AN OVERVIEW OF SKIPJACK GROWTH IN THE ATLANTIC: KNOWLEDGE AND UNCERTAINTIES

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SUMMARY

This document makes a global overview of the today knowledge and uncertainties concerning skipjack growth in the Atlantic. This work is based on work from the literature and from a reanalysis of the growth of skipjack recoveries, in the Atlantic and in other oceans. It appears that the skipjack recoveries available today in the Atlantic are the only way to evaluate growth, but that this data set is quite weak in term of its geographical coverage, number of tags, and their limited durations at liberty. The much faster growth of skipjack that has been observed in the temperate areas is tentatively explained. The paper also concludes that the Von Bertalanffy model may not be convenient to describe the real growth of skipjack, first because of the too fast growth during the pre recruitment phase (between birth and 40 cm) and because of the quite complex growth of skipjack that are seasonally migrating in temperate and in equatorial waters. Various recommendations are made to improve the knowledge on skipjack growth, most of them targeting the large scale tagging program planned by ICCAT.

RÉSUMÉ

Le présent document fait le bilan des connaissances et des incertitudes entourant actuellement la croissance du listao dans l'Atlantique. Ces efforts reposent sur des travaux documentés et sur une ré-analyse de la croissance des récupérations de listaos, dans l'Atlantique et d'autres océans. Il semblerait que les données disponibles des marques récupérées sur des listaos dans l'Atlantique soient le seul moyen d'évaluer la croissance, même si ces données sont assez limitées en termes de couverture géographique, nombre de marques et durée limitée en liberté. La croissance beaucoup plus rapide du listao qui a été observée dans les eaux tempérées est expliquée à titre provisoire. Le document conclut également que le modèle de croissance Von Bertalanffy pourrait ne pas être approprié pour décrire la croissance réelle du listao, tout d'abord en raison de la croissance trop rapide pendant la phase de pré-recrutement (entre la naissance et 40 cm) et en raison de la croissance assez complexe du listao qui migre de façon saisonnière dans les eaux tempérées et équatoriales. Diverses recommandations sont formulées en vue d'améliorer les connaissances sur la croissance du listao, la plupart d'entre elles étant axées sur le programme de marquage à grande échelle prévu par l'ICCAT.

RESUMEN

Este documento presenta una visión global de los actuales conocimientos e incertidumbres sobre el crecimiento del listado en el Atlántico. Este trabajo se basa en trabajos de la bibliografía y en un reanálisis del crecimiento mediante las recuperaciones de listado, en el Atlántico y en otros océanos. Parece que las recuperaciones de listado disponibles actualmente en el Atlántico son la única forma de evaluar el crecimiento, pero este conjunto de datos es bastante limitada en términos de cobertura geográfica, número de marcas y sus duraciones limitadas en libertad. Se explica provisionalmente el crecimiento mucho más rápido del listado que ha sido observado en zonas templadas del Atlántico. El documento concluye también que el modelo de crecimiento de von Bertalanffy podría no ser adecuado para describir el crecimiento real del listado, en primer lugar debido al crecimiento rápido, durante la fase de pre-reclutamiento (entre el nacimiento y 40 cm) y debido al crecimiento más complejo del listado que migra estacionalmente a aguas templadas y ecuatoriales. Se realizan diversas recomendaciones para mejorar los conocimientos sobre el crecimiento de listado, la mayoría de ellas dirigidas al programa de marcado a gran escala previsto por ICCAT.

KEYWORDS

Tuna, Skipjack, Growth curves, Atlantic

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1. Introduction

Results from tagging programs are the only way to estimate skipjack growth, then there is a need to review the results of the past ICCAT skipjack recoveries (from the literature and from the tagging/recovery data) and then to make recommendations in order (1) to improve their analysis and (2) to improve the efficiency of the future ICCAT tagging program on skipjack.

