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Assessing the operational feasibility of stereo-video and evaluating monitoring options for the Southern Bluefin Tuna Fishery ranch sector

K. Phillips, V. Boero Rodriguez, E. Harvey, D. Ellis, J. Seager, G. Begg, J. Hender

Project No. 2008/044

2008/044 Assessing operational feasibility of stereo-video and evaluating monitoring options for the Southern Bluefin Tuna Fishery ranch sector

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OBJECTIVES:
1. Assess the accuracy and precision of stereo-video length measurements obtained under operational conditions
2. Develop statistically robust sample sizes and sampling regimes that will collect a subset of stereo-video length measurements representative of the length distribution in a transfer
3. Assess the robustness and suitability of the stereo-video equipment in operational conditions
4. Develop options for converting stereo-video length measurements into weight estimates

Non technical summary

Outcomes achieved to date

Outcomes of this project are an assessment of the accuracy and precision of length measurements of southern bluefin tuna (SBT) obtained from a commercially leased stereo-video camera during transfer between ranch pontoons; an assessment of the physical robustness of the stereo-video camera unit; four sampling regimes that may be applied by management to stereo-video length measurements of SBT obtained during transfer; and a list of options for converting stereo-video length measurements of SBT to weight estimates for catch acquittal purposes.

Background and experimental set-up

This report provides results from field trials designed to test the accuracy, precision and robustness of stereo-video cameras under at-sea research transfer conditions in Australia's southern bluefin tuna (SBT) ranching sector.

In late March 2008, 563 SBT were transferred from a commercial tow pontoon to a holding pontoon on a lease site in Spencer Gulf near Port Lincoln. Of these, 474 SBT were measured with calipers and transferred into the first of two research pontoons prior to transfer. A subset (*n* >30) were individually marked with colour-coded tailstrops that were visible in stereo-video footage. These tailstropped SBT were also measured using a fish-measuring cradle. Differences in caliper and cradle measurements of direct length ranged from 0 to 12 cm.

Between 7 and 9 April 2008, 16 transfers comparable to commercial transfers were conducted between the two research pontoons under variable environmental conditions. All 16 transfers were successfully recorded by a commercially leased stereo-video camera mounted on the transfer gate.

Physical robustness in operational conditions

The stereo-video camera was easily mounted on the transfer gate, recorded all 16 transfers without interruption, remained calibrated throughout the trials and proved robust under operational conditions.

Accuracy and precision of stereo-video length measurement

Manual measurements of SBT fork length (FL, cm) were obtained from stereo-video footage. Measurements were taken from multiple frames recorded of individual SBT as they swam through the transfer gate. Analysis of variance (ANOVA) of (a) mean length from multiple frames of individual SBT per transfer and (b) maximum length from multiple frames of individual SBT per transfer (using only frames in which SBT appeared to be straight, not flexing) revealed that, in most cases, stereo-video length measurement does not differ significantly among transfers.

Statistical models were developed to predict length distributions from (a) mean length from multiple frames of individual SBT per transfer, and (b) maximum length from multiple frames of individual SBT per transfer. Means of predicted lengths from the model based on stereo-video mean length from multiple frames differed by <3 cm from the mean of direct caliper length measurements. In 7 of 16 transfers, this difference was <1 cm, and in another 7 transfers this difference was 1 cm. Means of predicted lengths from the model based on stereo-video maximum length from multiple frames differed by 0–2 cm from the mean of direct caliper length measurements. In 3 of 16 transfers, this difference was <1 cm, and in 9 transfers this difference was <2 cm.

Sampling regimes

Until software capable of taking automated fish length measurements from stereo-video footage becomes available, a portion of SBT in a transfer may be sampled and used to predict the length distribution of the whole population in the transfer. Four sampling regimes were tested using stereo-video length measurements: simple random sample of 10% of the population (i.e. of all SBT recorded during transfer); systematic random sample of 10% of the population; simple random sample of 20% of the population; systematic random sample of 20% of the population. Differences between mean direct caliper length of the population and mean sample lengths were <2 cm regardless of sampling regime.

Options for converting stereo-video lengths into weight estimates

A list of available length-weight data pairs is provided, together with suggestions for future collection programs of length-weight data pairs. Data include length-weight pairs from fishing grounds in the Great Australian Bight, CCSBT data and conversion factors, and data from current monitoring practices.

Key words southern bluefin tuna · stereo-video · transfer · Commission for the Conservation of Southern Bluefin Tuna (CCSBT)

Acknowledgements

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Background

Over 99% of Australia's catch allocation of southern bluefin tuna (SBT, *Thunnus maccoyii*) is captured by purse-seine vessels in the Great Australian Bight and transported live to the tuna-ranching offshore zone in the Spencer Gulf near Port Lincoln, South Australia, for ranching in grow-out pontoons for up to 6 months before harvest (herein referred to as Australia's ranching sector) (Larcombe & Begg, 2008). Unlike other SBT fishing sectors (for example longlining) in which SBT are brought on deck, most SBT captured by the Australian industry for the ranching sector are not handled until harvest. As a consequence, length and weight data cannot be collected at the time of capture. Mean length and weight are instead based on a sample of 40 SBT of ≥10 kg from each tow pontoon as it arrives in Port Lincoln, and means from each tow pontoon are in turn scaled up to estimate Australian catch per quota year (*Southern Bluefin Tuna Fishery Management Plan 1995*). Although an independent review of Australia's ranching sector concluded that regulation of the industry is a rigorous and well-managed process, some members questioned Australia's system of calculating catches by the ranching sector at the 13th meeting of the Commission for the Conservation of Southern Bluefin Tuna (CCSBT13) (Anon, 2006a).

For a number of years, Australia has investigated monitoring and data validation measures that could be used to reduce uncertainties in catch calculation. Most research has been dedicated to the development and testing of stereo-video camera systems, which can be mounted on the transfer gate as SBT are transferred from tow pontoons into grow-out pontoons and thereby increase the amount of individual fish length data collected from Australia's ranching sector and hence improve estimation of catch.

Provisional work on stereo-video in an operational environment identified a number of issues (relating to hardware, deployment and sampling and measurement regimes) to be addressed before a decision can be reached on whether this technology can be used to monitor Australia's catch of SBT in the Great Australian Bight (Harvey et al., 2001, 2003a,b, 2005). In January 2007, the Australian Fisheries Management Authority (AFMA), responsible for the day-to-day management of Australia's SBT fishery, convened a Stereo-Video Working Group (SVWG) to develop a project to evaluate stereo-video technology. The SVWG concluded that the following were immediate priorities for determining the utility of stereo-video for ongoing monitoring of SBT catch:

- evaluation of the accuracy and precision of stereo-video under a range of conditions comparable to actual ranch transfer conditions, particularly with regard to variable light and water visibility
- evaluation of the accuracy and precision of stereo-video with a range of fish lengths
- assessment of the physical robustness of the equipment under operational conditions.

This report presents the results from the second year (Stage II) of a research project designed to address the above priorities identified by the SVWG by comparing direct measurements of SBT lengths with stereo-video measurements made under variable conditions in a research operational environment. Assessment of the accuracy and precision of stereo-video required that repeated measurements of both (a) individual SBT length and (b) length-frequency distributions of the population in a pontoon be taken from multiple transfers.

In December 2007, AFMA and the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) agreed to fund the stereo-video research project designed to address priorities identified by the SVWG. The Fisheries Research and Development Corporation (FRDC) also agreed in 2008 to contribute funds.

Need

Improvement of data verification is a serious issue for all SBT fisheries (Anon, 2006b). The issue of systemic biases in the catch monitoring system currently used in Australia's SBT ranch sector remains unresolved (Anon, 2006a), and there is a domestic and international need to improve confidence in the acquittal of SBT captured by Australia's surface fishery against the national catch allocation.

Stereo-video is the most likely candidate to complement or replace the existing catch monitoring system in Australia's SBT ranch sector. However, the accuracy and precision of stereo-video equipment under a range of conditions comparable to actual ranch transfer conditions must first be determined before implementation of the technology can be considered. Problems with the installation and physical robustness of the equipment identified during previous field trials must also be resolved.

Finally, there is a need to determine how stereo-video lengths could be converted to weights for catch acquittal, should implementation of this technology be considered further.

Objectives

The objectives of the Stage II (2008 field work) stereo-video research project were to:

1. assess the accuracy and precision of stereo-video length measurements obtained under operational conditions
2. develop statistically robust sample sizes and sampling regimes that will collect a subset of stereo-video length measurements representative of the length distribution in a transfer
3. assess the robustness and suitability of the stereo-video equipment in operational conditions
4. develop options for converting stereo-video fish length measurements into weight estimates.

Materials and methods

Capture and tagging of SBT

A 10 t research mortality allowance (RMA) of SBT allocated to Australia at CCSBT14 (Anon, 2007) was captured in the Great Australian Bight at around 33°27'S, 132°19'E between 17 February and 2 March 2008 as part of a larger commercial catch by the purse-seine vessel FV *Independence* and transferred into a tow pontoon. The SBT were then towed to Port Lincoln by the vessel FV *Salt River*, and on 19 March 2008 a 40-fish sample was taken from the tow pontoon to estimate mean weight of ≥10 kg SBT (verified by Protec Marine Pty Ltd in accordance with current catch reporting requirements). This 40-fish sample was observed by an AFMA representative. Based on the mean weight of 17.13 kg obtained from the 40-fish sample, a total of 563 SBT were transferred into a holding pontoon on 20 March to give an RMA of approximately 9.6 t.

On 27 and 28 March 2008, 474 SBT from the holding pontoon were caught using a baited hook and handline, tagged with conventional CCSBT dart tags, measured to the nearest 1 cm from the snout to the caudal fork (fork length, FL, cm) with a set of large calipers, and transferred via a stainless steel slide into the first of two research pontoons (32 m diameter) moored on a commercial lease site. The research pontoon configuration is shown in Figure 1. Note that research pontoons used in this study were smaller than typical commercial grow-out pontoons (40–45 m diameter).

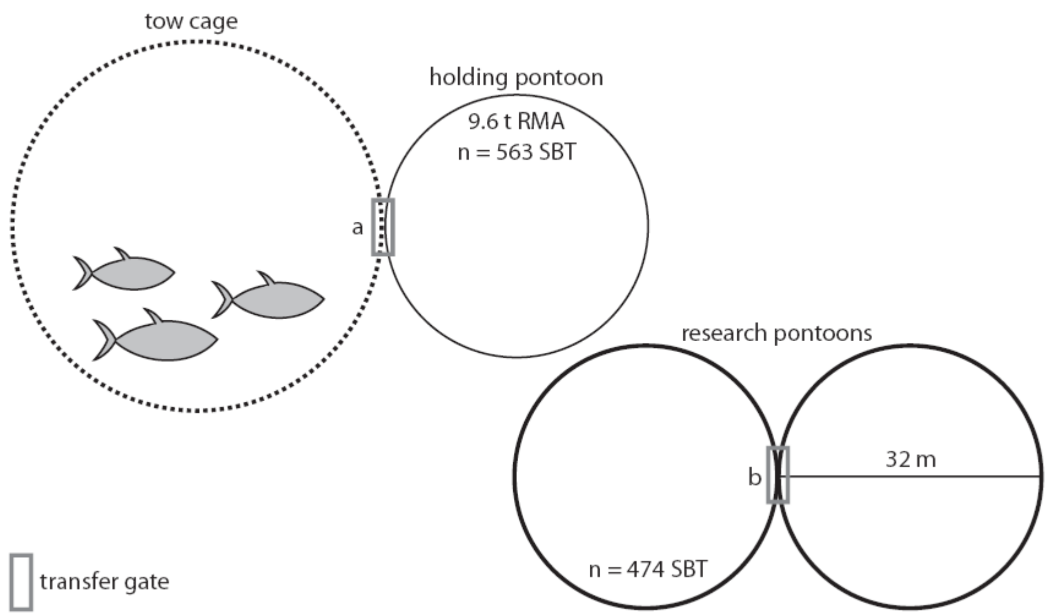


Figure 1. Transfer of SBT from the tow pontoon to research pontoons. Based on mean weight (17.13 kg) of the 40-fish sample taken from the tow pontoon on 19 March, 563 SBT were counted through transfer gate (a) by conventional underwater video. A subset (*n* = 474) was then hooked by handline, tagged with conventional spaghetti tags and transferred by stainless steel slide into the first of two 32 m diameter research pontoons. SBT were transferred multiple times (*n* = 16) through transfer gate (b) between 7 and 9 April.

Immediately before the first transfer on 7 April 2008, and again following the first transfer of 8 April 2008, a subset of the 474 SBT (n = 42) in the research pontoon were again caught by hook and handline, and colour-coded tailstrops attached around the caudal peduncle. A second set of length measurements were taken for these SBT using a fish-measuring cradle (as opposed to the calipers used on 27 & 28 March). The tailstrops were made of two lengths (short, long) of synthetic webbing (black, white, grey, red or yellow) (Figure 2). Each tailstrop could be individually identified in the stereo-video footage (see Figure 4), and allowed multiple measurements of individual SBT to be compared among multiple transfers. That is, in addition to comparing the length-frequency distribution of stereo-video measurements from multiple transfers against direct length measurements, the accuracy and precision of stereo-video could also be assessed from measurements of individual SBT. Several tailstrops fell off shortly after attachment, and data were attained for 36 SBT.

