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Tentative sequential population analysis of Indian Ocean skipjack catch at size

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Summary

This paper is attempting to do a simplified sequential population analysis of skipjack CAA based on 2 average CAS estimated during the 2004-2013 period (original and corrected ones), and assuming various levels of natural mortality at age. It was first noticed that when the estimated CAA is showing a very low apparent total mortality between the various ages estimated by slicing (using the Eveson & al 2014 growth curve), the life expectancy of tagged skipjack recovered is very short, showing an apparent total yearly mortality estimated at about 2.0. As a result of this basic inconsistency between CAA and natural mortality, all ASP have been providing totally unrealistic results, estimating very low fishing mortality exerted at all ages. An ad hoc analysis of the recovery data has been done, and it is showing that skipjack growth rates appear to be highly variable between individuals. If this result is confirmed by further statistical analysis, it would mean that there is a very poor relationship between skipjack sizes and ages, medium & large sizes skipjack being probably dominated by young fast growing skipjack, while the old skipjack surviving in the population are probably rare. This question is quite fundamental and its potential consequences in the functioning and results of the SS3 model should be carefully examined.

1- Introduction

There is now a good knowledge of skipjack growth in the IO following the successful tagging program ran by the IOTC some years ago; skipjack natural mortality at age is also better estimated today. Furthermore, the IOTC secretariat has been estimating a vector of skipjack CAS by gear based on size data of landed catches done on several major fleets. On the other side, it appears that skipjack stock assessment analysis tend to be highly complex, and their results still widely uncertain and often unrealistic. These problems in all the skipjack stock assessments are due to multiple cascading problems, among them the lack of any reliable abundance index (unfortunately there is no lonline CPUE available for any skipjack stock) and the permanent changes developed by most skipjack fisheries. Multiple changes have been permanently observed in most FAD fisheries, changes that have been permanently modified the fishing patterns of the fleets and most often increasing their efficiency. As a typical result, in many stock assessment models results, these major changes in the fisheries are transformed into artificial changes in the estimated population (as shown by Fonteneau et al 1998)

In this difficult context of the skipjack stock assessment, when some RFOs are using complex statistical models (MFCL by WCPFC, SS3 by IOTC) to assess skipjack stocks, when other RFOs are exploring a wide range of models such as the ICCAT in 2014 (but with limited results), when the IATTC prefers to follow the status of its skipjack stock based on various skipjack fishery indicators (Maunder 2014).

Our opinion is that the basic methods based on size SPA, based on the knowledge of an average skipjack CAS (a basic information that is not really handled in most of the statistical models), and also of its growth and natural mortality at age, could be an interesting target (in addition to indicators and complex models). This analysis could allow for instance to better understand and estimate the characteristics of the skipjack stock, to better evaluate our uncertainties in the skipjack biology (for instance in its natural mortality at age or it age length relationship), in its growth and to better understand its exploitation by fisheries. This paper will target these goals.

2- Material & methods

This work will intend to run simplified Sequential Population Analysis (SPAs) based on the average CAS of the skipjack fisheries in the entire Indian Ocean during an average of the 2004-2013 period (then assuming a single stock and one kind of equilibrium in the stock & fisheries during this period). The Catch at size vector (later called CAS) is based on the data set estimated and proposed by the IOTC, see figure 1b (M. Herrera). This basic CAS is the average catch at size caught by the combined fisheries (and also by each gear) during the 10 years average period 2004-2013. However, it appears that when the CAS of PS and of BB is based on good size sampling, the CAS of the combined other gears are widely questionable (when these catches are important in weight and in numbers). As the CAS of these other gears presently estimated by the IOTC are very atypical compared with the CAS of the 2 well sampled gears, our alternate hypothesis will be that the CAS caught by “other” gears had in fact the same profile as the PS+BB CAS. This estimated average vector of CAS is show by gear on figure 1a.