2. Material and methods

Basic data: the ICCAT tagging and recovery file. This file has already been analyzed by various authors (Bard and Antoine 1986, Hallier et Gaertner 2006). Skipjack recovery data obtained from other RFO (Fonteneau and Hallier 2014). Growth rates at sizes obtained from tagging programs are easily and well estimated by the growth rates between tagging and recovery, this value being assigned to the average size class between tagging and recovery (Fonteneau and Gascuel 2008 method). Potential bias in this method are dependent of the growth model, sizes at tagging and recoveries and durations at liberty. These biases are easily estimated by simulation: if skipjack growth is following a Von Bertalanffy pattern in the studied size range, this simulation shows that there is no risk of significant bias in the estimated skipjack growth rates in the results of the Fonteneau and Gascuel 2008 method. This result is well shown by **Figure 1:** showing solely a small bias underestimating the real growth rates at all sizes at rates between 1 and 2%.

3. Results and discussion

3.1 Atlantic skipjack growth rate at size and modelled growth

Skipjack growth analysis in the literature (Bard and Antoine 1986, Hallier and Gaertner 2008), both based on a Von Bertalanffy model, are showing a typical and clear distinction between 2 growth patterns: slow growth in equatorial areas and much faster growth in **northern temperate areas** (shown by Bard-Antoine 1986 and by Hallier and Gaertner 2008). These results concerning the Atlantic skipjack growth in the Atlantic are summarized in table 1: It should also be kept in mind that these various Von Bertalanffy growth curves between 40 cm and their corresponding L infinity estimated, also correspond to a linear decline of growth rates as a function of skipjack sizes, see **Figure 2**. This figure is showing well that, even if the K and L infinity parameters are quite different, the growth rates estimated by the 2 papers and authors, are in fact quite similar: at all sizes and in each area. However, differences in growth rates are quite large and in both models, between the northern temperate and equatorial areas.

Skipjack growth rates at size measured by tagging in the Atlantic are showing a rather strange flat profile, and limited visible decline of growth rates at increasing sizes (as expected in the Von Bertalanffy models, see **Figure 3**, that have been most often used to analyze skipjack growth). Surprisingly, this profile of growth rates at size appears to be typical of skipjack growth rates worldwide. Unfortunately there is a quite wide uncertainty in these estimated Atlantic growth rates, because of the quite small numbers of recoveries that can be used in growth studies (only 3444) and because many skipjack recoveries have been poorly documented skipjack in the Atlantic (in term of their sizes and/or time at liberty).

In reality, large parts of the skipjack eastern stock are clearly moving each year to the northern areas, and many/most individuals are probably following a composite growth curve that will be studied and better estimated in paragraph 3.6.

3.2 Growth rates of juvenile skipjack (between birth and 40 cm) and duration of its juvenile life?

The real age of skipjack at about 40 cm (or 1.2kg), their full recruitment size in the surface fisheries, remains highly questionable. In most Von Bertalanffy models with an unknown Tzero, this early period of the skipjack life would need very long durations: between 1 and 2 years! In reality, this early period of the skipjack life would appear to be very short: based on recoveries of skipjack in the 30-40 cm in other areas, and based on the universal rule that in this range of sizes tuna growth is most often very fast (bigeye and yellowfin cases): if these very small tunas want to survive in the open ocean, they need to grow very fast! An absolute age close to 6 months at 40 cm, as estimated in the Indian Ocean by Eveson *et al.* 2014, appears to be a realistic result, then assuming very fast growth rates during this period (an average of 6.6 cm/month. This hypothesis of an early period of fast growth should be the only one used in stock assessment models, this biological point being of some importance in the stock recruitment relationship and in the analysis of recruitment variability (even if this early period takes place before the recruitment in the fisheries).

It should also be kept in mind that this question on the growth of juvenile skipjack also cast a fundamental question on the use of the Von Bertalanffy curve to describe skipjack growth: this model may be a valid one, for adult skipjack, but it cannot describe the real growth between its birth and its death. This conclusion would follow the conclusion obtained by Lester *et al*. 2004 following their comprehensive discussion of the Von Vertalanffy growth that: *"the parameters of the Von Bertalanffy equation are simple functions of age at maturity and reproductive investment. This equation provides a good description of somatic growth after maturing, but not before"*.