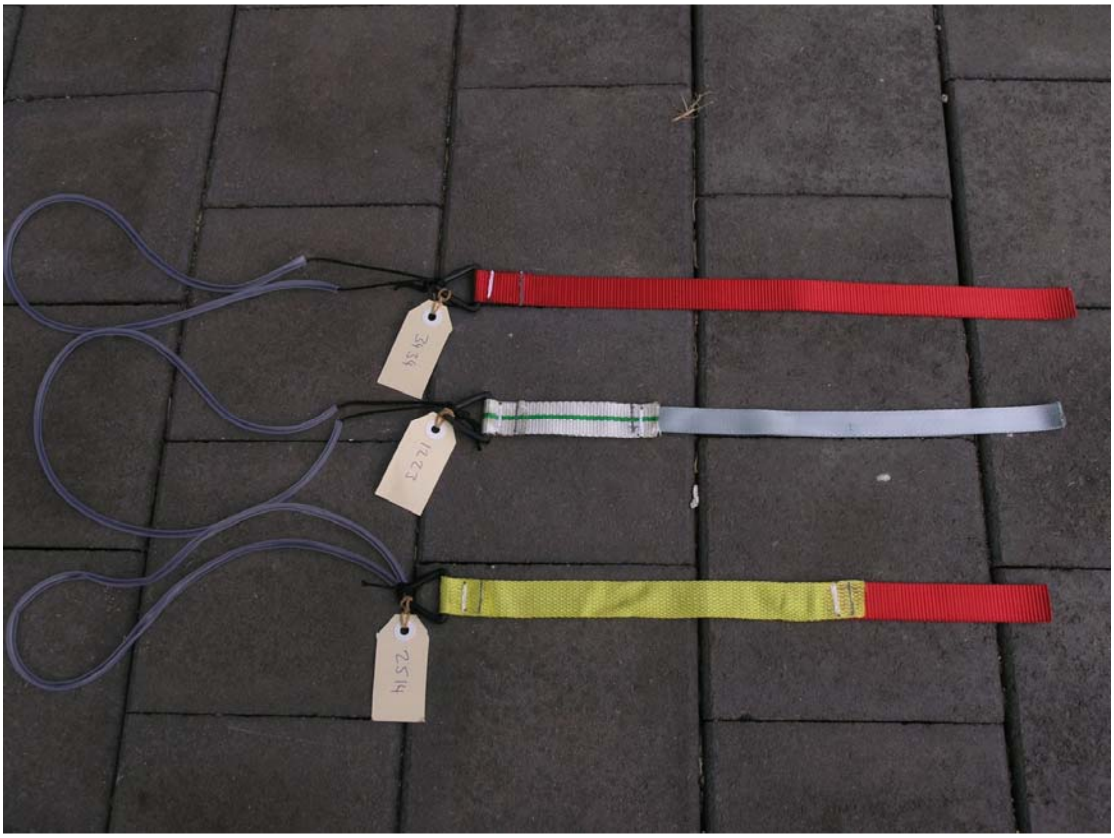


Figure 2. Colour-coded tailstrops, which were attached around the caudal peduncle to individually mark a subset of SBT in transfers.

Stereo-video camera

The camera system used to record the transfers was supplied by AQ1 Systems Pty Ltd and comprised two Pulnix TMC 1327 Gigagbit Ethernet (GigE) cameras, positioned approximately 700 mm apart and directed inward at 6° (Figure 3). This system, which also incorporated power converters and an Ethernet switch, was contained within an aluminium underwater housing and mounted on a bracket on the transfer gate. The cameras were connected to an onboard logging computer by a 30 m umbilical cord that supplied power and allowed communication and synchronisation between the computer and cameras. The computer was installed with MotionLogging software that automatically controlled image brightness (through gain and shutter speed adjustments) and logged frames only when SBT were detected within the field of view (see Harvey et al., 2003a). MotionLogging software was provided by SeaGIS Pty Ltd. Images were recorded in compressed Audio Video Interleaved (AVI) file format directly onto the computer's hard drive. A light logger was attached to the transfer gate so that light could be included as a continuous variable in subsequent analyses.

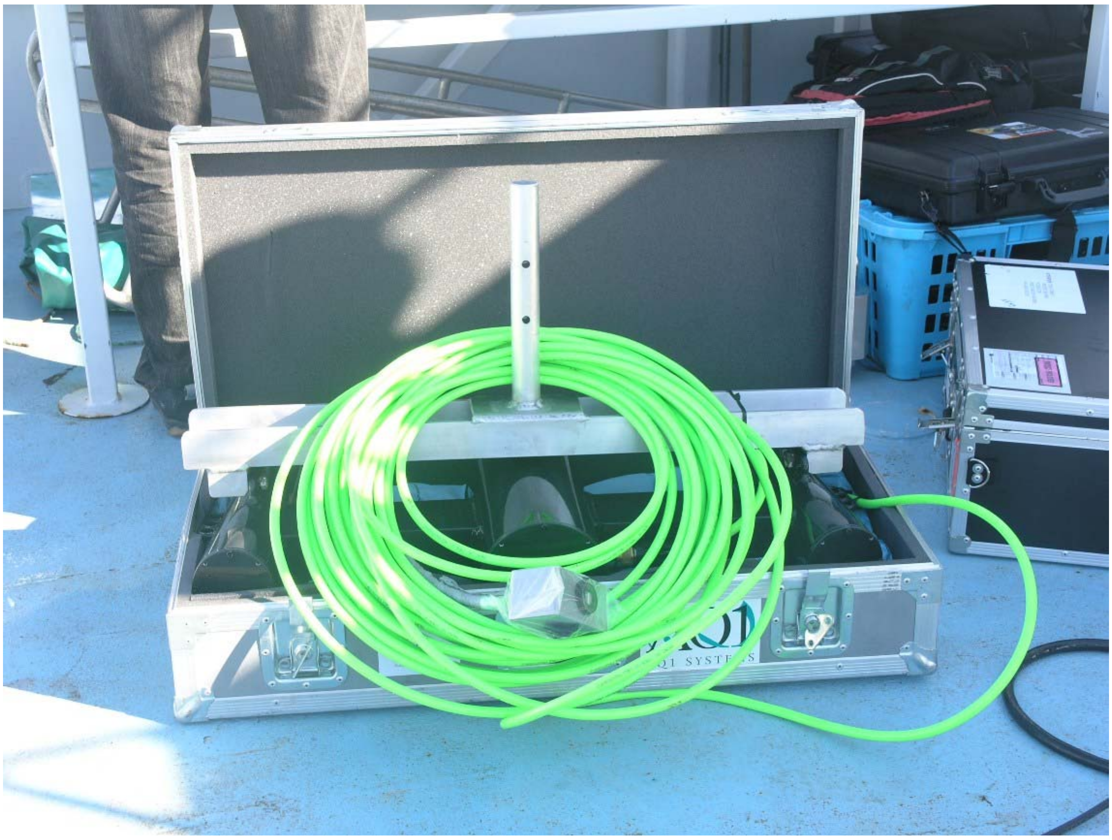


Figure 3. Commercially leased stereo-video camera system and 30 m umbilical chord

Calibration of stereo-video

The stereo-video was calibrated in the Port Lincoln Leisure Centre pool on 2 April 2008 as described by Harvey et al. (2002, 2003a). The calibration was performed by recording imagery of a 1 × 1 × 0.5 m purpose-built calibration frame and processing the images using the CAL software package (www.seagis.com.au/bundle.html). Subsequent measurements were completed using the PhotoMeasure photogrammetric measurement software (www.seagis.com.au/photo.html). The GigE stereo-video camera was calibrated with a network precision of 1:16 000 and average image residual of 0.12 pixels (Table 1).

Table 1. GigE camera configuration parameters

Item	Value	Precision
Base separation (X)	699.0019 mm	821 µm
Delta Omega	1.39968°	22”
Left Phi	–5.46119°	128”
Left Kappa	–2.08007°	95”
Right Phi	6.14435°	185”
Right Kappa	–0.81479°	78”

These results were verified using a calibrated scale bar (a) immediately after calibration and (b) *in situ* in the research pontoons (to check that cameras remained within reasonable calibration limits after deployment in an operational setting) (Table 2). The scale bar has an accurately calibrated length (908.7 ± 0.1 mm) between two circular reflective targets. Measurements of the scale bar provide an independent validation of the system’s calibration integrity, and give an indication of the best possible measurement accuracy the systems can achieve.

Table 2. Validation of stereo-video camera calibration; *n* = number of measurements of a 908.7±0.1 mm scale bar

Date	Location	n	Distance from camera	Mean (±SD) length of measurements
2 Apr 08	Port Lincoln pool, immediately after calibration	9	1.0–4.5 m	909.2±2.4 mm
8 Apr 08	*In situ*, mounted on transfer gate	10	1.3–2.1 m	910.6±0.9 mm
9 Apr 08	*In situ*, mounted on transfer gate	10[a]	1.6–3.4 m	909.0±1.5 mm

[a]Footage recorded after completion of final transfer on 9 April

Length measurement

Technicians did not have access to the caliper or cradle length measurements of the SBT in each transfer until they had completed all measurements. Therefore, manual measurements were not biased by *a priori* knowledge of the actual length distribution in the research pontoons.

Measurements of SBT length from the stereo-video imagery were made manually by up to four technicians (depending on the transfer) using PhotoMeasure. Two AVI files containing images from the left and right cameras were imported into PhotoMeasure, and paired images were synchronised using the time code recorded in the top left corner of each image. Measurements were made by manually locating the tip of the lower jaw and the caudal fork (fork length, FL, cm) of the target SBT within the synchronised video streams using cursor positioning and mouse clicks. The two pairs of image coordinates were converted into coordinates in three-dimensional object space (x, y and z) and an estimator of the quality (root mean square residual, also known as residual parallax) and precision of the measurement logged. To obtain length measurements, the three-dimensional distances between consecutive point measurements (tip of the lower jaw and caudal fork) were computed automatically. The distance from the tip of the lower jaw to the central point between the camera lenses and the angle of the point of interest relative to the camera centres were also automatically computed (Figure 4). In each transfer a number of SBT were partially or completely obscured by other SBT, whereby either the tip of the lower jaw and/or caudal fork could not be viewed. Measurements of these obscured SBT were discarded (see Table 8 for proportions of recorded and measurable SBT per transfer). For those SBT without tailstrops, measurements were only taken from frames in which the SBT appeared to be straight (i.e. body not flexed); up to five measurements were taken for individual SBT without tailstrops per transfer (see Harvey et al., 2003b). For those SBT with tailstrops, the maximum number of measurements were taken ($n \leq 16$) regardless of whether the SBT appeared to be straight or flexing. This allowed comparison of minimum, median, mean and maximum length measurements of individually marked SBT to be compared among transfers.

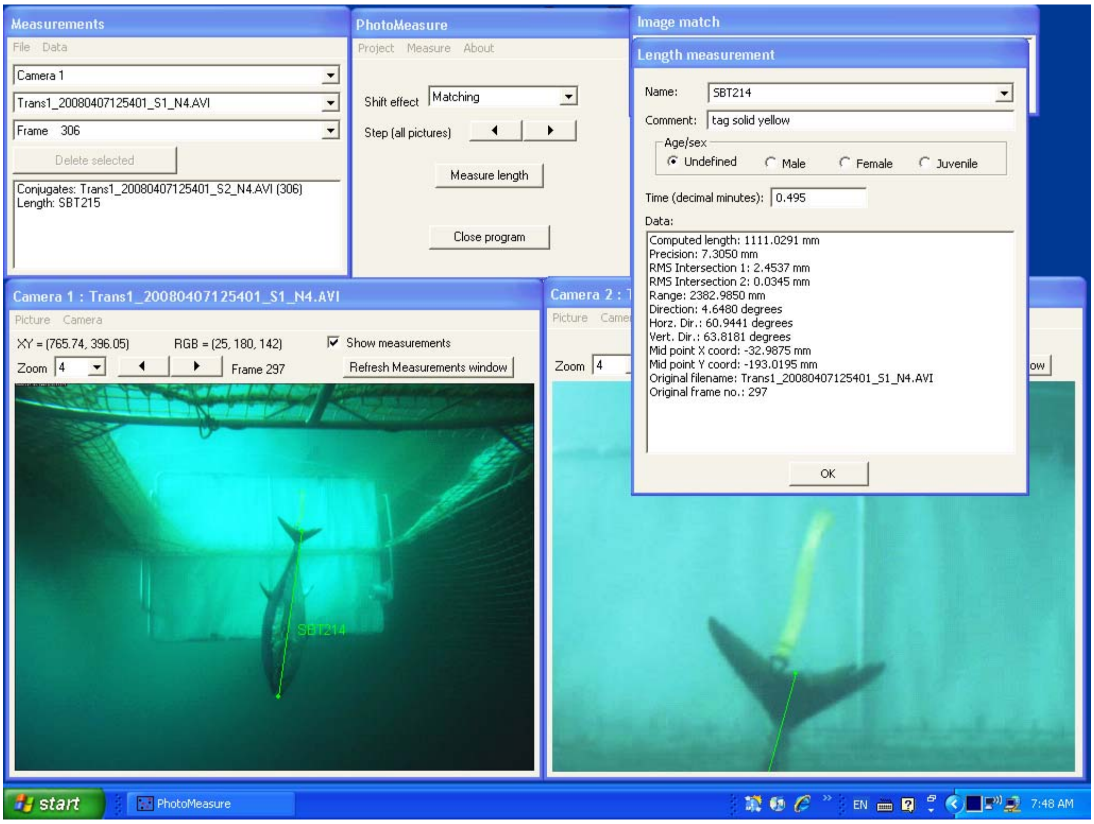


Figure 4. Measurement of an SBT from stereo-video footage using PhotoMeasure. This SBT was individually marked by a colour-coded tailstrop (solid yellow) attached around the caudal peduncle.

Statistical analysis

Analysis of variance (ANOVA) was used to test for differences in stereo-video length measurements of individual tailstropped SBT among transfers. In addition, box plots of minimum, maximum, mean, and 25th and 75th percentiles were drawn to compare distributions of direct caliper length measurements against distributions predicted from stereo-video length measurements using a series of statistical models, and distributions predicted from a selection of these models using one of four sampling regimes. Proportion histograms of stereo-video length measurements per transfer are given in Appendix 2a.

Modelling stereo-video length measurements of tailstropped SBT

The tailstropped (i.e. individually marked) SBT were used to test the effect of technicians and variable light on stereo-video length measurements through a series of models that predicted direct fish lengths from the stereo-video length measurements. Such predicted lengths can be converted to weights and used to estimate total catches.

The mean light measurement from the light logger mounted on the transfer gate was calculated for each transfer, and the following linear regression model fitted:

$$\textit{Direct caliper length} = \alpha + \beta_1 \textit{stereo-video mean length} + \beta_2 \textit{light} + \beta_3 \textit{technician} + \varepsilon \qquad (1)$$

where α, β_1, β_2 and β_3 are the regression parameters and ε the standard error, which are assumed to have a Gaussian distribution, be independent of each other and with a mean of zero and variance of σ^2.

The technician effect was found to be non-significant and so was deleted from the model. Other models tested included random effects for individual SBT, transfer, technician and some combinations of all, but all variables proved to be non-significant.

