Update of estimation for the unaccounted catch mortality in Australian SBT farming in 2015

豪州畜養ミナミマグロの未考慮漁獲量推定の 2015 年の更新

Itoh, Tomoyuki[1] and Sayako Takeda[2]
1: National Research Institute of Far Seas Fisheries,
Fisheries Research Agency
2: Fisheries Agency of Japan

要約

CCSBT 委員会は第 20 回年次会合において、全ての未考慮の漁獲死亡の影響評価を ESC に付託した。我々は、オーストラリア畜養に関係する表層漁業の漁獲について、未考慮の漁獲死亡量推定を継続して実施している。本文書では 2014 年までの推定値を求める。従来の成長率推定方法を変更し、体長ベースの成長率を用いた。また、これまでの解析に対して示唆された可能性のある問題点について検討し、多くは解決された。

SRP 標識データから推定した畜養魚の成長率は他のマグロ属野生魚の成長率と同程度にしかならなかった。豪州政府が報告する畜養終了後の収穫漁獲量を 40/100 尾サンプリングに基づく年齢組成から達成する成長率は、SRP 標識データから求めた成長率に比較して著しく高く、太平洋クロマグロ畜養魚の成長率よりも著しく高いことから、事実である可能性は低いと考えられた。

SRP 標識データから求めた成長率で推定した豪州まき網の漁獲量は、報告漁獲量よりも 724 トンから 2,546 トン、平均 1,702 トン多かった。推定超過漁獲量は報告量よりも 14% から 56%、平均 35.5%大きかった。推定超過漁獲量の割合は年々、増加する傾向にあった。

未考慮漁獲量および年齢組成の調節に際しては、本結果の年別の推定値（平均 35.5%）または 40%以上を用いた結果も考慮するべきである。本文書の解析の信頼性についてはオーストラリアが CCSBT 事務局に報告している CDS の個体別体長体重データを解析することで検証できる。ESC は、ステレビデオカメラシステムの導入によって信頼できる体長デ

ータを取得することでこの漁獲量に関わる不確実性に対する懸念を払拭することを、委員会に勧告すべきである。

Abstract

The CCSBT Extended Commission (EC) requested the Extended Scientific Committee (ESC) to conduct sensitivity analyses around all sources of unaccounted catch mortality of southern bluefin tuna (SBT) at the 20th annual meeting. We have been continuing estimation of possible unaccounted catch mortality relating to farming in the Australian surface fishery. We provide updated estimation up to 2014 in this document. We changed the estimation method to use growth rate in fork length. We also made comments for the suggestions given for our previous analyses and we believe most of them were resolved.

Growth rates of farmed SBT estimated from CCSBT-SRP tagging data were as low as those of other *Thunnus* species in wild. Assumed growth rates, which explain reported amount of catch for Australian purse seine with 40/100 fish size sampling for the total amount of harvested farm fish, were extremely higher than growth rate from SRP tagging data and growth rate of farmed Pacific bluefin tuna, and then appear to be highly unlikely.

The Australian surface catches were estimated, by using SRP tagging growth rate, to be higher than reported catches by annual amounts ranging from 724 tons to 2,546 tons, with a mean of 1,702 tons. The estimated proportion of this excess of the reported catch ranged from 14% to 56% with a mean of 35.5%, and is in increasing trend over time.

When considering unaccounted catches and adjustment of age composition, the mean of 35.5%, and even the possibility of values >40% should be considered. Reliability of our results can be further evaluated by analyzing CDS data which includes individual body weight information for all of the farmed individuals that Australia reported to Secretariat. Furthermore, the ESC should recommend the EC to dispel the concern of this uncertainty on catch by recommending immediate implementation of the stereo video camera system to provide reliable length data.

緒言

ミナミマグロ *Thnnus maccoyii* の資源管理は、2011 年に CCSBT において管理方式(MP)による TAC 決定システムが導入されたことで、新たな時代を迎えた。MP の導入はマグロ類の地域漁業管理機関においては初めての事例であり、CCSBT の取組みは世界的に注目を集めている(Hillary et al. 2015)。

一方、当然のことながら、適切な資源管理のためには、MP のように科学的な根拠に基づく漁獲枠の設定とともに、設定された漁獲枠に対する遵守を確保することが必要である。近年、CCSBT とその加盟国は遵守の強化に精力的に取り組んできた。しかしながら、漁獲枠の相当部分を占める畜養セクターに付随する表層漁業においては、漁獲量の過小報告のリスクが解決されないままとなっている。畜養にまき網で漁獲された種苗を利用する場合、ハンドリングによる種苗の死亡リスクを軽減するため、まき網から生け簀への移送量は推定値となる。このため畜養魚の漁獲量については高い不確実性が存在し、例えば大西洋クロマグロにおいては 1990 年代半ばからの畜養向けまき網漁獲の増加に伴って深刻な過小報告があり、資源の保全を損なうと考えられている(Anon. 2010)。このため、ICCAT においては、2012 年にステレオビデオカメラ又は同等の正確性を持つ代替技術により 100%の活け込みをカバーすることが義務化され(Recommendation 12-03)、2013 年には活け込まれる魚の 20%以上を測定すること等が規定された(Recommendation 13-08)。

ミナミマグロについては、活け込み時に数千尾ほどの原魚の中から 40 尾を抽出サンプリングし、その平均体重で全漁獲量、活け込み量を推定する方法が唯一の畜養国である豪州によって用いられてきた。豪州は、2013 年からはサンプリング尾数を 100 尾に増加させているが、本質的な問題解決には結びついていない。抽出サンプリングによる漁獲量推定には根本的な問題があるものと考えられる。

豪州畜養魚の年齢組成に関わる不確実性については、2005 年に問題が指摘され(Anon. 2005)、独立レビューではデータ不足から結論が出なかった(Anon. 2006)が、その後の畜養後の体長体重測定データから大きなバイアスが存在することが強く示唆された(Itoh et al. 2009a, 2009b, 2010, 2011, 2012, 2014)。その推定されたバイアス(過剰漁獲)は、毎年の報告量に対して 1054 トン(20%)から 2366 トン(61%)、平均 1640 トン(34.5%)にも及んだ。

CCSBT 委員会は第 20 回年次会合において、全ての未考慮の漁獲死亡を含めた資源評価の感度分析を実施し、その影響を評価することを ESC に付託した(Anon. 2013)。1000 トンを超える未考慮漁獲死亡量は可能性のある未考慮漁獲死亡量の中でも最大規模のものであり、詳細な検討が必要である。

本文書はオーストラリア畜養に関係する表層漁業の漁獲について、未考慮漁獲死亡量の推定を 2014 年まで更新するものである。また、これまでの解析に対して示唆された問題点に対してコメントする。

Introduction

The management of southern bluefin tuna (*Thunnus maccoyii*; SBT) stock entered a new era with implementation of a management procedure (MP) in the CCSBT in 2011. The implementation of this MP was the first such instance amongst all the tuna-RFMOs, and has attracted attention worldwide (Hillary et al. 2015).

Without doubt, appropriate stock management requires not only setting catch limits on the basis of sound science, as reflected by the MP, but also securing compliance with such catch limits. In this regard, the CCSBT and its Members have rigorously reinforced compliance measures and efforts over recent years. However, a major uncertainty related to the catch taken has remained unresolved in purse seine fishery associated with the farming sector, which catches a considerable portion of the global TAC for SBT. When accounting for the wild fish caught by purse seine in tuna farming operations, the amount of catch is not measured directly but rather estimated in order to minimize the risk of death by handling. For this reason, it has been widely acknowledged that there can be a high level of uncertainty in estimation of the catch made for farming. For example, catches of Atlantic bluefin tuna (*Thunnus thynnus*) in the East Atlantic and Mediterranean were seriously underreported from the mid-1990s along with the development of farming in that region, and ICCAT considered that the underreporting of that catch had undermined conservation of the stock (Anon. 2010). To cope with this problem, ICCAT has introduced a regulation that a program using a stereo video system or an equivalently precise alternative technique must cover 100% of all caging operations (ICCAT Recommendation 12-03). In addition, at the ICCAT Commission meeting in 2013, it was agreed that the sampling intensity for stereo video systems may not be below 20% of the amount of fish being caged (ICCAT Recommendation 13-08).

For SBT, Australia, the only member nation with farming operating, has employed an estimation method which samples 40 individual fish from groups of several thousand fish just before transferring them to pens, measures them, and uses the average weight for estimation of their age composition and the total weight of the fish at the time of their capture. Although Australia has increased the number of sampled fish from 40 to 100 since 2013, the associated estimation accuracy does not appear to have been improved substantially. It seems that intrinsic problems remain with the current catch estimation method based upon sampling.

The uncertainty associated with age composition of farmed SBT was pointed out in 2005 (Anon. 2005). The issue was reviewed by the independent panel but they did not reach a final conclusion due to scarcity of data (Anon. 2006). However, the existence of

a large bias became more evident following subsequent studies based on a large amount of data for length and weight measurements of fish after farming (Itoh et al. 2009a, 2009b, 2010, 2011, 2012, 2014). The estimated excess annual catches, relating this uncertainty, were large as ranged from 1054 tons (20%) to 2,366 tons (61%) with mean of 1,640 tons (34.5%) in the previous analyses.

The EC requested at its 20th annual meeting to ESC to conduct sensitivity analysis around all sources of unaccounted catch mortality (Anon. 2013). Possible unaccounted mortality that may exceed 1000 tons is the largest one among several candidates of unaccounted catch mortality and detail evaluation is required on this uncertainty.

This paper provides SBT unaccounted catch mortality of surface fishery relating Australian farming up to 2014. Values in previous years are revised with new growth rates. In addition, we respond to comments which have given for our previous analyses.

材料と方法
使用データ

推定には、豪州のまき網で漁獲し畜養に使用した魚について、漁期年別の統計値を用いた。オーストラリア漁期は 12 月から 11 月までである。12 月から 3 月がまき網漁獲の主漁期であることから、本研究では前年 12 月からその年の 11 月までで漁期年を表記した。例えば、2014 年度は 2013 年 12 月から 2014 年 11 月までである。

統計値は漁獲、畜養開始時、畜養終了後の収穫時について必要となる (Fig.1)。オーストラリアのまき網による報告漁獲量、漁獲尾数および年齢別漁獲尾数は、CCSBT から 2015 年 1 月に各国に配布された CD に含まれたデータベースの値を用いた (Table 1, Table 2)。最近年については 2015 年データ交換で示された値を用いた。ただし 2001 年と 2002 年についてはまき網による統計値が独立していなかったので、漁獲重量については CCSBT-ESC/1309/SBT Fisheries-Australia (Hobsbawn et al. 2013)の Table1 の値を、漁獲尾数については延縄を除いた漁法の尾数を用いた。

畜養魚について、野生魚（畜養原魚）の漁獲重量、生け込み尾数、畜養後の収穫時の尾数および重量については、2001 年から 2009 年までは TIS の Yearly Farm Data Summary の値を使用した。2010 年から 2014 年までは、半年ごとに各国に配布される CDS 情報の値を使用した。

野生魚の体長体重関係は、解析対象とする豪州沿岸の未成魚について求めた Robins (1963)のものを用いた。近年のデータと比較した結果、Robins (1963)の体長体重関係を使用することに問題はないと判断された (Attachment 1 を参照)。畜養魚の体長体重関係は、2007 年 7 月の生鮮魚 4267 個体の体長、製品重量 GG から求めたもの (Itoh et al. 2012)

を用いた。畜養魚の製品重量から原魚重量への換算については、原魚重量は製品重量の 1.12 倍＋1kg の関係を用いた（Anon. 2014b）。

　本文書で、収穫とは畜養が終了し、取り上げて殺した時点をいう。

SRP 標識データからの畜養魚の成長率の推定

　これまで CCSBT-SRP 標識放流における畜養魚の成長量を体重で求めた値を使用してきた（Sakai et al. 2009）。畜養魚の年齢組成の推定過程においては、体重から体長に Robins (1963)の体長体重関係式で変換していた。OMMP5 において、よりシンプルに体長での成長量で計算することが提案された。そこで、体長の成長量を求めた。

　また、これまで von Bertalanffy 成長式のパラメータ K による表現を行ってきた (Itoh et al. 2014)。von Bertalanffy－K で表現することは全ての年齢について統一した値で検討できる長所がある。しかし成長量を直感的に把握しにくいこと、単純な von Bertalanffy 成長式ではミナミマグロの成長を近似しにくいことといった問題点があった。そこで、各年齢における畜養半年後時点までの成長量で表現することに変更した。

　Sakai et al.(2009)で使用した 142 個体のデータのうち、外れ値および負の成長をしたデータを除いた 123 個体のデータを用いた。日成長率は体長の増加に伴って有意に低下したことから、体長を変数として含めた一次式で表した。

漁獲月の推定

　野生魚の漁獲時と CCSBT の年齢区分である 1 月 1 日との漁獲時期の差、または CCSBT における年齢別平均体長値との差については、漁獲月にずれがあるものとみなして調整した（Table 3）。年齢別漁獲尾数と年齢別平均体重との積が TIS（または CDS）に記載された漁獲総重量に合致するように、調整する漁獲月数 adj.mon$_y$を求めた。

$$W_{JAN,i} = Robins\ A \times \left(L_{JAN,i}\right)^{Robins\ B} \tag{1}$$

$$W.catch_{y,i} = W_{JAN,i} \times adj.mon_y \times \frac{1}{12} \times \left(W_{JAN,i+1} - W_{JAN,i}\right) \tag{2}$$

$$\min\left(abs\left[W.TIS.catch_y - \sum_{i=0}\left(W.catch_{y,i} \times N_{y,i} \times \frac{N.Trans_y}{\sum_i N_{y,i}}\right)\right]\right) \tag{3}$$

　ここで、

L$_{JAN,i}$: ミナミマグロ野生魚 *i* 歳における 1 月 1 日時点の平均尾叉長(cm)。CCSBT で使用している値を使用。

Age	Age1	Age2	Age3	Age4	Age5	Age6	Age7
Fork	49.4	79.4	97.2	110.2	121.2	130.6	138.4

length

Robins A、Robins B：Robins(1963)における野生魚の体長体重関係式の係数。Robins A=3.13088*10^{-5}、Robins B=2.9058

W$_{JAN,i}$：ミナミマグロ野生魚 i 歳における 1 月 1 日時点の平均体重(kg)。原魚重量。

adj.mon$_y$：漁期年 y 年の 1 月 1 日からの月数。

W.catch$_{y,i}$：漁期年 y 年の豪州まき網によるミナミマグロ野生魚 i 歳におけるまき網漁獲時点の平均体重(kg)。原魚重量。

N$_{y,i}$：漁期年 y 年の豪州まき網によるミナミマグロ i 歳魚の漁獲尾数。

N.Trans$_y$：漁期年 y 年の豪州まき網による TIS（または CDS）に記載されたミナミマグロ合計生け込み尾数。曳航中の死亡個体は含んでいない。

W.TIS.catch$_y$：漁期年 y 年の豪州まき網による TIS（または CDS）に記載されたミナミマグロ合計漁獲重量。

報告漁獲量からの畜養魚の成長率の推定

"年齢別漁獲尾数" と "収穫時の推定体重" との積の合計が"TIS および CDS における収穫時の合計重量"に合致するように畜養期間中の日成長率を推定した。体長に対する一次式において、傾きは SRP 標識データで求めたのと同じものを使用し、切片を調整した。

漁期年 y 年、i 歳魚の畜養後(畜養期間 0.5 年間)の体長 L.Harv$_{y,i}$および原魚重量 W.Harv$_{y,i}$ は以下で計算できる（Anon. 2014b）。

$$L.Harv_{y,i} = L_{JAN,i} + (I_y + L_{JAN,i} \times a) \times 365 \times (0.5 - \frac{adj.mon_y}{12}) \tag{5}$$

$$W.Harv_{y,i} = exp\left(\frac{1}{b.harv} \times \left(log(L.Harv_{y,i}) - log(a.harv)\right)\right) * 1.12 + 1 \tag{6}$$

I_y と a は日成長率一次式の切片と傾き、a.harv、b.harv は畜養魚の体長体重関係式のパラメータ値。

次式を最小とする I_yを求める。

$$min\left(abs\left(W.TIS.Harv_y - \sum_{i=0}\left(W.Harv_{y,i} \times N_{y,i} \times \frac{N.TIS.Harv_y}{\Sigma_i N_{y,i}}\right)\right)\right) \tag{7}$$

W.TIS.Harv$_y$：漁期年 y 年の TIS における収穫合計重量 (kg)。原魚重量。

N.TIS.Harv$_y$：漁期年 y 年の TIS における収穫合計尾数。

仮定した成長率による年齢組成と漁獲重量の推定

与えた成長率に合致するように畜養魚の年齢組成をシフトさせ、漁獲量を推定した

（Table 3）。成長率は、CCSBT の SRP 標識データから推定した畜養魚の成長率を用いた（Case1）。また、畜養魚の成長が体長においては野生魚と同じとの仮定でも計算を行った（Case2）。この仮定は、ICCAT において大西洋クロマグロの資源評価モデルに使用するデータのベースケースとされている（Anon 2014a, Fonteneau 2013）。

これらの成長率に対応した漁期年 y 年、i 歳魚の畜養後の体長 L.Harv2$_{y,i}$、原魚重量 W.Harv2$_{y,i}$は以下で計算できる。

$$L.Harv2_{y,i} = L_{JAN,i} + (I_y + L_{JAN,i} \times a) \times 365 \times (0.5 - \frac{adj.mon_y}{12}) \qquad (8)$$

$$W.Harv2_{y,i} = exp\left(\frac{1}{b.harv} \times \left(log(L.Harv2_{y,i}) - log(a.harv)\right)\right) * 1.12 + 1 \qquad (9)$$

次式を最小とする α_y を求める。

$$\min\left(abs\left(W.TIS.Harv_y - \sum_{i=1}\left(W.Harv2_{y,i} \times \{N_{y,i}(1 - \alpha_y) + N_{y,i-1 \times}\alpha_y\} \times \frac{N.TIS.Harv_y}{\sum_i N_{y,i}}\right)\right)\right) \qquad (10)$$

α_y：漁期年 y 年にある年齢から 1 歳上の年齢へシフトさせる個体数の割合。ただし α_y>1 の場合は 2 歳上の年齢にシフトさせた。

豪州が漁期年 y 年にまき網で漁獲した重量は以下で計算される。

$$W.Est_y = \sum_{i=1}\left[(N_{y,i} \times (1 - \alpha_y) + N_{y,i-1} \times \alpha_y) \times W.catch_{y,i}\right] \times \frac{TotalN_y}{\sum_i N_{y,i}} \qquad (11)$$

TotalN$_y$：漁期年 y 年に豪州がまき網で漁獲した合計尾数。年齢別漁獲尾数の合計と異なる場合があるので補正する。
W.Est$_y$：漁期年 y 年に豪州がまき網で漁獲した推定重量（kg）。

Materials and methods
Data used

Values from the statistics of the Australian purse seine catch for farming operations separated into "fishing years" were used for estimation. An Australian fishing year begins in December and finishes in November (the main season for purse seine fishing is usually from December to March). A fishing year therefore represents a period from December of the previous year to November of that year in the present study, e.g. the 2014 fishing year means the period from December 2013 to November 2014.

