Unaccounted catch mortality in Australian SBT farming fishery between 2001 and 2013 estimated from information of TIS and CDS

TIS／CDS 情報に基づく 2001 年から 2013 年までの豪州畜養魚の漁獲量解析

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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)。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、未考慮の漁獲死亡を推定する。

2001 年から 2013 年までに豪州が報告した漁獲、畜養開始時、畜養終了後の収穫時の統計値を用いて、畜養期間の成長率を推定すると、年別の von Bertalanffy 成長式のパラメータ値 K で 0.456 から 0.825、平均 0.587 であった。この野生魚より数倍高く、キハダよりも高い VBK をミナミマグロ畜養魚が実現するとは到底思えない。一方、利用可能な畜養期間中の成長率情報を使うと推定漁獲量は報告漁獲量よりも 1054 トンから 2366 トン、平均 1640 トン多かった。超過漁獲量は報告量よりも 20%から 61%、平均 34.5%大きかった。超過漁獲量の割合は年々、増加する傾向にあった。推定方法によっては、超過漁獲量は平均 2021 トン、超過量の割合は 42.4%に及んだ。OMMP5 における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 34.5%）または 40%以上を用いた結果も考慮するべきである。また、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提供することで、この問題を早急に解決すべき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 as part of the ESC's planned 2014 stock assessment at the 20th annual meeting. The present paper provides estimates of unaccounted catch mortality relating to farming in the Australian surface fishery.

Using statistics between 2001 and 2013 reported by Australia, including the number and weight at the time of the wild catch, the start of farming (caging) and the end of farming (harvesting), growth rates by year were estimated in terms of parameter of K of von Bertalanffy growth equation (VBK). The VBK values estimated ranged from 0.456 to 0.825 with a mean of 0.587, and are several times higher than that of wild SBT, and higher even than any other *Thunnus* species including yellowfin tuna. It seems highly unlikely that farmed SBT can attain such high growth rates.

As an alternative explanation, by using available information on growth rates of farmed SBT, the Australian surface catches were estimated to be higher than reported catches by annual amounts ranging from 1054 tons to 2366 tons, with a mean of 1640 tons. The proportion of this excess of the reported catch ranged from 20% to 61% with a mean of 34.5%, and has been increasing over time. Using another calculation approach, the mean excess catch was estimated to be 2021 tons corresponding to a proportion of 42.4%. When considering unaccounted catches and adjustment of age composition, the OMMP5 should take these values into account using the mean of 34.5%, and even the possibility of values >40%. Furthermore, the ESC should recommend that the EC attempt to resolve this issue by recommending immediate implementation of the stereo video camera system to provide reliable length data.

緒言

2011年にCCSBTにおいて管理方式（MP）によるミナミマグロTAC決定システムが導入されたことで、ミナミマグロは新たな資源管理の時代を迎えた。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。

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である。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1万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。

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）。

これを受けて、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、未考慮の漁獲死亡を推定するものである。

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より確実になった（Itoh et al. 2009a, 2009b, 2010, 2011, 2012）。

2007年から2009年の畜養魚を対象にした解析では、多数の測定データを元に混合正規分布で年齢分解する方法を用いた（Itoh et al. 2009a, 2009b, 2010）。2010年畜養魚では畜養魚が大型化し、体長組成での混合正規分布が技術的に困難となったことから、年齢スライシング法によって解析した。本手法は混合正規分布での解析手法に比較して頑健性は低いとされた（Anon. 2011）が、共通した2007年から2009年畜養魚に対して類似した結果を提示した（Itoh et al. 2011）。

これらの個体別体長体重データに基づいた解析は高い精度を有するものの、守秘義務のあるデータであることから他国の検証が実施できないとの批判があった。

そこで本研究では、畜養前と後の漁獲尾数・重量に、畜養中の成長率を仮定した単純な解析を行った。本手法は、全ての CCSBT メンバーが容易に実施できる透明性を確保したものである。また対象解析年度を拡大できる長所がある。

Introduction

The southern bluefin tuna (*Thunnus maccoyii*; SBT) stock entered a new stock management era with the agreement upon and 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.

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 last year, 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 a few 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 EC agreed at its annual meeting in 2013 to request ESC "to conduct sensitivity analysis around all sources of unaccounted catch mortality as part of the ESC's planned 2014 stock assessment and to incorporate this information in its advice on the existence of exceptional circumstances and approach to follow as defined in the Management Procedure in accordance with the meta-rule process" and "to provide preliminary advice to CCSBT 21 on the impact of any unaccounted catch mortalities on the stock assessment projections" (Anon. 2013). In this regard, we provide estimates of unaccounted catch of purse seine fishery associated with the farming sector in this paper.

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).

In those analyses of farmed fish for 2007-2009, age composition was estimated by applying mixed normal distributions to length frequencies which were derived from the size measurement data for a large number of fish (Itoh et al. 2009a, 2009b, 2010). We also applied the cohort slicing method to estimate the age decomposition for farmed fish over 2007-2010; this was because fish used in farming operation had become larger in 2010, and this made the estimation with mixed normal distributions difficult because the different cohorts were less easily distinguished. Although it was noted that the analysis using cohort slicing seemed less robust than that using mixed normal distribution (Anon. 2011), the two methods provided similar results for farmed fish for each year between 2007 and 2009 (Itoh et al. 2011).

Even though analyses based on the dataset from individual length and weight measurements appeared to provide results with high accuracy, there was criticism that no verification could be carried out by other Members for reasons of data confidentiality.

The analyses in this paper are therefore based on a relatively simple approach using several pieces of information including numbers and total weight before and after farming, as well as an assumed growth rate during farming. This approach provides transparency as all the information used is available to all the CCSBT Members. It has the further advantage of allowing an expansion of the years considered in the 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。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。すなわち例えば、2012 年度は 2011 年 12 月から 2012 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 2014 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 2 年間については 2014 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 2013 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。

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。

漁獲月の推定

野生魚の漁獲時における 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。

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

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

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

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 length	49.4	79.4	97.2	110.2	121.2	130.6	138.4

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。

漁獲量からの成長式パラメータの推定

“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 von Bertalanffy 成長式のパラメータ K(VBK)を推定する。

CCSBT で用いている年齢別体長から、単純な VBK パラメータを 2-6 歳魚に当てはめて求めた。t0 については、畜養魚は高い VBK 値によって畜養開始時点から急激に成長するので、VBK 値と畜養開始年齢に応じて高齢にシフトさせて再調整した。

$$t0.rev_{y,i} = \frac{1}{K_y} \times \left[\left(i + \frac{adj.mon_y}{12}\right) \times \left(K_y - vbk1\right) + vbk1 \times t0\right] \qquad (4)$$