The model in Eq. (1) was then fitted without the technician effect:

$$\textit{Direct caliper length} = \alpha + \beta_1 \textit{stereo-video mean length} + \beta_2 \textit{light} + \varepsilon \qquad (2)$$

The diagnostics for Eq. (2) were acceptable and the assumptions seemed to hold (Appendix 1a). The R^2-value of this model was 98% and residuals ranged from –3.3 to 3.2 cm. Table 3 gives the model parameters for Eq. (2), which indicate that the intercept was non-significant while the two main effects were highly significant.

Table 3. Parameters for Eq. (2)

	Parameter	Error	p-value
Intercept	0.4620	0.6675	0.4890
Stereo-video mean length	0.9780	0.0068	<0.0001
Light	0.0126	0.0027	<0.0001

Although light was significant, we decided to remove this variable and re-run the model to see how it was affected:

$$\textit{Direct caliper length} = \alpha + \beta_1 \textit{stereo-video mean length} + \varepsilon \qquad (3)$$

The diagnostics for Eq. (3) were again acceptable and the assumptions seemed to hold (Appendix 1b). The R^2-value for Eq. (3) was 98%, and residuals ranged from –3.6 to 3.3 cm. That is, Eq. (3) fitted the data very well and was simpler than Eq. (2), and hence was the accepted model. Table 4 gives the model parameters for Eq. (3), indicating that the intercept and main effect were significant.

Table 4. Parameters for Eq. (3)

	Parameter	Error	p-value
Intercept	1.3493	0.6592	0.0415
Stereo-video mean length	0.9751	0.0070	<0.0001

Multiple frames of individual SBT: which measurement is best?

One of several foreseen applications of stereo-video technology involves the gradual replacement of manual measurement of stereo-video lengths with partially or fully automated measurement software. To automate the measurement of SBT lengths from stereo-video footage, it may be necessary to measure all frames in which an SBT appears with no capacity for discriminating between frames in which an SBT appears to be straight and frames in which it is flexing. If automated software calculates the mean length measurement of an SBT from multiple frames, then the mean will be biased by any frames in which the SBT is flexing. An option may be to identify the maximum length of an SBT from multiple frames. Therefore, it was decided to fit the model in Eq. (2) with the maximum length of individual tailstropped SBT from each transfer instead of mean length:

$$\textit{Direct caliper length} = \alpha + \beta_1 \textit{stereo-video maximum length} + \beta_2 \textit{light} + \varepsilon \qquad (4)$$

The diagnostics for Eq. (4) were not as good as those of the previous models. The distribution of the residuals has a slightly heavier lower tail. However, this is to be expected when the maximum is used because the model tends to underestimate length (Appendix 1c). The R^2-value for this model was 95% and residuals ranged from –7.5 to 5.0 cm. Table 5 gives the model parameters for Eq. (4), indicating that the intercept and main effects were significant.

Table 5. Parameters for Eq. (4)

	Parameter	Error	p-value
Intercept	3.0097	1.1546	0.0096
Stereo-video max. length	0.9327	0.0115	<0.0001
Light	0.0128	0.0047	0.0072

We again decided to simplify the model by deleting the light variable such that:

$$\textit{Direct caliper length} = \alpha + \beta_1 \textit{stereo-video maximum length} + \varepsilon \qquad (5)$$

The residuals did not deteriorate to a great extent when light was removed from the model (Appendix 1d). The R^2-value for this model was 95% and residuals ranged from –8.1 to 5.3 cm. Table 6 gives the model parameters for Eq. (5), indicating that the intercept and main effect were significant.

Table 6. Parameters for Eq. (5)

	Parameter	Error	p-value
Intercept	3.9085	1.1164	0.0005
Stereo-video max. length	0.9299	0.0116	<0.0001

Results

Transfers

The first transfer between the two research pontoons was conducted in overcast conditions (7/8 cloud cover) around midday, 12:40 to 13:10 h, on 7 April 2008. Although all SBT were transferred successfully, it was decided that the method of transfer and vessel configuration could be improved and trials were suspended until the following day. On 8 April, 11 transfers were completed between 10:20 and 16:00 h in bright conditions with variable cloud cover (3/8 to 7/8 cloud cover). A final four transfers were conducted on 9 April between 09:00 and 10:15 h in mainly clear conditions (1/8 to 2/8 cloud cover). Two 9 × 6 m shade cloths were positioned on the surface of the water on either side of the transfer gate during these final four transfers in an attempt to dissipate and dampen the light and increase the environmental variability under which the transfers were recorded. Mean light levels recorded during each transfer are given in Figure 5.

Some mortalities were recorded between the time of tagging and the final transfer: 426 SBT were transferred on 7 April, and the final transfer of 9 April comprised 385 SBT (n = 41 mortalities; see Table 8).

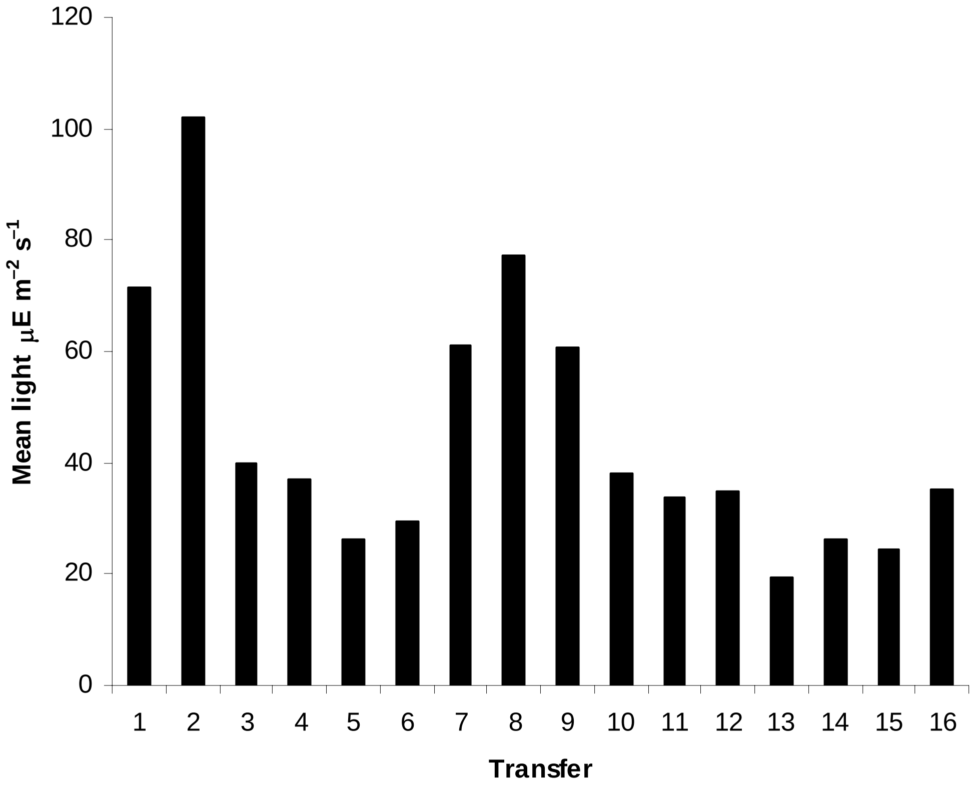


Figure 5. Mean light recorded during each transfer.

Physical robustness in operational conditions

All 16 transfers were successfully recorded by the stereo-video camera on the transfer gate. The system was small and easily managed by one person (Figure 6), and could be mounted on a bracket on the transfer gate within a matter of minutes. No problems were encountered with power supply or image recording during any of the transfers, and the cameras remained calibrated after the system was deployed on the research pontoon (see Table 2). The 30 m cable used during these trials required that the vessel with onboard computer be within ~20 m of the transfer gate. However, with enough lead time, a 70 m cable can be ordered from the USA. The camera housing proved to be robust, with no visible damage reported after 16 transfers.

Figure 6. Stereo-video camera being retrieved from the transfer gate.

Direct length measurements

Mean and median lengths measured with calipers were identical to the nearest cm, and ranged from 98 cm (Transfers 13 to 16) to 99 cm FL (Transfers 1 to 12). Standard deviations were always 11 cm. The largest SBT in Transfers 1 to 12 was 129 cm FL, and that in Transfers 13 to 16 was 127 cm FL. The smallest SBT in all transfers was 72 cm FL.

Unlike data collected during previous stereo-video trials (Harvey et al., 2001, 2003a,b, 2005; Hender & Findlay, 2007), direct length measurements were taken from live SBT rather than SBT killed after harvest. The difficulty in measuring live SBT lead to some errors in direct length measurements, as can be seen in a comparison of caliper and cradle length measurements of SBT tagged with tailstrops (Table 7). Differences between caliper and cradle measurements ranged from 0 to 12 cm as a consequence of human error introduced when handling large, live fish that are not anaesthetised. When comparing the accuracy and precision of stereo-video measurements of tailstropped SBT, those SBT with length discrepancies of ≥4 cm were excluded from analyses (n = 5).

The accuracy/variability of direct length measurements must be considered foremost in any discussion of the accuracy and precision required for potential implementation of stereo-video in Australia's SBT ranching sector.

Table 7. Difference (cm) in caliper and cradle length measurements of SBT individually marked with tailstrops (*n* = 36 SBT)

SBT tailstrop ID	caliper cm	cradle cm	difference cm	SBT tailstrop ID	caliper cm	cradle cm	difference cm
1124	97	97	0	1325	88	90	2
1523	100	100	0	1421	81	83	2
2215	89	89	0	1521	91	93	2
2311	84	84	0	1522	94	96	2
2312	107	107	0	2112	107	109	2
2514	90	90	0	2211	107	109	2
3232	84	84	0	2214	98	100	2
1123	83	84	1	2411	89	91	2
1223	79	80	1	2513	84	86	2
1425	102	103	1	3333	107	109	2
1524	99	100	1	2114	94	97	3
2113	100	101	1	2213	96	99	3
2115	95	96	1	2511	105	108	3
2315	84	85	1	1324	97	93	4
3131	81	82	1	1225	93	98	5
3434	87	86	1	1122	90	96	6
1125	99	101	2	3535	102	113	11
1221	88	90	2	2512	100	112	12

Stereo-video measurements

Scale bar

An ANOVA on repeated measurements (*n* = 9–10) of the scale bar immediately after calibration in the Port Lincoln swimming pool (2 April) and in the pontoons on 8 and 9 April (Table 2) revealed no significant difference in calibration. This indicates that the system was robust to transportation and deployment on the transfer gate and that the calibration of the system was stable and applicable to all 16 transfers.

Proportion of SBT measured per transfer

The stereo-video camera was not able to film all SBT swimming through the transfer gate. At the beginning of Transfer 1 several SBT swam between pontoons before divers were able to notify personnel on board that the transfer gate had been opened, and in all transfers a small proportion of SBT swam through the gate without passing through the field of view of the motion detector[1]. As a proportion of total SBT in each transfer, 74–95% were recorded by stereo-video, and measurements were obtained for 53–90% (Table 8). Measurements could not be made for every SBT recorded in the stereo-video footage owing to obstruction by other SBT or flexing of an SBT as it swam through the transfer gate. Measurements could be taken from >90% of recorded SBT in

[1]Alteration to the field of view of the motion detector, or removal of the motion detector software, would allow 100% of SBT to be recorded (though not measured; see 'Sampling regimes' on page 25).

12 of 16 transfers, and measurements were obtained for >75% of total SBT in 13 of 16 transfers (Table 8).

Table 8. Number of SBT per transfer, number and % recorded by stereo-video (SV), number and % of recorded SBT that could be measured, and % of total SBT measured

Transfer	no. in transfer	no. recorded by SV	% recorded by SV	no. recorded SBT measured	% recorded SBT measured	% total SBT measured
T1[a]	426	371	87	367	99	86
T2	422	399	95	376	94	89
T3	412	381	92	369	97	90
T4	411	378	92	364	96	89
T5	410	369	90	346	94	84
T6	408	366	90	353	96	87
T7	407	370	91	339	92	83
T8	406	355	87	335	94	83
T9	406	314	77	241	77	59
T10	406	357	88	327	92	81
T11	406	299	74	217	73	53
T12	406	361	89	334	93	82
T13	385	336	87	322	96	84
T14	385	322	84	287	89	75
T15	385	313	81	280	89	73
T16	385	325	84	310	95	81

[a]All 4 technicians measured all SBT in Transfer 1 so that a technician effect could be tested. Results here are for Technician 1 only

Comparison among technicians

For Transfer 1, all four technicians made ≤5 manual measurements of individual SBT without tailstrops (and ≤16 manual measurements of tailstropped SBT) so that a technician effect could be tested. For each technician, mean length measurements were calculated for individual SBT using only frames in which an SBT appeared to be straight (i.e. body not flexed). Quantile-Quantile plots (QQ-plots) of each technician mean were then plotted against the direct caliper length measurements (Figure 7). In these plots the distributions of all technician measurements were similar to that of caliper measurements. Only Technician 1 seemed to produce quantiles slightly higher than the caliper measurements. To test the hypothesis that at least one of these distributions had a different median, a Kruskal-Wallis test was performed. The p-value of this test was 0.49; therefore, this hypothesis was rejected and the medians of these distributions were not considered to differ significantly from one another. It was concluded that there was no technician effect in Transfer 1, so for the remaining 15 transfers stereo-video length measurements were made by one technician only. Technician 1 measured Transfers 14, 15, 16 and the second half of Transfer 8; Technician 2 measured SBT in Transfer 1 only; Technician 3 measured transfers 2, 3, 4, 5, 6, 7 and the first half of Transfer 8; and Technician 4 measured Transfers 9, 10, 11, 12 and 13.

