CCSBT-ESC/0909/11

Australian Government
Bureau of Rural Sciences

Converting stereo-video length measurements to weight estimates for Australia’s surface fishery

**Josh Humphries, Katrina Phillips,
Veronica Boero Rodriguez, Gavin Begg**

Postal address:
Bureau of Rural Sciences
GPO Box 858
Canberra, ACT 2601

Executive Summary

Background

In September 2007 and April 2008, field trials were conducted to assess the operational feasibility of monitoring catch of southern bluefin tuna (SBT) by the Australian surface fishery using stereo-video cameras. Although not conducted under commercial conditions, the trials indicated that stereo-video cameras provide accurate and precise length measurements of SBT during transfer between pontoons, and that they are physically robust and suitable for use in a commercial environment. Further work identified during the trials was the determination of an acceptable length-weight conversion factor for estimating SBT weight from stereo-video length measurements.

Existing length-weight data

Four SBT length-weight data sets were available for this study, differing in terms of the location of data collection, the period of data collection, the fishing fleet or agency responsible for data collection, or the handling of SBT prior to measurement. These were collated from (1) poling operations in the Great Australian Bight in the late 1980s to late 1990s; (2) research conducted in the Great Australian Bight by CSIRO between 2004 and 2006; (3) the 40-fish sampling procedure currently used to monitor catch by the Australian surface fishery; and (4) individual length-weight data submitted by the Republic of Korea through the CCSBT data exchange.

Review and analysis

Time, space, fleet and handling practices may significantly affect the length-weight relationship of SBT. This report reviewed existing literature variability in the length-weight relationship of southern and northern bluefin tuna, then statistically analysed variability among the four available data sets.

Main findings

Analysis indicated that the weight of juvenile SBT is tightly correlated with length regardless of the effects of space and time, and that the length-weight relationship is relatively uniform over a range of circumstances. Therefore, data sets were aggregated and two conversion factors derived: a conversion factor from all four data sets ($W = 3.55912 \times 10^{-5} L^{2.86506}$), and a conversion factor from the three Australian data sets ($W = 2.64217 \times 10^{-5} L^{2.933509}$).

Stakeholder consultation

Adoption of a length-weight conversion factor will involve consultation with Australia’s SBT ranching industry and other stakeholders in keeping with the Australian Government’s domestic fishery management practices.

Contents

Background

In September 2007 and April 2008, a series of field trials were conducted in collaboration with the Australian southern bluefin tuna (SBT) (*Thunnus maccoyii*) ranch sector to assess the operational feasibility of monitoring catch via stereo-video camera technology. These trials represented a major output of the Australian Government's committment to the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) to investigate potential improvements to catch-monitoring methods in the sector (Harvey et al. 2003, Phillips et al. 2009). The trials indicated that stereo-video cameras currently available provide accurate and precise length measurements of SBT during transfer between pontoons, and that they are physically robust and suitable for use in a commercial environment. Further work identified during the trials was the determination of an acceptable length-weight conversion factor for estimating SBT weight from stereo-video length measurements for catch acquittal and other purposes. A list of options for converting stereo-video length measurements into weight estimates was provided in a report to the Fisheries Research and Development Corporation (Phillips et al. 2009). The current report reviews published literature on the length-weight relationship of northern and southern bluefin tuna, analyses existing SBT length-weight data sets listed by Phillips et al. (2009), and provides options on the use of length-weight conversion factors for Australia's SBT ranch sector.

Temporal and spatial changes in SBT length-weight relationship

The existing SBT length-weight data sets analysed in this report differ in terms of the location of data collection (e.g. Great Australian Bight vs. Indian Ocean), the period of data collection (spanning 1987 to 2008), the fishing fleet or agency responsible for data collection (e.g. CSIRO or the Korean longline fleet), and the handling of SBT prior to measurement (wild capture by longline or poling vessels vs. captive SBT towed to ranching sites). The length-weight relationship may vary among data sets on a spatial or temporal basis as a result of environmental conditions or physiological status (Aguado-Gimenez & Garcia-Garcia 2005). If the length-weight relationship does vary significantly among sampled populations, then application of a poorly fitting conversion factor could result in biased estimates of total catch weight from stereo-video length measurements (Gerritsen & McGrath 2007), which could lead to uncertainty in catch acquittal in the ranch sector. Previous research on the variability of the length-weight relationship of bluefin tuna is documented below.

Have changes in growth rate affected the length-weight relationship?

Various studies have suggested that there has been an increase in the growth rate of SBT over the last 40 years. This is especially evident in growth rates of juveniles of 1–4 years (Hsu et al. 2000, Leigh 2000, Hearn & Polacheck 2002, Polacheck et al. 2004, Farley & Gunn 2007). The growth rate of juvenile SBT appears to have increased to the extent that SBT spawned from the 1980s onwards are 1 year younger than fish of the same length spawned during the 1960s (Hearn & Polacheck 2002) (Fig. 1). There is currently no literature documenting whether an increased growth rate resulted in a change to the length-weight relationship of juvenile SBT. However, evidence from a recent study conducted on northern bluefin tuna (NBT) (*Thunnus thynnus thynnus*) suggests that, in juveniles at least, the length-weight relationship may not vary with changes in growth rate (Aguado-Gimenez & Garcia-Garcia 2005). The authors hypothesised that this was because younger NBT (less than 160 cm) have a higher metabolism than older NBT, which does not allow them to accumulate somatic resources. Aguado-Gimenez & Garcia-Garcia's (2005) research corroborated similar results from a previous NBT study (Katavic et al. 2002).

