catches and thus increase the quality of the basic catch and size data available for assessments. Currently those catches are included with those from the main purse seine fleet in the ICCAT Task I data used for the assessments.

Mean average weight of bigeye tuna decreased prior to 2004 but has remained relatively stable at around 10 kg for the last decade. This mean weight, however, is quite different for the different fishing gears in recent years, around 55 kg for longliners, around an average of 10 kg for baitboats, and 6 kg for purse seiners. Since 2000, several longline fleets have shown increases in the mean weight of bigeye tuna caught, with the average longline-caught fish increasing from 40 kg to 60 kg between 2000 and 2008. During the same period, purse seine-caught bigeye tuna had average weights between 5 and 6 kg. Average weight of bigeye tuna caught in free schools is more than double the average weight of those caught around FADs. Since 1991, when bigeye catches were identified separately for FADs for EU and other CPCs purse seine fleets, the majority of bigeye tuna are caught in sets associated with FADs; particularly since the mid-2000s (60%-80%). Similarly, baitboat-caught bigeye tuna weighed between 6 and 10 kg up to 2011, but with greater inter-annual variability in average weight compared to longline or purse seine caught fish, while it increased to around 18 kg in 2014 to decrease to 10 kg again since then.

The main change from the previous assessment was the development and use of a single Joint Longline standardized abundance index (Hoyle *et al*., 2018) instead of each individual CPC's standardized CPUE indices used in the 2015 assessment. The joint longline standardized index for 1959-2017 was constructed using detailed operational data of major longline fleets (Japan, Korea, United States and Chinese Taipei) (**BET-Figure 4**).

The development of this joint standardized CPUE index was motivated to reduce data conflicts that arise when CPUE trends differ for different fleets in the same period. This can occur when available data are sparse, when the fishery occurs at the extremes of the spatial distribution of the stock and/or does not represent a meaningful proportion of the stock biomass, or when the index references only a small portion of the age or size distribution. This can also occur when there are important changes in fisheries operations (e.g. targeting, regulations, spatial distribution) that cannot be addressed in the standardization process.

It was concluded that the joint longline index was an improvement over fleet-specific indices because of the integrated temporal and spatial coverage it afforded to index stock biomass, and because it minimizes data conflicts in the stock assessment models. The joint index uses the vessel effect that accounts for different fishing efficiency of each vessel. The selectivity used to model the index should reflect the selectivity of the combined fleets used to produce the index. The use of the index in the stock assessment model requires an assumption of its selectivity (size composition), which should reflect the selectivity of the combined fleets used to produce the index. However, given the modelled shift in the selectivity of Chinese Taipei since 2003, size composition data from Chinese Taipei was not used to estimate selectivity of the joint index in the stock assessment to maintain continuity of the time series.

Moreover, a number of standardized indices of abundance were developed by national scientists for selected fleets for which data were available at finer spatial and/or temporal resolution for the assessment. These indices represented data from six different fleets: five longline fleets (Japan, Uruguay, Brazil, Chinese Taipei, USA) and one baitboat fleet (EU-Spain operating off Dakar) which were used in different stock assessment methods as sensitivity runs (**BET-Figure 5**).

BET-3. State of the stock

The 2018 stock assessment was conducted using similar assessment models to those used in 2015 but updating data and new relative abundance indices up to 2017. Stock status evaluations for Atlantic bigeye tuna used in 2018 several modeling approaches, ranging from non-equilibrium (MPD) and Bayesian state-space (JABBA) production models to integrated statistical assessment models (Stock Synthesis). Different model formulations considered to be plausible representations of the stock dynamics were used to characterize stock status and the uncertainties in stock status evaluations.

The Stock Synthesis integrated statistical assessment model allows the incorporation of more detailed information, both for the biology of the species as well as fishery data, including the size data and selectivity by different fleet and gear components. As Stock Synthesis allows modelling of the changes in selectivity of different fleets as well as to investigate the effect of the length/age structure of the catches of different fisheries in the population dynamic, productivity and fishing mortality, it was the agreed model to be used for the management advice. The Stock Synthesis uncertainty grid includes 18 model configurations that were investigated to ensure that major sources of structural uncertainty were incorporated and represented in the assessment results. Although the results of two production models, non-equilibrium and Bayesian state-space, are not used for management advice they supported the Stock Synthesis stock assessment results.

Results of the uncertainty grid of Stock Synthesis runs (**BET-Table 2**) show a long-term decline in SSB with the current estimate being at the lowest level in the time series (**BET-Figure 6**) and increasing trend of fishing mortality (average F on ages 1-7) starting in the early 1990s, with the highest fishing mortality at 1994 and has remained high since then (**BET-Figure 6**).

SS3 uncertainty grid, despite a broad range of assumptions regarding stock productivity (steepness) and model parameterization, shows trajectories of increasing F decreasing B towards the red area of the Kobe plot ($F > F_{MSY}$ and $SSB < SSB_{MSY}$), overfishing starting in around 1994 and an overfished stock at around 1996-1997, and being in the red quadrant of the Kobe plot since then (**BET-Figure 7**). According to the results of the SS3 uncertainty grid, Atlantic bigeye stock is currently overfished (SSB/SSB_{MSY} =0.59, ranging from 0.42 to 0.80) and undergoing overfishing (F/F_{MSY} = 1.6, ranging from 1.14 to 2.12) with very high probability (99%) (**BET-Figure 8**).

The current MSY may be below what was achieved in past decades because overall selectivity has shifted to smaller fish. Calculations of the time-varying benchmarks from SS3 uncertainty grid show a long-term increase in SSB_{MSY} and a general long-term decrease in MSY (**BET-Figure 9**).

The Committee is confident that uncertainty of the stock assessment results has decreased from previous stock assessments. This is likely the result of the use of the improved joint LL index, the confirmation that catches continue to exceed TACs, and the use of a single model platform for the provision of the management advice.

BET-4. Outlook

Projections were conducted for the uncertainty grid Stock Synthesis for a range of fixed catches from 35,000 to 90,000 t for 15 years (which corresponds to 2 generation times of bigeye) from 2019-2033.

For some of the projections, the modelled stock could not sustain higher constant catches over several years in the long term (**BET-Table 3**). In such cases, projections were adjusted to prevent this undesirable projection behavior and made it possible to produce Kobe 2 Strategic Matrices. The results of projections of the Stock Synthesis are provided in the form of Kobe 2 Strategic Matrices including with probabilities that overfishing is not occurring ($F \le F_{MSY}$), stock is not overfished ($SSB \ge SSB_{MSY}$) and the joint probability of being in the green quadrant of the Kobe plot (i.e. $F \le F_{MSY}$ and $SSB \ge SSB_{MSY}$) (**BET-Table 4**).

It was noted in 2018 that the modeled probabilities of the stock achieving levels consistent with the Convention objective of the projected time period in 2028 and 2033 was 28% and 44%, respectively, for a future constant catches of 65,000 t, which is the TAC established in Rec. 16-01. Projections with the current TAC level are not expected to end overfishing ($F < F_{MSY}$) with 50% probability until 2032. Higher probabilities of rebuilding require longer timeframes and/or larger reduction of current catches (**BET-Table 4**). It was also noted that the modeled probabilities of the stock being in the green quadrant at the end of the projected time period in 2033, as well as the probability to end overfishing by 2033, was 1% for a future constant catch at current levels of around 78,482 t. Moreover, when projecting at current catch level 56% of the model runs resulted in SSB levels below 10% of SSB_{MSY} by 2032 (**BET-Table 3**).

It needs to be noted that projections made by the Committee assume that future constant catches represent the total removals from the stock, and not just the reported catches. Projections also assume that the current selectivity pattern will be maintained. Any future changes in selectivity due to changes in the ratios of relative mortality exerted by the different fleets – such as an increase in the relative mortality of small fish – will change and add to the uncertainty of these projections.