ここで、

t0.rev$_y$：VBK 値に応じて調整した漁期年 y 年、i 歳魚の t0 値。

K_y：漁期年 y 年の VBK 推定値。

vbk1、vbL、t0：野生魚の 2-6 歳に当てはめた von Bertalanffy 成長式の K（0.21862）、L-infinity(166.72 cmFL)及び t0 (-0.96811 year)。

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 $W.Harv_{y,i}$ は以下で推測できる。

$$L.Harv_{y,i} = vbL \times \left[1 - e^{-K_y \times \left(i + \frac{adj.mon_y}{12} + 0.5 - t0.rev_{y,i}\right)}\right] \quad (5)$$

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

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 K_y を求める。

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

$W.TIS.Harv_y$：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。

成長式パラメータからの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 における標識放流データから推定した畜養魚の成長率と、体長においては畜養魚の成長は野生魚と同じ（Anon. 2014）との仮定を用いた。

SRP 標識放流で畜養魚から再捕された 141 個体のデータから畜養時の半年間の体重増加は、2 歳魚 1.818 倍、3 歳魚 1.544 倍、4 歳魚 1.448 倍と推定されている（Sakai et al. 2009 CCSBT-ESC/0909/31)。5 歳以上では 4 歳と同じ、1 歳魚は野生の 2 歳魚と 1 歳魚との体重比の半年分（2.724 倍）と仮定した。2 月時点の野生魚が半年間で到達する体長を求め、2 歳魚から 6 歳魚までに当てはめて VBK を求めた（Fig. 2)。同様に体重増加の 1 標準偏差を加えた場合、引いた場合の VBK も求めた。

畜養魚の成長について、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。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 2014, Fonteneau 2013)。

以上から以下の 4 ケースで推定した。

ケース 1：SRP 標識放流データの成長率の平均値を使用した場合。

ケース 2：SRP 標識放流データの成長率の平均値+1SD を使用した場合。

ケース 3：SRP 標識放流データの成長率の平均値－1SD を使用した場合。
ケース 4：体長において畜養魚成長は野生魚と同じとした場合。

この VB パラメータに対応した漁期年 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。

$$L.Harv2_{y,i} = vbL \times \left[1 - e^{-vbk2\times\left(i+\frac{adj.mon_y}{12}+0.5-t02\right)}\right] \quad (8)$$

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

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

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。

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

$TotalN_y$：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

2012 fishing year means the period from December 2011 to November 2012.

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 the CD which was distributed by the CCSBT Secretariat to each Member in January 2014 (Table 1, Table 2). The data for the most recent two years were obtained from the 2014 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 2013, these numbers were obtained from Catch Documentation Scheme (CDS) statistics which were distributed to the CCSBT Members every six months.

The length-weight relationship in Robins (1963), which was based on young fish distributed in Australian coastal waters, was used for wild fish. The length-weight 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.

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).

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

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

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

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=3.13088*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 parameter from total catch weight

The value of *K* parameter in the von Bertalanffy growth equation (VBK) 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).

The VBK for wild fish were estimated by applying the von Bertalanffy growth curve for length at age between age 2 and 6. The value of t_0 was re-adjusted according to estimated VBK and age at the start of farming, as farmed fish grow according to different VBK values after caging.

$$t0.rev_{y,i} = \frac{1}{K_y} \times \left[\left(i + \frac{adj.mon_y}{12}\right) \times \left(K_y - vbk1\right) + vbk1 \times t0\right] \quad (4)$$

where t0.rev$_y$ = re-adjusted t_0 in the fishing year y for age i fish according to the estimated VBK;

K$_y$ = estimated VBK for the fishing year y;

vbk1, vbL, t0 = parameters of K (0.21862), L-infinity (166.72 cm FL) and t_0 (-0.96811 year) in the von Bertalanffy growth curve for wild fish in age between 2 and 4.

The fork length (L.Harv$_{y,i}$) and whole weight (W.Harv$_{y,i}$) of SBT after farming (the farming period is assumed to be 0.5 year) of age i in the fishing year y are estimated using the following equations.

$$L.Harv_{y,i} = vbL \times \left[1 - e^{-K_y \times \left(i + \frac{adj.mon_y}{12} + 0.5 - t0.rev_{y,i}\right)}\right] \quad (5)$$

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

where *a.harv* and *b.harv* are parameters of the length-weight relationship of farmed fish.

A value which minimize K$_y$ in the following equation should be obtained.

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

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 parameters

The total catch weight was estimated by shifting the age composition of farmed fish according to the growth rate given (Table 3). Four growth rates during the period of farming were assumed as detailed below.

The mean growth ratios in body weight during half a year of farming were estimated as 1.818 for age 2, 1.544 for age 3 and 1.448 for age 4 from 141 individual fish which were tagged wild and recaptured as farmed in the SRP tagging program (Sakai et al. 2009 CCSBT-ESC/0909/31). The growth ratio for age 5 or more was assumed to be same as for age 4. The growth ratio for age 1 was assumed to be equivalent to the half annual growth of wild age 1 fish (2.724). Fork lengths after half a year from the length of wild fish at February between age 2 and 6 were calculated, and then VBK was estimated (Fig. 2). VBKs were estimated similarly for growth ratios for the mean +/- one standard deviation.

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. This is the assumption made for the base case for the stock assessment of Atlantic bluefin tuna in ICCAT (Anon. 2014, Fonteneau 2013).

Thus, in summary, four growth rate cases were considered.

Case 1: the mean of the growth rate from the SRP tagging data was used.

Case 2: the mean + 1 SD of the growth rate from the SRP tagging data was used.

Case 3: the mean - 1 SD of the growth rate from the SRP tagging data was used.

Case 4: the growth in body length was assumed to be same for both wild and farmed fish.

The fork lengths ($L.Harv2_{y,i}$) and whole body weights ($W.Harv2_{y,i}$) of SBT after farming (at harvest) for age i during fishing year y according to the VBKs were calculated using the following equations.

$$L.Harv2_{y,i} = vbL \times \left[1 - e^{-vbk2\times\left(i+\frac{adj.mon_y}{12}+0.5-t02\right)}\right] \quad (8)$$

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

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

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.

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

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

豪州が報告した野生からのまき網漁獲量と収穫漁獲量を整合させる VBK は、0.456 から 0.825、平均 0.587 であった（Table 4）。

SRP 標識から求めた畜養期間の成長率の平均値（ケース 1；VBK=0.224）に対して、推定漁獲量は報告漁獲量よりも 1054 トンから 2366 トン、平均 1640 トン多かった(Table 5、Fig. 3)。超過漁獲量は報告量よりも 20%から 61%、平均 34.5%大きかった。超過漁獲量の割合は年々、増加する傾向にあった（Fig. 4)。

SRP 標識から求めた畜養期間の成長率の設定によって推定漁獲量は大きく変動した。平均値+1SD（ケース 2：VBK=0.276）では超過漁獲量は平均 334 トン、7.5%であるが、平均値-1SD（ケース 3：VBK=0.180）では平均 3619 トン、75.3%であった。

体長成長は畜養魚と野生魚とで同じと仮定した場合（ケース 4：VBK=0.219）には、超過漁獲量は平均 2021 トン、超過量の割合は 52.4%に及んだ。

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（Fig. 3)。詳細は Itoh et al.(2012)を参照。今回の漁獲量推定は、2008 年、2009 年はほぼ一致し、2007 年は過小推定であった。

Results

The VBK values that are consistent with two statistics reported from Australia, i.e, the total purse seine catch weight and the total harvest weight for farmed fish, ranged from 0.456 to 0.825 with a mean of 0.587 (Table4).