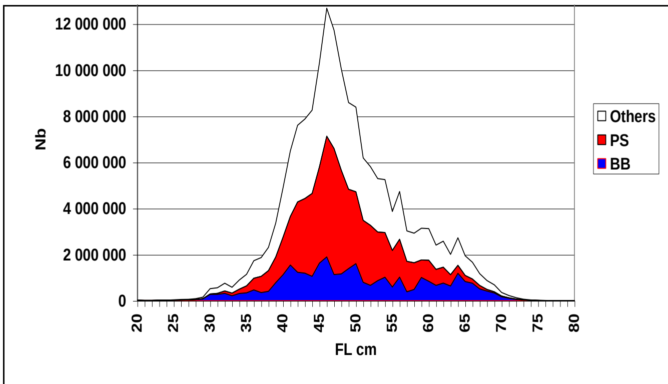

Figure 1a: Average skipjack total catch by size & by gear during the period 2004-2013 (IOTC file), but extrapolating PS and BB CAS to total catches

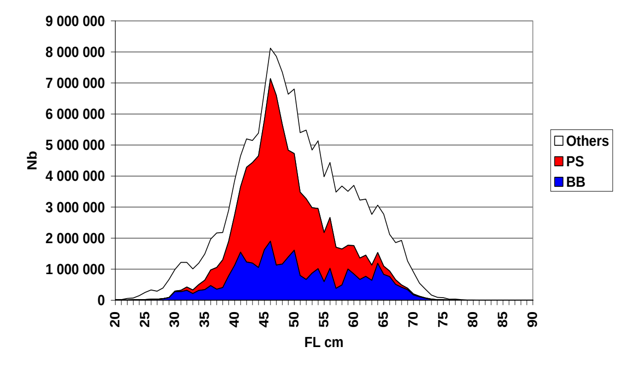

Figure 1b: Average skipjack total catch by size & by gear during the period 2004-2013 (original IOTC file),

Figure 2 is showing the total catch at size estimated following those 2 rules, i.e. based on the IOTC CAS and entirely based on size samples taken on PS & BB.

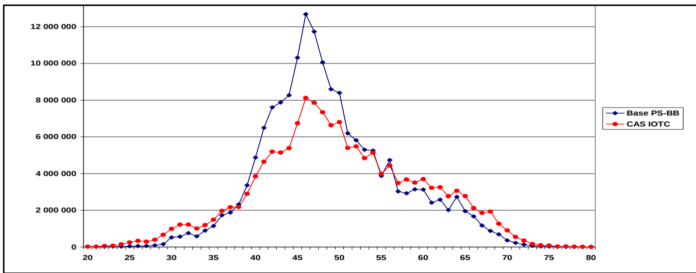

Figure 2: Comparison of the 2 skipjack CAS vectors used in the present work

SPA may simply be conducted based on the yearly catch at age estimated by slicing of this CAS; all the fishes caught at a given size are assumed to follow the average theoretical relationship between size and age given by the Eveson et al 2014.

However there is no doubt that such slicing of the CAS is a questionable method as there is always a basic variability between the growth rates of individual tunas at any given age. This variance of skipjack growth rates cannot be estimated by age reading because age reading of otoliths do not allow to estimate skipjack ages; it will be tentatively estimated based on the variability of growth rates of tagged & recovered skipjack. These growth rates of skipjack tagged and recovered have been estimated based on the IOTC recovery file, these calculations being done as described in the annex 1. This analysis of the skipjack growth rates is potentially based on a subset of 10288 skipjack recoveries that have been selected for their good quality.

Furthermore, this paper will also estimate the apparent total mortality estimated at a yearly scale of the recoveries of skipjack: a data set of 17.300 recoveries has been selected in the IOTC recovery file (without selection concerning size at recovery and keeping all the recoveries registered in the IOTC file at a known date).

3- Skipjack growth curve and natural mortality at age & size

3-1- Skipjack Growth

The growth rates at size estimated by Eveson & al 2014 have been used as being the best one to describe skipjack growth as they are based on a comprehensive statistical analysis of all the recovery data. This growth curve and their corresponding growth rates at size are given on figure 3, in comparison with the growth rates at size estimated in a VB model.

