

AUSTRALIAN SOUTHERN BLUEFIN TUNA
INDUSTRY ASSOCIATION LTD (ASBTIA)

A Review of Tuna Growth Performance in Ranching and Farming Operations

Brian Jeffriess
Australian SBT Industry Association

This work is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without prior written permission from the Australian Southern Bluefin Tuna Industry Association.

Requests and inquiries concerning reproduction and rights should be addressed to the
Australian Southern Bluefin Tuna Industry Association,
PO Box 1146
PORT LINCOLN
South Australia 5606
austuna@bigpond.com

Executive Summary

Background

Since 2008, Japan has annually submitted a number of papers (except 2013) to the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) Extended Scientific Committee (ESC) and other CCSBT meetings concluding there is unaccounted catch mortality in the Australian southern bluefin tuna (SBT) ranching process (ie the Australian surface fishery). While Japan appears to be accepting that Australia is declaring the correct number of SBT caught, their main point is that the method of estimating the weight (~3,100 fish @ 100 fish ≥ 10kg sample/tow) is potentially under-stating the weight into the pontoons.

Japan has also continually declined official requests to supply the data that they have used to make their calculations. This is despite Australia tabling data which shows Japan's conclusions as implausible when measured against the literature and benchmarks used in tuna farming in Japan, Europe, North America and Australia.

This uncertainty raised by the Japanese studies has led to the ESC deciding to run various scenarios of unaccounted catch in the Australian ranching catch in the operating model. Specifically, the Japanese have stated that the growth rates they have calculated in their studies for the SBT in the Australian farm sector are too high compared with wild SBT growth. This is despite official visits by the Japanese Government, industry and scientists (invited) and the CCSBT Quality Assurance Review (QAR) consultants in 2014 to study the weight sampling process and all other parts of the supply chain.

Issues

Again, Japan has repeatedly declined to provide the raw data used in its calculations so that it can be cross-checked. In a normal process this would be a necessary first step – particularly given the history of incomplete data in the CCSBT. Japan has indicated the source of the data is packing lists of Australian ranching exports to Japan. The chain of custody of these lists, which normally exist for fresh fish only, is that they were rarely provided to the Japanese agent and the product and lists remained the property of the Australian exporter. We would be pleased to authorise Japan to provide the lists so that the data can be confirmed.

More important is that the claims in Japan's papers have never been tested against the very large public data base on tuna ranching and farming. As one base literature source on the issue notes – "*Models for wild SBT are unlikely to be applicable to farmed fish.*" (Gunn et al. 2002).

Growth rates are much faster in intensive farms than in the wild. This is not surprising – because it is one of the main purposes of aquaculture, particularly where it can take advantage of seasonal growth, daily availability of higher quality feed, and an environment largely without marine predators.

Purpose

The aim of this review is to:

- (1) Outline some of the large literature base on growth in tuna farming and ranching, including the relevance of wild growth models to intensive and often seasonal livestock production.
- (2) Test the plausibility of Japan's conclusions against Feed Conversion Ratio (FCR) and other farming benchmarks.
- (3) Identify a solution to Japan's reluctance to provide the raw data behind their calculations.
- (4) Note other issues with Japan's methodology (e.g. using wild tagged fish data).
- (5) Raise topics for discussion and recommendations

Outcomes

Information derived from scientific literature suggests farm growth performance of Southern Bluefin Tuna (SBT) is comparable with the growth performance of Atlantic Bluefin Tuna and Pacific Bluefin Tuna (PBT) raised in farms in their respective areas. This is equally supported through an economic analysis and growth comparisons which do not support hypotheses on unaccounted catch mortality.

Recommendations

To measure fish size into farms, there is a need to review use of data from catch and release studies for the determination of length / age coefficients due to the stress as a direct result of handling and tagging. The resulting impacts could create incorrect length/age coefficients.

Many of the issues/assumptions raised by Japan have been sufficiently addressed in this review using research information from all tuna ranching growing regions. However, it may still be helpful for Japan to provide the raw data used in its calculations, for validation by the Australian ranching tuna industry.

If the CCSBT is to enter the field of tuna farming growth rates, it may be prudent for the CCSBT to seek external advice on issues within the ranching environment, as aquaculture science is a specialised field. One example raised in this paper is the importance of understanding the farm Feed Conversion Ratio (FCR) as a way of calibrating other data. In the case of FCR, the benchmarks are in the literature and the background data is often publicly available (see pages 15-16 of this paper).

Another example is the use in Japan's papers of the 1963 Robins conversions when the more recent literature shows growth at age has increased significantly. A further example is the use by Japan of annualised growth comparisons despite the specialised farm literature showing markedly greater growth in the seasonal growth in wild fish, and that this is utilised by Australian ranching.

Finally, the CCSBT may require advice on the Bioenergetics models which often reflect tuna farming parameters.