The estimated total catch weight during a fishing year for the mean growth rate derived from the SRP tagging data (Case 1, VBK=0.224) was larger than the reported catch weight by an amount ranging from 1054 to 2366 tons, with a mean of 1640 tons (Table 5, Fig. 3). These estimated amounts were larger than reported by an amount ranging from 20% to 61 %, with a mean of 34.5%. There was a tendency for such excess ratios to increase with year (Fig .4).

The ranges in the estimated total catch weight are largely a consequence of the assumptions for the growth rate during farming period which was estimated from the SRP tagging data (Table 5, Fig. 3). The mean excess amount was 334 tons (7.5%) for mean + 1SD (Case 2, VBK = 0.276), and 3619 tons (75.3 %) for mean – 1SD (Case 3, VBK = 0.180).

In the case of same growth in body length for wild and farmed fish (Case 4, VBK = 0.219), the mean excess amount was 2021 tons, with a mean excess ratio of 42.4% compared to the reported catch.

These estimated values were compared to previous estimates reported which were derived using the mixed-normal distributions or the cohort slicing method (Fig. 3). (Itoh et al. (2012) provides further details.) The values estimated in the present study were similar to those from these previous studies for 2008 and 2009 (and 2010 for cohort slicing only), but were underestimates for 2007 (Table 6）.

考察

野生魚に単純なバータランフィー成長式を当てはめた場合、ミナミマグロの VBK は 0.219 であった。近縁の太平洋クロマグロでは VBK=0.173（Shimose et al. 2009)、大西洋クロマグロでは VBK=0.089（Restrepo et al. 2010）が報告されている。短命で成熟が早く成長の速いキハダでは VB-K は 0.557-0.596（Wild 1986 1977-1979 年の毎年の値）と報告されている。ビンナガでは北太平洋資源で 0.184、南太平洋資源で 0.134（Labelle et al. 1993、Wells et al. 2011)、メバチの大西洋資源で 0.180 が報告されている（Hallier et al. 2005)。ミナミマグロの VBK はマグロ属の中で中程度の値を示している。

太平洋クロマグロでは飼育魚の成長式が得られている(Masuma 2008)。野生魚の VBK が 0.173（Shimose et al. 2009）であるのに対して、鹿児島県奄美大島の飼育では VB-K=0.250、沖縄県八重山の飼育では VB-K=0.332 であった。ただし、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)。

本研究で報告漁獲量と整合させた VBK は 0.456 から 0.825、平均 0.587 であった。畜養魚の成長が早く、高水温飼育下では高い VBK を示す場合はあるようだが、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)、野生魚より数倍高く、キハダよりも高い VBK をミナミマグロ畜養魚が実現するとは到底思えない。

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を 2007 年から 2009 年畜

養魚に対して実施した。また、少し簡略的な年齢スライシング法で体長組成を分解する方法を 2007 年から 2010 年の畜養魚に対して実施した。本研究では対象年度を 2001 年から 2013 年までの 13 年間に拡大した。

その結果、従来の推定値は本研究のケース 1 またはケース 4 と近い値となった。2007 年には、本研究のケース 1 、ケース 4 の方が過小に推定された。よって、推定結果はほぼ一貫した結果が得られるものの、本研究の方が過小推定である可能性が示唆された。

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。グローバル TAC の 18%（2013 年 10,949 トンに対するケース 1 の 2021 トン）にも及ぶ漁獲量の不確実性は看過できない。推定される超過割合は年々増加している。

早急な解決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）。このため、事態は後退するばかりであり、この問題の解決の目途は立っていない。

OMMP5 では未報告漁獲量を考慮した MP への評価を実施する必要がある。少なくとも 20%から 61%、平均 34.5%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。

我々は、以下を ESC および年次会合に提言することを提案する。

- 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。
- 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 34.5%）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、ステレオビデオカメラシステムの早急な導入によってこの問題を解決すべきである。また、畜養の成長率に関する情報を提示すべきである。
- ESC は、ステレビデオカメラシステムの導入によってこの問題を早急に解決すべきことを委員会に勧告すべきである。

Discussion

When the von Bertalanffy growth equation was applied to wild fish lengths at age between ages 2 and 6, the VBK for SBT was 0.219. In two closely-related *Thunnus* species, VBKs have been reported as 0.173 for Pacific bluefin tuna (*T. orientalis*; Shimose et al. 2009) and 0.089 for Atlantic bluefin tuna (Restrepo et al. 2010). For yellowfin tuna *T. albacares*, which is known for its short life span and rapid growth, VBKs are 0.557-0.596 (Wild 1986). For albacore, *T. alalunga*, VBKs are 0.184 for the north Pacific stock and 0.134 for the south Pacific stock (Labelle et al. 1993, Wells et al. 2011). For bigeye tuna, *T. obesus*, a VBK value of 0.180 has been reported for the Atlantic stock (Hallier et al. 2005). Thus the value of VBK for wild SBT is moderate amongst *Thunnus* species.

The growth curve under captive conditions was derived for Pacific bluefin tuna (Masuma 2008). Compared to VBK of 0.173 for wild fish (Shimose et al. 2009), those for caged tuna were higher: for example the value for the Amami-Oshima in Kagoshima Prefecture was 0.250 and that in Yaeyama in Okinawa Prefecture was 0.332. However, it has been observed that higher ambient water temperature relates to faster growth in Pacific bluefin tuna farming (Masuma et al. 2008). The mean annual water temperatures were 20-28 degrees C in Amami-Oshima and 20-31 degrees C in Yaeyama, both of which were much higher than that for the wild Pacific bluefin tuna feeding grounds due to the lower latitude. The growth of Pacific bluefin tuna 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 estimated VBKs consistent with the reported catch ranged from 0.456 to 0.825, with a mean of 0.587 in the present study. Even though some tuna in farming condition may achieve higher growth rates in high ambient water temperature, the water temperature in Port Lincoln where SBT farming is conducted is relatively low at 15-21 degrees C (Hayward et al. 2009). It seems highly unlikely that farmed SBT attain such a fast growth rate that their VBK is several times higher than that of wild SBT, or even higher than that for yellowfin tuna.

