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2007-2010 年のオーストラリアのミナミマグロ畜養魚の年齢組成、成長及び漁獲重量の解析

Analyses on age composition, growth and catch amount of southern bluefin tuna used for farming in 2007-2010

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要約

2007-2010 年のオーストラリアにおけるミナミマグロ畜養魚について、日本に輸入された魚の収穫時のサイズデータから解析した。ある解析では、体長組成に合うような混合正規分布を当てはめることで年齢組成を推定した。別の解析では、成長を仮定して年齢スライシング法で年齢分解し、豪州が主張する年齢組成や漁獲量との整合性を検証した。

推定の結果は、いずれの年も 3 歳魚が最も多く、4 歳魚が続き、2 歳魚は少なかった。4 歳魚が最も多いと推定された場合もあった。これは、2 歳魚が最も多くて 4 歳魚は極めて少ないとする豪州の主張とは大きく異なった。年齢スライシング法で求めた漁獲量は、2007 年は 8273 トン（豪州主張 5,342 トン）、2008 年は 6659 トン（5,211 トン）、2009 年は 6675 トン（5,022 トン）、2010 年は 5689 トン（3,935 トン）であった。混合正規分布と年齢スライシング法とで推定した漁獲量は相互によく一致した。

豪州が主張する漁獲量に対応したバータランフィー成長式の成長係数（VB-K）は 0.51-0.81 である。このような、ミナミマグロ野生魚（VB-K=0.22）より数倍高く、成長の速いキハダよりも高い VB-K をミナミマグロ畜養魚が実現するとは到底考えられない。現状の 40 尾サンプリングには大きなバイアスがあり、40 尾サンプリングの値を基に計算される年齢組成、漁獲重量にも影響を及ぼしていると考えられた。

Summary

For farmed SBT in Australia, data of size measurement at harvest for fish imported to Japan between 2007 and 2010 were analyzed. In an analysis, age composition was estimated by applying mixed normal distribution to length frequency. In another analysis, growth of farmed fish were assumed in three cases and length frequency was divided by age with age-slicing method, and then examined consistency with the age composition and total catch weight that Australia claimed. In the result, age-3 fish or age-4 fish was dominated, but few in age-2 fish in all the years. It was quite different to Australian claim that age-2 fish was dominated but few in age-4 fish.

Estimated total catch was similar to each other between the two methods using mixed normal distribution and age slicing. The estimated total catches in age slicing, based on growth rate derived from of tag recapture data, were 8,273 t (5,342 t in Australian report) in 2007, 6,659 t (5,211 t) in 2008, 6,675 t (5,022 t) in 2009 and 5,689 t (3,935 t) in 2010. The von Bertalanffy growth curve parameter VB-K values corresponded with Australia claimed catch was 0.51-0.81. It is highly unlikely that SBT farmed fish attain VB-K several times as high as that of wild SBT (VB-K=0.22) and higher than that of fast grow tuna, such as yellowfin tuna. It was considered that there was a large bias in 40 fish sampling for farming fish and it effected on the age composition and total catch amount in the Australian purse seine catch which calculated from the data of 40 fish sampling.

諸言

2011 年に CCSBT において管理方式（MP）によるミナミマグロの 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 による TAC 決定システム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、このため CCSBT におけるミナミマグロの資源管理には世界の注目が集まっている。当然のことながら、適切な資源管理のためには厳格な検査、モニタリングを通じた適切な漁業管理が必要である。CCSBT では 2000 年に TIS を、2010 年にさらに発展した CDS を導入し、また、漁獲個体には固有番号を刻印した管理タグを装着することを義務付けることにより、本種資源の漁獲、水揚げ、貿易までを追跡・確認できるようにしている。日本漁船に対してはさらに RTMP による日別即時報告、外国港での陸揚げ禁止、日本の指定された港以外での陸揚げ禁止、漁獲された全てのミナミマグロに対する政府職員による水揚げ検査が義務付けられている。

一方、ミナミマグロの最大漁獲枠（2012 年 TAC の 43%）を有するオーストラリアは漁獲枠のほとんど全てを巻き網で漁獲し畜養種苗に用いている（Hobsbawn et al. CCSBT-ESC/1107/SBT Fisheries -Australia）。畜養種苗は、巻き網によって囲ってから飼育生簀に移送しているが、ハンドリングによる死亡のリスクを軽減するために生簀への移送量は推定値である。このためマグロ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用の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(ICCAT 2010)。

ミナミマグロについては、生け込み時に数千から 1 万尾の中から 40 尾を抽出サンプリングし、その平均体重で全漁獲量、生け込み量を推定している。これまでにも我々は畜養魚における 40 尾サンプリングにはバイアスがある可能性を指摘してきた。

40 尾サンプリングに変わるものとして、豪州政府はステレビデオカメラシステムの導入試験を進めてはいるが、その進捗は遅く、2011 年の遵守委員会では 10.5%の個体について測定を開始したと言及したのみで詳細な記述はなく（CCSBT-CC/1110/11）、今 ESC でようやく結果が示される予定である。

我々は本文書で、2007-2010 年の畜養魚について、40 尾サンプリングでは年齢推定の観点でバイアスがある可能性が高いこと、それに付随して報告漁獲量が実際の漁獲よりも過小になっている可能性が高いことを示す。解析には日本に輸入された畜養魚の収穫時のサイズ測定データを用いた。解析 1 では、体長組成に合うような混合正規分布を当てはめることで年齢組成を推定した。解析 2 では、成長を仮定してスライシング法で年齢分解し、豪州が主張する年齢組成や漁獲量との整合性を検証するアプローチをとった。なお、本論文で使用した 2007 年から 2010 年のデータはこれまでにも解析に使用

している（CCSBT-ESC/0909/29、CCSBT-ESC/0909/30、CCSBT-ESC/1009/21、CCSBT-ESC/1107/26）が、本論文ではより包括的に、また異なるアプローチで解析している。

Introduction

Southern bluefin tuna *Thunnus maccoyii* (SBT) stock meets a new stock management era with implementation of the management procedure (MP) in CCSBT in 2011. Implementation of MP, a decision system for the total allowable catch (TAC), was the first case in all the tuna-RFMOs, which would attract attention from all over the world. Without doubt, it requires appropriate fishery management through strict surveillance and monitoring for appropriate stock management. CCSBT introduced the trade information scheme (TIS) in 2000 and further developed to introduce catch documentation scheme (CDS) in 2010. It was obligated to attach a management tag with an individual number printed to each SBT individuals caught so that every SBT individual can be tracked and confirmed throughout the process of catch, landing and export/import. In addition, for Japanese fishing vessels, daily reporting in RTMP, ban on landing at foreign port, ban on landing at port other than authorized, and strict inspection by government stuff at landing for all the SBT caught have been obligated.

On the other hand, Australia, the largest TAC holder in CCSBT (43 % of 2012 TAC), used most of their TAC for purse seine catch which utilized for farming (Hobsbawn et al. CCSBT-ESC/1107/SBT Fisheries -Australia). In many countries, tuna school for farming is enclosed by purse seine net and then transported to cage pens. In order to minimize the risk of death by handling, the amount of catch is not measured but estimated. Therefore, it has been widely acknowledged that there is a high level of uncertainty for its catch estimation for farming. For example, catches of Atlantic bluefin tuna in the East Atlantic and Mediterranean were seriously under-reported from the mid-1990s along with development of farming, and the ICCAT Committee considered that the underreporting of the catch as having undermined conservation of the stock (ICCAT 2010).

In the SBT farming, 40 fish individuals have been caught among several thousand fish just before distributed to pens and its average weight was used for estimate age composition and its total weight. We have been pointed out several times that there was a significant bias in the 40 fish sampling (e.g. CCSBT-ESC/0909/29).

As an alternative monitoring method to the 40 fish sampling, Australian government has been carried out implementation experiments of stereo video camera system for years, however its progress is slow. In the Compliance Committee in CCSBT in 2011, Australia described they measured 10.5 % farmed fish with the stereo video camera system but none of its detail was shown (CCSBT-CC/1110/11). The detailed results are expected to be shown in the current ESC.

In this paper, we will show that there is a high possibility of bias in the 40 fish sampling for the 2007-2010 farmed fish in terms of age composition which causes an underestimation of total catch. Data of size measurement at harvest for fish imported to Japan were used for analyses. In the analysis 1, age

composition was estimated by applying mixed normal distribution to length frequency. In the analysis 2, growth of farmed fish were assumed in three cases, length frequency was divided by age with age-slicing method and examined consistency with the age composition and total catch weight that Australia reported. The data have already used in previous analyses (CCSBT-ESC/0909/29, CCSBT-ESC/0909/30, CCSBT-ESC/1009/21, CCSBT-ESC/1107/26) but we conducted more comprehensive and different approach in this study.

解析 1　混合正規分布による年齢分解

Analysis 1:　Age decomposition by mixed normal distribution

材料と方法

2007 年 5 月以降、日本に輸入する畜養ミナミマグロについては、収穫時の個体ごとの体長及び体重を報告するよう、農林水産省が輸入業者に対して指令している。これにより収集されたハーベストサイズデータを解析に用いた。表 A1 に月別収集個体数を示す。2007-2010 年の合計は 420 千個体以上に及ぶ。若干の体長、体重値のエラーレコードを除いた 174,980 個体（2007 年）、94,352 個体（2008 年）、61,843 個体（2009 年）、89,004 個体（2010 年）を解析対象とした。

体長（尾叉長 cm）と体重（鰓と内臓を除いた製品重量 kg）の両方が得られたデータ(N=76,080（2007 年）、N=57,233（2008 年）、N=58,964（2009 年）、N=49,948（2010 年）)を用いて、体重体長換算式のパラメータ値を計算した。収穫月別に有意に異なった（F=971、p<0.01　2007 年）（F=132、p<0.01 2008 年）、（F=1291、p<0.01 2009 年）、F=2031、p<0.01（2010 年）ことから、式(1)の体重体長換算のパラメータ値は月別、生鮮／冷凍別に求めた（表 A2、図 A1）。

$$FL = a_{i,k} \times PW^{b_{i,k}}, \qquad (1)$$

ここで、FLは尾叉長(cm)、PWは体重(kg)、iは収穫月、kは生鮮また冷凍、$a_{i,k}$、$b_{i,k}$は月・生鮮冷凍別の定数。

求めた体重体長換算式を用いて、収穫時サイズデータの体重データを体長に変換し、出荷状態（生鮮、冷凍運搬船、冷凍コンテナ）別、月別に 1cm 階級ごとにまとめた。このデータセットを解析 2 でも共通して使用した。

得られた年、出荷状態、月別体長組成を式(2)によって 1-4 個の正規分布から構成される混合正規分布で近似した。適当な初期値について残差平方和が最小となるようGauss-Newton algorithmによる非線形最小二乗法でパラメータベクトルΘ（μ_2，μ_3，μ_4，μ_5，σ_2，σ_3，σ_4，σ_5，k_2，k_3，k_4）の最大 11 パラメータの解を求めた。なお、$\sum_{i=2}^{n} k_i = 1$により、最高齢のk_iは計算できる（e.g. $k_4=1-k_2-k_3$)ので、推定不要である。正規分布の数は、解が得られ、得られた平均値、標準偏差が妥当（e.g. $\mu_2<\mu_3<\mu_4$，$\sigma_4<6$）である最大のものを選択した。

$$SSQ = \sum_{x=\min L}^{\max L} \left(H_x - \sum_{\alpha=2}^{n} k_\alpha \frac{1}{\sqrt{2\pi\sigma_\alpha^2}} \exp\left(-\frac{(x-\mu_\alpha)^2}{2\sigma_\alpha^2} \right) \right)^2 \qquad (2)$$

ここで、

x：1cm ごとの体長階級

$minL$：最小体長階級

$maxL$：最大体長階級

H_x：x cmの体長頻度

n：年齢区分数（1,2,3,4 のいずれか）

得られた正規分布は 2 歳から 5 歳の年齢に対応させた。ただし 2008 年畜養魚では、3 歳と 4 歳の中間的な位置に正規分布の平均値が位置したことなど正規分布と年齢との対応が解釈困難な場合があった。そこで 2008 年正規分布と年齢の対応は、最も可能性が高いと思われる場合（Base case）に加えて、低年齢に対応すると仮定した場合（Lower age case）、高年齢に対応すると仮定した場合（Higher age case）についても年齢組成を求めた。

続いて、サイズ測定個体数の推定から日本に輸入された魚全体の推定へ拡張した。まず日本に輸入された収穫月別尾数を、輸入統計（日本が CCSBT に提出）の月別製品重量から計算した。ここで生鮮魚は収穫月に輸入されるとした（式 3)。一方、冷凍魚は、収穫時サイズデータにおける収穫月と輸入申請月との関係を集計した結果、収穫月から輸入申請までにタイムラグがあるようであった。検討の結果、2007 年畜養の冷凍魚は収穫月から 1.5 ヵ月後に輸入されると仮定した。2008 年蓄養の冷凍魚は 7 月の輸入はその月に収穫され、8 月の輸入は 7 月に収穫、9 月以降の輸入は 8 月に収穫されたとした。2009 年蓄養の冷凍魚は 6 月以前の輸入物は前年の収穫とみなして除外し、8 月と 9 月の輸入は 7 月の収穫物、9 月以降の輸入は 8 月の収穫物とみなした。なお、解析 2 のスライシング法に関係する 2010 年蓄養の冷凍魚は、7 月の輸入は 6 月の収穫物、8 月の全てと 9 月の半分の輸入は 7 月の収穫物、9 月の半分と 10 月の輸入は 8 月の収穫物とみなした。

$$n_i = W_j \times \frac{1}{A_i} \qquad (3)$$

ここで、

n_i：収穫i月の生鮮魚の輸入尾数

W_j： j月に輸入された生鮮魚の輸入重量(kg)

A_i：ハーベストデータから求めた収穫i月の生鮮魚の平均体重 (kg)

日本に輸入された魚全体の年齢別漁獲尾数を推定するに際しては、サイズ測定個体数が全体の一部であることを考慮し、ブートストラップ（1000 回のリサンプリング）で信頼範囲を求めた（式 4)。冷凍魚の年齢組成は、冷凍運搬船と冷凍コンテナ船それぞれの年齢組成に対して、それぞれの測定個体数で重み付けをした。まき網で漁獲した時点の野生魚の平均体重を掛けて漁獲重量を求めた（式 5)。野生魚の平均体重は、CCSBT で使用している 1 月 1 日時点の各年齢の体長間を直線補完して、収穫時

サイズデータにおいて最も生け込み時期頻度が高かったのが 2 月であったことから、2 月中央時点の体長に対応する体重を、Robins(1963)の関係式から推定した。

$$n_{\alpha} = \sum_{k=1}^{2}\sum_{i=2}^{10}\left(sample(m_{i,k} \times k_{\alpha,i,k}, n_{i,k}) \times \frac{n_{all}}{\sum_{i=2}^{10} n_{i,k}} \right) \quad (4)$$

$$w_{import} = \sum_{\alpha=2}^{5} n_{\alpha} \times a_{wild} \times \left(FL_{\alpha,2}\right)^{b_{wild}} \quad (5)$$

ここで、

n_{α}：日本に輸入された α 歳魚の尾数

w_{import}：日本に輸入された魚の原魚重量合計

$m_{i,k}$：ハーベストデータにおける収穫i月、生鮮冷凍kの測定尾数。

$n_{i,k}$：収穫i月、生鮮冷凍kの輸入尾数。(3)式で求めた。

$k_{\alpha,i,k}$：収穫i月、生鮮冷凍k、 α 歳の個体数割合。(2)式で求めた。

n_{all}：日本に輸入された尾数の総数。

$FL_{\alpha,i}$：野生魚の α 歳、漁獲i月の体長(cm)。

a_{wild}、b_{wild}：尾叉長－原魚重量の関係式　$\text{原魚重量} = a_{\text{wild}} \times \text{尾叉長}^{b_{wild}}$　の係数。

sample(x,y)：サンプルデータ x から y 個をリサンプリングする。

次いで、年齢別漁獲尾数および漁獲重量を豪州まき網による総漁獲尾数に引き伸ばした（式 6、式 7）

$$N_{\alpha} = n_{\alpha} \times \frac{N_{all}}{\sum_{\alpha=2}^{5} n_{\alpha}} \quad (6)$$

$$PSW = W_{import} \times \frac{N_{all}}{\sum_{\alpha=2}^{5} n_{\alpha}} \quad (7)$$

ここで、

N_{α}：豪州まき網が漁獲した α 歳魚の尾数。CCSBTの漁獲データベース（2012 年 1 月配布版）から求めた。

PSW：豪州まき網が漁獲したミナミマグロの重量（kg）。CCSBT の漁獲データベース（2012 年 1 月配布版）におけるテーブル（Official Catch）から、豪州のまき網漁獲を抽出。収穫されて日本に輸出された魚以外にも、曳航中の死亡個体、畜養中の死亡個体、米国等へ輸出した個体、TIS での輸入申請が遅かった分、もしかしたら収穫されずに継続して畜養されている、もしかしたら畜養されずに収穫された個体を含む。

N_{all}：豪州がまき網で漁獲した漁期年（前年 12 月から）の合計尾数。条件はPSWと同じ。

分析には R（Version 2.8.1 for Windows）を用いた。

Material and method

The Ministry of Agriculture, Forestry and Fisheries of Japan requested importers to submit data on the length and weight at harvest of farmed SBT which is imported to Japan after May 2007. The size data of harvested SBT imported to Japan, reaching a total of 420 thousands individuals from 2007 to 2010, were used for the analysis (Table A1). After removing several anomalous records, data used were 174,980 individuals in 2007, 94,352 in 2008, 61,843 in 2009 and 89,004 in 2010.

Using data for which both length and weight information was available (N=76,080 in 2007, N=57,233 in 2008 年, N=58,964 in 2009 and N=49,948 in 2010), parameters for the weight-length relationship were estimated by applying the least squares method for logarithmic scaled length (fork length in cm) and weight (gilled and gutted in kg) as follows:

$$FL = a_i \times PW^{b_i}, \qquad \text{(Eq-1)}$$

where FL is the fork length in cm, PW is the processed weight (gilled and gutted with tail) in kg, and a_i and b_i are month-specific parameters to be estimated. Because the fatness index (PW/FL^3) differed significantly by month in all the years, the weight-length relationships were estimated by month and fate (fresh/frozen) (Table A2, Fig. A1).

Weight values were converted to length by using the monthly weight-length relationships by month and fate. Next, length frequencies by one centimeter bin by month and fate (fresh, frozen fish from freezer vessels and frozen fish from freezer containers) were produced. This dataset was also used for analysis 2.

From one to four normal distributions were fitted to decompose the length frequency by minimizing Eq-2. The largest dimension considered for the parameter vector Θ (μ_2, μ_3, μ_4, μ_5, σ_2,σ_3, σ_4, σ_5, k_2, k_3, k_4) was 11. This vector includes the mean, standard deviation and relative strength of each normal distribution, and these were estimated by the non-linear least squares method with the Gauss-Newton algorithm to minimize the sum of squares. Because k_i of the maximum age can be calculated from $\sum_{i=2}^{n} k_i = 1$ (e.g. $k_4=1-k_2-k_3$), the number of parameters to be estimated can be reduced by one. Among the cases with two to four normal distributions, the case with the maximum number of distributions which nevertheless gave appropriate means and standard deviations (e.g. $\mu_2<\mu_3<\mu_4$, $\sigma_4<6$) was chosen.

$$SSQ = \sum_{x=\min L}^{\max L} \left(H_x - \sum_{\alpha=2}^{n} k_\alpha \frac{1}{\sqrt{2\pi\sigma_\alpha^2}} \exp\left(-\frac{(x-\mu_\alpha)^2}{2\sigma_\alpha^2} \right) \right)^2 \qquad \text{(Eq-2)}$$

where x is the length class of one centimeter bin; $minL$ is the class of the minimum length; $maxL$ is the class of the maximum length; H_x is the frequency in length class of x cm; and n is the number of age classes among 1, 2, 3, and 4.

Derived normal distributions were assigned to age between 2 and 5. However, some normal distributions in the 2008 farmed fish were not easy to be assigned its age because the mean of normal distributions located in middle between age-3 and age-4. Then, we considered three cases for the 2008 farmed fish; the case that appeared to be most likely (Base case), assigned to be lower age (Lower age case), and assigned to be higher age case (Higher age case).

