Estimation of growth in farmed Southern Bluefin Tuna using the CCSBT conventional tagging data

CCSBT 通常標識放流データを用いた蓄養ミナミマグロの成長率の推定

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要約

2001-2007 年の CCSBT 標識放流事業にて通常標識を装着・放流されたミナミマグロについて、放流後 30 日以内に豪州まき網により採捕され、畜養された後に養殖業者から再捕報告された 141 尾の成長率を計算した。CCSBT 標識データベースに記録された放流時の体長から蓄養前の重量を推算し、蓄養後の重量と比較することで蓄養期間中の体重増加率を求めた。その結果、2 歳魚では平均 161 日間で 1.8±0.4 倍（平均±標準偏差、以下同じ）に体重増加した一方で、3 歳魚では平均 165 日間で 1.5±0.3 倍、4 歳魚以上では平均 195 日間で 1.4±0.3 倍にしか成長しないものと推定された。標識魚と非標識魚の蓄養後の体長-体重関係より、標識の有無の肥育への影響は少ないものと考えられた。今回推定された成長率と比べ、豪州が TIS で報告した成長率は非現実的に過大である。

Summary

We calculated the growth increments of SBT which were tagged in the CCSBT tagging program, caught by purse seine within 30 days of tagging, and then farmed in a fish pontoon. The CCSBT tagging database includes tag/recapture data for 8842 SBT which were tagged over 2001-2007 and reported from tuna farms. Among the 8842 SBT, 141 individuals, which were caught by purse seine within 30 days of their tagging, are used for present analysis. For our calculations of the growth increments, the initial weight was estimated from the body length at tagging, and the final weight was the value reported from the farming pontoons. The results indicated a growth increment through farming as a multiplicative factor of 1.8±0.4 (average ± 1SD) for age 2 fish (the average period in the farm for these tagged fish was 161 days), 1.5±0.3 for age 3 fish (165 days), and 1.4±0.3 for ≥ age 4 fish (195 days). A comparison of length-weight relationships suggests that fattening of farmed SBT is scarcely-affected by the presence or absence of tag. The analysis concludes that growth increments which were reported by Australia in their Yearly TIS Farm summary were unrealistically overestimates.

1. 緒言 Introduction

オーストラリアにおけるミナミマグロの蓄養は 1991 年に始まった（Hobsbawn et al., 2008）。現在、蓄養原魚は豪州大湾においてまき網により漁獲され、曳き舟によってポートリンカーンの蓄養生簀へ移送されている（Phillips and Findlay, 2008）。当初は年間 20 トンの活け込みに留まっていたが、1999 年には 5000 トンに達し、現在は豪州のミナミマグロ漁獲割当量の大半を占めている（約 5200-5300 トン）（Hobsbawn et al., 2008）。豪州は 1997 年以降、年間 6000-9000 トンのミナミマグロを刺身・寿司用の食材として日本に輸出しており、その大部分は蓄養魚である。

豪州は Yearly TIS Farm summary において、2002-2007 年の蓄養場における成長率は 1.896-2.205 で推移したと報告している。この成長率の正確性を検証するためには、蓄養開始・終了時の魚体サイズを正確に測定するべきであるが、水中で魚体サイズを測定できるステレオビデオカメラ（Phillips et al., 2008）は商業生簀に未だ導入されていない。また、個体毎の成長追跡に使用でき得る Tag Seeding での放流・再捕魚体サイズは商業的機密性の問題により公開されていない（Anon. 2006）。

個体別の蓄養場での成長を追跡する代替のデータとして、豪州大湾で行われていた CCSBT の SRP タギングでの標識・再捕時魚体サイズデータがある。2001-2007 年に実施されていた標識放流では、放流海域と豪州のまき網漁獲海域が極めて近く、放流直後に再捕され蓄養されたのちに回収報告された魚体が複数存在する。本文書では CCSBT 標識放流データベースからこれらのデータを抽出し、豪州の蓄養場での成長率を推定した。

Farming of southern bluefin tuna (SBT) has been conducted since 1991 in Port Lincoln, South Australia (Hobsbawn et al., 2008). Recent tuna farming involves purse seining the schools of SBT in the Great Australian Bight (CCSBT Statistical area 3), transferring them to floating pens, towing the pens and finally transferring the fish to farm pontoons (Phillips and Findlay, 2008). The first trial farms in the earliest years fattened about 20t of SBT, and recent commercial farms have cultivated 5200-5300t SBT (Hobsbawn et al., 2008). In recent years, Japan imported about 6000t-9000t SBT per year from Australia, and most of those SBT were farmed fish.