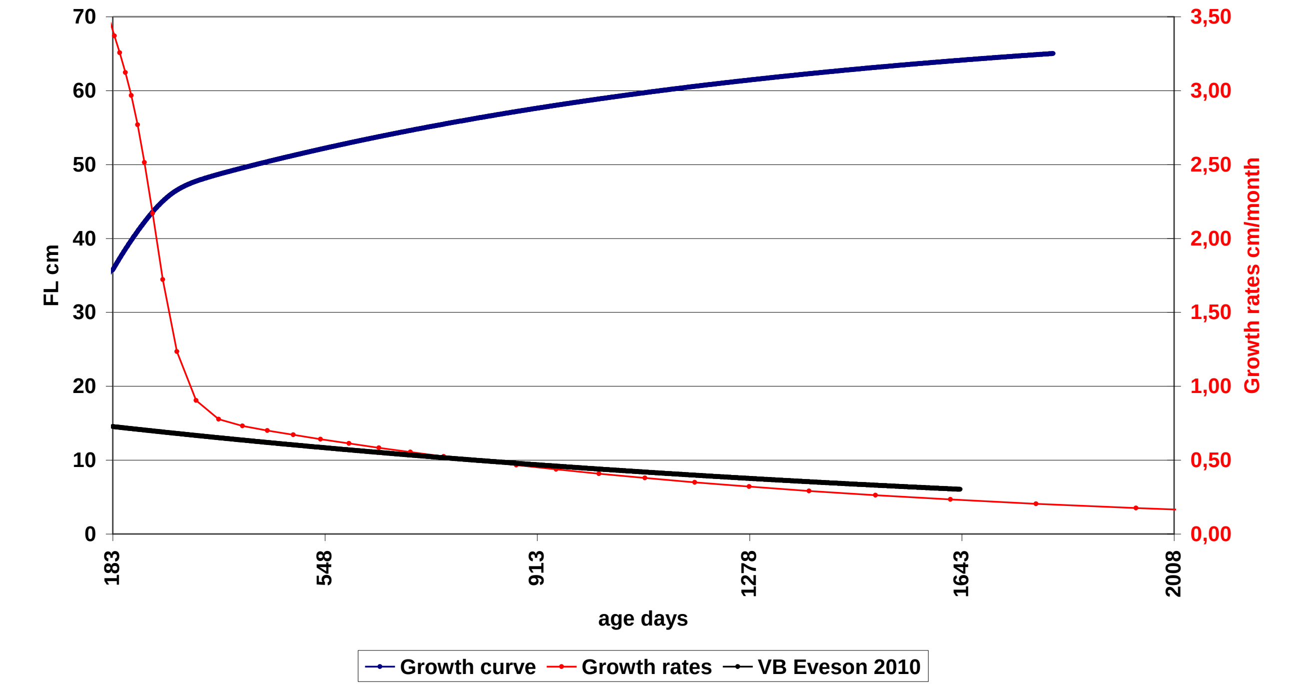

Figure 3: Growth curve and growth rates at size proposed for the Indian Ocean skipjack by Eveson et al 2014 (and growth rates at age previously estimated by Eveson et al using a VB model)

In this growth curve based on a LogVB model, the growth rate of juvenile skipjack at sizes under 45 cm is much faster than in the traditional VB model. Based on tagging data and on the biology of very young tunas (tuna larvae and early juveniles of tunas need to grow very fast in order to survive), this result is probably a fully valid one. The slicing of the 2 CAS tables following this growth allows to estimate 2 vectors of catch at age during the studied period, table 1.

Table 1: Estimated skipjack catch at age during the average period 2004-2013, based on 2 hypothetical CAS, and estimated by slicing based on the Eveson et al 2014 LogVB growth curve.

FL	Age years	CAA PS-BB	CAA IOTC
20-48cm	0	94 153	72 839
49-54cm	1	39 537	34 286
55-59cm	2	17 708	19 081
60-62cm	3	7 859	10 178
63-64 cm	4	5 193	6 428
>65cm	5+	7 031	11 921
	Total	77 329	81 893

An important point to note in this table is that the numbers of skipjack caught at successive ages in both CAA are showing a moderate rate of decline: an apparent yearly rate Z close to only 0.8 between ages 1, 2 and 3, and even lower between age 3 and 4 (and a group group 5+ with larger catches than at age 4). Consequently there is a surprisingly large proportion of skipjack over 63 cm (or 5 kg, then at a theoretical age over 4 years) in both CAA estimated by slicing: 11 % of total catches (in numbers) in the IOTC CAS or 7% in the corrected CAS.

These estimated catch at age may for instance be compared, at a logarithmic scale, with the decay of skipjack yearly recoveries (figure 4 & 5).