In the previous analyses, a method based on assuming mixed normal distributions for length frequencies, which was considered to be relatively robust, was used for farmed SBT for 2007-2009. Furthermore, the relatively simpler cohort slicing method was used for the length frequencies of farmed fish over 2007-2010. In present study, the years considered have been extended to as long as the 13 years between 2001 and 2013.

In the results, estimates from the previous studies were similar to those for Case 1 or Case 4 in the present study. For 2007, Case 1 and Case 4 in the present study resulted in underestimates. This suggests that generally consistent results have been obtained from different methods, though there might be some underestimation for the present study.

The EC requested the ESC to conduct sensitivity analysis for all sources of unaccounted catch mortality in the 2014 stock assessment and to evaluate its effect on Management Procedure in accordance with the meta-rule process. It is impossible to ignore the uncertainty in catch as large as 18% of the global TAC (2021 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 settlement on this issue 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. Without any clear timeframe for introduction of the system, this situation is getting worse, and there is no prospect to resolve this issue.

In the OMMP5 meeting, we have to evaluate the effects of unaccounted catch mortality on the MP. Results of present study suggest that unaccounted catch mortality in the Australian purse seine catch for farming sector would be, at least, from 20% to 61%, with a mean of 34.5% 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.

We propose that the OMMP5 group suggest the following to the ESC and the EC.

- 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 34.5%, 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 using reliable scientific data.

- 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.

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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%

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%

The value from the CDS was used in 2012.

Table 3. Procedure used in estimation

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	1	0	0	0	0	0	0	0
1	0	49.4	49.8	2.68	0	71.82	9.49	0	0	0	0	0	0	0
2	42,736	79.4	79.6	10.47	434	90.86	18.56	38983	723457	14,340	266,116	150,139	15,782	165,241
3	221,365	97.2	97.4	18.78	4,031	106.08	29.34	201927	5923947	98,920	2,902,031	1,857,706	108,870	2,044,566
4	18,807	110.2	110.3	27.01	493	118.25	40.63	17155	697109	133,961	5,443,486	3,618,310	147,435	3,982,262
5	4,225	121.2	121.3	35.58	146	127.98	51.60	3854	198865	12,263	632,752	436,320	13,496	480,208
6	889	130.6	130.7	44.18	38	135.75	61.71	811	50045	2,735	168,765	120,804	3,010	132,955
7	0	138.4	138.5	52.26	0	141.97	70.72	0	0	513	36,253	26,792	564	29,486
8	0	145.1	145.2	59.94	0	146.93	78.54	0	0	0	0	0	0	0
Total	288,022				5,141			262,730	7,593,423	262,730	9,449,403	6,210,071	289,157	6,834,719
														$W.Est_y$

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)
0.6322	p.shift	α_y	Proportion of age shift to attain VBK given
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	1	0	0	0	0	0	0	0
1	0	49.4	49.9	2.69	0	71.90	9.52	0	0	0	0	0	0	0
2	33,520	79.4	79.7	10.50	350	90.92	18.60	32335	601310	14,603	271,558	153,269	15,138	158,888
3	223,242	97.2	97.4	18.81	4,173	106.13	29.38	215346	6326722	114,985	3,378,166	2,162,547	119,200	2,241,833
4	20,825	110.2	110.4	27.04	560	118.29	40.68	20089	817150	127,166	5,172,768	3,438,532	131,828	3,564,599
5	2,837	121.2	121.4	35.61	100	128.01	51.64	2736	141307	12,252	632,703	436,318	12,701	452,315
6	564	130.6	130.7	44.20	25	135.78	61.75	544	33609	1,746	107,841	77,199	1,810	80,030
7	155	138.4	138.5	52.29	8	141.99	70.75	149	10571	366	25,891	19,136	379	19,837
8	0	145.1	145.2	59.96	0	146.95	78.56	0	0	82	6,437	4,913	85	5,093
Total	281,143				5,216			271,200	7,930,668	271,200	9,595,363	6,291,914	281,143	6,522,594
														$W.Est_y$

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)
0.5484	p.shift	α_y	Proportion of age shift to attain VBK given
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	1	0	0	0	0	0	0	0
1	138	49.4	55.2	3.61	0	75.55	10.93	130	1418	46	498	164	48	174
2	61,166	79.4	82.8	11.74	713	93.85	20.40	57636	1176030	20,316	414,549	238,466	21,561	253,074
3	182,579	97.2	99.7	20.12	3,648	108.47	31.36	172040	5394391	97,796	3,066,427	1,967,366	103,787	2,087,883
4	31,709	110.2	112.3	28.44	896	120.16	42.65	29879	1274207	122,136	5,208,613	3,473,324	129,618	3,686,094
5	1,561	121.2	123.0	37.04	57	129.50	53.49	1471	78690	19,907	1,064,765	737,297	21,126	782,463
6	693	130.6	132.1	45.56	31	136.97	63.42	653	41391	1,184	75,076	53,942	1,256	57,246
7	174	138.4	139.7	53.59	9	142.94	72.21	164	11821	481	34,736	25,780	511	27,360
8	0	145.1	146.2	61.15	0	147.71	79.81	0	0	106	8,479	6,496	113	6,894
Total	278,020				5,355			261,972	7,977,949	261,972	9,873,143	6,502,835	278,020	6,901,188
														$W.Est_y$

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)
0.6490	p.shift	α_y	Proportion of age shift to attain VBK given
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	1	0	0	0	0	0	0	0
1	150	49.4	53.4	3.28	0	74.34	10.44	144	1502	74	768	241	77	252
2	124,070	79.4	81.8	11.31	1,399	92.88	19.79	118852	2352234	60,815	1,203,606	687,814	63,485	718,012
3	171,987	97.2	98.9	19.67	3,372	107.70	30.69	164754	5056240	142,312	4,367,513	2,799,314	148,560	2,922,218
4	2,253	110.2	111.7	27.96	63	119.54	41.99	2159	90635	81,652	3,428,211	2,283,224	85,237	2,383,469
5	0	121.2	122.5	36.55	0	129.01	52.87	0	0	1,055	55,799	38,580	1,102	40,273
6	0	130.6	131.6	45.10	0	136.58	62.86	0	0	0	0	0	0	0
7	139	138.4	139.3	53.15	7	142.62	71.72	133	9561	68	4,886	3,621	71	3,780
8	103	145.1	145.8	60.75	6	147.46	79.40	99	7823	164	12,997	9,944	171	10,381
Total	298,703				4,848			286,140	7,517,994	286,140	9,073,780	5,822,737	298,703	6,078,385
														$W.Est_y$