The estimation was then expanded from samples for which the size was measured to all of the farmed SBT imported to Japan. The total number of SBT imported to Japan by month was calculated from the monthly total SBT product weight in the Japan Import Statistics which have been submitted to CCSBT. Fresh fish were assumed to be imported in the same month that they were harvested (Eq-3). For frozen fish, information of harvest month and imported month were analyzed using the size data at harvest, and it was inferred as follows; SBT in 2007 was imported after 1.5 month from harvested; SBT of 2008 imported in July was harvested in July, imported in August was harvested in July and imported after September was harvested in August; SBT of 2009 imported before July was assumed to be harvested in previous year and excluded for the analysis, imported in August and September was harvested in July, imported after October was harvested in August. It was assumed that SBT of 2010, only used for analysis 2, imported in July was harvested in June, imported in August and half of September was harvested in July and imported in September (half) and October was harvested in August.

$$n_i = W_j \times \frac{1}{A_i} \qquad \text{(Eq-3)}$$

where n_i is the number of fresh SBT imported in harvest month i; W_j is the weight of fresh SBT imported in month j (kg); and A_i is the average body processed weight of fresh SBT in harvest month i (kg).

Confidence intervals for the estimated age composition (in number) of SBT imported to Japan were calculated using bootstrapping (1000 resamples) (Eq-4). Age compositions for frozen SBT were weighted by the number of fish measured from freezer vessels and from freezer containers. The weight of imported SBT at the time of the purse seine catch was calculated (Eq-5). As transfer from towing pens to farming cages was most frequent in February for the individual size data used in this analysis, length at the mid-February was calculated based on information on the length at age on 1st January, which is as used in CCSBT, and on interpolation. Finally, the calculated length on the mid-February was converted to body weight using the length-weight relationship for wild fish in southern Australia (Robins 1963).

$$n_\alpha = \sum_{k=1}^{2} \sum_{i=4}^{10} \left(sample(m_{i,k} \times k_{\alpha,i,k}, n_{i,k}) \times \frac{n_{all}}{\sum_{i=4}^{10} n_{i,k}} \right) \qquad \text{(Eq-4)}$$

$$w_{import} = \sum_{\alpha=2}^{5} n_{\alpha} \times A \times FL_{\alpha,2}^{B} \qquad \text{(Eq-5)}$$

where n_{α} is the number of SBT in age α imported to Japan; w_{import} is the total weight of whole SBT imported to Japan; $m_{i,k}$ is the number of fish measured in harvest month i of fresh/frozen state k; $n_{i,k}$ is the number of SBT imported in harvest month i of fresh/frozen state k.as estimated using Eq-3; $k_{\alpha,i,k}$ is the proportion of number of age a SBT in harvest month i of fresh/frozen state k as estimated by minimizing Eq-2; n_{all} is the total number of SBT imported to Japan from Australia; $FL_{\alpha,i}$ is the length at month of catch i of age a SBT (cm); A,B are the parameters of length-weight relationship of *Whole weight=A x Fork length*^{B}; and *sample(x,y)* is the resample y individual data from sample size of x.

In the next step, the catch-at-age and catch weight were scaled upwards to the total number of SBT caught by Australian purse seiners (Eq-6 and Eq-7).

$$N_{\alpha} = n_{\alpha} \times \frac{N_{all}}{\sum_{\alpha=2}^{5} n_{\alpha}} \qquad \text{(Eq-6)}$$

$$PSW = W_{import} \times \frac{N_{all}}{\sum_{\alpha=2}^{5} n_{\alpha}} \qquad \text{(Eq-7)}$$

where N_{α} is the total number of age a SBT caught by Australian purse seine. It was derived from CCSBT catch database distributed in January 2012. *PSW* is the weight of Australian purse seine catch (kg). It was derived from CCSBT catch database distributed in January 2012. Note that fate of SBT caught was not only exported to Japan. It also included fish died during towing, fish died during farming, fish harvested but exported other countries, such as USA, possibly delayed apply for TIS, possibly fish not harvested and continued farming, and possibly fish harvested before farmed. N_{all} is the total number of SBT caught by Australia from December in previous year. Its conditions were as same as *PSW*.

The computer package R, version 2.8.1 for Windows, was used for the calculations conducted.

結果

ハーベストデータには、年間 61 千から 187 千個体のサイズデータが含まれた（表 A2）。日本への輸出個体数に対する年別測定個体割合は、生鮮魚では 45-86%であった。冷凍魚では 2009 年に 7%と低かったものの、他の年は 28-63%に及んだ。年、月、生鮮冷凍別の測定個体数は、収穫が少なかった場合を除いて 3 千個体から 67 千個体であった。

2007 年、2008 年、2009 年の 4 月から 10 月の生鮮魚と、冷凍運搬船の冷凍魚、冷凍コンテナ船の冷凍魚で区分した全ての体長頻度は、2 個から 4 個の正規分布から成る混合正規分布で近似された（表 A3、図 A2）。グラフ上で、求めた混合正規分布は体長頻度に良くフィットしていることが分かる。体長 130cm 以上については正規分布がカバーできていない部分もあり（例えば 2007 年生鮮魚 7 月）、こ

れはわずかにサイズや年齢の過小推定につながる。

2010 年畜養魚では、生鮮用、冷凍用で区分した全ての体長頻度は、個体数の少なかった 2 月を除き、1 個から 3 個の正規分布から成る混合正規分布で近似され、体長頻度に良くフィットしたものの、各正規分布は年齢に対応しているとは思われなかった（図示せず。CCSBT-ESC/1107/26 Fig.3 にある）。このため、以後の混合正規分布の解析において 2010 年データは対象から外した。

正規分布の平均値は、体長約 92cm、約 106cm、約 120cm、約 130cm に見られた。野生魚の年齢別体長と比較すると、それらが 2 歳、3 歳、4 歳、5 歳魚に相当することが分かる。4 月から 8 月では野生魚の年齢別体長よりも正規分布の平均値のほうがやや大きかった。

2008 年には体長約 95cm に平均値を持つ正規分布は標準偏差が大きく推定された場合もあり（生鮮の 7 月、冷凍運搬船の 7 月、8 月、冷凍コンテナの 8 月）、必ずしも 2 歳には対応していなかった。ベースケースではこれらを全て 3 歳魚とみなした。低年齢を仮定したケースでは生鮮、冷凍運搬船の 7 月の魚が 2 歳魚とみなして計算したが、2 歳魚はその一部で多くは 3 歳魚であったと思われ、低年齢を仮定したケースは過小の年齢組成を示しているだろう。

また 2008 年の体長約 115cm に平均値を持つ正規分布については 3 歳と 4 歳の境界付近に位置し、判断が困難であった（生鮮 6 月、7 月、9 月。冷凍船 7 月、8 月、冷凍コンテナ船 8 月）。これらを 3 歳としてベースケースにしたが、年齢を過小に推定したものであろう。ベースケースと高齢を仮定したケースの中間的なものが真の値に最も近いと思われる。

推定した年齢組成を表 A4、図 A3 に示す。いずれの年も 3 歳魚が最も多く、4 歳魚が続き、2 歳魚は 7-18%と少なかった。これは、2 歳魚が最も多くて 4 歳魚は極めて少ないとする豪州の主張とは大きく異なった。

推定したオーストラリアのまき網による漁獲重量を表 A5、図 A4 に示す。2007 年は 8271 トン（豪州主張 5,342 トンの 1.55 倍）、2008 年は 6112-7170 トン（5,211 トンの 1.17-1.38 倍）、2009 年は 6749 トン（5,022 トンの 1.34 倍）であった。

ブートストラップで推定した母集団（日本への輸出個体全体）の年齢別尾数範囲及び合計重量における分散は極めて小さかった（表 A5）。これはサイズデータのカバー率が高かったことによる。冷凍運搬船と冷凍コンテナ船とで扱われた魚の年齢組成はほとんど同じであった。このため、冷凍魚の扱いを冷凍運搬船と冷凍コンテナ船に区分しても結果にほとんど影響を及ぼさなかった。

Result

The harvest size dataset included from 61 thousands to 187 thousands individuals per year (Table A2). The proportion of size measured individuals to the number of SBT which exported to Japan by year was 45-86 % for fresh fish. In frozen SBT, the proportions were 26-63 % except 7% in 2009. The numbers of fish size measured by year, month and fate (fresh/frozen) were ranged between 3 thousands to 67 thousands, except when few fish were harvested.

All of the monthly length frequencies, between 2007 and 2009, were decomposed into between two and

four normal distributions for each of fresh SBT, frozen SBT from freezer vessels and frozen SBT from freezer containers (Table A3 and Fig. A2). The mixed normal distributions fitted the length frequency distributions well. Normal distribution was not always estimated for large fish of more than 130 cm FL, whose length frequency distribution did not show a peak in some months (e.g. fresh fish in July 2007). This leads to a slight underestimation of the age composition for higher ages in the present study.

In the 2010 farmed fish, length frequencies were fitted well with mixed normal distributions consisted of 1 to 3 normal distributions except February when small number of individuals harvested. However, it was not appeared that each normal distributions was corresponded with age (figure was not shown in this paper, but see Fig. 3 in CCSBT-ESC/1107/26). Thus, the 2010 data was not included in the analysis of mixed normal distribution in the following.

The mean values of the normal distributions were around 95 cm FL, 106 cm FL, 120 cm FL and 130 cm FL. Comparison to the length-at-age of wild fish suggests that these normal distributions corresponded with age-2, age-3, age-4 and age-5, respectively. The mean values of the normal distributions were slightly larger than the length-at-age of wild fish between April and August.

In the 2008 fish, normal distributions with mean of around 95 cmFL had large standard deviation and did not necessarily correspond with age-2 (fresh in July, freezer vessel in July and August, and freezer container in August). It was assumed as age-3 in the base case. In the lower age case, fish of fresh and freezer vessel in July were assumed to be age-2. However, it appears that age-2 is only a part and that age-3 consists of a large part, and suggested that the lower age case lead underestimation in age.

Also in the 2008 fish, normal distributions with mean of around 115 cmFL located near the boundary of age-3 and age-4, then it was difficult to assign its age (fresh in June, July and September, freezer vessel in July and August, and freezer container in August). It was assumed as age-3 in the base case, however, it would lead underestimation in age. Intermediate between the higher age case and the base case seems to be appropriate.

Age compositions estimated are shown in Table A4 and Fig. A3. In all the years, age-3 fish were dominated followed by age4, and age-2 fish were not many as 7-18%. It was quite different with Australian report that age-2 fish were dominated and age-4 fish were few.

Estimated total catch in weight by Australian purse seine are shown in Table A5 and Fig. A4. It was 8,271 ton (1.55 times of Australia's report of 5,342 t) in 2007, 6,112-7,170 ton (1.17-1.38 times of 5,211 t) in 2008 and 6,749 ton (1.34 times of 5,022 t) in 2009.

Variances of estimated number of fish by age and estimated total weight of the all SBT imported to Japan obtained from bootstrapping were small (Table A5). This is due to the facts that coverage of the size data was high. Age compositions of freezer vessel were similar to that of freezer container. Therefore, separation of frozen fish into fish of freezer vessel and fish of freezer container affected little on the result.

解析 2　Age スライシング法による年齢分解
Analysis 2: Age decomposition by age slicing

材料と方法

畜養後のハーベストサイズデータによる体長組成に対して、Age スライシング法による年齢分解を年齢・月別体長カットポイントを変えた以下の 3 つのケースで行った（表 B1）。

ケース 1：野生魚と同じ成長で、各月の成長は一定を仮定。野生魚の年齢別体長は、CCSBT で使用しているものを使用(図 B1)。年齢・月別体長カットポイントは CCSBT において半年前の平均体長として求められている。

ケース 2：CCSBT 通常標識再捕データから求めた、畜養ミナミマグロの体重増加率（2 歳、3 歳、4 歳の各年齢の平均推定値）（Sakai et al. 2009）を 6 ヶ月間の体重増加率として使用した（図 B1）。1 歳の増加率は 2 歳、3 歳、4 歳の値から式(8)で求めた。5 歳以上は 4 歳の増加率と同じと仮定した。

$$\begin{aligned} R_1 &= R_2 \times (R_2 - R_3)/(R_3 - R_4) \\ R_2 &= 1.818 \\ R_3 &= 1.544 \\ R_4 &= 1.448 \\ R_{>4} &= R_4 \end{aligned} \qquad (8)$$

ここで、R_j：j歳魚の六ヶ月間の体重増加率。

収穫時サイズデータにおいて最も生け込み時期頻度が高かったのが 2 月であったことから、2 月の中央点を野生魚の漁獲日とした。まず 2 月の各年齢の下限体長をケース 1 に従って直線補完で求めた（式 9）。次いで各年齢の下限体長から、野生魚の体長体重関係式（Robins 1963）で 2 月時点の原魚重量に変換した（式 10）。次いで体重増加率を掛けて 8 月時点の体重を求めた（式 11）。次いでオーストラリアが使用している製品重量＝原魚重量/1.12-1kg の関係（CCSBT-ESC/1107/04）を用いて製品重量に変換した。そして、畜養魚について求めた 8 月の体重体長関係式（表 A1）で 8 月時点の体長に変換し、8 月時点の畜養収穫魚の年齢区分下限体長を得た（式 12）。2 月と 8 月の体長の差から各月の年齢区分下限体長を内挿、外挿して推定した。

$$LL_{Feb,j} = LL_{Jan,j} + (LL_{Jan,j+1} - LL_{Jan,j})/12, \qquad (9)$$

$$LW_{Feb,j} = a_{wild} \times (LL_{Feb,j})^{b_{wild}}, \qquad (10)$$

$$LW_{Aug,j} = LW_{Feb,j} \times R_j \qquad (11)$$

$$LL_{Aug,j} = a_8 \times (LW_{Aug,j} / WP)^{b_8} \qquad (12)$$

ここで、$LL_{Jan,j}$はCCSBTで使用される 1 月 1 日時点のj歳の下限体長、$LL_{Feb,j}$は 2 月中央時点のj歳の下限体長、$LW_{Feb,j}$は 2 月中央時点のj歳の下限体重、$LW_{Aug,j}$は 8 月中央時点のj歳の下限体重、$LL_{Aug,j}$は 8 月中央時点のj歳の下限体長、a_{wild}、b_{wild}は野生魚の体長体重換算式の定数、a_8、b_8は式(1)で求めた畜養魚の 8 月の体重体長換算式の定数、WPは原魚重量と製品重量の換算係数。

ケース 3 : 推定されたまき網漁獲時の重量が豪州報告値と同じになるように、成長率を調整した。成長は、野生魚のうちと畜養期間とで異なる係数の VB 式(式 13)に従うとした。

$$l_t = l_\infty\left[1 - e^{-K(t-t_0)}\right] \quad (13)$$

ここで、L_∞は極限体長、Kは成長係数、t_0はl_t=0 時のt値。

野生魚のゆるやかな成長をしていた魚が畜養開始から成長速度が大きくなるイメージである(図 B2)。この図では、例として魚を 3 歳と仮定する。野生魚の VB 式から畜養開始時（2 月中央点）の尾叉長は 97.2cm と計算され、これは Robins(1963)により原魚重量 18.7kg に相当する。半年後に野生魚ならば 103.7cm に達する。オーストラリアが主張するように畜養期間中に体重で 2.0 倍に成長すると仮定すると収穫時の原魚重量は 37.4kg であり、製品重量で 32.4kg となる。解析 1 で求めた体重体長関係式（例として 2007 年 7 月の生鮮のものを使用）により 114.9cmFL と計算される。L-infinity を固定した場合、97.2cm と 114.9cm の 2 点を 3.0 歳から 3.5 歳で通る VB 式のパラメータ K 及び t0 は一意に定まる。この例では K=0.602、t0=1.558 となる。このように畜養期間の成長については VB パラメータ K により議論でき、魚の年齢に依存せずに統一的に扱うことができる。

野生魚の VB 式パラメータは CCSBT で用いている体長別年齢値を元にした。この値は、6 個のパラメータを使い、季節による成長速度の差も含んだ複雑なモデル（VBlog k モデル）によって推定された（Eveson CCSBT-ESC/1107/9)。これらの値は単純な VB 式では当てはまらない（図 B3)。1 歳のプロットを含めてフィットさせた VB 式では本研究で対象とする 2-4 歳の当てはまりが特に悪かった。そこで 2 歳から 6 歳までのプロットに対して当てはめた VB 式を本研究の野生魚の VB 成長式として用いた（L-infinity= 166.72 cm、K= 0.219、t0= -0.968)。

畜養期間の VB（VB_farm）の K は次のように求めた。まず K を任意に設定する。L-infinity は野生魚の VB と同じ 166.72 cm に固定する。収穫月 HM に収穫された体長 X の個体（複数）を考える。ある年齢に対して 2 月中央時点の体長は野生魚の VB から求まり、これを代入して VB_farm の各年齢の t0 が計算される。VB_farm 曲線に沿った HM 時の体長を 2 歳から 5 歳までそれぞれに計算し、実際の収穫時体長 X に最も近い計算体長の年齢を割り当てる。畜養魚の WL 関係式を用いて製品重量を計算する。製品重量を原魚重量に変換する。求めた原魚重量に個体数をかけてその年・収穫月・体長・生鮮冷凍別の原魚重量を求め、これを全収穫月、全年齢、生鮮/冷凍で足しあげてハーベストサイズデータ全体での漁獲量を求める。次いで、解析 1 と同様に輸入尾数全体に拡大し、さらにオーストラリアまき網による全漁獲重量に拡大する。非線形最小二乗法により上記のプロセスを繰り返し、オーストラリアまき網漁獲量に合致する K の最適解を求めた。

Material and method

Age decomposition by age slicing method was applied to the length frequency derived from the harvest size data in three cases in which different monthly length-at-age (Table B1).

Case 1: Same growth as SBT in wild. It assumed constant growth all the year. Length-at-age used was that used in CCSBT (Fig. B1). The length cut point by age was defined as the mean length-at-age at half a year before in CCSBT.

Case 2: Growth rate in weight of farmed fish derived from CCSBT conventional tagging recapture data, mean of age-2, age-3 and age-4, was used (Sakai et al. CCSBT/ESC/0909/31) (Fig. B1). It assumed growth in 6 months. Growth rate in age-1 was assumed as Eq-8. Growth rate of age more than 4 was assumed as same as that of age-4.

$$\begin{aligned} R_1 &= R_2 \times \left(R_2 - R_3\right)/\left(R_3 - R_4\right) \\ R_2 &= 1.818 \\ R_3 &= 1.544 \\ R_4 &= 1.448 \\ R_{>4} &= R_4 \end{aligned} \qquad \text{(Eq-8)}$$

where R_j is the growth rate in weight in 6 months of age-*j* fish.

As transfer from towing pens to farming cages was most frequent in February for the individual size data used in this analysis, lower limit length as at the mid-February was calculated based on information on the lower limit length at age on 1st January, which is as used in CCSBT, and on interpolation (Eq-9). Then, the calculated length on the mid-February was converted to body weight using the length-weight relationship for wild fish in southern Australia (Robins 1963) (Eq-10). Body weight at the mid-August was calculated by multiplying the weight growth by case (Eq-11). Whole body weight was converted to gilled and gutted weight by using the relationship that gilled and gutted weight = whole weight/1.12 + 1kg (CCSBT-ESC/1107/04). The gilled and gutted weight was converted to fork length at the mid-August by using weight-length relationship of farmed fish in August (Table A1) and obtained the lower cut point at age for farmed fish (Eq-12). The lower cut point of other months was interpolated or extrapolated based on length difference between February and August.

$$LL_{Feb,j} = LL_{Jan,j} + 1.5 \times \left(LL_{Jan,j+1} - LL_{Jan,j}\right)/12, \qquad \text{(Eq-9)}$$

$$LW_{Feb,j} = a_{wild} \times \left(LL_{Feb,j}\right)^{b_{wild}}, \qquad \text{(Eq-10)}$$

$$LW_{Aug,j} = LW_{Feb,j} \times R_j \qquad \text{(Eq-11)}$$

$$LL_{Aug,j} = a_8 \times \left(LW_{Aug,j}/WP\right)^{b_8} \qquad \text{(Eq-12)}$$

where $LL_{Jan,j}$ is the lower limit length in age-j at January 1st used in CCSBT; $LL_{Feb,j}$ is the lower limit

length at the mid-February in age-j; $LW_{Aug,j}$ is the lower limit whole body weight at the mid-August; $LL_{Aug,j}$ is the lower limit length at the mid-August in age-j; a_{wild} and b_{wild} are parameters of length-weight relationship of wild fish; a_8 and b_8 are the parameters of weight-length relationship of farmed fish in August obtained by Eq-1; *WP* is the conversion coefficient between whole weight and processed weight.

Case 3: Growth rate was adjusted to the estimated catch by purse seine became same as Australia reported. Growth was assumed to follow von Bertalanffy growth curve (VB, Eq-13) but had different parameter values for wild and farmed periods.

$$l_t = l_\infty\left[1 - e^{-K(t-t_0)}\right] \qquad \text{(Eq-13)}$$

where L_∞ is the asymptotic length; *K* is the growth rate parameter, and t_0 is the theoretical age when a fish would have length zero.