The statistics required are the times of the catches made, the start of farming (caging) and the end of farming (harvesting) (Fig. 1). The data on the total catch reported by number and weight, and the catch in terms of numbers at age for the Australian purse seine fishery, were obtained from the database included in a CD which was distributed by the CCSBT Secretariat to each Member in January 2015 (Table 1, Table 2). The data for the most recent year were obtained from the 2015 data exchange process. However, for 2001 and 2002, as the total catch data were not separated by fishing gear, the catch weights in Table 1 of CCSBT-ESC/1309/SBT Fisheries-Australia (Hobsbawn et al. 2013) were used as the catch weight for farming, and the catch numbers from the CD database for all gears except longline were used as the catch numbers for farming.

For farming data, the total weight of wild fish captured for farming, the total number of fish transferred into farms, and the total whole weight and number of fish harvested from farms were obtained from Yearly Farm Data Summary of the Trade Information Scheme (TIS) between 2001 and 2009. Between 2010 and 2014, these numbers were obtained from Catch Documentation Scheme (CDS) statistics which were distributed to the CCSBT Members every six months.

The length-weight (LW) relationship in Robins (1963), which was based on young fish distributed in Australian coastal waters, was used for wild fish. Comparison to data in recent years shows that using the LW relationship in Robins (1963) is appropriate (see Attachment 1). The LW relationship used for farmed fish was obtained from the measurement of 4267 harvested fresh individuals, for which both fork length and gilled and gutted weight were measured in July 2007 (Itoh et al. 2012 CCSBT-ESC/1208/30). Gilled and gutted weight was converted to whole weight by multiplying by 1.12 and then adding 1kg, based on the method used by Australia (Anon. 2014b).

In this paper, "harvest" means the time SBT is grown out in the farming and killed.

Estimation of growth rate of farming fish based on SRP tagging data

In our previous analyses, growth rates of farmed fish in body weight, which derived from CCSBT-SRP tagging data, was used (Sakai et al. 2009). Then, body weight was converted to fork length using the LW relationship of Robins (1963) in the process to estimate age composition of farmed fish. In OMMP5, it was suggested to use growth rate in fork length, instead of body weight, in order to make the process simple. We follow such a reasonable suggestion and calculate growth rate in fork length.

Also in our previous analyses, growth rate was represented with parameter K of von Bertalanffy growth curve (Itoh et al. 2014). It has a merit that allows to express growth of various ages by one single value. However, it has demerits such that it is

difficult to understand the growth rates intuitively and that a simple von Bertalanffy growth curve is not necessarily appropriate to approximate growth of SBT. Therefore, the growth rate in this paper is expressed as the growth in half a year in farming by age.

SRP tagging data recaptured after farming were used. Among 142 individuals used in Sakai et al. (2009), subset of 123 individuals was selected after excluding anomalous or negative growth records. Because daily growth rate decreased significantly as fork length increased, daily growth rate is expressed as linear equation including fork length as variable.

Estimation of the month of capture

The difference between the actual date of wild capture and January 1st as the defined birth date for any age for SBT, or the difference of fork length between that at the actual wild capture and January 1st, was adjusted by using the mean difference between actual catch date and January 1st (Table 3). The adjustment for the number of months from January 1st $adj.mon_y$ was estimated so that the product of the catch-at-number multiplied by average body weight by age equaled the total catch weight reported in the TIS (or CDS).

$$W_{JAN,i} = Robins\ A \times \left(L_{JAN,i}\right)^{Robins\ B} \tag{1}$$

$$W.catch_{y,i} = W_{JAN,i} \times adj.mon_y \times \frac{1}{12} \times \left(W_{JAN,i+1} - W_{JAN,i}\right) \tag{2}$$

$$\min\left(abs\left[W.TIS.catch_y - \sum_{i=0}\left(W.catch_{y,i} \times N_{y,i} \times \frac{N.Trans_y}{\sum_i N_{y,i}}\right)\right]\right) \tag{3}$$

where $L_{JAN,i}$ = average fork length (cm) of wild SBT at January 1st for age i. The values used by the CCSBT were applied:

Age	Age1	Age2	Age3	Age4	Age5	Age6	Age7
Fork length	49.4	79.4	97.2	110.2	121.2	130.6	138.4

Robins A, Robins B = parameters of the length-weight relationship for wild SBT in Robins (1963). Robins A=3.13086*10⁻⁵, Robins B=2.9058;

$W_{JAN,i}$ = average whole body weight (kg) of wild SBT at January 1st of age i;

$adj.mon_y$ = the number of months from January 1st to capture during fishing year y;

$W.catch_{y,i}$ = average whole body weight (kg) of wild SBT at wild capture by the purse

seine fishery in the fishing year y;

$N_{y,i}$ = the number of SBT captured by the purse seine fishery of age i during fishing year y;

N.Trans$_y$ = the total number of SBT transferred into cages reported in the TIS (or CDS) during fishing year y; this does not include mortality during towing; and

W.TIS.catch$_y$ = the total weight of SBT reported in the TIS (or CDS) during fishing year y.

Estimation of growth rate of farming corresponds to reported catch

Daily growth rate during farming was estimated so that the product of the catch-by-number and the average body weight at harvest by age equaled to the total harvested weight reported in the TIS (or CDS). In linear equation of growth rate to fork length, the slope was assumed to be the same to the equation derived from the SRP tagging data, and intercept was estimated for each year.

$$L.Harv_{y,i} = L_{JAN,i} + \left(I_y + L_{JAN,i} \times a\right) \times 365 \times (0.5 - \frac{adj.mon_y}{12}) \tag{5}$$

$$W.Harv_{y,i} = exp\left(\frac{1}{b.harv} \times \left(log\left(L.Harv_{y,i}\right) - log(a.harv)\right)\right) * 1.12 + 1 \tag{6}$$

where I_y and a are intercept and slope of linear equation, respectively, and *a.harv* and *b.harv* are parameters of the length-weight relationship of farmed fish.

A value which minimize I_y in the following equation should be obtained.

$$\min\left(abs\left(W.TIS.Harv_y - \sum_{i=0}\left(W.Harv_{y,i} \times N_{y,i} \times \frac{N.TIS.Harv_y}{\sum_i N_{y,i}}\right)\right)\right) \tag{7}$$

where W.TIS.Harv$_y$ = the total weight of the SBT harvested in whole weight reported in the TIS (or CDS) for the fishing year y;

N.TIS.Harv$_y$ = the total number of SBT harvested in the TIS (or CDS) for the fishing year y.

Estimation of total catch weight from growth rates assumed

The total catch weight was estimated by shifting the age composition of farmed fish according to the growth rate given (Table 3). Growth rates assumed for farming SBT were those derived from the SRP tagging data (case1). In addition, an alternative computation assumed that the growth in body length of farmed fish is the same as that

of wild fish, although growth in body weight and also fatness are much larger in farmed fish (case 2). This is the assumption made for the base case for the stock assessment of Atlantic bluefin tuna in ICCAT (Anon. 2014, Fonteneau 2013).

The fork lengths (L.Harv2$_{y,i}$) and whole body weights (W.Harv2$_{y,i}$) of SBT after farming for age i during fishing year y were calculated using the following equations.

$$L.Harv2_{y,i} = L_{JAN,i} + (I_y + L_{JAN,i} \times a) \times 365 \times (0.5 - \frac{adj.mon_y}{12}) \tag{8}$$

$$W.Harv2_{y,i} = exp\left(\frac{1}{b.harv} \times \left(log(L.Harv2_{y,i}) - log(a.harv)\right)\right) * 1.12 + 1 \tag{9}$$

A value which minimize α_y in the following equation should be obtained.

$$min\left(abs\left(W.TIS.Harv_y - \sum_{i=1}\left(W.Harv2_{y,i} \times \{N_{y,i}(1 - \alpha_y) + N_{y,i-1 \times \alpha_y}\} \times \frac{N.TIS.Harv_y}{\sum_i N_{y,i}}\right)\right)\right) \tag{10}$$

where α_y = the ratio of the number of fish shifted to one age older in the fishing year y. α_y >1 means shifted to two ages older.

The total catch weight by Australian purse seine fishery during fishing year y is calculated as follows.

$$W.Est_y = \sum_{i=1}\left[(N_{y,i} \times (1 - \alpha_y) + N_{y,i-1} \times \alpha_y) \times W.catch_{y,i}\right] \times \frac{TotalN_y}{\sum_i N_{y,i}} \tag{11}$$

where TotalN$_y$ = the total number caught by the Australian purse seine fishery during fishing year y. This adjustment was necessary because the sum of the catch-at-age was different to this value in some years;

W.Est$_y$ = the total weight of catch (kg) by the Australian purse seine fishery during fishing year y.

結果
SRP 標識データからの畜養魚の成長率の推定

SRP 標識データの体長成長を Fig. 2 に示す。放流時の体長に対する日成長率を Fig. 3 に示す。成長に関する各種統計値を Table 4 にまとめた。畜養魚の個体別の成長率は個体差もあるが、3 歳魚で 6 ヶ月間では 13.33±0.68%（平均±SE）体長が増加（1.13 倍の体長にな

る）すると推定された（Fig. 4）。比較のためにミナミマグロ野生魚の成長もプロットした。例えば、野生の 3 歳魚は平均で 6 ヶ月間に 1.089 倍になる。この計算では野生魚については成長の季節変化を考慮し、7 月から 9 月の冬季には成長しないと仮定し、1 歳分の成長量は 9 ヶ月で達成するとして成長率を求めている。この比較から、畜養魚の体長における成長は同年齢の野生魚よりも高いことが分かる。

　なお、Sakai et al.(2009)では 6 ヶ月間の平均体重成長率を 2 歳魚 1.818 倍、3 歳魚 1.544 倍、4 歳魚 1.448 倍と推定した。標識魚の体長データに基づく本推定で、同様に Robins(1963) の体長体重関係を使用すると体重成長率は 2 歳魚 1.750 倍、3 歳魚 1.520 倍、4 歳魚 1.343 倍であり、ほぼ類似した結果が得られている（Table 4）。

　6 ヶ月間の成長量を他のマグロ属魚類と比較した（Table 5）。例えばミナミマグロ 3 歳魚は、3.0 歳時に 97.2cmFL である。6 ヵ月後に野生魚は 105.9cm、SRP 標識データから求めた畜養魚では 110.1cm に達する計算になる。97.2cmFL から 6 ヶ月間で、大西洋クロマグロ（ABF、*T. thynnus*）は 111.3cm に達し、太平洋クロマグロ（PBF、*T. orientalis*）は 115.7cm、メバチ（BET、*T. obesus*）は 112.4cm に達する。キハダ（YFT、*T. albacares*） は最も成長量が大きく 130.0cm に達する計算になる。これらの比較から、ミナミマグロの成長量はマグロ属 5 種の中で最低であること、畜養したミナミマグロでも、あるサイズでは大西洋クロマグロやメバチに近いが、やはり最低であると推定された。

報告漁獲量からの畜養魚の成長率の推定

　豪州政府が報告する畜養終了後の収穫漁獲量を、40/100 尾サンプリングに基づく年齢組成から達成する成長率を求めた（Fig. 4、Table 6）。SRP 標識データから求めた成長率に比較して著しく高かった。

　畜養魚の成長は太平洋クロマグロでも得られているので比較した（Masuma 2008）（Table 6）。ミナミマグロ 3 歳魚に相当する 97.2cmFL の太平洋クロマグロの畜養魚は、6 ヶ月で 124.5cm（八重山で飼育）から 125.9cm（奄美で飼育）に達した。しかし、元々両魚種が 6 ヶ月間で成長する量は異なるので、以下の RFW(Ratio of farmed fish growth to wild fish growth)で比較した。

$$\text{RFW} = \frac{Growth\ increment\ of\ farmed\ fish\ in\ 6\ months\ (cm)}{Growth\ increment\ of\ wild\ fish\ in\ 6\ months\ (cm)}$$

　太平洋クロマグロの RFW はミナミマグロ 3 歳魚相当の 97.2cmFL からは RFW=1.47（八重山）および 1.55（奄美）であった。ミナミマグロの畜養成長率で、SRP 標識データから求めたものでは RFW=1.49 でほぼ一致した。ただし 2 歳魚と 4 歳魚ではミナミマグロ畜養魚の RFW が低かった。豪州漁獲量と 40/100 尾サンプリングから求めた 3 歳魚の成長率では RFW=2.32 から 4.07 と極めて高かった。

仮定した成長率による年齢組成と漁獲重量の推定

　ミナミマグロ畜養魚の成長率が SRP 標識データから求めたような値の場合（Case1；6ヶ月で 2 歳魚は 20.0%、3 歳魚は 13.3%、4 歳魚は 8.0%の体長増加）、年齢組成は高齢にシフトし、推定漁獲量は報告漁獲量よりも 724 トンから 2,546 トン、平均 1,702 トン多かった（Table 3、Table 7、Fig. 5）。推定された超過漁獲量は報告量よりも 14%から 56%、平均 35.5%大きかった。推定された超過漁獲量の割合は年々、増加する傾向にあった（Fig. 6）。

　体長成長は畜養魚と野生魚で同じと仮定した場合（ケース 2）には、超過漁獲量は平均 2,289 トン、超過量の割合は 47.6%と推定された。

　混合正規分布や年齢スライシング法を使用した従来の漁獲量推定値と比較する（Table 8, Fig. 5）。詳細は Itoh et al.(2012)を参照。今回の Case1 での漁獲量推定はほぼ一致したが、わずかに過小推定であった。

Results

Estimation of growth rate of farming fish based on SRP tagging data

　Growth in length of SRP tagging data is shown in Fig. 2 by age.　Daily growth rate is plotted against fork length at release in Fig. 3.　Statistics of growth were summarized in Table 4.　For example in age-3 fish, growth rate of farmed fish in six months was estimated as 13.33 ±0.68% (mean ± SE) (fish reached 1.13 times in fork length after half a year) though some variation among individuals (Fig. 4).　For comparison, growth of wild fish was also drawn on the figure; age-3 wild fish become 1.089 times in fork length in half a year, by taking into account of seasonal growth change and assumed no growth in winter between July and September, thus one year growth increment was attained in nine months.　Higher growth of farmed fish in length is suggested in this comparison.

　By the way, Sakai et al. (2009) estimated growth in body weight in six months as 1.818 times in age-2, 1.544 times in age-3 and 1.448 in age-4.　Growth rates in the present study based on fork length, converted to body weight by using Robins (1963), produced 1.750 times in age-2, 1.520 times in age-3 and 1.343 times in age-4 (Table 4). No substantial difference was observed between the two methods.

　Six months growth in SBT was compared to that in other *Thunnus* species (Table 5). For example, mean fork length of age-3 SBT is 97.2 cmFL at age-3.　After six months, it becomes 105.9 cmFL in wild SBT and 110.1 cmFL in farmed SBT using growth rate of SRP tagging.　Wild *Thunnus* fish grow in six months from 97.2 cmFL to 111.3 cmFL in Atlantic bluefin tuna (ABF, *T. thynnus*), 115.7 cmFL in Pacific bluefin tuna (PBF, *T. orientalis*) and 112.4 cmFL in bigeye tuna (BET, *T. obesus*).　Yellowfin tuna (YFT, *T. albacares*) is estimated to become the largest as 130.0 cmFL.　These comparison shows that SBT grow the slowest in the five *Thunnus* species in wild condition, and also the

slowest even they are farmed, though similar to that of ABF and BET in some size.

Estimation of growth rate of farming corresponds to reported catch

Growth rates by year were also estimated for farmed SBT which attain reported harvest total weight from age compositions based on the 40/100 fish sampling (Fig. 4, Table 6). These were quite higher than growth rates estimated from SRP tagging data.