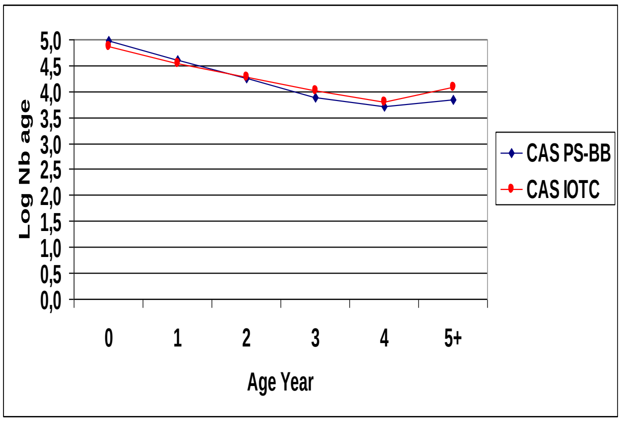	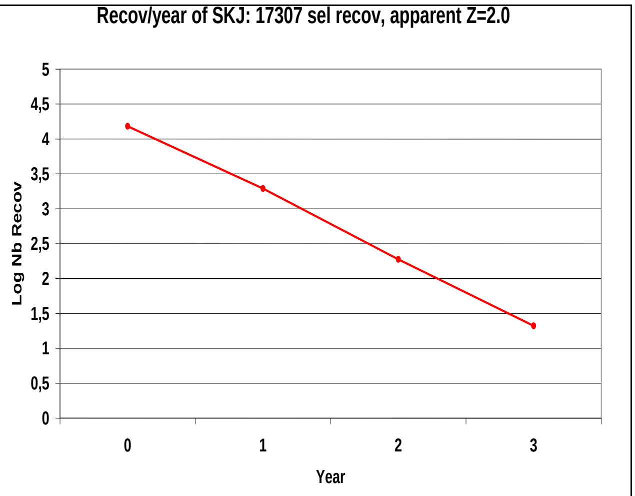
Figure 4: Log of CAA based on slicing of the 2 skipjack CAS estimated in the Indian Ocean during the 2004-2013 period and the Eveson et al 2014 growth curve	Figure 5: Log of the numbers of skipjack recoveries as a function of number of years at liberty(17307 recoveries, an apparent Z=2.0)

The comparison between figures 4 & 5 is showing the marked difference between the slow decline of the estimated CAA over the years (figure 4) and the fast decay at Z=2.0 of the skipjack recoveries (figure 5).

However, this trend of low or very low total mortality estimated in the CAA (figure 4) may in fact be totally artificial and due to the slicing method used: if there is a large variability of growth between individuals, then the CAA estimated by the slicing method may be widely or totally wrong. In the absence and impossibility to estimates the inter individual variability of growth based on age readings of skipjack hard parts (as it can be done for other tuna species), it remains possible to analyse the tagging & recovery data in order to evaluate this variance of growth.

As an example, we have selected the recoveries of skipjack tagged in the same small range of sizes between 50 and 52 cm (modal sizes tagged, see figure 6): in this range of only 3 cm of fork length, a large number of 24258 individual have been tagged, and among these tagged skipjack, 2909 have been recovered with reliable information on their growth rates (see annex1). Furthermore, among these recoveries, 228 skipjack have been recovered about 1 year after their tagging (i.e. during a period of 1 year + or – 1 month). The apparent growth of this peculiar sub set of recovered skipjack is shown by figure 6.