The assumed growth was that fish grew slowly in wild period and suddenly grew fast since onset of farming (Fig. B2). As an example, in Fig. B2, fish was assumed to age-3. Fork length at the onset of farming (mid-February) is 97.2 cm based on VB of wild fish (see below), corresponding to 18.7 kg in whole weight by length-weight relationship of Robins (1963). Half a year later, fish reaches 103.7 cm if it were wild fish. If assume 2.0 times grow in body weight during farming, as Australia claims, body weight at harvest is 37.4 kg in whole weight and 32.4 kg in processed weight. It can be converted to 114.9 cmFL by using weight-length relationship derived in the analysis 1 (fresh fish in July 2007 was used). When L_∞ was fixed, the parameter values of *K* and t_0 are determined for VB that through two points of 97.2 cmFL at age-3.0 and 114.9 cmFL at age-3.5. In this example, VB-K=0.602 and t_0=1.558. In such a way, growth in farmed period can be summarized as VB-K value, which allows us to understand growth irrelevant to ages.

VB parameters of wild fish were based on the length-at-age used in CCSBT. These values were estimated from a complicated model (VB log k model) using 6 parameters and incorporate seasonal growth change (Eveson CCSBT-ESC/1107/9). These values do not fit well with a simple VB (Fig. B3). When try to fit from age-0 to older, fit of VB was not good especially for age 2-4 which were important in the present study. Therefore, fit was applied only for between age-2 and age-6 and derived parameter values were used for wild fish growth in the present study (L_∞= 166.72 cm, *VB-K*= 0.219, t_0= -0.968).

VB-K in the farmed period was calculated as follows. K value was set arbitrary at first. L_∞ was fixed as same as that of wild fish, 166.72 cm. Let consider individuals of fork length *X* cm in harvest month. For an age, fork length at the mid-February, which was determined from VB of wild fish, allow to calculate t_0 of each age in VB of farmed fish. Fork length in harvest month at age between 2 and 5 along VB of farmed fish were calculated and the age whose length was closest to the actual length at harvest was chosen. The length was converted to processed weight by using the weight-length relationship of farmed fish, and to whole weight. The whole body weight was multiplied by the number

of individuals of the size, and then obtained whole weight by year, harvest month, length and fate. It was summed up for all harvest month, all the ages, and both fate and obtained total catch in weight for whole the harvest data. As same as in analysis 1, it was raised to whole the imported fish, and then further raised to whole the catch of Australian purse seine. This procedure was repeated by using the non linier least squares method until VB-K value that corresponds with Australian purse seine catch amount was obtained.

結果

野生魚の成長と体長成長が同一であることを仮定した Case1 において、魚は 3 歳魚を例とすると次のように成長する（表 B1、図 B1）。2 月の蓄養開始時に 97.7 ㎝であった魚は 6 か月後に 104.2 ㎝と 1.067 倍に成長する。体重は、2007 年生鮮魚の 7 月の体長体重関係を使用した場合、19.0kg から 27.8kg と 1.467 倍に成長する。

年、月、生鮮冷凍別の体長頻度分布に対して想定された年齢別平均体長値（図 B4 の□で囲まれた黒い数字）は体長モードの山にほぼ対応した（図 B4）。得られた年齢区分で尾数を集計すると表 B2 及び図 B5 に示すように、3 歳魚または 4 歳魚が優先した。漁獲量は 2007 年から 2010 に 5822-8486 トンと推定された。

蓄養期間の成長を含む標識魚から推定された体重成長率を基本とした Case2 において、魚は 3 歳魚を例とすると次のように成長する（表 B1、図 B1）。2 月の蓄養開始時に 98.8 ㎝であった魚は 6 か月後に 107.1 ㎝と 1.083 倍に成長する。体重は、2007 年生鮮魚の 7 月の体長体重関係を使用した場合、19.6kg から 30.1kg と 1.538 倍に成長する。Case1 よりわずかに大きな成長率に過ぎなかった。

年、月、生鮮冷凍別の体長頻度分布に対して想定された年齢別平均体長値（図 B4 の□で囲まれた赤い数字）は体長モードの山にほぼ対応した（図 B4）。得られた年齢区分で尾数を集計すると表 B2 及び図 B5 に示すように、2007 年は 2 歳魚 13%、3 歳魚 46%、4 歳魚 33%、5 歳魚 6%、2008 年は 2 歳魚 17%、3 歳魚 58%、4 歳魚 23%、5 歳魚 2%、2009 年は 2 歳魚 21%、3 歳魚 37%、4 歳魚 38%、5 歳魚 4%、2010 年は 2 歳魚 3%、3 歳魚 29%、4 歳魚 50%、5 歳魚 16%であった。年変動はあるが 3 歳魚または 4 歳魚が優先する点は共通していた。2009 年には 3 歳魚よりも 4 歳魚の割合が大きくなり、2010 年にはさらに 4 歳魚の割合が大きくなって 5 歳魚も 16%出現するなど、魚の高齢化が見られた。

推定したオーストラリアのまき網による漁獲重量を表 B3、図 B6 に示す。2007 年は 8273 トン（豪州主張 5,342 トンの 1.55 倍）、2008 年は 6659 トン（5,211 トンの 1.28 倍）、2009 年は 6675 トン（5,022 トンの 1.33 倍）、2010 年は 5689 トン（3,935 トンの 1.45 倍）であった。

豪州の主張する漁獲量を基準として VB の K を調節した Case3 では、2007 年の VB-K=0.708、2008 年の VB-K=0.512、2009 年の VB-K=0.620、2010 年の VB-K=0.806 と野生魚の VB-K=0.219 に対して極めて高い値が計算された。魚は 2010 年の 3 歳魚を例とすると次のように成長することとなる（表 B1、図 B1）。2 月の蓄養開始時に 98.6 ㎝であった魚は 6 か月後に 121.2 ㎝と 1.229 倍に成長する。これは野生魚の体長成長における 2 年間分の成長（5 歳で 122.7 ㎝）を 0.5 年間でほぼ達成することに相当する。

体重は、2007 年生鮮魚の 7 月の体長体重関係を使用した場合、19.5kg から 43.8kg と 2.248 倍に成長する。

年、月、生鮮冷凍別の体長頻度分布に対して想定された年齢別平均体長値（図 B4 の○で囲まれた緑色の数字）は、2 月及び 3 月には体長モードの山にほぼ対応したものの、その後は合致しなかった（図 B4）。年齢組成は、豪州が主張する年齢組成とほぼ一致した（図 B5）。

最後に、解析 1（混合正規分布）と解析 2（スライシング法）で推定した漁獲量並びに豪州が報告した漁獲量とを比較した（図 B6）。2007 年、2009 年に解析 1 と解析 2 が推定した値は極めて似ていた。2008 年は解析 2 の結果が解析 1 の高齢を仮定したケースとベースケースとの中間に位置した。

Results

In Case 1 which assumed farmed fish growth in length was as same as that of wild fish, age-3 fish, as an example, grow as follows (Table B1, Fig. B1). Fish of 97.7 cm at onset of farming in February reach 104.2 cm (1.067 times) in six months. Body weight increased from 19.0 kg to 27.8 kg (1.467 times) when weight-length relationship in July 2007 for fresh fish was used.

Mean length-at-age assumed by year, month and fate (black square in Fig. B4) was roughly corresponded with length frequency modes (Fig. B4). The number of fish was summed up based on the estimated age cut points as shown in Table B2 and Fig. B5. Age-3 or age-4 was dominated. The catch weight was estimated as 5,822-8,486 tons between 2007 and 2010.

In Case 2 which assumed farmed fish growth was as same as tagged and farmed fish, age-3 fish grow as follows (Table B1, Fig. B1). Fish of 98.8 cm at onset of farming in February reach 107.1 cm (1.083 times) in six months. Body weight increased from 19.6 kg to 30.1 kg (1.538 times) when weight-length relationship in July 2007 for fresh fish was used. Growth in Case 2 was slightly larger than growth in Case 1.

Mean length-at-age assumed by year, month and fate (red square in Fig. B4) was roughly corresponded with length frequency modes (Fig. B4). The number of fish was summed up based on the estimated age cut points as shown in Table B2 and Fig. B5. Age compositions were as follows. In 2007, age-2 was 13 %, age-3 was 46 %, age-4 was 33 % and age-5 was 6 %. In 2008, age-2 was 17 %, age-3 was 58 %, age-4 was 23 % and age-5 was 2 %. In 2009, age-2 was 21 %, age-3 was 37 %, age-4 was 38 % and age-5 was 4 %. In 2010, age-2 was 3 %, age-3 was 29 %, age-4 was 50 % and age-5 was 16 %. While there was fluctuation among years, it was common that age-3 fish or age-4 fish was dominated. Along year passed, the proportion of higher age was increased such as proportion of age-4 became larger than that of age-3 in 2009, and proportion of age-4 was further increased in 2010 as well as age-5 fish occurred as 16 % in 2010.

The estimated catch weight of Australian purse seine was shown in Table B3 and Fig. B6. It was 8,273 ton (1.55 times of Australian report of 5,342 t) in 2007, 6,659 ton (1.28 times of 5,211 t) in 2008, 6,675 ton (1.33 times of 5,022 t) in 2009 and 5,689 ton (1.45 times of 3,935 t) in 2010.

In Case 3 which was adjusted VB-K to the estimated catch by purse seine became same as Australia reported, high values of VB-K were calculated (VB-K =0.708 in 2007, 0.512 in 2008, 0.620 in 2009 and 0.806 in 2010). It was quite higher than SBT in wild (VB-K=0.219). Age-3 fish in 2010 would grow as follows (Table B1 and Fig. B1). Fish of 98.6 cm at onset of farming in February reach 121.2 cm (1.229 times) in six months. It is equivalent to that farmed fish within half a year attain growth of two years in wild (122.7 cm in age-5 in wild). Body weight increased from 19.5 kg to 43.8 kg (2.248 times) when weight-length relationship in July 2007 for fresh fish was used.

Mean length-at-age assumed by year, month and fate (green circle in Fig. B4) was not corresponded with length frequency modes, though it was corresponded in February and March (Fig. B4). The age compositions were similar to those Australia reported (Fig. B5).

Finally, estimated catch amount of Australian purse seine was compared between analysis 1 and 2, as well as Australia reported (Fig. B6). The values from analysis 1 and analysis 2 were quite similar in 2007 and 2009. In 2008, the result of analysis 2 was located in the middle of the higher age case and the base case in the analysis 1.

考察
Discussion

オーストラリアのまき網で漁獲されたミナミマグロは、年齢組成や漁獲量の点において、豪州がCCSBT に報告しているものと本研究で推定したもの（混合正規分布やスライシング法の Case2）とで大きく異なった。

この原因として、我々はオーストラリアのサイズサンプリングにバイアスがある可能性が最も高いと考えた。曳航生簀から畜養生簀に分配する前の段階で 40 尾サンプリングが行われる。この時に無作為ではなく、小型魚が選択して漁獲されるのであれば、見掛け上の高成長が引き起こされる。

この他の原因としては以下が考えられる。次にこれらの妥当性について考察したい。

(1) 畜養ミナミマグロは野生魚よりも高速で成長する。
(2) 冷凍魚の収穫から輸入までに想定した期間が実際と異なっている。
(3) ハーベストサイズデータが少なく、偏りがあるため代表性がない。
(4) 畜養魚は想定よりも長期間飼育されている。
(5) 豪州の報告尾数に誤りがある。

(1) 畜養ミナミマグロは野生魚よりも高速で成長するのか？

豪州が主張する漁獲量に対応した VB-K は 0.51-0.81 であり、これは例えば 3 歳魚の体重が半年間で 1.88-2.25 倍になることに相当する。一方、ミナミマグロ野生魚の VB-K は 0.22 であり、畜養魚が太ることを勘案しても 3 歳魚の半年間の体重増加は 1.47 倍であった。一方、標識再捕魚から推定された畜養期間の成長は半年間での体重増加が 1.54 倍であり、野生魚の成長と近かった（Sakai et al. CCSBT/ESC/0909/31）。標識再捕データを用いたミナミマグロの成長の解析においても、畜養魚と野生

魚との間で体長の成長の差が無いことを仮定しており（Eveson CCSBT-ESC/1107/9）、求められた年齢別体長値は CCSBT の資源評価に用いられている。

マグロ属魚類の中で、ミナミマグロは最も長寿命で成熟が遅い。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）、メバチでは大西洋資源で 0.180 が報告されている（Hallier et al. 2005）。

ミナミマグロの近縁種である太平洋クロマグロ *Thunnus orientalis* では、野生魚の VB-K 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 が、沖縄県八重山の飼育では VB-K=0.332 が得られている(Masuma 2008)。また、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っている。他方、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）。このように、高水温で飼育された場合には高い VBK を示す場合はあるが、ポートリンカーンの水温は 15-21℃と低い（Hayward et al. 2009）。

以上のことから、野生魚より数倍高く、短命で成熟が早く成長の速いキハダよりも高い VBK をミナミマグロ畜養魚が実現するとは到底考えられない。

(2) 冷凍魚の収穫から輸入までに想定した期間が実際と異なっているのか？

冷凍畜養魚の収穫から輸入までの期間について、本推定では収穫から 1-2 ヶ月程度と想定した。実際に輸入した時期がこれと異なった場合、使用する平均体重値が異なるため日本の輸入尾数が変化する。しかしながら引き伸ばし率がわずかに変化するだけであり、オーストラリアのまき網漁船が漁獲した全体の尾数は変わらない。

また、輸入業者が日本政府への輸入申請を翌年まで行わない場合、翌年の漁獲物として混入されるため推定に影響を及ぼす。しかしながら、冷凍畜養魚の輸入には 7-10 月頃をピークとした明瞭な周年変化があること、輸入せずに保持しておく動機が考えにくいことから、このようなケースはほとんどないと考えられる。

(3) ハーベストサイズデータが少なく、偏りがあるため代表性がないか？

本推定においては、収穫個体総数に対して生鮮魚では 45-86%が測定され、冷凍魚では 2009 年のみ 7%と低かったものの、他の年は 28-63%に及んでいる。また、年、月、生鮮冷凍別の測定個体数は、3000 から 67 千個体に及んでおり、データが少ないとは考えられない。

測定の偏りについては、ブートストラップリサンプリングによるハーベストサイズデータから輸入魚全体への推定値において分散が極めて小さかったことから、特殊なサイズの魚が測定されなかった可能性を完全には排除できないものの、結果を大きく変えるほどの偏りがあるとは考えにくい。

なお、オーストラリア関係者からは冷凍魚において、冷凍運搬船と冷凍コンテナ船とで魚体サイズが大きく異なるとの指摘があったが、両者を区別して推定しても結果にほとんど違いはなかった。

(4) 畜養魚は想定よりも長期間飼育されているか？

本推定では飼育期間を最長 1 年間と想定した。種苗生産実験のために残される魚も若干あるようだ

が、半年程度でほとんどすべての魚を収穫していると想定されている。

(5) 豪州の報告尾数に誤りがあるか？

オーストラリアが尾数を過小に報告している可能性は、蓄養生簀への移送時に AFMA が委託した業者がビデオ映像を撮影して 100%を計数していること（Hobsbawn et al. CCSBT-CC/1110/SBT Fisheries – Australia）、推定された日本への輸入個体数と整合性があることから、小さいと考えられる。

以上のことから、現状の 40 尾サンプリングには大きなバイアスがあり、40 尾サンプリングの値を基に計算される年齢組成、漁獲重量にも影響を及ぼしていると考えられた。

There was a large discrepancy in SBT caught by Australian purse seine, in terms of age composition and total catch amount, between Australia reported to CCSBT and estimation in the present study (mixed normal distribution and age slicing in Case 2).

For the reason of the discrepancy, we considered that there was a large bias in the size sampling for fish used for farming. Just before transport SBT to farm cages from a towing pen, so called 40 fish sampling was conducted. If fish were caught not in random but chosen smaller fish, it cause merely apparent high growth rate.

There might be other reasons as follows. We discuss further these.

(1) SBT in farmed condition grow much faster than wild fish,

(2) The assumed time period between harvested and imported were quite different with actual time period,

(3) Harvest size data collected were small in number and not fully representative,

(4) Fish grow on a longer time in the pens than assumed, or

(5) The number of SBT farmed was not correct.

(1) Did SBT in farmed condition grow much faster than wild fish?

VB-K values corresponded with Australia reported catch was 0.51-0.81 which was that age-3 fish grow 1.88-2.25 times in weight within half a year. VB-K of wild fish was 0.22 which was that age-3 fish grow 1.47 times in weight in half a year. The estimated growth rate in body weight for half a year farmed period based on CCSBT tag recapture data was 1.54 times, close to that of wild fish (Sakai et al. CCSBT/ESC/0909/31). In the study for SBT growth by using the CCSBT tag recapture data, it was assumed that “there is no evidence that growth in terms of length differs between farm and wild recaptures” (Eveson CCSBT-ESC/1107/9) and the derived length-at-age from the study was used in the current stock assessment in CCSBT.

It is known that SBT has long longevity and late mature age among *Thunnus* species. In yellowfin tuna *T. albacares* in the eastern Pacific which has short longevity, early mature age and grow rapidly, VB-K of 0.557-0.569 in different years were reported (Wild 1986). VB-K values were reported for albacore *T. alalunga* in the north Pacific as 0.184 and in the south Pacific as 0.134 (Labelle et al. 1993, Wells et al. 2011) and for bigeye tuna *T. obesus* in the Atlantic as 0.180 (Hallier et al. 2005).

For Pacific bluefin tuna *T. orientalis*, more closely related species to SBT, VB-K of wild fish reported was 0.173 (Shimose et al. 2009), however, higher values of VB-K of farmed fish of this species were reported as 0.250 in Amami-Oshima in Kagoshima Prefecture or 0.332 in Yaeyama in Okinawa Prefecture (Masuma 2008). It was observed that the higher its water temperature was, the faster Pacific bluefin tuna in captivity grow (Masuma et al. 2008). Water temperature of year round in Yaeyama was 20-31 ºC and Amami-Oshima was 20-28 ºC, both of which would be higher temperature than wild fish experienced because both places located in lower latitude area than Pacific bluefin tuna distributed. On the other hand, growth of Pacific bluefin tuna in captive in Wakayama Prefecture, where have lower water temperature, was not fast and growth in length was similar to that of wild fish (Masuma et al. 2008). Thus, fish farmed in high water temperature would have grown fast and show high VB-K values. However, water temperature in Port Lincoln was relatively low as 15-21 ºC (Hayward et al. 2009).

Therefore, it is highly unlikely that SBT farmed fish attain VB-K several times as high as that of wild SBT and higher than that of short live, early mature and fast grow tuna, such as yellowfin tuna.

(2) Was the assumed time period between harvested and imported quite different with actual time period?

The time period between harvested and imported was assumed 1-2 months in the present study. If actual month imported were different with this, average body weight used was changed and then the number of SBT imported to Japan was changed. However, it was only a slight change of raising factor to whole the Australian purse seine catch, and the total number of Australian purse seine catch was not changed.

If importer did not apply to Japanese government for their import until the next year, the fish would be contaminated in next year and affect estimation. However, because import of frozen fish had clear annual cycle with a peak around July-October and there is no incentive to keep the product not imported in economic view point, such a case would be few.

(3) Was harvest size data collected small in number and not fully representative?

In the present study, size data were collected for 45-86 % individuals to the total harvested fish in fresh product. It was 28-63 % in frozen product except 7 % in 2009. The number of size measured by year, month and fate ranged from 3000 to 67 thousands. The number of size sample was substantial.

Quite small variance in the bootstrap resampling when rose from the harvest size data to all the imported

fish suggest representativeness of the data, though any particular fish (in small number) might not have sampled.

By the way, Australia pointed out that size of fish was quite different between freezer vessel and freezer container among frozen product, there was little difference in the results even if both were distinguished.

(4) Did fish grow on a longer time in the pens than assumed?

In this study it was assumed SBT farmed less than one year. It appears that there was several SBT for experiment for spawning and grow more than one year, it is considered that most fish was harvested after half a year.

(5) Was the number of SBT farmed not correct?

The possibility of under reporting in number by Australian government would be low because Australia claimed that 100% of fish transferred to farm cage were monitored and counted on video taken by the AFMA-contracted monitoring company (Hobsbawn et al. CCSBT-CC/1110/SBT Fisheries – Australia) and there were certain consistency to the number of SBT imported to Japan.