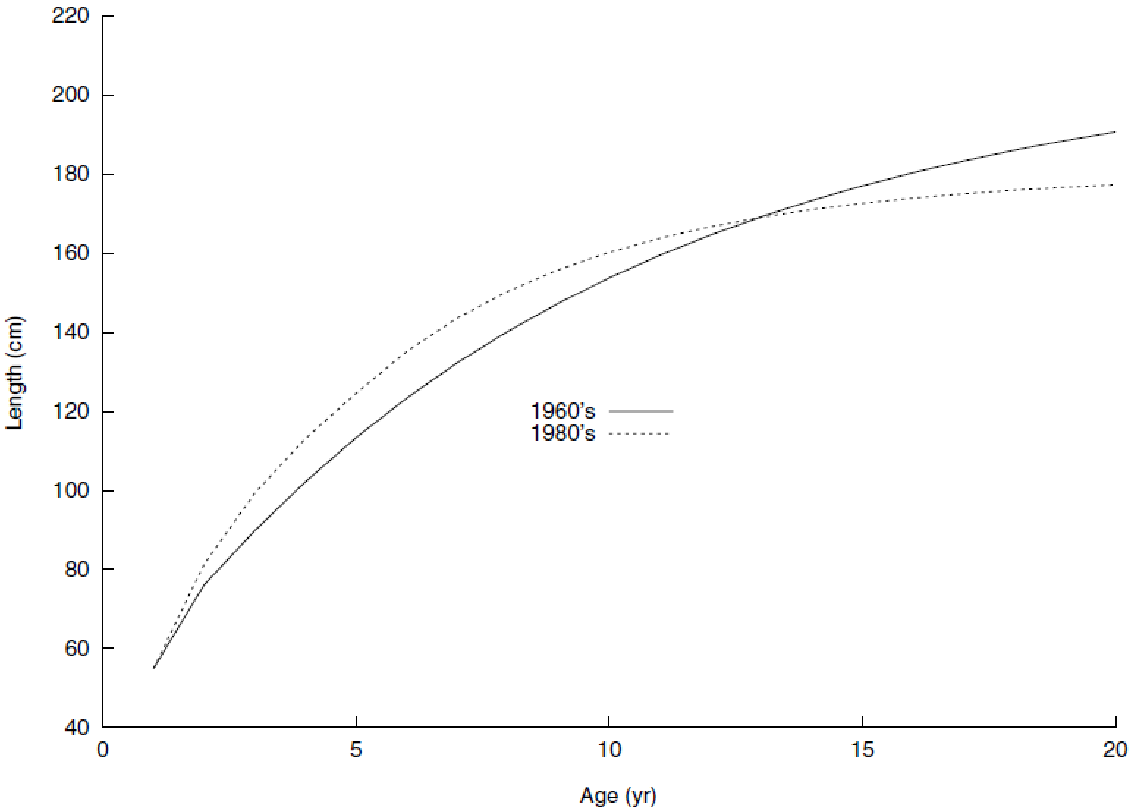

Fig. 1. Hearn and Polacheck (2002) comparison of 1960s and 1980s best-fit estimates for the expected length of SBT as a function of age, assuming that the expected age of an age-1 fish is 55 cm

Because the afore-mentioned studies were based on a different species of tuna and in a ranch environment, care needs to be taken when interpreting what these studies might mean for the wild SBT population. Nonetheless, the SBT that are captured in the Australian surface fishery are juveniles less than 160 cm in length, and it is possible that the length-weight relationship of juvenile SBT is similarly stable in spite of changes to the growth rate. Without collecting new length, weight and direct age data from the fishing grounds to compare with historical data, it is uncertain whether this would be the case.

Does the length-weight relationship vary among fishing grounds?

It is assumed that the global SBT population is one discrete stock that migrates throughout the southern parts of all oceans (Polacheck et al. 2004). The stock is targeted throughout its range, mostly by longline fleets but also by purse seine in localised areas. In the longline fishery, length and weight measurements can be easily taken as fish are brought on deck. However, Australia's SBT ranch sector (representing over 99% of Australia's SBT fishery) captures SBT by purse-seine in the Great Australian Bight (GAB). Captured juveniles are towed from the GAB in large (~45 m diameter) pontoons back to ranch sites near Port Lincoln, South Australia. A sample of 40 fish (the '40-fish sample') is taken from each tow pontoon to establish mean length and weight, which is then scaled up by the number of fish to estimate the catch by the sector per quota year (*Southern Bluefin Tuna Fishery Management Plan 1995*). The SBT are then transferred into grow-out pontoons, where they are fattened for up to 6 months prior to harvesting, which represents the first occasion that the majority of fish are handled directly. As such, since the establishment of ranching, very few length-weight measurements have been taken at the time of capture in the GAB.

While the longline fisheries provides the best opportunity to collect contemporary length-weight measurements of SBT at the time of capture, there is no spatial overlap between the Australian surface fishery and the operation of longline fleets. The SBT stock may encounter different environmental (e.g. feeding) conditions throughout its migratory range, which may affect the length-weight relationship among capture sites, notably between the location of the surface fishery and various longline fishing grounds (Andrade & Campos 2002).

There is currently no literature documenting spatial variation in the length-weight relationship of SBT. However, one such study has been conducted for NBT captured from different sites (Hsu et al. 2000). Like SBT, the global population of NBT is considered to be one discrete stock. Hsu et al. (2000) observed no significant difference in the length-weight relationship among samples of NBT from the south-western north Pacific, the north-western Pacific, and the Sea of Japan. If this also holds for SBT, contemporary length and weight measurements taken by longline fleets may be useful for establishing a length-weight conversion factor for the Australian surface fishery.

Need

When estimating the weight of SBT from stereo-video length measurements, it is important to ensure that the conversion factor provides an acceptable estimation of pre-capture weight. Historical measurements of length and weight from the GAB may not be suitable for determining a current conversion factor because of recent changes in the biological parameters of the juvenile portion of the SBT stock. Contemporary length and weight measurements of SBT captured by the Australian ranch sector are taken after tow-back to ranch sites, which may take several weeks; thus, measurements collected during the 40-fish sample may not represent the length-weight relationship on the fishing grounds. The opportunity exists to use recent juvenile data collected by longline fleets of other CCSBT members and available through the CCSBT data exchange. However, the location and time of capture differs to that of the Australian ranch sector, and differences in the length-weight relationship may exist as a result of feeding or other environmental variables. Therefore, short of conducting a study to determine an accurate length-weight relationship at the site of capture for the Australian surface fishery, it is necessary to explore a combination of available data sets to determine a ‘best fit’ relationship for juvenile SBT.