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)
0.4889	p.shift	α_y	Proportion of age shift to attain VBK given
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	75.00	10.71	335	3589	104	1,108	358	109	377
2	187,707	79.4	82.4	11.54	2,160	93.41	20.12	178192	3585898	55,259	1,112,014	637,737	58,210	671,798
3	138,514	97.2	99.4	19.91	2,750	108.12	31.05	131493	4082995	163,771	5,085,272	3,261,028	172,517	3,435,193
4	8,089	110.2	112.0	28.22	228	119.88	42.34	7679	325169	93,258	3,948,959	2,631,772	98,239	2,772,330
5	640	121.2	122.8	36.82	24	129.28	53.21	608	32350	5,496	292,395	202,325	5,789	213,131
6	765	130.6	131.9	45.35	35	136.79	63.16	726	45870	645	40,709	29,231	679	30,792
7	40	138.4	139.5	53.39	2	142.80	71.99	38	2731	514	36,979	27,426	541	28,891
8	0	145.1	146.0	60.97	0	147.60	79.63	0	0	26	2,088	1,599	28	1,684
Total	336,110				5,199			319,071	8,078,603	319,071	10,519,525	6,791,476	336,112	7,154,196
														$W.Est_y$

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)
0.6912 p.shift α_y Proportion of age shift to attain VBK given
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	74.23	10.40	4252	44224	1,786	18,573	5,807	1,919	6,239
2	138,097	79.4	81.7	11.27	1,595	92.79	19.74	132037	2606020	57,918	1,143,124	652,874	62,234	701,528
3	179,246	97.2	98.9	19.63	3,606	107.63	30.63	171380	5249481	148,560	4,550,478	2,916,360	159,631	3,133,694
4	1,553	110.2	111.6	27.92	44	119.49	41.93	1485	62271	100,029	4,193,905	2,792,900	107,484	3,001,033
5	745	121.2	122.4	36.51	28	128.96	52.81	712	37624	1,161	61,299	42,377	1,247	45,535
6	0	130.6	131.6	45.06	0	136.54	62.81	0	0	413	25,953	18,620	444	20,008
7	0	138.4	139.3	53.11	0	142.60	71.68	0	0	0	0	0	0	0
8	0	145.1	145.8	60.71	0	147.44	79.36	0	0	0	0	0	0	0
Total	324,088				5,288			309,866	7,999,619	309,866	9,993,333	6,428,937	332,958	6,908,038
														$W.Est_y$

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)
0.5800 p.shift α_y Proportion of age shift to attain VBK given
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	74.54	10.52	1166	12267	298	3,133	992	313	1,044
2	223,673	79.4	82.0	11.38	2,479	93.04	19.89	207372	4125110	53,827	1,070,749	612,549	56,641	644,564
3	129,846	97.2	99.1	19.74	2,497	107.83	30.80	120383	3707756	185,157	5,702,758	3,655,668	194,834	3,846,733
4	7,706	110.2	111.8	28.04	210	119.64	42.09	7145	300755	91,464	3,850,154	2,564,739	96,244	2,698,786
5	854	121.2	122.5	36.63	30	129.09	52.97	792	41946	5,522	292,528	202,303	5,811	212,876
6	0	130.6	131.7	45.18	0	136.64	62.95	0	0	590	37,119	26,640	620	28,032
7	0	138.4	139.4	53.23	0	142.68	71.80	0	0	0	0	0	0	0
8	0	145.1	145.9	60.82	0	147.50	79.47	0	0	0	0	0	0	0
Total	363,336				5,221			336,858	8,187,834	336,858	10,956,440	7,062,891	354,464	7,432,035
														$W.Est_y$

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)
0.7446 p.shift α_y Proportion of age shift to attain VBK given
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	1	0	0	0	0	0	0	0
1	203	49.4	49.8	2.68	1	71.84	9.50	187	1776	114	1,079	305	123	331
2	118,697	79.4	79.7	10.48	1,241	90.88	18.57	109230	2028432	66,440	1,233,803	696,182	72,198	756,518
3	194,370	97.2	97.4	18.79	3,645	106.10	29.35	178868	5249857	151,541	4,447,793	2,847,230	164,675	3,093,994
4	11,060	110.2	110.4	27.02	298	118.26	40.65	10178	413720	76,375	3,104,511	2,063,615	82,994	2,242,464
5	266	121.2	121.3	35.59	9	127.99	51.61	245	12640	4,143	213,822	147,447	4,502	160,226
6	158	130.6	130.7	44.19	7	135.76	61.73	145	8958	184	11,375	8,142	200	8,848
7	0	138.4	138.5	52.27	0	141.97	70.73	0	0	57	4,028	2,977	62	3,235
8	0	145.1	145.2	59.94	0	146.94	78.55	0	0	0	0	0	0	0
Total	324,754				5,202			298,853	7,715,381	298,853	9,016,411	5,765,897	324,754	6,265,616
														$W.Est_y$

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)
0.3924 p.shift α_y Proportion of age shift to attain VBK given
1.0867 p.N.Rep (Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Table 3. (cont.)

Year=2009

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	145	49.4	52.0	3.03	0	73.35	10.06	127	1280	40	405	122	46	139
2	125,556	79.4	80.9	10.97	1,371	92.09	19.30	109900	2121334	34,846	672,618	382,399	39,710	435,771
3	165,762	97.2	98.3	19.32	3,185	107.07	30.16	145092	4375354	121,031	3,649,765	2,337,826	137,923	2,664,125
4	15,659	110.2	111.1	27.58	430	119.04	41.45	13706	568178	103,537	4,292,006	2,856,038	117,988	3,254,666
5	541	121.2	122.0	36.17	19	128.61	52.37	473	24794	9,521	498,622	344,361	10,850	392,424
6	0	130.6	131.3	44.74	0	136.25	62.41	0	0	324	20,202	14,481	369	16,502
7	0	138.4	139.0	52.80	0	142.37	71.33	0	0	0	0	0	0	0
8	0	145.1	145.6	60.43	0	147.25	79.06	0	0	0	0	0	0	0
Total	307,663				5,005			269,299	7,090,940	269,299	9,133,617	5,935,227	306,886	6,763,628
														$W.Est_y$

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)
0.6837 p.shift α_y Proportion of age shift to attain VBK given
1.1396 p.N.Rep (Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2010

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	262	49.4	51.9	3.01	1	73.28	10.03	205	2060	27	273	82	35	105
2	53,601	79.4	80.9	10.95	586	92.03	19.27	41914	807554	5,727	110,348	62,712	7,324	80,199
3	126,360	97.2	98.3	19.29	2,432	107.02	30.12	98808	2975792	49,447	1,489,176	953,842	63,234	1,219,810
4	29,152	110.2	111.1	27.56	802	119.00	41.41	22796	944099	88,744	3,675,352	2,445,555	113,490	3,127,468
5	2,828	121.2	122.0	36.14	102	128.58	52.33	2211	115735	20,071	1,050,390	725,369	25,667	927,629
6	0	130.6	131.2	44.71	0	136.23	62.38	0	0	1,919	119,682	85,784	2,454	109,704
7	0	138.4	139.0	52.78	0	142.35	71.30	0	0	0	0	0	0	0
8	0	145.1	145.6	60.40	0	147.24	79.04	0	0	0	0	0	0	0
Total	212,204				3,922			165,935	4,845,240	165,935	6,445,221	4,273,343	212,204	5,464,914
														$W.Est_y$