BET-5. Effect of current regulations

During the period 2005-2008 an overall TAC was set at 90,000 t. The TAC was later lowered (Rec. 09-01 and later modified by Rec. 14-01) to 85,000 t. Estimates of reported catch for 2009-2015 (**BET-Table 1**) have been always lower than 85,000 t. The TAC was again reduced to 65,000 t in Recommendation 15-01 which entered into force in 2016 and Recommendation 18-01. Catches in 2016-2017 exceeded the TAC by 20% and those in 2018 by 13%, contributing to further declines in stock size since 2015. Note that because the current TAC does not affect all countries that can catch bigeye tuna, the total catch removed from the stock can exceed the TAC.

Concern over the catch of small bigeye tuna partially led to the establishment of spatial closures to surface fishing gear in the Gulf of Guinea (Recs. 04-01, 08-01, 11-01, 14-01, 15-01). The Committee examined trends on average bigeye tuna catches by areas as a broad indicator of the effects of such closures as well as changes in juvenile bigeye and yellowfin catches due to the moratorium. The efficacy of the area-time closure agreed in Rec. 15-01 was evaluated by examining fine-scale (1ºx1º) skipjack, yellowfin, and bigeye catch by month distributions. After reviewing this information, the Committee concluded that the moratorium has not been effective at reducing the mortality of juvenile bigeye tuna, and any reduction in bigeye tuna mortality was minimal, largely due to the redistribution of effort into areas adjacent to the moratorium area and increase in number of fishing vessels.

BET-6. Management recommendations

The Atlantic bigeye tuna stock in 2017 was estimated to be overfished and that overfishing was occurring. Maintaining the catches at 2016-2018 levels in the future (around 77,000 t and about 20% greater than the 65,000 TAC), will reduce the probability of achieving Convention objectives by 2033 ($B>B_{MSY}$, $F<F_{MSY}$) to around 1% (**BET-Table 4**).

The Committee notes that current and previous FOB time area closures and possible future changes of the allocation of catch to different gears provide some benefits to the stock (sections 19.2 and 19.4, SCRS 2018 report). The necessary reduction of fishing mortality on bigeye tuna required for stock recovery, however, cannot be achieved only with such measures. The Commission should urgently ensure that catches are appropriately reduced to end overfishing and allow the stock to recover following the Decision Framework adopted in paragraph 3 of Rec. 11-13.

The Commission should be aware that increased harvests on small fishes could have had negative consequences for the productivity of bigeye tuna fisheries (e.g. reduced yield at MSY and increased SSB required to produce MSY) (**BET-Figure 9**) and, therefore, should the Commission wish to increase long-term sustainable yield, the Committee continues to recommend that effective measures be found to reduce fishing mortality of small bigeye tunas.

ATLANTIC BIGEYE TUNA SUMMARY

Maximum Sustainable Yield	76,232 t (72,664-79,700 t)[1]
Current (2018) Yield	73,366 t[2]
Relative Spawning Biomass (SSB_{2017}/SSB_{MSY})	0.59 (0.42-0.80)[1]
Relative Fishing Mortality (F_{2017}/F_{MSY})	1.63 (1.14-2.12)[1]
Stock Status (2017)	Overfished: Yes[3] Overfishing: Yes[3]
Conservation & management measures in effect:	Rec. 16-01, Rec. 18-01 – Total allowable catch for 2016-2019 was set at 65,000 t for Contracting Parties and Cooperating non-Contracting Parties, Entities or Fishing Entities. – Be restricted to the number of their vessels notified to ICCAT in 2005 as fishing for bigeye tuna. – Specific limits of number of longline boats; China (65), Chinese Taipei (75), Philippines (5), Korea (14), EU (269) and Japan (231). – Specific limits of number of purse seine boats; EU (34) and Ghana (17). – No fishing with natural or artificial floating objects during January and February in the area encompassed by the African coast, 20º W, 5ºN and 4ºS. – No more than 500 FADs active at any time by vessel. – Use of non-entangling FADs.

[1] Combined result of SS3 18 uncertainty grid. Median and 10 and 90% percentile in brackets.
[2] Reports for 2018 reflect most recent data but should be considered provisional.
[3] Probability of overfished > 99%, probability of overfishing > 99%.

BET-Table 1. Estimated catches (t) of bigeye tuna (Thunnus obesus) by area, gear and flag. (v2, 2019-10-02)
BET-Tableau 1. Prises estimées (t) de thon obèse (Thunnus obesus) par zone, engin et pavillon.(v2, 2019-10-02)
BET-Tabla 1. Capturas estimadas (t) de patudo (Thunnus obesus) por area, arte y bandera. (v2, 2019-10-02)

			1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
TOTAL	A+M		134933	128148	120803	110280	107994	121541	103510	91051	75658	87487	89981	67956	59192	69998	63172	76426	76041	76606	71457	66954	75019	79524	79109	78585	73366
Landings		Bait boat	20358	25697	18352	21289	19190	22200	12149	14391	8455	11235	20259	13124	10631	10333	6335	11565	7853	12849	10510	9214	8726	8020	6787	8436	7940
		Longline	78908	74872	74930	68312	71857	77227	72011	56123	47351	55356	49400	37961	34182	46231	41063	43533	42516	37899	34930	32245	36769	40362	36321	35156	32032
		Other surf.	967	551	353	534	428	672	451	766	221	447	286	716	527	431	192	241	470	813	1101	2742	4950	5957	6395	7144	4567
		Purse seine	32668	25361	26628	19152	15531	20258	17537	19516	19418	19582	19016	15129	13310	12311	14810	20007	24209	23767	24080	22122	23965	24159	28418	26838	27749
Landings(FP)		Purse seine	2032	1667	540	993	989	1184	1363	257	214	867	1019	1026	542	692	772	1081	994	1277	823	632	609	989	1187	972	1049
Discards		Longline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	2	0	0	27
		Purse seine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	38	2
Landings	CP	Angola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	**0**
		Barbados	0	0	0	24	17	18	18	6	11	16	19	27	18	14	14	7	12	7	15	11	26	30	19	16	29
		Belize	0	10	0	5	195	0	134	96	0	0	0	0	4	60	70	234	249	1218	1242	1336	1502	1877	1764	1961	2135
		Brazil	601	1935	1707	1237	776	2024	2768	2659	2582	2455	1496	1081	1479	1593	958	1189	1173	1841	2120	3623	6456	7750	7660	7258	5096
		Canada	111	148	144	166	120	263	327	241	279	182	143	187	196	144	130	111	103	137	166	197	218	257	171	214	237
		Cape Verde	385	271	299	228	140	9	2	0	1	1	1	1077	1406	1247	444	545	554	1037	713	1333	2271	2764	1680	1107	1418
		China PR	428	476	520	427	1503	7347	6564	7210	5840	7890	6555	6200	7200	7399	5686	4973	5489	3720	3231	2371	2232	4942	5852	5514	4823
		Curaçao	0	0	1893	2890	2919	4016	3098	3757	2221	3203	3526	27	416	252	1721	2348	2688	3441	2890	1964	2315	2573	3598	2844	3530
		Côte d'Ivoire	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	790	576	47	507	635	441	12	544	1239	384
		EU.España	22096	17849	15393	12513	7110	13739	11250	10133	10572	11120	8365	7618	7454	6675	7494	11966	11272	13100	10914	10082	10736	10058	11469	11544	8400
		EU.France	12263	8363	9171	5980	5624	5529	5949	4948	4293	3940	2926	2816	2984	1629	1130	2313	3329	3507	3756	3222	3549	2548	4566	4039	4055
		EU.Ireland	0	0	0	4	0	0	0	10	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		EU.Italy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
		EU.Poland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		EU.Portugal	3099	9662	5810	5437	6334	3314	1498	1605	2590	1655	3204	4146	5071	5505	3422	5605	3682	6920	6128	5345	3869	3135	2187	3146	4405
		EU.United Kingdom	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	32	0	0	0	0	0	0	0	0	**0**
		El Salvador	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	992	1450	1826	2634
		FR.St Pierre et Miquelon	0	0	0	0	0	0	0	90	21	0	28	6	0	2	3	0	2	0	0	0	0	0	0	0	**0**
		Gabon	87	10	0	0	0	184	150	121	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		Ghana	4738	5517	4751	10174	10647	11704	5632	9864	6480	9061	17888	8860	2307	2559	3372	4515	6253	3541	4468	2963	4175	5918	5194	3838	3571
		Grenada	10	10	0	1	0	0	0	0	0	0	0	0	0	10	31	0	0	0	0	0	0	0	0	0	
		Guatemala	0	0	0	0	0	0	0	0	0	736	831	998	949	836	998	913	1011	282	262	163	993	340	1103	1602	1488
		Guinea Ecuatorial	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	50	0	58	0	3	10	17	4	11	7
		Guinée Rep.	0	334	2394	885	0	0	0	0	0	0	0	0	0	0	0	0	328	322	1516	1429	902	0	0	0	
		Honduras	0	61	28	59	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Iceland	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		Japan	38503	35477	33171	26490	24330	21833	24605	18087	15306	19572	18509	14026	15735	17993	16684	16395	15205	12306	15390	13397	13603	12390	10365	10994	9854
		Korea Rep.	386	423	1250	796	163	124	43	1	87	143	629	770	2067	2136	2599	2134	2646	2762	1908	1151	1039	675	562	432	623
		Liberia	53	57	57	57	57	57	57	57	57	57	0	0	0	0	0	0	0	0	0	0	0	0	27	98	1
		Libya	500	400	400	400	400	400	400	31	593	593	0	0	4	0	0	0	0	0	0	0	0	0	0	0	**0**
		Maroc	977	553	654	255	336	1444	1160	1181	1154	1399	1145	786	929	700	802	795	276	300	300	308	300	309	350	410	500
		Mauritania	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**0**
		Mexico	4	0	2	6	8	6	2	2	7	4	5	4	3	3	1	1	3	1	1	2	1	2	2	3	3
		Namibia	715	29	7	46	16	423	589	640	274	215	177	307	283	41	146	108	181	289	376	135	240	465	359	141	109
		Nigeria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	**0**
		Norway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		Panama	13234	9927	4777	2098	1252	580	952	562	211	0	1521	2310	2415	2922	2263	2405	3047	3462	1694	2774	2315	1289	2337	1664	2067
		Philippines	0	0	0	0	1154	2113	975	377	837	855	1854	1743	1816	2368	1874	1880	1399	1267	532	1323	1964	0	0	0	