Objectives

The objectives of this study were to:

1. Explore differences in the length-weight relationship of juvenile SBT among existing data sets
2. Provide options for suitable conversion factors for the estimation of weight from stereo-video length measurements for catch acquittal purposes

Methods

The length-weight relationship

The length-weight relationship of SBT is described by the equation $W = \alpha L^{\beta}$, where W is the weight (kg), L is fork length (cm), and α and β are constants. This relationship can also be described by a linear equation for log (ln)-transformed length and weight measurements, i.e. $\ln W = \ln\alpha + \beta \ln L$, where $\ln\alpha$ is the *y*-intercept and β the slope of the line.

Length-weight data sets

Four length and weight data sets were used to explore options for converting SBT length measurements into weight estimates:

- Great Australian Bight poling data set (1987–1998; n = 1781); annotated as ‘GAB’ in figures and tables
- CSIRO research data set (2004–2006; n = 109); annotated as ‘CSIRO’
- 40-fish sample data set (1995–2008; n = 15 859); annotated as ‘40-fish’
- Korean longline data set available through the CCSBT data exchange (2006–07; n = 616); annotated as ‘KR’

The first two data sets were compiled from measurements taken on the GAB fishing grounds. The larger of the two data sets (the GAB poling data) includes measurements that were taken from 1781 SBT between the 1987–88 and 1997–98 fishing seasons. The length measurements of these fish ranged from 82 to 132 cm, and the weight measurements ranged from 12 to 49 kg. The natural log (ln)-transformed, linear length-weight relationship of this data set had an R^2 value of 0.9529 [$\ln W = (2.912 \times \ln L) - 10.373$]. However, because of the change in the juvenile growth rate over recent decades, it is possible that these data no longer represent the current length-weight relationship of the population fished by the Australian ranch sector.

CSIRO also collected length-weight measurements of 112 SBT from the GAB fishing grounds between 2004 and 2006 (two collection programs: n = 21 in 2004–06, and n = 88 in 2005–06). The length measurements of these SBT ranged from 60 to 119 cm and the weight measurements from 4.8 to 38 kg. The ln-transformed, length-weight relationship of these SBT had an R^2 value of 0.9640 [$\ln W) = (2.806 \times \ln L) - 9.910$]. While this data set provided recent length and weight measurements, the sample size was too small for use in any robust analysis.

The largest of all the data sets was the 40-fish sample (n = 15 870). These measurements are collected on an ongoing basis from each tow cage as part of the current monitoring procedure (*Southern Bluefin Tuna Fishery Management Plan 1995*). Length measurements in this data set ranged from 52 to 137 cm and weight measurements from 2.85 to 50 kg. The ln-transformed, length-weight relationship of these SBT had an R^2 value of 0.9398 [$\ln W = (2.803 \times \ln L) - 9.946$]. The advantage of the 40-fish data set is that it contains data from many individuals collected over many fishing seasons, dating from 1995 to the most recent season. However, these measurements were collected after tow-back from the capture site and weight loss cannot be discounted.

The fourth and final data set consisted of measurements taken by the Korean longline fleet in the Indian Ocean (n = 616) during the 2006–07 fishing season, available through the CCSBT data exchange. The length measurements ranged from 80.5 to 190 cm and weight measurements from 8 to 117 kg. The ln-transformed, length-weight relationship of these SBT had an R^2 value of 0.9589 [$\ln W = (2.948 \times \ln L) - 10.768$]. The SBT taken by this sector of the fishery overlap in size with those taken by the Australian ranch sector. However, the length-weight relationship of SBT could differ between fishing grounds, and there is no information describing how measurements were taken (e.g. after fish were bled, or after a prolonged period *post-mortem* leading to possible shrinkage before measurement).

Data analysis

Data sets were explored graphically by plotting weight against length. Plots were created for each data set/sub-set to investigate variance in the length-weight relationship as a result of season, location or tow cage effect. In addition, a condition index (Fulton's K: $K = 100\,000W \times L^{-3}$) (Fulton 1904) was calculated and a spread of boxplot values used to compare among groups (data set, season, tow cage effect).

Linear regression models were used to compare differences in the length-weight relationship among groups of data. A group indicator variable was included in the linear regression model and a full model fitted as follows:

$$\ln W = \alpha + \beta_1 \ln L + \beta_{2i}\mathrm{group}_i + \beta_{3i}\ln L \times \mathrm{group}_i \qquad (1)$$

where α and β_1 are the line intercept and slope for the first group, respectively; β_{2i} is the difference between group 1 and group i for the intercept; and β_{3i} is the differences between group 1 and group i for the slope. To test if the group effect and its interaction with lnL were significant, a model without the interaction, and without the interaction and group effect, were also fitted. An analysis of variance (ANOVA) was then performed with the three models to evaluate the significance of the interaction and the group effect. If the ANOVA indicated that the three models were significantly different, then the intercept and slope differed for each group. If only the second model (group effect) was significantly different, then the groups had the same slope but different intercept. Lastly, if no model was significantly different, then all groups had the same slope and intercept in the linear relationship.

Results

Variability within data sets

Removal of outliers

Preliminary exploration of the data highlighted anomalous measurements taken in the 40-fish sample during the 1996–97 fishing season. It was apparent that longer SBT sampled from two tow cages were considerably lighter in weight than similar sized fish sampled from other tow cages that fishing season (Fig. 2). As such, all measurements from these two cages were excluded from further analyses. Several other pairs of anomalous length-weight data pairs were apparent in the 40-fish data set, but these were singular events that did not seem to be related to specific tow cages, and were thus retained in the data set.