Contents

A REVIEW OF TUNA GROWTH PERFORMANCE IN RANCHING AND FARMING OPERATIONS	1
EXECUTIVE SUMMARY	3
BACKGROUND	6
GROWTH PERFORMANCE IN TUNA RANCHING AND FARMING	7
<i>MEDITERRANEAN ATLANTIC BLUEFIN TUNA (ABT).....</i>	<i>7</i>
<i>JAPAN PACIFIC BLUEFIN TUNA (PBT)</i>	<i>8</i>
<i>MEXICAN PACIFIC BLUEFIN TUNA (MPBT)AND OTHER TUNA</i>	<i>9</i>
<i>AUSTRALIAN SOUTHERN BLUEFIN TUNA (SBT)</i>	<i>9</i>
GROWTH PERFORMANCE IN WILD TUNA	10
APPLYING WILD TUNA STOCK MODELS DERIVED FROM CATCH AND RELEASE CONVENTIONAL TAGS.....	10
ASSUMPTIONS TO INFORM ANALYSIS OF UNACCOUNTED CATCH MORTALITY OF AUSTRALIAN RANCHED SOUTHERN BLEUFIN TUNA.....	11
<i>BACKGROUND TO THE RAW DATA USED IN THEIR CALCULATIONS</i>	<i>11</i>
<i>APPLICATION OF 141 TAGGED WILD FISH CAUGHT AND TRANSFERRED INTO FARMS</i>	<i>12</i>
<i>IMPACT OF ENVIRONMENTAL CONDITIONS ON GROWTH PERFORMANCE</i>	<i>13</i>
<i>BIAS IN AVERAGE WEIGHT SAMPLE TO DETERMINE VOLUME OF CATCH.....</i>	<i>14</i>
<i>THE ECONOMIC AND FEED CONVERSION RATIO (FCR) IMPLICATIONS BENCHMARKED INTERNATIONALLY</i>	<i>15</i>
DISCUSSION POINTS FOR PARTICIPANTS OF THE CCSBT EXTENDED SCIENTIFIC COMMITTEE.....	16
REFERENCES.....	17

Background

There are 3 types of Bluefin tuna growout systems:

1. Ranching of larger fish (input weight 8 – 200kg)

This process was developed in Australia in 1991 through a joint project between the Japanese Government and the Australian Southern Bluefin Tuna Industry Association (ASBTIA), and the technology transferred to the Mediterranean and Mexico in the early 2000s.

Wild Bluefin are captured live by purse seine, transferred underwater into specially designed tow pontoons, and towed to ranching areas. In general, tuna are maintained for 5-8 months except in specialist long-term grow-out areas including Croatia and Mexico.

The average size of wild capture fish has been approximately 15-20kg in Australia, 15-25kg in Mexico and 8-200kg in the Mediterranean.

2. Ranching in Japan (input weight 400g – 1kg)

The traditional method used in Japan is capturing small Bluefin with an average weight of 500g and then on-growing for a period of 3-4 years depending on geographical location.

3. Farming (hatchery raised)

Hatchery raised PBT have been commercially available in Japan since 2010 and now comprises one-third of total seed stock into all farms in Japan. This is farming in the true sense as stock is raised from the egg rather than the ranching approach in (1) and (2) above. It normally takes about 3 months for a hatchery fingerling to reach 500g.

The ranching growout strategy varies considerably between regions. In Australia, the fish feed immediately at a high level – up to ~10% of body weight/day at peak feeding times (Ellis, 2013). In other regions, the literature suggests a delay before higher feeding levels begin, and then not to the same level as Australia.

Growth performance in tuna ranching and farming

Mediterranean Atlantic Bluefin Tuna (ABT)

The following table depicts growth performance in Atlantic bluefin tuna *Thunnus thynnus*

Table 1. Summary of growth performance studies of Mediterranean Atlantic bluefin tuna, *Thunnus thynnus*

Reference	Conclusion
Kataviæ et al. (2001)	In a trial conducted in the Adriatic Sea over 17 months (June 1999-December 2000) the results showed a much faster growth in length and weight in farms than in the wild. For example, in the 85-120cm category (10-25kg) the monthly growth was 2.16cm and 2.42kg. This was despite an initial tagging mortality of 50%, plus 5% during the trial, indicating stress on all tagged fish.
Cort (2003)	Summer growth in wild ABT aged 1-3 years is 5-6 times more intensive than their winter growth.
Ticina et al. (2007)	ABT of 12kg reached a whole weight of 45kg after 18 months. In the same period tunas with an initial weight of 5kg increased their weight up to 25-30kg – normally achieved over 3 years in the wild.
Ticina et al. (2007)	Tuna reared from 4-8 months had higher SGR values than those reared for 17-20 months. In the shorter grow-out, the SGR values are mostly related to summer growth.
ICCAT (2009) SCRS report	Cage trials in Croatia (SCRS/2009/190) have confirmed the gain estimates applicable to small fish, with 10kg fish reaching 45kg after 18 months and a further doubling to 90kg after another 12 months.
Deguara et al. (2010)	A 4 month trial in Malta (February to June 2009) on 5-6 year old Atlantic Bluefin Tuna achieved a 43.5% increase in weight and an increase in length from 142.5 cm to 157.9cm. In the wild, such ABT age groups take over one year to gain that length.
ICCAT (2009) SCRS Report	Apparent growth gain in both length and weight of individual fish held in farms is much higher than observed for wild fish over a wide range of sizes.
Tzoumas et al. (2010)	<i>“the length of fish (ABT) in cultured conditions can grow faster than in the wild and have a big impact on the overall weight gain.”</i>
Galaz (2011)	In cages with just young tunas, growth is more important as the direct competition for food has been removed. Data suggests juveniles under 20kg originating from the Balearic Islands show significant weight increase reaching a SGR of 88.8 % in November (121 days).