In conclusion, there is a large bias in the 40 fish sampling and it affects on the age composition and total catch amount which calculated from the data of the 40 fish sampling.

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図表キャプション

表 A1　ハーベストサイズデータのデータ数。年、月、生鮮／冷凍別のデータ数、体重と体長の両方がある個体数、体重体長関係式のパラメータ a,b の値

表 A2　体重測定尾数と日本への輸入尾数推定値。年、月、生鮮・冷凍別。

表 A3　正規分布のパラメータ値±SE。年、月、生鮮・冷凍、冷凍船・冷凍コンテナ別。

表 A4　推定した年齢組成。日本の輸入魚全体にレイズした。

表 A5　推定した漁獲量。年別。メディアン、5%、95%。

図 A 1　体長体重プロット。年、月別。回帰式で実線は生鮮魚、点線は冷凍魚。

図 A2　体長頻度と混合正規分布。年、月、生鮮・冷凍、冷凍船・冷凍コンテナ別。

図 A3　混合正規分布で推定した年齢組成。

図 A4　混合正規分布で推定したオーストラリアのまき網による漁獲量。灰色棒が推定漁獲量、白棒は豪州の報告漁獲量。2008 年の○は年齢を多めに推定したケース（Higher age）、△は年齢を少なめに推定したケース（Lower age）。

表 B1　ケースごとに仮定した六か月間の年齢別の尾叉長、体重増加率。

表 B2　推定年齢組成。年、ケース別。

表 B3　漁獲量の推定。年、ケース別。

図 B1　3 ケースで想定した成長。上：体長の成長、下：体重の成長。2 月に畜養を開始した後の 10 月までの成長を年齢別にプロット。黒線は CCSBT で用いている年齢当たりの体長および変換した体重。

図 B2　スライシング法における VB-K 値の計算の例。本文を参照。

図 B3　野生魚の VB のフィット。

図 B4　体長組成とカットポイント。

図 B5　年齢組成の図。

図 B6　スライシング法で推定した漁獲量。

図 B7　解析 1 と解析 2 の推定漁獲量の比較。

Table and Figure for the analysis 1

Table A1　Number of harvest size data.　The number of individual by year, month and fresh/frozen and the number of individuals both length and weight were obtained, and parameter valuess of a and b of weight-length relationship.

Year	Fresh/Frozen	Month	N_data	N_data both length and weight	a	b
2007	Fresh	Apr	368	284	38.038	0.322
		May	1,891	1,479	40.777	0.298
		Jun	2,425	1,672	38.912	0.313
		Jul	5,715	4,267	37.288	0.324
		Aug	8,001	5,957	36.260	0.331
		Sep	6,878	5,089	35.943	0.337
		Oct	3,603	2,278	38.314	0.321
		sub-total	28,881	21,026		
	Frozen	Jul	36,273	8,040	37.670	0.322
		Aug	67,274	21,976	35.492	0.341
		Sep	42,552	25,038	36.763	0.335
		sub-total	146,099	55,054		
	Total		174,980	76,080		

Year	Fresh/Frozen	Month	N_data	N_data both length and weight	a	b
2008	Fresh	Feb	93	93	35.742	0.340
		Mar	520	430	40.785	0.301
		Apr	4,492	3,513	35.074	0.344
		May	5,647	4,404	36.954	0.329
		Jun	3,840	3,108	39.290	0.310
		Jul	5,613	4,709	39.102	0.310
		Aug	6,338	5,394	38.774	0.312
		Sep	5,571	5,372	36.755	0.332
		Oct	937	937	38.699	0.320
		sub-total	33,051	27,960		
	Frozen	Jul	31,053	20,340	40.187	0.305
		Aug	30,248	8,933	37.528	0.328
		sub-total	61,301	29,273		
	Total		94,352	57,233		

Year	Fresh/Frozen	Month	N_data	N_data both length and weight	a	b
2009	Fresh	Mar	1,179	1,018	43.134	0.283
		Apr	5,127	4,478	40.949	0.298
		May	6,652	6,037	40.227	0.301
		Jun	8,025	7,151	39.106	0.310
		Jul	8,402	7,904	38.323	0.316
		Aug	10,125	10,077	38.468	0.317
		Sep	8,453	8,435	38.531	0.320
		Oct	1,395	1,392	38.771	0.322
		sub-total	49,358	46,492		
	Frozen	Jul	5,134	5,122	37.411	0.324
		Aug	7,351	7,350	37.167	0.327
		sub-total	12,485	12,472		
	Total		61,843	58,964		

Year	Fresh/Frozen	Month	N_data	N_data both length and weight	a	b
2010	Flesh	Mar	659	260	38.612	0.319
		Apr	2,807	631	37.022	0.333
		May	4,315	2,079	37.895	0.327
		Jun	3,306	871	36.955	0.330
		Jul	6,629	2,202	38.524	0.317
		Aug	7,350	1,677	39.946	0.309
		Sep	5,039	238	41.918	0.296
		sub-total	30,105	7,958		
	Frozen	Jun	1,189	1,185	39.431	0.312
		Jul	39,455	27,155	38.043	0.319
		Aug	18,255	13,650	37.560	0.326
		sub-total	58,899	41,990		
	Total		89,004	49,948		

TableA2　Number of size measured in the harvest size data and the estimated number of fish imported in Japan by year, month and fresh/frozen.

Year	Month	N_Fresh measured	N_Frozen measured	N_Fresh imported	N_Frozen imported	% Fresh measured	% Frozen measured
2007	4	368		1,651		22%	
	5	1,891		2,117		89%	
	6	2,425		2,496		97%	
	7	5,715	36,273	5,617	84,405	102%	43%
	8	8,001	67,274	10,513	85,405	76%	79%
	9	6,878	42,552	7,538	49,415	91%	86%
	10	3,603	12,441	3,848	34,360	94%	36%
	Total	28,881	158,540	33,779	253,586	86%	63%
		187,421		287,364		65%	

Year	Month	N_Fresh measured	N_Frozen measured	N_Fresh imported	N_Frozen imported	% Fresh measured	% Frozen measured
2008	2	93					
	3	520		462		113%	
	4	4,492		4,882		92%	
	5	5,647		7,046		80%	
	6	3,840		4,879		79%	
	7	5,613	31,053	6,661	35,210	84%	88%
	8	6,338	30,248	7,864	182,234	81%	17%
	9	5,571		5,489		101%	
	10	937		1,590		59%	
	Total	32,958	61,301	38,874	217,444	85%	28%
		94,259		256,318		37%	

Year	Month	N_Fresh measured	N_Frozen measured	N_Fresh imported	N_Frozen imported	% Fresh measured	% Frozen measured
2009	3	1,179		1,521		78%	
	4	5,127		9,466		54%	
	5	6,652		15,790		42%	
	6	8,025		16,596		48%	
	7	8,402	5,134	25,420	98,268	33%	5%
	8	10,125	7,351	24,448	72,496	41%	10%
	9	8,453		14,589		58%	
	10	1,395		1,913		73%	
	Total	49,358	12,485	109,743	170,764	45%	7%
		61,843		280,507		22%	

Year	Month	N_Fresh measured	N_Frozen measured	N_Fresh imported	N_Frozen imported	% Fresh measured	% Frozen measured
2010	3	659		775		85%	
	4	2,807		4,296		65%	
	5	4,315		5,836		74%	
	6	3,306	1,189	7,141	1,793	46%	66%
	7	6,629	39,455	11,304	72,850	59%	54%
	8	7,350	18,255	9,648	56,634	76%	32%
	9	5,039		8,055		63%	
	10			1,773		0%	
	Total	30,105	58,899	48,829	131,278	62%	45%
		89,004		180,107		49%	

Table A3　Estimated parameter values (± standard error) of the mixed normal distribution by year, month.fresh/frozen and freezer vessel or freezer container for frozen product.

year	FleshFrozen	Month	N_normdist	pN1	pN2	pN3	pN4	L_Mean_N1	L_Mean_N2	L_Mean_N3	L_Mean_N4	L_SD_N1	L_SD_N2	L_SD_N3	L_SD_N4
2007	2	4	2	68.6 ±2.93%	31.4 ±2.93%			105.8 ±0.15cm	117.2 ±0.48cm			3.2 ±0.15cm	4.1 ±0.49cm		
2007	2	5	3	7.8 ±0.75%	68.9 ±1.20%	23.4 ±1.41%		93.3 ±0.49cm	105.9 ±0.05cm	118.0 ±0.24cm		4.0 ±0.52cm	3.3 ±0.06cm	4.5 ±0.24cm	
2007	2	6	4	12.2 ±4.39%	61.9 ±3.57%	24.3 ±1.28%	1.6 ±5.80%	98.0 ±3.19cm	106.8 ±0.05cm	119.0 ±0.24cm	133.2 ±0.52cm	7.4 ±2.09cm	3.0 ±0.08cm	4.6 ±0.23cm	1.6 ±0.51cm
2007	2	7	3	8.5 ±0.83%	50.0 ±1.35%	41.5 ±1.59%		92.0 ±0.49cm	106.4 ±0.10cm	120.6 ±0.14cm		4.0 ±0.51cm	4.2 ±0.13cm	4.5 ±0.14cm	
2007	2	8	3	8.5 ±0.68%	50.8 ±1.38%	40.7 ±1.54%		91.2 ±0.34cm	105.4 ±0.11cm	120.7 ±0.21cm		3.3 ±0.34cm	4.3 ±0.12cm	5.6 ±0.21cm	
2007	2	9	4	1.5 ±0.40%	49.9 ±1.02%	41.4 ±2.21%	7.2 ±2.46%	91.4 ±0.83cm	105.8 ±0.09cm	120.1 ±0.18cm	133.2 ±1.10cm	2.4 ±0.83cm	4.1 ±0.09cm	4.9 ±0.27cm	4.6 ±0.84cm
2007	2	10	4	2.3 ±0.76%	54.2 ±1.52%	36.0 ±5.63%	7.5 ±5.88%	93.3 ±1.24cm	105.4 ±0.08cm	122.1 ±0.85cm	133.6 ±1.61cm	3.2 ±1.27cm	3.7 ±0.10cm	6.3 ±0.90cm	4.1 ±1.03cm
2007	3	7	4	9.4 ±0.76%	54.9 ±1.08%	33.1 ±1.20%	2.7 ±1.78%	93.3 ±0.37cm	106.2 ±0.07cm	119.7 ±0.12cm	132.4 ±1.36cm	3.8 ±0.38cm	3.8 ±0.09cm	4.1 ±0.18cm	3.7 ±1.34cm
2007	3	8	3	6.6 ±1.23%	53.0 ±1.88%	40.4 ±2.24%		93.1 ±0.90cm	106.4 ±0.12cm	120.0 ±0.14cm		4.1 ±0.86cm	4.3 ±0.17cm	4.1 ±0.14cm	
2007	3	9	4	3.5 ±0.33%	38.7 ±0.66%	50.5 ±1.22%	7.3 ±1.43%	93.3 ±0.27cm	107.2 ±0.08cm	120.7 ±0.06cm	131.8 ±0.72cm	2.5 ±0.27cm	4.7 ±0.10cm	3.7 ±0.07cm	4.6 ±0.60cm
2007	4	7	4	1.8 ±0.31%	62.1 ±0.71%	31.1 ±1.20%	5.0 ±1.43%	90.2 ±0.72cm	107.0 ±0.05cm	119.1 ±0.10cm	130.7 ±0.86cm	3.1 ±0.71cm	4.2 ±0.05cm	3.7 ±0.13cm	4.4 ±0.76cm
2007	4	8	4	5.9 ±0.33%	59.1 ±0.51%	30.3 ±0.72%	4.7 ±0.94%	90.0 ±0.22cm	104.7 ±0.04cm	120.0 ±0.08cm	132.6 ±0.56cm	3.2 ±0.22cm	4.5 ±0.05cm	4.1 ±0.11cm	4.0 ±0.54cm
2007	4	9	3	11.9 ±0.44%	52.4 ±0.93%	35.7 ±1.03%		91.5 ±0.18cm	105.8 ±0.06cm	119.2 ±0.13cm		3.8 ±0.18cm	4.1 ±0.07cm	4.9 ±0.12cm	
2007	4	10	3	5.3 ±0.82%	48.6 ±1.47%	46.1 ±1.68%		92.7 ±0.74cm	106.9 ±0.11cm	120.9 ±0.13cm		3.9 ±0.74cm	4.5 ±0.16cm	4.5 ±0.12cm	
2008	2	3	1	101.4 ±1.92%				106.0 ±0.10cm				4.5 ±0.10cm			
2008	2	4	2	3.9 ±0.93%	96.1 ±0.93%			85.2 ±1.07cm	103.9 ±0.09cm			3.3 ±1.05cm	5.3 ±0.08cm		
2008	2	5	2	90.5 ±1.31%	9.5 ±1.31%			105.0 ±0.08cm	116.7 ±0.47cm			4.4 ±0.08cm	3.2 ±0.44cm		
2008	2	6	3	7.3 ±1.36%	74.2 ±4.68%	18.4 ±4.87%		94.4 ±1.05cm	106.1 ±0.15cm	114.2 ±0.79cm		4.5 ±0.93cm	3.4 ±0.14cm	3.6 ±0.45cm	
2008	2	7	4	10.1 ±3.13%	41.5 ±7.11%	40.2 ±6.46%	8.2 ±10.10%	97.3 ±1.72cm	106.1 ±0.19cm	114.3 ±0.58cm	130.2 ±1.92cm	4.9 ±1.10cm	3.2 ±0.21cm	4.7 ±0.54cm	6.8 ±1.54cm
2008	2	8	4	10.1 ±1.07%	50.7 ±2.40%	30.0 ±3.09%	9.2 ±4.06%	94.9 ±0.52cm	106.7 ±0.11cm	116.6 ±0.18cm	127.6 ±1.43cm	4.2 ±0.43cm	3.8 ±0.16cm	3.6 ±0.23cm	5.8 ±1.04cm
2008	2	9	2	36.0 ±3.73%	64.0 ±3.73%			106.3 ±0.25cm	116.5 ±0.38cm			3.8 ±0.18cm	5.6 ±0.26cm		
2008	2	10	2	24.5 ±5.48%	75.5 ±5.48%			106.1 ±0.56cm	115.2 ±0.40cm			3.5 ±0.36cm	4.8 ±0.27cm		
2008	3	7	4	10.7 ±7.88%	67.6 ±14.64%	18.6 ±14.63%	3.1 ±22.14%	96.8 ±3.86cm	106.3 ±0.35cm	114.8 ±1.54cm	126.1 ±18.71cm	4.5 ±2.76cm	3.2 ±0.45cm	3.5 ±1.79cm	6.0 ±14.00cm
2008	3	8	4	15.6 ±2.80%	38.2 ±5.92%	45.3 ±5.06%	0.9 ±8.27%	95.4 ±1.19cm	105.5 ±0.18cm	114.7 ±0.65cm	131.3 ±3.33cm	5.5 ±0.95cm	3.1 ±0.21cm	5.5 ±0.54cm	3.1 ±3.32cm
2008	4	8	3	22.6 ±1.41%	45.2 ±2.13%	32.2 ±2.56%		96.1 ±0.36cm	105.1 ±0.07cm	114.3 ±0.19cm		4.8 ±0.26cm	3.1 ±0.08cm	4.4 ±0.14cm	
2009	2	3	2	37.3 ±7.77%	62.7 ±7.77%			105.1 ±1.02cm	112.8 ±0.27cm			4.5 ±0.56cm	3.4 ±0.14cm		
2009	2	4	2	29.5 ±1.58%	70.5 ±1.58%			104.2 ±0.17cm	113.6 ±0.10cm			3.3 ±0.13cm	3.9 ±0.08cm		
2009	2	5	2	39.2 ±3.11%	60.8 ±3.11%			106.8 ±0.39cm	115.9 ±0.16cm			4.4 ±0.25cm	3.7 ±0.10cm		
2009	2	6	3	6.1 ±1.02%	28.2 ±2.51%	65.7 ±2.71%		96.1 ±0.93cm	107.6 ±0.19cm	116.6 ±0.15cm		4.4 ±0.91cm	3.1 ±0.19cm	4.1 ±0.11cm	
2009	2	7	3	13.1 ±1.54%	14.5 ±2.36%	72.3 ±2.82%		94.6 ±0.79cm	105.8 ±0.30cm	116.6 ±0.13cm		5.4 ±0.70cm	3.2 ±0.33cm	5.0 ±0.11cm	
2009	2	8	3	20.2 ±2.93%	38.2 ±6.81%	41.6 ±7.42%		94.3 ±0.59cm	105.3 ±0.36cm	116.5 ±0.58cm		4.1 ±0.34cm	4.6 ±0.57cm	5.1 ±0.31cm	
2009	2	9	4	18.7 ±0.90%	29.5 ±3.98%	46.7 ±12.73%	5.1 ±13.37%	94.2 ±0.19cm	104.0 ±0.16cm	114.1 ±0.73cm	125.5 ±9.47cm	3.4 ±0.18cm	3.0 ±0.19cm	5.3 ±1.00cm	5.4 ±4.06cm
2009	2	10	3	31.8 ±0.90%	56.5 ±1.25%	11.7 ±1.54%		95.6 ±0.13cm	105.6 ±0.05cm	116.2 ±0.32cm		3.6 ±0.13cm	2.9 ±0.06cm	3.6 ±0.32cm	
2009	3	7	3	27.7 ±10.77%	33.7 ±19.65%	38.6 ±22.41%		97.9 ±1.11cm	107.7 ±1.26cm	118.5 ±1.07cm		3.1 ±0.79cm	4.2 ±2.47cm	3.6 ±0.77cm	
2009	3	8	3	11.0 ±2.29%	45.7 ±8.21%	43.2 ±8.52%		93.8 ±0.45cm	104.7 ±0.64cm	116.4 ±0.90cm		2.0 ±0.45cm	4.1 ±0.66cm	4.6 ±0.71cm	
2009	4	7	3	36.7 ±1.03%	27.1 ±2.44%	36.2 ±2.65%		93.2 ±0.10cm	104.7 ±0.27cm	116.6 ±0.33cm		2.8 ±0.10cm	3.6 ±0.31cm	4.7 ±0.31cm	

Table A4 Estimated age composition in Japanese imported fish.

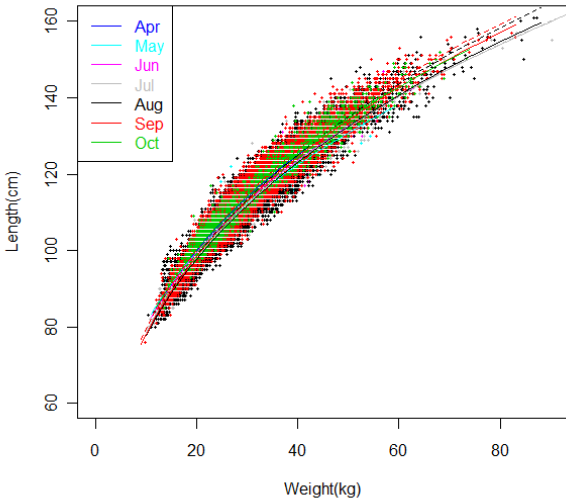
Year	Case	Age2	Age3	Age4	Age5
2007		6.8%	51.1%	39.5%	2.6%
2008	Base	11.6%	85.7%	1.6%	1.2%
	Higher age	11.6%	48.0%	39.2%	1.2%
	Lower age	13.3%	83.9%	1.6%	1.2%
2009		18.4%	34.4%	47.0%	0.3%

Table A5 Estimated total amount by year for Japanese imported fish (J) and total Australian purse seine catch (A) in median and 5 and 95 percentile.