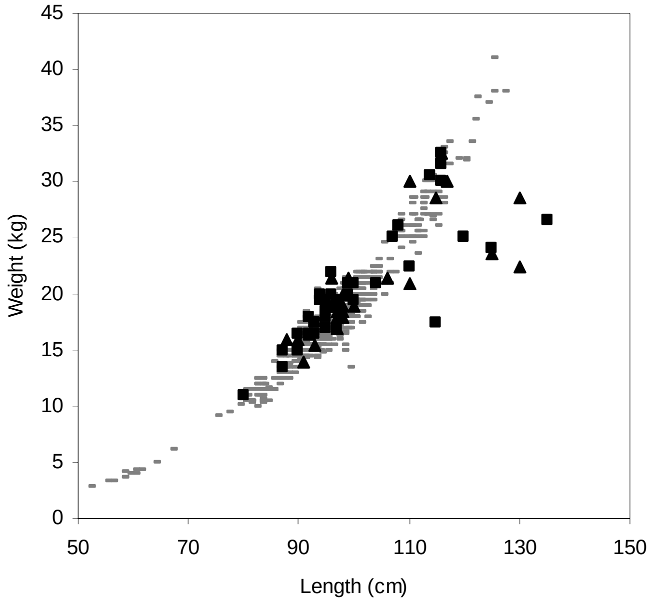

Fig. 2. Scatter plot of SBT length and weight measurements from the 40-fish sample during the 1996–97 fishing season. The triangle (▲) and square (■) data points represent measurements from two tow cages with anomalous data, which were subsequently excluded

Variability in the 40-fish sample: tow cages

To investigate within-season variability, comparisons were made among tow cages within each of the three recent fishing seasons for which tow cage data were available (2005–06 to 2007–08). When weight was plotted against length, the regression appeared to be similar among all tow cages within each of the three fishing seasons explored (Fig. 3). However, because of the large number of data points, it was not possible to clearly interpret the effect of tow cage as a variable. A linear regression model (Eq. 1) was fitted with tow cage as the group factor. An ANOVA indicated that the three models were significantly different; that is, the log-transformed, linear length-weight relationship had a different intercept and different slope for each tow cage. However, the R^2 value for every model was over 90%, which meant that over 90% of the variability in the length-weight relationship was explained by the model giving what could be called a ‘tight fit’, with small errors in the parameters then being divided by a number of observations (over 1000 in this case), leading to significant differences in parameters.

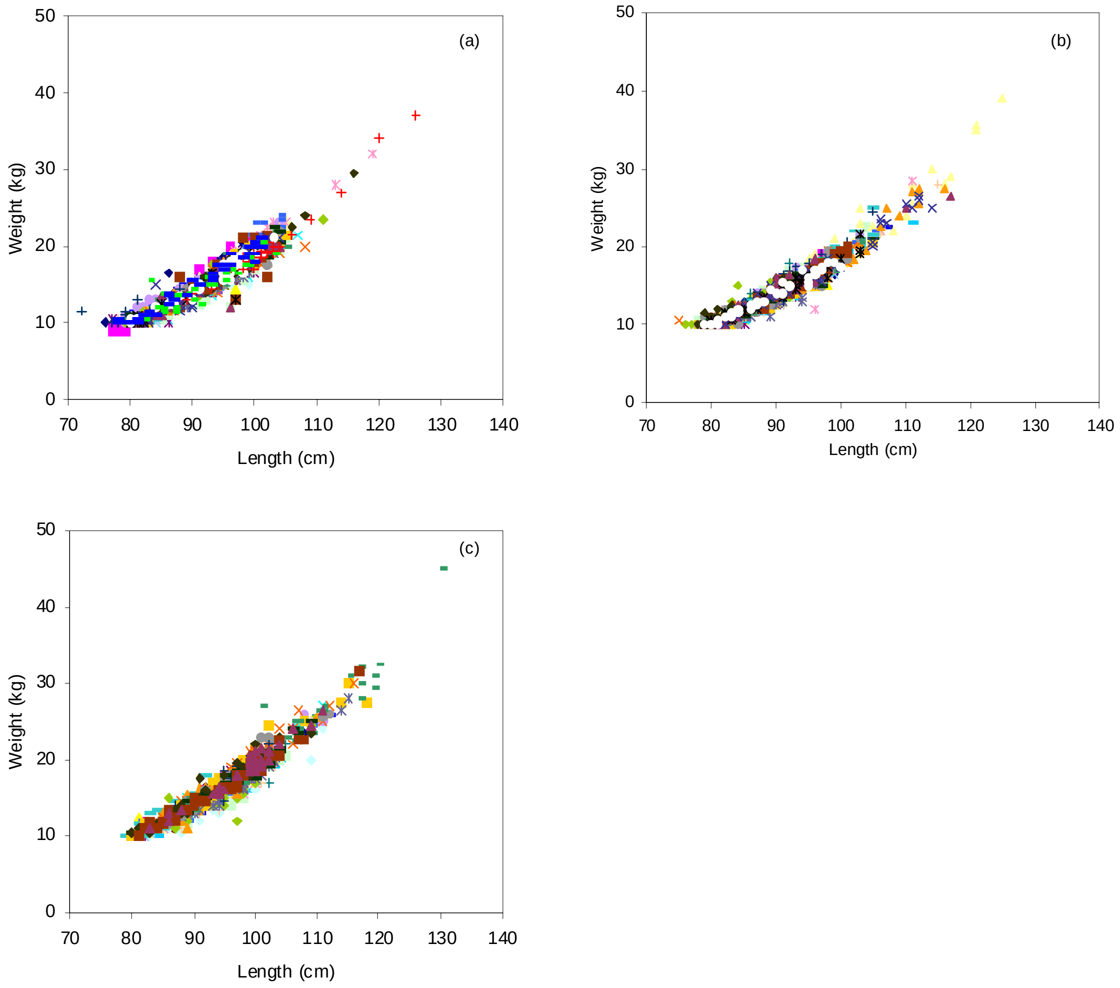

Fig. 3. Comparison of SBT length-weight relationship of 40-fish sample among tow cages within fishing seasons (a) 2005–06 (n = 36 tow cages), (b) 2006–07 (n = 33 tow cages), and (c) 2007–08 fishing seasons (n = 30 tow cages). Each tow cage is represented by a different coloured symbol

This variation was explored graphically by calculating a condition index for individual SBT from length and weight (Fulton's K) and plotting the spread per season (Fig. 4). A lot of 'noise' was apparent among tow cages, with no discernable trend over individual fishing seasons. It is quite likely that there was a significant tow cage effect propagating this within-season variability, possibly stemming from different feeding practices used by different companies.