Australia reported in the “Southern Bluefin Tuna Trade Information Scheme Yearly Farm Data Summary” that the growth increment through farming was a multiplicative factor of 1.880-2.205 over 2001-2008. To validate this reported growth amount, the fish size before / after farming need to be monitored without sampling bias. Size data collected during the tag seeding experiments might include useful information to inform this; however these data have not been available for CCSBT for analysis for reasons of commercial confidentiality (Anon. 2006). Australia has emphasized the benefits of availability of the stereo video camera to measure the individual fish size under water (Phillips et al., 2008); however such a camera system has not as yet been introduced in the commercial farm pontoons.

As alternative information to address the growth increment during farming, there are some size data for CCSBT SRP tagged fish which were recaptured by purse seine near immediately after tagging in Great Australian Bight, and reported again after farming. These data were archived in the CCSBT tagging database, and all CCSBT members can access them. In this document, we estimated the farming growth increment using these individual size data over the period 2001-2007.

2. 材料と方法 Materials and methods

CCSBT 標識放流データベースによると、2001-2007 年に CCSBT-SRP タギングによって 38813 尾のミナミマグロが豪州大湾より標識放流されている。そのうち 8842 尾は豪州まき網により漁獲され、蓄養場の養殖生簀から再捕報告された。分析には、それらの再捕データから、以下の基準を満たす個体（141 尾）を抽出し使用した（Fig. 1)。

- 標識放流後 30 日以内に、まき網で漁獲され蓄養される。
- 蓄養期間（まき網で再捕されてから蓄養場で報告されるまで）が 365 日を越えない。
- 放流時の体長および回収時の体重（全体 or 製品重量）の不明なデータを除く。

まず、既往の天然魚の体長-体重関係式（Robins 1963）と放流時の体長から、放流時の全体重量を推定した。次に、蓄養終了時の全体重量を各々の個体について抽出した。蓄養終了時の全体体重が無い個体については、豪州で公式に使用されている変換式（製品重量*1.12+1（kg)）を用いて推定した。推定された放流時/蓄養終了時の重量から、下式に基づき体重増加率を求め、年齢群別に比較した。個体ごとの年齢は、放流時の体長に CCSBT で使用されている月別体長-年齢関係式を当てはめ推定した。体長に対する年齢の境界は以下のようになった ; 87cm 未満は 2 歳以下、87-103cm は 3 歳、104cm 以上は 4 歳以上。

増加率 ＝ 蓄養終了時の重量 / 放流時の重量

さらに豪州蓄養場から再捕報告された全標識魚（2001-2007 年）の蓄養終了時の体長-体重データを、既往の天然魚の体長-体重関係式（Robins 1963）および、日本政府により収集された豪州から輸入される生鮮蓄養みなみまぐろの体長-体重データと比較することで、蓄養魚、天然魚、および標識魚の体長-体重関係の相違を検討した。

The CCSBT tagging database, indicates that 38813 SBT individuals were tagged in the Great Australian Bight during the CCSBT SRP tagging program over 2001-2007, and 8842 of those were purse seined with data reported from the farming pontoons after fattening. We extracted 141 SBT individuals from the tag-recapture data in this database to estimate the growth increment during farming under the following conditions (Fig. 1);

- Purse seined within 30 days after tagging.
- Fattening period (from recapture date by the purse seine to reported date at farming pontoons) was no more than a year.
- Body length data at tag and release are available.
- Body weight data after fattening are available.

First, we estimated the initial weight (whole body weight at the time of tagging and release) from the body length (fork length) based on the length-weight relationship for young wild fish in Robins (1963). Secondly, we obtained the final weight (whole body weight after fattening) for the individual fishes from the database. For the data without whole body weight, we estimated this from processed weight by multiplying 1.12 and adding 1kg. This conversion formula has been used to estimate the total catch weight taken by the Australian fishery (CCSBT Secretariat 2008). From these estimated initial / final weights, we calculated the growth increment according to the equation below. These growth increments were compared using Welch's one-way test for each age group. The ages of SBT were estimated using the monthly body length at age relationships which was used in CCSBT. According to this method, the ages of SBT were sliced as follows; <87 cmFL for age $\leq$2, 87-103 cmFL for age 3, $\geq$104 cmFL for age $\geq$4.

$$\textit{Growth increment} = \textit{final weight} / \textit{initial weight}$$

In addition, we calculated the length-weight relationship for tagged fish after farming over the period 2001-2007 by using the least squares method, and compared it with the previous relationship for wild fish (Robins 1963). The difference in length-weight relationships after farming between the tagged fish and untagged fish was also compared. Body size data (length and weight) of untagged fish after farming were collected from the importer by the Fisheries Agency of Japan.

