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UPDATE OF THE AGEIT SOFTWARE TO INCORPORATE NATURAL AND FISHING MORTALITY IN THE ESTIMATION OF CATCH AT AGE FROM CATCH AT SIZE: APPLICATION TO THE AGEING OF YELLOWFIN TUNA CAS 2016

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SUMMARY

Age composition is important information to understand the dynamics of the fish populations. In the case of Atlantic tunas, due to the multinational, wide and varied distribution of fisheries, almost all sampling comes from commercial fisheries with few if any sampling for direct aging. Hence, most of the ageing for tunas is estimated from length frequency samples. In the case of tropical tunas the standard approach in ICCAT has been estimating catch at age (CAA) assuming a particular growth model and "slicing" the catch at size (CAS) at given fixed time intervals (quarterly). Recently, for both BET and YFT this approach was improved by incorporating variance of size at age in the growth model allowing estimating a probability of age at size for a given time interval.

RÉSUMÉ

La composition par âge constitue une information importante pour comprendre la dynamique des populations de poissons. Dans le cas des thonidés de l'Atlantique, en raison de la distribution multinationale, large et variée des pêcheries, pratiquement tout l'échantillonnage provient des pêcheries commerciales, avec un volume très limité, voire inexistant, d'échantillonnage aux fins de la détermination directe de l'âge. C'est pourquoi la plupart de la détermination de l'âge des thonidés est estimée à partir des échantillons de fréquence des longueurs. Dans le cas des thonidés tropicaux, l'approche standard de l'ICCAT a été d'estimer la prise par âge (CAA) en postulant un modèle de croissance particulier et en "découpant" la prise par taille (CAS) à des intervalles de temps fixes (trimestriellement). Récemment, pour le thon obèse et l'albacore, cette approche a été améliorée en incorporant la variance de la taille à l'âge dans le modèle de croissance, ce qui permet d'estimer une probabilité d'âge par taille pour un intervalle de temps donné.

RESUMEN

La composición por edad es una información importante para entender la dinámica de las poblaciones de peces. En el caso de túnidos del Atlántico, debido a la distribución amplia, multinacional y variada de las pesquerías, casi todo el muestreo procede de las pesquerías comerciales, con poco o nada de muestreo para determinación directa de la edad. Por tanto, la mayor parte de la edad de los túnidos se ha estimado a partir de muestras de frecuencias de tallas. En el caso de los túnidos tropicales, el enfoque estándar en ICCAT ha consistido en estimar la captura por edad (CAA) asumiendo un modelo de crecimiento específico y "recortando" la captura por talla (CAS) en intervalos de tiempo fijos determinados (trimestralmente). Recientemente, tanto para el patudo como para el rabil se ha mejorado este enfoque incorporando la variación de talla por edad en el modelo de crecimiento, lo que permite estimar una probabilidad de edad por talla para un intervalo de tiempo determinado.

KEYWORDS

Ageing, catch at age, catch at size, natural mortality

Introduction

Age composition is important information to understand the dynamics of the fish populations. Having annual length, weight and age information allows following year-classes through time to understand growth and specifics of the dynamics of fish stocks and its response to environmental and fishing mortalities. Size and age are often collected from fisheries and surveys; however appropriate sampling can be limited by resources or the

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characteristics of the fisheries. In the case of Atlantic tunas, due to the multinational, wide and varied distribution of fisheries, almost all sampling comes from commercial fisheries with few if any sampling for direct aging. Hence, most of the ageing for tunas is estimated from length frequency samples. There are two main approaches to “ageing” annual size data; length frequency analysis where the overall size distribution is de-convoluted into the size composition of each age class as a mixture of size distributions (MacDonald 1987), or assuming a particular growth model and estimating the probability of age at a given size, normally incorporating some variance of size at age (Schnute and Fournier 1980). There are also some alternative that combined both approaches, usually given some prior information for the mean size in the length frequency analysis (MacDonald and Pitcher 1979).

In the case of tropical tunas the standard approach in ICCAT has been estimating catch at age (CAA) assuming a particular growth model and “slicing” the catch at size (CAS) at given fixed time intervals (quarterly). For both BET and YFT in 2011 this approach was improved by incorporating variance of size at age in the growth model allowing estimating a probability of age at size for a time interval (Ortiz and Palma 2012). However, in this methodology it was assumed that for a given size all ages will have a probability only determined by the growth model ignoring that the number of fish of older ages is much lower due to the exponential decline in numbers at age as result of natural and other mortalities, e.g. the probability that a fish will survive until age *x* and reach size *y*.