3.3 Why such a much faster growth of skipjack in temperate areas?

This differential growth between temperate and equatorial growth can easily be explained by a rather strong hypothesis:

1) It is well accepted that skipjack are + or – continuously spawning when they are in warm equatorial waters over 25°C.
2) It is also well accepted, and strongly confirmed by recent work by AZTI scientists, that skipjack do not have fat reserves in their body, and that they are using in real time their feeding energy: having too much sex, their growth is reduced.
3) On the opposite skipjack living in temperate waters at SST lower than 25°C, where skipjack are often abundant (Mauritania, Canary, Azores, Angola, Brazil, etc....), in areas without sexual activities and where they use all their feeding energy to live and to growth, their growth is expected to be much more active.
4) Also taking note that these cold waters areas are often coastal upwelling areas of high biological productivity with large biomass of small pelagic available as a more abundant food for skipjack (Senegal, Mauritania, Angola…).

This pattern of faster growth of skipjack in temperate areas could also explain why skipjack growth is much faster in the EPO[2] (**Figure 3**), mostly a feeding area often with SST lower than 25°C, when growth rates are much lower in the WPFC, an area dominated by skipjack spawning in the warm pool. This pattern of faster growth of skipjack in temperate areas could also explain the rather flat profile of the growth rate at size observed worldwide (shown by **Figure 3**): when skipjack are growing, they are more and more frequently moving to temperate waters, then reducing their reproduction and improving their feeding and their grow rates. Simply moving from equatorial growth rates to temperate ones.

3.4 Overview of skipjack growth in other oceans:

The various Von Bertalanffy growth curves estimated by scientists in the various oceans and at different periods are quite difficult to compare because widely distinct K and Linfinity may often correspond to very similar growth rates at size. A simple way to avoid this difficulty is to compare the average growth rates at size estimated between tagging and recovery by the Fonteneau and Gascuel 2008 method. This comparative analysis has been done by Fonteneau and Hallier 2014 based on the numbers of skipjack recoveries given in **Table 2**.

The average growth rates estimated by the Fonteneau and Gascuel method in the various oceans are shown by **Figure 3**. These apparent Growth rates at size of skipjack appear to be:

- Very similar skipjack in the Atlantic and Western Pacific. The Average growth rates at size between 45 and 65 cm are nearly identical in the WPO and Atlantic oceans, but growth rates of juvenile skipjack <45 cm (1.7kg) are much higher in the WPO, especially at sizes <35 cm (0.75kg) (**figure 4).** It can be noted on this figure that the uncertainties in the Atlantic growth rates are much larger than in the Western Pacific Ocean, mainly because of the smaller number of tags recovered in the Atlantic.
- On the opposite significantly distinct average growth rates have been observed between the Indian Ocean (slow growth) and the Eastern Pacific (fast growth): skipjack growth rates being on the average 3 times larger in the EPO (**Figure 5**). It can also be noted on this figure that the uncertainties in the Eastern Pacific growth rates are much larger than in the Indian Ocean, mainly because of the smaller number of tags recovered in the first area.

[2] EPO : Eastern Pacific Ocean.

3.5 Skipjack durations at liberty

Atlantic skipjack recoveries are widely dominated by very short duration at liberty: only 74 individuals (1.72% of recoveries) have been showing in the Atlantic durations at sea over 12 months! On the opposite a widely distinct pattern of durations have been observed in other oceans, for instance in the Indian Ocean: on a total of 12500 well documented skipjack recoveries, 1737 recoveries have been observed after more than 1 year at liberty (14%), 171 skipjack showing duration at sea over 2 years (and few skipjack reaching durations of 5 years at sea!). As a result, today analysis of the skipjack growth are based on these Atlantic short term recoveries and they remain quite weak, because they are lacking the long term recoveries that are integrating skipjack movements between temperate and equatorial waters, and measuring well the long term growth pattern and the real asymptotic size of the species.