3. 結果 Results

分析に供された標識再捕個体は、2002年12月-2007年1月に南緯32.1-34.7度、東経131.9-134.8度にて放流された(Fig. 2)。当該魚は放流後平均15.4日で豪州まき網により漁獲され、平均165.8日間養殖場にて蓄養されていた。その放流時の体長は平均91.3cm（最小69cm、最大120cm）であり、同海域で放流された全個体と比べて、体長90cm以上の個体が多かった（Fig. 3)。再捕個体の放流時の推定体重は平均16.1kg、蓄養終了時の全体重量は平均25.4kgである。したがって、放流から蓄養終了までの体重増加は平均1.6倍（標準偏差±0.4、最大3.1、最少0.7）と推算された（Table 1)。体重増加率には年齢間（放流時年齢2歳以下、3歳、4歳以上）で有意な差が認められ（Welch's ANOVA P<0.001 Fig. 4)、若齢個体ほど増加率が大きい傾向がみられた。

標識魚の蓄養終了時の体長-体重関係をFig. 5に示す。最小二乗法により推定された体長-体重関係式とRobins（1963）による式との比較により、蓄養魚は天然魚よりも体長あたりの体重が重いことが示された。また、標識魚は非標識魚と比べて120cmFL以上の大型魚で重量が軽い傾向が有るものの、標識魚が多く回収されている120cmFL以下では体長-体重関係に大きな差は見られなかった。

The 141 tagged fish which we used in this analysis were released from the Great Australian Bight (S32.1-34.7, E131.9-134.8) during the period December 2002- January 2007 (Fig. 2). They were purse-seined within an average of 15.4 days after tagging, and fattened in the farming pontoons for an average of 165.8 days. Their fork length at the time of tagging was an average of 91.3 cm (minimum 69 cm, maximum 120 cm), which was larger than that of all tagged fish; fork length of most frequently released SBT in same area was 70-80 cm (Fig. 3). Estimated individual weight at the time of tagging was an average of 16.1 kg, and the reported weight after farming averaged 25.4 kg (Table 1). Based on these data, the average growth increment was estimated as a multiplicative factor of 1.6 (standard deviation 0.4, minimum 0.7, maximum 3.1). Significant differences by age group were found in Welch's one-way test for the growth increment (P <0.01); the younger age group had a larger growth increment than the older age group (Fig. 4). Fig. 5 shows the relationships between the fork length and body weight of tagged fish and untagged fish after farming. We estimated length-weight curves using the least squares method to be "Log_{10}Weight= -3.45301+ 2.42584* Log_{10}Length" for tagged fish and "Log_{10}Weight= -4.275188+ 2.832175* Log_{10}Length" for untagged fish. When compared to the formula of Robins (1963) for wild fish, these formulae showed that the farmed fish had heavier body weights than the wild fish. Untagged fishes tend to be heavier than tagged fishes over 120 cmFL; however there were no substantial differences evident in comparing these length-weight relationships for smaller fishes (e.g. under 120 cm FL).

4. 考察　Discussion

今回の分析で使用した標識魚には、放流時の体長で 90-100cmFL（3 歳）にモードが見られた。同海域で放流された全標識魚には 70-80cmFL（2 歳）にモードが見られることから、豪州大湾では 2 歳よりも 3 歳以上のミナミマグロがまき網により狙われていると推察された。

標識魚のデータを使用している以上、結果の解釈にあたり標識による魚体への影響を無視することは出来ない。かつて Hampton（1986）は、ミナミマグロ野生魚の標識放流/回収データから、標識魚が非標識魚と比べて痩せていることを示した。その結果に基づくと、標識魚は非標識魚よりも 5-10%程度重量が軽いことが示唆される。しかし、今回、蓄養後の体長-体重関係を標識魚と非標識魚で比較すると、標識魚は体重にばらつきが見られるものの、大型個体を除くと、非標識魚に比べ極端にやせた個体が多いわけではなく、野性魚と比べて肥満していることが示された。すなわち、蓄養場という特殊な環境では、魚体の肥育に対し標識の有無による影響は小さいと解釈できる。

今回の標識魚の分析によると、蓄養期間において 2 歳魚では平均 161 日間で約 1.8 倍に体重増加した一方で、3 歳魚では 165 日間で 1.5 倍、4 歳魚以上では 195 日間で 1.4 倍しか増加しなかった。このような若齢個体の早い成長は、マグロ類に限らず多くの魚種で見られる普遍的な現象である（例えば大西洋クロマグロ（Gimenez and Garcia 2005）、大西洋マダラ（Bjornsson and Stelnarsson 2002）など）。