1. Materials and Methods

In the algorithms for ageing CAS (R script Ageit) therefore, it was incorporated into the estimation of the probability of age at size the conditioning that numbers of fish at age are declining exponentially with increase in age due to natural and fishing mortality (Z = F + M). In this case it was assumed the exponential decline of a single cohort through its time life. Specifically, the underlying survival curve θ_a for age group a that is fully recruited to the sampling fishery.

$$\theta_a = c^{-Za}$$

Where c is a constant and Z is the total mortality. This assumption is satisfied when recruitment and mortality are constant over time for all age groups. This basically assumed an in equilibrium population, the algorithms input a vector of natural mortality at age (Ma) constant for all years, and vector(s) of fishing mortality by age (Fa) constant or variable by year. It is also assumed that the annual growth is constant and independent of density effects, the algorithm need to fix a given birthday time interval within the year.

The probability density function (pdf) of length $f_a(L)$ for each age a is a function of the growth parameters user defined, assuming a Gaussian distribution with mean μ_a and standard deviation σ_a, given by

$$f_a(L) = \frac{1}{\sqrt{2\pi}\,\sigma_a} \exp\left[\frac{1}{2\sigma_a^2}(L - \mu_a\right]$$

Then, the probability that a length measurement falls into interval *l* for age *a* is

$$\psi_{la} = \int_l^{l+1} f_a(L)dL$$

That is the area under the pdf that covers the interval length *l.* The expected number of individuals of age *a* is θ_a while the expected number of individuals of age a and length l is $\theta_a\psi_{la}$. Finally the expected number of individuals of length *l* is then sum of probabilities over all ages,

$$L_l = L\sum_{a=r}^{A} \psi_{la}\,\theta_a$$

Thus, the probability of age at size $p(Age \mid size)$ is estimated as

$$\hat{p}(Age \mid size) = p(Age|size\ \theta_{L_{inf},K,to,\sigma}) \times \frac{N_{age}}{\sum_{i=0}^{\max\_age} N_i}$$

Where N_{age} is the expected numbers of fish at age following the exponential decline of a cohort given the total mortality Z.

The algorithms were tested by using the same data input with the ageit program estimating probability of age at size considering or not a mortality-at-age vector.

As example, the CAS of yellowfin tuna was used to compare the estimated CAA results when included the expected exponential decline of the cohorts with age due to mortality. In this case it was only assumed a natural mortality component (e.g. F = 0). It was assumed that yellowfin followed a von Bertalanffy growth model as defined by Draganik and Pelczarski (1984), with the following parameters: i) asymptotic size (L_{inf}) = 192.24 cm. ii) K = 0.370. iii) t_0 = -0.0033, and iv) overall coefficient of variance of size at age = 0.1619 (**Figure 1**). The range of ages for analysis was set from age 0 to age 19 as the maximum age, and age 11 as the plus group. It was assumed that ages plus to maximum age have the same mortality and variance at size parameters. Probabilities of age at size were estimated for time period of 3 months (e.g. quarterly annual growth), with the birth of fish in the first quarter. The size interval was set to 1 cm FL.

The natural mortality by age vector (M_a) (**Figure 2**) and the multiplier for the age coefficient of variance of size at age were:

	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+
Ma	1.758	0.889	0.672	0.576	0.525	0.495	0.476	0.463	0.455	0.450	0.446	0.443
CV m	0.9651	0.7003	0.4026	0.2677	0.2677	0.2677	0.2677	0.2677	0.2677	0.2677	0.2677	0.9651

2. Results and discussion

Table 1 presents the estimated CAA matrices with and without considering mortality using the yellowfin 2016 CAS. As expected the number of fish per year are exactly the same, however the age distribution did varied. As expected when accounted for the decline in number of fish as they get older (**Figure 3**), the probability of age at size is shifted to younger age classes having higher probability at a given size (**Figure 4 and 5**).

In the case of yellowfin tuna catch at age is predominantly of younger ages 0 to 3 accounting for over 80% of the total catch (**Figure 6**). When taking into account the declines in number of fish due to mortality, at least natural mortality is clear that the catch proportions of younger ages increases markedly, particularly for age 1 through the whole time period, while the proportions of older ages decreased (**Figure 7**).

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Table 1. Estimated yellowfin tuna CAA matrices with and without considering age mortality decline of cohorts.