			1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
		Russian Federation	0	0	13	38	4	8	91	0	0	0	0	1	1	26	73	43	0	0	0	0	0	0	0	0	**0**
		S. Tomé e Príncipe	3	6	4	5	6	5	4	4	4	4	11	6	4	0	92	94	97	100	103	107	110	633	421	393	482
		Senegal	123	357	190	272	789	1372	915	1159	497	322	490	770	1318	1293	734	1144	969	479	436	606	369	1031	1500	2978	2870
		Sierra Leone	0	0	0	0	0	0	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		South Africa	79	27	7	10	53	55	249	239	341	113	270	221	84	171	226	159	145	153	47	435	332	193	121	257	282
		St. Vincent and Grenadines	812	519	596	545	1937	2940	1921	1143	130	103	18	0	114	567	171	293	396	38	25	16	30	496	622	889	428
		Trinidad and Tobago	29	27	37	36	24	19	5	11	30	6	5	9	12	27	69	56	40	33	33	37	59	77	37	25	17
		U.S.A.	1402	1209	882	1138	929	1263	574	1085	601	482	416	484	991	527	508	515	571	722	867	881	892	1082	568	836	921
		U.S.S.R.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		UK.Bermuda	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		UK.Sta Helena	6	10	10	12	17	6	8	5	5	4	6	18	25	18	28	17	11	190	51	19	17	44	77	70	45
		UK.Turks and Caicos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0	**0**
		Uruguay	37	80	124	69	59	28	25	51	67	59	40	62	83	22	27	201	23	15	2	30	0	0	0	0	**0**
		Vanuatu	2713	2610	2016	828	0	314	0	0	0	0	104	109	52	132	91	34	42	39	23	9	4	0	0	0	**0**
		Venezuela	457	457	189	274	222	140	221	708	1241	847	1060	243	261	318	122	229	85	264	98	94	169	132	156	318	202
	NCC	Chinese Taipei	19680	18023	21850	19242	16314	16837	16795	16429	18483	21563	17717	11984	2965	12116	10418	13252	13189	13732	10805	10316	13272	16453	13115	11845	11630
		Guyana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	25	34	22
	NCO	Argentina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Benin	9	9	9	30	13	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Cambodia	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Congo	9	9	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Cuba	7	7	5	0	0	0	0	0	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Dominica	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Faroe Islands	0	0	0	0	0	11	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		NEI (ETRO)	356	915	0	7	0	0	0	362	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		NEI (Flag related)	8964	10697	11862	16565	23484	22190	15092	7907	383	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Saint Kitts and Nevis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	
		Seychelles	0	0	0	0	0	0	58	0	162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Sta. Lucia	0	0	0	0	0	0	0	1	2	2	0	2	0	0	0	0	0	0	0	0	0	6	10	24	13
		Togo	23	6	33	33	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Landings(FP)	CP	Belize	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	46	42	16	41	23	0	0	0	
		Cape Verde	0	0	0	0	0	0	0	0	0	0	0	75	28	37	38	61	102	40	22	45	97	0	0	0	
		Curaçao	0	0	0	0	0	0	0	0	0	0	0	13	25	20	13	117	59	46	60	34	42	0	0	0	
		Côte d'Ivoire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	95	45	0	0	0	0	
		EU.España	605	371	58	255	328	487	474	0	0	223	244	143	88	49	190	250	211	216	98	80	143	0	0	0	
		EU.France	970	713	314	437	467	553	607	229	205	446	397	222	79	26	51	150	122	394	192	56	54	0	0	0	
		Guatemala	0	0	0	0	0	0	0	0	0	0	0	56	28	15	26	9	18	6	11	5	15	0	0	0	
		Guinée Rep.	0	0	0	0	0	0	0	0	0	0	0	72	0	60	20	22	74	203	288	245	209	0	0	0	
		Panama	0	0	0	0	0	0	0	0	0	0	0	151	106	135	97	85	38	70	41	80	27	0	0	0	
	NCO	Mixed flags (EU tropical)	457	582	169	301	193	143	281	28	8	198	378	294	189	348	337	375	324	257	0	0	0	989	1187	972	1049
Discards	CP	Canada	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		EU.France	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	38	2
		Japan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26
		Korea Rep.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
		South Africa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	NCC	Chinese Taipei	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	

BET-Table 2. Details of the 18 Stock Synthesis uncertainty grid run specifications for the Atlantic bigeye tuna. M refers to the natural mortality reference (0.28, M ref) and alternative (0.35, M alt).

Stock Synthesis Uncertainty Parameters	Name			Nº scenarios in the grid
CPUE	Joint LL index split (1959-1978 without vessel identification and 1979-2017 with vessels identification)			1
Natural Mortality (M)	M ref (0.28)	M alt (0.35)		2
Steepness (h)	0.7	0.8	0.9	3
Relative importance of the size data (Lambda)		0.1		1
Recruitment annual variation (SigmaR)	0.2	0.4	0.6	3
Total number of scenarios in the grid				**18**

BET-Table 3. Percent of the model runs that resulted in SSB levels <= 10% of SSB_{MSY} during the projection period in a given year for a given catch level (in 1000 t) for Atlantic bigeye tuna.