Regarding the farmed tuna, growth rate is available in PBF (Masuma 2008) and then compared (Table 6). Fish in 97.2 cmFL, corresponding to age-3 SBT, grew in six month to 124.5 cmFL (captive in Yaeyama) and 125.9 cmFL (captive in Amami). Because intrinsic ability on growth differ in the two species, comparisons were made in the following index, RFW (Ratio of farmed fish growth over wild fish growth).

$$\text{RFW} = \frac{Growth\ increment\ of\ farmed\ fish\ in\ 6\ months\ (cm)}{Growth\ increment\ of\ wild\ fish\ in\ 6\ months\ (cm)}$$

RFWs of PBF from 97.2 cmFL were 1.47 in Yaeyama and 1.55 in Amami. RFW of SBT in age-3 based on SRP tagging data was 1.49, similar value to PBF. However, RFWs was lower in age-2 and age-4 of SBT farmed. In contrast, RFWs of age-3 SBT for growth corresponds to Australian reported catch and the 40/100 fish sampling were quite high in the range from 2.32 to 4.07.

Estimation of total catch weight from growth rates assumed

In the case 1, where the mean growth rate derived from the SRP tagging data used (case 1, fork length increase was 20.0% in age2, 13.3% in age3 and 8.0% in age 4 in six months), age composition was shifted to higher age and then the estimated total catch weight during a fishing year was larger than the reported catch weight by an amount ranging from 724 to 2,546 tons, with a mean of 1,702 tons (Table 3, Table 7, Fig. 5). These estimated amounts were larger than reported ranging from 14% to 56 %, with a mean of 35.5%. There was an increasing trend for such excess ratios as year progressed (Fig .6).

In the case 2, where assumed same growth in body length for wild and farmed fish, the mean estimated excess amount was 2,289 tons, with a mean excess ratio of 47.6% compared to the reported catch.

These estimated values were compared to previous estimates, derived using the mixed-normal distributions or the cohort slicing method (Table 8, Fig. 5). Details were described in Itoh et al. (2012). The values estimated in the present study (case 1) were similar to those in previous analysis, but were slightly underestimates.

考察

　ミナミマグロの2歳から4歳に相当する80cmFLから110cmFLのサイズ範囲において、ミナミマグロ野生魚の成長は他のマグロ属魚類よりも遅かった。これはミナミマグロの、最大到達体長は小さくはないが、長寿命で、成熟が遅い生物学的特性から、この体長範囲では成長が遅かったと考えられる。

　畜養された魚は豊富な餌が与えられることによって野生魚よりも成長が速いと期待される。SRP標識データでは体重増加（Sakai et al. 2009）だけでなく、体長増加においても畜養魚の成長が野生魚の成長を上回ることが示唆された。畜養SBTは80cmFLから100cmFLでは大西洋クロマグロやメバチに近い成長速度を示したが、110cmFLではそれらの成長速度には及ばなかった。また太平洋クロマグロやキハダの成長速度には畜養ミナミマグロのものは及ばなかった。

　豪州政府が報告した漁獲量（まき網で巻いた時点）、40/100尾サンプリングによるサイズデータと収穫重量（蓄養後に殺した時点）とを説明する畜養SBTの成長率推定値は非常に高かった。年別推定値の中ではキハダの成長率さえ上回る値もあった。畜養太平洋クロマグロは高い成長速度を示したが、元々の成長能力を考慮して、畜養成長量を野生魚成長量で割ったRFWで比較すると、報告漁獲量を説明する畜養ミナミマグロのRFWは極めて高い2.32から4.07にもなった。

　一方、SRP標識データから求めた場合、97.2cmFLの畜養ミナミマグロのRFWは1.49であり、畜養太平洋クロマグロの値と類似した。79.4cmFLや110.2cmFLにおいては、SRP標識データによる畜養ミナミマグロのRFWが蓄養太平洋クロマグロのものよりも低くなった。太平洋クロマグロの畜養においては高水温ほど成長が早い関係が見られている（Masuma et al. 2008）。八重山での周年水温は20-31℃、奄美大島では20-28℃であり、どちらもクロマグロの野生の成育場より低緯度にあり高水温環境となる。水温の低い和歌山県では畜養魚の成長は遅く、体長の成長は野生魚と同等であった（Masuma et al. 2008）。ミナミマグロの場合、ポートリンカーンの水温は15-21℃と低いことから（Hayward et al. 2009）、RFWが太平洋クロマグロよりミナミマグロで低いことは納得できることである。

　以上から、SRP標識データから求めた畜養ミナミマグロの成長率は、他のマグロ属魚類や畜養太平洋クロマグロの成長率と比較して妥当な値と考えられた。40/100尾サンプリングに関係した成長率は既存の情報では考えられない値であった。この高い成長率の真偽は、独立で客観的な科学データによって証明されるべきである。

　これまで、体長組成を混合正規分布で分解するロバストな方法が2007年から2009年畜養魚に対して実施された（Itoh et al. 2012）。また、少し簡略な方法として年齢スライシング法で体長組成を分解する方法が2007年から2010年の畜養魚に対して実施された。成長率を仮定して、一旦von Bertalanffy成長式のパラメータを求める方法で、対象年度を2001

年から 2013 年までの 13 年間に拡大された（Itoh et al. 2014）。本研究では成長率を、von Bertalanffy 成長式を経由しない直接的な方法で再推定した。その結果、推定結果はこれまでの結果とほぼ一貫したものが得られた。本研究の方が過小推定である可能性も示唆された。

　CCSBT 委員会からは、全ての死亡要因を考慮した資源評価とともに、含まれていない死亡量の MP への影響を考慮するタスクが付託されている。本研究の推定によれば漁獲量の不確実性はグローバル TAC の 21%（2013 年 10,949 トンに対するケース 1 の 2,346 トン）にも及び、これは看過できるものではない。またこの不確実性は年々増加傾向にある。

　早急な不確実性の払拭が必要であるにもかかわらず、2013 年年次会合において、豪州政府はステレオビデオカメラシステムによる体長測定を 2013 年 12 月に開始するとの CCSBT 年次会合における自国の表明（Anon. 2012）を反故にし、国内的な都合でステレビデオカメラシステムの導入を遅らせている（Anon. 2013）。

　未報告漁獲量を考慮した MP への評価を実施するには、少なくとも 14%から 56%、平均 35.5%の過剰漁獲量を考慮する必要がある。しかし、本推定が過小推定である可能性を考慮すると、現実に起こり得る事態を確実に含めた試算をするためには、平均 40%またはそれ以上でも評価を実施する必要があるだろう。

　これまでの解析結果について、ESC 等ではいくつかの問題点の指摘や提案があった。これらにコメントする。我々は多くの問題は解決済みと考える。
　　1.　Robins(1963)の体長体重関係式は適切とは限らない。
Attachment1 に示した通り、適切と考えられる。

　　2.　Hastie による指摘（CCSBT-EC/0610/21）。
2006 年に行われた畜養魚の成長のレビューに対するコメントである。混合正規分布を仮定した年齢分解について、データが不足していること、全ての年齢で同じ成長率を仮定していること、混合正規分布の各正規分布における平均と分散を直線的に変化すると仮定したこと、標準誤差が示されていないことが問題と指摘した。
　その後、日本に輸入された個体別の体長体重測定データが大量に得られた(e.g. Itoh et al. 2009b)。混合正規分布の年齢分解方法を改善し、各正規分布の平均と分散は独立に推定された。推定の標準誤差も求められた。

　　3.　標識装着の成長への影響
Hampton(1986)で示されたように、標識放流は魚への負担が大きく、成長量の研究には不適切とする主張（Jeffriess 2014）。
　以下の情報から、標識がマグロ類の成長に大きな影響を与えるかとは思われない。通常

標識を装着した魚がすぐに摂餌を開始することは良く知られている（Hallier and Fonteneau 2015）。ミナミマグロでも竿釣りからの放流魚が6-10日で竿釣りによって多数が再捕された(Hampton 1986)。Jeffriess (2014)が引用した Itoh et al. (2003)は、太平洋クロマグロへのアーカイバルタグ装着のものであり、不適切な引用である。腹腔内にアーカイバルタグを装着した場合でさえ、魚は生存し、一か月後には通常の摂餌に戻っていた。野生魚と比較した短期間の魚の痩せや体長成長の低下は、同論文で報告されていない。

　　Hampton(1986)は、体長体重関係を標識再捕魚と標識を装着していない魚とを、コンディションファクター（W/L³）で比較した。94%の標識魚は20日以下の再捕であった。平均コンディションファクターが標識魚は野生魚の93.36%であったと報告している。しかしこの方法は異なる個体間を比較した間接的な比較であり、批判もある。"*This method (deviations from the expected relationship) has recently been criticized as inaccurate and irrelevant to condition and likelihood of survival (Green, 2001).*" (Willis and Hobday 2015).

　　Hearn and Polacheck (2003)は、Hampton(1986)に言及しながら、体長成長への標識装着の影響はないと結論付けている。"*With respect to tagging effects, Hampton (1986) and Hearn (1986) have shown that there can be a significant weight loss of 7–12% for tagged fish in the first month after release. However, tagged fish recover this weight loss within a year at liberty, and there is no apparent difference between tagged and untagged fish after this time (Hearn, 1986). (There is little information available on weight loss of tagged fish at liberty between one month and one year.) In terms of length, Hearn and Hampton could not detect a reduction of growth from growth increment residuals in the tag-return data even within the first 30 days after release. Limited data from the effect of handling and tagging fish in commercial farm pens indicated no retardation in growth in length after 150 days. These farm fish did show a loss in weight when first caged, but the weight was regained over a period of a few months (Anonymous); therefore we do not think that tagging had any substantial effect on the growth rate of tagged fished in our study.*"

4.　日本は畜養サイズデータを公開しない（Jeffriess 2014）

　　畜養収穫時の個体別体長体重データは、秘匿性を条件に水産庁が輸入業者から収集したものであり、公開はできない。ただしこの解析は2007年から2010年畜養魚に対して使用した方法であり、成長率を仮定して2001年から2014年畜養魚に用いた方法ではCCSBTメンバーに公開されているCDSサマリーの情報を使用している。手法の透明性は確保されており、また誰でも計算によって検証できる状況にある。

　　個体別体重データはCDS（CTF）によって収集されている。全個体にわたって得られているこのデータを使用すれば、日本の推定方法の検証も可能であり、サンプリングが一部

分であるとの問題も解決できる。

5. 経済的にコストが合わない（Jeffriess 2014）

Jeffriess（2014）に示されている試算には疑問がある。このパラメータでは、207万ドルの利益しか出ない。この金額は40/100尾サンプリングのバイアスおよび過剰漁獲の有無によって変わらない。豪州が主張する畜養開始平均体重を使用しても、コストは$29/kgであり、販売価格$15.23を大きく上回っている。示された数値、または我々の計算には間違いがあるようだ。1kgあたりのコスト、売り上げ合計、合計利益を含めて、計算仮定の詳細を、豪州が主張する畜養開始平均体重を使用した場合も含めて両方について示すことを要請したい。

6. von Bertalanffy 成長式では不適切（Jeffriess 2014）

"Models for wild SBT are unlikely to be applicable to farmed fish." (Gunn et al. 2002)を根拠としているが、同文献が入手できない。

Gunn, J., Patterson, T. and Rough, K. (2002). Experimental analyses of the effects of ration and feeding frequency on the thermodynamics, energetics, growth and condition of farmed Southern Bluefin Tuna. CSIRO Marine Research. FRDC Project 97/363. May 2002.

文献を提供してもらってから検討したい。なお、今回の解析では von Bertalanffy 成長式は使わなかった。

7. SRP タグからの成長率は体重ではなく体長にした方がよい。（OMMP5）

本解析はそれに対処した。推定法方がシンプルになった。体長体重関係式への依存も減少した。

8. 畜養の成長率は条件によって大きく変わる。一部サンプルでの結論は不適切。

2007年から2010年に収集した個体別サイズデータのサンプルは決して少なくはない。平均値を大きく変えるほどに特異的な、サンプリングされていないデータが存在するとは考えがたい。しかし、畜養生簀ごとなどの個別の条件を考慮すれば推定精度はさらに向上できるだろう。時期、畜養生簀ごとの成長の変異についての具体的なデータの提供を豪州に要請したい。また、CDSによる全個体の個体別体重データはこの問題を避けることができ、解析を推進すべきである。

9. 大西洋クロマグロ、太平洋クロマグロの畜養魚では野生魚よりも成長が速いとの多くの研究結果が示されている（Jeffriess 2014）

問題となっているのは、畜養魚の成長が野生魚よりも速いかではなく、どの程度速いか

である。Jeffriess（2014)で具体的な成長率が示された事例で、豪州報告漁獲量に対応した成長率を支持するものはなかった（Attachment 2)。またその多くは、SRP タグからの成長率が妥当であることを支持した。

Discussion

Comparing in *Thunnus* species, SBT grow slower than other species in the range of 80cmFL to 100 cmFL, in SBT age of 2 to 4.　This is probably due to the aspect of SBT biological characteristics; while the maximum attainable body length is not so small (>180 cmFL), long life span (> 40 years) and late maturity (> age-8) may resulted in slower growth in this fork length range.

It is not surprising that farmed fish which fed a plenty of food grow faster than wild fish.　The SRP tagging data suggested that SBT farmed fish grew faster than wild fish not only in body weight (Sakai et al. 2009) but also in fork length.　Growth of farmed SBT was as fast as those of ABF and BET in 80-100 cmFL, but slower in 110 cmFL. Growth of farmed SBT was slower than those of PBF and YFT.

Growth rates of farmed SBT which can explain three sets of information (the total catch amount in wild, size data from 40/100 fish sampling and total amount at harvest after farming) were estimated to be extremely high.　There were several years that exceeding even the growth rate of YFT.　Farmed PBF suggested relatively high growth rate, however, when compared in RFW (ratio of farmed fish growth over wild fish growth) by taking account of difference of intrinsic growth ability by species, the RFW were quite higher in age-3 SBT (2.32-4.07) than PBF in same size (1.47 and 1.55).

On the other hand, when the SRP tagging data were used, RFWs of farmed SBT were lower than those of PBF in the same size in age-2 and age-4, though similar in age-3. It has been observed that higher ambient water temperature relates to faster growth in PBF (Masuma et al. 2008).　The mean annual water temperatures were 20-28 degrees C in Amami and 20-31 degrees C in Yaeyama, both of which were much higher than that for the wild PBF feeding grounds due to the lower latitude.　The growth of PBF farmed in Wakayama Prefecture, where the water temperature is lower than in the two places described above and presumably similar to or slightly higher than for the wild fish feeding ground, was slower and similar to that of wild fish (Masuma et al. 2008).　The water temperature in Port Lincoln where SBT farming is conducted is relatively low at 15-21 degrees C (Hayward et al. 2009).　It appears to be reasonable that SBT farmed in Port Lincoln showed lower RFW than PBF.

Therefore, from these comparisons, growth rate of farmed SBT based on the SRP tagging data seems more plausible.　Those relevant to the 40/100 fish sampling seems

highly unlikely. Such a large uncertainty, especially for the extremely high growth rate relevant to the 40/100 fish sampling, should be addressed by using independent and actual scientific data on growth.

So far, analysis of decomposition of length frequency into age with normal distributions, relatively robust method, was carried out for farmed SBT between 2007 and 2009 (Itoh et al. 2012). Another method using age-slicing for decomposition of length frequency into age, slightly simpler than the first method, was applied to farmed SBT between 2007 and 2010. Further method expanded the period subject for 13 years from 2001 to 2013 (Itoh et al. 2014). This method assumed growth rates and converted it into parameters of von Bertalanffy growth curve. In this paper, we propose another method, slight modification of Itoh et al. (2014), which uses assumed growth rate in body length as it is, not go through von Bertalanffy growth curve. The present method provided consistent results with those from previous methods. It was also suggested slightly underestimate of catch in the present method.

The EC requested at its 20th annual meeting to ESC to conduct sensitivity analysis around all sources of unaccounted catch mortality (Anon. 2013). It is impossible to ignore the uncertainty in catch as large as 21% of the global TAC (2,346 tons in Case 1 compared to the 10,949 tons TAC in 2013). The increasing trend with year in the ratio measuring the excess is also of concern.

Urgent measures to clear out this uncertainly is necessary. The Australian government has postponed implementation of the stereo video camera system for domestic reasons (Anon. 2013), in spite of their own statement of intent in 2012 that fish length measurement using the stereo video camera system would be implemented by December 2013.

In the ESC, we have to evaluate the effects of unaccounted catch mortality on the stock assessment and management. Results of present study suggest that unaccounted catch mortality in the Australian purse seine catch for farming sector would be, at least, from 14% to 56%, with a mean of 35.5% of reported catch. However, taking into account the possibility that the present study provides underestimates, and in order to cover whole the range that may be plausible, examination using values with a mean of 40% or more may be necessary.

Several comments and pointing out of problems have been made for our previous analyses in elsewhere including ESC and OMMP meetings. Our comments for them

are as follows.   We believe that most of issues has already solved.

1. Concerns of using length-weight relationship in Robins (1963).

We considered this issue and see Attachment 1.   It is considered to be appropriate to use the LW relationship of Robins (1963) for wild fish in the farming subject in recent years.

2. Concerns from Hastie (CCSBT-EC/0610/21)

The comments was given by paper for the independent review of farming growth in 2006.   It raised several concerns for the age decomposition method using mixed-normal distributions that based on small number of data, that assumed same growth rate over all ages, that assumed linear change of mean and variance of normal distribution in the mixed-normal distribution, and that standard errors were not shown.

After the independent review, data from a large number of individual length-and-weight were obtained (e.g. Itoh et al. 2009b).   Method for age decomposition by using mixed-normal distribution was improved, and then mean and variance of each normal distribution were estimated independently.   Standard errors of estimates were also calculated.