Estimation with out Mortality at age consideration

YearC	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+	Total
1960	533,673	904,895	490,781	463,470	133,399	30,215	8,545	3,046	1,372	760	495	1,942	2,572,595
1961	467,368	796,425	407,511	383,024	115,804	26,910	7,878	2,883	1,319	737	483	1,909	2,212,251
1962	474,281	763,713	470,197	468,503	115,525	23,511	5,382	1,569	609	305	187	676	2,324,457
1963	870,375	1,484,822	383,591	418,148	154,826	36,651	10,949	3,779	1,574	803	489	1,691	3,367,699
1964	975,897	1,622,609	612,215	436,987	127,899	22,118	3,856	930	328	160	99	393	3,803,490
1965	907,345	1,554,823	533,495	370,928	185,800	40,295	9,473	2,615	953	457	272	961	3,607,416
1966	168,226	1,645,965	434,676	313,503	178,048	40,858	9,299	2,708	1,060	538	334	1,248	2,796,463
1967	1,197,481	626,145	506,272	327,429	126,875	38,993	9,773	2,854	1,088	535	324	1,224	2,838,994
1968	394,042	1,938,672	502,092	547,920	217,880	59,905	17,155	5,689	2,424	1,313	870	4,357	3,692,319
1969	811,014	1,061,589	1,473,681	454,303	137,675	38,237	13,673	5,909	3,093	1,970	1,497	10,110	4,012,750
1970	1,585,590	1,592,318	522,898	475,381	152,704	44,175	13,701	5,128	2,574	1,753	1,553	18,115	4,415,891
1971	1,089,165	2,051,853	573,599	327,325	182,715	48,162	14,169	5,266	2,522	1,571	1,251	11,851	4,309,448
1972	1,756,804	2,371,700	702,225	406,275	160,890	60,488	22,185	9,598	5,721	4,709	4,732	52,505	5,557,833
1973	2,446,888	1,782,133	720,218	490,947	214,974	72,606	25,394	9,838	4,603	2,697	1,970	14,683	5,786,950
1974	2,475,012	3,579,613	910,236	503,299	236,973	82,754	29,000	11,480	5,398	3,037	1,994	7,873	7,846,668
1975	1,064,324	2,003,135	923,552	546,341	422,324	164,728	55,155	20,600	9,353	5,170	3,365	13,188	5,231,235
1976	2,516,582	2,814,718	624,586	651,646	375,956	136,076	47,394	18,838	9,153	5,371	3,662	15,533	7,219,513
1977	2,037,743	2,481,837	905,667	660,039	373,091	125,705	41,215	15,601	7,265	4,120	2,739	11,160	6,666,183
1978	1,436,876	2,720,549	1,048,119	829,898	356,089	96,932	28,986	11,344	5,654	3,455	2,487	13,184	6,553,574
1979	2,124,056	2,490,400	945,541	799,506	355,502	85,804	23,657	8,532	3,946	2,247	1,504	6,229	6,846,924
1980	2,629,928	2,964,673	1,101,341	738,831	357,764	87,459	24,607	8,849	4,021	2,237	1,463	5,751	7,926,924
1981	6,123,137	3,772,565	1,128,586	717,804	537,076	145,794	36,483	11,378	4,643	2,409	1,509	5,645	12,487,029
1982	4,058,805	5,935,250	1,055,636	934,399	473,193	133,070	35,747	11,559	4,763	2,460	1,526	5,542	12,651,950
1983	4,483,135	4,329,738	1,423,007	843,198	467,424	123,930	34,437	11,913	5,233	2,845	1,833	7,070	11,733,763
1984	4,656,686	6,017,650	926,753	438,929	140,494	34,030	8,735	2,862	1,204	632	396	1,460	12,229,831
1985	4,388,118	5,365,717	1,419,794	725,066	424,655	85,934	17,840	4,959	1,871	916	549	1,901	12,437,319
1986	4,783,158	5,009,095	815,541	893,215	402,257	91,214	20,644	6,079	2,375	1,187	721	2,536	12,028,022