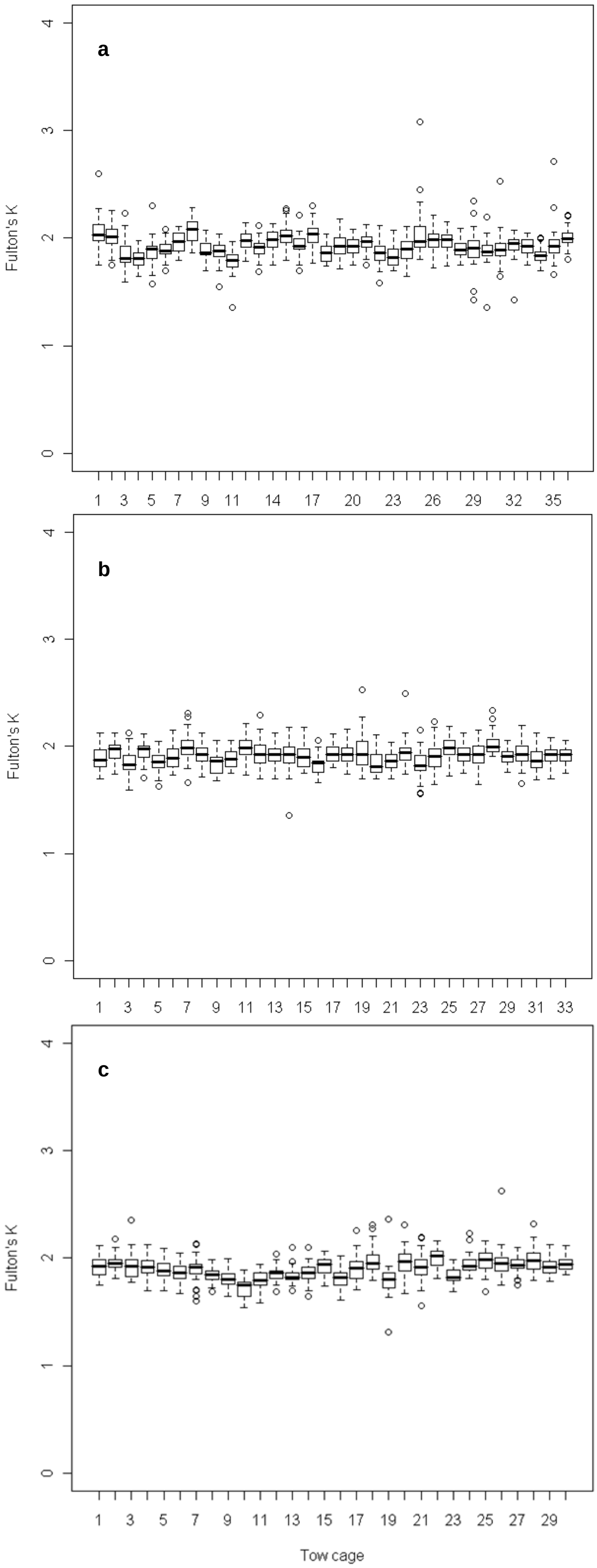

Fig. 4. Southern bluefin tuna condition factor (Fulton's K) per tow cage per fishing season: (a) 2005-06, (b) 2006-07, (c) 2007-08; 40-fish sample data

Other sources of within-season variability (namely temporal variability) were not explored because 40-fish sample data are collected within a narrow window of the year (generally between February and early April), and it was assumed that the length-weight relationship would not differ substantially over this period as a result of natural environmental variability.

Variability in the 40-fish sample: fishing season

Annual variability in the length-weight relationship of 40-fish sample data was investigated among fishing seasons from 1995–96 to 2007–08 (Fig. 5a). Once again, when weight was plotted against length, the relationship appeared to be similar among all fishing seasons. A linear regression model (Eq. 1) was fitted with season as the group factor. An ANOVA indicated that the three models were significantly different; that is, the log-transformed, linear length-weight relationship had a different intercept and different slope for each fishing season. However, the R^2 value for every model was again over 90% (i.e. this model was also a ‘tight fit’), with small errors in the parameters being divided by the number of observations—over 15 000 in this case—leading to significant differences in parameters.

The regression lines of the log-transformed, linear length-weight relationship for each season were plotted for comparison (Fig. 5b), and appeared to be very similar for all seasons except 1998–99. The condition factor derived from length and weight (Fulton’s K) was again plotted, this time by fishing season. On a seasonal basis, the ‘noise’ in the 40-fish sample data appears to diminish, producing a more stable condition factor over the fishing season (Fig. 6). The mean value of Fulton’s K in each fishing season is almost constant throughout the data set, at just under 2.0.