3. Concern for impact of tag attachment on growth

Concern was made for conventional tags attachment on growth (Jeffriess 2014).   It claimed tagging data were inappropriate for growth study because it give serious impact on SBT as shown in Hampton (1986).

Through examination in peer reviewed literatures including Hampton (1986), we conclude that tag attchment does not affect growth, especially in body length, of tunas seriously.

It is well known that onventional tagged tuna resume feeding immediately, and resulted in recaptured in pole-and-line in several times in successive days (Hallier and Fonteneau 2015).   In SBT, the most frequent period in Hampton (1986) in which fish released with conventional tags recaptured, presumably by pole-and-line, was 6-10 days after release.   Jeffriess (2014) referred Itoh et al. (2003) that observed less frequent feeding after release in PBF, but such a reference was inappropriate because it was "archival tagged" fish implemented in fish body cavity with surgery.   The paper compared growth and fatness of recaptured fish against wild fish and did not report severe influence in short period at liberty.

Hampton (1986) compared the condition factor (W/L^3) of recaptured tagged fish to untagged fish.   94% of tagged fish were at liberty less than 20 days.   He reported

mean condition factor of tagged fish was 93.36% of that in wild fish. This method is indirect comparison between different individual and there is criticize. "*This method (deviations from the expected relationship) has recently been criticized as inaccurate and irrelevant to condition and likelihood of survival (Green, 2001).*" (Willis and Hobday 2015).

Hearn and Polacheck (2003) concluded, with referring Hampton (1986), that tagging had no substantial effect on the growth in body length even within the first 30 days. "*With respect to tagging effects, Hampton (1986) and Hearn (1986) have shown that there can be a significant weight loss of 7–12% for tagged fish in the first month after release. However, tagged fish recover this weight loss within a year at liberty, and there is no apparent difference between tagged and untagged fish after this time (Hearn, 1986). (There is little information available on weight loss of tagged fish at liberty between one month and one year.) In terms of length, Hearn and Hampton could not detect a reduction of growth from growth increment residuals in the tag-return data even within the first 30 days after release. Limited data from the effect of handling and tagging fish in commercial farm pens indicated no retardation in growth in length after 150 days. These farm fish did show a loss in weight when first caged, but the weight was regained over a period of a few months (Anonymous); therefore we do not think that tagging had any substantial effect on the growth rate of tagged fished in our study.*"

4. Japan should allow to use the raw size data of farmed fish (Jeffriess 2014)

It is quite difficult to open the data of individual length-and-weight at harvest because it was collected from importers by Fishery Agency of Japan under a condition of confidentiality. However, the data only used for our analysis of 2007-2010 farmed fish. The current estimation for 2001-2014 farmed fish, assuming growth rate, only uses information shown in CDS summary which available to all CCSBT Members. Transparency of information used as well as methods is ensured, and calculation can be evaluated anyone.

Individual weight data have been collected by CDS (Catch Tagging Form, CTF) for all the individuals farmed and harvested. Using this data allows evaluation of our estimation and solve the limitation of our estimation that data coverage is not 100%.

5. Economically implausible (Jeffriess 2014)

Jeffriess (2014) showed economic variables of SBT farming.

We had some questions on the calculation. With the parameter values given, the total benefits, in our calculation, was only 2.08 million dollars. This value does not

change with the uncertainty of farming growth.   The total cost per kg was high as $29/kg even if mean body weight of onset of farming used as Australia claimed.   It is much higher than the reported actual price $15.23/kg.   It seems that there is incorrect in our calculation or values shown on the paper.

We would like to request to show both two calculations with detail process, including total cost per kg, total sales account, and total benefit.   One is in Japan's methodology and the other based on Australia reported body weight at wild capture.

6.   growth model of von Bertalanffy is inappropriate for SBT (Jeffriess 2014)

Jeffriess (2014) referred to "*Gunn, J., Patterson, T. and Rough, K. (2002). Experimental analyses of the effects of ration and feeding frequency on the thermodynamics, energetics, growth and condition of farmed Southern Bluefin Tuna. CSIRO Marine Research. FRDC Project 97/363. May 2002.*"   The paper is not available for us.   We would like to request providing the paper for us.   After the paper is provided, we will consider.   Note that we didn't use von Bertalanffy growth parameter in the present analysis.

7.   Body length, instead of body weight, should be used for the growth rate from the SRP tagging data (OMMP5)

We followed the suggestion.   The estimation procedure become simple.   The degree of dependence on a LW relationship was decreased.

8.   Growth rate of farmed fish varies largely.   Results based on sample from a small part of whole is not appropriate.

The size data collected between 2007 and 2010 was not a small size.   It is hardly believe the existence of any special data which not sampled yet and could change the mean value of our estimation.   However, it is better to taking into account the detail farming condition of each of farm for estimation so that the estimate results must become more accurate.   We would like to request Australia to provide actual scientific data of growth variance by season, farming cage, farming condition, and in any category Australia think necessary for farming study.

In addition, the CDS data what contains all the farmed individuals can avoid such limitation.   Analysis using the CDS data of farming SBT should be encouraged.

9.   Higher growth rates are performed in farming in literatures for ABF and PBF (Jeffriess 2014)

The point is NOT farmed fish grow faster than wild fish. The point is HOW fast farmed fish grow than wild fish. We examined growth rate in Jeffriess (2014) which actual growth information was shown (Attachment 2). None of them support the high growth rates of SBT which relevant to 40/100 fish sampling and reported catch amount. Most of them support the growth rate for farmed SBT based on the SRP tagging data.

結論

我々は、以下を ESC に提案する。

- CCSBT は豪州畜養に関する潜在的で規模の大きな問題が存在することを認識すべきである。この問題は、CCSBT の対外的信頼性、ミナミマグロの資源管理、特に世界的に注目されている MP による資源管理を損なう恐れがある。科学データ面では、漁獲量、年齢組成に影響を及ぼし、頑健な資源評価を阻害する。

- ESC は、オーストラリアまき網の漁獲量および年齢組成の調節に際しては、本結果の年別の推定値（平均 35.5%）または 40%以上を用いた結果も考慮するべきである。

- 豪州は、この不確実性に関する懸念を早急に払拭するために必要な具体的な行動を実施すべきである。それにはステレオビデオカメラシステムの早急な導入による検証データの入手、畜養の成長率に関する情報の提供、及び我々の解析結果を検証するための CDS の畜養魚全個体の個体別データのメンバー科学者への提供を含む。

- ESC は、ステレビデオカメラシステムの導入によってこの不確実性の問題を早急に払拭すべきことを委員会に勧告すべきである。

Conclusion

We propose followings to the ESC.

- The CCSBT should recognize the presence of this potentially large-scale issue related to Australian SBT farming. This issue involves a high risk of damaging the credibility of the CCSBT, and the stock management of SBT by means of the MP which has attracted worldwide attention. In terms of the scientific data, it may seriously affect catch and age composition estimates and hinders accurate and robust stock assessment.

- When considering unaccounted catches and adjustment of age composition by year, the ratio estimated in the present study (a mean of 35.5%, which should perhaps be even higher than 40%) should be taken into account for Australian purse seine catch.

- Australia should resolve the issue by a full scale implementation of the stereo video camera system, including providing outputs of length measurements. In addition,

they should provide information of the extent of farming growth estimated by using reliable scientific data.　CDS data which including individual body weight for all the farmed individuals should be available for Member scientists in order to evaluate our results.

- The ESC should recommend to the EC that the issue should be resolved immediately by full scale of implementation of the stereo video camera system.

References

Anonymous 2005 Report of the Extended Commission of the Twelfth Annual Meeting of the Committee.　Taipei, Taiwan. October 2005.

Anonymous 2006 Independent review of Australian SBT farming operations anomalies. CCSBT/0607/12.

Anonymous 2010 Report for biennial period, 2010-11. PART I (2010) - Vol. 1. English version COM. Madrid, Spain. 2011

Anonymous 2012 Report of the Nineteenth Annual Meeting of the Commission. Takamatsu City, Japan. October 2012.

Anonymous 2013 Report of the Twentieth Annual Meeting of the Commission. Adelaide, Australia. October 2013.

Anonymous 2014a Report of the 2014 ICCAT bluefin data preparatory meeting. Madrid, Spain. May 2014.

Anonymous 2014b. Secretariat review of catches. CCSBT-ESC/1409/04(Rev.1)

Fonteneau, A. 2013 On the potential use of size measurements by observers in the farms for the estimation of Mediterranean BFT Catch at size. ICCAT SCRS/2013/076.

Hallier, J.P., B. Stequert, O. Maury and F. X. Bard. 2005. Growth of bigeye tuna (*Thunnus obesus*) in the eastern Atlantic Ocean from tagging-recapture data and otolith readings. (ICCAT SCRS/2004/039). Col. Vol. Sci. Pap. ICCAT, 57(1): 181-194.

Hallier, J. P. and A. Fonteneau 2015. Tuna aggregation and movement from tagging data: A tuna "hub" in the Indian Ocean.　Fish. Res. 163: 34-43.

Hastie, T. 2006. Peer review of the 'Report of the independent review of the Australian SBT farming operations anomalies'.　CCSBT-EC/0610/21.

Hayward, C. J., N J Bott, and B F Nowak 2005. Seasonal epizootics of sea lice, Caligus spp., on southern bluefin tuna, *Thunnus maccoyii* (Castelnau), in a long-term

farming trial. Journal of Fish Diseases 32:101-106.

Hearn W. S. and T. Polacheck 2003. Estimating long-term growth-rate changes of southern bluefin tuna (*Thunnus thynnus*) from two periods of tag-return data. Fish. Bull. 101:58-74.

Hillary, R., A. L. Preece, C. R. Davies, H. Kurota, O. Sakai, T. Itoh, A. M. Parma, D. S. Butterworth, J. Ianelli and T. A. Branch 2015 A scientific alternative to moratoria for rebuilding depleted international tuna stocks. Fish Fish. (in press; available on-line).

Hobsbawn, P.I., H. M. Patterson and I. Stobutzki 2013 Australia's 2011-12 southern bluefin tuna fishing season. CCSBT-ESC/1309/SBT Fisheries-Australia.

Itoh, T., S. Tsuji and A. Nitta (2003) Migration patterns of young Pacific bluefin tuna (*Thunnus orientalis*) determined with archival tags. Fish. Bull. 101. 514-534.

Itoh, T., T. Sakamoto, and T. Yamamoto 2009a. Follow-up analysis on age composition of southern bluefin tuna used for farming in 2007. CCSBT/ESC/0909/29.

Itoh, T., T. Sakamoto, and T. Yamamoto 2009b. Analysis of age composition of southern bluefin tuna used for farming in 2008. CCSBT/ESC/0909/30.

Itoh, T., T. Kawashima, and T. Yamamoto 2010. Analysis of age composition of southern bluefin tuna used for farming in 2009. CCSBT/ESC/1009/21.

Itoh, T., T. Kawashima, and M. Mishima 2011. Analysis of age composition and catch amount of southern bluefin tuna used for farming in 2010. CCSBT-ESC/1107/26.

Itoh, T., Y. Akatsuka, T. Kawashima and M. Mishima 2012. Analyses on age composition, growth and catch amount of southern bluefin tuna used for farming in 2007-2010. CCSBT/ESC/1208/30.

Itoh, T., K. Suzuki and S. Takeda 2014. Unaccounted catch mortality in Australian SBT farming fishery between 2001 and 2013 estimated from information of TIS and CDS. CCSBT-OMMP/1406/09(Rev).

Jeffriess, B. 2014. A review of tuna growth performance in ranching and farming operations. CCSBT-ESC/1409/11.

Masuma, S. 2008. Development on techniques of stock enhancement for Pacific Bluefin tuna *Thunnus orientalis* by the Fisheries Research Agency (formerly, Japan Sea Farming Association). J. Fisheries Technology 1: 21-36.

Masuma, S., S. Miyashita, H. Yamamoto, and H. Kumai 2008. Status of bluefin tuna farming, broodstock management, breeding and fingerling production in Japan. Review in Fisheries Science. 16:385-390.

Restrepo, V.R., G.A. Diaz, J.F. Walter, J. Neilson, S.E. Campana, D. Secor, and R.L. Wingate. 2010. An updated estimate of the growth curve of Western bluefin tuna.

Aquatic Living Resources 23: 235-342.

Robins, J. P. 1963. Synopsis of biological data on bluefin tuna *Thunnus thynnus maccoyii* (Castelnau) 1872. Species synopsis No. 17. FAO Fisheries Biology Synopsis No. 60.

Sakai, O., Itoh, T., and T. Sakamoto 2009. Estimation of growth in farmed Southern Bluefin Tuna using the CCSBT conventional tagging data. CCSBT/ESC/0909/31.

Shimose, T., T. Tanabea, K-S Chen and C-C Hsu 2009 Age determination and growth of Pacific bluefin tuna, *Thunnus orientalis*, off Japan and Taiwan. Fish. Res. 100: 134–139.

Wild, A., 1986. Growth of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean based on otolith increments. Bull. IATTC, 18(6): 421-482.

Willis, J. and A. J. Hobday 2008. Application of bioelectrical impedance as a method for estimating composition and metabolic condition of southern bluefin tuna (*Thunnus maccoyii*) during conventional tagging. Fisheries Res. 93: 64-71.

Table 1.　Data on the total weight of SBT caught for Australian farming

Fishing year	Period	Official weight	TIS	CDS	TIS or CDS/Official weight
2001	Dec 2000–Nov2001	5,162,000	5,141,446		99.6%
2002	Dec 2001–Nov2002	5,234,000	5,216,065		99.7%
2003	Dec 2002–Nov2003	5,374,626	5,354,939		99.6%
2004	Dec 2003–Nov2004	4,873,701	4,847,861		99.5%
2005	Dec 2004–Nov2005	5,213,693	5,198,504		99.7%
2006	Dec 2005–Nov2006	5,301,706	5,288,123		99.7%
2007	Dec 2006–Nov2007	5,229,957	5,220,813		99.8%
2008	Dec 2007–Nov2008	5,211,480	5,201,973		99.8%
2009	Dec 2008–Nov2009	5,026,407	5,005,419		99.6%
2010	Dec 2009–Nov2010	3,930,541		3,922,372	99.8%
2011	Dec 2010–Nov2011	3,871,605		3,863,160	99.8%
2012	Dec 2011–Nov2012	4,484,736	4,474,113	4,452,665	99.3%
2013	Dec 2012–Nov2013	4,198,281		4,194,783	99.9%
2014	Dec 2013–Nov2014	5,029,299		5,024,276	99.9%

Unit is in kg.　Value in CDS was used in 2012.

Table 2.　Data on the number of SBT caught for Australian farming

Fishing year	Period	N_Raised	Catch-At-Age	TIS	CDS	TIS or CDS/N_Raised
2001	Dec 2000–Nov2001	289,157	288,022	279,287		96.6%
2002	Dec 2001–Nov2002	281,143	281,143	279,456		99.4%
2003	Dec 2002–Nov2003	278,020	278,020	276,117		99.3%
2004	Dec 2003–Nov2004	298,703	298,703	297,748		99.7%
2005	Dec 2004–Nov2005	336,112	336,110	335,088		99.7%
2006	Dec 2005–Nov2006	332,958	324,088	332,104		99.7%
2007	Dec 2006–Nov2007	354,464	363,336	353,864		99.8%
2008	Dec 2007–Nov2008	324,754	324,754	324,160		99.8%
2009	Dec 2008–Nov2009	306,886	307,663	306,060		99.7%
2010	Dec 2009–Nov2010	212,204	212,204		211,749	99.8%
2011	Dec 2010–Nov2011	232,614	220,242		232,077	99.8%
2012	Dec 2011–Nov2012	307,896	320,268	307,139	305,727	99.3%
2013	Dec 2012–Nov2013	259,337	259,337		259,125	99.9%
2014	Dec 2013–Nov2014	268,518	268,518		254,214	94.7%

The value from the CDS was used in 2012.