1987	6,508,710	5,048,048	1,059,671	706,387	428,750	83,147	17,723	5,114	1,986	994	605	2,152	13,863,287
1988	5,431,074	5,295,891	1,001,214	861,180	279,863	54,643	10,696	2,812	1,019	484	284	950	12,940,111
1989	5,653,588	5,058,181	1,017,582	893,525	557,195	133,851	32,532	10,425	4,421	2,369	1,519	5,876	13,371,063
1990	7,302,394	4,570,109	903,354	1,131,702	697,853	185,932	48,119	15,863	6,832	3,701	2,393	9,389	14,877,642
1991	7,413,844	5,608,871	884,416	802,690	561,987	145,325	37,443	12,573	5,556	3,075	2,020	8,107	15,485,905
1992	6,790,992	5,026,611	1,055,544	841,711	515,213	139,202	35,409	11,335	4,669	2,410	1,493	5,403	14,429,993
1993	8,352,319	7,483,710	892,483	814,030	505,427	114,444	25,301	7,672	3,172	1,688	1,089	4,439	18,205,774
1994	6,342,360	6,800,115	1,417,894	739,592	496,109	120,401	26,786	8,001	3,254	1,702	1,076	4,099	15,961,388
1995	6,555,866	5,291,747	1,083,661	763,389	458,104	101,941	22,501	6,847	2,838	1,502	956	3,659	14,293,011
1996	4,883,768	4,873,679	1,032,828	786,874	440,878	100,117	22,509	6,760	2,728	1,406	876	3,232	12,155,655
1997	5,890,048	5,492,228	777,287	642,110	464,054	106,643	23,321	7,034	2,915	1,553	997	3,911	13,412,101
1998	5,670,916	6,308,181	757,454	629,883	499,922	134,667	32,519	10,061	4,104	2,126	1,327	4,911	14,056,071
1999	5,705,633	10,339,608	745,327	503,669	377,902	102,890	26,875	9,055	4,071	2,345	1,621	7,454	17,826,451
2000	6,994,678	6,126,948	1,011,276	619,676	304,704	87,312	25,077	8,847	3,969	2,205	1,450	5,851	15,191,994
2001	5,652,038	9,723,800	1,111,036	772,482	336,580	79,962	21,283	7,484	3,415	1,928	1,280	5,212	17,716,499
2002	7,064,288	6,339,010	820,297	653,737	391,644	90,238	20,518	6,166	2,464	1,253	769	2,746	15,393,130
2003	6,367,631	6,619,744	719,315	535,682	313,750	90,734	27,292	10,317	4,900	2,828	1,903	7,863	14,701,958
2004	7,538,683	5,668,017	889,442	519,361	277,958	94,393	34,052	14,518	7,316	4,310	2,906	11,784	15,062,739
2005	5,383,685	5,672,430	527,744	450,338	300,429	86,600	23,971	8,137	3,536	1,916	1,236	4,810	12,464,831
2006	2,130,881	7,683,835	670,684	420,849	277,958	95,186	30,739	11,735	5,553	3,197	2,151	8,934	11,341,703
2007	5,296,046	4,765,787	561,637	400,247	270,038	90,297	28,494	10,830	5,172	3,023	2,066	8,915	11,442,552
2008	3,694,886	6,624,867	530,795	445,119	349,078	111,810	32,978	11,758	5,318	2,983	1,980	8,171	11,819,744
2009	3,508,099	5,987,469	438,917	514,681	418,990	130,992	37,713	13,248	5,921	3,274	2,140	8,482	11,069,925
2010	5,309,076	6,051,928	637,527	370,756	330,188	128,565	40,644	14,547	6,419	3,477	2,229	8,519	12,903,874
2011	4,562,592	6,229,764	636,673	427,506	277,149	93,011	28,273	10,102	4,519	2,490	1,621	6,387	12,280,086
2012	3,689,638	6,303,556	725,074	454,769	296,397	86,551	25,025	8,776	3,868	2,114	1,377	5,577	11,602,721
2013	3,040,359	6,157,913	607,421	401,070	269,546	85,548	25,726	9,198	4,100	2,247	1,456	5,681	10,610,265
2014	4,700,562	6,346,227	680,032	427,219	234,914	65,722	17,958	6,118	2,675	1,459	946	3,737	12,487,571