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)
0.8676 p.shift α_y Proportion of age shift to attain VBK given
1.2788 p.N.Rep (Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2011

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	45.3	2.03	0	68.58	8.36	0	0	0	0	0	0	0
2	79,888	79.4	77.0	9.48	798	88.27	17.06	75034	1279943	29,109	496,549	276,068	32,737	310,476
3	100,303	97.2	95.4	17.71	1,872	104.01	27.66	94209	2606192	36,548	1,011,062	647,237	41,103	727,906
4	30,915	110.2	108.7	25.85	842	116.60	38.95	29037	1130891	57,190	2,227,371	1,478,633	64,318	1,662,923
5	7,261	121.2	119.9	34.39	263	126.66	50.00	6820	341019	60,307	3,015,494	2,074,233	67,823	2,332,757
6	1,492	130.6	129.5	43.04	68	134.70	60.27	1401	84428	18,315	1,103,804	788,265	20,598	886,511
7	312	138.4	137.5	51.17	17	141.12	69.45	293	20367	4,468	310,254	228,606	5,024	257,098
8	43	145.1	144.3	58.94	3	146.26	77.44	41	3142	898	69,544	52,925	1,010	59,522
Total	220,215				3,863			206,835	5,465,982	206,835	8,234,076	5,545,967	232,614	6,237,192
														$W.Est_y$

-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)
1.6121 p.shift α_y Proportion of age shift to attain VBK given
1.1246 p.N.Rep (Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Year=2012

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	2,955	49.4	55.5	3.67	10	75.77	11.02	2683	29557	1,474	16,241	5,405	1,561	5,723
2	221,420	79.4	83.0	11.81	2,497	94.02	20.51	201052	4124217	111,685	2,291,007	1,319,443	118,247	1,396,974
3	84,400	97.2	99.8	20.20	1,627	108.61	31.47	76636	2411960	132,687	4,176,032	2,679,810	140,484	2,837,277
4	10,870	110.2	112.4	28.52	296	120.27	42.76	9870	422067	39,949	1,708,305	1,139,442	42,297	1,206,396
5	623	121.2	123.1	37.12	22	129.59	53.60	566	30341	4,758	254,994	176,621	5,037	186,999
6	0	130.6	132.2	45.65	0	137.04	63.51	0	0	255	16,198	11,641	270	12,325
7	0	138.4	139.8	53.67	0	143.00	72.30	0	0	0	0	0	0	0
8	0	145.1	146.2	61.22	0	147.76	79.89	0	0	0	0	0	0	0
Total	320,268				4,453			290,808	7,018,142	290,808	8,462,777	5,332,362	307,896	5,645,693
														$W.Est_y$

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)
0.4505 p.shift α_y Proportion of age shift to attain VBK given
1.0588 p.N.Rep (Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

The value p.shift in 2011, 1.6121, means 61.21% of age_i in number should be shift to age_{i+2}.

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	74.52	10.52	0	0	0	0	0	0	0
2	117,218	79.4	81.9	11.37	1,332	93.02	19.88	11501	228679	747	14,856	8,498	7,615	86,605
3	135,534	97.2	99.1	19.74	2,673	107.81	30.79	13298	409451	11,618	357,713	229,303	118,408	2,336,982
4	5,950	110.2	111.8	28.03	167	119.63	42.08	584	24568	12,473	524,899	349,649	127,116	3,563,508
5	635	121.2	122.5	36.63	23	129.08	52.96	62	3302	550	29,125	20,141	5,604	205,271
6	0	130.6	131.7	45.17	0	136.64	62.94	0	0	58	3,670	2,634	594	26,841
7	0	138.4	139.4	53.22	0	142.67	71.80	0	0	0	0	0	0	0
8	0	145.1	145.9	60.81	0	147.50	79.46	0	0	0	0	0	0	0
Total	259,337				4,195			25,446	666,000	25,446	930,262	610,225	259,337	6,219,207
														$W.Est_y$

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)
0.9350	p.shift	α_y	Proportion of age shift to attain VBK given
10.1917	p.N.Rep		(Total number of SBT Australian reported)/(Total number of catch-at-age harvested)

Table 4. Estimated value of the parameter *K* of the von Bertalanffy growth equation (VBK) for farmed SBT, based on the Australian reported purse seine catch

Year	VBK
2001	0.565
2002	0.528
2003	0.574
2004	0.500
2005	0.589
2006	0.540
2007	0.612
2008	0.456
2009	0.587
2010	0.670
2011	0.825
2012	0.481
2013	0.698
Average	0.587

Table 5. Reported and estimated Australian purse seine catches by fishing year.

Fishing year is expressed as 2012 for the period between Dec. 2011 and Nov. 2012. Growth rate is from CCSBT SRP conventional tagging data for cases 1, 2 and 3.

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 was used

Year	W.Reported	W.Estimated	W.Excess	percent.excess
2001	5,162	6,835	1,673	32%
2002	5,234	6,523	1,289	25%
2003	5,375	6,901	1,527	28%
2004	4,874	6,078	1,205	25%
2005	5,214	7,154	1,941	37%
2006	5,302	6,908	1,606	30%
2007	5,230	7,432	2,202	42%
2008	5,211	6,266	1,054	20%
2009	5,026	6,764	1,737	35%
2010	3,931	5,465	1,534	39%
2011	3,872	6,237	2,366	61%
2012	4,485	5,646	1,161	26%
2013	4,198	6,219	2,021	48%
Average			1,640	34.5%
Total			21,315	

Case2

Growth rate of mean + 1 standard deviation was used

Year	W.Reported	W.Estimated	W.Excess	percent.excess
2001	5,162	5,451	289	6%
2002	5,234	5,248	14	0%
2003	5,375	5,487	112	2%
2004	4,874	4,864	−10	0%
2005	5,214	5,673	460	9%
2006	5,302	5,477	175	3%
2007	5,230	5,891	661	13%
2008	5,211	5,212	0	0%
2009	5,026	5,375	349	7%
2010	3,931	4,361	431	11%
2011	3,872	4,985	1,113	29%
2012	4,485	4,484	−0	0%
2013	4,198	4,948	750	18%
Average			334	7.5%
Total			4,343	

Table 5. (cont.)