Table 3. Procedure used in estimation of catch-at-age and total catch in wild of farmed SBT

Year=2001

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	0	49.4	49.8	2.68	0	68.49	8.33	0	0	0	0	0	0	0
2	42,736	79.4	79.6	10.47	434	93.29	20.05	38983	781648	18,102	362,968	189,537	19,923	208,602
3	221,365	97.2	97.4	18.78	4,031	108.03	30.98	201927	6255427	114,648	3,551,650	2,153,075	126,180	2,369,645
4	18,807	110.2	110.3	27.01	493	118.82	41.23	17155	707236	116,126	4,787,319	3,136,586	127,806	3,452,083
5	4,225	121.2	121.3	35.58	146	127.94	51.56	3854	198710	10,979	566,061	390,637	12,083	429,930
6	889	130.6	130.7	44.18	38	135.74	61.70	811	50032	2,441	150,600	107,828	2,686	118,674
7	0	138.4	138.5	52.26	0	142.21	71.09	0	0	434	30,880	22,701	478	24,984
8	0	145.1	145.2	59.94	0	147.77	79.91	0	0	0	0	0	0	0
Total	288,022				5,141			262,730	7,993,054	262,730	9,449,478	6,000,364	289,157	6,603,918
														$W.Est_y$

0.1612	adj.mon	adj.mon$_y$	Adjustment of number of month to the time of catch
0.9697	p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
0.5356	p.shift	α$_y$	Proportion of age shift
1.1006	p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2002

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	0	49.4	49.9	2.69	0	68.44	8.31	0	0	0	0	0	0	0
2	33,520	79.4	79.7	10.50	350	93.24	20.02	32335	647328	17,661	353,556	185,363	18,308	192,159
3	223,242	97.2	97.4	18.81	4,173	107.99	30.94	215346	6663467	132,292	4,093,499	2,488,043	137,142	2,579,262
4	20,825	110.2	110.4	27.04	560	118.79	41.19	20089	827508	108,701	4,477,714	2,939,245	112,686	3,047,006
5	2,837	121.2	121.4	35.61	100	127.92	51.53	2736	141015	10,611	546,833	377,882	11,000	391,736
6	564	130.6	130.7	44.20	25	135.73	61.68	544	33570	1,539	94,930	68,035	1,596	70,530
7	155	138.4	138.5	52.29	8	142.20	71.08	149	10620	329	23,358	17,183	341	17,813
8	0	145.1	145.2	59.96	0	147.77	79.90	0	0	68	5,418	4,066	70	4,215
Total	281,143				5,216			271,200	8,323,509	271,200	9,595,308	6,079,816	281,143	6,302,720
														$W.Est_y$

0.2063	adj.mon	adj.mon$_y$	Adjustment of number of month to the time of catch
0.9940	p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
0.4538	p.shift	α$_y$	Proportion of age shift
1.0367	p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2003

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	138	49.4	55.2	3.61	0	66.41	7.66	130	995	16	120	56	17	60
2	61,166	79.4	82.8	11.74	713	91.11	18.71	57636	1078250	7,059	132,064	82,858	7,492	87,934
3	182,579	97.2	99.7	20.12	3,648	106.19	29.42	172040	5061981	71,421	2,101,446	1,436,788	75,796	1,524,803
4	31,709	110.2	112.3	28.44	896	117.46	39.82	29879	1189752	154,910	6,168,404	4,405,338	164,399	4,675,203
5	1,561	121.2	123.0	37.04	57	127.01	50.43	1471	74189	26,456	1,334,121	979,857	28,076	1,039,882
6	693	130.6	132.1	45.56	31	135.13	60.86	653	39726	1,373	83,540	62,539	1,457	66,370
7	174	138.4	139.7	53.59	9	141.91	70.64	164	11564	594	41,945	31,822	630	33,771
8	0	145.1	146.2	61.15	0	147.71	79.81	0	0	144	11,491	8,804	153	9,343
Total	278,020				5,355			261,972	7,456,457	261,972	9,873,131	7,008,063	278,020	7,437,366
														$W.Est_y$

2.3142	adj.mon	adj.mon$_y$	Adjustment of number of month to the time of catch
0.9932	p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
0.8795	p.shift	α$_y$	Proportion of age shift
1.0613	p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2004

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	150	49.4	53.4	3.28	0	67.02	7.86	144	1130	59	466	195	62	203
2	124,070	79.4	81.8	11.31	1,399	91.78	19.12	118852	2271971	49,100	938,587	555,314	51,255	579,695
3	171,987	97.2	98.9	19.67	3,372	106.76	29.90	164754	4926504	137,782	4,119,990	2,710,206	143,831	2,829,198
4	2,253	110.2	111.7	27.96	63	117.88	40.25	2159	86889	97,699	3,932,424	2,731,930	101,988	2,851,876
5	0	121.2	122.5	36.55	0	127.30	50.77	0	0	1,268	64,401	46,367	1,324	48,403
6	0	130.6	131.6	45.10	0	135.31	61.11	0	0	0	0	0	0	0
7	139	138.4	139.3	53.15	7	142.00	70.77	133	9433	55	3,890	2,922	57	3,050
8	103	145.1	145.8	60.75	6	147.72	79.82	99	7864	177	14,116	10,743	185	11,215
Total	298,703				4,848			286,140	7,303,792	286,140	9,073,873	6,057,677	298,703	6,323,640
														$W.Est_y$

1.6056	adj.mon	adj.mon$_y$	Adjustment of number of month to the time of catch
0.9968	p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
0.5876	p.shift	α$_y$	Proportion of age shift
1.0439	p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Table 3.　(cont.)

Year=2005

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1	353	49.4	54.4	3.45	1	66.68	7.75	335	2598	51	392	175	53	184
2	187,707	79.4	82.4	11.54	2,160	91.41	18.89	178192	3366114	27,148	512,845	313,319	28,598	330,053
3	138,514	97.2	99.4	19.91	2,750	106.45	29.64	131493	3897192	171,152	5,072,611	3,407,995	180,292	3,590,010
4	8,089	110.2	112.0	28.22	228	117.65	40.01	7679	307262	112,827	4,514,479	3,184,006	118,853	3,354,058
5	640	121.2	122.8	36.82	24	127.14	50.58	608	30754	6,613	334,501	243,471	6,966	256,474
6	765	130.6	131.9	45.35	35	135.21	60.97	726	44281	626	38,160	28,384	659	29,900
7	40	138.4	139.5	53.39	2	141.95	70.69	38	2682	622	44,005	33,234	656	35,009
8	0	145.1	146.0	60.97	0	147.71	79.81	0	0	32	2,572	1,964	34	2,069
Total	336,110				5,199			319,071	7,650,883	319,071	10,519,564	7,212,548	336,112	7,597,757

$W.Est_y$

1.9905 adj.mon	$adj.mon_y$	Adjustment of number of month to the time of catch	
0.9970 p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)	
0.8492 p.shift	α_y	Proportion of age shift	
1.0534 p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)	

Year=2006

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1	4,447	49.4	53.3	3.25	15	67.08	7.87	4252	33477	1,387	10,919	4,510	1,490	4,846
2	138,097	79.4	81.7	11.27	1,595	91.85	19.15	132037	2529002	45,932	879,768	517,765	49,355	556,350
3	179,246	97.2	98.9	19.63	3,606	106.82	29.95	171380	5132202	144,870	4,338,306	2,843,916	155,666	3,055,852
4	1,553	110.2	111.6	27.92	44	117.92	40.29	1485	59840	115,965	4,672,250	3,237,832	124,607	3,479,123
5	745	121.2	122.4	36.51	28	127.32	50.80	712	36191	1,233	62,647	45,024	1,325	48,379
6	0	130.6	131.6	45.06	0	135.33	61.14	0	0	480	29,346	21,631	516	23,243
7	0	138.4	139.3	53.11	0	142.00	70.78	0	0	0	0	0	0	0
8	0	145.1	145.8	60.71	0	147.72	79.82	0	0	0	0	0	0	0
Total	324,088				5,288			309,866	7,790,713	309,866	9,993,236	6,670,678	332,958	7,167,793

$W.Est_y$

1.5426 adj.mon	$adj.mon_y$	Adjustment of number of month to the time of catch	
1.0247 p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)	
0.6738 p.shift	α_y	Proportion of age shift	
1.0745 p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)	

Year=2007

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1	1,257	49.4	53.7	3.33	4	66.91	7.82	1166	9118	162	1,267	540	170	568
2	223,673	79.4	82.0	11.38	2,479	91.67	19.05	207372	3949689	29,823	568,012	339,378	31,381	357,116
3	129,846	97.2	99.1	19.74	2,497	106.67	29.82	120383	3589938	195,283	5,823,528	3,855,602	205,490	4,057,116
4	7,706	110.2	111.8	28.04	210	117.81	40.18	7145	287054	104,646	4,204,388	2,934,381	110,116	3,087,747
5	854	121.2	122.5	36.63	30	127.25	50.71	792	40157	6,262	317,554	229,395	6,589	241,384
6	0	130.6	131.7	45.18	0	135.28	61.07	0	0	682	41,638	30,804	717	32,414
7	0	138.4	139.4	53.23	0	141.98	70.74	0	0	0	0	0	0	0
8	0	145.1	145.9	60.82	0	147.71	79.82	0	0	0	0	0	0	0
Total	363,336				5,221			336,858	7,875,956	336,858	10,956,386	7,390,100	354,464	7,776,346

$W.Est_y$

1.7226 adj.mon	$adj.mon_y$	Adjustment of number of month to the time of catch	
0.9739 p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)	
0.8610 p.shift	α_y	Proportion of age shift	
1.0523 p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)	

Year=2008

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	203	49.4	49.8	2.68	1	68.47	8.33	187	1557	137	1,137	366	148	398
2	118,697	79.4	79.7	10.48	1,241	93.28	20.04	109230	2189077	79,844	1,600,157	836,640	86,764	909,150
3	194,370	97.2	97.4	18.79	3,645	108.02	30.97	178868	5539078	160,101	4,957,925	3,008,070	173,977	3,268,773
4	11,060	110.2	110.4	27.02	298	118.81	41.22	10178	419487	55,638	2,293,120	1,503,313	60,460	1,633,602
5	266	121.2	121.3	35.59	9	127.94	51.55	245	12625	2,922	150,621	103,988	3,175	113,000
6	158	130.6	130.7	44.19	7	135.74	61.69	145	8953	172	10,612	7,600	187	8,259
7	0	138.4	138.5	52.27	0	142.21	71.09	0	0	39	2,780	2,044	42	2,221
8	0	145.1	145.2	59.94	0	147.77	79.91	0	0	0	0	0	0	0
Total	324,754				5,202			298,853	8,170,777	298,853	9,016,352	5,462,021	324,754	5,935,404

$W.Est_y$

0.1755 adj.mon	$adj.mon_y$	Adjustment of number of month to the time of catch	
0.9982 p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)	
0.2695 p.shift	α_y	Proportion of age shift	
1.0867 p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)	

Table 3. (cont.)

Year=2009

Age i	CAA $N_{y,i}$	L.Jan $L_{JAN,i}$	mean.L	mean.W $W.catch_{y,i}$	subSumWildW	harv.L $L.Harv2_{y,i}$	harv.W $W.Harv2_{y,i}$	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	145	49.4	52.0	3.03	0	67.56	8.03	127	1022	37	296	112	42	127
2	125,556	79.4	80.9	10.97	1,371	92.36	19.47	109900	2139487	31,952	622,035	350,640	36,412	399,581
3	165,762	97.2	98.3	19.32	3,185	107.25	30.31	145092	4397777	120,103	3,640,348	2,319,905	136,866	2,643,703
4	15,659	110.2	111.1	27.58	430	118.24	40.62	13706	556739	107,001	4,346,292	2,951,586	121,935	3,363,549
5	541	121.2	122.0	36.17	19	127.54	51.07	473	24177	9,870	504,028	356,979	11,247	406,803
6	0	130.6	131.3	44.74	0	135.47	61.33	0	0	336	20,618	15,039	383	17,138
7	0	138.4	139.0	52.80	0	142.07	70.88	0	0	0	0	0	0	0
8	0	145.1	145.6	60.43	0	147.73	79.84	0	0	0	0	0	0	0
Total	307,663				5,005			269,299	7,119,202	269,299	9,133,616	5,994,261	306,886	6,830,901

W.Est$_y$

1.0361 adj.mon	adj.mon$_y$	Adjustment of number of month to the time of catch
0.9948 p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
0.7101 p.shift	α$_y$	Proportion of age shift
1.1396 p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2010

Age i	CAA $N_{y,i}$	L.Jan $L_{JAN,i}$	mean.L	mean.W $W.catch_{y,i}$	subSumWildW	harv.L $L.Harv2_{y,i}$	harv.W $W.Harv2_{y,i}$	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	262	49.4	51.9	3.01	1	67.61	8.04	205	1651	17	140	52	22	67
2	53,601	79.4	80.9	10.95	586	92.40	19.49	41914	817074	3,740	72,899	40,947	4,782	52,364
3	126,360	97.2	98.3	19.29	2,432	107.29	30.34	98808	2997920	46,735	1,417,982	901,537	59,767	1,152,920
4	29,152	110.2	111.1	27.56	802	118.26	40.65	22796	926588	92,367	3,754,431	2,545,384	118,123	3,255,134
5	2,828	121.2	122.0	36.14	102	127.56	51.09	2211	112982	21,052	1,075,529	760,824	26,922	972,970
6	0	130.6	131.2	44.71	0	135.49	61.35	0	0	2,024	124,170	90,496	2,588	115,730
7	0	138.4	139.0	52.78	0	142.08	70.89	0	0	0	0	0	0	0
8	0	145.1	145.6	60.40	0	147.73	79.85	0	0	0	0	0	0	0
Total	212,204				3,922			165,935	4,856,216	165,935	6,445,150	4,339,240	212,204	5,549,185

W.Est$_y$

0.9947 adj.mon	adj.mon$_y$	Adjustment of number of month to the time of catch
0.9979 p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
0.9153 p.shift	α$_y$	Proportion of age shift
1.2788 p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2011

Age i	CAA $N_{y,i}$	L.Jan $L_{JAN,i}$	mean.L	mean.W $W.catch_{y,i}$	subSumWildW	harv.L $L.Harv2_{y,i}$	harv.W $W.Harv2_{y,i}$	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1	0	49.4	45.3	2.03	0	70.74	9.10	0	0	0	0	0	0	0
2	79,888	79.4	77.0	9.48	798	95.42	21.42	75034	1607553	10,642	227,992	100,925	11,968	113,504
3	100,303	97.2	95.4	17.71	1,872	109.80	32.52	94209	3063446	77,754	2,528,360	1,376,958	87,445	1,548,576
4	30,915	110.2	108.7	25.85	842	120.14	42.63	29037	1237726	84,966	3,621,793	2,196,785	95,556	2,470,583
5	7,261	121.2	119.9	34.39	263	128.88	52.72	6820	359531	25,886	1,364,616	890,331	29,112	1,001,298
6	1,492	130.6	129.5	43.04	68	136.38	62.59	1401	87680	6,051	378,747	260,445	6,806	292,905
7	312	138.4	137.5	51.17	17	142.54	71.65	293	21014	1,244	89,120	63,647	1,399	71,580
8	43	145.1	144.3	58.94	3	147.91	80.15	41	3252	292	23,424	17,225	329	19,372
Total	220,215				3,863			206,835	6,380,202	206,835	8,234,054	4,906,316	232,614	5,517,817

W.Est$_y$

−1.6364 adj.mon	adj.mon$_y$	Adjustment of number of month to the time of catch
1.0539 p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
0.8582 p.shift	α$_y$	Proportion of age shift
1.1246 p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2012

Age i	CAA $N_{y,i}$	L.Jan $L_{JAN,i}$	mean.L	mean.W $W.catch_{y,i}$	subSumWildW	harv.L $L.Harv2_{y,i}$	harv.W $W.Harv2_{y,i}$	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1	2,955	49.4	55.5	3.67	10	66.31	7.63	2683	20482	924	7,055	3,388	979	3,587
2	221,420	79.4	83.0	11.81	2,497	91.00	18.64	201052	3747518	71,012	1,323,636	838,939	75,185	888,235
3	84,400	97.2	99.8	20.20	1,627	106.09	29.34	76636	2248672	158,197	4,641,820	3,195,011	167,492	3,382,751
4	10,870	110.2	112.4	28.52	296	117.39	39.75	9870	392303	53,638	2,131,941	1,529,895	56,790	1,619,792
5	623	121.2	123.1	37.12	22	126.96	50.37	566	28515	6,665	335,740	247,439	7,057	261,978
6	0	130.6	132.2	45.65	0	135.10	60.82	0	0	371	22,572	16,939	393	17,935
7	0	138.4	139.8	53.67	0	141.90	70.62	0	0	0	0	0	0	0
8	0	145.1	146.2	61.22	0	147.71	79.81	0	0	0	0	0	0	0
Total	320,268				4,453			290,808	6,437,491	290,808	8,462,764	5,831,611	307,896	6,174,279

W.Est$_y$

2.4391 adj.mon	adj.mon$_y$	Adjustment of number of month to the time of catch
0.9546 p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
0.6555 p.shift	α$_y$	Proportion of age shift
1.0588 p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Table 3.   (cont.)

Year=2013

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1	0	49.4	53.7	3.33	0	66.92	7.83	0	0	0	0	0	0	0
2	117,218	79.4	81.9	11.37	1,332	91.68	19.05	11501	219134	5,306	101,086	60,342	54,073	614,984
3	135,534	97.2	99.1	19.74	2,673	106.68	29.83	13298	396674	6,135	182,986	121,077	62,522	1,233,971
4	5,950	110.2	111.8	28.03	167	117.81	40.18	584	23459	6,465	259,793	181,240	65,890	1,847,135
5	635	121.2	122.5	36.63	23	127.25	50.72	62	3162	7,193	364,798	263,441	73,305	2,684,897
6	0	130.6	131.7	45.17	0	135.29	61.07	0	0	314	19,207	14,206	3,205	144,785
7	0	138.4	139.4	53.22	0	141.98	70.75	0	0	34	2,376	1,788	342	18,218
8	0	145.1	145.9	60.81	0	147.71	79.82	0	0	0	0	0	0	0
Total	259,337				4,195			25,446	642,429	25,446	930,246	642,093	259,337	6,543,989
														$W.Est_y$

1.7116	adj.mon	$adj.mon_y$	Adjustment of number of month to the time of catch
0.9992	p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
1.5387	p.shift	α_y	Proportion of age shift
10.1917	p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2014

Age	CAA	L.Jan	mean.L	mean.W	subSumWildW	harv.L	harv.W	caa.harv.rep	subSumHarvRepW	caa.harv.est	subSumHarvEstW	subSumWildEstW	caa.wild.est	subSumWildEstW2
i	$N_{y,i}$	$L_{JAN,i}$		$W.catch_{y,i}$		$L.Harv2_{y,i}$	$W.Harv2_{y,i}$							
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1	345	49.4	53.8	3.35	1	66.87	7.81	327	2551	155	1,210	519	164	549
2	80,597	79.4	82.0	11.41	918	91.63	19.02	76303	1451275	36,349	691,361	414,632	38,395	437,962
3	142,503	97.2	99.1	19.77	2,815	106.63	29.79	134912	4019013	104,091	3,100,872	2,058,078	109,948	2,173,881
4	42,498	110.2	111.8	28.07	1,192	117.78	40.15	40234	1615380	90,022	3,614,328	2,527,020	95,088	2,669,209
5	2,340	121.2	122.6	36.66	86	127.23	50.69	2215	112290	22,208	1,125,746	814,255	23,458	860,071
6	31	130.6	131.7	45.21	1	135.27	61.05	29	1764	1,179	71,958	53,284	1,245	56,282
7	205	138.4	139.4	53.25	11	141.98	70.73	194	13697	107	7,569	5,698	113	6,019
8	0	145.1	145.9	60.84	0	147.71	79.82	0	0	102	8,127	6,195	108	6,544
Total	268,518				5,024			254,214	7,215,970	254,214	8,621,172	5,879,682	268,518	6,210,517
														$W.Est_y$

1.7676	adj.mon	$adj.mon_y$	Adjustment of number of month to the time of catch
0.9990	p.N.trans		(Total numper of transported in TIS)/(Total number in Catch-at-age)
0.5259	p.shift	α_y	Proportion of age shift
1.0563	p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

When the value p.shift exceeded 1.0, in 2011, (proportion -1) in age_i was shifted to age_{i+2}.