Estimation with Mortality at age consideration (M)

YearC	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+	Total
1960	533,752	950,170	547,719	404,954	107,537	21,863	4,793	1,197	362	132	56	60	2,572,595
1961	467,438	838,038	450,790	337,400	92,817	19,561	4,466	1,145	352	129	55	59	2,212,251
1962	474,349	788,374	536,009	404,564	99,221	17,630	3,233	721	210	77	33	36	2,324,457
1963	870,506	1,533,099	396,700	390,405	134,623	31,253	8,036	2,081	611	213	87	86	3,367,699
1964	976,038	1,688,913	627,276	387,618	106,652	14,447	1,923	377	121	54	29	42	3,803,490
1965	907,479	1,622,642	514,567	361,790	161,775	31,698	5,775	1,165	313	111	48	53	3,607,416
1966	168,243	1,719,633	406,087	309,548	154,844	30,347	5,673	1,327	416	166	79	100	2,796,463
1967	1,197,550	711,987	481,159	293,120	116,933	30,802	5,696	1,153	304	110	56	124	2,838,994
1968	394,108	2,001,418	520,810	516,898	192,763	49,436	11,280	2,852	956	463	319	1,015	3,692,319
1969	811,038	1,222,243	1,412,563	389,961	119,827	34,216	11,331	4,074	1,882	1,232	1,013	3,369	4,012,750
1970	1,585,650	1,638,267	547,995	441,278	134,204	37,828	10,302	3,717	2,251	2,107	2,264	10,027	4,415,891
1971	1,089,201	2,156,271	519,445	315,657	165,022	39,726	10,392	3,384	1,681	1,359	1,377	5,934	4,309,448
1972	1,756,897	2,487,904	656,914	369,516	150,453	55,642	19,703	10,108	8,457	8,335	7,975	25,928	5,557,833
1973	2,447,016	1,876,429	708,647	456,405	196,330	64,284	19,615	6,160	2,582	1,710	1,547	6,225	5,786,950
1974	2,475,082	3,696,153	883,741	464,935	219,448	73,352	22,710	7,011	2,393	942	423	477	7,846,668
1975	1,064,338	2,149,306	862,252	534,943	407,393	149,054	43,515	12,836	4,308	1,685	754	849	5,231,235
1976	2,516,686	2,915,165	618,040	633,847	353,708	124,294	37,942	11,958	4,296	1,776	827	972	7,219,513
1977	2,037,833	2,624,131	867,918	625,863	350,083	112,048	32,069	9,801	3,487	1,447	681	823	6,666,183
1978	1,436,935	2,882,852	1,010,353	773,100	323,990	83,071	24,238	8,743	3,836	2,075	1,338	3,043	6,553,574
1979	2,124,095	2,579,610	990,943	744,073	313,007	69,384	17,269	5,148	1,829	761	361	444	6,846,924
1980	2,629,974	3,066,875	1,122,936	698,788	314,718	69,740	16,637	4,605	1,516	587	260	288	7,926,924
1981	6,123,214	3,929,223	1,065,586	719,435	498,887	117,734	24,217	5,777	1,728	639	279	310	12,487,029
1982	4,058,906	6,078,366	1,042,397	895,125	434,177	110,005	24,278	5,862	1,708	606	254	265	12,651,950
1983	4,483,203	4,555,201	1,317,788	810,821	427,188	103,883	24,965	6,814	2,223	861	384	432	11,733,763
1984	4,656,873	6,176,896	843,707	392,058	124,544	27,389	6,046	1,535	466	169	72	77	12,229,831
1985	4,388,197	5,630,950	1,252,701	708,763	377,329	65,017	11,036	2,322	625	210	85	84	12,437,319
1986	4,783,308	5,105,178	854,088	837,903	359,357	70,694	13,221	2,946	818	280	114	115	12,028,022
1987	6,508,847	5,189,513	1,014,731	694,653	377,813	62,983	11,168	2,459	686	237	98	100	13,863,287
1988	5,431,203	5,413,227	1,020,086	782,981	244,220	40,364	6,298	1,234	315	102	40	39	12,940,111
1989	5,653,646	5,197,326	991,540	888,570	503,070	106,608	22,046	5,448	1,655	609	262	282	13,371,063
1990	7,302,474	4,673,951	952,357	1,106,961	641,342	153,014	33,949	8,777	2,775	1,057	467	519	14,877,642
1991	7,414,028	5,744,269	849,292	805,257	516,301	118,912	26,569	7,138	2,345	917	412	465	15,485,905
1992	6,791,106	5,176,980	1,026,154	813,599	475,730	112,828	24,498	6,082	1,811	649	272	284	14,429,993
1993	8,352,487	7,609,265	874,828	806,013	453,649	86,931	16,176	3,917	1,260	534	279	434	18,205,774
1994	6,342,448	7,010,671	1,315,656	717,442	457,087	93,837	17,700	4,265	1,315	497	220	249	15,961,388
1995	6,556,009	5,451,709	1,036,026	735,230	414,510	78,827	14,971	3,701	1,162	444	198	225	14,293,011
1996	4,883,892	5,027,149	986,384	763,008	397,248	77,883	14,784	3,511	1,054	389	169	185	12,155,655
1997	5,890,130	5,613,231	737,610	642,389	425,376	82,133	15,232	3,780	1,228	491	228	273	13,412,101
1998	5,671,075	6,419,491	723,346	637,002	466,146	108,518	22,267	5,433	1,642	605	262	285	14,056,071
1999	5,705,689	10,467,795	682,296	505,549	350,060	84,844	19,623	5,751	2,259	1,098	600	886	17,826,451
2000	6,994,734	6,274,251	948,185	592,405	280,657	74,230	18,690	5,365	1,867	777	371	461	15,191,994
2001	5,652,115	9,863,946	1,089,326	723,786	298,613	65,253	15,786	4,660	1,647	678	316	372	17,716,499
2002	7,064,402	6,433,398	812,288	640,479	354,043	70,298	13,514	3,179	925	327	136	140	15,393,130
2003	6,367,700	6,710,111	708,773	519,556	286,914	77,375	21,003	6,421	2,265	922	424	492	14,701,958
2004	7,538,741	5,778,937	855,884	494,550	258,303	86,711	30,569	11,190	4,289	1,794	827	944	15,062,739
2005	5,383,724	5,747,241	512,962	447,675	276,807	72,028	17,044	4,619	1,526	605	277	323	12,464,831
2006	2,130,910	7,778,547	640,889	408,968	262,164	83,848	23,847	7,421	2,716	1,157	555	680	11,341,703
2007	5,296,060	4,836,589	552,548	390,673	253,646	78,681	22,055	7,013	2,680	1,201	605	802	11,442,552
2008	3,694,917	6,706,872	508,464	448,679	328,119	95,948	24,759	7,197	2,539	1,072	519	659	11,819,744
2009	3,508,125	6,041,830	449,560	527,321	393,279	110,379	27,193	7,624	2,573	1,028	470	543	11,069,925
2010	5,309,118	6,138,160	608,795	367,522	323,728	113,831	30,055	8,193	2,601	979	426	466	12,903,874
2011	4,562,632	6,315,925	610,097	418,050	260,754	81,056	21,517	6,232	2,126	852	389	455	12,280,086
2012	3,689,660	6,396,812	701,864	443,378	272,612	72,268	17,988	4,947	1,659	695	347	490	11,602,721
2013	3,040,406	6,242,544	579,309	391,680	253,593	74,573	19,472	5,475	1,811	710	321	372	10,610,265
2014	4,700,592	6,431,009	662,133	402,800	216,825	55,114	13,234	3,658	1,222	489	226	270	12,487,571