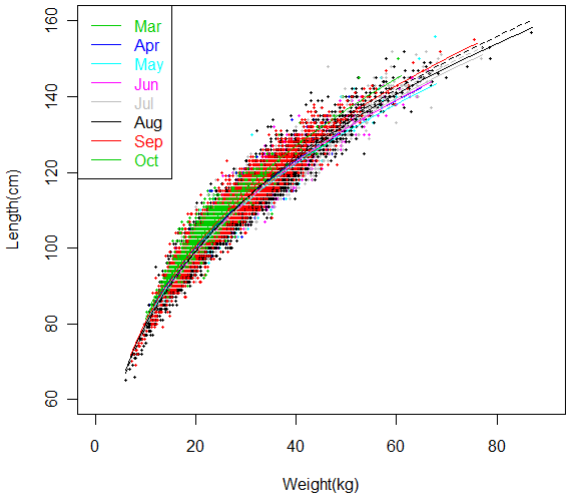
2007	Item	N_Age2	N_Age3	N_Age4	N_Age5	N_total	GT_caught
	JMedian	17,110	129,161	100,030	6,698	252,999	5,759
	J5%	17,401	129,115	99,758	6,725	252,999	5,755
	J95%	17,306	128,356	100,537	6,800	252,999	5,763
	AMedian	24,572	185,490	143,655	9,619	363,336	8,271
	A5%	24,990	185,424	143,264	9,658	363,336	8,264
	A95%	24,853	184,334	144,383	9,766	363,336	8,277

2008	Item	N_Age2	N_Age3	N_Age4	N_Age5	N_total	GT_caught
Base	JMedian	37,553	278,227	5,235	3,739	324,754	4,861
	J5%	37,883	277,924	5,256	3,692	324,754	4,859
	J95%	37,367	278,328	5,164	3,895	324,754	4,864
	AMedian	29,851	122,954	100,555	2,954	256,314	6,159
	A5%	29,923	123,462	99,883	3,046	256,314	6,156
	A95%	29,553	123,005	100,803	2,953	256,314	6,163
Higher age	JMedian	29,851	122,954	100,555	2,954	256,314	5,659
	J5%	29,923	123,462	99,883	3,046	256,314	5,654
	J95%	29,553	123,005	100,803	2,953	256,314	5,663
	AMedian	37,822	155,785	127,405	3,743	324,754	7,170
	A5%	37,913	156,428	126,553	3,859	324,754	7,164
	A95%	37,444	155,849	127,719	3,741	324,754	7,175
Lower age	JMedian	34,116	215,122	4,078	2,998	256,314	4,824
	J5%	34,565	214,593	4,133	3,023	256,314	4,821
	J95%	34,076	214,993	4,121	3,124	256,314	4,827
	AMedian	43,226	272,563	5,167	3,799	324,754	6,112
	A5%	43,794	271,893	5,237	3,830	324,754	6,109
	A95%	43,175	272,400	5,221	3,958	324,754	6,116

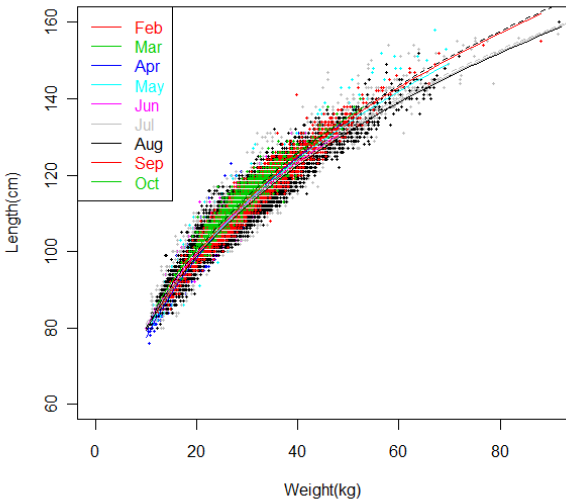
2009	Item	N_Age2	N_Age3	N_Age4	N_Age5	N_total	GT_caught
	JMedian	51,536	96,414	131,797	755	280,502	6,173
	J5%	51,929	96,263	131,560	750	280,502	6,168
	J95%	51,568	95,713	132,497	724	280,502	6,178
	AMedian	56,338	105,398	144,078	825	306,640	6,749
	A5%	56,768	105,233	143,819	820	306,640	6,743
	A95%	56,373	104,632	144,843	791	306,640	6,754



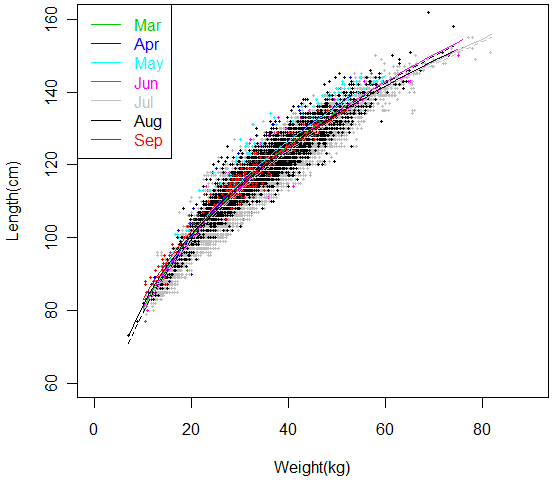
(Year 2007)



(Year 2009)



(Year 2008)



(Year 2010)

Fig. A1 Weight length plots by year and month. Solid lines are for fresh fish and broken lines are for frozen fish.

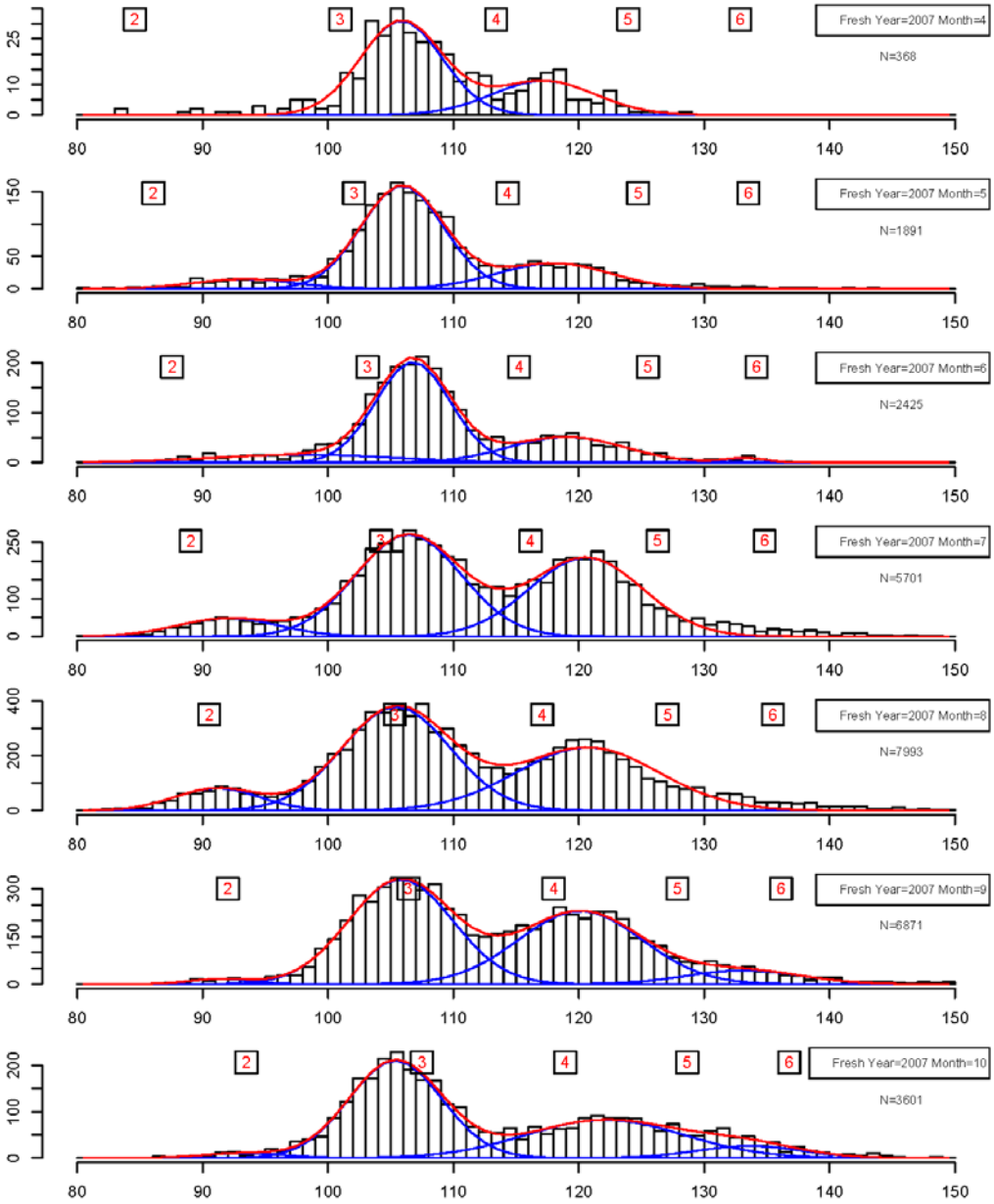


Fig. A2 Length frequency and applied mixed normal distribution by year, month, fresh/frozen and freezer vessel or freezer container for frozen product.

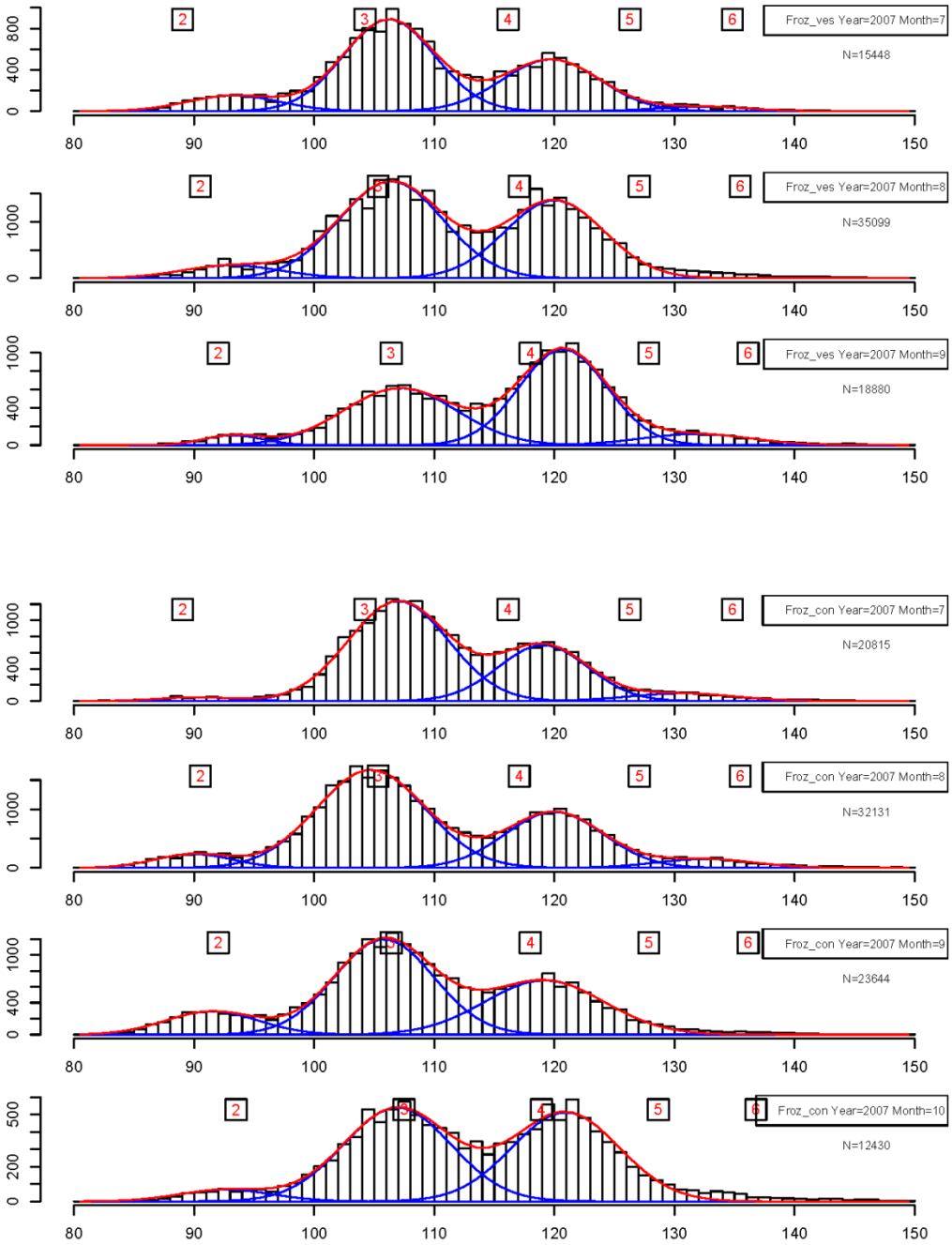


Fig. A2 (Continued, No 2)

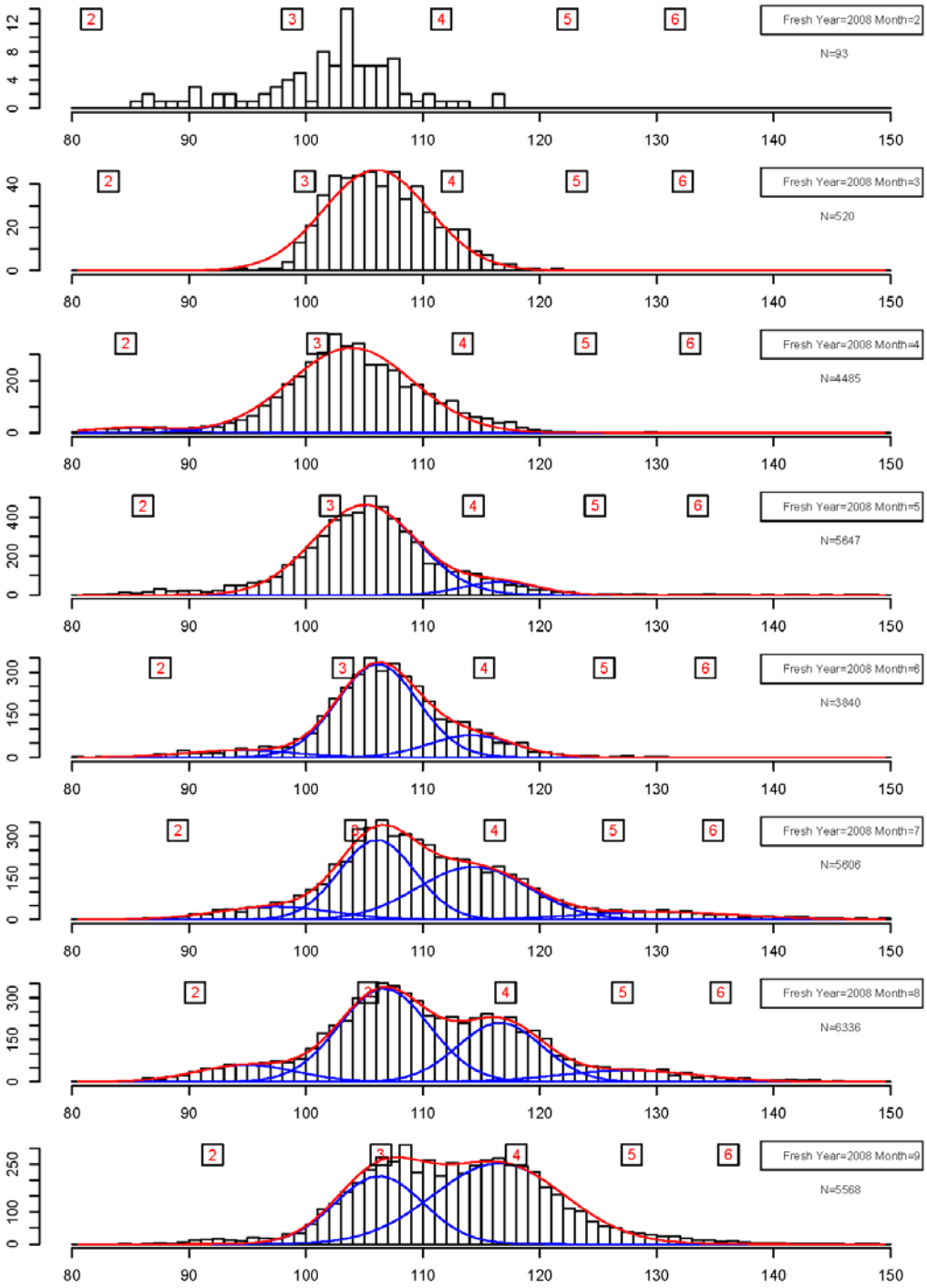


Fig. A2 (Continued, No 3)

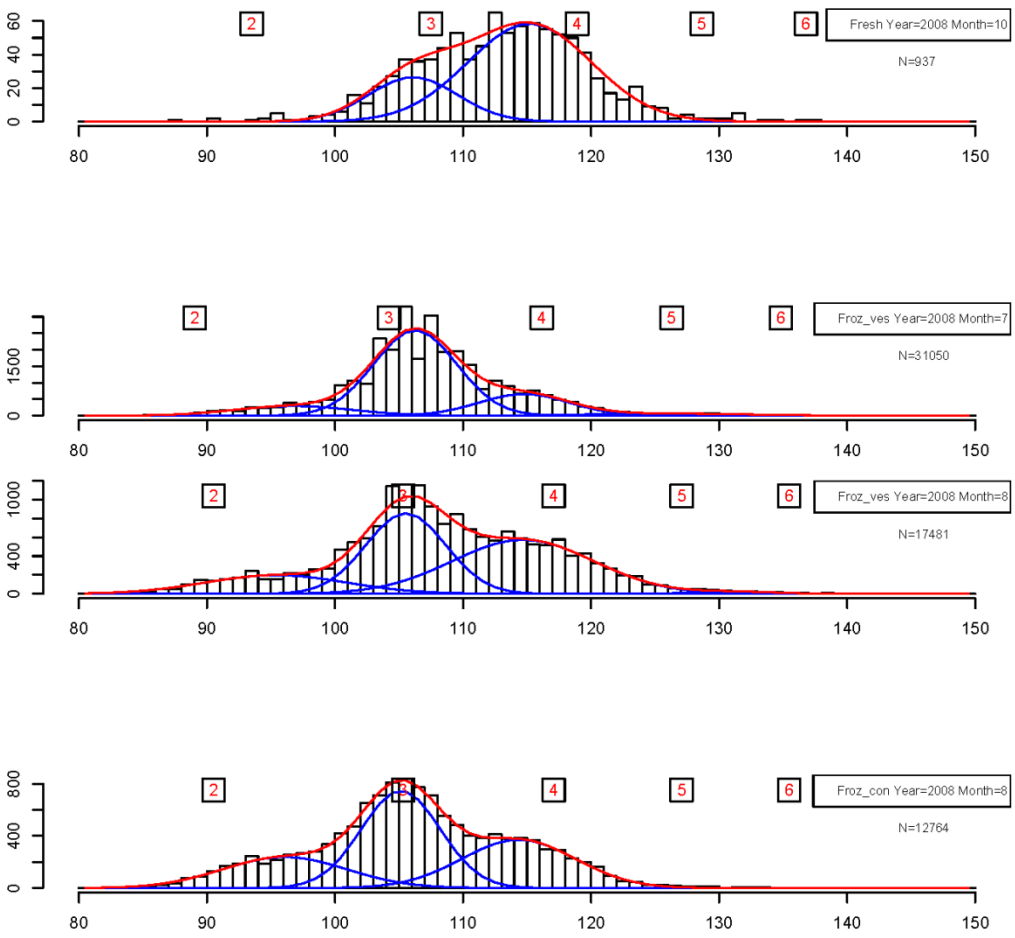


Fig. A2 (Continued, No 4)