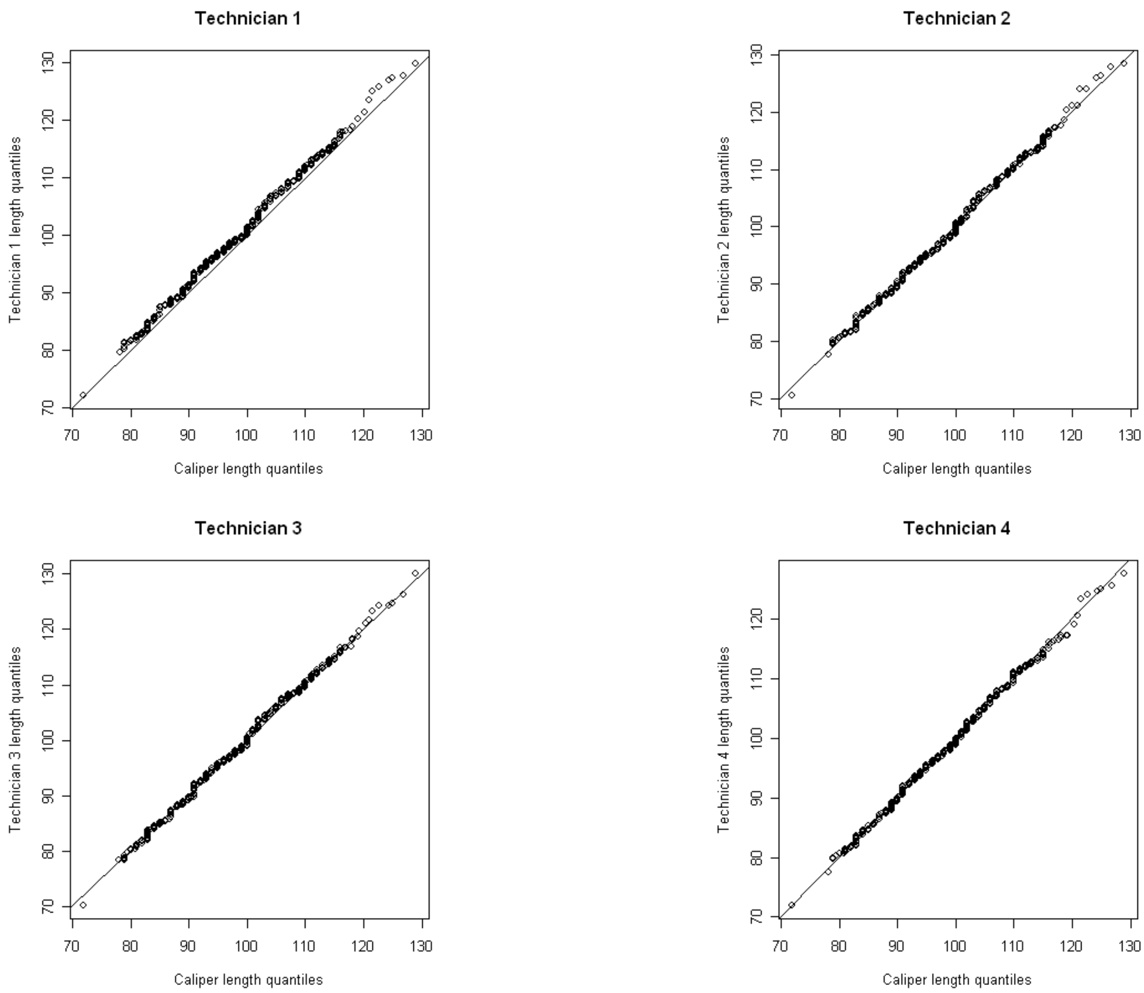


Figure 7. QQ-plots of direct caliper length measurements against mean stereo-video measurements (straight frames only) of individual SBT for each technician, Transfer 1.

Comparison of tailstropped SBT among transfers

The accuracy and precision of stereo-video length measurements of individual SBT were determined by comparing multiple measurements of tailstropped SBT among transfers.

The direct length of tailstropped SBT was measured using a cradle in addition to calipers, and some large discrepancies between these direct length measurements were recorded (Table 7). When these discrepancies were ≥4 cm, the tailstropped SBT were removed from analyses (*n* = 5, i.e. SBT with tailstrop IDs 1324, 1225, 1122, 3535 and 2512). The total number of observations of the 31 tailstropped SBT analysed for the 16 transfers was 332. The number of observations varied from transfer to transfer because in several transfers some tailstropped SBT were obscured by other SBT or did not pass through the field of view of the motion detector.

The distribution of (a) mean length from multiple frames of tailstropped SBT per transfer and (b) maximum length from multiple frames of tailstropped SBT per transfer were compared against both caliper and cradle direct length measurements in Figure 8. Stereo-video length measurements appeared to be more similar to cradle than caliper length measurements, suggesting that the latter were more erroneous. Distributions of mean lengths (Figure 8a) are in most cases more closely aligned with direct length measurements than are distributions of maximum length (Figure 8b) (e.g. Tailstrop ID 1521 in Figure 8). For many tailstropped SBT, the distribution of mean length measurements from multiple transfers was similar to or less than the difference between the two direct length measurements.

For most tailstropped SBT, stereo-video length measurements did not differ significantly among transfers (Table 9). When mean lengths from multiple frames per transfer were compared, a significant difference was observed for one SBT ($p < 0.05$). In this instance, mean lengths from 9 transfers differed by 0–5 cm from the direct lengths. Likewise, a significant difference was noted for one SBT when maximum length from multiple frames per transfer were compared ($p < 0.05$); for this SBT, maximum lengths from 7 transfers differed by 1–3 cm from the direct length.

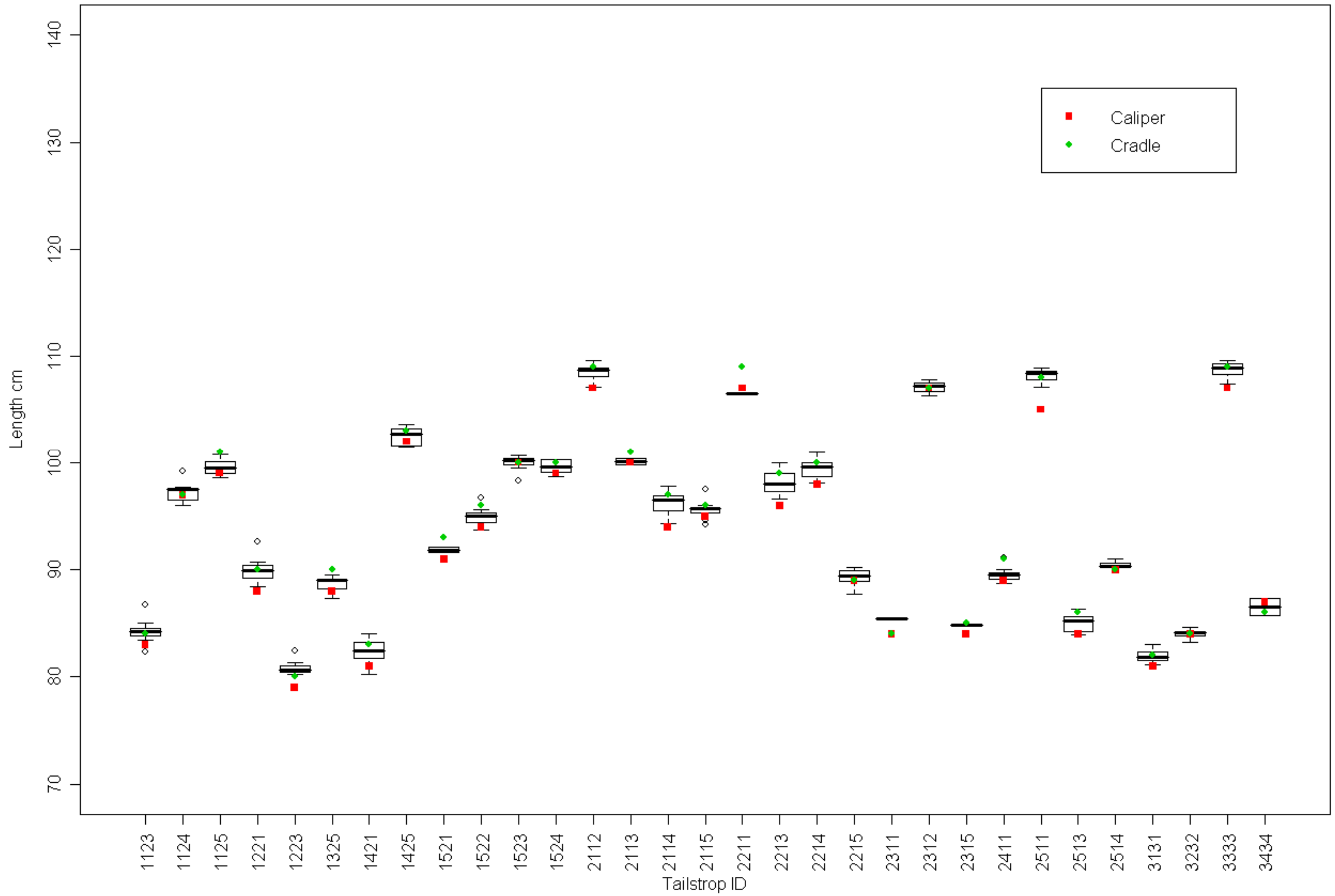


Figure 8a. Tailstropped SBT. Box plot of mean length of multiple frames recorded per transfer, compared with caliper (red square) and cradle (green circle) direct length measurements.

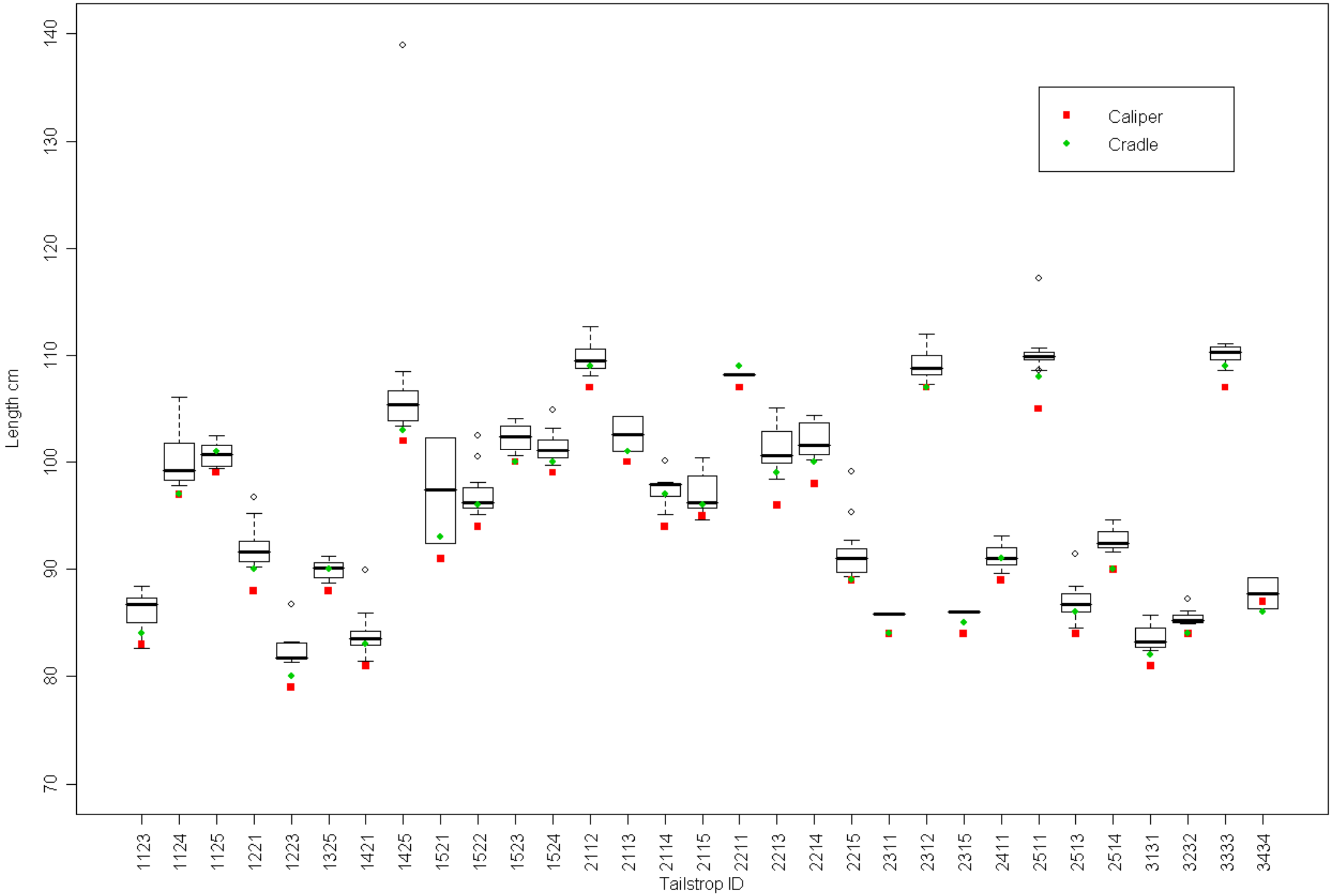


Figure 8b. Tailstropped SBT. Box plot of maximum length of multiple frames recorded per transfer, compared with caliper (red square) and cradle (green circle) direct length measurement

Table 9. ANOVA of stereo-video lengths of tailstropped SBT among transfers, comparing (a) mean length of individual SBT from multiple frames per transfer, and (b) maximum length of individual SBT from multiple frames per transfer. *, $p < 0.05$

Tailstrop ID	No. transfers	(a) Mean from multiple frames: significant?	(b) Max. from multiple frames: significant?
1123	13	–	–
1124	8	–	–
1125	8	–	–
1221	9	*	–
1223	10	–	–
1325	16	–	–
1421	13	–	–
1425	10	–	–
1521	2	–	–
1522	11	–	–
1523	11	–	–
1524	9	–	–
2112	12	–	–
2113	2	–	–
2114	7	–	–
2115	10	–	–
2213	13	–	–
2214	15	–	–
2215	16	–	–
2312	10	–	–
2411	10	–	–
2511	13	–	–
2513	13	–	–
2514	3	–	–
3131	12	–	–
3232	7	–	*
3333	11	–	–
3434	2	–	–

Modeled length distributions

In order to identify which model provides the best prediction of direct length distribution, four sets of length distributions were analysed and compared against direct measurements:

- stereo-video mean length of individual SBT per transfer
- stereo-video maximum length of individual SBT per transfer
- predicted length per individual SBT from Eq. (3)
- predicted length per individual from Eq. (5).