Japan Pacific Bluefin Tuna (PBT)

The following table depicts growth performance in Japanese Pacific bluefin tuna *Thunnus orientalis*

Table 2. Summary of growth performance studies of Japanese Pacific bluefin tuna, *Thunnus orientalis*

Reference	Conclusion																																
Ikeda (2003)	<p>PBT at the Wakayama (Kinki University) research station stocked at 150-500g could achieve a weight of 50kg in 3 years.</p> <p>PBT at Okinawa of same input size could achieve 100kg in 4 years. Wild PBT are 30kg at 3 years, and 40kg at 4 years.</p>																																
Masuma et al. (2008)	Concluded farmed PBT exceeded growth of wild PBT																																
Goto (2014)	<p>The most recent data we have seen is where two trials with a trial manufactured feed and a baitfish control showed similar length and weight growth for both feeds. The manufactured feed results were:</p> <p>Trial One</p> <table> <tr> <td>Place</td> <td>Nagasaki</td> </tr> <tr> <td>Period</td> <td>16/6/13 to 16/12/13</td> </tr> <tr> <td>Water temp</td> <td>16-29°C</td> </tr> <tr> <td>Feeding</td> <td>Once/day for 6 days/week</td> </tr> <tr> <td>Feed rate</td> <td>1.5-2.0%BW/day</td> </tr> <tr> <td>FCR</td> <td>3.8</td> </tr> <tr> <td>Weight growth</td> <td>Start 16kg – end 33.5kg</td> </tr> <tr> <td>Length growth</td> <td>Start 89cm – end 113cm</td> </tr> </table> <p>Trial Two</p> <table> <tr> <td>Place</td> <td>Kagoshima</td> </tr> <tr> <td>Period</td> <td>7/11/13 to 26/5/14</td> </tr> <tr> <td>Water temp</td> <td>19-24°C</td> </tr> <tr> <td>Feeding</td> <td>Once/day for 6 days/week</td> </tr> <tr> <td>Feed rate</td> <td>1.5-2.5%BW/day</td> </tr> <tr> <td>FCR</td> <td>3.7</td> </tr> <tr> <td>Weight growth</td> <td>Start 9kg – end 18.5kg</td> </tr> <tr> <td>Length growth</td> <td>Start 77cm – end 98.5cm</td> </tr> </table>	Place	Nagasaki	Period	16/6/13 to 16/12/13	Water temp	16-29°C	Feeding	Once/day for 6 days/week	Feed rate	1.5-2.0%BW/day	FCR	3.8	Weight growth	Start 16kg – end 33.5kg	Length growth	Start 89cm – end 113cm	Place	Kagoshima	Period	7/11/13 to 26/5/14	Water temp	19-24°C	Feeding	Once/day for 6 days/week	Feed rate	1.5-2.5%BW/day	FCR	3.7	Weight growth	Start 9kg – end 18.5kg	Length growth	Start 77cm – end 98.5cm
Place	Nagasaki																																
Period	16/6/13 to 16/12/13																																
Water temp	16-29°C																																
Feeding	Once/day for 6 days/week																																
Feed rate	1.5-2.0%BW/day																																
FCR	3.8																																
Weight growth	Start 16kg – end 33.5kg																																
Length growth	Start 89cm – end 113cm																																
Place	Kagoshima																																
Period	7/11/13 to 26/5/14																																
Water temp	19-24°C																																
Feeding	Once/day for 6 days/week																																
Feed rate	1.5-2.5%BW/day																																
FCR	3.7																																
Weight growth	Start 9kg – end 18.5kg																																
Length growth	Start 77cm – end 98.5cm																																

Mexican Pacific Bluefin Tuna (MPBT) and other tuna

The following table depicts growth performance in Mexican bluefin tuna *Thunnus orientalis*

Table 3. Summary of growth performance studies of Mexican Pacific bluefin tuna, *Thunnus orientalis*

Reference	Conclusion		
Sylvia et al. (2002)	Growth performance of tunas over a 2.5 month period in water temperature 18-22 ⁰ C		
	Species (kg)	Start wt (kg)	Final wt
	PBT	45	70
	Bigeye (<i>Thunnus obesus</i>)	25-30	45
	Yellowfin (<i>Thunnus albacares</i>)	20-25	35

Australian Southern Bluefin Tuna (SBT)

The following table depicts growth performance in southern bluefin tuna *Thunnus maccoyii*

Table 4. Summary of growth performance studies of Australian Southern bluefin tuna, *Thunnus maccoyii*

Reference	Conclusion				
Gordon et al. (2006)	Examples from confidential feed research in 2002 showed the following growth performance				
	Days in culture	Start wt (kg)	Start length (cm)	Finish wt (kg)	Finish length (cm)
	173	16	95	30.13	108
	170	14.5	97	28.7	109
	174	26	112	45.3	120
	The growth achieved was despite high mortality levels as a result of tagging and an 18-day weaning period for manufactured feeds.				
Ellis (2013)	Specific Growth Rates in feed trials in 2005 were around 60% better than Atlantic Bluefin of the same size and age, and held for a similar period, as reported in Ticina (2007). This is despite noting a period of suppressed feeding in the SBT trials – apparently due to blood fluke infections (<i>Cardicola forsteri</i>).				