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Table 4 Statistics of growth of farming SBT from SRP tagging data

Fish	Variable	Period	Age-2	Age-3	Age-4	説明
Wild	Fork length	0	79.4	97.2	110.2	野生魚の1月1日時点の体長
Wild	Fork length	1 year	97.2	110.2	121.2	野生魚の翌年の体長
Wild	Growth rate in length	1 year	0.224	0.134	0.100	野生魚の1年間の成長率
Wild	Growth rate in length	6 month	0.149	0.089	0.067	野生魚の6ヶ月の成長率。冬季3ヶ月はゼロ成長を仮定。
Farmed	N	variety	39	75	9	個体数
Farmed	Growth rate in length	variety	0.181	0.124	0.092	標識魚の平均成長率
Farmed	Growth rate in length	variety	0.093	0.071	0.050	標識魚の成長率のSD
Farmed	Growth rate in length	variety	0.015	0.008	0.017	標識魚の成長率のSE
Farmed	Growth rate in length	6 month	0.200	0.133	0.080	標識魚の6ヶ月の平均成長率
Farmed	Growth rate in length	6 month	0.118	0.059	0.043	標識魚の6ヶ月を仮定した成長率のSD
Farmed	Growth rate in length	6 month	0.019	0.007	0.014	標識魚の6ヶ月を仮定した成長率のSE
Wild	Fork length	6 month	91.3	105.9	117.5	野生魚の6ヶ月の到達体長。冬季3ヶ月はゼロ成長を仮定。
Wild	Whole body weight	0	10.4	18.7	26.9	野生魚の1月1日の体重。RobinsLW使用。
Wild	Whole body weight	6 month	15.6	23.9	32.4	野生魚の6ヶ月での到達体重。RobinsLW使用。
Farmed	Fork length	6 month	95.3	110.1	119.0	畜養魚の6ヶ月での到達体長
Farmed	Whole body weight	6 month	18.2	28.4	36.1	畜養魚の6ヶ月での到達体重。RobinsLW使用。
Farmed	Growth rate in weight	6 month	1.750	1.520	1.343	畜養魚の6ヶ月間の体重増加率
Farmed	Growth rate in weight in Sakai et al. (2009)	6 month	1.818	1.544	1.448	畜養魚の6ヶ月間の体重増加率（Sakai et al. 2009）

Growth rate in length in 6 months is (growth increment in 6 months)/(length at start).

Table 5 Comparison of length growth in six months among five *Thunnus* species, including SBT

Species	Wild or farm	SBT Age-2			SBT Age-3			SBT Age-4		
		L_{start}	L_6 months later	Increment	L_{start}	L_6 months later	Increment	L_{start}	L_6 months later	Increment
SBT	wild	79.4	91.3	11.9	97.2	105.9	8.7	110.2	117.5	7.3
SBT	Farm.Tag	79.4	95.3	15.9	97.2	110.1	12.9	110.2	119.0	8.8
ABF	wild	79.4	94.6	15.2	97.2	111.3	14.1	110.2	123.4	13.2
PBF	wild	79.4	100.1	20.7	97.2	115.7	18.5	110.2	127.2	17.0
BET	wild	79.4	96.8	17.4	97.2	112.4	15.2	110.2	123.7	13.5
YFT	wild	79.4	118.4	39.0	97.2	130.0	32.8	110.2	138.6	28.4

Unit is in centimeter.

References are as follows; ABF (Atlantic bluefin tuna *Thunnus thynnus*) is Restrepo et al. (2010), PBF (Pacific bluefin tuna, *T. orientalis*) is Shimose et al. (2009), BET (Bigeye tuna, *T. obesus*) is Hallier et al.(2005), and YFT (Yellowfin tuna, *T. albacares*) is Wild (198).

Table 6 Length growth of farming SBT and farming PBF

Species	Wild or farm	SBT Age-2				SBT Age-3				SBT Age-4			
		L_{start}	L_6 months later	Increment	Ratio Farm/Wild	L_{start}	L_6 months later	Increment	Ratio Farm/Wild	L_{start}	L_6 months later	Increment	Ratio Farm/Wild
SBT	wild	79.4	91.3	11.9		97.2	105.9	8.7		110.2	117.5	7.3	
SBT	Farm.Tag	79.4	95.3	15.9	1.34	97.2	110.1	12.9	1.49	110.2	119.0	8.8	1.21
SBT	Farm2001	79.4	110.3	30.9	2.61	97.2	120.6	23.4	2.70	110.2	128.8	18.6	2.54
SBT	Farm2002	79.4	109.5	30.1	2.53	97.2	119.7	22.5	2.60	110.2	128.0	17.8	2.42
SBT	Farm2003	79.4	121.1	41.7	3.52	97.2	131.4	34.2	3.95	110.2	139.6	29.4	4.01
SBT	Farm2004	79.4	114.0	34.6	2.92	97.2	124.3	27.1	3.12	110.2	132.5	22.3	3.04
SBT	Farm2005	79.4	120.2	40.8	3.44	97.2	130.4	33.2	3.84	110.2	138.7	28.5	3.88
SBT	Farm2006	79.4	115.3	35.9	3.03	97.2	125.6	28.4	3.28	110.2	133.8	23.6	3.22
SBT	Farm2007	79.4	119.4	40.0	3.37	97.2	129.7	32.5	3.75	110.2	137.9	27.7	3.78
SBT	Farm2008	79.4	107.0	27.6	2.33	97.2	117.3	20.1	2.32	110.2	125.5	15.3	2.09
SBT	Farm2009	79.4	114.4	35.0	2.95	97.2	124.6	27.4	3.17	110.2	132.9	22.7	3.09
SBT	Farm2010	79.4	116.7	37.3	3.14	97.2	127.0	29.8	3.43	110.2	135.2	25.0	3.41
SBT	Farm2011	79.4	111.2	31.8	2.68	97.2	121.5	24.3	2.80	110.2	129.7	19.5	2.65
SBT	Farm2012	79.4	118.9	39.5	3.33	97.2	129.2	32.0	3.69	110.2	137.4	27.2	3.71
SBT	Farm2013	79.4	122.2	42.8	3.61	97.2	132.5	35.3	4.07	110.2	140.7	30.5	4.16
SBT	Farm2014	79.4	113.3	33.9	2.86	97.2	123.6	26.4	3.04	110.2	131.8	21.6	2.94
PBF	wild	79.4	100.1	20.7		97.2	115.7	18.5		110.2	127.2	17.0	
PBF	Farm.Amami	79.4	111.1	31.7	1.53	97.2	125.9	28.7	1.55	110.2	136.7	26.5	1.56
PBF	Farm.Yaeyama	79.4	110.7	31.3	1.51	97.2	124.5	27.3	1.47	110.2	134.7	24.5	1.44

Unit is in centimeter, except ratio Farm/Wild (RFW).

Table 7.　Reported and estimated Australian purse seine catches by fishing year.

Fishing year is expressed as 2014 for the period between Dec. 2013 and Nov. 2014.
Growth rate is from CCSBT SRP conventional tagging data for cases 1.
W.Reported: Catch amount reported in tons
W.Estimated: Estimated amount of catch based on the farming growth rate given
W.Excess: Estimated excess amount of catch
percent.excess: Proportion of estimated excess amount of catch to catch amount reported (%)

Case1
Growth rate of mean of SRP tagging data was used

Year	W.Reported	W.Estimated	W.Excess	percent.excess
2001	5,162	6,604	1,442	28%
2002	5,234	6,303	1,069	20%
2003	5,375	7,437	2,063	38%
2004	4,874	6,324	1,450	30%
2005	5,214	7,598	2,384	46%
2006	5,302	7,168	1,866	35%
2007	5,230	7,776	2,546	49%
2008	5,211	5,935	724	14%
2009	5,026	6,831	1,804	36%
2010	3,931	5,549	1,619	41%
2011	3,872	5,518	1,646	43%
2012	4,485	6,174	1,690	38%
2013	4,198	6,544	2,346	56%
2014	5,029	6,211	1,181	23%
Average			1,702	35.5%
Total			23,830	

Case2
Growth rate is assumed to be same as that of wild fish in body length

Year	W.Reported	W.Estimated	W.Excess	percent.excess
2001	5,162	7,324	2,162	42%
2002	5,234	7,000	1,766	34%
2003	5,375	7,845	2,470	46%
2004	4,874	6,866	1,992	41%
2005	5,214	8,155	2,942	56%
2006	5,302	7,780	2,479	47%
2007	5,230	8,413	3,183	61%
2008	5,211	6,748	1,536	29%
2009	5,026	7,466	2,439	49%
2010	3,931	5,993	2,062	52%
2011	3,872	6,323	2,451	63%
2012	4,485	6,618	2,133	48%
2013	4,198	6,980	2,782	66%
2014	5,029	6,672	1,642	33%
Average			2,289	47.6%
Total			32,039	

Table 8. Comparison of reported and estimated Australian purse seine catches by fishing year.

Year	Australia reported	Itoh et al. 2012 Mixed normal distribution	Itoh et al. 2012 Cohort slicing	Present study Case1	Present study Case2
2001	5,162			6,604	7,324
2002	5,234			6,303	7,000
2003	5,375			7,437	7,845
2004	4,874			6,324	6,866
2005	5,214			7,598	8,155
2006	5,302			7,168	7,780
2007	5,230	8,271 (8,264-8,277)	8,273	7,776	8,413
2008	5,211	6,159 (6,156-6,163)	6,659	5,935	6,748
2009	5,026	6,749 (6,773-6,754)	6,675	6,831	7,466
2010	3,931		5,689	5,549	5,993
2011	3,872			5,518	6,323
2012	4,485			6,174	6,618
2013	4,198			6,544	6,980
2014	5,029			6,211	6,672

Median (5%-95%)
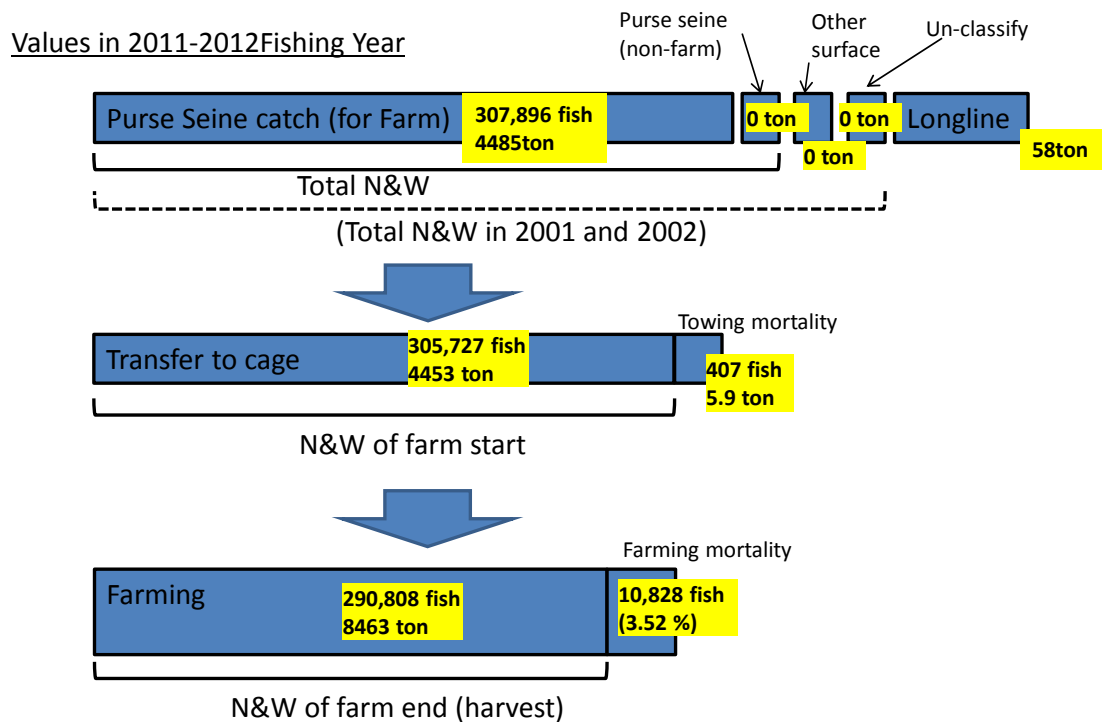
Fig. 1. Diagram showing the estimation from catch through the start to the end of farming
The numbers are statistics in the 2012 fishing year (Dec 2011-Nov 2012) for reference.
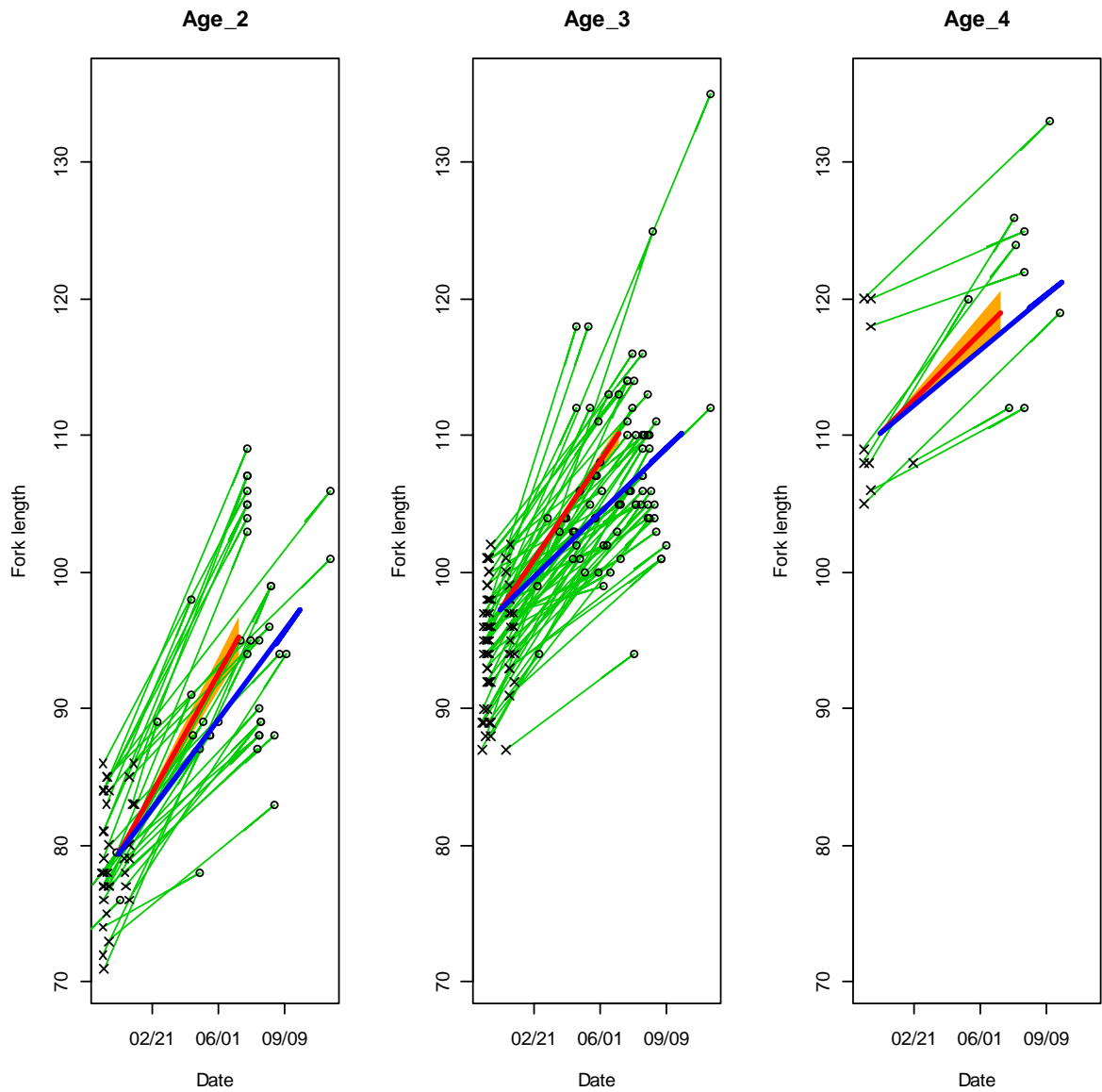
Fig. 2　Fork length plots of SBT at release and recapture in SRP tagging data by age