Catch	Perc0.1 2024	Perc0.1 2025	Perc0.1 2026	Perc0.1 2027	Perc0.1 2028	Perc0.1 2029	Perc0.1 2030	Perc0.1 2031	Perc0.1 2032	Perc0.1 2033
35	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
37.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
40	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
42.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
45	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
47.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
50	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
52.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
55	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
57.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
62.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
65	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%
67.5	0%	0%	0%	0%	0%	0%	6%	17%	17%	17%
70	0%	0%	0%	0%	0%	11%	17%	17%	17%	22%
72.5	0%	0%	0%	0%	11%	17%	17%	28%	33%	33%
75	0%	0%	0%	11%	17%	28%	33%	33%	33%	33%
77.5	0%	0%	6%	17%	28%	33%	33%	33%	56%	56%
80	0%	0%	17%	33%	33%	33%	44%	61%	67%	67%
82.5	0%	6%	22%	33%	39%	61%	61%	67%	67%	78%
85	0%	17%	33%	39%	61%	67%	67%	78%	78%	83%
87.5	0%	28%	39%	50%	61%	67%	78%	83%	83%	94%
90	11%	33%	50%	61%	67%	78%	83%	94%	94%	100%

BET-Table 4. Estimated probabilities of the Atlantic bigeye tuna stock being below F_{MSY} (overfishing not occurring), above B_{MSY} (not overfished) and above B_{MSY} and below F_{MSY} (green zone) in a given year for a given catch level ('000 t), based upon Stock Synthesis 2018 assessment outcomes.

a) Probability of Overfishing Not Ocurring (F <= F_{MSY})

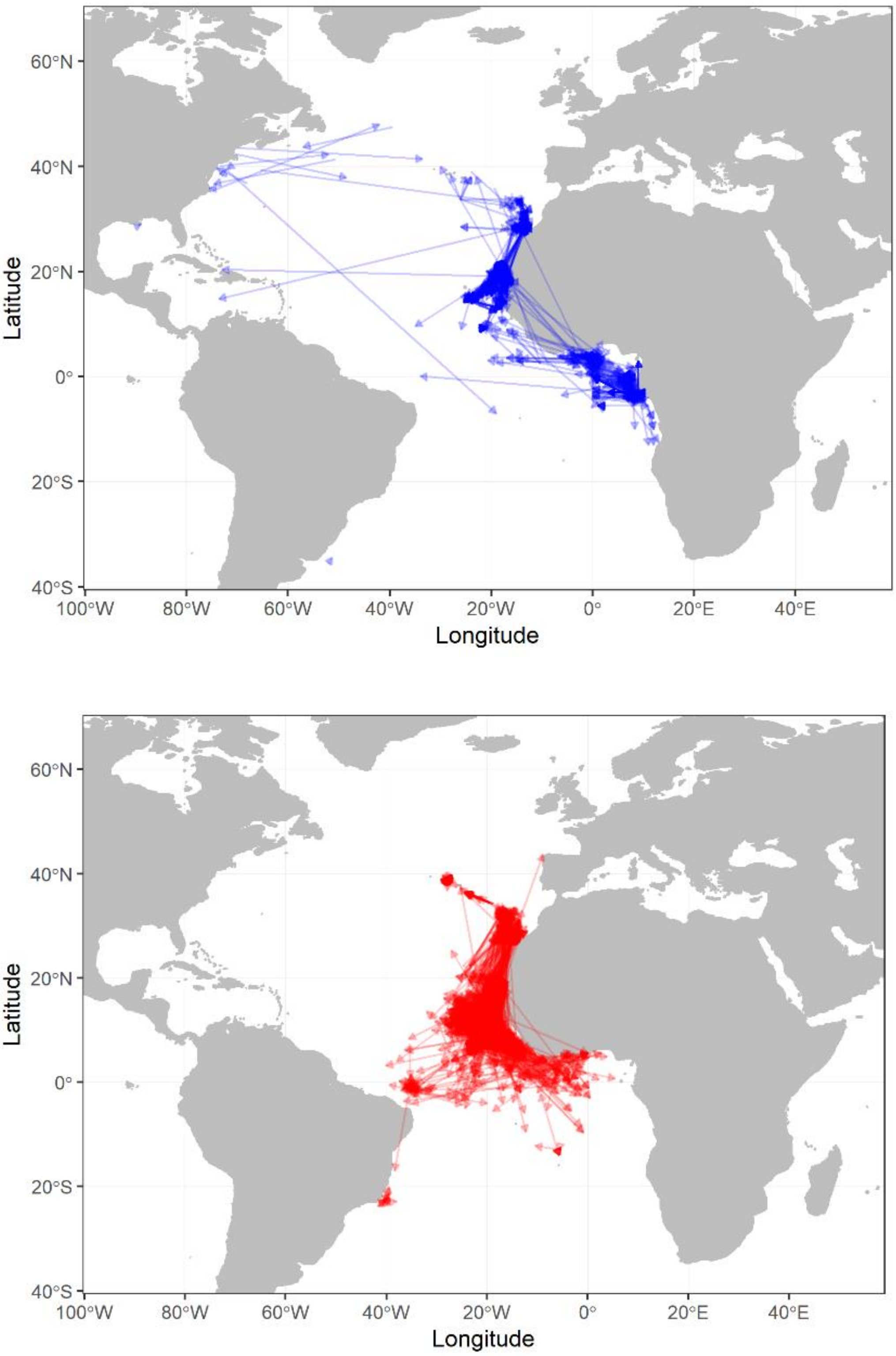
Catch	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
35	93	98	99	100	100	100	100	100	100	100	100	100	100	100	100
37.5	88	95	98	99	100	100	100	100	100	100	100	100	100	100	100
40	80	91	96	98	99	100	100	100	100	100	100	100	100	100	100
42.5	72	85	92	96	98	99	100	100	100	100	100	100	100	100	100
45	63	75	86	91	95	97	99	99	100	100	100	100	100	100	100
47.5	53	67	77	85	91	94	97	98	99	100	100	100	100	100	100
50	44	56	68	76	83	88	92	95	97	98	99	100	100	100	100
52.5	35	46	58	66	75	80	85	89	92	95	96	98	99	99	100
55	28	37	48	55	63	70	75	79	84	87	90	93	94	96	97
57.5	22	29	37	44	52	58	63	69	73	77	79	82	85	88	89
60	17	22	29	35	42	47	51	57	60	64	67	70	72	74	76
62.5	12	17	21	26	32	36	40	45	48	51	53	57	59	60	62
65	9	12	16	19	23	27	32	34	38	40	43	46	47	50	50
67.5	7	8	11	13	16	19	23	27	30	34	36	39	41	42	42
70	4	6	7	9	12	14	16	20	25	28	31	32	33	34	34
72.5	3	5	6	6	8	10	13	17	22	23	23	24	25	24	23
75	2	3	3	5	6	8	11	15	16	16	16	14	12	8	6
77.5	1	2	3	3	4	7	10	11	12	10	7	4	1	1	1
80	1	1	1	2	3	5	8	9	6	3	1	0	0	0	0
82.5	1	1	1	2	3	5	6	5	2	1	0	0	0	0	0
85	1	1	1	1	2	4	4	1	0	0	0	0	0	0	0
87.5	0	0	1	1	2	3	1	0	0	0	0	0	0	0	0
90	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0

b) Probability of Not Overfished (SSB >= SSB_{MSY})