豪州政府が Yearly TIS Farm summary にて報告している蓄養魚の成長率は、最大で 2.205（2007 年）、最低でも 1.880（2008 年）であり、今回の分析で最も高い成長率を示した 2 歳魚の数値をも上回る（Table 2）。蓄養されているミナミマグロは 2 歳魚が主体ではなく、3 歳以上の個体が多数含まれる可能性が高い（Itoh and Sakamoto 2008）ことを考慮すると、豪州の報告している成長率は非現実的に過大である。

Tagged and recaptured SBT which were reported from farming pontoons had a dominant length mode around 90-100 cm FL (age 3) at the time of tagging. In contrast, fish which were tagged and released in the same area were mainly age 2. This difference suggests that Australian purse seiners targeted age 3 and older SBT in the Great Australian Bight.

Since we use tagging data to analyze growth increments, we must consider the effect of the tagging on the body condition. In the early 1980s, Hampton (1986) analyzed the catch data for wild tagged/untagged SBT and reported that tagged fish were thinner than untagged fish. Based on the comparison of condition factors in his results, we can infer that tagged fish had a 5-10% lighter body weight than untagged fish. On the other hand, based on the our comparison of the length-weight relationships for tagged/untagged SBT after farming, both tagged fish and untagged fish in the farming pontoon were similarly fatter than wild fish except for the larger sized fish (e.g. over 120 cm FL). This result suggests that fattening of farmed SBT is scarcely-affected by the presence or absence of a tag under certain circumstances such as those associated with a farming pontoon.

In the present analysis, based on the size data for tagged fish, the weight of age 2 fish increased by a multiplicative factor of 1.8 for an average of 161 days of farming, age 3 fish increased by a factor of 1.5 (for 165 days), and age 4 and older fish increased their weight by a factor of 1.4 (for 195 days) on average. Greater growth of younger (and smaller) fish is commonly observed in not only tuna species but also other fish (e.g. Atlantic Bluefin tuna (Gimenez and Garcia 2005), Atlantic cod (Bjornsson and Stelnarsson 2002)).

According to the Yearly TIS Farm summary, farming growth increments for recent years have reflected multiplicative factors of up to 2.205 (in the 2007 farming season), and at least 1.880 times (in the 2008 farming season). These values are higher than the estimated growth increment for age 2 fish in our analysis (Table 2). Given that farmed fish were not mainly age 2, but possibly older than age 3 (Itoh and Sakamoto 2008), it seems very likely that the growth increments which were reported by Australia were unrealistically overestimates.

Reference

Anon. 2008 Report of the Thirteenth Meeting of the Scientific Committee. 81p

Bjornsson, B. and A. Stelnarsson. 2002 The food-unlimited growth rate of Atlantic cod (*Gadus morhua*). Canadian Journal of Fisheries and Aquatic Sciences 59, 494–502.

CCSBT Secretariat 2008 Secretariat Review of Catches CCSBT-ESC/0809/06

Gimenez, F., and B. Garcia. 2005 Growth, food intake and feed conversion rates in captive Atlantic Bluefin tuna (*Thunnus thynnus* Linnaeus, 1758) under fatting conditions. Aquaculture Research 36, 610-614

Hampton, J. 1986 Effect of tagging on the condition of Southern Bluefin Tuna, *Thunnus maccoyii* (Castlenau). Australian Marin and Freshwater Research 37, 699-705

Hobsbawn, P. I., K. Phillips, and G. Begg. 2008 Australia's 2006–07 Southern Bluefin Tuna Fishing Season. CCBST-ESC/0809/SBT Fisheries – Australia

Itoh, T. and T. Sakamoto. 2008 Analysis on age composition of southern bluefin tuna used for farming. CCSBT-ESC/0809/39

Phillips, K. and J. Findlay. 2008 Southern bluefin tuna fishery, In: Larcombe, J., Begg, G. (eds) 2008, Fishery Status Reports 2007: Status of fish stocks managed by the Australian Government. Bureau of Rural Sciences, Canberra, Australia. pp 93-102.

Phillips, K., V. B. Rodriguez, E. Harvey, D. Ellis, J. Seager, G. Begg, N. Honda, K. Shibata, J. Hender. 2008 Assessing the accuracy and precision of stereo-video and sonar length measurements of southern bluefin tuna (*Thunnus maccoyii*) CCSBT ESC/0809/12

Table 1 Growth increments which have been estimated from the size data from SBT which were tagged in CCSBT tagging program, caught by purse seine within 30 days of tagging, and then farmed in a fish pontoon.