Age was estimated by fork length at release. Cross denotes fork length and date at release, open circle denotes fork length and date at recapture in farming (harvest and killed). Each green line is drawn for each tagged individuals. Blue thin line shows growth of wild SBT, which assumed annual growth in nine months taking into account growth stop in winter. Red line shows mean growth rate of SRP tagged fish from January 1st for six months, with 1 standard error as shown as yellow polygon.
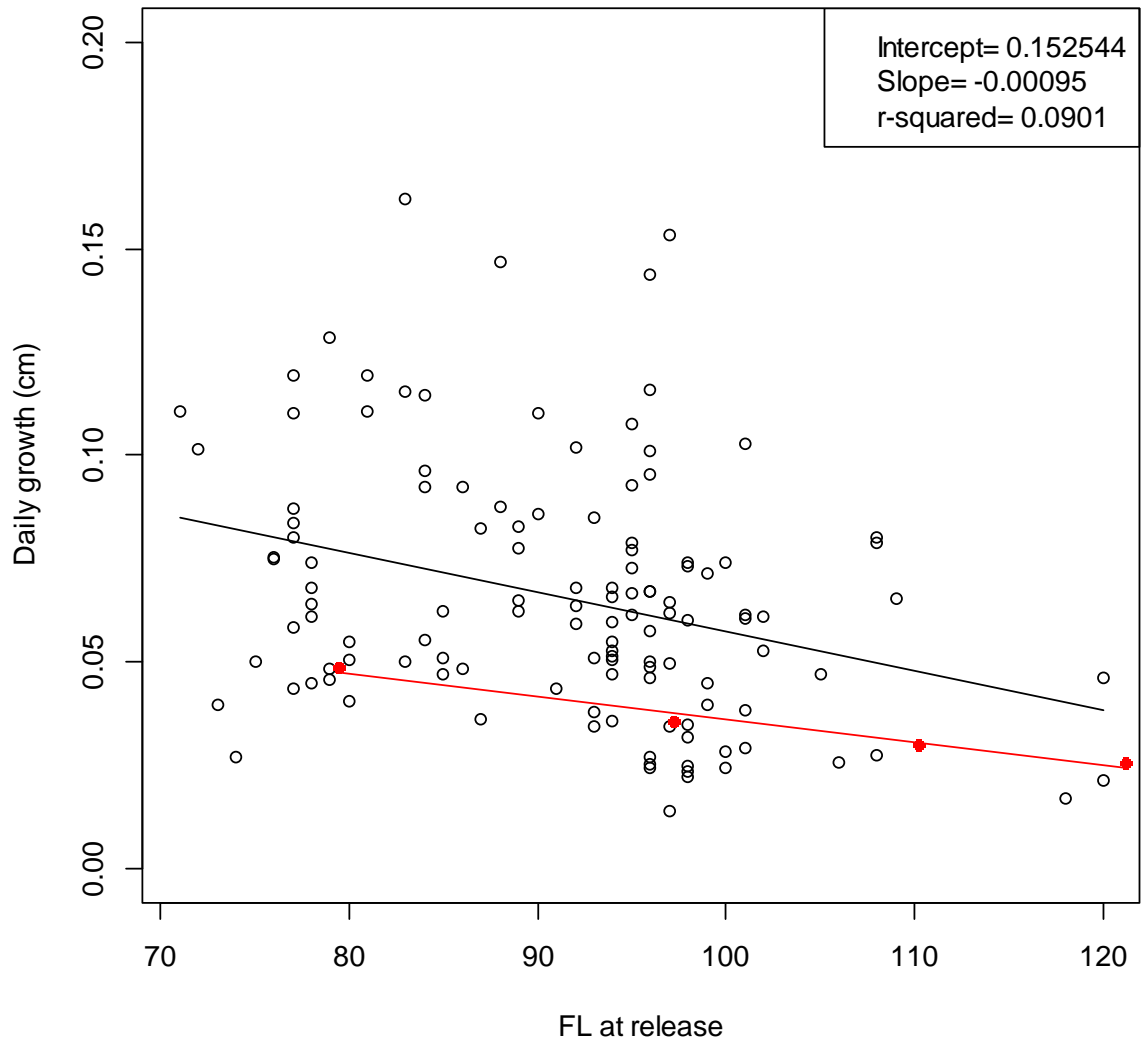
Fig. 3   Daily growth in fork length of farmed SBT in SRP tagging data

Black line denotes a regression line for the daily growth in SRP tagging.   Red line with dots is a regression line for growth of wild fish.
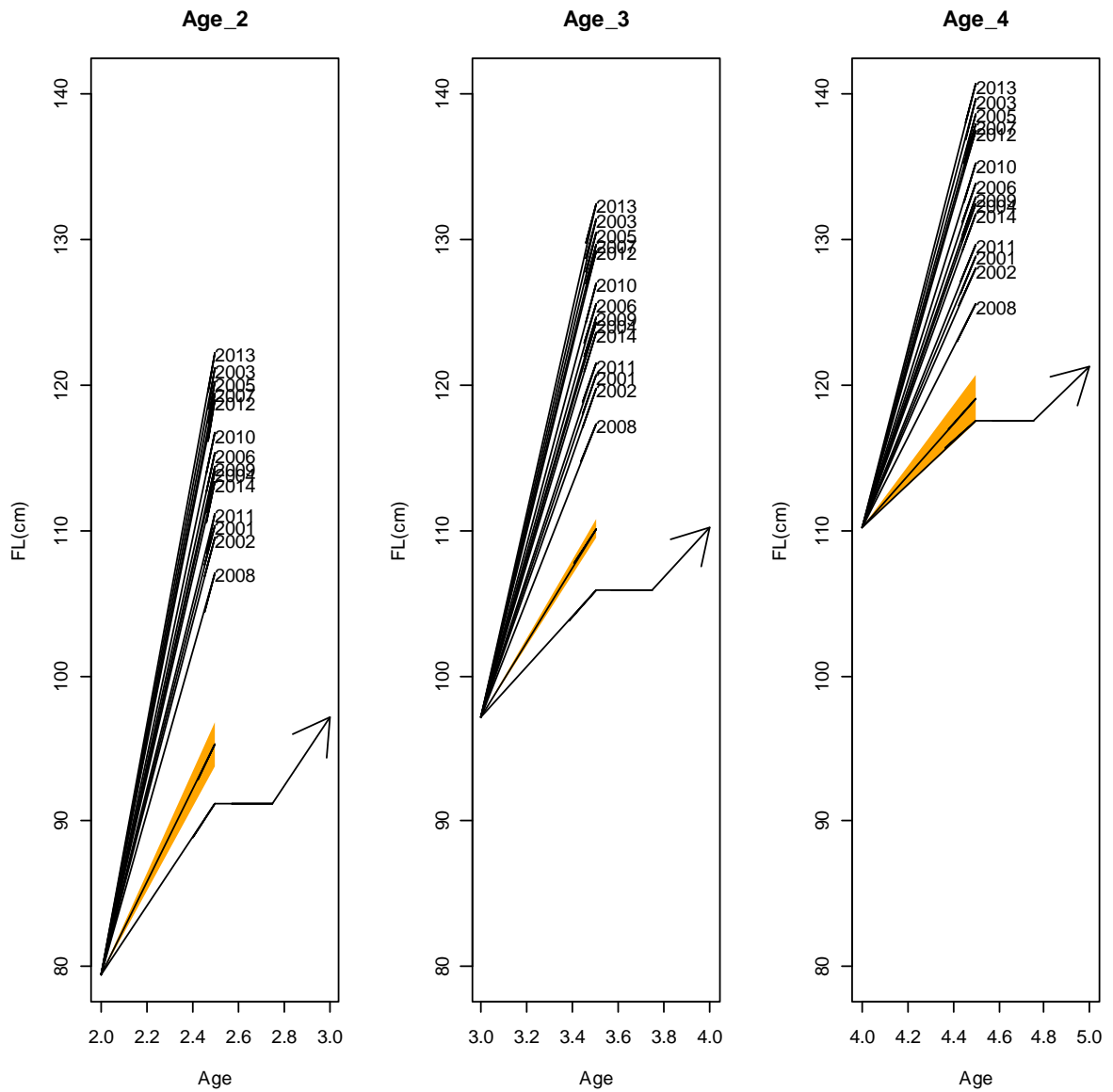
Fig. 4   SBT growth in fork length by age assumed for farmed fish

Black arrows denote growth of wild SBT used in CCSBT, assuming no growth in winter between July and September.   Yellow polygons denote growth from SRP tagging data of mean with 1 standard error.   Black lines are assumed growth rate of farmed fish estimated from 40/100 fish sampling and reported catch amount by fishing year.
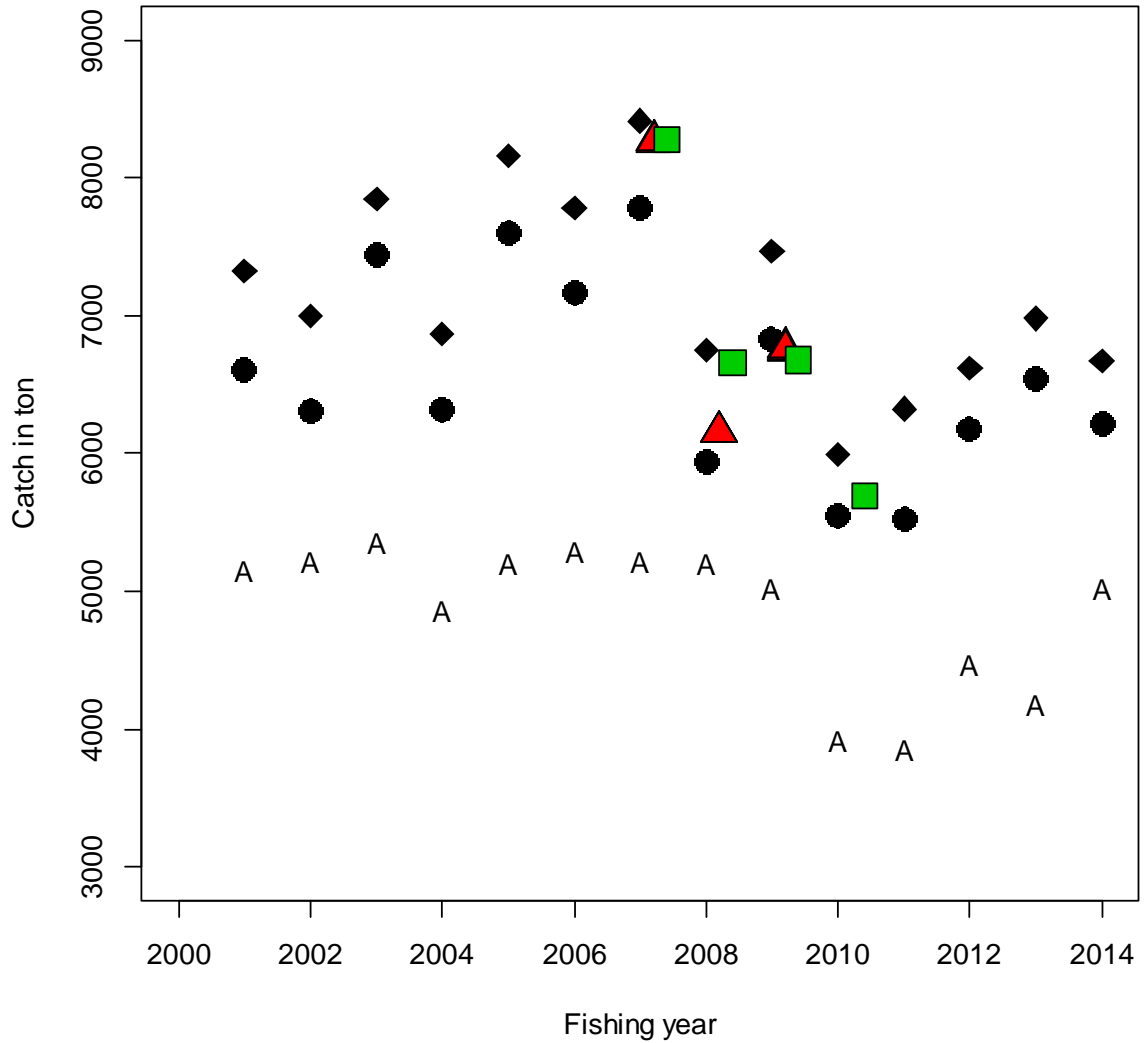
Fig. 5.   Estimated SBT catch amount by the Australian purse seine fishery by fishing year

A denotes catch Australia reported. The black circle ● denotes the estimated catch based on the mean growth rate obtained from the CCSBT SRP conventional tagging data (Case 1). The black diamond ◆ denotes the estimated catch assuming the growth rate for body length in farmed fish is same as that in wild fish (Case 2). The red triangles ▲ are the catch amounts estimated in a previous study that decomposed ages by applying mixed normal distributions to length frequency data (Itoh et al. 2012).   The green squares ■ are the catch amounts estimated in a previous study that decomposed age by applying the cohort slicing method to length frequency data (Itoh et al. 2012).
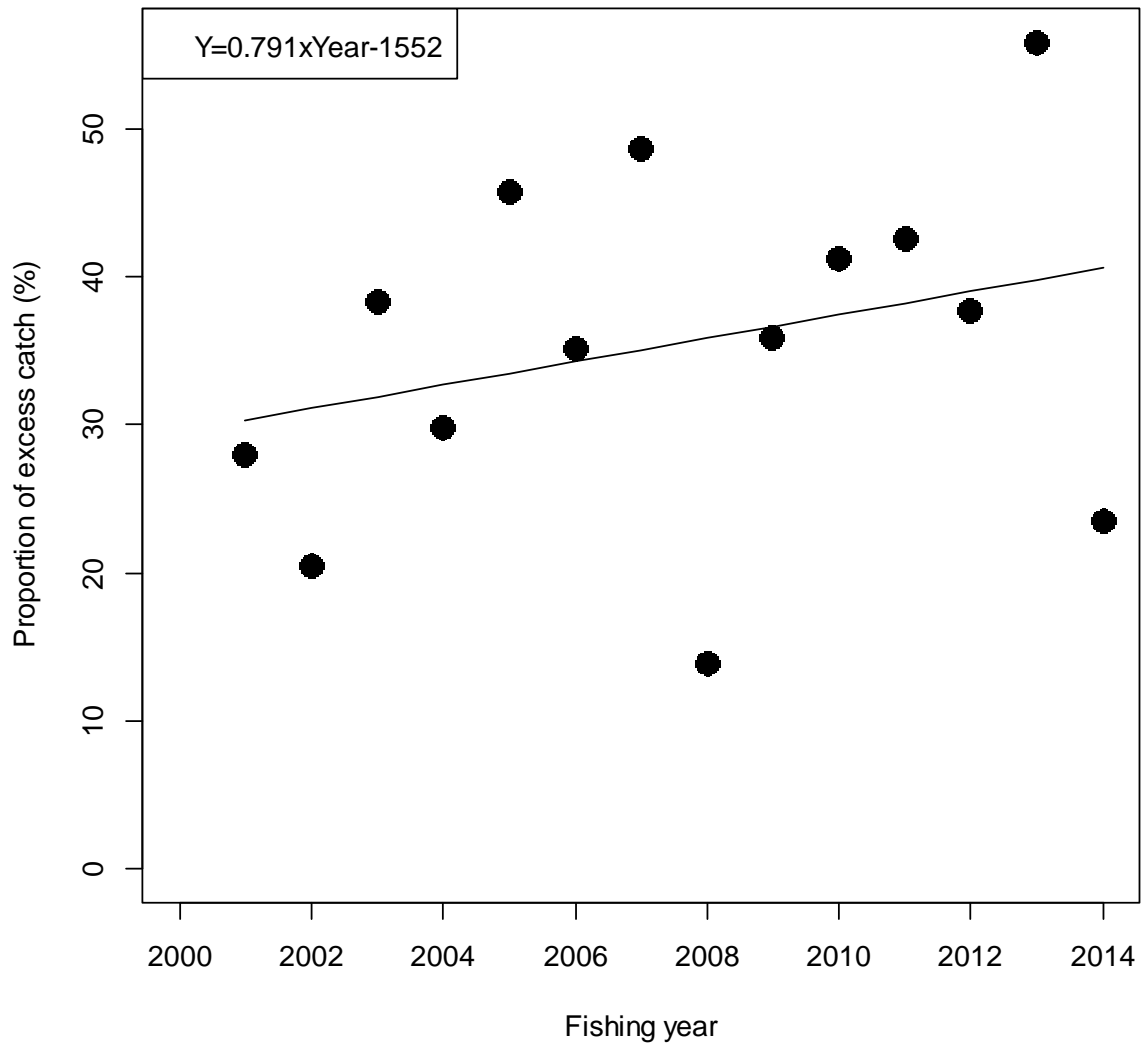
Fig. 6. Plots of proportion of excess catch to the reported catch by fishing year in
Australian farmed SBT.
Case 1 estimation is shown.