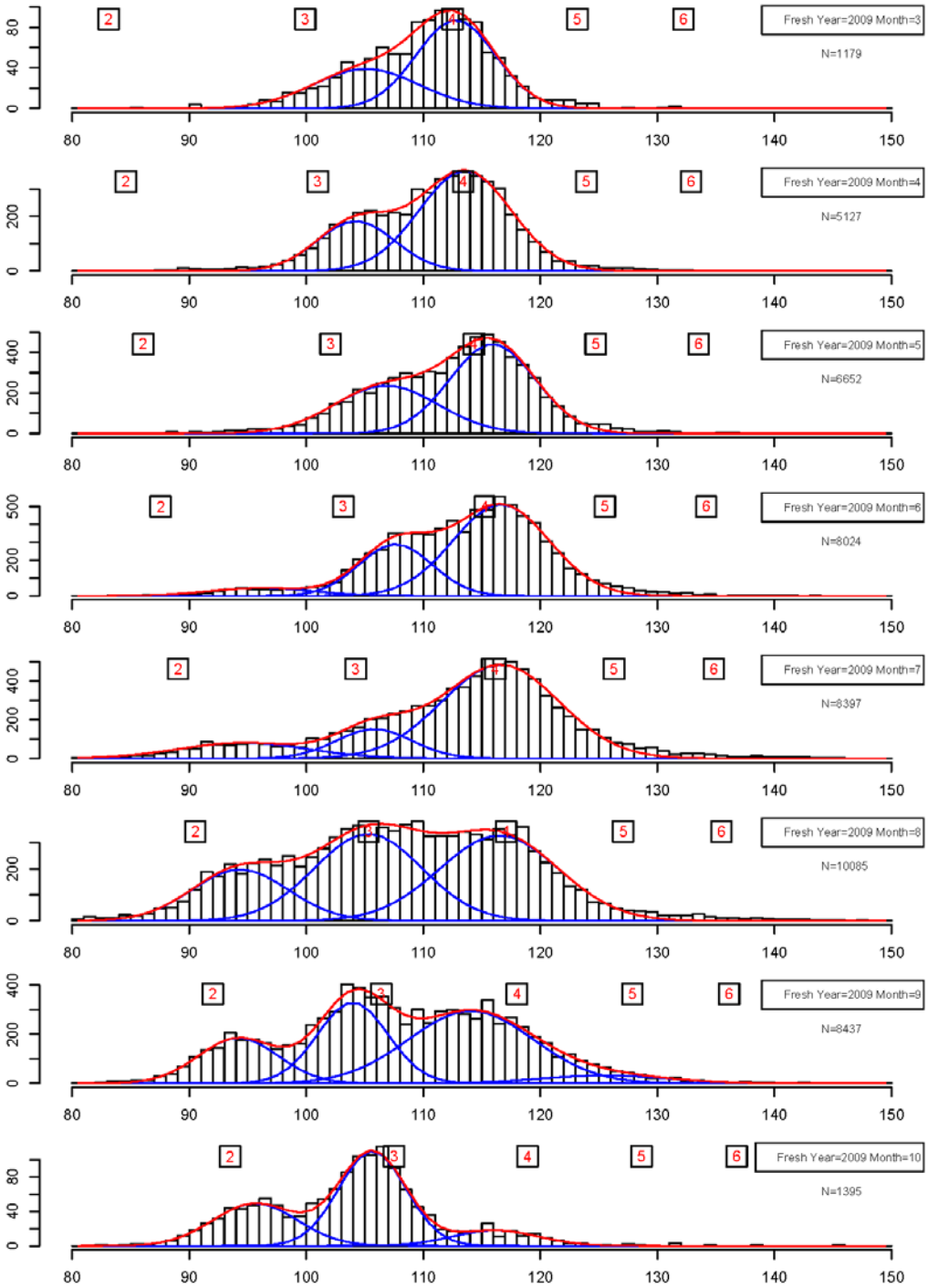


Fig. A2 (Continued, No 5)

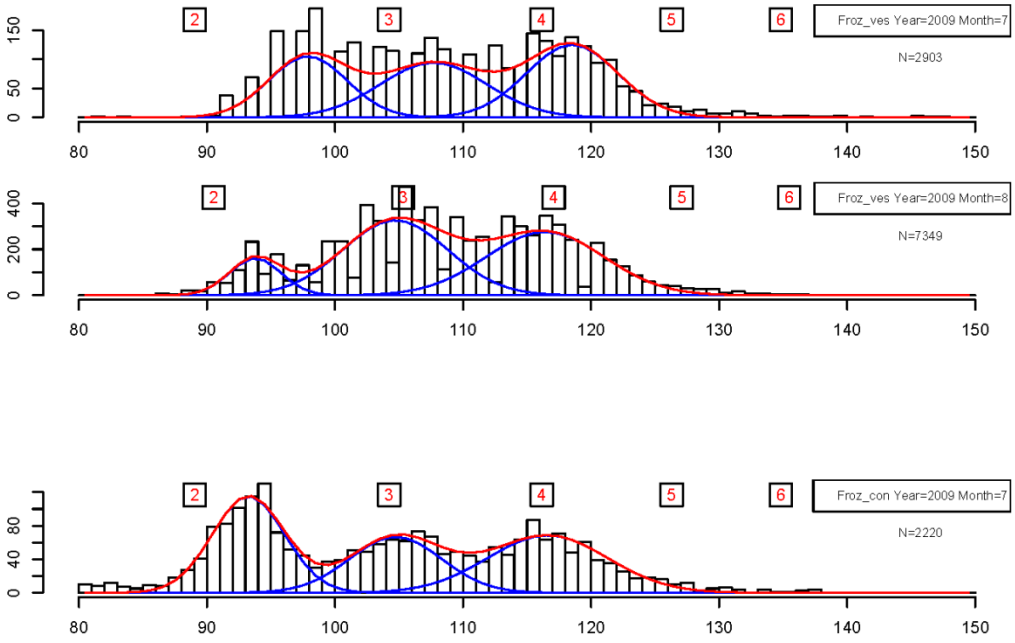


Fig. A2 (Continued, No 6)

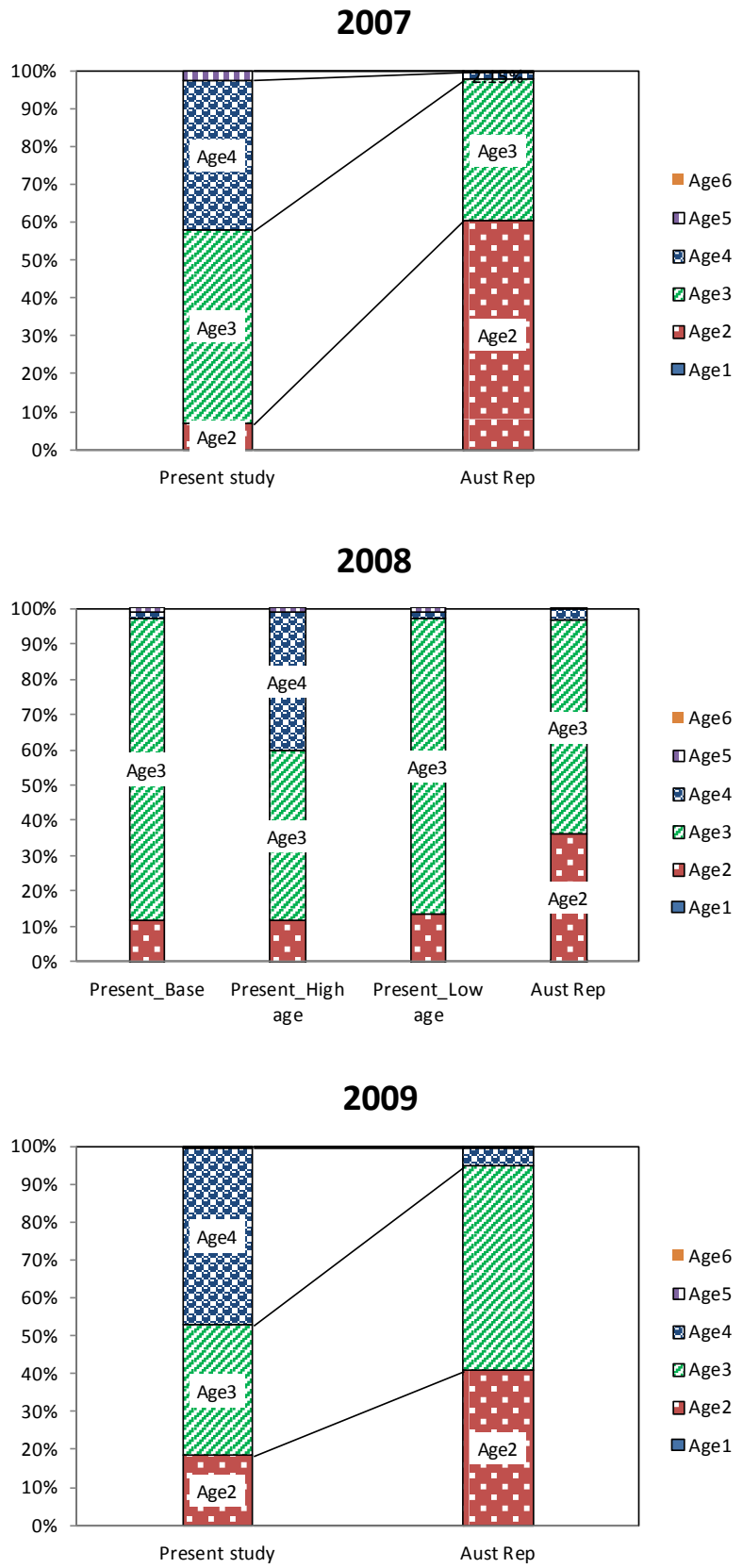


Fig. A3 Age compositons estimated by the mixed normal distribution.

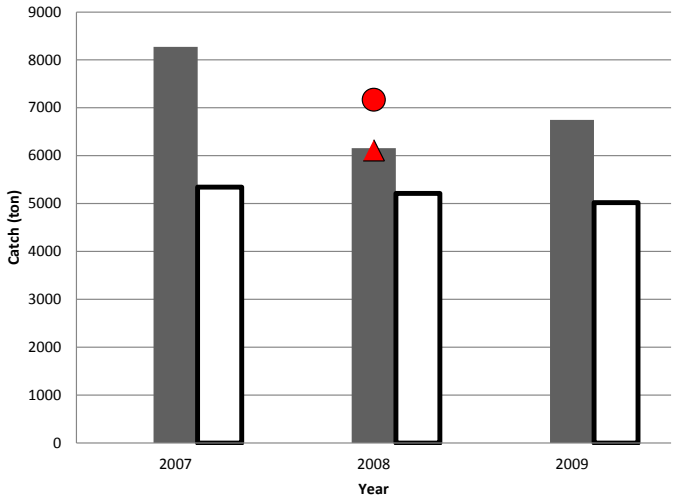


Fig. A4 Estimated total catch of Australian purse seine.

Grey bar denotes estimated in the present study and white bar denotes reported by Australia. In 208, circle is the higher age case and triangle is the lower age case.

Table and Figure for the analysis 2

Table B1　Fork length and body weight in six months by assumed case.

Item	Case	Unit	Age1	Age2	Age3	Age4	Age5	Age6
Fork length at farm start in Feb	Case1(wild)	cmFL	50.7	80.1	97.7	110.7	121.6	130.9
	Case2	cmFL	53.2	81.6	98.8	111.6	122.4	131.6
	Case3 2007	cmFL	61.2	81.9	98.6	112.0	122.7	131.4
	Case3 2008	cmFL	61.2	81.9	98.6	112.0	122.7	131.4
	Case3 2009	cmFL	61.2	81.9	98.6	112.0	122.7	131.4
	Case3 2010	cmFL	61.2	81.9	98.6	112.0	122.7	131.4
Fork length after 6 months farmed	Case1(wild)	cmFL	65.7	89.0	104.2	116.2	126.3	134.8
	Case2	cmFL	69.6	93.7	107.1	117.9	128.9	138.2
	Case3 2007	cmFL	92.7	107.2	118.9	128.3	135.8	141.9
	Case3 2008	cmFL	85.0	101.1	114.0	124.3	132.6	139.3
	Case3 2009	cmFL	89.3	104.5	116.7	126.6	134.4	140.8
	Case3 2010	cmFL	96.2	110.1	121.2	130.1	137.3	143.1
Growth in 6 months	Case1(wild)	times	1.296	1.111	1.067	1.050	1.039	1.030
	Case2	times	1.309	1.148	1.083	1.057	1.053	1.050
	Case3 2007	times	1.514	1.308	1.206	1.146	1.107	1.080
	Case3 2008	times	1.389	1.234	1.156	1.110	1.081	1.061
	Case3 2009	times	1.459	1.276	1.184	1.130	1.096	1.072
	Case3 2010	times	1.572	1.343	1.229	1.162	1.119	1.089
Whole weight at farm start in Feb	Case1(wild)	kg	2.8	10.7	19.0	27.2	35.8	44.4
	Case2	kg	3.2	11.2	19.6	27.9	36.5	45.0
	Case3 2007	kg	4.9	11.4	19.5	28.2	36.8	44.8
	Case3 2008	kg	4.9	11.4	19.5	28.2	36.8	44.8
	Case3 2009	kg	4.9	11.4	19.5	28.2	36.8	44.8
	Case3 2010	kg	4.9	11.4	19.5	28.2	36.8	44.8
Whole weight after 6 months farmed in Aug	Case1(wild)	kg	7.4	17.5	27.8	38.5	49.6	60.4
	Case2	kg	8.7	20.3	30.1	40.3	52.7	65.1
	Case3 2007	kg	19.7	30.3	41.3	52.0	61.8	70.6
	Case3 2008	kg	15.3	25.4	36.4	47.3	57.5	66.8
	Case3 2009	kg	17.7	28.1	39.1	49.9	59.9	68.9
	Case3 2010	kg	22.0	32.7	43.8	54.3	63.9	72.4
Growth in 6 months	Case1(wild)	times	2.644	1.641	1.467	1.414	1.384	1.362
	Case2	times	2.688	1.807	1.538	1.444	1.445	1.445
	Case3 2007	times	4.032	2.662	2.122	1.845	1.681	1.576
	Case3 2008	times	3.139	2.233	1.868	1.677	1.564	1.491
	Case3 2009	times	3.624	2.469	2.009	1.771	1.629	1.538
	Case3 2010	times	4.503	2.880	2.248	1.926	1.737	1.616

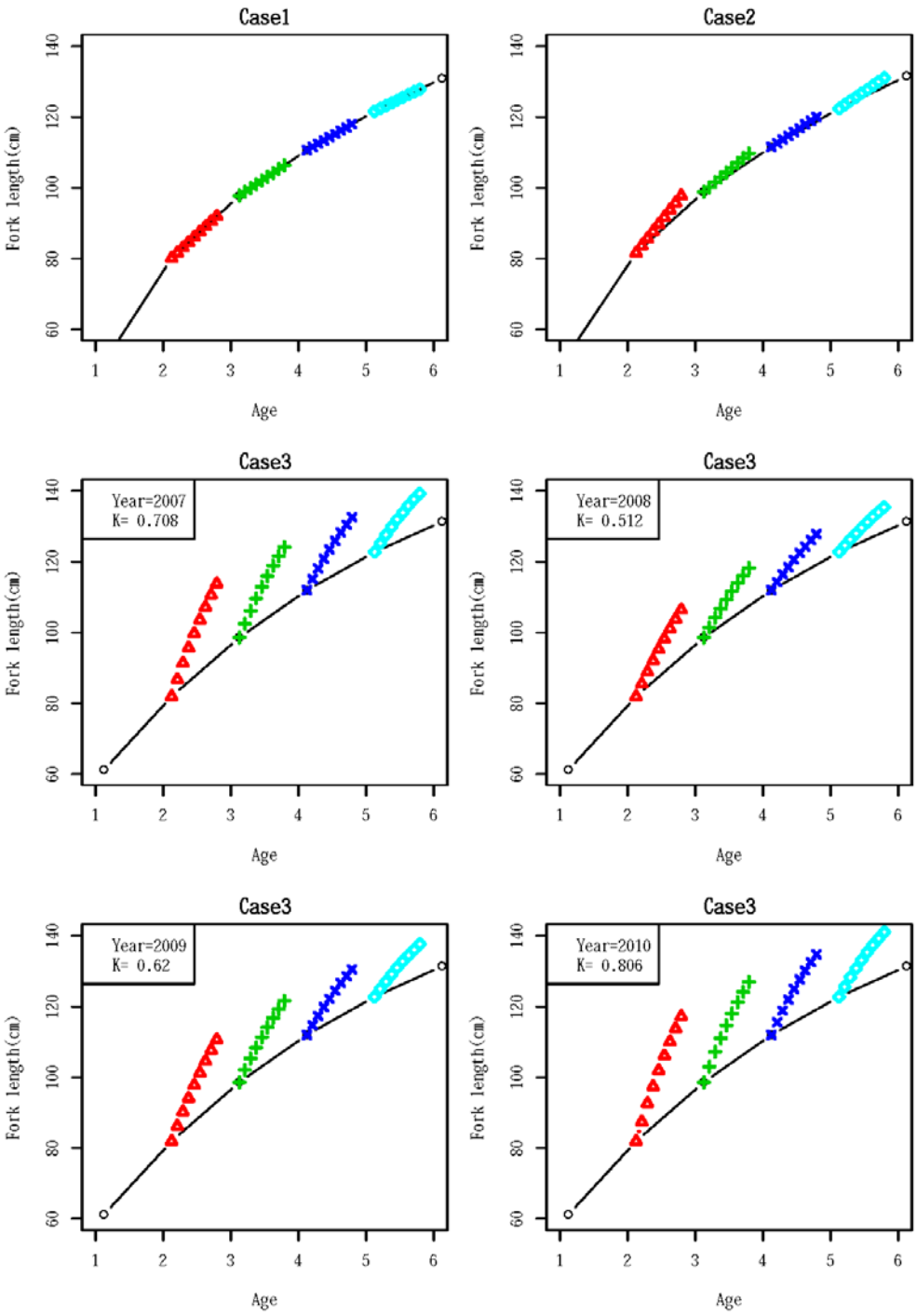
Table B2 Estimated age composition by year and case in Japanese imported fish.

Case	Year	Age1	Age2	Age3	Age4	Age5	Age6
Case1	2007	0.07%	10.22%	47.64%	31.20%	8.59%	2.29%
	2008	0.04%	14.57%	59.20%	23.32%	2.37%	0.49%
	2009	0.26%	19.04%	37.18%	37.25%	5.47%	0.79%
	2010	0.01%	2.60%	27.99%	46.42%	19.33%	3.64%
Case2	2007	0.04%	12.64%	45.94%	33.47%	6.49%	1.42%
	2008	0.02%	16.52%	58.39%	22.97%	1.80%	0.30%
	2009	0.19%	20.70%	37.04%	37.59%	3.96%	0.52%
	2010	0.01%	2.96%	28.78%	49.83%	16.13%	2.30%
Case3	2007	13.58%	44.22%	31.00%	8.21%	1.79%	0.59%
	2008	4.58%	43.55%	43.47%	7.27%	0.90%	0.23%
	2009	10.06%	36.13%	38.31%	13.87%	1.23%	0.33%
	2010	3.59%	31.36%	44.45%	16.37%	3.36%	0.79%

Case	Year	Age1	Age2	Age3	Age4	Age5	Age6
Aust Rep	2007	11.19%	56.50%	30.03%	2.05%	0.24%	0.00%
	2008	3.31%	39.95%	53.28%	3.35%	0.06%	0.05%
	2009	23.29%	67.98%	8.71%	0.02%	0.00%	0.00%
	2010	0.13%	22.69%	61.20%	14.60%	1.38%	0.00%

Table B3 Estimated total amount by year and case for Australian purse seine catch.

Year	Case1	Case2	Case3	Aust. Report
2007	8,486	8,273	5,340	5,342
2008	6,767	6,659	5,205	5,211
2009	6,805	6,675	5,021	5,022
2010	5,822	5,689	3,928	3,935


Case1
Case2
Case3
Year=2007
K= 0.708
Case3
Year=2008
K= 0.512
Case3
Year=2009
K= 0.62
Case3
Year=2010
K= 0.806
Fork length(cm)
Age

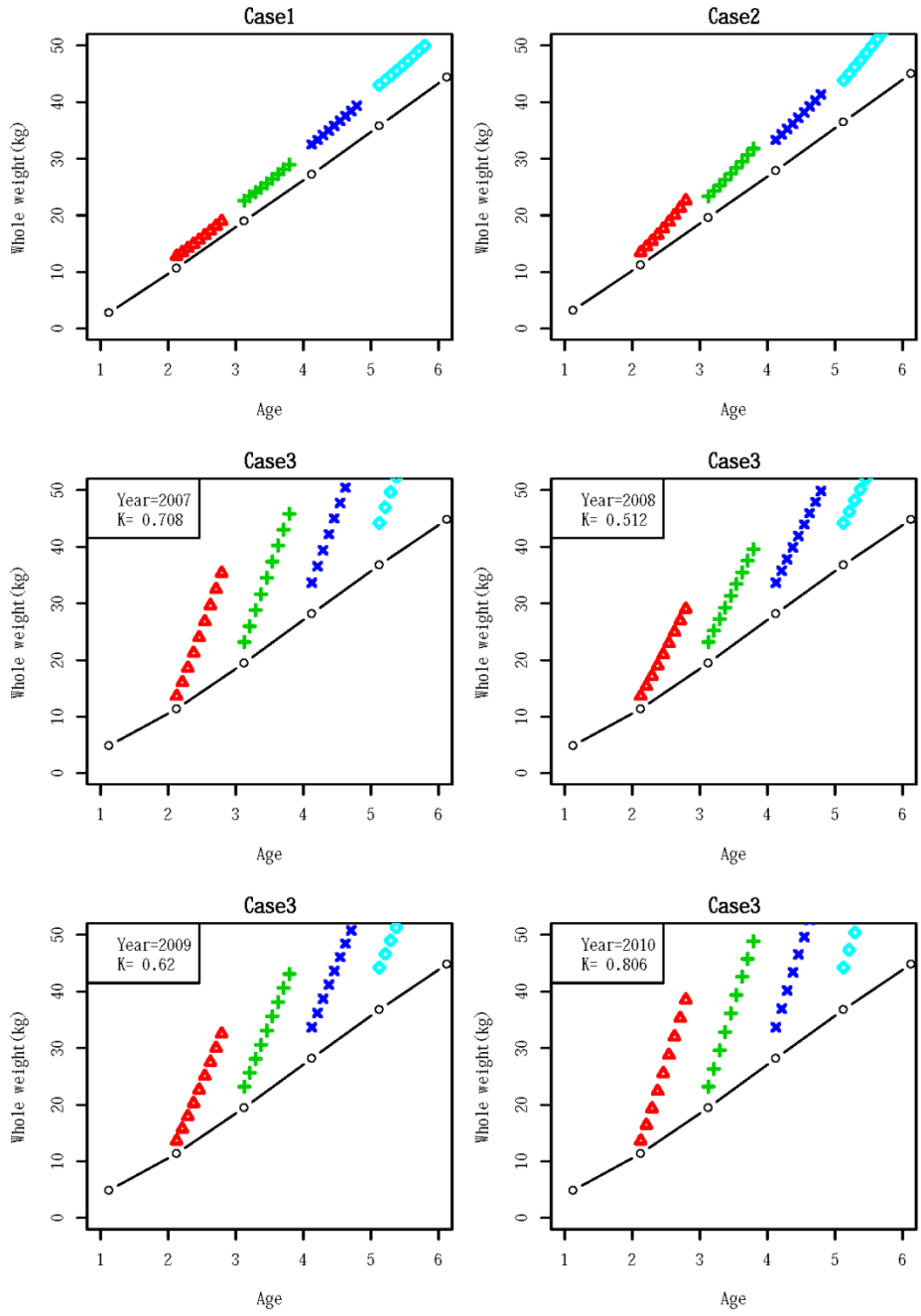


Fig. B1 Growth of SBT assumed in the three cases. Upper 6 panels: growth in fork length. Lower 6 panels: growth in whole body weight. Length/weight by age from February when farming started to October were plotted. Solid lines denote length/weight-at-age of wild fish used in CCSBT.