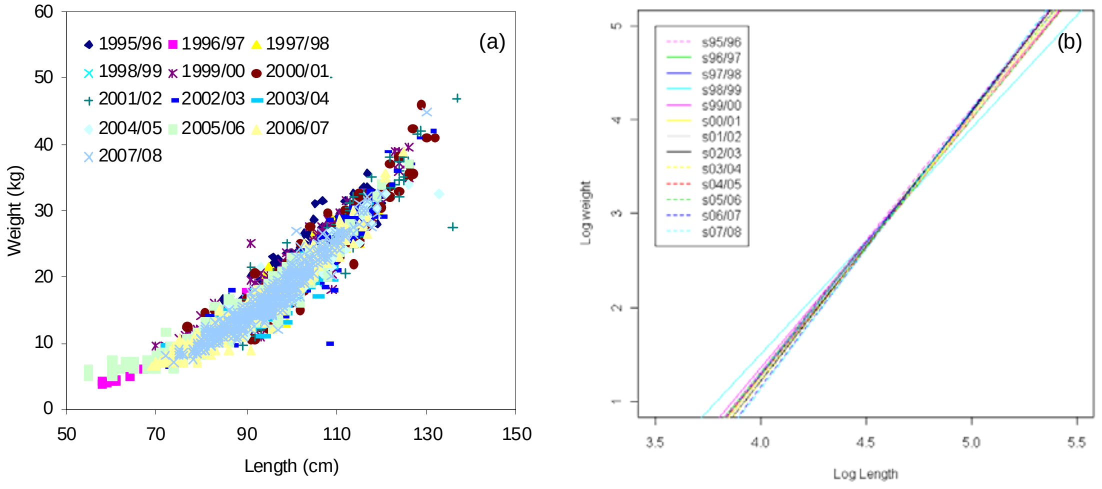

Fig. 5. (a) Scatter plot of SBT length and weight measurements from the 40-fish sample for each fishing season from 1995–96 to 2007–08, and (b) linear regressions of the log-transformed length-weight relationship for each season

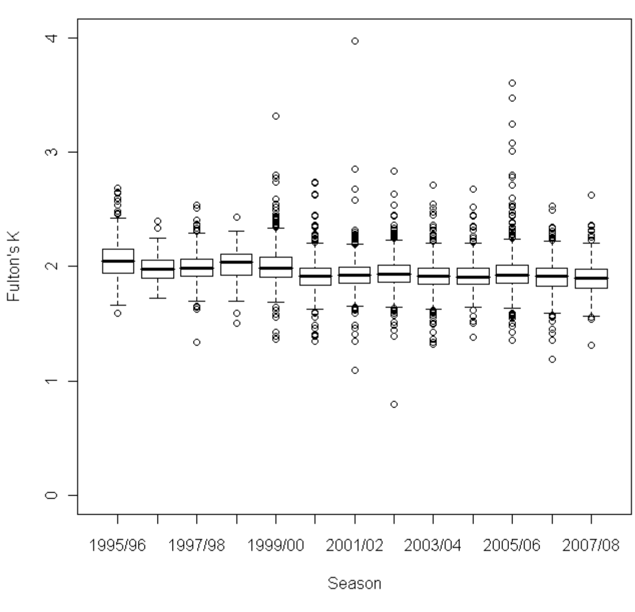

Fig. 6. Southern bluefin tuna condition factor (Fulton's K) per fishing season (1995-96 to 2007-08); 40-fish sample data

Variability in the GAB data set: fishing season

Temporal variability in the length-weight relationship of the GAB data set was explored among fishing seasons from 1987–88 to 1997–98 (Fig. 7). Similar to the 40-fish sample, when weight was plotted against length the relationship appeared similar among fishing seasons. However, the regression analysis again suggested significant variability among fishing seasons.

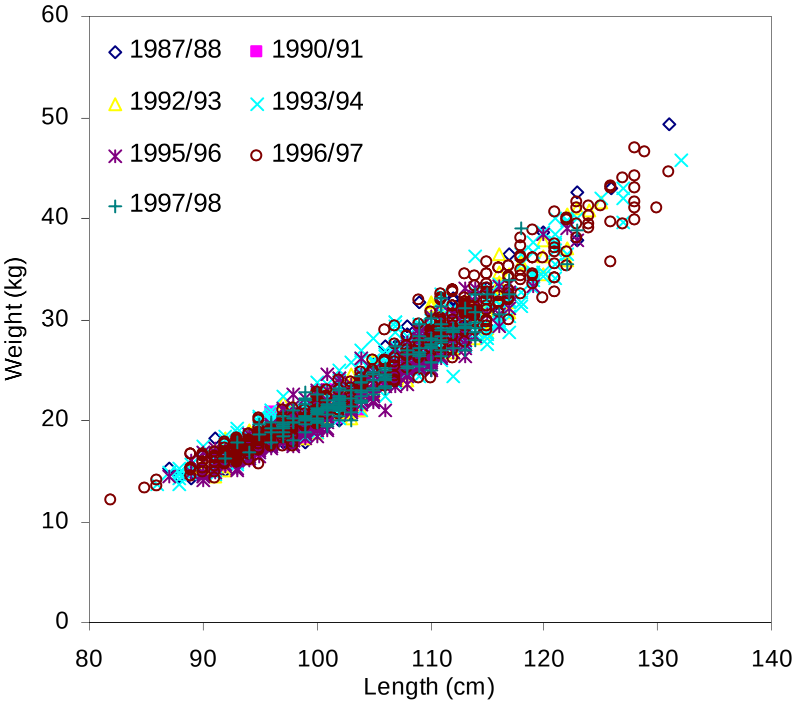

Fig. 7. Scatter plot of SBT length and weight measurements from the GAB data set for each fishing season from 1987–88 to 1997–98

The condition factor (Fulton's K) of the GAB data set was investigated among seasons using boxplots (Fig. 8). There was no discernable trend over time in the condition factor from 1987–88 to 1997–98. Furthermore, the range of median values (2.04 in 1990–91 to 2.1 in 1996–97) and the overall 'noise' were reasonably small, indicating a relatively stable condition factor among seasons for the 10-year period investigated.