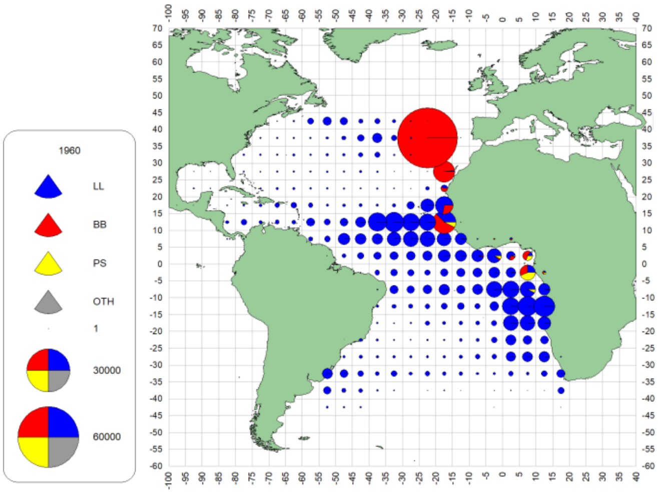
Catch	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
35	0	3	11	26	46	62	77	88	94	97	99	100	100	100	100
37.5	0	3	10	24	41	58	73	82	90	95	98	99	100	100	100
40	0	2	9	21	37	53	67	78	87	93	96	98	99	100	100
42.5	0	2	9	19	33	49	62	73	81	89	94	96	98	99	100
45	0	2	8	17	30	43	56	67	76	84	90	94	96	98	99
47.5	0	2	7	15	26	37	50	60	70	78	84	90	93	96	98
50	0	2	6	13	22	33	44	55	63	70	77	84	88	92	94
52.5	0	2	5	11	20	28	37	47	55	62	70	76	80	85	89
55	0	2	5	10	17	25	32	40	48	55	61	67	72	76	80
57.5	0	2	4	9	14	20	26	35	40	47	52	56	62	67	70
60	0	2	4	7	12	17	23	29	35	39	44	49	52	55	59
62.5	0	1	3	6	10	14	19	24	29	33	37	41	44	48	51
65	0	1	3	5	8	12	16	19	24	28	31	35	38	42	44
67.5	0	1	2	4	7	9	12	16	19	24	28	32	34	36	37
70	0	1	2	3	5	8	10	12	17	20	26	27	27	28	29
72.5	0	1	2	3	4	6	8	11	15	19	18	19	20	19	19
75	0	1	2	3	4	5	7	10	14	13	13	12	9	6	4
77.5	0	1	2	2	3	4	7	9	10	10	7	4	2	1	1
80	0	1	1	2	3	3	5	8	7	4	2	0	0	0	0
82.5	0	1	1	1	2	3	6	6	3	1	0	0	0	0	0
85	0	1	1	1	1	3	4	2	1	0	0	0	0	0	0
87.5	0	0	1	1	1	3	2	1	0	0	0	0	0	0	0
90	0	0	1	1	1	3	1	0	0	0	0	0	0	0	0

c) Probability of Not Overfished (SSB >= SSB_{MSY}) and Overfishing not occurring (F <= F_{MSY})

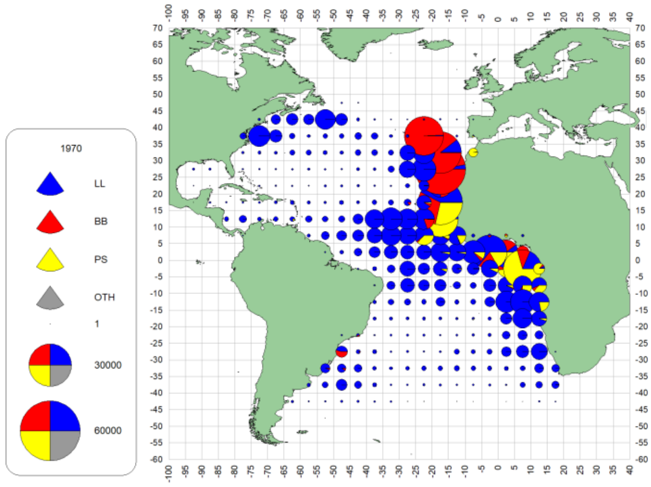
Catch	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
35	0	3	11	26	46	62	77	88	94	97	99	100	100	100	100
37.5	0	3	10	24	41	58	73	82	90	95	98	99	100	100	100
40	0	2	9	21	37	53	67	78	87	93	96	98	99	100	100
42.5	0	2	9	19	33	49	62	73	81	89	94	96	98	99	100
45	0	2	8	17	30	43	56	67	76	84	90	94	96	98	99
47.5	0	2	7	15	26	37	50	60	70	78	84	90	93	96	98
50	0	2	6	13	22	33	44	55	63	70	77	84	88	92	94
52.5	0	2	5	11	20	28	37	47	55	62	70	76	80	85	89
55	0	2	5	10	17	25	32	40	48	55	61	67	72	76	80
57.5	0	2	4	9	14	20	26	35	40	47	52	56	62	67	70
60	0	2	4	7	12	17	23	29	35	39	44	49	52	55	59
62.5	0	1	3	6	10	14	19	24	29	33	37	41	44	48	51
65	0	1	3	5	8	12	16	19	24	28	31	35	38	42	44
67.5	0	1	2	4	7	9	12	16	19	24	28	32	34	36	37
70	0	1	2	3	5	8	10	12	17	20	26	27	27	28	29
72.5	0	1	2	3	4	6	8	11	15	19	18	19	20	19	19
75	0	1	2	3	4	5	7	10	14	13	13	12	9	6	4
77.5	0	1	2	2	3	4	6	9	10	10	6	4	1	1	1
80	0	1	1	2	3	3	5	8	6	3	1	0	0	0	0
82.5	0	1	1	1	2	3	5	5	2	1	0	0	0	0	0
85	0	0	1	1	1	3	4	1	0	0	0	0	0	0	0
87.5	0	0	1	1	1	2	1	0	0	0	0	0	0	0	0
90	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0



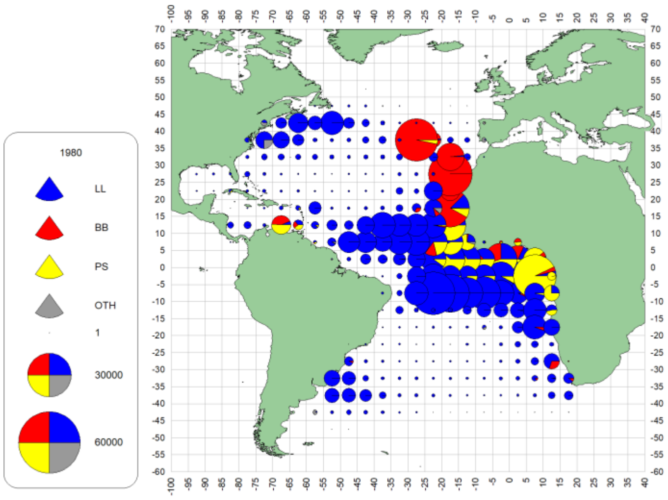
BET-Figure BET-1. Apparent movements (straight line distance between the tagging location and that of recovery) calculated from conventional tagging from the historical ICCAT tagging database (top panel) and the current AOTTP activities (bottom panel).