Australia had an intensive research program on development of alternative feeds (to wet feeds) in the 1990's and first half of the 2000's when the focus shifted to fish health. As a result there was no specific research on growth rates – but data on wet feed controls and on manufactured trials are available.

Growth performance in wild tuna

The Commonwealth Scientific Industrial Research Organisation (CSIRO) has completed various studies in wild SBT fishery growth and dynamics since the 1960's (Polacheck et al., 2004). A significant portion of this research has been based on tag and release data obtained by inserting conventional dart tags at the base of the second dorsal fin locking in the pterigiophores and recovered through fishing mortality. This information has been used to define age growth coefficients despite a rising amount of information suggesting tagging impacts on growth performance of southern bluefin tuna (Glencross et al., 2002; Gunn et al., 2002; Ellis, 2013), other tunas (Ticina, 2007) and other species of fish (Loftus et al., 1988; Keiffer et al., 1995; Phillip et al., 1997; Crozier and Kennedy, 2002; McLeay et al., 2002).

On a positive note, Hearn (1990) noted SBT grew from 3kg to 15kg in 10 months (tagged January/February) in the Great Australian Bight. According to Hearn, a high growth rate was most conspicuous in fish tagged in Jan/Feb and recovered 2-6 months later. This was supported by Glencross et al. (2002) who noted a one-year tag recapture growth performance of 3kg to 16.6kg.

The literature notes both:

- (1) The increase in SBT growth rates in recent decades. For example, “the increase in growth rates is substantial, so that a fish, on average, would have been expected to take four years to grow from 55 cm to 111 cm in the 1960s, but only three years to do so in the 1980s.” (Leigh & Hearn 2000)
- (2) There is a marked seasonal growth variation in SBT (Leigh & Hearn 2000). Utilising this strong seasonal growth is the foundation of the Australian ranching system.

Applying wild tuna stock models derived from catch and release conventional tags

Major problems exist when applying growth information derived from catch and release data obtained from wild or free roaming southern Bluefin tuna.

The first problem is the impact of tagging on obtaining robust information to determine growth. It has been demonstrated there can be a significant weight loss of 7-12% for tagged fish in the first month after release (Hampton 1986; Hearn, 1990). In another study PBT did not feed normally for approximately the first 30 days after release so that data for the first 60 days after tagging was excluded from an analysis of PBT feeding frequency and temperature preferences (Itoh et al, 2003). However, it has been reported tagged fish recover weight loss after a year at liberty and tagged wild fish in farm pens indicated no retardation in length growth after 150 days (Hearn and Polacheck, 2003). Quantifying age / growth coefficients is always going to be challenging for wild or free roaming fish as defining length at age is a direct relationship of tagging.

Whilst some authors have speculated fish in captivity will rebound or undertake a period of compensatory growth following tagging (Ticina et al., 2007; Ellis, 2012), the handling and tagging impact can be very significant. In two related but different studies SBT were observed to have no growth 5 weeks after tagging (Glencross et al., 2002) and mortality in one trial pontoon reached 37% and low food intakes as a direct result. This handling stress potentially had long lasting impacts on fish physiology whilst compromising growth performance (Gunn et al., 2002). The stress through handling and tagging resulting in high mortalities of tagged SBT was reported in another trial (Gordon et al., 2006). In one study Atlantic Bluefin tuna reported negative Specific Growth Rate (SGR) 44-53 days post tagging and no significant increase in condition factor compared with untagged fish (Ticina et al., 2007). These authors went on to state

“Consequently growth rates calculated on the basis of tag-recapture data probably underestimates overall growth performance of small BFT farmed in given conditions.”

To manage these tagging influences in growth and nutrition trials Ellis (2013) advises comparisons

should be made between the differences in treatments as opposed to absolute SBT growth performance.

Gunn et al. (2002) summarises further issues including

“Models for wild SBT are unlikely to be applicable to farmed fish for two major reasons. Firstly, the stocking and harvesting cycle involved in SBT aquaculture means that growth in the farming environment is generally measured on an intra-annual basis. Data used for standard growth curves, either gathered by direct ageing methods or from tagging experiments are generally collected over inter-annual time scales. This means that the magnitude of error acceptable from growth models based on inter-annual data may be too great for useful predictions of short-term growth. Secondly, the growth of wild fish is probably related to intra-annual variation in food availability, and migration costs dependent on different environmental conditions. Farm conditions are very different to those in the wild and may alter growth rates considerably via different consumption rates, possibly restricted activity levels and altered thermal conditions.”

Gunn et al (2002) found that the von Bertalanffy model did not perform well with the variance in the data being too great to obtain plausible parameter estimates. The relatively short time span of farm growth data restricts the usefulness of the von Bertalanffy in this situation as the variance in the data is too large relative to the growth being modelled. Furthermore, *“the parameter estimates of the von Bertalanffy growth function (VBGF) (used) were not plausible and the model predicted growth badly.”*

The bioenergetics models indicate the large degree to which tunas utilise energy for movement rather than growth, and why Food Conversion Ratios (FCR) are relatively high in tuna ranching compared with other fish. Gunn et al. (2002) notes:

“Tunas have generally been found to turn over energy at a high rate through continuous swimming for ram ventilation and through the need to cover large distances in order to find food in an uncertain and patchy pelagic environment.”

“it is possible that taking away the need for active foraging and the restriction of the cage significantly alters the activity pattern from those (compared with) those in the wild. This will undoubtedly alter the energy budget and growth of the fish.”