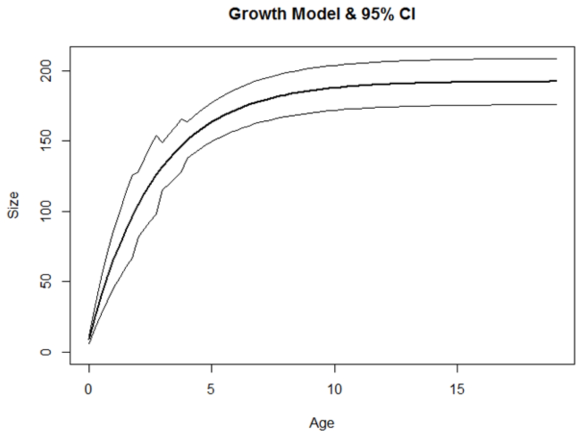


Figure 1. Assumed growth of size at age functional model (Draganik & Pel…) of yellowfin tuna with 95% confidence intervals to estimate CAA from size distribution of catch (CAS).

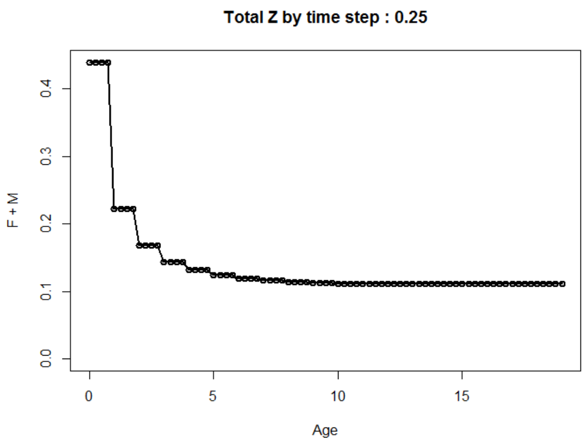


Figure 2. Assumed natural mortality at age and time step (quarter) for yellowfin tuna. (F = 0).

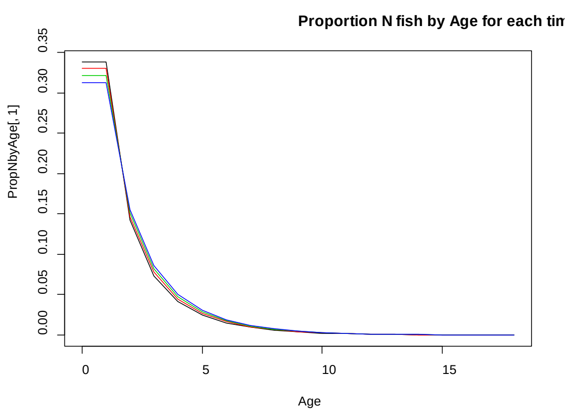


Figure 3. Estimated proportion of number of fish by age and quarter based on the exponential decline of cohorts due to mortality.