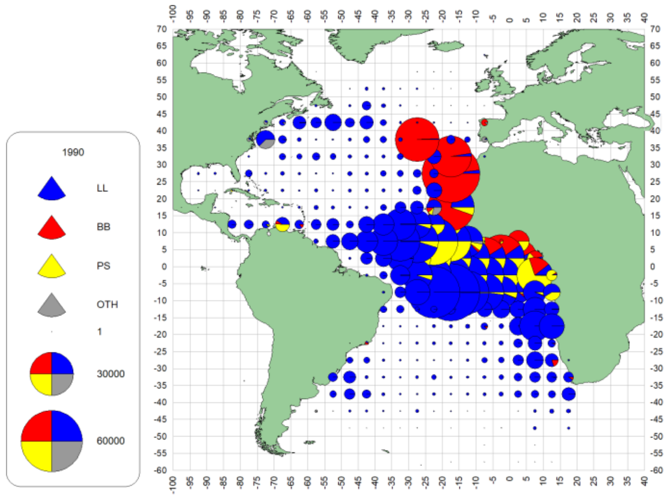
a. BET (1960-69)



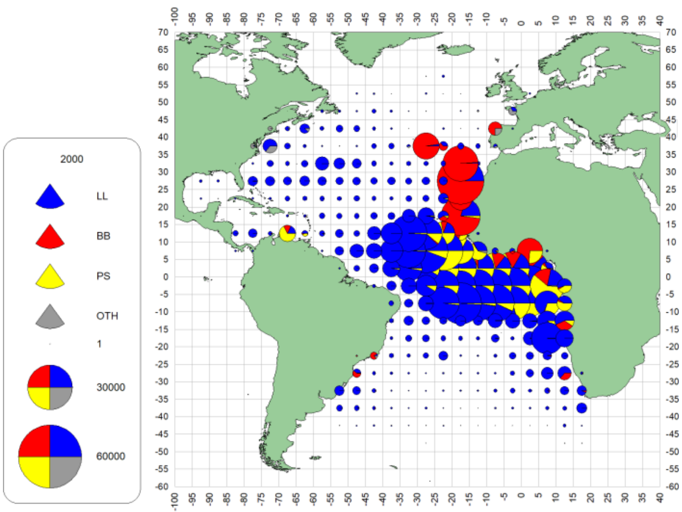
b. BET (1970-79)



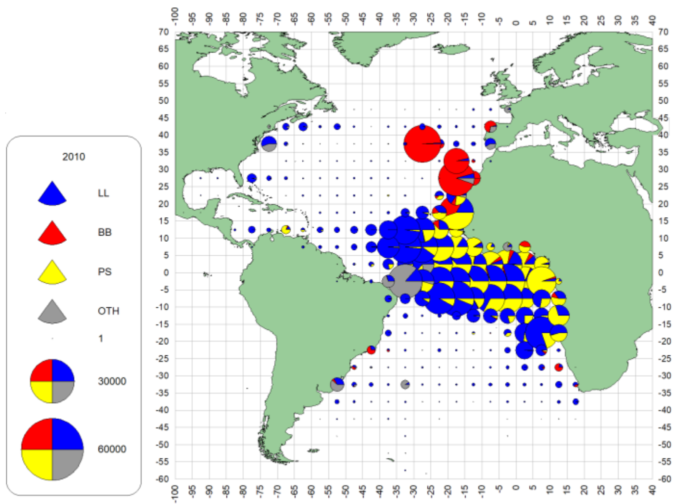
c. BET (1980-89)



d. BET (1990-99)

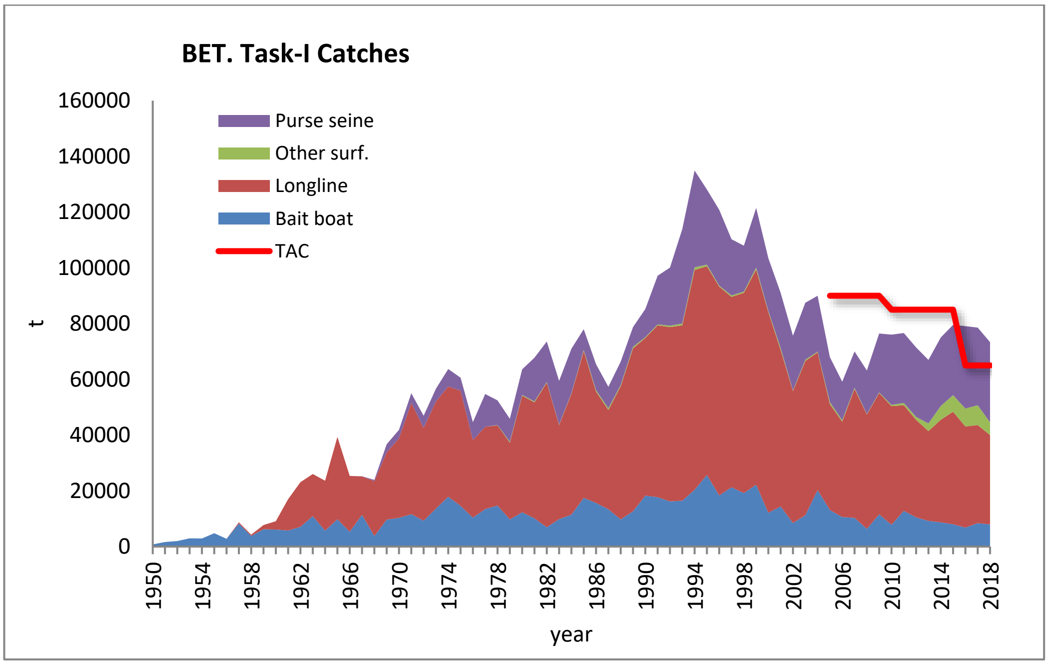


e. BET (2000-09)

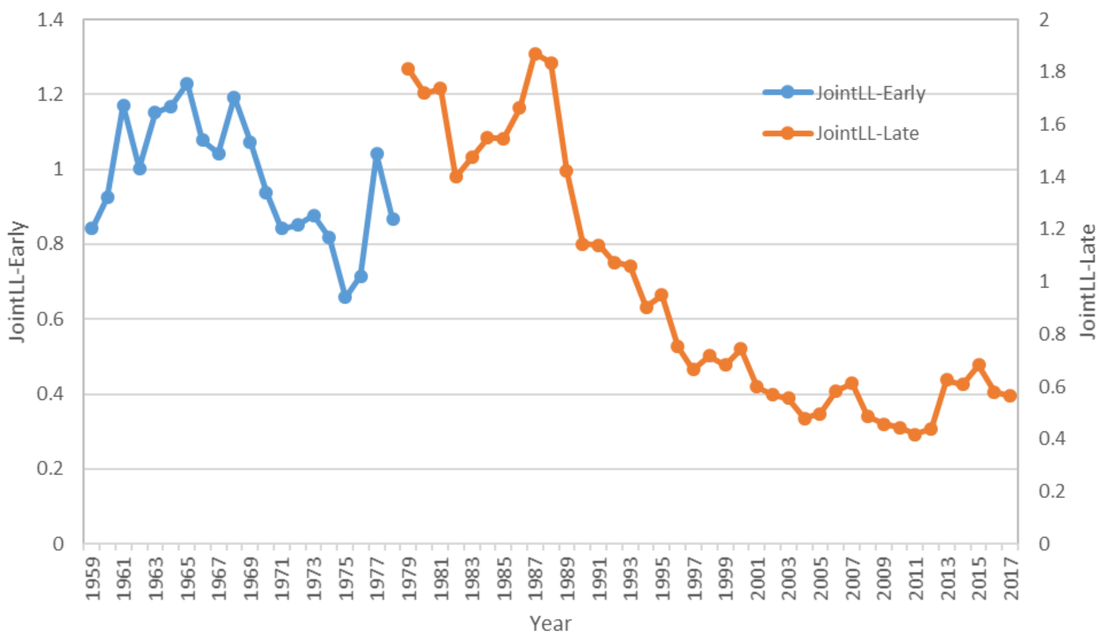


f. BET (2010-17)