A bioenergetic model approach is now widely used in Australian tuna ranching operations to optimise growth and performance (Gunn et al., 2002; Ellis, 2013).

Assumptions to inform analysis of *Unaccounted catch mortality of Australian ranched southern bleufin tuna*

Background to the raw data used in Japanese calculations

The raw data used in Japan's calculations is a smaller issue than the on-farm literature base on growth, but there is a simple solution to allow the data to be provided.

Itoh et al. (2012) outlined the data used in its calculations as follows:

“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. 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.”

Data for which both length and weight information was available was (N=76,080 in 2007, N=57,233 in 2008, N=58,964 in 2009 and N=49,948 in 2010).

To understand the background to the data, it may be helpful to understand the supply chain for fresh and frozen Australian ranched SBT:

1. The Catch Documentation Scheme (CDS) was not implemented until 2010 so therefore reporting of length was not required in the 2007-2009 period.
2. Japan indicated in its early analyses that the data they were using was “Packing lists information from Japanese buyers.” (see CCSBT-EC/0610/35). The packing lists for fresh fish normally show only a total weight shipment. For frozen fish, a packing list consists of number of fish in weight categories.
3. For fresh shipments, the fish are actually owned by the Australian exporter so that any documentation was owned by the Australian company. What is referred to in documents such as CCSBT-EC/0610/35 as “Japanese buyers” are actually agents of the Australian company, not a buyer. These agents simply take a commission (normally 3.5%) on the sale.
4. Fresh SBT shipments are not randomly selected and are specifically chosen for the Japanese market and larger and higher conditioned fish are selected.
5. In discussions with fresh product agents, all have rejected that any documents they may have held have been supplied to anyone else. In addition length/weight data could not come from auctioneers who have no reason to know the length of individual fish or record this information.
6. The number of samples used by Japan in 2007 and 2008 is more than the number of fresh ranched SBT shipped to Japan in those years.
7. For frozen SBT, there are two channels:
 - a. Japanese freezer/reefer vessels handle the large majority of frozen fish. The fish are slung onto these boats in groups of 5-15 fish.
 - b. Some SBT are shipped via freezer container, particularly to smaller buyers who do not have the volume for a freezer boat.
8. The freezer boat process is that the SBT are harvested at the pontoons, gilled and gutted, and then taken to the freezer boat, then slung as above. Because the fish are then graded depending on size, quality and condition, a representative of the Australian company is always on the freezer boat. After finishing the final processing on the freezer boat, the SBT are then frozen.
9. To our knowledge, until 2014, there has never been any indication that fish were measured and they were seldom individually weighed by the frozen buyer, and even now it is normally only a small sample to monitor condition (eg the first 100 fish).

Japan’s reason for not supplying the raw data is that they may be breaching confidence with those agents in Japan, which handle Australia’s fresh SBT. However, because these Japanese companies are only agents, the data actually belongs to the Australian tuna ranching company.

Therefore, as the owners of the data, the Australian industry is pleased to provide the permission to Japan to provide it back to us for cross-checking.

Application of 141 tagged wild fish caught and transferred into farms

These fish were caught within 30 days of tagging with the average period between tag and catch being 15.4 days (Sakai et al., 2009).

Most of the literature on growth performance in intensive tuna production is based on tagged fish. The following estimated mean growth ratios have been produced (Sakai et al., 2009).

Age 2 – 1.818

Age 3 – 1.544

Age 4 – 1.448

The assumption in Itoh et al. (2014) is that tagged fish retain the *same or greater weight* from the point of tagging in the wild to entry into the farms.

This appears to be the opposite of the information presented in this review in respect to growth achieved by bluefin tunas worldwide. The information in the literature clearly shows the impact of tagging and handling in controlled research experiments focused on growth.

Impact of environmental conditions on growth performance

Itoh et al. (2014) note the following von Bertalanffy Growth coefficient K (VBKs) for various wild tuna species

SBT (ages 2-6)	0.219
Pacific BT	0.173
Atlantic BT	0.089
Bigeye	0.180
Yellowfin	0.557
Albacore	0.134

As reported in the Mediterranean, Mexican and Japan growth performance sections of this paper, growth in farms is dimensionally greater than these wild VBK's. Part of the reason is that the above VBK's are not seasonally based (Gunn et al., 2002), and cover a range of age groups with different growth patterns.

Itoh et al. (2014) note that different captive Pacific Bluefin growth rates in different farms in Japan could be related to higher water temperatures and compares the temperatures in Japan with the lower ones in Port Lincoln. However, this is in contrast to very high growth rates achieved in both weight and length in water temperatures averaging 16.9°C (Deguara et al. 2010).

The bioenergetics model of Gunn et al. (2002) found that food consumption is the key indicator of growth – a linear relationship between consumption and growth and predicted higher temperatures should result in more efficient assimilation rates. However, thermoregulation may “buffer” SBT metabolism to temperature effects to a degree that is not found in other ectothermic fish. They found temperature much less important in the case of SBT and that it is relatively unimportant in determining growth.

These researchers concluded that it is plausible there is an optimum temperature range for growth performance in SBT, with a peak occurring around 18°C. This may be related to activity levels due to water temperature or changes in metabolic demands due to water temperature. This is consistent with the findings of Ellis (2013) that SBT feel greater heat stress at water temperatures above 20°C. This is perhaps also consistent with Itoh et al. (2003) who found PBT preferred a temperature range of 14-20°C.