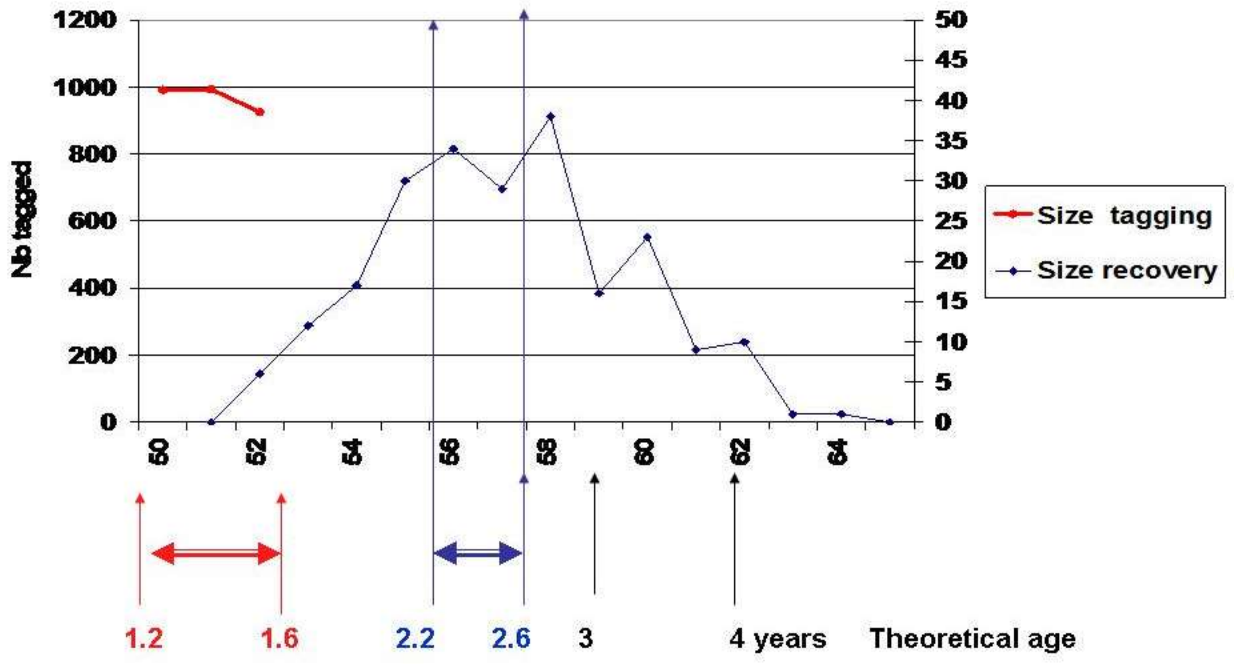

Figure 6: Sizes at recovery and estimated ages at recovery (based on the avrega of the Eveson at al growth curve) of skipjack tagged between 40 and 52 cm and recovered 1 year after (+ or – 1 month)

Based on their average growth curve proposed by Evesopn & al 2014, the ages at tagging of these skipjack tagged between 50 and 52 cm can be estimated between 1.2 and 1.6 years. In the hypothesis that each individual skipjack has been following the average Eveson et al 2014 growth curve, they should have been recovered 1 year after at sizes between 56 cm (fishes tagged at 50.0cm) and 58.0 cm (fishes tagged at 52.9cm). However, one year after their tagging, sizes of recovered skipjack are showing a much larger large variability: fork length at recovery being measured between 52 cm and 64 cm (figure 6). Then it appears that, while the average growth of this group of fish has been following very well the Eveson & al 2014 growth curve, the variance of the sizes at recovery appears to be very wide: recovered sizes showing a large proportion of smaller and of much larger fishes than the average growth. As a result, the age of all the fast growing recoveries would be widely overestimated by the slicing method. There are still significant errors in the recovery file, even after its filtering (annex 1), for instance due to errors in size at tagging or recovery, and to errors in the durations at liberty. These errors are probably explaining part of this large variance in the recovered sizes. However, based on these results, it should be accepted, at least as a working hypothesis, that there is a potentially important variance of growth rates and growth curves between individuals in the skipjack stock. The variance of adult sizes is a biological factor always observed for all species: all population of every species are showing a mixture of large and of small individuals, most often in relation with their genetics and heterogeneity in their habitat. In the case of skipjack, this basic heterogeneity in adult sizes may also be increased by the heterogeneous habitat of adult skipjack: these fishes may live in warm equatorial waters or in temperate waters in distinct ecosystems, where they are probably showing distinct growth rates (adult skipjack potentially showing a much faster growth when they are living in cold waters, Fonteneau 2014).

It should also be kept in mind that subsequently, it would be very difficult or impossible to estimate a realistic skipjack CAA based on a slicing of its CAS: simply because in this hypothesis the important[1] group of large skipjack in the CAS, for instance at sizes over 55 cm, would not be a group of old individuals because this group is probably widely dominated by fast growing younger skipjack (that are dominant in numbers in the stock, because they are young) in relation with the high natural mortality suffered by skipjack. As an example, in a cohort suffering an annual rate of total mortality Z=1.5, probably a realistic level for skipjack, then the cohort will loose each year 78% of its members. In such context, younger tunas will be most often widely dominant against older tunas. This trend in the number at age in a skipjack stock is also well confirmed by the high apparent total mortality estimated from recoveries. This apparent Z is not really fully quantitative, as it was estimated based on a simplified calculation done without incorporating changes in reporting rates of tags, shedding rates, and other factors conditioning Z. However, This very high apparent total estimated from tagging recoveries is probably indicative of the very high mortality, total & probably natural, suffered by skipjack during its exploited life. No doubt: skipjack are different from bluefin or bigeye!

3-2- skipjack Natural mortality at size

Natural mortality at size appears to be the most important parameter in most analytical stock assessment, as well as in any size VPA. On one side, skipjack natural mortality is a parameter that is very difficult to estimate, but on the other side the recovery data are probably and by far, the best way to estimate it.