Furthermore it would be important to understand the causes of this major discrepancy in the durations between tagging and recovery observed in the various oceans, and to explain why we have obtained in the Atlantic so few long term skipjack recoveries? Potential causes are the following:

1) Higher total mortality in the Atlantic?
2) Reduced catchability at increased sizes because of fish behaviour or because of their movement outside fishing zones?
3) Lower F in the Atlantic?
4) Lower reporting rates of large skipjack?
5) High type 2 tag shedding?
6) Too small number of tags and large % of short term recoveries, then reducing the potential of long term recoveries?

This basic uncertainty in the Atlantic recoveries would need to be better understood and explained.

3.6 Skipjack equatorial and northern growth: towards a migratory growth model

There is in the Atlantic a typical and clear distinction between 2 growth patterns: slow growth in equatorial areas and much faster growth in northern temperate areas (well shown by Bard and Antoine 1986 and also analyzed by Hallier and Gaertner 2008, see **Figure 6**). In reality, large parts of the skipjack Eastern stock are clearly moving each year to the northern areas, many/most individuals probably will follow a composite growth curve combining the 2 growth curves.

A simple FORTRAN program following the growth of a migrating skipjack: assuming 2 known daily growth that are typical of 2 N and S areas: here the 2 N and S growth patterns proposed by Bard and Antoine 1986 and by Hallier and Gaertner 2008. Skipjack was born in the southern equatorial area and stay during X days in this area. At a given date, the fish moves to the temperate area, and its shows the daily growth rate of this area: the skipjack stay a given period of Y days in temperate waters (5 months, starting on May 1st in the present simulations). After this period our simulated fish moves to the equatorial areas, where its growth rates are reduced following the Equatorial growth curve. This N-S seasonal movement and the subsequent growth patterns are maintained during 5 years. A typical migratory growth curve obtained by this simple model (assuming each year 5 months of temperate migration) is shown for the Bard and Antoine 1986 and for the Hallier and Gaertner 2008 growth curves by **Figure 7**. As a result, the growth of this migrating skipjack is well known: its individual growth will simply be dependent of the duration of its holidays in the temperate and equatorial areas.

4. Conclusion and recommendations

Present results from the ICCAT tagging programs remain quite insufficient to estimate skipjack growth in the Atlantic. There is no doubt that great care should be developed in the AOTTP planned by ICCAT to estimate well skipjack growth at all sizes, and also to understand better the peculiarities of the skipjack growth pattern in various ecosystems.

As a conclusion, the following list of recommendation should be a positive base to progress in this field:

- In general: recoveries should be carefully measured by field scientists/technicians and their time at liberty well identified (as in the IOTTP); these information and their uncertainties should be carefully entered in the tagging/recovery database.
- Very small skipjack, for instance in the size range between 30 and 40 cm, should be actively tagged in selected spots during the planned AOTTP (possibly using smaller tags?). The analysis of fishery data should help to identify these time and area strata.
- Smaller sizes of the skipjack caught off Brazil should be tagged, and their size at recovery carefully measured in order to estimate the skipjack growth rate of this very peculiar group of fish.
- Sexes of large skipjack recovered (for instance at sizes larger than 60 cm) should be identified, as the asymptotic size of male and female may be distinct (as it was concluded in the Indian Ocean on yellowfin and bigeye by Fonteneau and Ariz 2014).
- Growth of juvenile skipjack at sizes <40 cm (1.2 kg) should be better analyzed, understood (for instance using DEB models?), and introduced in the stock assessment models.
- Von Bertalanffy model appears to be widely questionable for skipjack: alternate growth models should be explored (DEB models?).
- The short durations at liberty observed in the Atlantic tagging results should be better explained
- ICCAT Skipjack stock assessment should be based on ad hoc *"migratory growth curves"*: assuming a fast growth of skipjack smaller than 40cm and a composite growth of individuals migrating between Equatorial and temperate areas.