In Japan, Masuma et al. (2008) found water temperature important in growth performance PBT at age zero reach the following weights after 3 years in culture

- 30-50kg in Shizuoka (north of Kinki)
- 50kg in central Japan (Kusimoto)
- 60kg at Kagoshima (south of Kinki)
- 75kg at Amami further south, and
- 100kg at Yaeyama (the southernmost island of Japan) after 4 years.

Possible reasons for the difference in growth could be related to

- Feed delivery and frequency
- Nutritional content of feed
- Development of the thermoregulatory capacity of small juvenile tuna. It is likely the southern warmer waters allow tuna to develop this capacity quicker thereby facilitating increased growth in the early stages
- It is likely small juvenile PBT do not have cold adapted enzymes to assist with digestion thereby holding back their digestive capability in cooler waters
- Site-specific conditions relating to bloodfluke infections of *Cardicola orientalis* and *C. opisthorchis*. These trematode parasites cause significant impacts to the cardiovascular system and result in depressed feeding, stress and mortality. For example, the SBT ranching mortalities were 10.5% and 13.5% in 2009 and 2010 respectively, before falling to ~ 1% in 2014 when a solution was found.
- SBT have very short towing periods allowing ranching companies to increase growth rapidly through optimised feeding strategies using *Formu-bait* © (van Barneveld and Ellis, 2007)
- From a health point of view SBT are very robust having survived high mortality in the wild (Nowak et al., 2003). The robustness of these fish when transferred to ranching pontoons was possibly one observation of the 2014 visits by the Japanese government and Industry, and the QAR experts.

Bias in average weight sample to determine volume of catch

Itoh et al. (2014) assumes there is a feeding hierarchy in the tow pontoon biasing the sample weight downward and/or that the sampler has a technique to target smaller fish.

There is no evidence to suggest smaller or larger fish are more aggressive feeders resulting in a sampling bias. Indeed, Galaz (2011) suggests feeding aggression of the bigger tuna is a key factor for tuna growth in fattening cages. Other studies suggest small tunas (100-160 cm) grow less than large tunas (Aguado and García-García 2005; Tzoumas et al. 2010). This result, among other reasons, is a reflection of the population structure within the different tuna cages. In those cages where large tunas are dominant (in terms of biomass), small tunas are almost totally suppressed from feeding and stay near the bottom of the net for nearly the entire feeding process. Only when (after a while) larger specimens significantly reduce their feeding activity smaller specimens begin to feed (Galaz, 2010).

There are strict rules to follow when catching fish to determine the average weight sample to eliminate catching bias in the Australian SBT ranching industry and these rules are defined in the SBT management plan (see www.afma.gov.au).

In brief, the sampling process involves spreading feed over a large area of the pontoon and a single hook thrown into the middle of the spread feed at the same time. An invitation was extended to Japanese scientists, government officials and industry to visit Port Lincoln in 2014 to observe this process first-hand. The QAR group also saw the weight sample in March 2014.

From a commercial farm husbandry and feed management perspective a range of techniques is used to eliminate feeding hierarchy including surface spreading and sub-surface feed delivery, feed timing and frequency, and satiation feeding.

Japan's claims - the economic and Feed Conversion Ratio (FCR) implications, benchmarked internationally

Australian SBT quota owners have the choice each year to use the quota for harvesting from the wild or catching for a growout operation. Growout, even for a short period, is a major risk because:

1. There is no forward market for SBT. Therefore when the SBT are caught for ranching, the operator takes the risk of not knowing the Yen price and exchange rate until the harvest up to 7-8 months later.
2. The risk of substantial mortalities
3. The capital assets of the quota owner can be used for either ranching or catching directly for the market.

If Japan's methodology was correct then no one would be ranching SBT. The reason is that the largest cost is feed and the foundation of ranching profitability is the Feed Conversion Ratio (FCR). Based on Japan's methodology, the following would apply in 2013.

Table 5. Assessing the economic viability based on an assumption of a 40% estimate of over catch

Item line	Value
Industry Average Weight (kg) – In/out whole wt	16.19/33.29
Imputed average weight gain (kg) in farm (whole kg) (Based on a hypothetical 40% estimate of overcatch (ie actual in-weight 22.67kg) ⁽¹⁾	10.62
Total industry whole weight increase (tonnes) – 255,486 fish x 10.62	2,713t
Imputed Feed Conversion Ratio (FCR) – whole weight (51,550t feed/2,713)	19.0
Imputed Feed Conversion Ratio (FCR) – processed weight	22.1
Imputed Feed cost (\$) for adding 1kg of processed weight (Bait is \$0.85/kg)	18.79
Feed cost is 40% of ex-farm cost so total cost/kg added ⁽²⁾	46.98
Price ranched product ex-pontoon \$/kg ⁽³⁾	15.23
Price Australian longline SBT \$/kg – for comparison	18.06

Notes to the table -

- (1) Data on average weights in/out of farm – Source: AFMA (supplied to CCSBT and Japan).
- (2) Local sardines – 33,500t (Source: PIRSA); imported (Source: Australian Bureau of Statistics)
- (3) Ex-farm price (Source: Australian Bureau of Statistics)

Therefore based on Japan's calculations it would be cost prohibitive to ranch tuna in Australia.