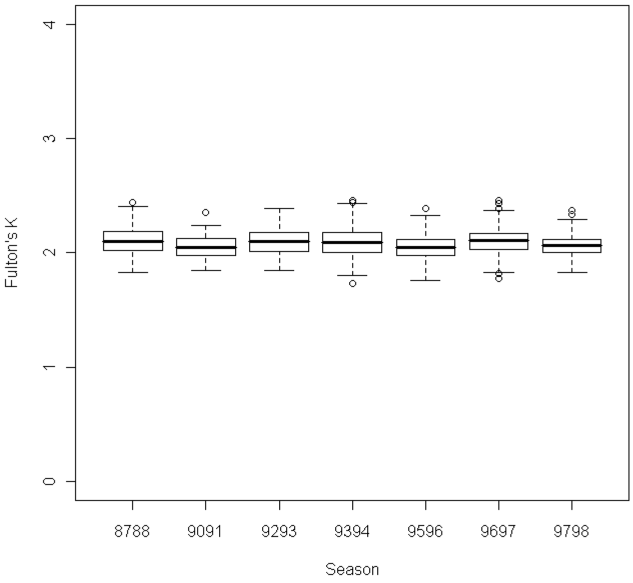

Fig. 8. Southern bluefin tuna condition factor (Fulton's K) per fishing season (1987–88 to 1997–98); GAB data set

Variability among data sets

Statistical variability within data sets was observed. This was most apparent among tow cages within a single fishing season, but depreciated when examined among fishing seasons over the time series. However, because no discernible trends were evident and a similar regression existed within data sets, we proceeded to investigate variability among the four existing data sets.

Graphical comparison of data sets

The length and weight measurements from all four data sets—the 40-fish sample, GAB 1995–98 (GAB), CSIRO 2004–06 (CSIRO) and the Korean longline data 2006–07—were plotted onto the one set of axes (Fig. 10). Graphically, the length-weight relationship appeared to be reasonably similar among all four data sets. Overall, the SBT measured on the GAB fishing grounds (i.e. GAB and CSIRO data sets) were of slightly greater weight per given length than SBT in the 40-fish sample and Korean longline data sets. However, the variability of all of the data sets was within the range of the 40-fish sample for SBT < 130 cm. The SBT sampled by the Korean longline fishery attained greater lengths than the SBT in the other three data sets (Australian waters); however, in general, the SBT sampled by the Korean fishery were of lesser weight per given length than SBT in the three Australian data sets.

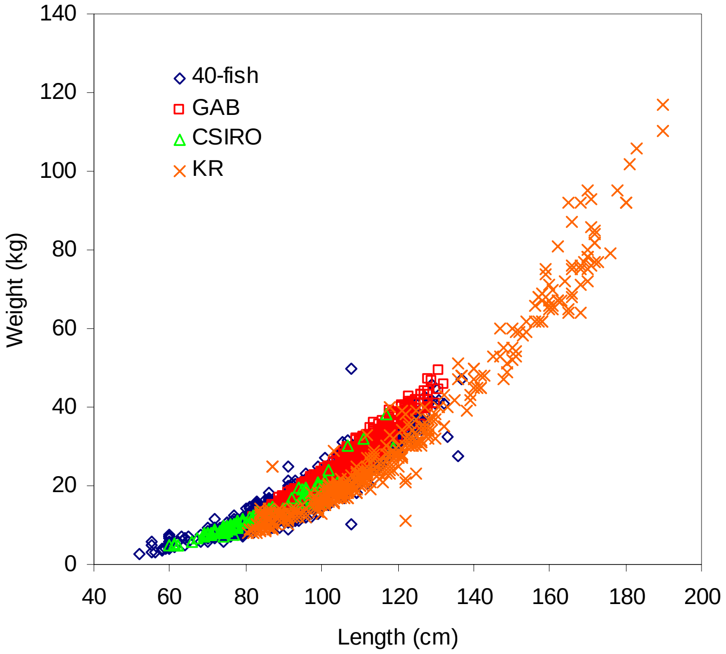

Fig. 10. Scatter plots of SBT length and weight measurements obtained from all four data sets investigated

Regression analysis

The results from the analysis of the full model (Eq. 1), in which each data set had a different *y*-intercept and slope, suggested that the length-weight relationship of the 40-fish sample was significantly different to that of the GAB and the Korean data. However, no significant difference was detected between the length-weight relationship of the 40-fish and CSIRO data sets.

Because the length-weight relationships of all four data sets appeared graphically to be quite similar, and because the significant differences in the regression analysis could be attributed to a 'tight fit' and large number of observations, a single conversion factor was determined. This was done by fitting a linear regression line to the log-transformed data. This factor can be used to convert length measurements of SBT to weight measurements and is expressed by the power function $W = 3.55912 \times 10^{-5}L^{2.86506}$, where W is the total fish weight (kg) and L is the fork length (cm) of the SBT. The same process was repeated using only the Australian data sets (GAB, CSIRO and 40-fish). This yielded a slightly different conversion factor, represented by the power function $W = 2.64217 \times 10^{-5}L^{2.933509}$.

Discussion

Comparison of all data sets

Graphically there was a high level of similarity in the length-weight relationship among all four data sets investigated. This suggested the relationship was relatively uniform over time (spanning 1988 [GAB data set] to 2008 [40-fish data set]) and space (Indian Ocean [KR data set] to the Great Australian Bight [CSIRO, GAB, 40-fish data sets]). Comparison of the regressions of data sets also indicated that the weight of juvenile SBT is tightly correlated with length regardless of the effects of time and space, consistent with research on juvenile NBT (e.g. Hsu et al. 2000, Aguado-Gimenez & Garcia-Garcia 2005). Yet, the regression analysis suggested that there were significant differences between some data sets. However, owing to the large sample size of the data sets and 'tight fit' (i.e. small errors), small standard errors in the parameters were obtained, which would have increased the sensitivity of the analysis to statistical differences.

Options for selecting a conversion factor

Although the length-weight relationship of SBT in the Korean data set was within the range of SBT in the GAB, CSIRO and 40-fish data sets, the fish sampled by the Korean fleet generally weighed less per given length than SBT in the latter three data sets. As such, two conversion factors were determined: one using all four data sets available, and one which excluded the Korean data set. The conversion factor derived from all four data sets predicts a lower weight than the conversion factor derived from the GAB, CSIRO and 40-fish data sets.