Natural mortality as a function of skipjack age has been estimated at various occasions and papers in the WCPFC area (inter alia by Hampton 2000 and by Rice & al 2014 in the western Pacific). These estimates of M at age were mainly based on the multiple tagging programs done on skipjack by the SPC since the late seventies. Alternate estimates concerning natural mortality at age of skipjack based on the IOTC recovery data has been also recently obtained by Bousquet et al (submitted 2014) but these results appear to be quite “unstable” and widely dependent of a multiple range of external parameters, for instance in relation with the fisheries. Alternate estimates based on a combination of various biological methods (Lorenzen, Gislason, etc..) and approximations was also recently proposed by Gaertner 2014 to the ICCAT SCRS 2014 meeting (same figure 7), but they have not been used in the tentative SPAs.

These 4 sets of potential skipjack Natural mortality at age are shown figure 7.

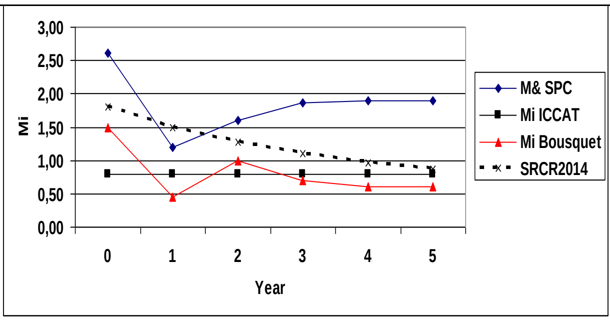

Figure 7: Yearly approximate levels of the various natural mortality at age estimated for skipjack

[1] skipjack >55cm: this group of large skipjack is important in the Indian Ocean, potentially reaching 40 % of total catches in weight

These vectors of natural mortality at size/age allow to estimate numbers of survivors under each of these vectors (virgin stocks) and under an hypothesis of moderately exploited stocks, for instance stocks that are suffering after their recruitment in the fisheries a fishing mortality equal to 50% of the natural mortality (Table 2). These estimated numbers based on various mortality rates have been calculated based on an initial recruitment of 100.000 individuals (a number corresponding to the number of skipjack tagged in the Indian Ocean).

Table 2: Yearly numbers of survivors in a simulated population, starting from a given recruitment of 100.000 at Tzero, and under various hypothesis of age specific Natural and fishing mortality (mortality is exerted during only ½ of the year at recruitment age of 0)

Natural mortality				Virgin stock			Exploited stock: F=M/2		
years	Mi SPC	Mi =0,8	MiBousquet	Mi SPC	Mi =0,8	Mii Bousquet	Ni SPC	Mi =0,8	Mi Bousquet
0	2,61	0,8	1,5	31132	77087	54322	16198	63113	37335
1	1,20	0,8	0,45	9377	34637	34637	2677	19009	19009
2	1,61	0,8	1	1883	15564	12742	241	5726	4242
3	1,87	0,8	0,7	291	6993	6328	15	1724	1484
4	1,90	0,8	0,6	44	3142	3473	1	519	603
5	1,90	0,8	0,6	7	1412	1906	0	156	245
6	1,90	0,8	0,6	1	634	1046	0	47	100
7	1,90	0,8	0,6	0	285	574	0	14	41
8	1,90	0,8	0,6	0	128	315	0	4	16
9	1,90	0,8	0,6	0	58	173	0	1	7

Furthermore, tagging & recovery results have been indicative that total mortality Z (F+M) suffered by all skipjack stocks in every oceans, as in the Indian Ocean, was estimated to be very high: the longest durations at sea of tagged skipjack have been very seldom reaching 4 years (when tagged YFT and BET may be recovered after 10 years at liberty or more). This result has been well confirmed for Indian Ocean skipjack, in the recovery file selected for growth study (10300 recoveries) is showing only 3 fishes with more than 3 years at sea (max=3,36 years at sea), and in the apparent yearly apparent total mortality Z of skipjack recoveries estimated at a high level close to 2.0 (figure 5 and table 3).