		≤ Age 2	Age 3	≥ Age 4	Total
Number of fish		48	83	10	141
Fork length at the time of tagging (cm)	(Average)	79.08	95.78	112.10	91.26
	(± S.D.)	4.43	3.63	5.84	10.51
Fork length at the time of harvest (cm)	(Average)	92.22	106.63	121.78	102.65
	(± S.D.)	10.99	6.69	6.24	11.89
Initial weight (kg)	(Average)	10.34	17.97	28.46	16.12
	(± S.D.)	1.66	1.95	4.35	5.36
Final weight (kg)	(Average)	18.8	27.42	40.16	25.39
	(± S.D.)	4.57	4.92	7.98	7.63
Fattening period (days)	(Average)	161.8	164.7	194.6	165.8
	(± S.D.)	76.83	60.57	62.39	66.68
Multiplicative growth increment	(Average)	1.814	1.544	1.448	1.629
	(± S.D.)	0.41	0.28	0.30	0.36

Table 2 Comparison of multiplicative growth increments between the reported values in the yearly TIS farm data summary and the values estimated from tagged fish.

Year	Whole Wt. Growth increment in Farming (reported in yearly TIS Farm data summary)	Estimated Growth increment by the tagging data (Present analysis)
2001	1.954	
2002	1.896	
2003	1.944	1.629 (≤ age 2: 1.818) (age 3: 1.544) (≥ age 4: 1.448)
2004	1.948	
2005	2.125	
2006	2.025	
2007	2.205	
2008	1.880	

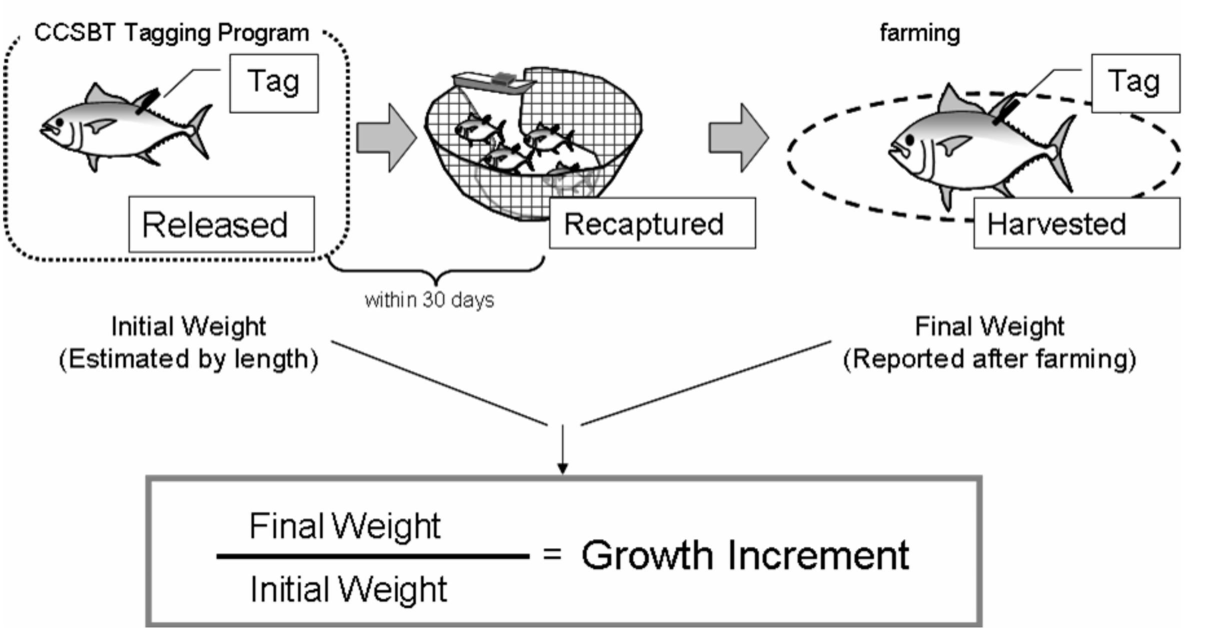

Fig. 1 Flow of analysis.