Another way of assessing the implications is comparisons with the FCR of tagged tunas in SBT and other tuna ranching/farming operations.

Table 6. Food conversion ratio based on growth and baitfish consumed by tagged tuna in research trials

Citation	Species	Food Conversion Ratio (whole wt)
Goto (2014)	Japanese PBT <i>Thunnus orientalis</i>	10.7
Sylvia et al. (2002)	Mexican PBT <i>Thunnus orientalis</i>	7.0
Gunn et al. (2002)	Australian SBT ⁽¹⁾ <i>Thunnus maccoyii</i>	10.0
Gordon et al. (2006)	Australian SBT ⁽¹⁾ <i>Thunnus maccoyii</i>	8.3

Notes to the table -

- (1) These tuna were tagged with conventional dart tags with associated impacts on physiology and growth performance

It is implausible that the FCR of untagged SBT in commercial operations could be double (worse) than that of tagged SBT required to meet the hypothesis of a 40% overcatch estimate into farms.

Discussion points for participants of the CCSBT Compliance Committee

We propose participants of the CCSBT Compliance Committee review this information in response to repeated claims by Japan of unaccounted catch mortality in the weight sample. Specifically, the CCSBT Compliance is encouraged to address the following points.

- There is a need to review data from catch and release studies in the wild fishery for the determination of length / age coefficients due to stressors as a direct result of handling and tagging. It is plausible that compromised SBT will falsely lower length/age relationships of free ranging SBT for a lengthy period.
- Many of the issues/assumptions raised by Japan have been sufficiently addressed using research information from all tuna ranching growing regions in this review. However, there is a requirement for Japan to provide raw data used in its calculations for validation by the Australian ranched tuna industry.
- It may be prudent for the CCSBT to seek external advice on issues within the ranching environment, as aquaculture science is a very specialist field. There are many examples in this paper (from the literature) that it is not appropriate to apply benchmarks on length and weight growth in the wild to farming and ranching operations.
- The conclusion of the CCSBT 2014 ESC (Attachment Five) that any future analysis of SBT farming would need to take into account:
 - “Data on when fish are put into farms and how long fish are held in the farms
 - Growth rate data from fish in farms compared to wild fish (other studies not CCSBT)
 - Growth rates of tagged fish from SRP that are subsequently harvested in farms
 - Feed conversion ratios for the farms
 - Differences in growth rates of each age group
 - Current wild growth rates.”

References

- Aguado-Giminez, F. and Garcia-Garcia, B (2005). Changes in some morphometric relationships in Atlantic bluefin tuna (*Thunnus thynnus* Linnaeus 1758) as a result of fattening process. *Aquaculture*, Volume 249, September 2005).
- Cort J. (2003). Age and growth of the bluefin tuna (*Thunnus thynnus thynnus*) of the Northeast Atlantic. In: Bridges, C.R., Gordin, H., Garcia, A. (Eds.), Proceedings of the Symposium on Domestication of the Bluefin Tuna, *Thunnus thynnus thynnus*, 3–8 February 2002.
- Crozier, W and Kennedy, G. (2002). Impact of tagging with coded wire tags on marine survival of wild Atlantic salmon (*Salmo salar* L.) migrating from the R. Bush. *Northern Ireland Fisheries Research*. 59 Vol 2, 209-215.
- Deguara S., Saviour, S., Caruana, S. and Agius, C. (2010). Results of the first growth trial carried out in Malta with 60kg farmed Atlantic Bluefin Tuna (*Thynnus thynnus* L.). SCRS/2009/134 Collect. Vol. Sci. Pap. ICCAT, 65(3): 782-786 (2010).
- Ellis, D. (2013). The measurement of visceral temperature patterns and implications for feeding practices in ranched southern bluefin tuna *Thunnus maccoyii*. Submitted in fulfillment for the degree of Master of Applied Science, June 2013, University of Tasmania.
- Galaz, T. (2011). Eleven years – 1995-2005 – of experience on growth of bluefin tuna (*Thunnus thynnus*) in farms. SCRS/2011/160 Collect. Vol. Sci. Pap. ICCAT, 68(1): 163-175.
- Glencross, B., Clarke, S. and Buchanan, J. (2002). Temporal Growth Patterns of Farmed Juvenile Southern Bluefin Tuna, *Thunnus maccoyii* (Castelnau) Fed Moist Pellets. *Journal of the World Agriculture Society*. June 2002.
- Gordon, R., Bayly, G. and Foster, C. (2006). Commercialisation trials for a manufactured tuna feed. Aquafin CRC Project 1A.3 January 2006.
- Goto, T. (2014). Development of artificial feed for farmed bluefin tuna, *Thunnus orientalis*, Nippon Suisan Kaisha. Presentation to WAS Conference, Adelaide, June 2014.
- Gunn, J., Patterson, T. and Rough, K. (2002). Experimental analyses of the effects of ration and feeding frequency on the thermodynamics, energetics, growth and condition of farmed Southern Bluefin Tuna. CSIRO Marine Research. FRDC Project 97/363. May 2002.
- Hampton, J. (1986). Effect of tagging on the condition of southern bluefin tuna, *Thunnus maccoyii* (Castelnau). *Australian Journal and Freshwater Research* 37 in 1986.
- Hearn, W. and Polacheck, T. (2003). Estimating long-term growth rate changes of southern Bluefin tuna (*Thunnus maccoyii*) from two periods of tag return data. *Fishery Bulletin* January 2003.
- Hearn, W. (1990). Comments on Optimal Growth of Southern Bluefin Tuna (SBT). CSIRO Division of Fisheries 6 April 1990.
- ICCAT. (2009). Report for the Biennial Period 2008-2009, Part II (2009), Vol 2. SCRS
- Ikeda, S. (2003). Rearing Market and domestic production of cultured tuna in Japan – cultured tuna in the Japanese market. In: Bridges, C.R., Gordin, H., Garcia, A. (Eds.), Proceedings of the 1st International Symposium on Domestication of the Bluefin Tuna, *Thunnus thynnus thynnus*, 3-8 February 2002. Cartagena, Spain. *Cah. Options Mediterr.*, vol. 60, pp. 83– 84.
- Itoh, Y., Tsuji, S. and Nitta, A. (2003). Migration patterns of young Pacific bluefin tuna (*Thunnus orientalis*) determined with archival tags. *Fishery Bulletin*, July 2003.
- Itoh, T., Akatsuka, Y., Kawashima, T., and Mishima, M (2012). Analyses on age composition, growth and catch amount of southern bluefin tuna used for farming in 2007-2101. Paper CCSBT-ESC/1208/30 to ESC 2012.
- Itoh, T., Suzuki, K. and Takeda, S. (2014). Unaccounted catch mortality in Australian SBT farming fishery between 2001 and 2013 estimated from information of TIS and CDS. Paper CCSBT-