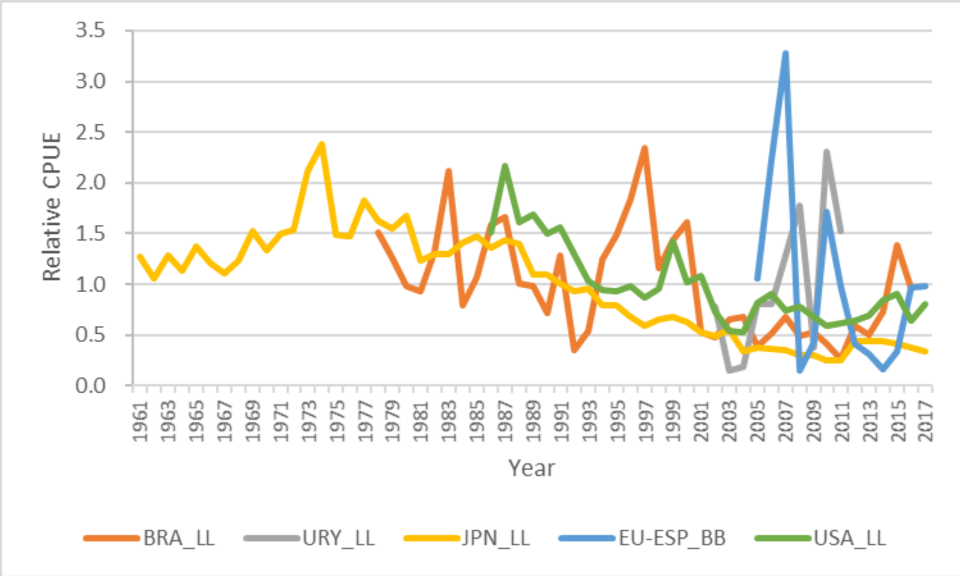
BET-Figure 2 [a-f]. Geographical distribution of the bigeye tuna catch by major gears and decade. The maps are scaled to the maximum catch observed during 1960-2017 (the last decade only covers 8 years).



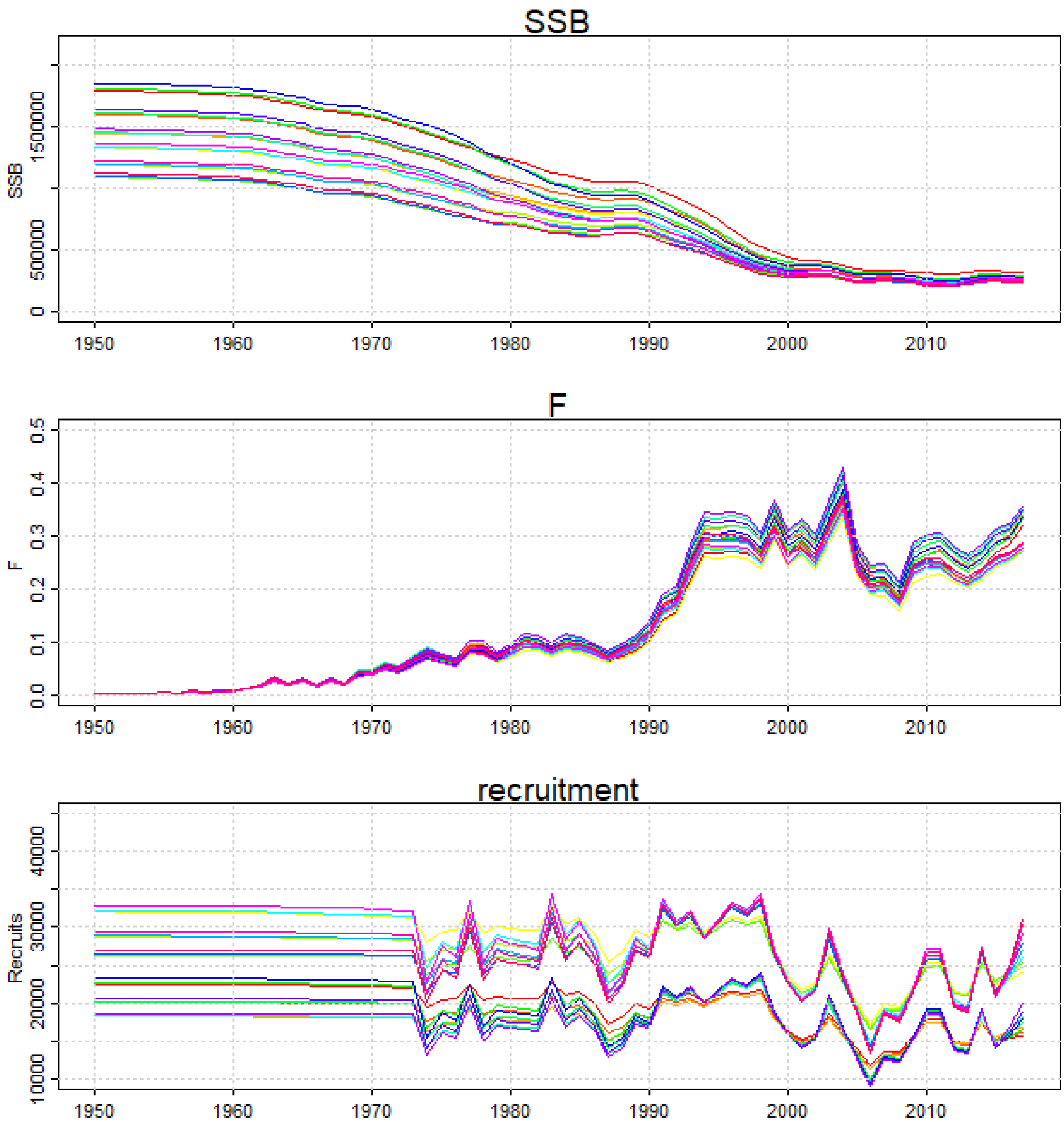
BET-Figure 3. Bigeye estimated and reported catches for all the Atlantic stock (t). The value for 2018 represents preliminary estimates because some countries have yet to provide data for this year or are under revision.



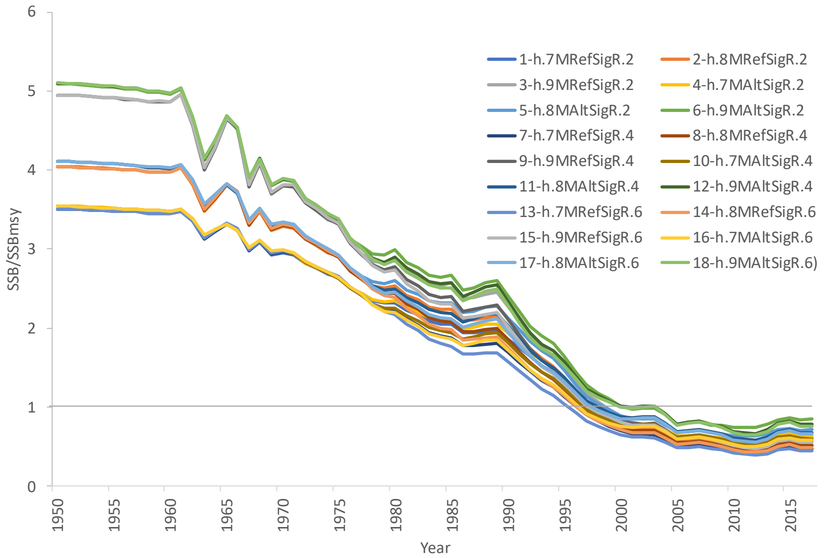
BET-Figure 4. Joint Longline index (1959-1978 without vessel identification and 1979-2017 with vessel identification included in the standardization) used in the integrated stock assessment models and the production assessment models. Note that the second time period of the split index is on the second y-axis.