Information on the methods used to collect individual length-weight measurements of SBT onboard Korean longliners was not available through the CCSBT data exchange. For example, the data set provides no information on whether the weight measurements of these SBT were taken before or after bleeding. Weight measurements taken after bleeding would not be directly comparable with weight measurements in the other available data sets. This could possibly account for why SBT measured by the Korean longline fleet were generally of lesser weight per given length than SBT in the other data sets. Furthermore, there is no information on how long SBT weights were taken after death. *Post mortem* shrinkage in length is a common phenomenon in fishes (Morison et al. 2003, Morison 2004), whereby contraction in total length over time increases the weight per given length. Shrinkage can begin to occur within the first 1–2 hours after death, so it is possible that shrinkage would begin even before a longline is hauled back on deck, not taking into account the length of time a fish is left on deck before measurement. Given this uncertainty associated with the Korean data set, a more conservative approach would exclude this data set from a single conversion factor applied to the Australian ranch sector.

Interim and longer-term options

The ideal data set on which to base a length-weight conversion factor in tandem with stereo-video for Australia's SBT ranch sector would include contemporary data obtained directly from the fishing grounds in the GAB. Although a review panel reached no definitive conclusion regarding weight loss during the tow (Fushimi et al. 2006), use of length-weight data collected directly from the GAB fishing grounds would avoid any potential impact of the tow back to ranching sites near Port Lincoln. None of the currently available data sets meet this requirement. However, in the longer term, a large amount of length-weight measurements from numerous fishing grounds will become available to the CCSBT courtesy of the Catch Documentation Scheme (CDS), to be implemented 1 January 2010. The *Resolution on the implementation of a CCSBT Catch*

Documentation Scheme (www.ccsbt.org) specifies that length and weight measurements be taken from every SBT commercially fished after 1 January 2010. One long-term option for a stereo-video conversion factor is for CCSBT to annually calculate a contemporary length-weight relationship, based on data submitted during the previous fishing year through the CDS. If this were to be agreed, then data collection protocols should include instructions for recording whether weight measurements were made prior to or after bleeding so that appropriate corrections could be made. In the interim, before implementation of the CDS and agreement among members and non-members on the use of length-weight data for such a purpose, a conservative option is to apply the conversion factor derived from the GAB, CSIRO and 40-fish sample data sets ($W = 2.64217 \times 10^{-5} L^{2.933509}$). This could be updated on an annual basis with new 40-fish sample data and any length-weight measurements from potential commercial poling ventures in the GAB. Final adoption of a length-weight conversion factor will involve consultation with Australia’s SBT ranching industry and other stakeholders in keeping with the Australian Government’s domestic fishery management practices.

References

Aguado-Gimenez F, Garcia-Garcia B (2005) Changes in some morphometric relationships in Atlantic bluefin tuna (*Thunnus thynnus* Linnaeus, 1758) as a result of fattening process. Aquaculture **249**:303–309

Andrade HA, Campos RO (2002) Allometry coefficient variations of the length-weight relationship of skipjack tuna (*Katsuwonus pelamis*) caught in the southwest South Atlantic. Fisheries Research **55**:307–312

Anon (2008) Annual Status Report: Heard Island and McDonald Islands Fishery. Australian Fisheries Management Authority, Canberra

DSI-Consulting (2007) Review of southern bluefin tuna catch monitoring procedures, CCSBT/ESC/0609/Info03. Eleventh annual meeting of the Extended Scientific Committee of CCSBT, 12–15 September 2007, Tokyo

Farley JH, Gunn JS (2007) Historical changes in juvenile southern bluefin tuna *Thunnus maccoyii* growth rates based on otolith measurements. Journal of Fish Biology **71**:852–867

Fulton TW (1904) The rate of growth of fishes. Fisheries Board of Scotland, Annual Report 22 Part 3, pp. 141–241

Fushimi H, Yamakawa T, O'Neill T, Battaglene S (2006) Independent review of Australian SBT farming operations anomalies. Independent report to CCSBT

Gerritsen HD, McGrath D (2007) Significant differences in the length-weight relationships of neighbouring stocks can result in biased biomass estimates: examples of haddock (*Melanogrammus aeglefinis*, L.) and whiting (*Merlangius merlangus*, L.). Fisheries Research **85**:106–111

Harvey E, Cappo M, Shortis M, Robson S, Buchanan J, Speare P (2003) The accuracy and precision of underwater measurements of length and maximum body depth of southern bluefin tuna (*Thunnus maccoyii*) with a stereo-video camera system. Fisheries Research **63**:315–326

Hearn WS, Polacheck T (2002) Estimating long-term growth-rate changes of southern bluefin tuna (*Thunnus maccoyii*) from two periods of tag-return data. Fisheries Bulletin, **101**:58–74

Hsu CC, Liu HC, Wu CL, Huang ST, Liao HK (2000) New information on age composition and length-weight relationship of bluefin tuna, *Thunnus thynnus*, in the southwestern North Pacific. Fisheries Sciences **66**:485–493

Katavic I, Ticina V, Franicevic V (2002) Rearing of small bluefin tuna (*Thunnus thynnus* L.) in the Adricatic Sea. Preliminary study. In: Bridges CR, Gordin H, García A (eds) Proceedings of the 1st International Symposium on DOTT, Cah. Options Méditerr. Vol. **60**:95–99

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

Morison A K (2004) Is *rigor mortis* the cause of *post-mortem* shrinkage in juvenile *Pagrus auratus*? Journal of Fish Biology **65**:883–888

Morison AK, Brown IW, Jones GK (2003) *Post mortem* shrinkage of four species of temperate and tropical marine fishes, without freezing or preservation. Journal of Fish Biology **62**:1435–1449

Phillips K, Rodriguez VB, Harvey E, Ellis D, Seager J, Begg G, Hender J (2009) Assessing the feasibility of stereo-video and evaluating monitoring options for the Southern Bluefin Tuna Fishery ranch sector, FRDC 2008/044. Fisheries Research and Development Corporation, Canberra

Polacheck T, Eveson JP, Laslett GM (2004) Increase in growth rates of southern bluefin tuna (*Thunnus maccoyii*) over four decades: 1960 to 2000. Canadian Journal of Fisheries and Aquatic Sciences **61**:307–322