Table 3: Total numbers of skipjack recovered as a function of their theoretical age at tagging and at recovery sizes, and average duration at sea of year tagging class

SKJ age (year)	0	1	2	3	4	5
Age at tagging	6694	3131	390	57	15	
Age at recovery	2261	5896	1884	205	35	6
Average days at sea of recoveries	132	219	347	406	311	608

Assuming that each of the recovered skipjack was tagged and recovered at its theoretical average size and age, as estimated by the Eveson et al 2014 growth curve, the absolute ages at skipjack recoveries has been estimated and this result is shown on the same table 3. These results would indicate that 6 year classes would be exploited today in the skipjack stock.

In the 2 hypothesis (1) that the tag shedding of skipjack was not high, for instance at a yearly rate of 5 % estimated by Gaertner and Hallier & al 2014 and (2) that catchability of adult skipjack is kept more or less constant for old individuals (without massive immigration outside the fishing zones), then a very high total mortality is the only way to explain the high apparent total mortality observed from skipjack recoveries. Furthermore, as most stock assessment of the skipjack stocks have been concluding that the exploitation rates of these stocks was quite moderate, then it would mean that a very high Natural mortality would probably be the dominant component in the very high Z previously estimated (as it has been estimated by the MFCL model on western Pacific skipjack, see Rice et an 2014).

4- Tentative SPAs on the average skipjack yearly catches at age

Any SPA is primarily based on an estimated vector of catch at age & on an hypothetical vector of natural mortality at age. This method is quite simple but powerful when CAA and Mi vectors are well estimated, and if the Fishing mortality or the population size is well estimated at any given time of the exploited file of the fish. In this case, its results are often fully realistic, allowing to estimate fishing mortalities and population sizes at age during the entire life of the exploited cohorts. However, any of these SPA will need to have consistent input data in order to be run, and this is not at all our skipjack case, because the apparent Z of the CAA is much lower than any of the 3 natural mortality assumed. As a result our SPAs are not at all in position to estimate any realistic results as they cannot converge to reasonable results simply because the level and trend of the assumed natural mortality at age is inconsistent with the trend of CAA. The results of all these potential SPA are always similar: they are all estimating that fishing mortality was very low during the entire life of the exploited fishes, and this is an absurd result. Typical results of these SPA are shown figure 8.

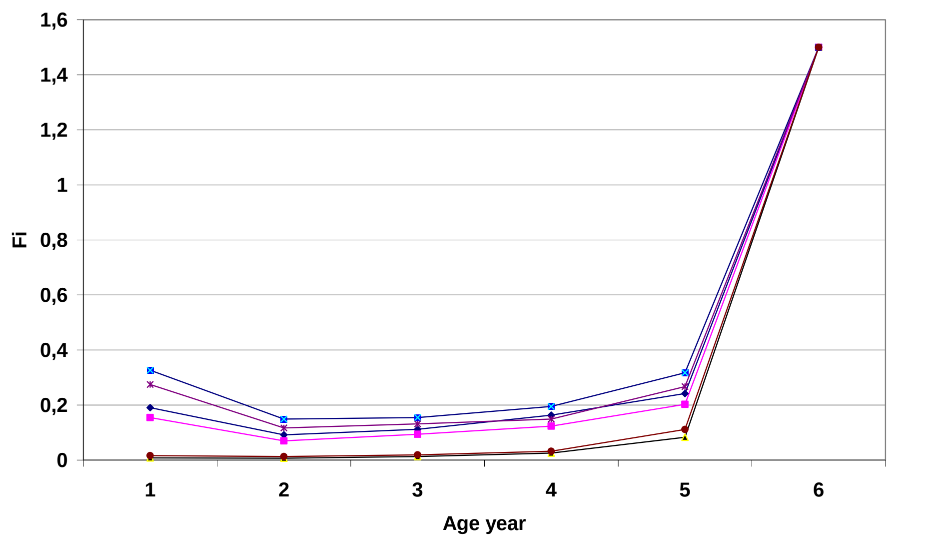

Figure 8: Examples of SPA results obtained from the various hypothesis of CAS and natural mortality, and always assuming a very high F.

This total failure of the present SPA done on the presently estimated CAA would appear to be mainly due to the major uncertainties in the CAA estimated by slicing and in their potential bias that are due to the variance in growth rates and the high natural mortality.

