AUSTRALIAN SOUTHERN BLUEFIN TUNA
INDUSTRY ASSOCIATION LTD (ASBTIA)

An updated Review of Tuna Growth performance in Ranching and Farming Operations

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Executive Summary

Purpose

(1) To test the most recent points made by Japan on its hypothesis that there is unaccounted for catch (UAM) in Australian ranching – through the average weight of the ~3,000 fish sample under-stating the weight (see ESC/1509/32 Rev).

(2) To reinforce Australia's continuing points (eg see ESC/1509/35 and CC/1401/Info) on all the data in the scientific and economic literature on issues such as effects of tagging, growth rates of other tunas in farms, and Feed Conversion Ratios (FCR).

Conclusion

The analysis in this Paper indicates that Japan's hypothesis of a UAM in Australian farms is not supported by any of the core tests normally used.

Background

Since 2008, Japan has annually submitted a number of papers (except 2013) to the ESC and/or CC with the hypothesis that there is unaccounted catch in the Australia ranching process. Japan appears to accept that Australia is declaring the correct number of SBT caught, and that the number of fish and tonnage harvested are accurate. Again, their point is that the method of estimating the weight (~3,000 fish @ 100 fish ≥ 10kg sample/tow) is potentially under-stating the average weight ***into*** the pontoons.

Japan's assessment is that "It seems highly unlikely that farmed SBT can obtain such high growth rates." Japan's reasoning is that there can't be such a significant difference in growth rates between wild and farmed SBT. They used this assumption to estimate that Australia's excess annual catches ranged from 1,642 tonnes (33%) in 2014 to 3,183 tonnes in 2007 (61%) , with a mean of 2,289 tonnes (47.6%)

Most recently, Australia has questioned the assumptions made in Japan's hypothesis, and requested that the data used by Japan be made available. Japan has declined to provide the data.

The issue has also been discussed in detail during:

(1) Official visits to the farm weight sampling by the Japanese Government, industry and scientists (invited)

(2) By the CCSBT Quality Assurance Review (QAR) consultants in 2014 to report from on-site observation of the weight sampling process and all other parts of the supply chain. The QAR audit report (CC/1410/10) concluded:

> "The QAR demonstrates that the management systems and processes applied by Australia to the SBT fishery have successfully ensured that reported Attributable SBT catch (ASBTC) has been below Australia's CCSBT allowable catch."

Then, in late August 2015, Japan submitted to the ESC a new hypothesis – using "growth rate in fork length, instead of body weight, in order to make the process simple." (ESC/1509/32(Rev)). Previously, Japan had just used growth rates of farmed fish in body weight, based on tagging data.

First core test of Japan's hypothesis – against feed used

In ESC/1509/32(Rev), Japan's comments on Australia's analyses have not questioned the accuracy of:

(1) Australia's total harvest – because this is data which is rigorously audited by AFMA, and can be cross-checked against a whole range of official data such as Australian export data, and the import data of Japan and other countries.

(2) The Feed Conversion Ratio (FCR) in farms – where the universal benchmark is 10 kg of feed to one kg in whole weight growth (see CC/1401/Info). Australia provided numerous literature sources for this, including from Japan and Australia.

(3) Total feed used in SBT ranching in Australia. This is derived from public data on the main feed source (South Australian sardines) plus imports ± stock holdings.

Using this data, Japan's UAM hypothesis in its Case 2 can be tested as follows for 2013 and 2014:

	Actual		**Japan's hypothesis**	
	2013	**2014**	**2013**	**2014**
Weight into farms (wh.t)	4,195	5,024	6,980	6,672
Minus mortalities (%)	1.34	3.15	1.34	3.15
After mortalities (wh.t)	4,139	4,866	6,886	6,462
Weight ex-farm (wh.t)	8,505	10,114	8,505	10,114
Weight added in farm (wh.t)	4,366	5,248	1,619	3,652
FCR (kg feed/wh. kg gain)	10:1	10:1	10:1	10:1
Implied feed used (tonnes)	43,660*	52,480	20,490	36,520
Actual feed used (tonnes)	47,759*	51,650	47,759	51,650

*This gap is due to a once-off large-scale trial from a different imported bait source.

Clearly, Japan's hypothesis does not meet this basic test.

Second core test of Japan's hypothesis – implied Condition Index (ex-farm)

Japan's hypothesis is that the SBT into the farm are at least one or two age groups older than indicated from the ~ 3,000 fish weight sample (eg see Japan's ESC/1509/32 – Table 6). This is based on a range of assumptions, including that length growth in the farms is the same as in the wild, and comparisons with other tunas, especially Pacific Bluefin Tuna (PBF).

What is generally agreed on is:

(1) The average whole weight out of the farms in any year – which is audited by AFMA, is in export data, and is part of the commercial transactions with buyers. For example, in recent years it has been:

	Average kg whole weight ex-farm
2012	29.01
2013	33.29
2014	38.98

Source: CCSBT yearly farm data summary

(2) Each country or species normally has a formula to quickly measure the quality or marketability of a harvested fish. In the case of ranched SBT it is called "Condition Index" (CI) which is generally to measure the fat level in a fish. A number of variations of the CI formula are used in Australia (including by the Japanese buyers), and elsewhere (eg see ESC/1509/32(Rev) – page 23) but all have the same result. Most often it is expressed as:

$CI = BW/L^3$ - Where BW is body weight in whole kg and L is metres fork length.

For example, the CI of a wild SBT in the GAB varies over the season, but averages around 18-20, only suitable for the low quality sashimi or canning markets. This is why the Australian industry and Japanese Government first trialled ranching in 1991 – to add condition and value to the wild SBT.

Post ranching, the normal CI is 24-27.