Case3

Growth rate of mean − 1 standard deviation was used

Year	W.Reported	W.Estimated	W.Excess	percent.excess
2001	5,162	8,929	3,767	73%
2002	5,234	8,528	3,294	63%
2003	5,375	9,012	3,637	68%
2004	4,874	7,986	3,112	64%
2005	5,214	9,377	4,164	80%
2006	5,302	9,070	3,768	71%
2007	5,230	9,741	4,512	86%
2008	5,211	8,234	3,022	58%
2009	5,026	8,856	3,829	76%
2010	3,931	7,121	3,190	81%
2011	3,872	7,736	3,864	100%
2012	4,485	7,441	2,956	66%
2013	4,198	8,126	3,927	94%
Average			3,619	75.3%
Total			47,044	

Case4

Growth rate is same as that of wild fish in body length

Year	W.Reported	W.Estimated	W.Excess	percent.excess
2001	5,162	7,215	2,053	40%
2002	5,234	6,889	1,655	32%
2003	5,375	7,279	1,904	35%
2004	4,874	6,451	1,577	32%
2005	5,214	7,586	2,372	45%
2006	5,302	7,328	2,026	38%
2007	5,230	7,886	2,656	51%
2008	5,211	6,657	1,446	28%
2009	5,026	7,161	2,134	42%
2010	3,931	5,786	1,856	47%
2011	3,872	6,555	2,683	69%
2012	4,485	6,016	1,532	34%
2013	4,198	6,582	2,384	57%
Average			2,021	42.4%
Total			26,278	

Table 6. 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	Present study Case3	Present study Case4
2001	5,162			6,835	5,451	8,929	7,215
2002	5,234			6,523	5,248	8,528	6,889
2003	5,375			6,901	5,487	9,012	7,279
2004	4,874			6,078	4,864	7,986	6,451
2005	5,214			7,154	5,673	9,377	7,586
2006	5,302			6,908	5,477	9,070	7,328
2007	5,230	8,271 (8,264-8,277)	8,273	7,432	5,891	9,741	7,886
2008	5,211	6,159 (6,156-6,163)	6,659	6,266	5,212	8,234	6,657
2009	5,026	6,749 (6,773-6,754)	6,675	6,764	5,375	8,856	7,161
2010	3,931		5,689	5,465	4,361	7,121	5,786
2011	3,872			6,237	4,985	8,069	6,555
2012	4,485			5,646	4,484	7,441	6,016
2013	4,198			6,219	4,948	8,126	6,582

Median (5%-95%)

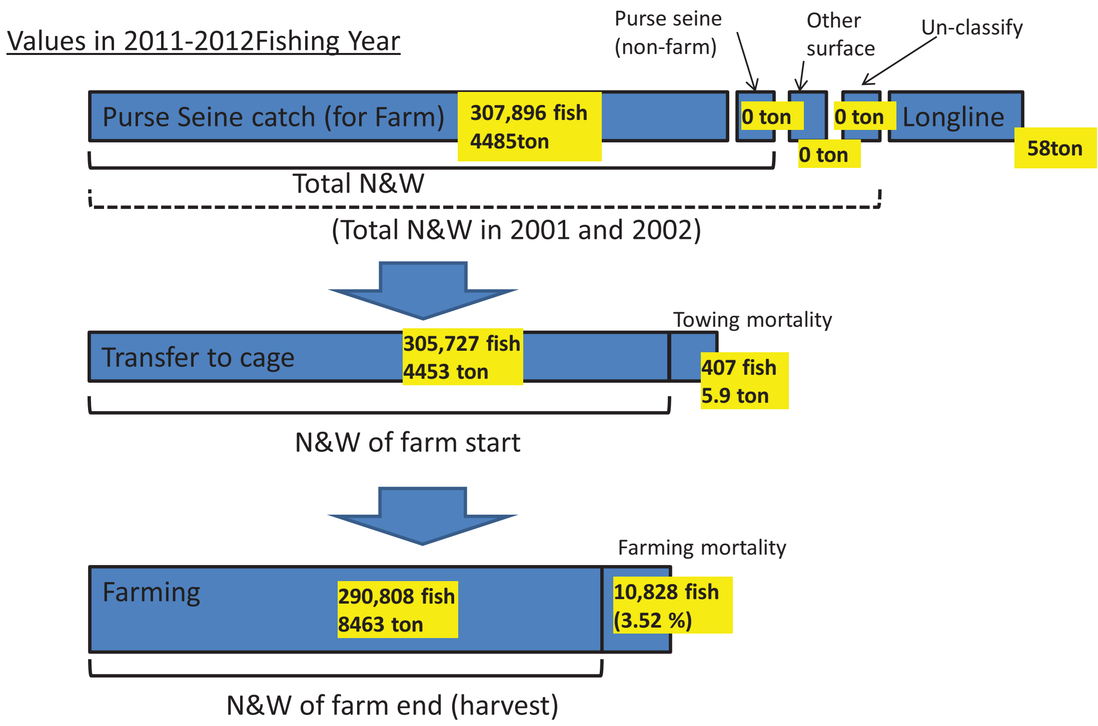

Fig. 1. Diagram showing the estimation from catch through the start to the end of farming

The numbers are statistics in the 2012 fishing year (Dec 2011-Nov 2012) for reference.

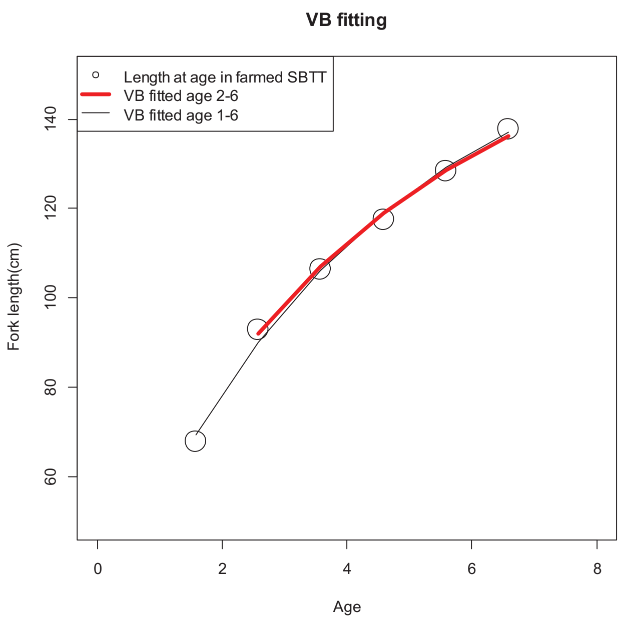

Fig. 2. The von Bertalanffy growth curve fitted to mean length at age for farmed fish which was calculated from the mean growth rate obtained from CCSBT SRP conventional tagging data (Sakai et al. 2009)