Box plots were drawn to analyse the distribution of these predicted values together with the direct caliper length measurements (Figure 9). The box plots were calculated per transfer because the number of SBT differed among transfers owing to mortalities. The model in Eq. (5) is the one that yields predicted values with the closest distribution to that of the direct caliper length distribution. However, there was little difference between distributions generated by Eqs. (3) and (5), and previous research on stereo-video length measurements of SBT indicated that mean rather than

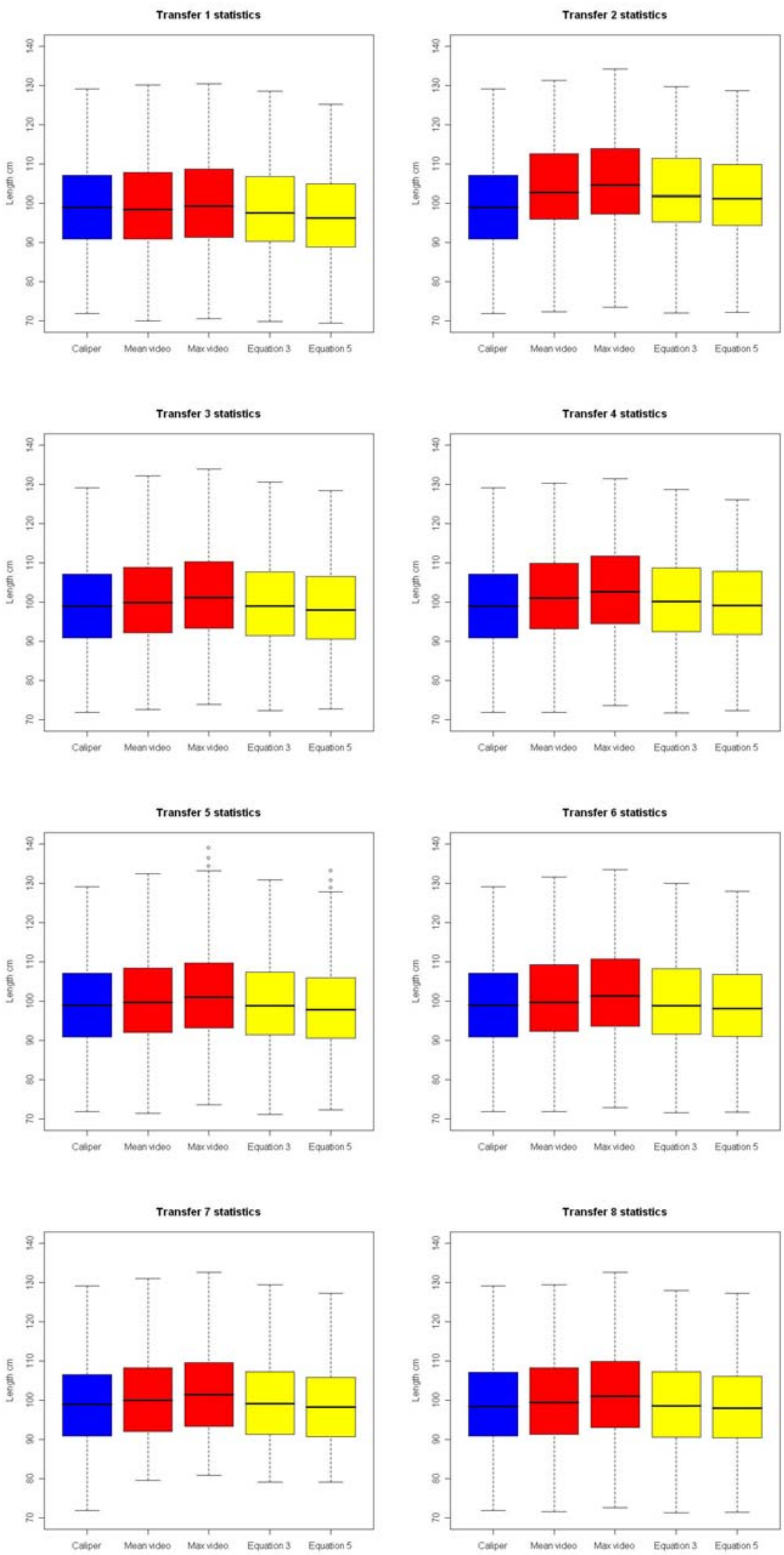


Figure 9. Direct caliper length distributions, distributions of stereo-video mean and maximum lengths from multiple frames of individual SBT per transfer, and predicted length distributions from Eqs. (3) & (5).

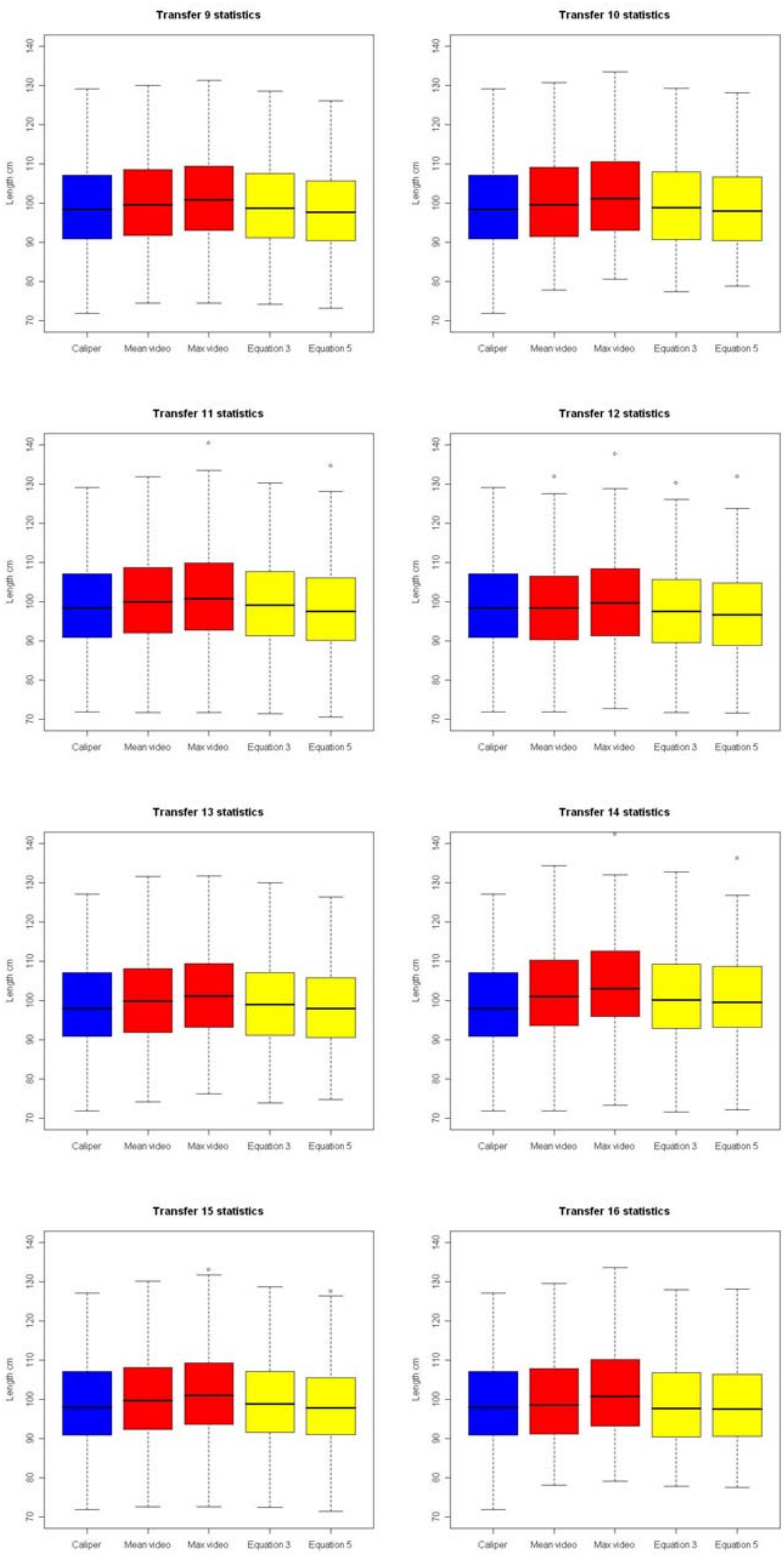


Figure 9. (cont'd) Direct caliper length distributions, distributions of stereo-video mean and maximum lengths from multiple frames of individual SBT per transfer, and predicted length distributions from Eqs. (3) & (5).

maximum length from multiple frames yields the most accurate length measurement (Figure 3. in Harvey et al., 2003a; see also Figure 8 herein).

Mean values from Figure 9 are also shown for comparison in Table 10.

Table 10. Mean direct length from caliper measurements, mean stereo-video length from multiple measurements per SBT, maximum stereo-video length from multiple measurements per SBT, and means predicted values per SBT from Eqs. (3) & (5). Means were calculated from all recorded and measured SBT in each transfer (i.e. not from tailstropped SBT only)

Transfer	Mean caliper length cm	Mean stereo-video length cm	Max. stereo-video length cm	Mean of model mean length (Eq. 3)	Mean of model max. length (Eq. 5)
T1	99	99	100	98	97
T2	99	103	105	102	101
T3	99	100	102	99	98
T4	99	101	103	100	100
T5	99	100	102	99	98
T6	99	100	102	100	99
T7	99	100	101	99	98
T8	99	100	101	99	98
T9	99	100	101	99	98
T10	99	100	102	99	98
T11	99	100	101	99	98
T12	99	99	100	98	97
T13	98	100	101	99	98
T14	98	101	104	101	100
T15	98	100	102	99	99
T16	98	99	101	99	98

Sampling regimes

In every transfer, a proportion of SBT will always be obscured by other SBT swimming closer to the stereo-video camera. It is unlikely that 100% of SBT in a transfer could be measured from the tip of the lower jaw to the caudal fork with the existing technology, at least on a consistent basis. To overcome this, sampling regimes can be developed so that a predetermined percentage of SBT is measured and used to predict the length distribution of the whole population in the transfer. If stereo-video is to be implemented as a catch monitoring tool in the future, it is important that this percentage of measurable SBT can be met in each and every transfer. In some aspects, the research transfers conducted during the current study were not representative of commercial transfers, notably in terms of the number of transfers conducted during a single day and the relatively short time between transfers: such factors are likely to have affected SBT behavior during transfer (particularly regarding schooling behavior and stratification by size with depth). However, as an indication, 53–90% of total SBT in each transfer could be measured during our study (Table 8).

Any sampling regime should be representative of the population of SBT in a tow pontoon. To avoid bias, every SBT must have the same probability of being measured. When testing sampling regimes for this study, two sampling methodologies were considered: a simple random sample and a systematic random sample. In a simple random sample of size n we select k SBT at random, while in a systematic random sample of size n of population size N, $k = N/n$ is calculated, an integer from 1 to k selected at random as the starting point and every kth measurable SBT is selected.

Because the number of SBT in a tow pontoon is large (usually well in excess of 5000 SBT, sometimes >10 000 SBT), it is possible to assume that the sample will be large and that the Central Limit Theorem applies. Therefore, the sample mean ($\hat{y}$) is approximately normally distributed with mean μ and variance σ^2/n, where μ is the population mean, σ^2 is the population variance and n is the sample size. Confidence intervals for the population mean are ($\hat{y} - z[\sigma \times \sqrt{n^{-1}}], \hat{y} + z[\sigma \times \sqrt{n^{-1}}]$), where z is 1.96, 2.33 and 2.58 for 95%, 98% and 99% confidence intervals, respectively. Hence, based on the variability in direct caliper length measurements (Table 11), the sample required to obtain a sample mean within e units of the population mean at α% confidence interval will be:

$$n_\alpha = (z_\alpha \frac{\sigma}{e})^2$$

Table 11. Sample size required for a predetermined error tolerance and confidence interval

Error tolerance *e* (cm)	Confidence %	Sample size (no. SBT)
1.0	99	749
1.5	99	333
2.0	99	187
1.0	98	611
1.5	98	271
2.0	98	153
1.0	95	432
1.5	95	192
2.0	95	108

The sample sizes in Table 11 were calculated from the mean and standard deviation of the direct caliper measurements of all SBT transferred into the research pontoons. These sample sizes are only an indication because the whole population mean and variance of tow pontoons arriving in Port Lincoln are neither sampled nor available for analysis. Uncertainty regarding the error tolerance will increase when direct length is estimated from stereo-video length measurements.

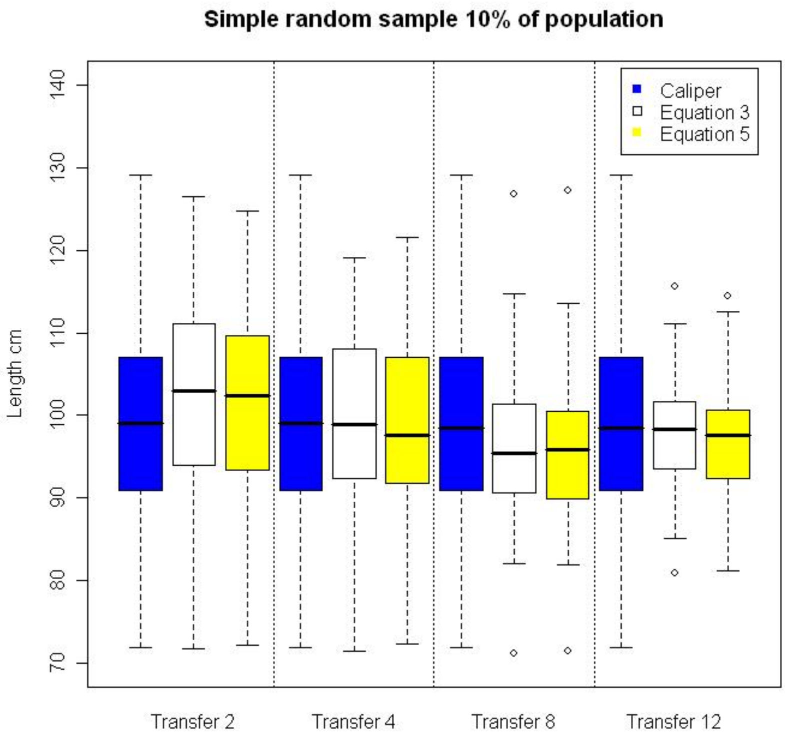
To give an indication of how well these sample sizes estimate the population mean, we considered all of the SBT measured with the calipers to be the population. Systematic and simple random samples of 10% and 20% of the population (stereo-video length measurements) were taken from four transfers, and box plots calculated. The samples were taken from Transfers 2, 4, 8 and 12, which were selected owing to their different characteristics:

- Transfer 2: many SBT swam back through the transfer gate and were potentially recorded and measured multiple times. Measurements of SBT swimming back through the transfer gate were removed from the data set, but multiple measurements of SBT without tailstrops swimming forward through the gate could not be identified or deleted. This can also happen during commercial transfers, so Transfer 2 was selected to represent a 'real-life' operational scenario

- Transfer 4: mean values of all stereo-video length distributions (of mean length of individual SBT from multiple frames; maximum length of individual SBT from multiple frames; and predicted values from Eqs. 3 & 5) were higher than mean direct caliper length. The mean of Eq. (5) was closest to mean direct caliper lengths
- Transfer 8: the mean of predicted values from Eq. (3) was the closest to mean direct caliper lengths
- Transfer 12: means of both Eqs. (3) and (5) were lower than mean direct caliper lengths.