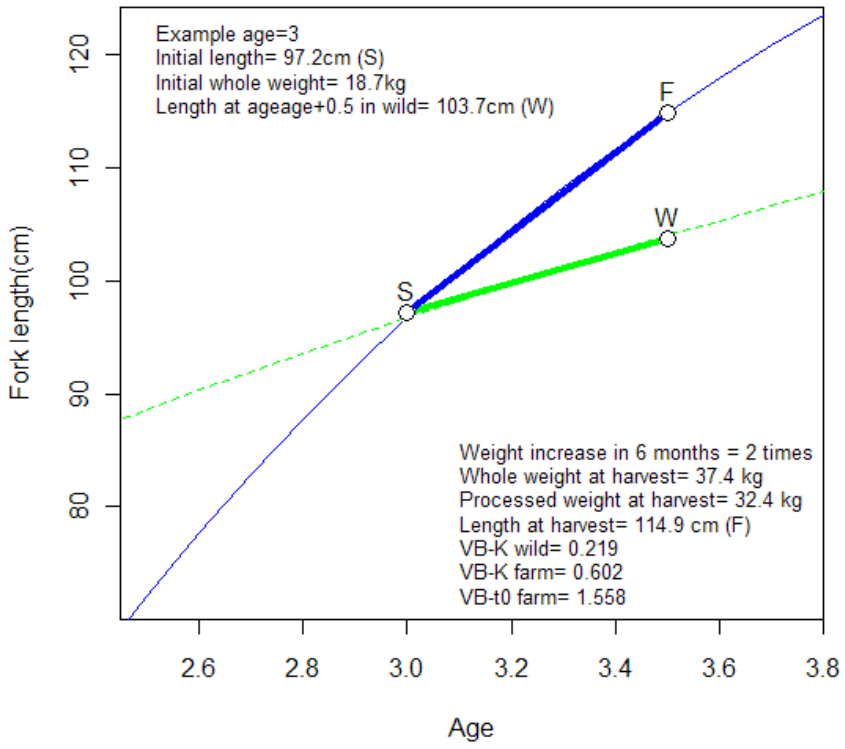


Fig. B2 Example of VB-K value calculation in the age slicing method. See text for explanation.

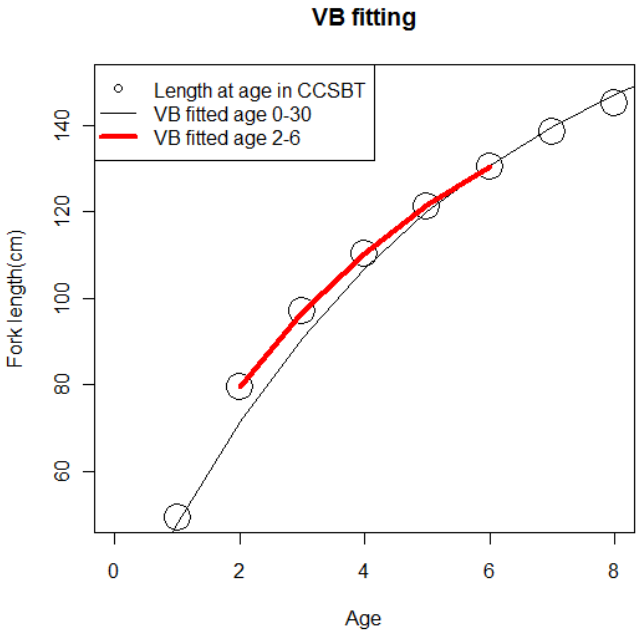


Fig. B3 VB fitting for wild fish growth.

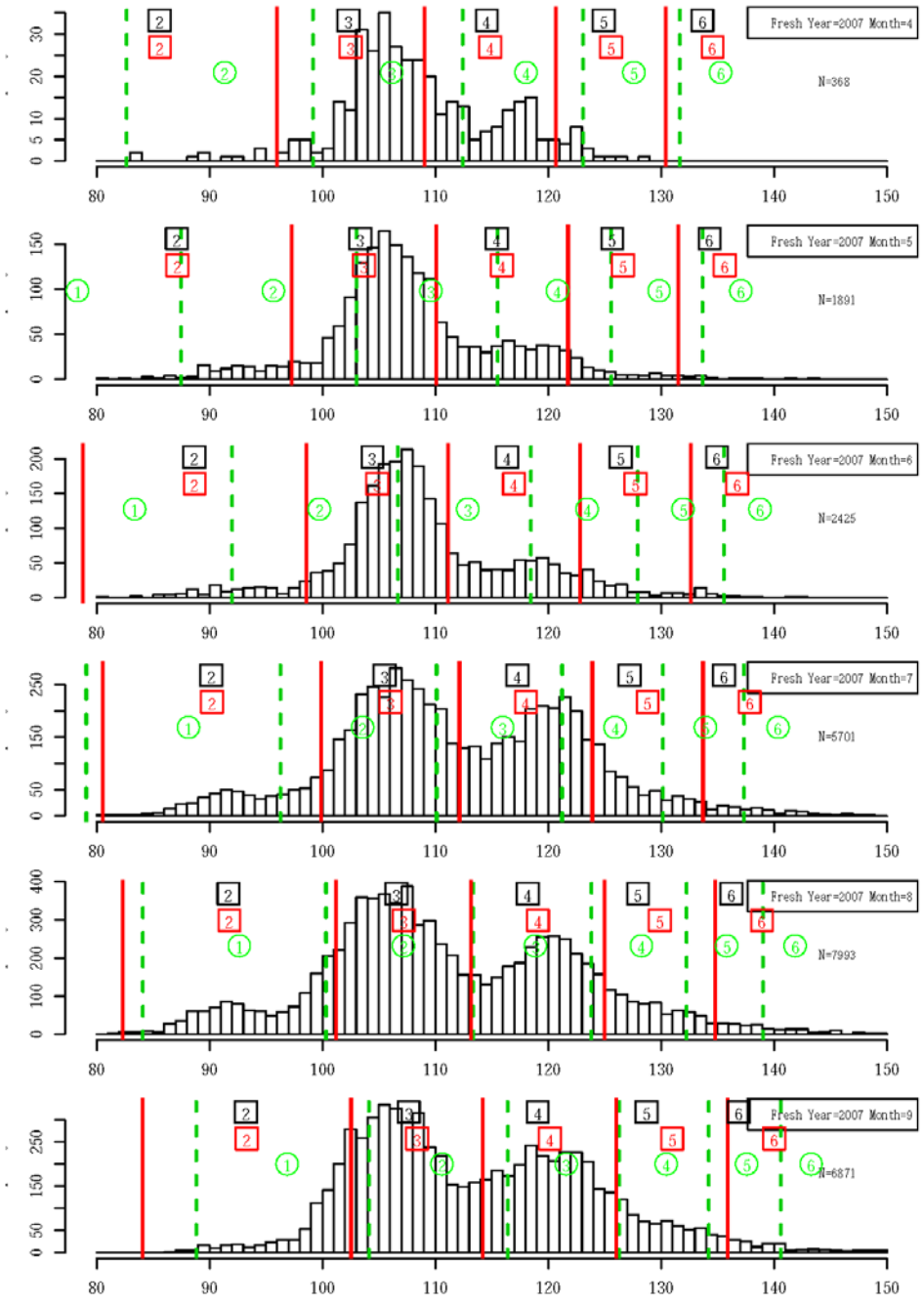


Fig. B4 Length frequency and cut points. Black square, red square and green circle denote mean length-at-age in Case 1, Case 2 and Case 3, respectively.

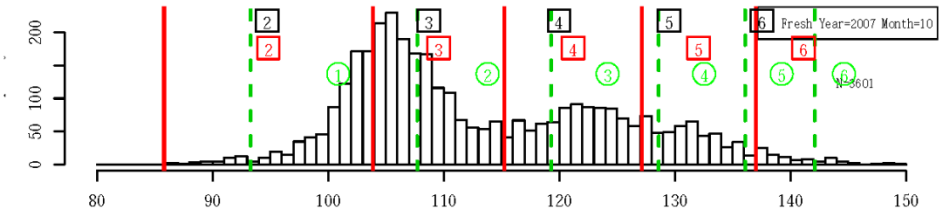


Fig. B4 (Continued, for fresh fish in 2007)

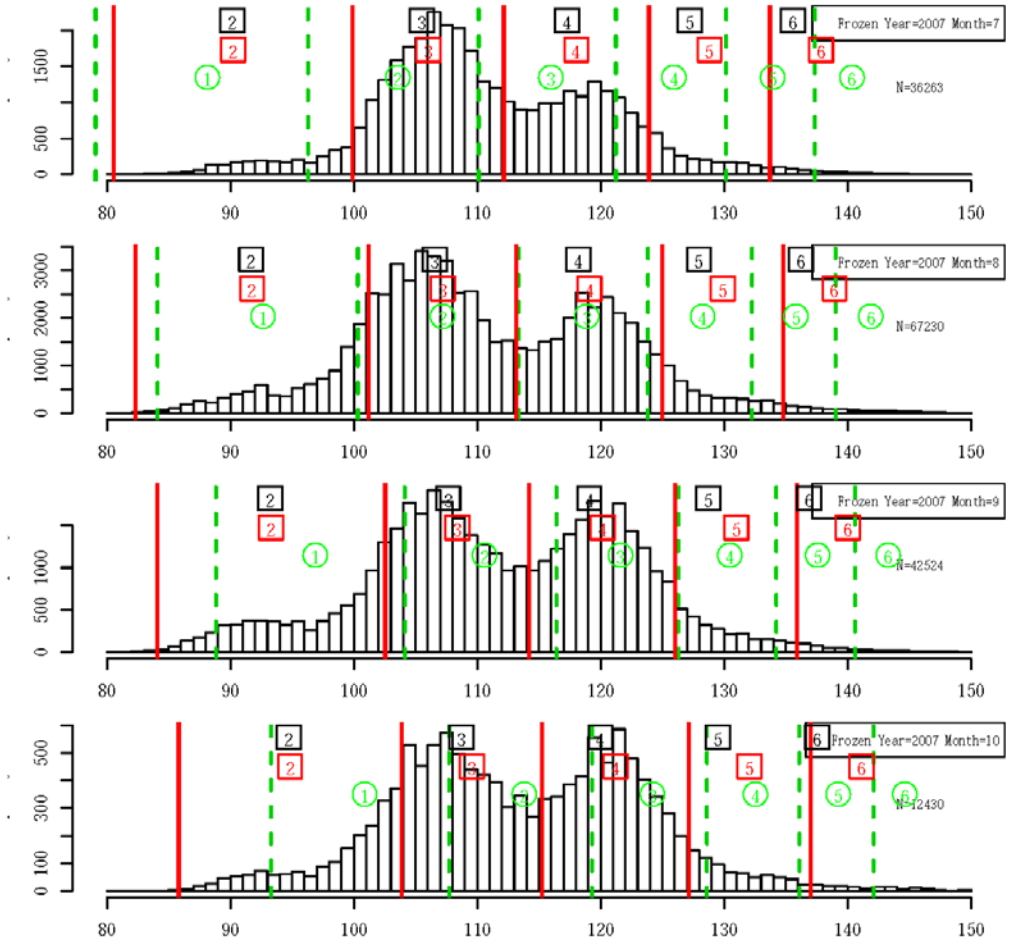


Fig. B4 (Continued, for frozen fish in 2007)

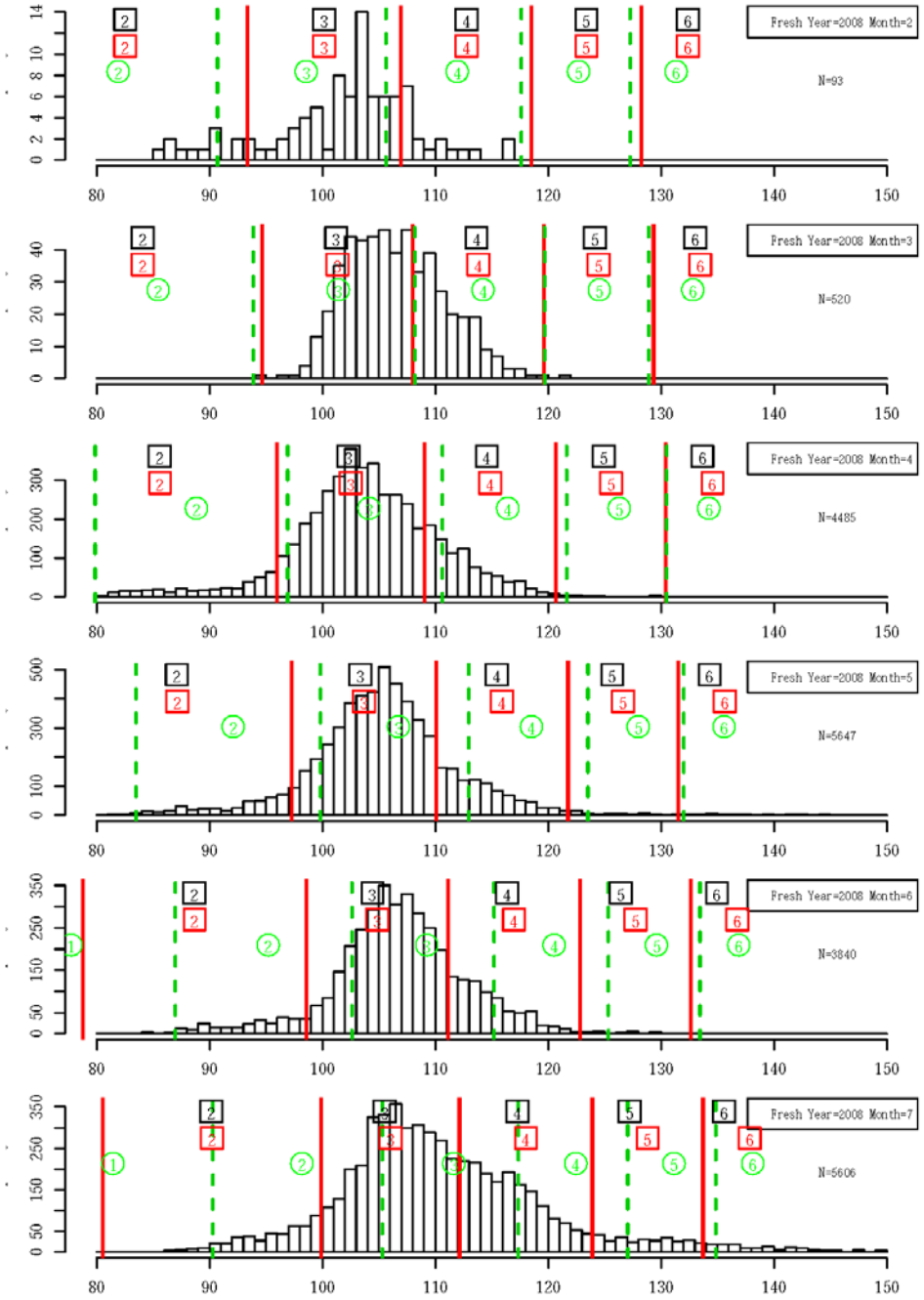


Fig. B4 (Continued, for fresh fish in 2008)

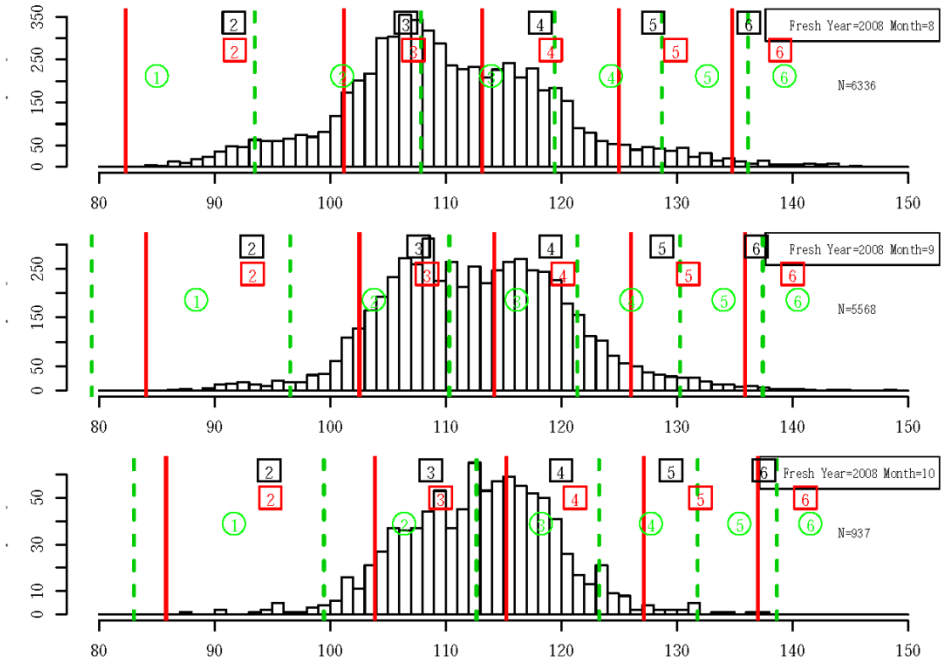


Fig. B4 (Continued, for fresh fish in 2008)

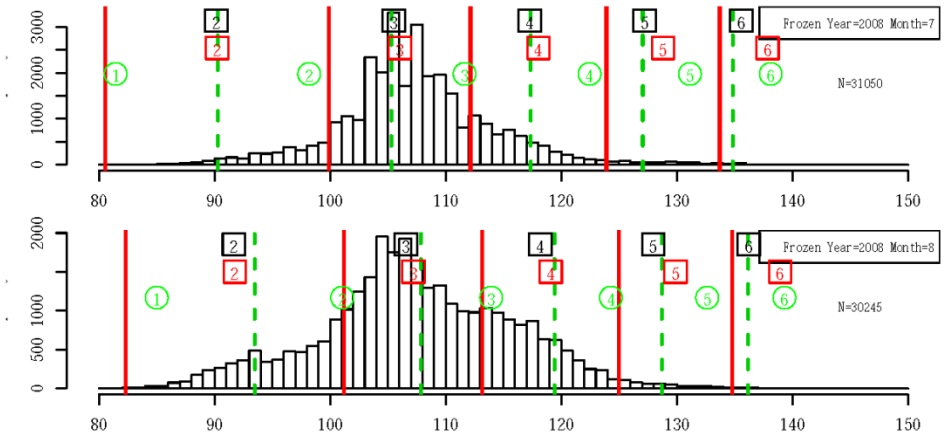


Fig. B4 (Continued, for frozen fish in 2008)