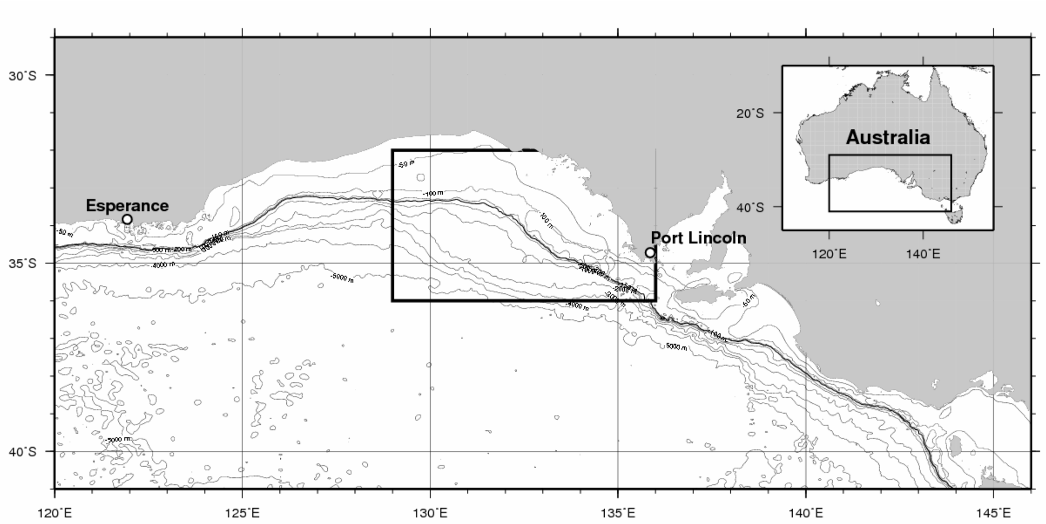

Fig. 2 Area of tagged and recaptured SBT for CCSBT conventional tags.

All fishes we used in this analysis were tagged and recaptured in the area surrounded by a black border line.