Box plots of predicted length distributions generated from sampling 10% and 20% of the population are shown in Figure 10. Mean values are also shown for comparison in Table 12: differences between sample means and the population mean vary from 0 to 2 cm regardless of sampling regime. In terms of mean values, there seems to be little difference among sampling regime. Sampling 10% of the population will be more cost-effective and, until an automated system is available, faster. Systematic random sampling is likely to be easier to implement than simple random sampling.

Predicted length distributions are usually smaller in range than the distribution of direct length, but this varies among transfers (e.g. see Transfer 12, systematic random sampling of 20% of the population). Note that the population size and hence sample sizes are small owing to the small number of SBT in the research pontoons ($n < 474$). Numbers in commercial transfers vary between 1500 and 4000 (typically between 2200 and 2600; T. Jones pers. comm.). When greater numbers of SBT are included in the sample (i.e. during commercial transfer), the error between sample mean and population mean will decrease and confidence will increase (Table 11), countering any increased uncertainty in the measurement error of stereo-video length measurements. This could be tested in future field trials.



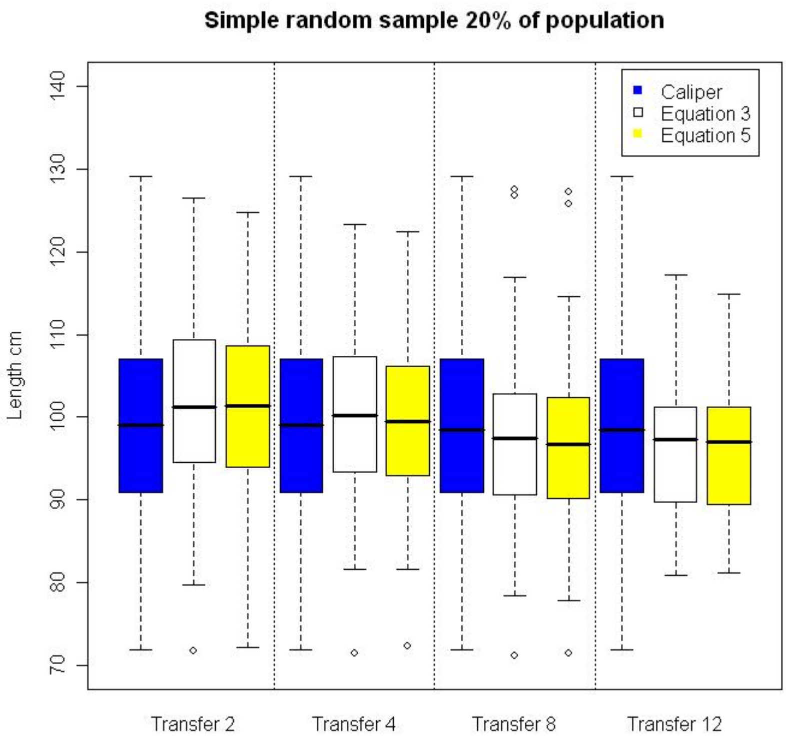
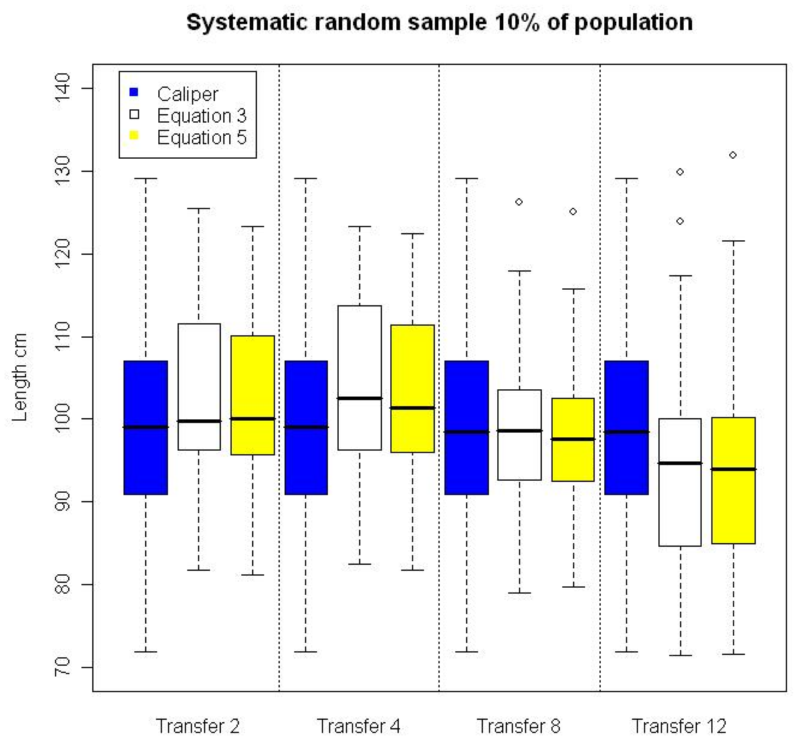


Figure 10. Distributions of direct length measurements and distributions generated from simple and systematic random sampling of 10% and 20% of the population (i.e. all SBT recorded in Transfers 2, 4, 8 and 12).



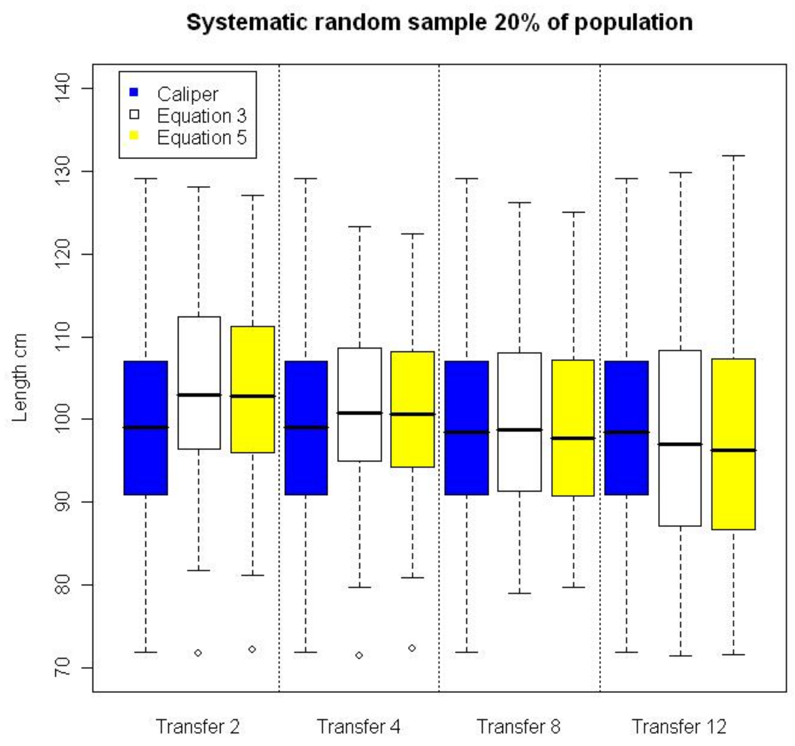


Figure 10. (cont'd) Distributions of direct length measurements and distributions generated from simple and systematic random sampling of 10% and 20% of the population (i.e. all SBT recorded in Transfers 2, 4, 8 and 12).

Table 12. Transfers 2, 4, 8 and 12. Mean direct caliper lengths, and mean stereo-video lengths, maximum stereo-video lengths, mean of values predicted by Eq. (3) and mean of values predicted by Eq. (5) under four sampling regimes: simple and systematic random sampling of 10% of the population; and simple and systematic random sampling of 20% of the population

Sampling regime	Transfer 2	Transfer 4	Transfer 8	Transfer 12
Mean direct caliper length cm	99	99	99	99
Simple random 10% of pop'n				
Eq. (3) mean	100	100	98	98
Eq. (5) mean	100	100	97	98
Systematic random 10% of pop'n				
Eq. (3) mean	100	101	98	100
Eq. (5) mean	100	101	97	99
Simple random 20% of pop'n				
Eq. (3) mean	100	99	99	98
Eq. (5) mean	100	98	99	97
Systematic random 20% of pop'n				
Eq. (3) mean	101	101	98	99
Eq. (5) mean	100	101	98	99

Options for converting stereo-video lengths to weights

Australia's national allocation of SBT is decremented by weight. If stereo-video is to be considered further as a catch monitoring tool, then SBT lengths obtained from stereo-video footage must be converted to SBT weight. Conversion factors may need to take into account potential changes in the length-weight relationship with age/size, as well as variability within and among fishing seasons. The following sets of length-weight data pairs from which conversion factors can be developed have been identified.

Existing length-weight data pairs

Data source: BRS; data collected directly from Great Australian Bight (GAB) fishing grounds

No. data pairs: n = 1781

Fishing season: 1987–88 to 1997–98

Description: data from SBT at capture, GAB

Advantage: this is the largest existing data set of length-weight pairs collected at capture, and will likely provide the most accurate conversion of SBT length to weight if it is assumed that the length-weight relationship hasn't changed significantly over the past decade

Disadvantage: possibly outdated; stock parameters may have changed since 1997–98 fishing season

Data source: CSIRO; data collected directly from GAB fishing grounds

No. data pairs: n = 109 (two data sets combined)

Fishing season: 2005–06 (n = 88); 2004–06 (n = 21)

Description: data from SBT at capture, GAB

Advantage: data obtained from the fishing grounds, unaffected by tow-back to Port Lincoln

Disadvantage: sample size small

Data source: 40-fish sample data

No. data pairs: n = 15859

Fishing season: 1995–96 to 2007–08

Description: 40-fish sample data collected through the current catch monitoring process after SBT are towed back from the GAB fishing grounds to Port Lincoln

Advantage: large sample size, collected throughout fishing season over many fishing seasons (including the most recent fishing seasons)

Disadvantage: potential weight loss during tow-back and potential biases in 40-fish samples

Data source: CCSBT data exchange (Republic of Korea)

No. data pairs: n = 616

Fishing season: 2006, 2007

Advantage: data obtained from longline fishing grounds

Disadvantage: it is possible that length-weight relationships have differed among longline fishing grounds and fishing grounds in the GAB

In addition, it may be possible to use the length-weight conversion factor currently applied by CCSBT to SBT under 130 cm (Robins, 1963). However, although the SBT used to develop this conversion factor were caught in Australian waters, the number of data pairs is unknown and it is highly likely that the growth rate and thus length-weight relationship of SBT migrating through the GAB has changed significantly since these data were collected.

Collection of new length-weight data pairs

It is possible that new length-weight data collection programs could be initiated to provide a length-weight conversion factor before implementation of stereo-video as a catch-monitoring tool is considered further. Plausible collection programs (which could be conducted by industry, AFMA observers, as part of existing catch-monitoring arrangements or separate research projects, or a combination) are listed below.

Data source: ongoing collection of length-weight data from SBT on the GAB fishing grounds

Advantage: these data would represent the length-weight relationship of SBT on the fishing grounds, provide the most accurate conversion of SBT length to weight, and reflect potential within- and among-fishing season changes in the length-weight relationship

Disadvantage: most expensive option; logistically more difficult than other options

Data source: ongoing collection of data through the 40-fish sample or similar sampling of SBT from tow cages on lease sites

Advantage: logistically easier and more cost-effective than data collection from the fishing grounds; this method could be used to obtain tow cage-specific length-weight relationships

Disadvantage: without additional data collection on the fishing grounds, weight loss during tow-back cannot be discounted. Hence, the validity of resultant conversion factors could not be assured

Data source: ongoing collection of data from juvenile SBT by foreign longline fleets

Advantage: with the agreement of other CCSBT members, data can be collected from juvenile (age 2, 3, 4) SBT outside the Australian Fishing Zone (as is already made available by the Republic of Korea through the CCSBT data exchange). This option is economical and would enhance collaboration between Australia and other CCSBT members.

Disadvantage: without additional data collection on the fishing grounds, the magnitude of differences in length-weight relationships among longline and GAB fishing grounds will remain unknown

Benefits

Results from our project provide stakeholders with confidence that commercially leased stereo-video cameras are physically robust and capable of recording accurate and precise length measurements of SBT during transfer. This project also provides one set of sampling regimes that will allow for flexibility in data provision for future field trials and, in the longer term, possible implementation of stereo-video as a catch-monitoring tool.

This project demonstrates effective collaboration between the Australian Government and industry to research new technology and methods for monitoring catch for an international fishery. It also demonstrates Australia's commitment to developing world's best practice techniques for the management of an aquatic natural resource.

Future field trials of stereo-video will rely heavily on the progress made through the current project and ongoing collaboration from industry.

Further development

Before full implementation of stereo-video may be considered, there is a need to simulate the commercial implementation of the technology and develop operational protocols from which to calculate aggregate catch within Australia's national allocation under CCSBT and meet AFMA's domestic management obligations to acquit SBT catch against individual statutory fishing right (SFR) holdings. Two issues in particular will need to be addressed in future trials:

1) Assessment under conditions of turbidity

Although the 16 transfers were conducted in conditions with variable light in April 2008, it was not possible to replicate the range of turbidity generally encountered during commercial transfers of SBT at Port Lincoln. Commercial transfers are conducted from tow cages (40–50 m diameter) into grow-out pontoons (also 40–50 m diameter). Tow cages can contain up to 200 t (>10 000 individual) SBT and are deeper than the 32 m diameter research pontoons used in this study. This number of fish and depth of the tow cage can lead to large amounts of sediment being stirred up, greatly reducing water clarity. Therefore, it may be necessary to assess the stereo-video camera during transfer from a commercial tow cage to a commercial grow-out pontoon to verify the accuracy and precision (e.g. using the scale-bar) under conditions more turbid than those experienced in the current study.