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Table 1. Von Bertalanffy growth parameters estimated by various papers for Atlantic skipjack in equatorial and northern temperate waters.

	area	"L infinity"	yearly k
Bard and Antoine 1976	**Temperate**	**80,00**	**0,60**
	Equatorial	**80,00**	**0,32**
Hallier and Gaertner 2008	**Temperate**	**112,34**	**0,14**
	Equatorial	**89,38**	**0,38**

Table 2. Number of skipjack tagged and recovered with know size and duration at sea (2005 being the last year for the Pacific Ocean).

	SKJ tagged	Growth Recoveries
Eastern Pacific	**131 227**	**754**
Western Pacific	**620 148**	**6 527**
Atlantic	**43 448**	**3 344**
Indian Ocean	**120 015**	**9 882**

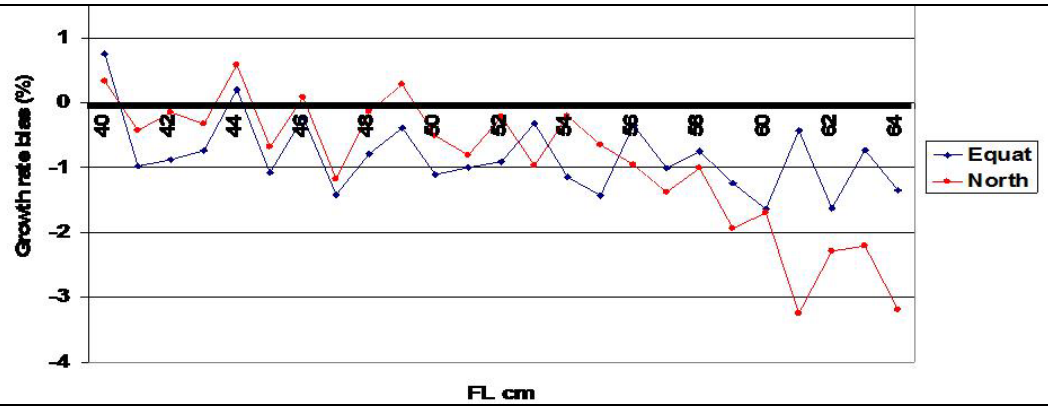

Figure 1. potential bias estimated by simulation (based on the sizes of tagged skipjack and on their observed durations at sea) in the results of the Fonteneau and Gascuel 2008 method (expressed in % of the real growth rates in the Von Bertalanffy models) estimating the growth rates at size (Von Bertalanffy models based on the Bard and Antoine 1986 parameters.

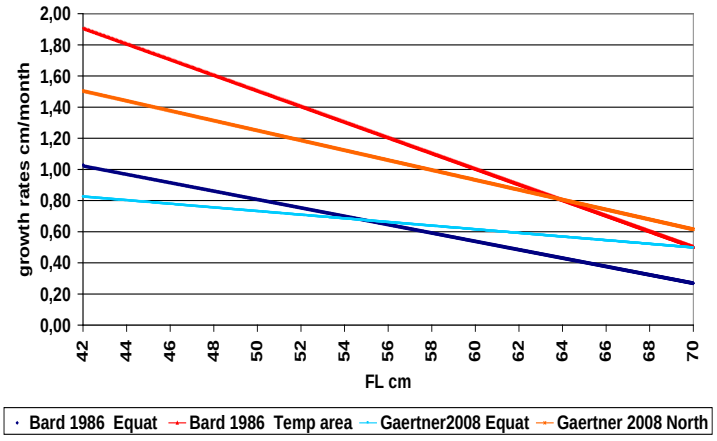

Figure 2. Growth rates at sizes estimated for Atlantic skipjack as a function of their fork length by various authors.