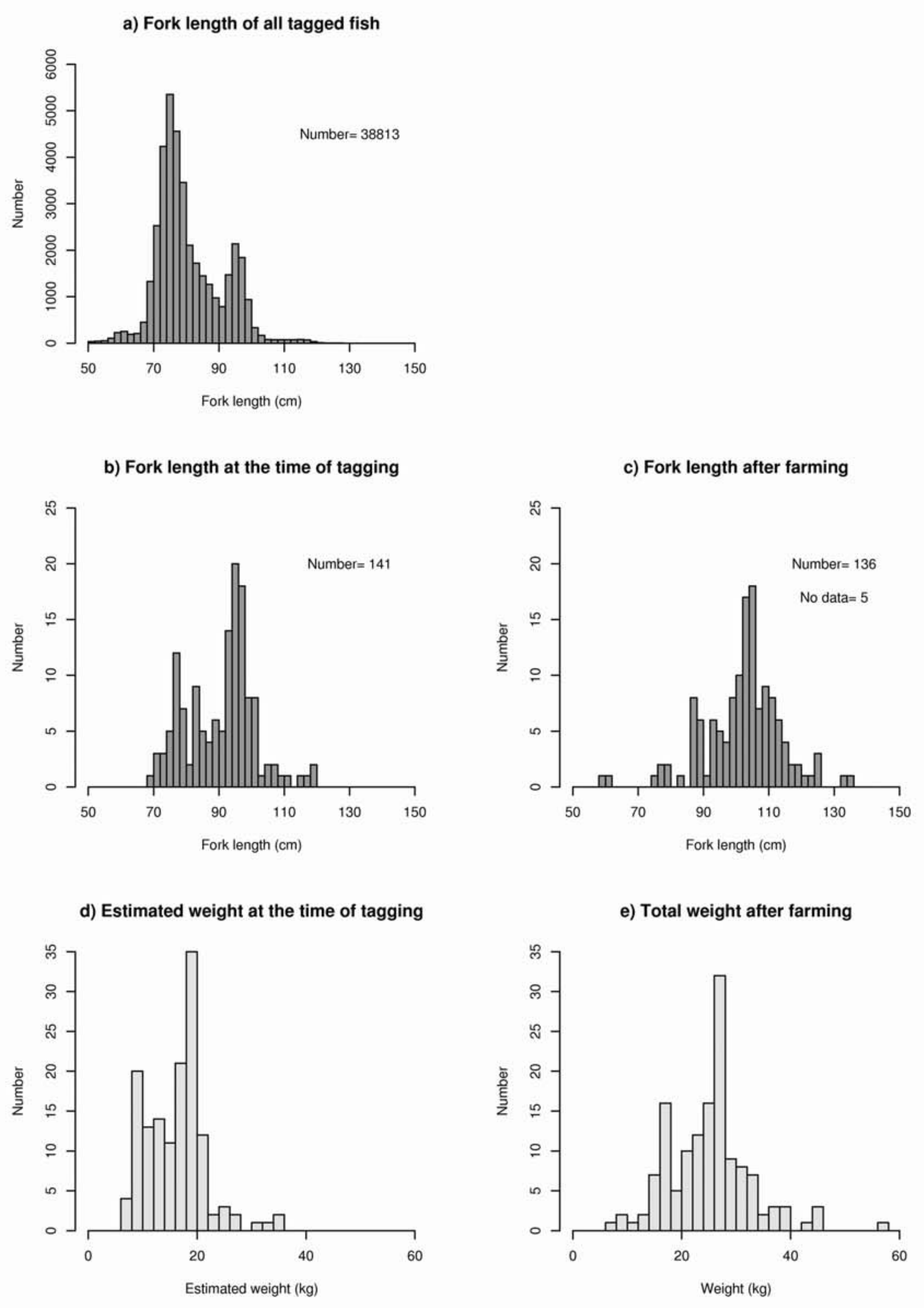

Fig. 3 Length / weight frequency distribution for tagged SBT

Fork length histogram of tagged fish at the GAB over 2002-2007 is shown in a). The histograms of the 141 tagged fish we used in this analysis are shown in b)-e); b) shows the initial fork length (fork length at the time of tagging), c) shows the final fork length (fork length after farming), d) shows the initial total weight which was estimated form the fork length at the time of tagging, and e) shows the final total weight reported from the farming pontoon.