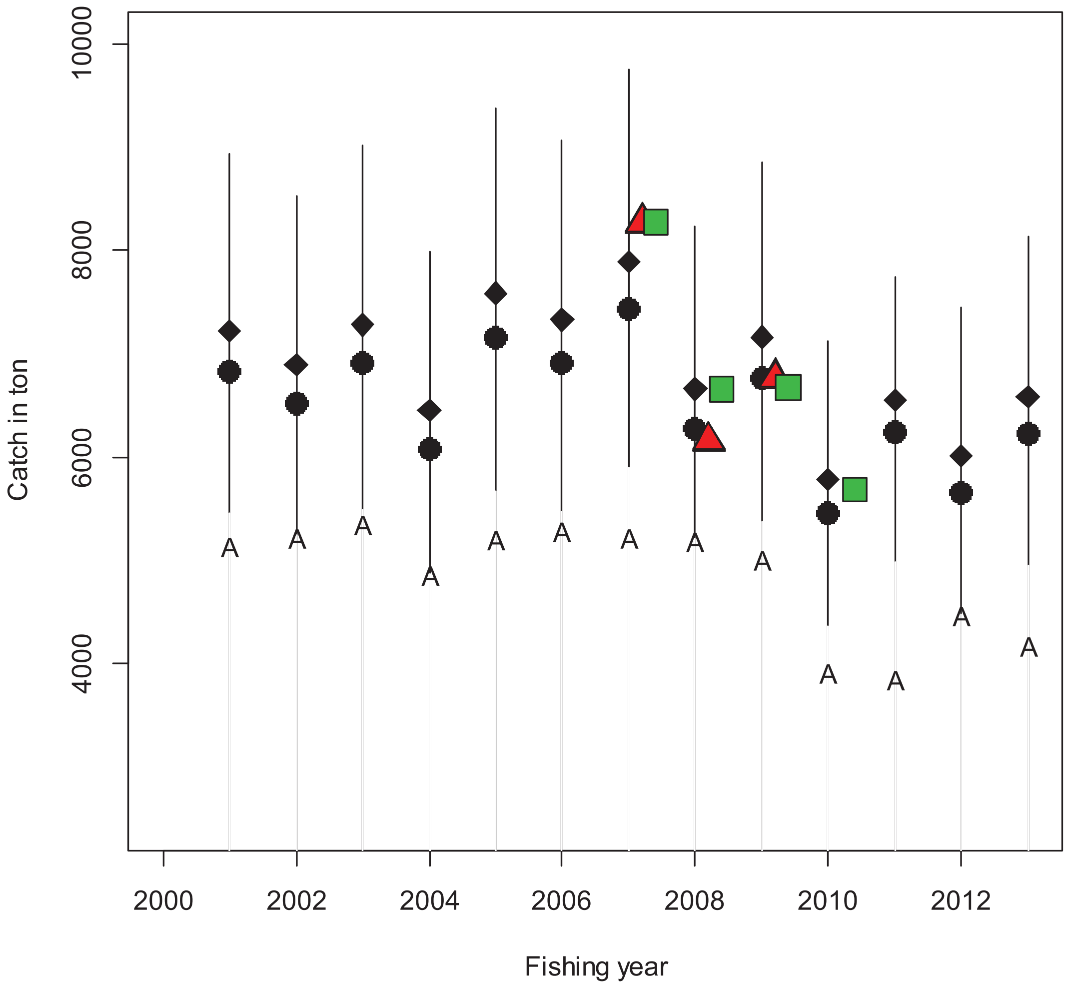

Fig. 3. SBT catch amount by the Australian purse seine fishery by fishing year

A denotes catch Australia reported. The black circle ● denotes the estimated catch based on the mean growth rate obtained from CCSBT SRP conventional tagging data (Sakai et al. 2009) (Case 1) with bars ranged from the mean+1SD (Case2) to mean-1SD (Case3). 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 4). 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).

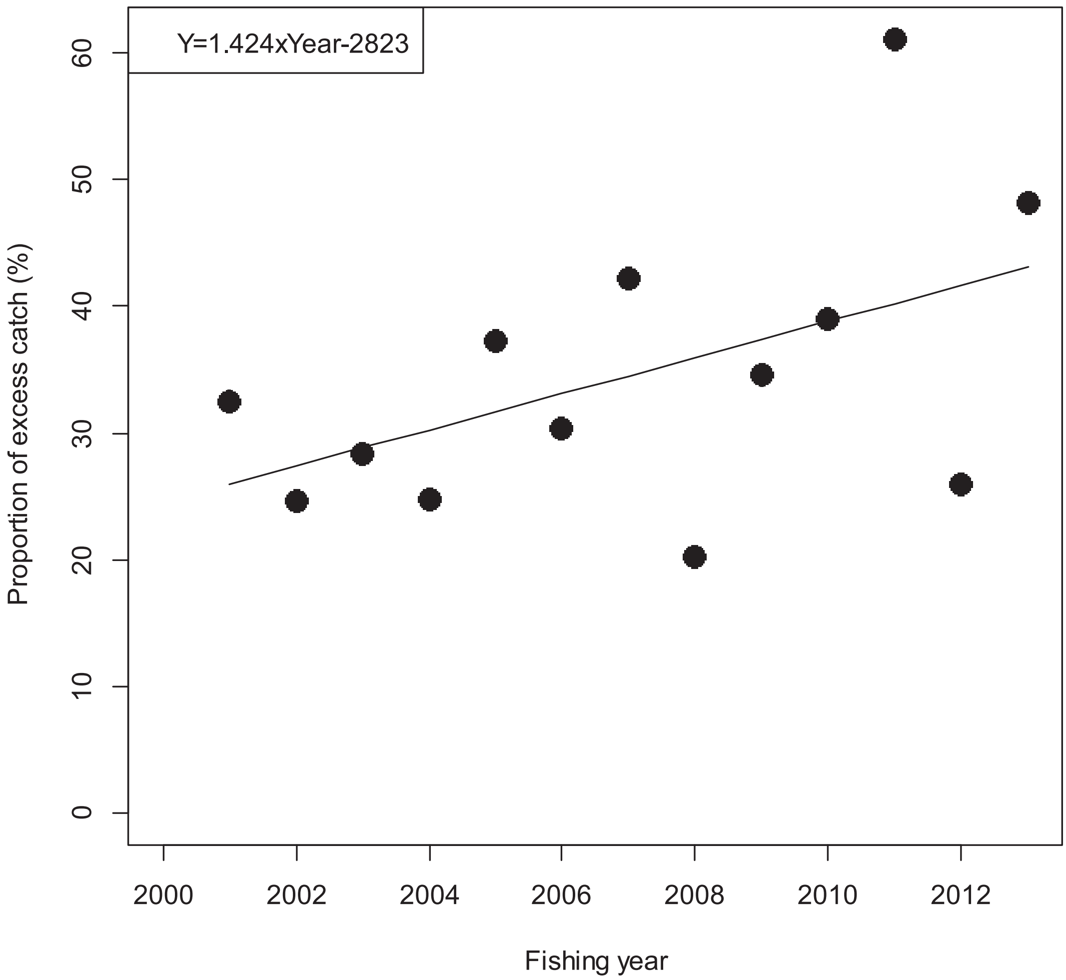

Fig. 4. Plots of proportion of estimated excess amount of catch to the catch amount reported by fishing year