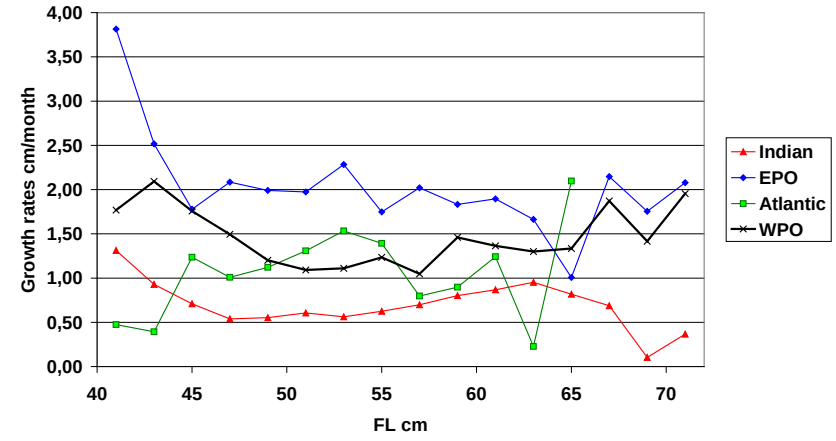

Figure 3. Growth rates at size of skipjack estimated in the various oceans.

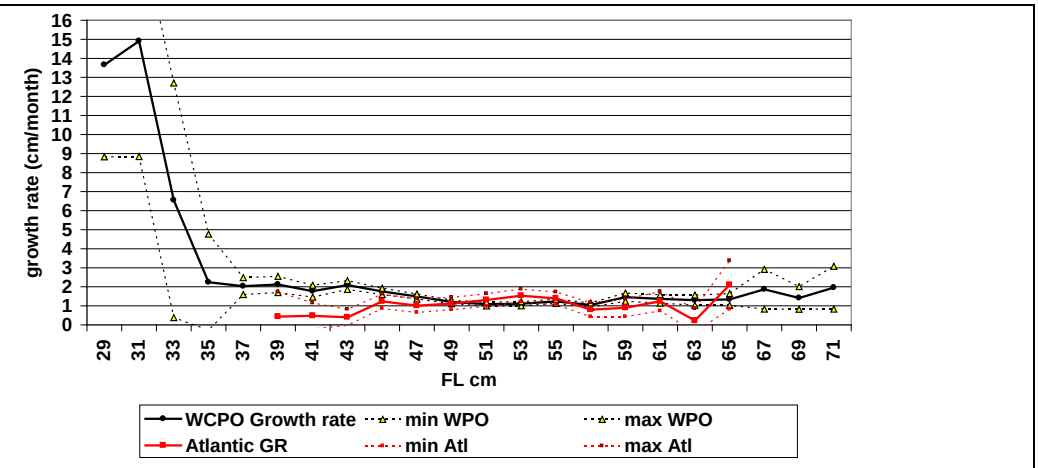

Figure 4. Average growth rates at size estimated for skipjack in the Atlantic and Western Pacific oceans, and uncertainty range in these average rates.

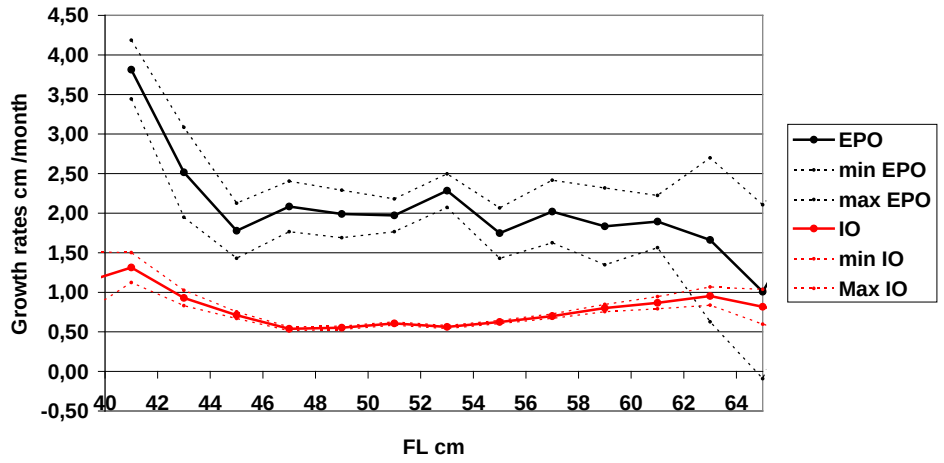

Figure 5. Average growth rates at size estimated for Skipjack in the Indian and Eastern Pacific oceans, and uncertainty range in these average rates.