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Evaluation of length-weight relationship in Robins（1963）

Robins 1963 の体長体重関係式の適切さ

　OMMP5（2014 年）で Robins（1963)の体長体重関係式の適切さが議論された。Robins (1963)では論文において体長体重関係式および曲線が示されているものの、測定個体数、具体的なプロットは示されておらず、信頼性が確保できない。また、50 年以上昔のデータであり、近年に当てはまるのかは定かではない。

　そこで、利用可能な近年のデータを用いて体長体重関係式を求めた。データは 2011 年から 2014 年の曳縄調査によるミナミマグロの体長体重データ（N=529）、ならびに 2011 年から 2014 年の RTMP データにおける体長体重データを用いた。求めるべき体長体重関係はまき網が漁獲する 12 月から 2 月のものである。曳縄調査は 1 月から 2 月に行われるので、全てのデータを用いた。ボックスプロットでチェックしたところ、RTMP データでは肥満度が 11 月から翌年 5 月に同様であったことから、それ以外の月は除いた。RTMP は製品重量であることから、1.15 倍して原魚重量とした（Anon. 2014）。まき網では大型魚はほとんど漁獲されないので、>140cm のデータは除いた（N=73,125）。

　体長体重関係式は以下のアロメトリー式で示される。

　$W = aL^b$

　Robins(1963)では a=3.130859x10^{-5} （原記載は 10$^{-4.161}$ でポンド単位）、b=2.9058 であった。我々のデータからは a=2.274358x10^{-5}, b=2.971 が得られた。両者にほとんど違いは見られなかった（Fig. A1）。よって、Robins(1963)の LW 関係式を解析に使用することは妥当と考えられた。

　There was a discussion at OMMP5（2014）whether the length-weight（LW） relationship of Robins（1963) is appropriate.　In the paper of Robins（1963), there was a figure of LW curve and parameter values of equation, but lacked information of the number of individual measured or actual plots of each individuals, then we could not ensure its reliability.　In addition, it should be confirmed that such a LW relationship obtained 50 years ago is applicable in recent years.

　We calculated LW relationships by using available data in recent years.　Data came from the trolling survey from 2011 to 2014（N=529）and RTMP data in the same years. The LW relationship should be derived is for Australian purse seine catch in the period from December to February.　All of data from the trolling survey were used because its periods were from January to February.　In the RTMP data, monthly condition index （W/L^3）was similar between November and May in an observation by box plots, then the

data in the period was used.   Weights in RTMP were converted to round weight by a factor of 1.15 (Anon. 2014).   Since large individuals are few in purse seine catch, data > 140 cmFL were excluded, resulted in records from 126,581 individuals in RTMP were used.

LW relationship was expressed as the following allometry equation.

$W=aL^b$

Parameters in Robins (1963) was a=3.130859×10^{-5} (original description was $10^{-4.161}$ as the unit was pound) and b=2.9058.   Our data provided a=2.274358×10^{-5} and b=2.971. Two curves agreed well each other (Fig. A1).   Therefore, it is considered to be appropriate to use the LW relationship in Robins (1963) for wild fish in the farming subject in recent years.

References

Anonymous 2014. Secretariat review of catches. CCSBT-ESC/1409/04(Rev.1)

Robins, J. P. 1963. Synopsis of biological data on bluefin tuna *Thunnus thynnus maccoyii* (Castelnau) 1872. Species synopsis No. 17. FAO Fisheries Biology Synopsis No. 60.
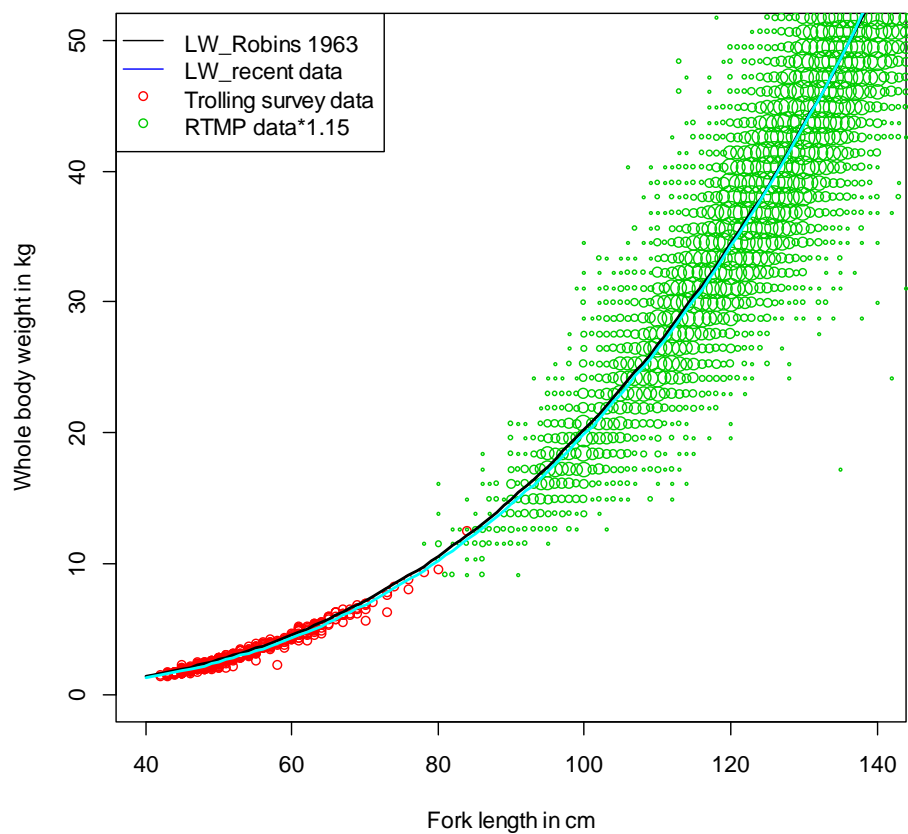
Fig. A1   Length-weight relationship of young SBT

Each plot in red is one individual measured in the trolling survey.   The numbers of
measured SBT in RTMP (green) are expressed as size of circles.

Evaluation of growth rate in farming of Atlantic, Pacific and southern bluefin tunas in literatures used in Jeffriess (2014)

Jeffriess(2014)で示された文献による大西洋クロマグロ、太平洋クロマグロ、ミナミマグロの畜養成長の検証

Jeffriess(2014 CCSBT-ESC/1409/11)において、ミナミマグロおよび近縁種である大西洋クロマグロおよび太平洋クロマグロについて、畜養魚の高い成長を示す証拠の情報としていくつかの文献情報が紹介された。その中で具体的な数字で示された事例について検討した。

【事例1】Kataviæ et al. (2002) より。大西洋クロマグロ。 "*In a trial conducted in the Adriatic Sea trial over 17 months (June 1999-December 2000) the results showed a much faster growth in length and weight in farms than in the wild. For example, in the 85-120cm category (10-25kg) the monthly growth was 2.16cm and 2.42kg. This was despite an initial tagging mortality of 50%, plus 5% during the trial, indicating stress on all tagged fish.*" (Table 1 in Jeffries 2014)

100cm の ABF が一ヶ月で畜養では 2.16cm 成長するとしている。Restrepo et al.(2009) では一ヶ月で野生魚は 1.59cm 成長する。よって、RFW=1.36。SBT3 歳魚の SRP タグから求めた RFW=1.49 を上回らない。

【事例2】Deguara et al. (2010) より。大西洋クロマグロ。 "*A 4 month trial in Malta (February to June 2009) on 5-6 year old Atlantic Bluefin Tuna achieved a 43.5% increase in weight and an increase in length from 142.5 cm to 157.9cm. In the wild, such ABT age groups take over one year to gain that length.*" (Table 1 in Jeffries 2014)

137 日間の実験で 142.5 cm から 157.9cm に成長したとしている。RFW=2.35 と計算された。SRP タグからの畜養 SBT の RFW を上回るが、豪州報告漁獲量に対応した RFW は下回る。また、ICCAT-SCRS での議論は明らかではないが、このレポートが出されてもなお、ICCAT-SCRS は畜養魚の体長成長は野生魚と同じと結論付けていることに留意すべきである。

【事例3】Galaz (2012)より。大西洋クロマグロ。"*In cages with just young tunas, growth is more important as the direct competition for food has been removed. Data suggests juveniles under 20kg originating from the Balearic Islands show significant weight increase reaching a SGR of 88.8 % in November (121 days).*" (Table 1 in Jeffries 2014)

20kg の魚が 4 ヶ月で 1.888 倍になるとしている。

Table 5. Weight increase data for juveniles caught in the Balearic Islands.

Month	Avg(Kg.)	Std Dev	n	Days	RGR%
July	19.5	2.7	27	0	--
August	22.1	3.9	11	31	13.5%
September	30.7	6.0	7	60	57.6%
October	--	--	--	91	--
November	36.8	4.7	52	121	88.8%
December	34.9	4.8	516	152	79.1%
January	34.4	4.4	108	167	76.5%

　上記（Table 5 of Galaz 2012）が、Jeffriess(2014)が参照した表であろう。11 月で 1.888 倍になっているが、6 ヶ月経って 1 月になっても 1.765 倍でしかない。Galaz(2012)は、冬季には成長が停滞するとしている。よって、6 ヶ月後の平均体重は 11 月、12 月、1 月の平均体重=35.0kg とした。大西洋クロマグロで体重 19.5kg は 3.32 歳と推定され、6 ヵ月後の体長は 112.2cmFL となる。畜養 ABF35.0kg の体長は Galaz(2012)で示された WL 関係式から、121.0cmFL と計算された。よって RFW=(121.0-103.1)/(112.3-103.1)=1.95。SRP タグからの畜養 SBT の RFW を上回るが、豪州報告漁獲量に対応した RFW は下回る。

　このレポートが出されてもなお、ICCAT-SCRS は畜養魚の体長成長は野生魚と同じと結論付けていることに留意すべきである。

　【事例 4】Goto(2014)より。太平洋クロマグロ。実験 1 では 2013 年 6 月 16 日の 89cm が 2013 年 12 月 16 日に 113cm に成長した。実験 2 では 2013 年 11 月 7 日の 77cm が 2014 年 5 月 26 日に 98.5cm に成長した。

　実験 1 では 89cmFL の魚で RFW=1.80、実験 2 では 77cmFL の魚で RFW=1.50 であった。SRP タグからの畜養 SBT の RFW を少し上回るが、豪州報告漁獲量に対応した RFW をはるかに下回る。

　【事例 5】Gordon et al.(2006)より。これはミナミマグロ畜養魚の成長の具体的数字を示した Jeffriess (2014)の中で唯一のもの。

Days in culture	Start	Finish	RFW estimated	Source
173 days	*95 cmFL*	*108 cmFL*	1.476	Jeffriess(2014)
170 days	*97 cmFL*	*109 cmFL*	1.477	Jeffriess(2014)
174 days	*112 cmFL*	*120 cmFL*	1.144	Jeffriess(2014)
6 months	97.2 cmFL	110.1 cmFl	RFW=1.49	SRP tag estimation in the present study
6 months	110.2 cmFL	119.0 cmFL	RFW=1.21	SRP tag estimation in the present study

　イタリックは Jeffeiess(2014)からの引用。SRP 標識データから求めた 6 ヶ月間の畜養魚

の体長成長とよく一致した。RFW の分母は、CCSBT で用いている年齢別平均値について、月別成長を直線と仮定し、冬季３ヶ月間は成長が停滞すると仮定して求めた。推定した RFW は、SRP タグからの畜養 SBT の RFW と同じか少し下回り、豪州報告漁獲量に対応した RFW をはるかに下回る。

　Jeffriess（2014)はこの実験での死亡率が高かったと記している。死亡率等の情報は示されていない。

　Jeffriess (2014 CCSBT-ESC/1409/11) introduced several cases of results in growth of farmed tuna (southern bluefin tuna *Thunnus maccoyii* SBT and its closely related species, Atlantic bluefin tuna *T. thynnus* ABF and Pacific bluefin tuna *T. orientalis* PBF) by referring to literatures.　Among them, we examined several cases that the actual data were available.

　<Case 1> From Kataviæ et al. (2002) for ABF

　"*In a trial conducted in the Adriatic Sea trial over 17 months (June 1999-December 2000) the results showed a much faster growth in length and weight in farms than in the wild. For example, in the 85-120cm category (10-25kg) the monthly growth was 2.16cm and 2.42kg. This was despite an initial tagging mortality of 50%, plus 5% during the trial, indicating stress on all tagged fish.*" (Table 1 in Jeffries 2014)

　It states that 100 cmFL ABF grew 2.16 cm per month.　Wild ABF at 100 cmFL grow 1.59 cm per month with growth equation in Restrepo et al. (2009).　Then, RFW is 1.36. This does not exceed the RFW value (1.49) for age-3 SBT derived from the SRP tagging data.

　<Case 2> From Deguara et al. (2010) for ABF.

　"*A 4 month trial in Malta (February to June 2009) on 5-6 year old Atlantic Bluefin Tuna achieved a 43.5% increase in weight and an increase in length from 142.5 cm to 157.9cm. In the wild, such ABT age groups take over one year to gain that length.*" (Table 1 in Jeffries 2014)

　It states fish grew from 142.5 to 157.9 cm in 137 days.　RWF is calculated as 2.35. It exceed the RFW value (1.49) for SBT derived from the SRP tagging data, but below the RWF corresponds to the total catch that Australia reported.

　Note that ICCAT-SCRS concluded that farm fish growth in length should be same as that of wild fish in their assessment calculation, even Deguara et al. (2010) and Galaz (2012) were available in the discussion.

<Case 3> From Galaz (2012) for ABF.

"*In cages with just young tunas, growth is more important as the direct competition for food has been removed. Data suggests juveniles under 20kg originating from the Balearic Islands show significant weight increase reaching a SGR of 88.8 % in November (121 days).*" (Table 1 in Jeffries 2014)

It states that body weight of 20 kg became 1.888 times in four months.

Following is the Table that Jeffriess (2014) would refer to (Table 5 of Galaz 2012).

Table 5. Weight increase data for juveniles caught in the Balearic Islands.

Month	Avg(Kg.)	Std Dev	n	Days	RGR%
July	19.5	2.7	27	0	
August	22.1	3.9	11	31	13.5%
September	30.7	6.0	7	60	57.6%
October	--	--	--	91	--
November	36.8	4.7	52	121	88.8%
December	34.9	4.8	516	152	79.1%
January	34.4	4.4	108	167	76.5%

While average growth in November was 1.888 times, the growth was 1.765 times in January after six months passed. Galaz (2012) stated that fish didn't grow in winter. Then, average growth in six months is expected to be 35.0 kg, by weighting average of November, December and January, which estimated to be 121.0 cmFL with LW equation in Galaz (2012). ABF of 19.5 kg is estimated to be age 3.32 with 103.1 cmFL and estimated to grow to 112.2 cmFL in six months. Then, RFW= (121.0-103.1)/(112.3-103.1)=1.95. It exceed the RFW value (1.49) for SBT derived from the SRP tagging data, but below the RWF corresponds to the total catch that Australia reported.

Note that ICCAT-SCRS concluded that farm fish growth in length should be same as that of wild fish in their assessment calculation, even Deguara et al. (2010) and Galaz (2012) were available in the discussion.

<Case 4> From Goto (2014) for PBF.

In experiment 1, fish grew from 89 cmFL on 16 June 2013 to 113 cmFL on 16 December 2013. In experiment 2, fish grew from 77 cmFL on 7 November 2013 to 98.5 cmFL on 26 May 2014.

RFWs are calculated as 1.80 for the experiment 1 and 1.50 for the experiment 2. It slightly exceed the RFW value (1.49) for SBT derived from the SRP tagging data, but far

below the RWF corresponds to the total catch that Australia reported.

<Case 5> From Gordon et al. (2006) for SBT

This is the only one information that actual SBT growth figures are present in Jeffriess (2014).

Days in culture	Start	Finish	RFW estimated	Source
173 days	*95 cmFL*	*108 cmFL*	1.476	Jeffriess(2014)
170 days	*97 cmFL*	*109 cmFL*	1.477	Jeffriess(2014)
174 days	*112 cmFL*	*120 cmFL*	1.144	Jeffriess(2014)
6 months	97.2 cmFL	110.1 cmFl	RFW=1.49	SRP tag estimation in the present study
6 months	110.2 cmFL	119.0 cmFL	RFW=1.21	SRP tag estimation in the present study

Italics are refer to Jeffriess (2014). Growth increment was agreed well to that from SRP tagging data. RFW was further calculated. For the denominator of RFW, monthly growth was assumed to be linier interpolation, with no growth in winter three months, between the mean length-at-age used in CCSBT. Estimated RFWs are similar or below the RFW value for SBT derived from the SRP tagging data, but far below the RWF corresponds to the total catch that Australia reported.

Jeffriess (2014) described mortality was high in this experiment. However, detail information about mortality and its influence on growth was not explained.

References

Deguara, S., S. Caruana and C. Agius (2010) Results of the first growth trial carried out in Malta with 60 kg farmed Atlantic bluefin tuna (*Thunnus thynnus* L.). SCRS/2009/134.

Galaz, T. (2012) Eleven years -1995-2005- of experience on growth of bluefin tuna (*Thunnus thynnus*) in farms. SCRS/2011/160.

Gordon, R., Bayly, G. and Foster, C. (2006). Commercialisation trials for a manufactured tuna feed. Aquafin CRC Project 1A.3 January 2006. (referred in Jeffriess 2014)

Goto, T. (2014). Development of artificial feed for farmed bluefin tuna, *Thunnus orientalis*, Nippon Suisan Kaisha. Presentation to WAS Conference, Adelaide, June 2014. (referred in Jeffriess 2014)

Jeffriess, B. 2014. A review of tuna growth performance in ranching and farming operations. CCSBT-ESC/1409/11.

Kataviæ, I., Tièina, V. and Franièeviæ, V. (2002). A preliminary study of the growth rate

of bluefin tuna from Adriatic when reared in the floating cages. SCRS/2001/092

Restrepo, V.R., G.A. Diaz, J.F. Walter, J. Neilson, S.E. Campana, D. Secor, and R.L. Wingate. 2010. An updated estimate of the growth curve of Western bluefin tuna. Aquatic Living Resources 23: 235-342.