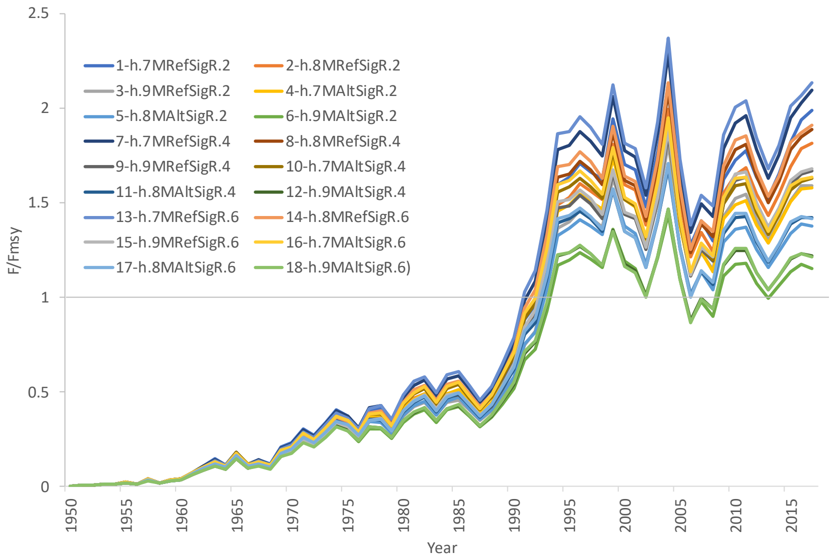


BET-Figure 5. Annual relative indices of abundances for bigeye tuna from different fleets used in the stock assessment as sensitivity runs.

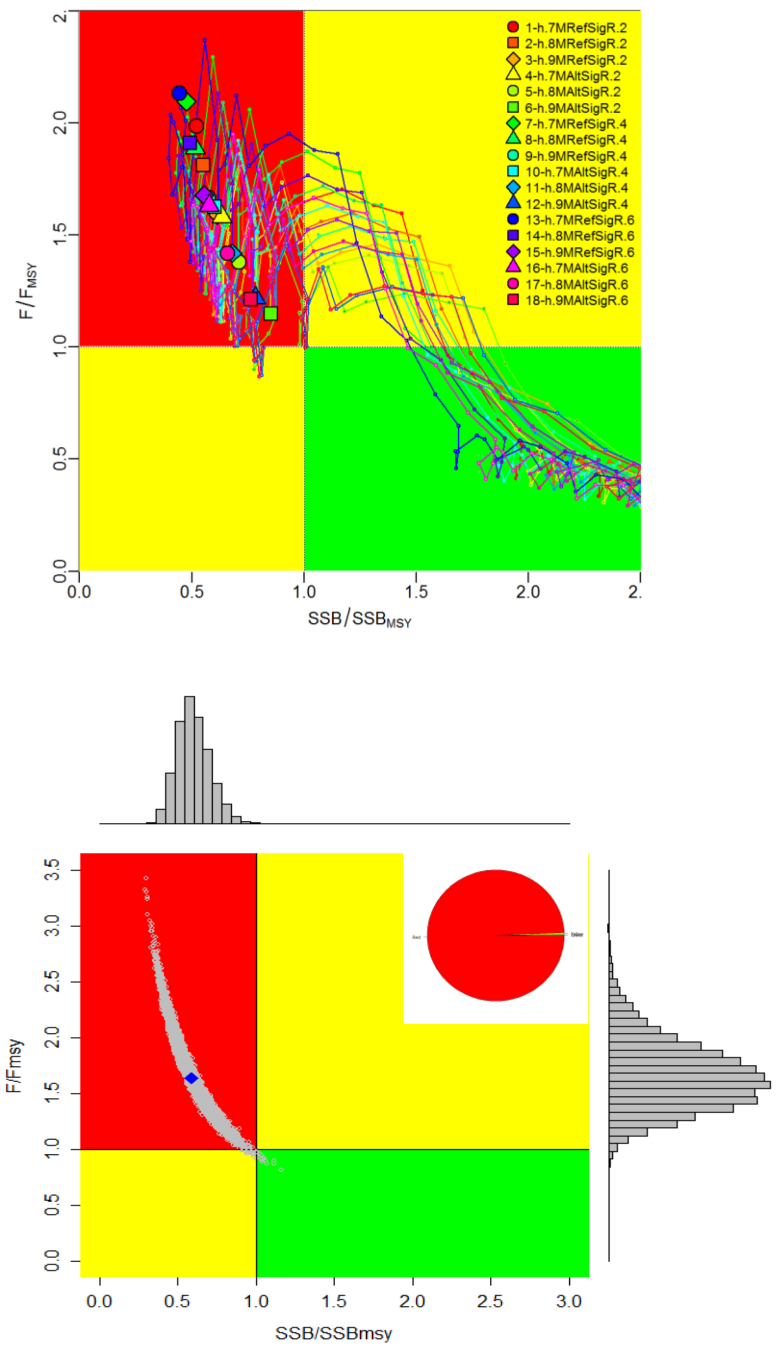


BET-Figure 6. Trajectories of Spawning Stock Biomass (SSB), Fishing mortality (average F on ages 1-7) and recruitment (age 0) for the 18 Stock Synthesis uncertainty grid runs for Atlantic bigeye tuna.

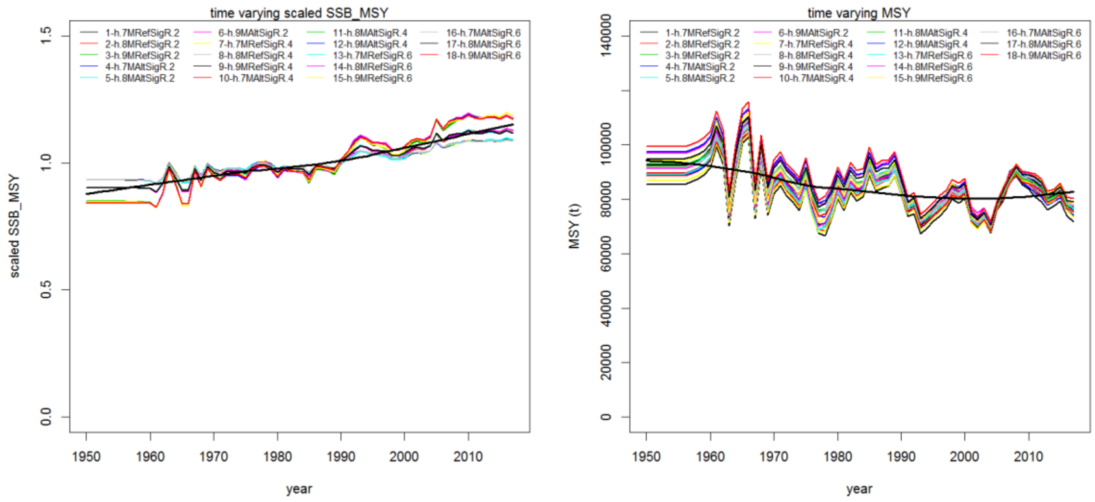




BET-Figure 7. Trajectories of SSB/SSB$_{MSY}$ and F/F$_{MSY}$ estimated from the 18 Stock Synthesis uncertainty grid runs for Atlantic bigeye tuna. For each run the benchmarks are calculated from the year-specific selectivity and fleet allocations.



BET-Figure 8 Stock Synthesis: (a) Kobe phase plot for the deterministic runs of the 18 Stock Synthesis uncertainty grid runs for Atlantic bigeye tuna. For each run the benchmarks are calculated from the year-specific selectivity and fleet allocations. (b) Kobe plot of SSB/SSB_{MSY} and F/F_{MSY} for stock status of Atlantic bigeye tuna in 2017 based on the log multivariate normal approximation across the 18 uncertainty grid model runs of Stock Synthesis with an insert pie chart showing the probability of being in the red quadrant (99.5 %), green quadrant (0.2 %), and in yellow (0.3 %). Blue square is the median and marginal histograms represent distribution of either SSB/SSB_{MSY} or F/F_{MSY}.



BET-Figure 9. Year-specific SSB at MSY and MSY for 18 SS3-uncertainty grid model runs for Atlantic bigeye tuna. Black solid line is a Loess smooth fitted across all runs.