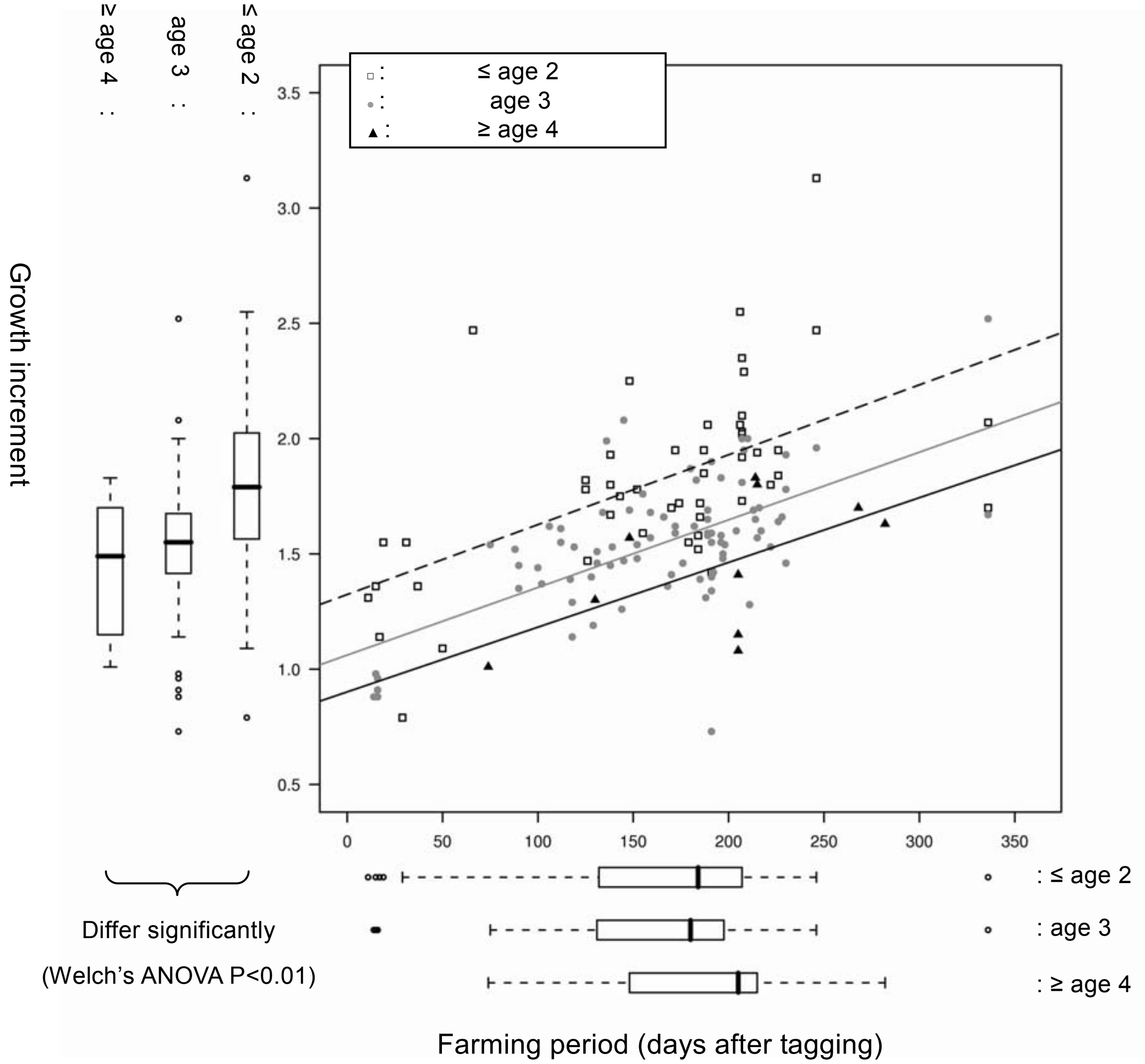

Fig. 4 Relationships between growth increment and farming period by age

Relationships between growth increments and farming period are plotted individually; squares show the age ≤ 2 data (n=48), gray circles show the age 3 data (n=83), and triangles show the age ≥ 4 data (n=10).

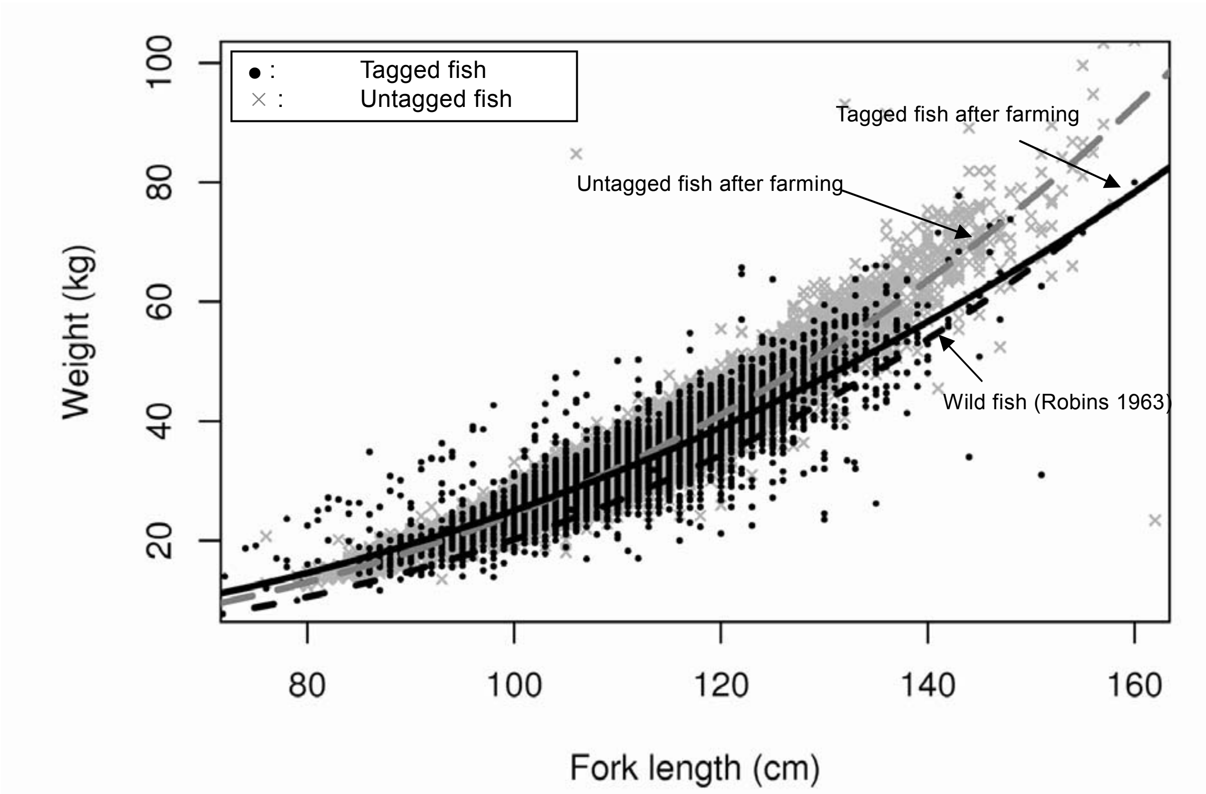

Fig. 5 Relationships between the fork length and body weight in tagged and untagged SBT after farming.

Individual size data after farming of tagged fish are plotted by black circles (n=6512), and the solid black line shows the curve fitted to those. Data for tagged fish were based on the CCSBT tagging database. Data for untagged fish are plotted using gray cross marks (n=30446), and the dashed gray line shows the curve fitted. Data for untagged fish were collected from the importer by the Fisheries Agency of Japan in 2008. The dotted black line shows the weight-length relationship for wild fish determined by Robins (1963).