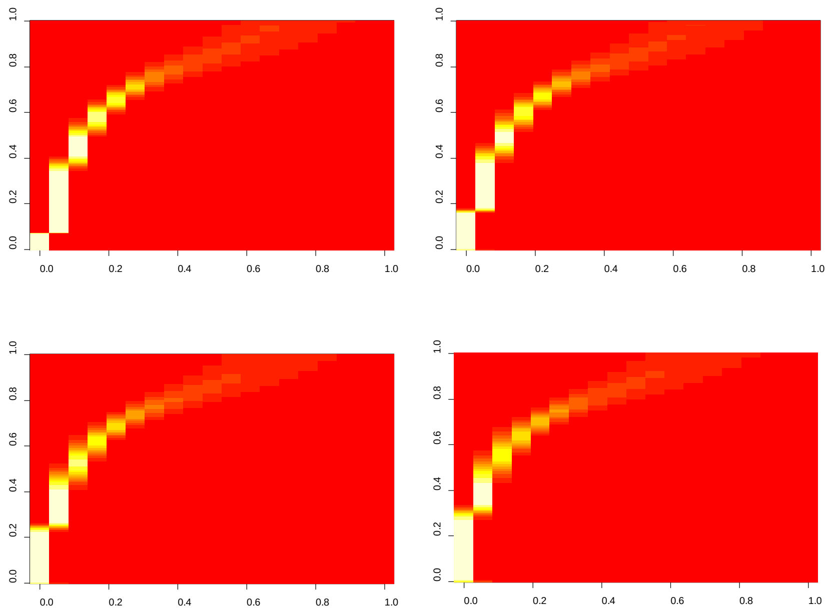


Figure 4. Level plot of the probability of size at age distribution for yellowfin tuna when mortality decline is considered. Each plot represents the quarterly probabilities with top-let being the quarter 1 (Jan-Mar) , top-right Q2 (Apr-Jun), bottom-left Q3 (Jul-Sep) and bottom-right Q4 (Oct-Dec). Higher probabilities indicated by white-yellow shades.

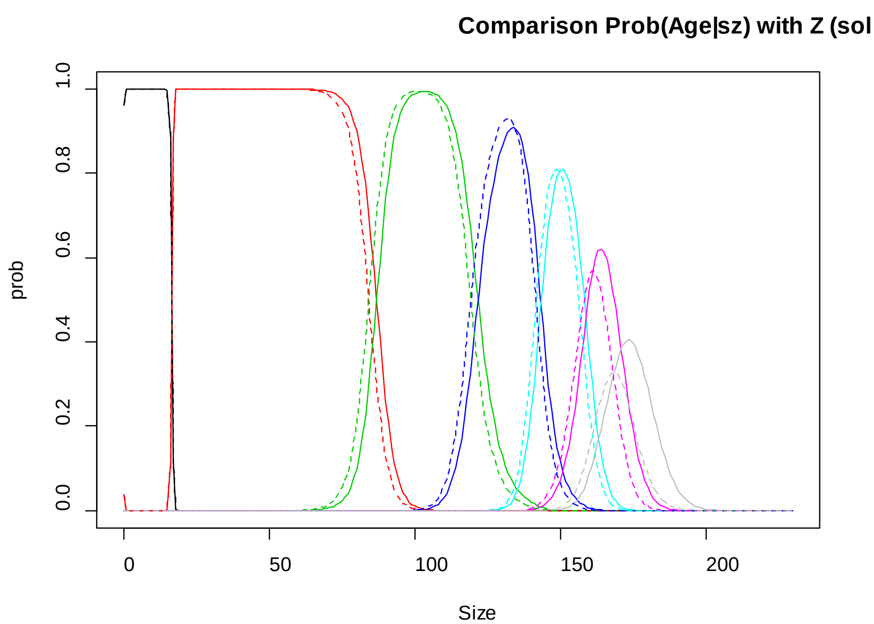


Figure 5. Comparison of the estimates probability of age at size (p(Age|size)) for yellowfin tuna when considering mortality of fish with age (solid lines) and when ignoring mortality (broken lines) for ages 0 to 6 (by colors).