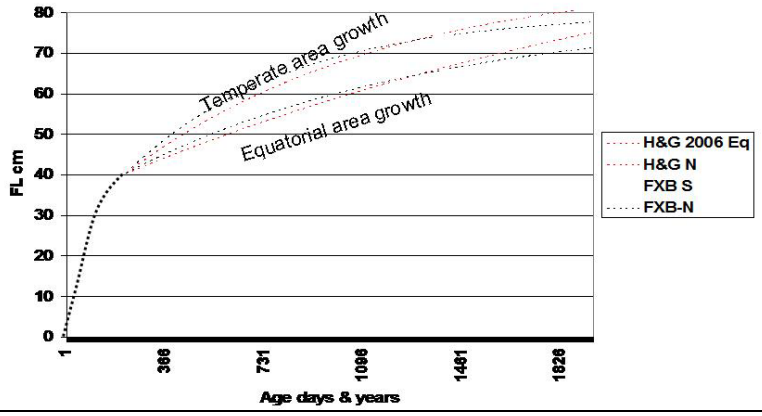

Figure 6. Atlantic skipjack growth estimated by various authors from tagging results in the equatorial and temperate areas (HandG: Hallier and Gaertner 2008, FXB: Bard et Antoine 1986).

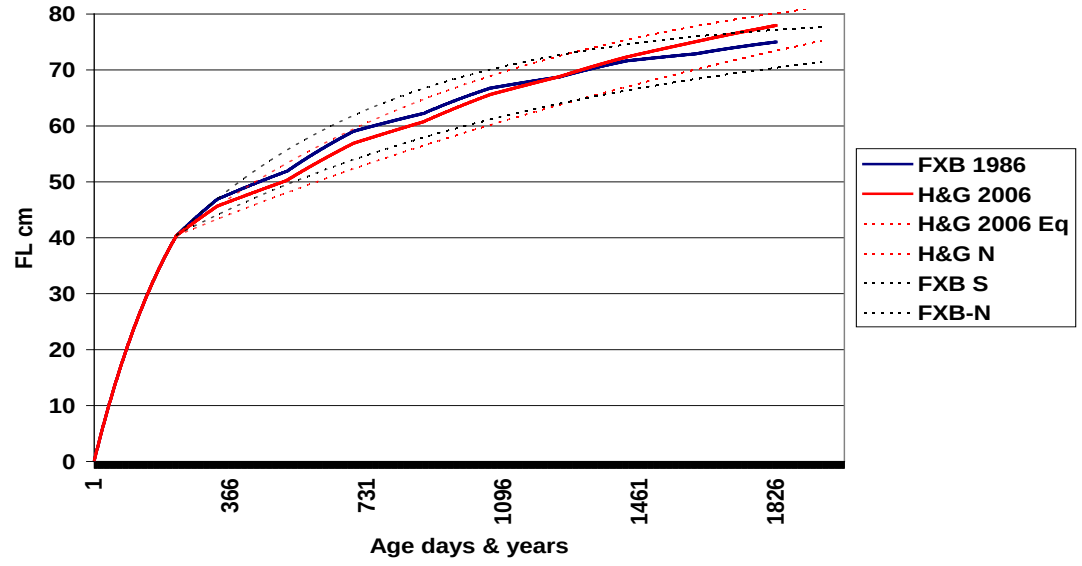

Figure 7. Expected growth curves of migrating skipjack, moving each year during 5 months in temperate areas, and following given growth curves.