5- Discussion and recommendations

There is no doubt that slicing of CAS has never been an ideal method to estimate CAA tables, but the difficulties faced in the building of a realistic CAA for Indian Ocean skipjack appear to be quite extreme ones because oif cascading factors: because of the high natural mortality of the species, of its fast growth and short duration of life between recruitment and death, and because of the apparently large variability of individual growth rates. As a result, it would appear that there may be an extreme mixing of distinct ages at all medium & large sizes of skipjack caught. In a BFT stock, slicing may not be an ideal method, but at least the various categories of ages can be distinguished in the CAS: in the case of an adult BFT from the Eastern Atlantic, age readings of otoliths are showing that a 5 years old BFT may show a fork length between 100 and 160 cm, when 10 years old BFT have been sampled between 100 and 160 cm, but at least these 2 groups of adult BFT can be identified in 2 distinct groups of sizes. On the opposite it would appear than the main size range of skipjack caught over 48 cm (at a theoretical average age close to 1 year) may show a wide range of real potential ages, possibly/probably including a dominance of fast growing skipjack with a real age under 1 year.

The high variance of skipjack growth rates has been seldom analyzed in the absence of age readings, but this question may be fundamental to do skipjack stock assessments: in this context it should be recommended to do an in depth statistical analysis of the recovery data allow to better estimate on a statistical basis the variability of individual skipjack growth rates (in line with the present quick study, figure 6). It can be expected that in the Indian Ocean, the large numbers of the skipjack recoveries and the good quality of this file should widely facilitate this analysis.

On the other side, this biological variability of skipjack growth rates may be quite easy to understand/explain, being in relation with its high natural mortality, its wide spawning strata (potentially a permanent spawning in the entire equatorial areas), and the great numbers of skipjack recruited yearly: numbers of skipjack recruited at 35 or 40 cm can probably be estimated in hundred of millions, possibly billions of individuals. During their adult lives (starting early at about 40 cm, less than 1 year) and at increasing sizes, it seems that these large (but quickly declining) cohorts of skipjack are + or - randomly exploring a wider and more temperate habitat, and potentially covering large distances in widely distinct areas (Fonteneau 2014). This potentially heterogeneous pattern in term of feeding and spawning may offer for multiple groups of individual skipjack distinct potentials for their individual growth (keeping in mind that skipjack life is short).

It should be envisaged that the basic problems faced by the SPAs tentatively used, will also be probably also faced by other stock assessment methods, such as SS3 or MFCL: these statistical methods are not explicitly taking into account the skipjack CAS of CAA tables (but simply size samples and catches by gear), but their best fit and best results have to be based on consistent relationship between sizes and ages of fish caught, and also of the very high natural and total mortalities suffered by skipjack during its short life. The tagging & recovery data that are now introduced in the Indian Ocean stock assessment model should be highly informative to condition the dynamics of the exploited stock. It is not clear at this stage to know how much the variance of growth rates can be estimated and well managed in the stock assessment statistical models. At least the multiple input & output parameters of the SS3 model that are in relation with growth, natural mortality and fishing mortality at age should be carefully examined by scientists having in view the conflict that have been faced in the present work concerning the input of the SPAs and of their lack of consistent results.

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Annex1

Handling of the IOTC recovery file

Growth rates can be estimated from the skipjack recoveries based on a selected data set. The most recent file of recoveries (September 2014) was used in the study. The following steps have been kept in the selection of the growth sample:
(1) only the recovered SKj tagged as skipjack are kept,
(2) all recoveries within 20 days after tagging have been eliminated
(2) only skipjack with known size at tagging are kept,
(3) quality of size at recovery classified as “good”
(4) All sizes at tagging have been corrected by a constant factor of 0.5 cm[2]. This correction has been done because all sizes at tagging in the IOTC file are given by 1 cm class, but corresponding to tagging length truncated to the lowest centimetre.
(5) Recovery files are given either in millimiters (and these sizes have been kept)or as recovered length truncated to the lowest centimetre. A constant 5mm have been added to each of these truncated size at recovery.
(6) recoveries with a relative potential error in their duration at sea estimated by the IOTC at a level over 10% have been eliminated.
(7) the 1% of highest and 1% of lowest growth rates have been eliminated from the original recovery file; this selection of growth rates that are estimated to be highly dubious has been done with a stratification of the recovery file in 3 groups of average size between tagging and recovery size: small (FL<45cm), medium and large skipjack (FL>55cm).

As a result, a basic subset of 10288 skipjack recoveries can be kept to estimate the growth rates at size.

[2] Adding 5mm at all tagging and recovery sizes recorded by rounded class of 1 cm, has never been done before to our knowledge, but we consider that this correction is probably necessary (and also widely conditioning all the growth rates that are estimated on short durations at sea).