2) Testing of sampling regime: do assumptions hold when *n* is increased?

Sampling regimes developed in the current study could only be tested using small absolute population and sample sizes owing to the relatively small number of SBT (n < 474) in the research pontoons. Any future field trials of stereo-video will provide an opportunity to test the sampling regime using greater numbers of SBT under commercial transfer conditions, which should reduce the error between sample mean and population mean and increase confidence in the predicted distributions of length.

Other matters that need to be resolved before commercial implementation of the stereo-video technology include (but are not limited to): the number of stereo-video units required for an adequate, cost-effective catch monitoring system; the time required to obtain lengths from stereo-video footage and implications for management; and the conversion of stereo-video lengths to estimates of aggregate catch in weight.

Planned outcomes

Outputs from this project have allowed the assessment of priority issues associated with the use of stereo-video technology in the SBT ranch sector under a range of conditions comparable to commercial transfer conditions. Outputs have made a valuable contribution to the Australian Farm Study, progress on which has been reported to the CCSBT on an annual basis since 2007.

Conclusion

Field work for Stage II of the project "Assessing operational feasibility of stereo-video and evaluating monitoring options for the Southern Bluefin Tuna Fishery ranch sector" was completed in early April 2008. A commercially leased stereo-video camera successfully recorded 16 complete transfers of SBT between two research pontoons using a 9.6 t RMA allocated to Australia at CCSBT14 in October 2007. Length measurements obtained from the stereo-video system were compared against direct length measurements of live SBT. Results are summarised under the relevant project objective.

Objective 1. Assess the accuracy and precision of stereo-video length measurements obtained under operational conditions

- Measurements of a scale-bar on each day of the field trials showed that the stereo-video camera remained calibrated throughout deployment on the transfer gate.
- ANOVA comparing multiple stereo-video length measurements of tailstropped SBT among transfers revealed that stereo-video length measurements do not differ significantly among transfer for almost all SBT.
- Models were developed to predict length distributions from (a) mean length from multiple frames of individual SBT per transfer (Eq. 3) and (b) maximum length from multiple frames of individual SBT per transfer (Eq. 5).
- Means of length distributions predicted by Eq. (3) differed by 0–3 cm from the mean of direct caliper length measurements. In 7 of 16 transfers this difference was 0 cm, and in another 7 transfers this difference was 1 cm.

- Means of length distributions predicted by Eq. (5) differed by 0–2 cm from the mean of direct caliper length measurements. In 3 of 16 transfers this difference was 0 cm, and in 9 transfers this difference was 1 cm.
- Further discussion of the accuracy and precision of stereo-video and its suitability for implementation in Australia's ranching sector must also consider the error inherent in direct length measurements of live SBT. The variability of stereo-video measurements among transfers was within the bounds of the variability in direct length measurements of live SBT taken with calipers and cradles.

Objective 2. Develop statistically robust sample sizes and sampling regimes for stereo-video measurement

- Using Eqs. (3) and (5), four sampling regimes were tested: simple random sample of 10% of the population (i.e. all SBT recorded during transfer); systematic random sample of 10% of the population; simple random sample of 20% of the population; systematic random sample of 20% of the population.
- Differences between mean direct caliper lengths of the population and mean sample lengths were 0–2 cm regardless of sampling regime.
- Distributions of predicted lengths generated by sampling regimes will improve when the number of SBT in a transfer is increased to levels typical of commercial transfers.

Objective 3. Assess the robustness and suitability of the stereo-video equipment in operational conditions

- The stereo-video camera supplied by AQ1 Systems proved to be robust and easy to implement in operational conditions. The system remained calibrated throughout deployment on the transfer gate.

Objective 4. Develop options for the conversion of stereo-video length measurements to weight estimates

- A list of options for the conversion of stereo-video length measurements to weight estimates was compiled for future evaluation.

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Appendix 1

Raw data are confidential and will not be made publicly available.

Appendix 2

Staff

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Dr Jim Seager, SeaGIS
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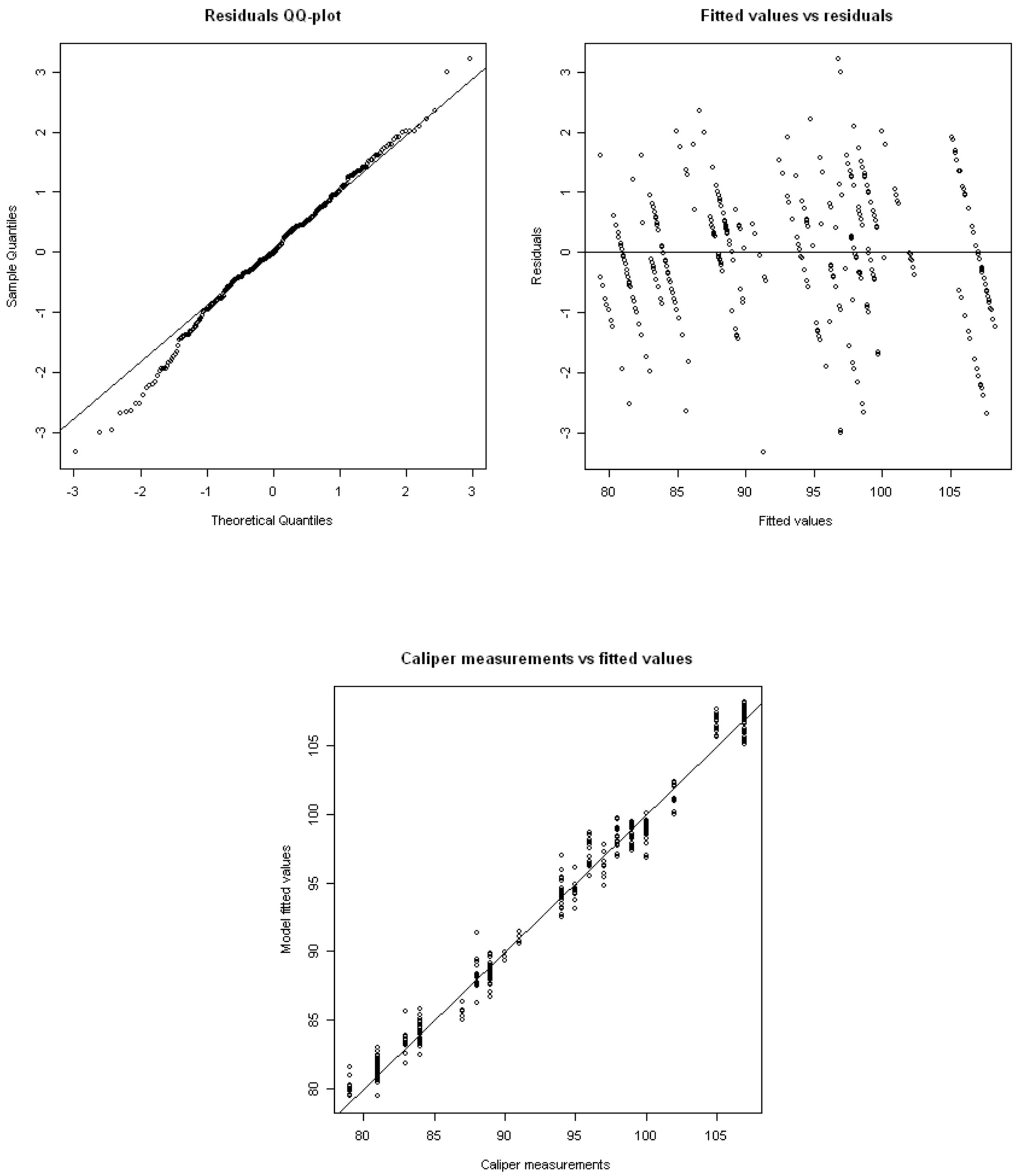
Mr Jay Hender, Fisheries and Marine Sciences Program, Bureau of Rural Sciences
Mr Tim Pitman, AQ1 Systems
Mr Ben Ford, Centre for Marine Futures, University of Western Australia
Mr Sam McMillan, Centre for Marine Futures, University of Western Australia
Ms Laura Fullwood, Centre for Marine Futures, University of Western Australia
Ms Danielle Foote, ASBTIA
Crew and divers contracted by ASBTIA

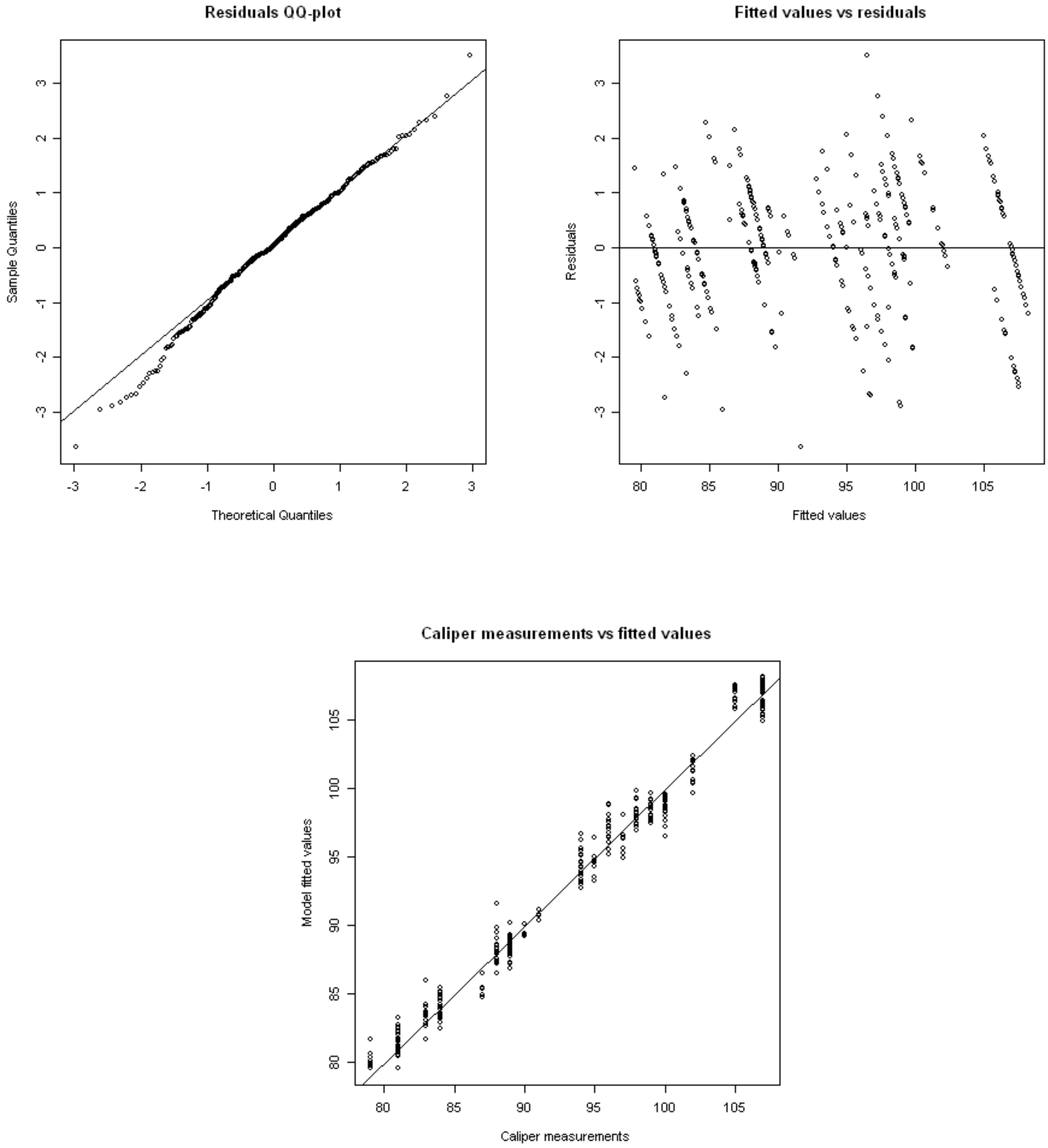
Field work was conducted by Katrina Phillips, Euan Harvey, David Ellis, Jim Seager, Tim Pitman, Jay Hender, Danielle Foote and crew and divers contracted by ASBTIA. Stereo-video measurements were completed by Euan Harvey, Ben Ford, Sam McMillan and Laura Fullwood. Statistical analyses were conducted by Veronica Boero Rodriguez.