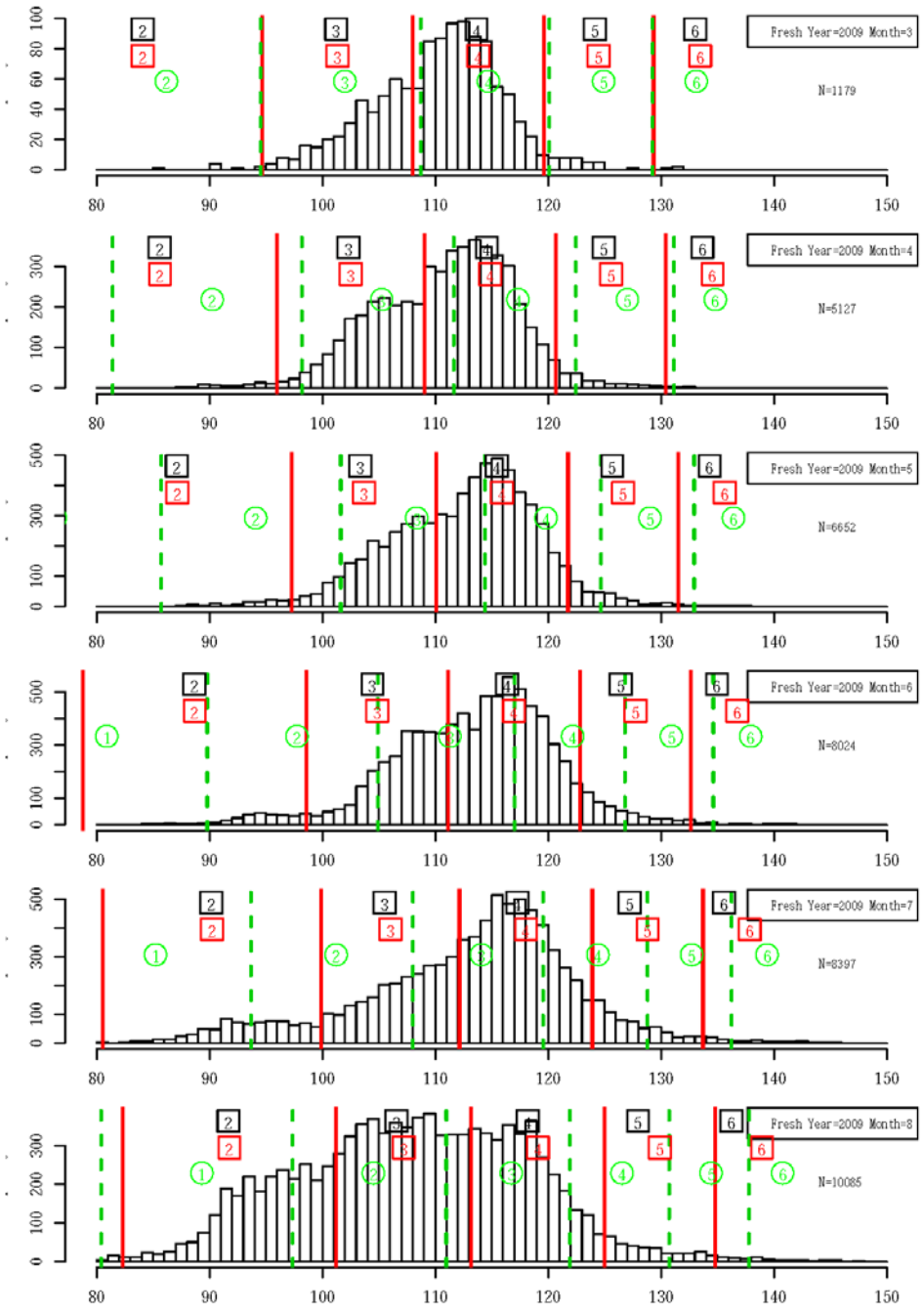


Fig. B4 (Continued, for fresh fish in 2009)

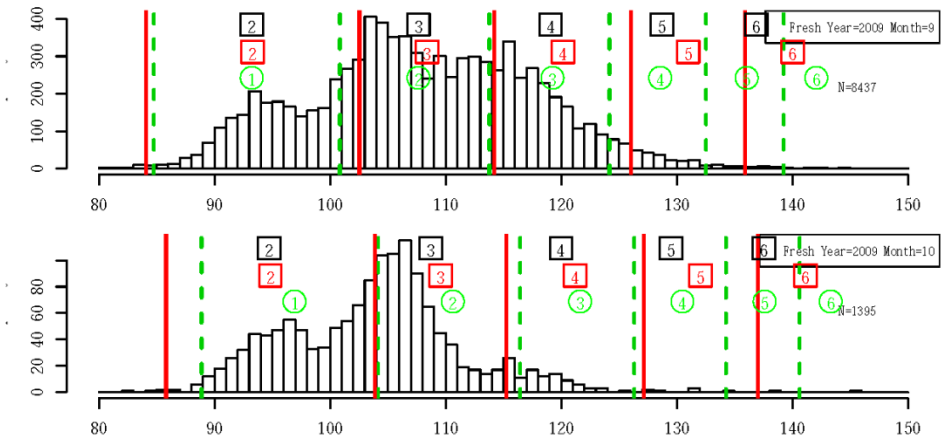


Fig. B4 (Continued, for fresh fish in 2009)

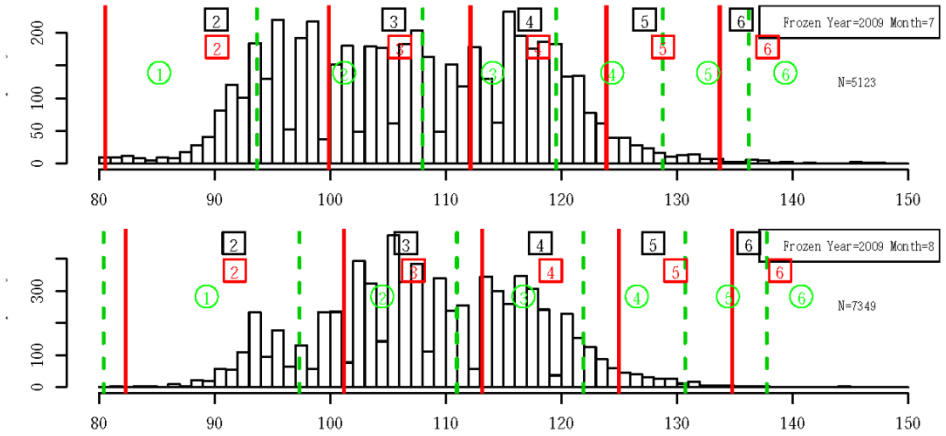


Fig. B4 (Continued, for frozen fish in 2009)

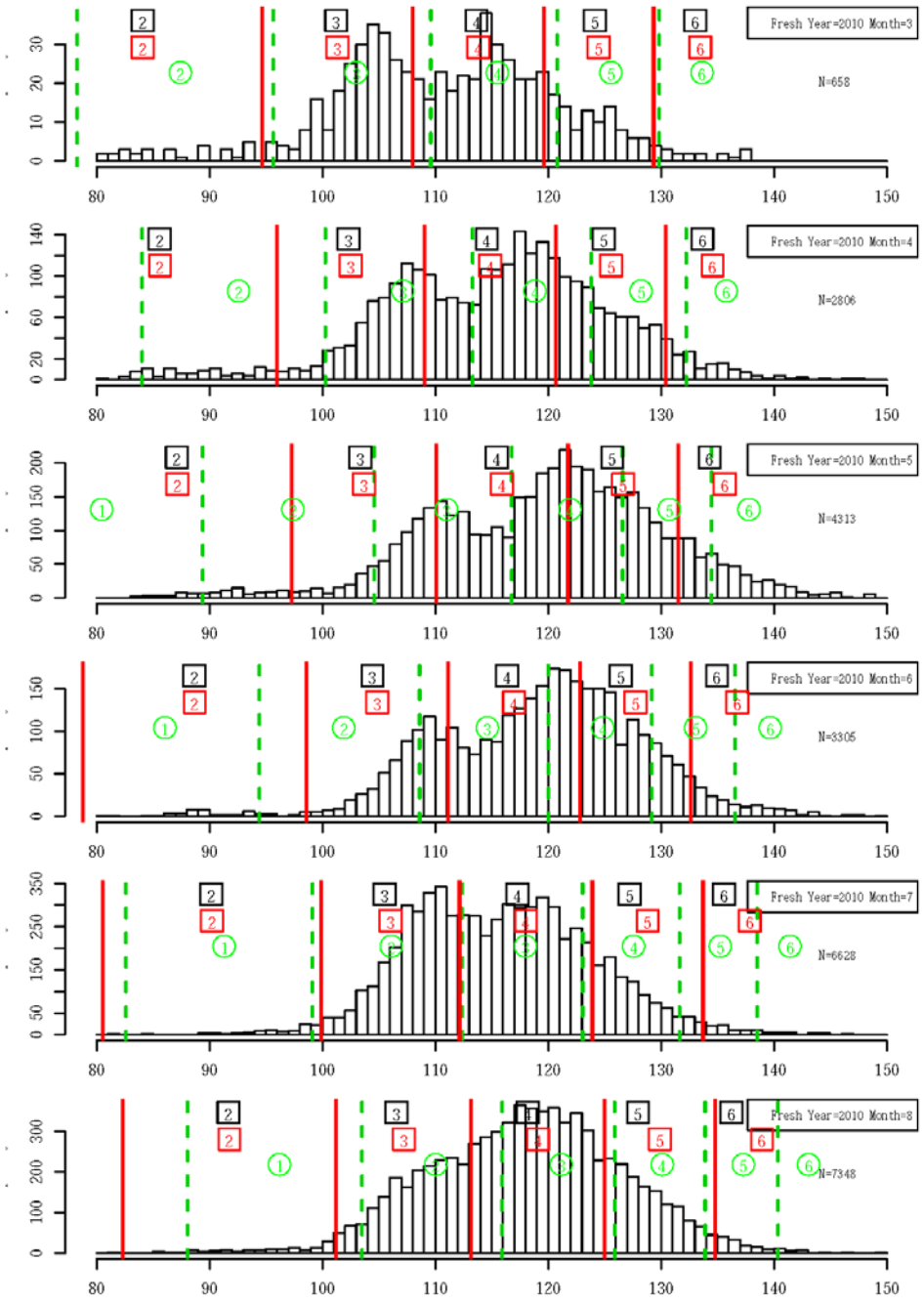


Fig. B4 (Continued, for fresh fish in 2010)

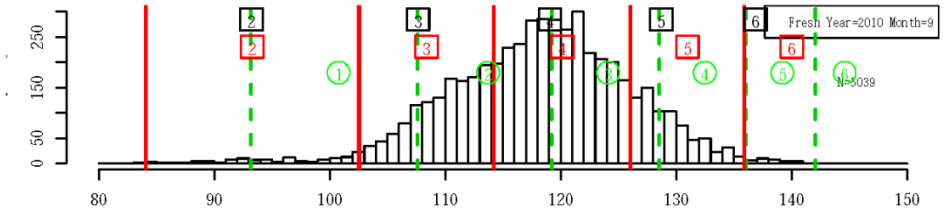


Fig. B4 (Continued, for fresh fish in 2010)

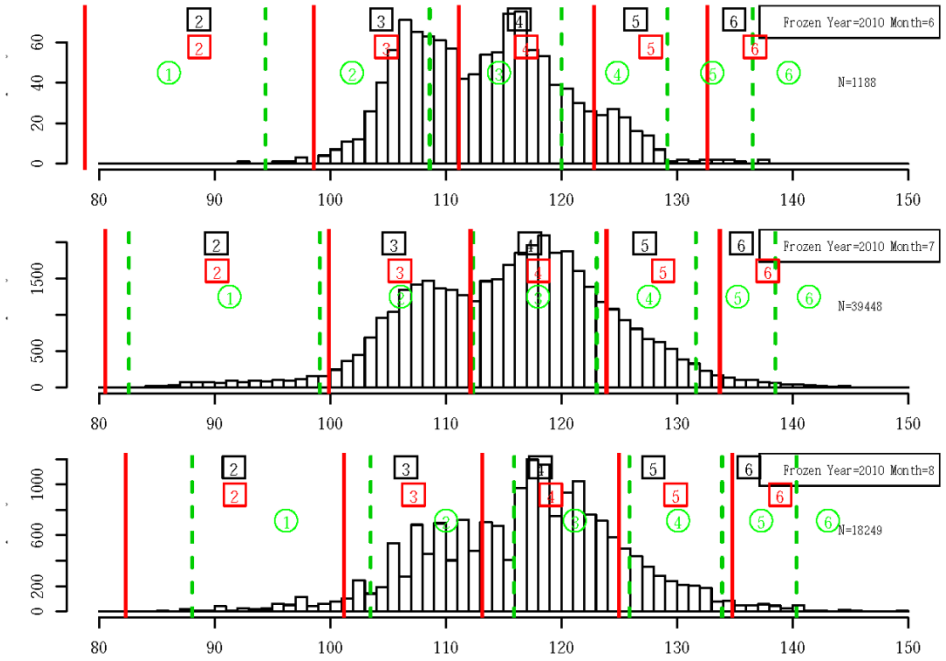


Fig. B4 (Continued, for frozen fish in 2010)

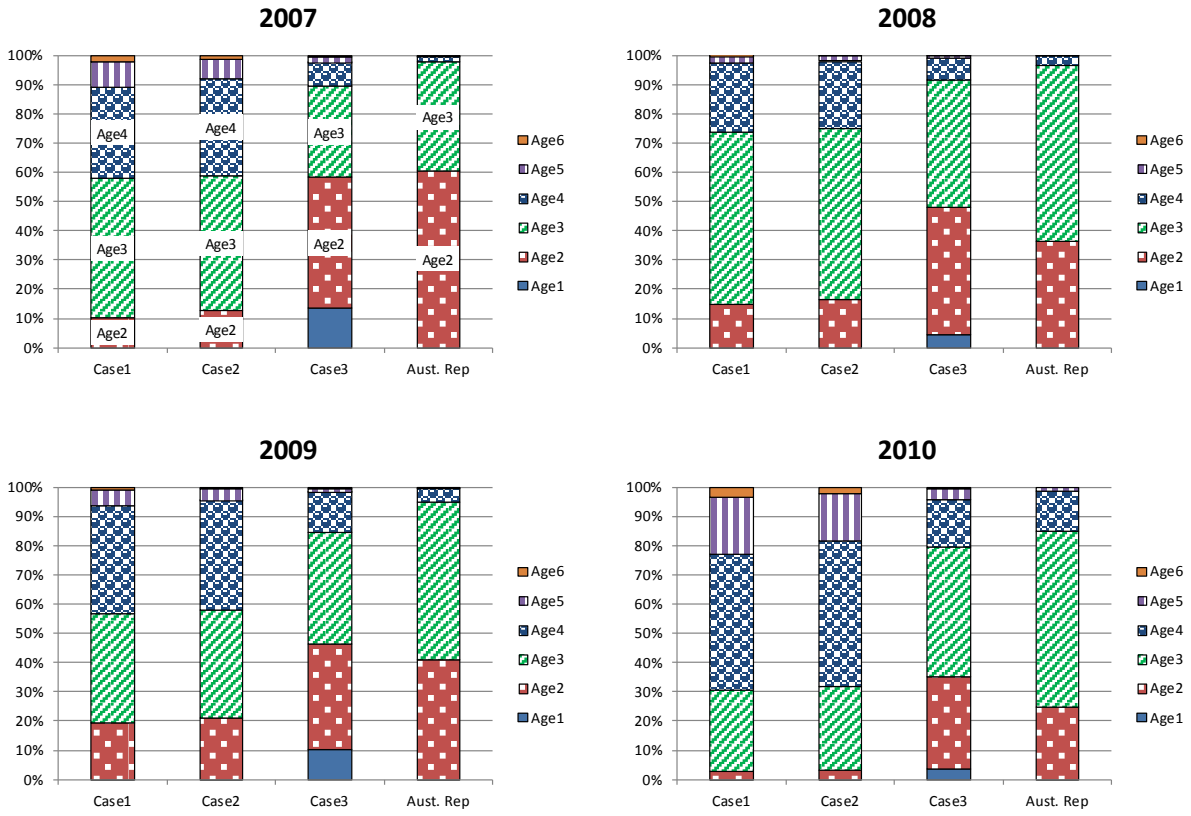


Fig. B5 Age compositions estimated by the age slicing method.

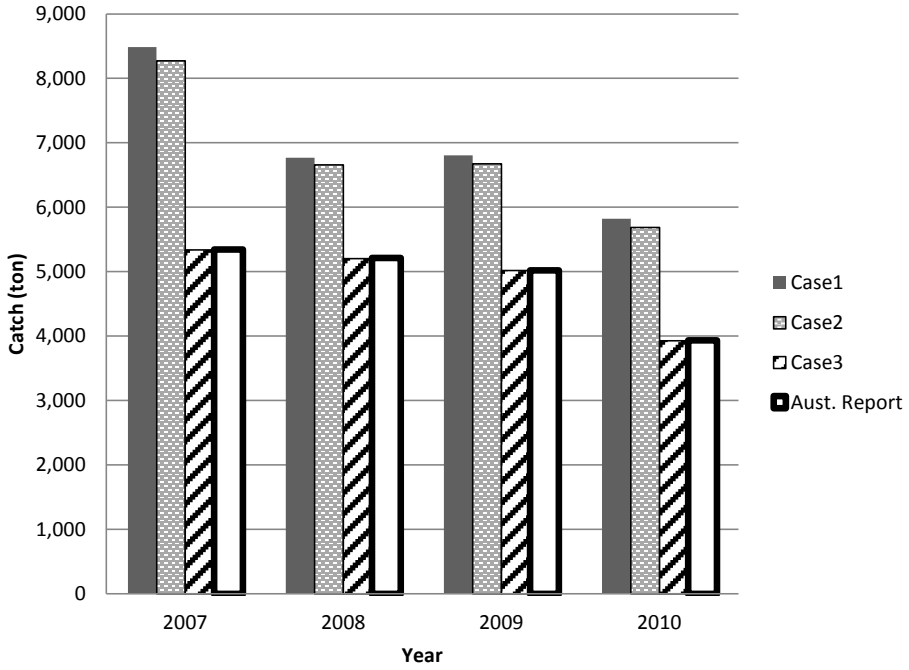


Fig. B6 Estimated total catch of Australian purse seine by the age slicing method.

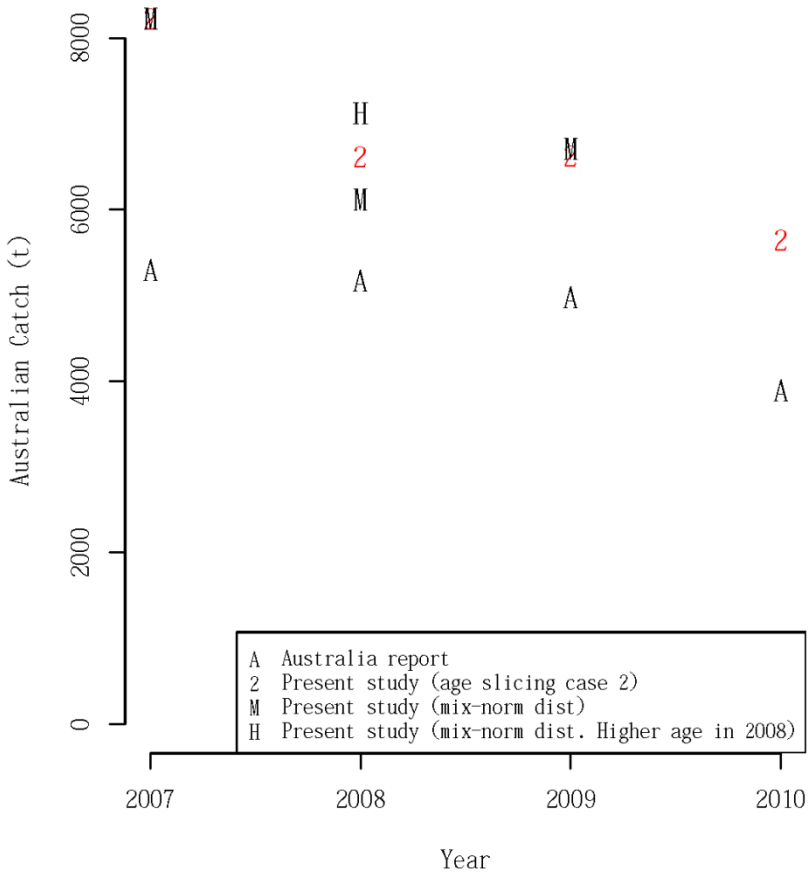


Fig. B7 Comparison of estimated catch of Australian purse seine between analysis1 and analysis 2.