OMMP/1406/09 (Rev). July 2014

Kataviæ, I., Tièina, V. and Franièeviaè, V. (2001). A preliminary study of the growth rate of Bluefin tuna from Adriatic when reared in floating cages. SCRS/2001/092

Keiffer, J. D., Kubacki, M. R., Phelan, F. J. S., Phillip D. P. and Tufts, B. L. (1995). Effects of catch and release angling on nesting smallmouth bass. Transactions of the American Fisheries Society. 124, 70-76.

Leigh, G & Hearn W (2000) - Changes in growth of juvenile southern bluefin tuna (*Thunnus maccoyii*): an analysis of length-frequency data from the Australian fishery. *Marine and Freshwater Research* 51(2) 143 – 154, year 2000.

Loftus, A.J., Taylor, W. W., and Keller, M. (1988). An evaluation of lake trout (*Salvelinus namaycush*) hooking mortality in the upper great lakes. Can. J. Fish. Aquat. Sci. 45, 1473-1479.

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

McLeay, L. J., Jones, G. K. and Ward, T. M. (2002). National Strategy for the Survival of Released Line-caught Fish: A Review of Research and Fishery Information. Fisheries Research and Development Corporation Project 2001/101. Henley Beach, South Australia. South Australian Research and Development Institute, 121 pp.

Norita T. (2002). Feeding of bluefin tuna : Experiences in Japan and Spain. In : Bridges C.R. (ed.), García, A. (ed.), Gordin, H. (ed.). *Domestication of the bluefin tuna Thunnus thynnus thynnus*.

Nowak, B., Rough, K., Ellis, D., Crane, M., Cameron, A. and Clarke, S. (2003). Aquafin CRC – Southern Bluefin Tuna Aquaculture Subprogram: A risk assessment of factors influencing the health of southern bluefin tuna. Fisheries Research and Development Corporation and Aquafin CRC.

Phillip, D. P., Toline, C. A., Kubacacki, M. R., Philipp, D. B. F. and Phelan, F. J. S. (1997). The impact of catch-and-release angling on the reproductive success of smallmouth bass and largemouth bass. North American Journal of Fisheries. 17, 557-567.

Polacheck, T., Eveson, J. P. and Laslett, G. M. (2004). Increase in growth rates of southern bluefin tuna (*Thunnus maccoyii*) over four decades: 1960 to 2000. Can. J. Fish. Aquat. Sci. 61, 307-322.

Robins, J. (1963). Synopsis of biological data on bluefin tuna *Thunnus thynnus maccoyii* (Castelnau). 1982 Species synopsis No. 17. FAO Fisheries Biology Synopsis No. 60.

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

Sylvia, P. Belle, S. and Smart, A. (2002). Current status and future prospective of bluefin tuna (*Thunnus thynnus orientalis*) farming in Mexico and the West Coast of the United States. In : Bridges C.R.(ed.), García A. (ed.), Gordin H. (ed.). *Domestication of the bluefin tuna Thunnus thynnus thynnus*.

Ticina, V., Katavic, I. and Grubisic, L. (2007). Growth indices of small northern bluefin tuna (*Thunnus thynnus*, L) in growth-out rearing cages.” *Aquaculture* (2007)

Tzoumas, A., Ramfos, A., De Metrio, G., Corriero, A., Spinos, E., Vavassis, C. and Katselis, G. (2010). Weight growth of Atlantic Bluefin Tuna (*Thynnus thynnus*, L.1758) as a result of a 6-7 months fattening process in the Central Mediterranean. SCRS/2009/135 Collect. Vol. Sci. Pap. ICCAT, 65(3): 787-800

van Barneveld R. and Ellis, D. (2007). Practical nutrition of farmed Southern Bluefin Tuna *Thunnus maccoyii*. Aquafin CRC, Adelaide. Commercial in confidence.