Under the extremes of Japan's hypothesis, an SBT in farms only grows in length at the same pace as in the wild (Japan's Case Two). Case one assumes that the SBT in farms grows at a slightly faster rate – the same as the SRP tagged SBT.

A way of testing this hypothesis is to examine the implications of Japan's hypothesis for CI levels. For example for an actual three-year old Japan's Case Two, see Table 6 in ESC/1509/32(Rev):

	Actual		**Japan's hypothesis**	
	2013	**2014**	**2013**	**2014**
Starting length (cm)	97.2	97.2	123.8	114.9
Ex-farm length (cm)	111.0	111.0	132.5	123.6
Whole wt ex-farm (kg)	33.29	38.98	33.29	38.98
Implied CI	24.4	28.5	14.3	20.6

Clearly the CI under Japan's hypothesis for a harvested farmed SBT is either much lower than a wild SBT, or equivalent to it. In neither case is it plausible.

<u>Other points made by Japan in ESC/1509/32(Rev)</u>

The main issues at this stage are:

(1) Japan notes that the ICCAT models still assume that the length growth in farms is still the same as in the wild – and so Japan maintains that assumption in its hypothesis on SBT, except that it also considers SRP tag results as one alternative. We suggest that the ICCAT position is not consistent with the evidence on Atlantic Bluefin Tuna (ABT) – see later. We also suggest that it is not consistent with the evidence on Pacific Bluefin Tuna (PBF) – for example, see below, and Table 6 in Japan's paper ESC/1509/32(Rev). Last, it is possible that ICCAT has not also taken into account seasonal growth differences.

(2) Japan could not access the CSIRO paper (Gunn et al, 2002) which notes that an FCR of 10:1 is normal, and "Models for wild SBT are unlikely to be applicable to farmed fish." I am getting an E-copy to provide to Japan.

(3) Japan has asked for more information on "growth variance by season, farming cage, farming condition, and in any category Australia think necessary for farming study." Japan has also requested further information on cost of feed and return on investment. Australia is happy to provide whatever we can and will liaise with Japan on the requests.

(4) Japan has again declined to provide the raw data on which it has based its hypothesis.

(5) Japan has rejected the evidence that tagging can affect growth in farms. Our view remains that that the evidence remains strong (see later).

<u>Different types of tuna farming/ranching</u>

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 approximately15-20kg 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 of 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. In other regions, the literature suggests a delay before higher feeding levels begin, and then not to the same level as Australia. This is because of the length of tow, the multiyear holding of the fish in other countries, and high feed cost in ranching operations.

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 trial over 17 months (June 1999-December 2000) the results showed a much faster growth in length and weight in farms than in the wild. For example, in the 85-120cm category (10-25kg) the monthly growth was 2.16cm and 2.42kg. This was despite an initial tagging mortality of 50%, plus 5% during the trial, indicating stress on all tagged fish.
Cort (2003)	Summer growth in wild ABT aged1-3 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)	"*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."*
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)	PBT at the Wakayama (Kinki University) research station stocked at 150-500g could achieve a weight of 50kg in 3 years. 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.
Masuma et al. (2008)	Concluded farmed PBT exceeded growth of wild PBT
Goto (2014)	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: ***Trial One*** Place: Nagasaki Period: 16/6/13 to 16/12/13 Water temp: 16-29^{O}C Feeding: Once/day for 6 days/week Feed rate: 1.5-2.0%BW/day FCR: 3.8(pellet); 10.5 (baitfish) Weight growth: Start 16kg – end 33.5kg Length growth: Start 89cm – end 113cm ***Trial Two*** Place: Kagoshima Period: 7/11/13 to 26/5/14 Water temp: 19-24^{O}C Feeding: Once/day for 6 days/week Feed rate: 1.5-2.5%BW/day FCR: 3.7(pellet); 10.5(baitfish) 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** / **Start wt (kg)** / **Final wt (kg)** PBT / 45 / 70 Bigeye (*Thunnus obesus*) / 25-30 / 45 Yellowfin (*Thunnus albacares*) / 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 et al. (2007). This is despite noting a period of suppressed feeding in the SBT trials – apparently due to blood fluke infections (*Cardicola forsteri*).

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), other tunas (Ticina et al. 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.

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), 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 more accurately 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 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 bluefin 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:

a. The Catch Documentation Scheme (CDS) was not implemented until 2010 so therefore reporting of length was not required in the 2007-2009 period.

b. 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.

c. 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.

d. Fresh SBT shipments are not randomly selected and are specifically chosen for the Japanese market and larger and higher conditioned fish are selected.

e. 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.

f. 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.

g. For frozen SBT, there are two channels:

    i. Japanese freezer/reefer vessels handle the large majority of frozen fish. The fish are slung onto these boats in groups of 5-15 fish.

    ii. Some SBT are shipped via freezer container, particularly to smaller buyers who do not have the volume for a freezer boat.

h. 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.

i. 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.

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. This is separate from Japan's methodology – but it will at least provide some cross-checking of the accuracy of the data base.

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 and in contrast to information presented in this review in respect to growth achieved by bluefin tunas worldwide and 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 compare 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 16.9^0C (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 18^0C. 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 20^0C. This is perhaps also consistent with Itoh et al. (2003) who found PBT preferred a temperature range of $14\text{-}20^0$ 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 blood fluke 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 2015 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, then 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/SBT/Pre-season Brief 2014-15).

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.

The Feed Conversion Ratio (FCR)

The evidence on FCR's includes the following:

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 *Thunnus orientalis*	10.5
Sylvia et al. (2002)	Mexican PBT *Thunnus orientalis*	7.0
Gunn et al. (2002)	Australian SBT[(1)] *Thunnus maccoyii*	10.0
Gordon et al. (2006)	Australian SBT[(1)] *Thunnus maccoyii*	8.3

Notes to the table -

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

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