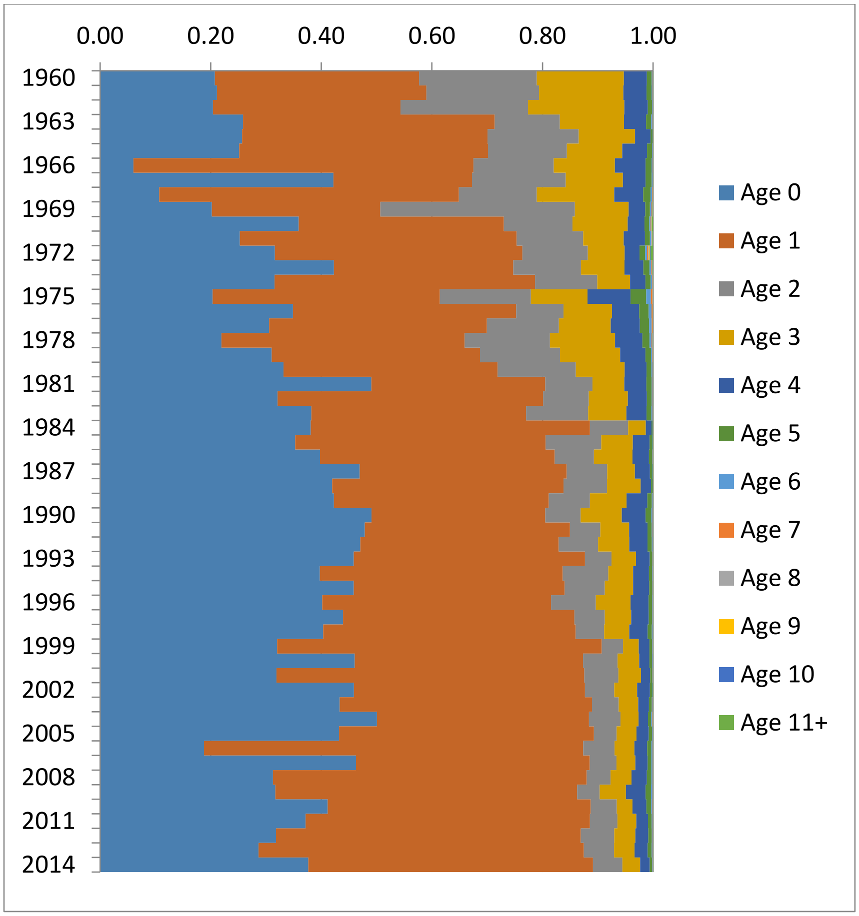
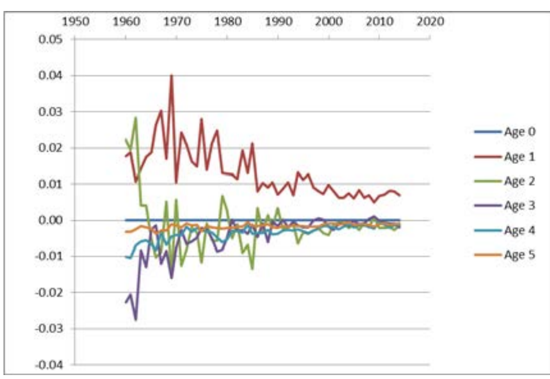


Figure 6. Annual yellowfin tuna catch at age (CAA) distribution 1960 – 2014, as estimated with the ageit program assuming a von Bertalanffy growth model (Draganik and Pelzarski.) and natural mortality decline of cohorts.



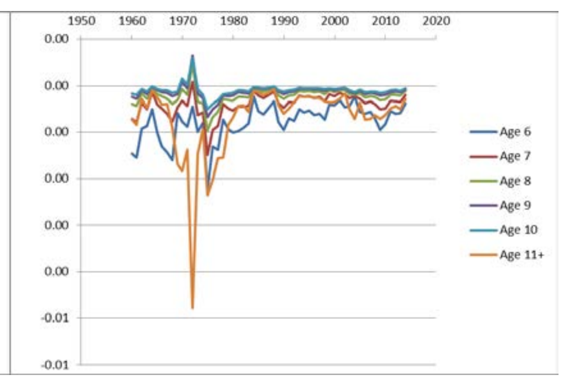


Figure 7. Difference between the yellowfin age proportions by year and age from the CAA matrices estimated when considered it or not the decline in numbers of fish due to natural mortality. Positive values indicate that the respective proportion of CAA increases when considering natural mortality. Negative values indicate a lower proportion of those ages in the CAA when natural mortality was considered