Appendix 3

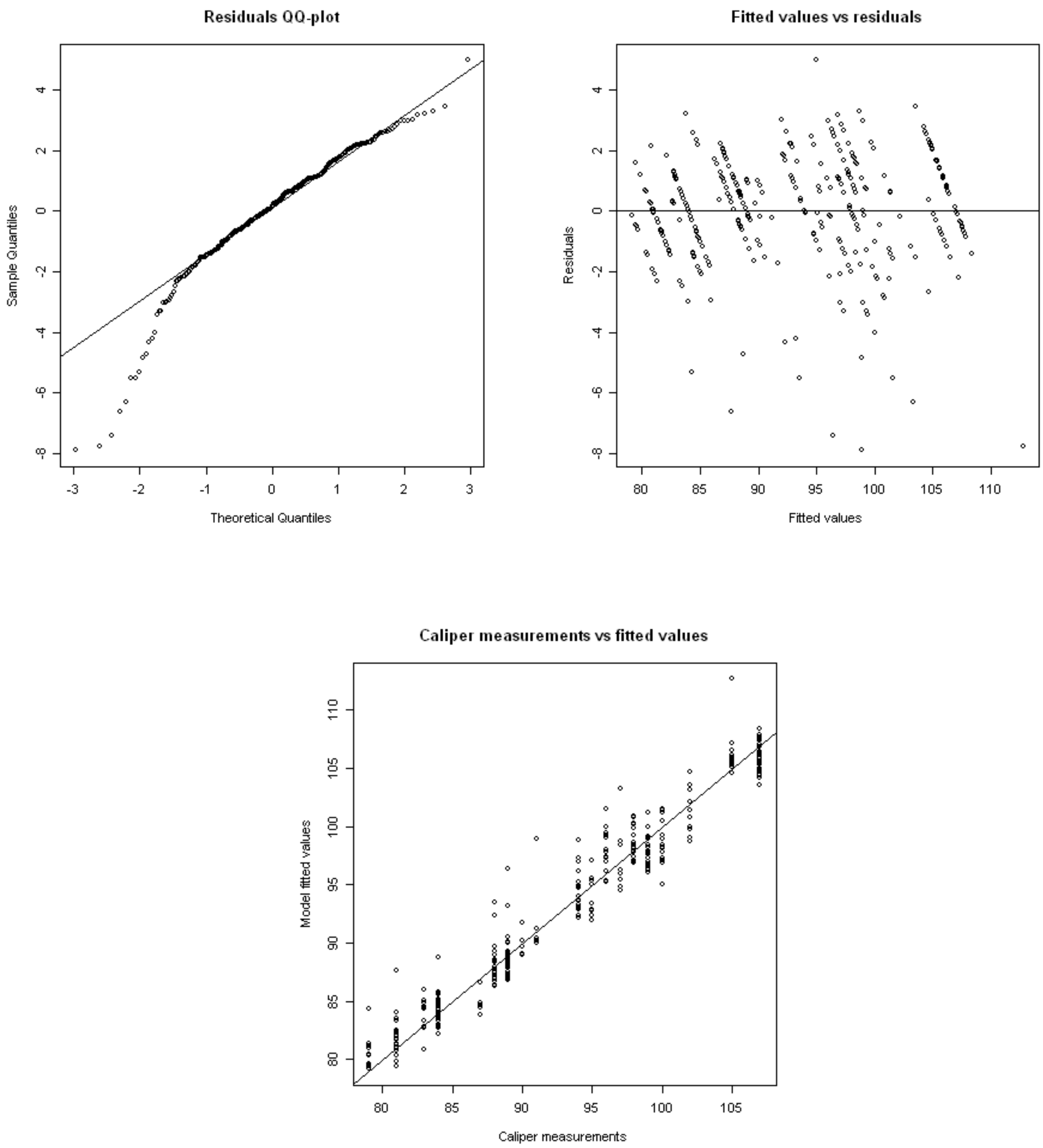
APPENDIX 3A. DIAGNOSTICS FOR EQS. 2, 3, 4 & 5.



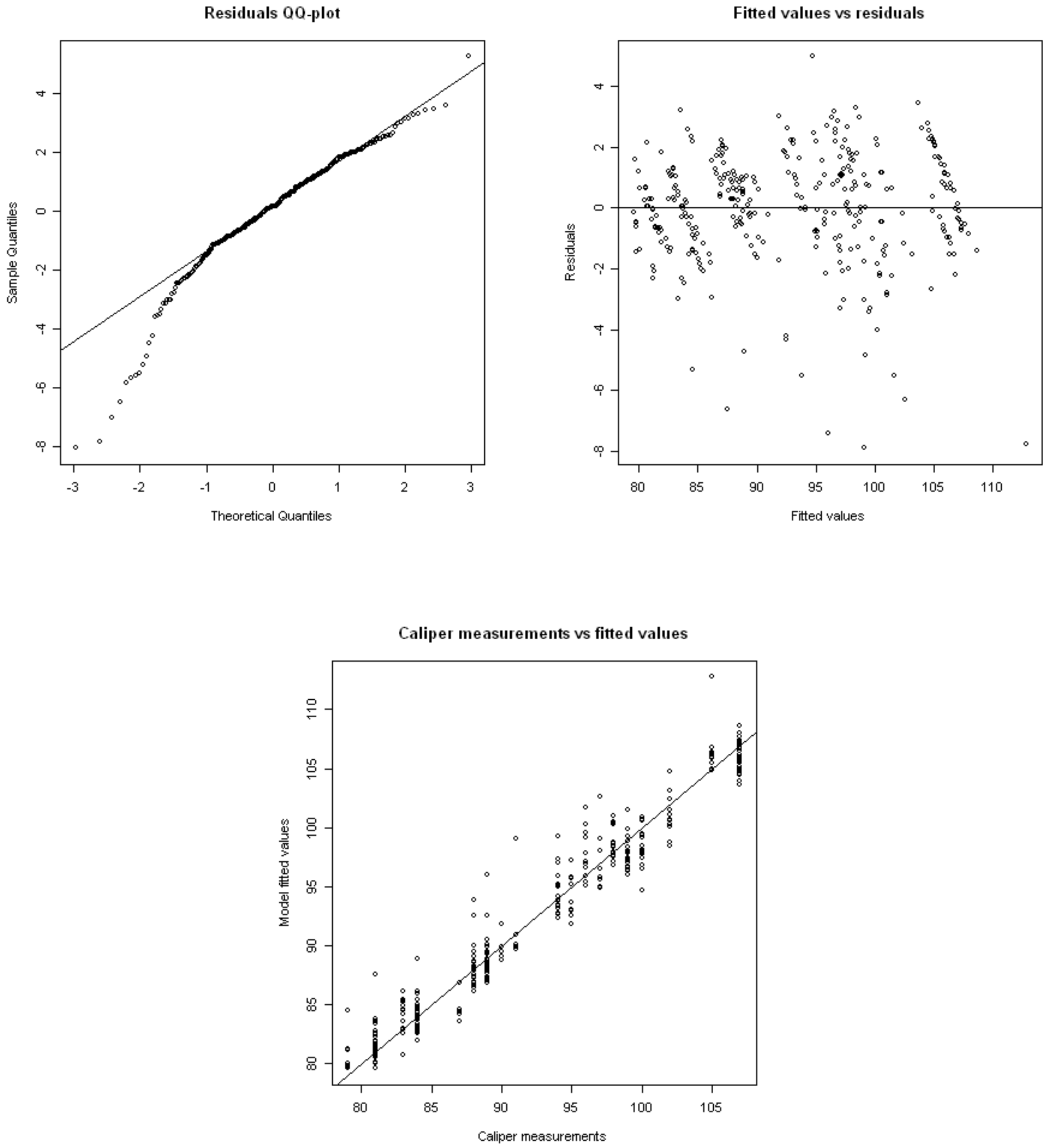
Appendix 3a(i). Diagnostics for Eq. (2).



Appendix 3a(ii). Diagnostics for Eq. (3).

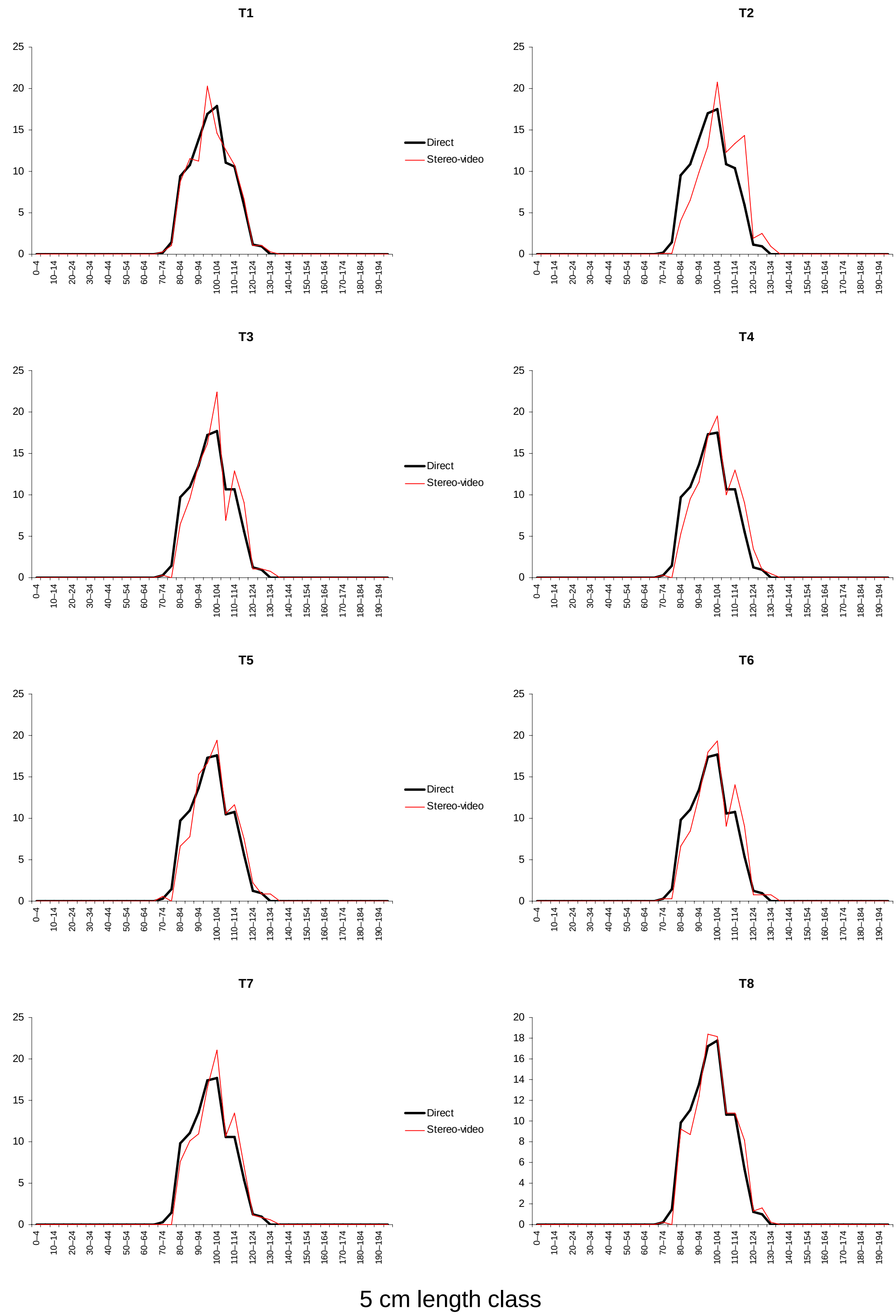


Appendix 3a(iii). Diagnostics for Eq. (4).

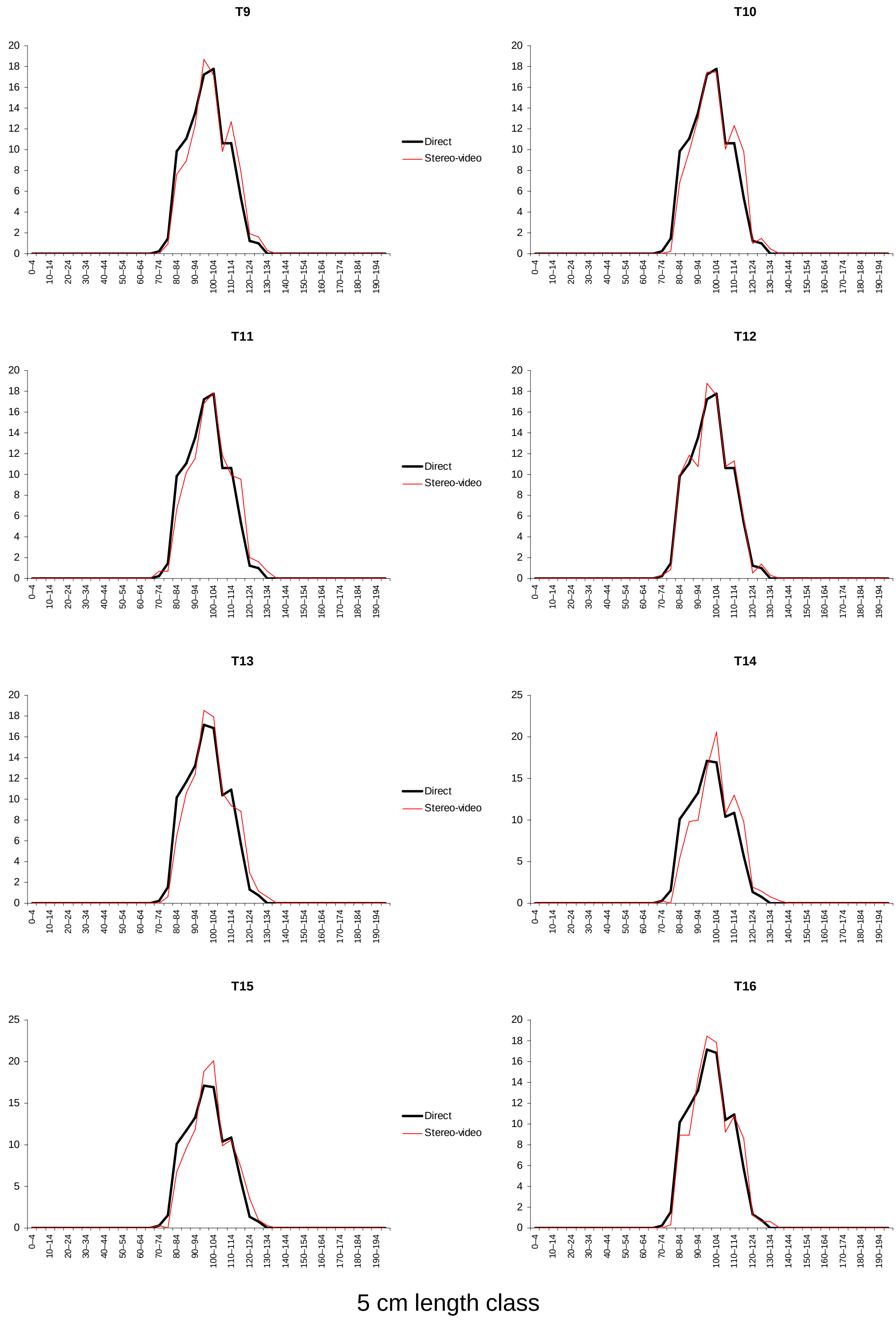


Appendix 3a(iv). Diagnostics for Eq. (5).

APPENDIX 3B. PROPORTIONAL HISTOGRAMS (%, 5 CM LENGTH CLASSES) OF DIRECT LENGTH MEASUREMENTS VS. MEAN LENGTH MEASUREMENTS (FROM ≤5 MEASUREMENTS PER INDIVIDUAL) OF SBT FROM STEREO-VIDEO FOOTAGE.



Appendix 3b. Transfer 1 to Transfer 8.



Appendix 3b (cont'd). Transfer 9 to Transfer 16