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TOWARDS DEVELOPING A PROCEDURE FOR THE ACCURATE AND PRECISE MEASUREMENT OF FORK LENGTH OF ATLANTIC BLUEFIN TUNA (*THUNNUS THYNNUS* L.) USING STEREOCAMERA TECHNOLOGY

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SUMMARY

The use of stereocamera (SC) systems to determine the weight of Atlantic bluefin tuna (ABFT) going into ABFT farm cages is considered an important element in the multiannual recovery plan for bluefin tuna in the Eastern Atlantic and Mediterranean. A pilot study was carried out in Malta with the SC from AQ1 Pty Systems Ltd (Australia) in which ABFT were filmed in a cage with the SC and subsequently harvested and individually measured for fork length (FL) with measuring callipers (MC). Using the Analyser software available with the SC, a procedure was established in order to obtain good accuracy and precision of FL estimation from the SC footage. If the procedure was followed completely, the average error between SC FL estimation and MC FL was 1.71%. If the % error associated with the calibration was considered, this average error was further reduced to 0.66%.

RÉSUMÉ

L'emploi de dispositifs de caméras stéréoscopiques pour déterminer le poids du thon rouge de l'Atlantique transféré dans des cages d'élevage pour thon rouge de l'Atlantique est considéré comme un élément important du programme de rétablissement pluriannuel pour le thon rouge dans l'Atlantique Est et la Méditerranée. Une étude pilote a été réalisée à Malte avec des caméras stéréoscopiques de AQ1 Pty Systems Ltd (Australie) dans laquelle des thons rouges de l'Atlantique étaient filmés dans une cage à l'aide de caméras stéréoscopiques et ensuite mis à mort et mesurés individuellement pour obtenir la longueur à la fourche (FL) au moyen de pieds à coulisse. En utilisant le logiciel Analyser disponible avec la caméra stéréoscopique, une procédure a été établie afin d'obtenir avec précision et exactitude l'estimation de la FL à partir de l'enregistrement des caméras stéréoscopiques. Si la procédure était suivie dans son intégralité, l'erreur moyenne entre la FL estimée par la caméra stéréoscopique et la FL mesurée avec un pied à coulisse était de 1,71%. Si l'erreur de pourcentage associée à la calibration était prise en compte, cette erreur moyenne était ramenée à 0,66%.

RESUMEN

El uso de sistemas de estereocámaras (SC) para determinar el peso del atún rojo del Atlántico (ABFT) que se introduce en las jaulas de las granjas de ABFT se considera un elemento importante en el plan de recuperación plurianual para el atún rojo en el Atlántico este y Mediterráneo. En Malta se llevó a cabo un estudio piloto con sistemas de estereocámaras de AQ1 Pty Systems Ltd. (Australia) en el que se filmó el atún rojo del Atlántico en una jaula con un sistema de estereocámaras y posteriormente fue sacrificado y medido individualmente en longitud a la horquilla (FL) con calibres de medición (MC). Utilizando el software de análisis disponible con el sistema de estereocámaras, se estableció un procedimiento para obtener una buena precisión y exactitud de la estimación de la longitud a la horquilla a partir de la grabación del sistema de estereocámaras. Si se sigue el procedimiento completamente, el error medio entre la estimación de la FL con el sistema de estereocámaras y la FL con los calibres de medición era de 1,71%. Si se considera el porcentaje de error asociado con la calibración, este error se reduce aún más, hasta el 0,66%.

KEYWORDS

Atlantic bluefin tuna, Thunnus thynnus*, Stereocamera, Fork length measurements, Accuracy, Precision*

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1. Introduction

As part of the management requirements set by ICCAT, CPCs are required to implement pilot studies to better estimate the round weight (RWT) of Atlantic bluefin tuna (ABFT) at catch and put into farm cages (ICCAT, 2012). One method of achieving this objective involves the use of stereocamera (SC) technology. For a number of years, various reports of trials relating to the use of such SC systems, or comparable systems, for the determination of ABFT fork lengths (FL) have been presented to the SCRS (for example, Anonymous, 2012a, b; Espinosa *et al*., 2012; Leon Grubišić *et al*., 2012; Ramfos *et al*., 2012). Some of these reports made use of the SC system available from AQ1 Systems Pty Ltd (Australia) which had developed such a system for southern bluefin tuna (*Thunnus maccoyii*).

The methods by which the AQ1 SC system have been applied in the field have varied to one extent or the other depending on practical considerations by the operators whilst in the cages. As a consequence of the fact that analysis of the footage has to be carried out manually in the current versions of the software available, it has been clear that a unifying methodology needs to be developed in order to standardise the FL measurement technique and to quantify the accuracy and precision of the measurements being taken. Such a methodology could also impinge on the method of obtaining the footage.

This paper presents results from a pilot study involving the FL measurements of individual ABFT with the AQ1 SC from farming cages whilst still alive and after being harvested and measured using measuring callipers (MC). The objectives of the pilot study were to quantify the precision and accuracy of the FL measurements taken by the AQ1 SC with the ultimate scope of establishing a universally applicable methodology. The paper indeed proposes a methodology of measurement which, if followed, enables the accurate and precise measurement of a fish to be taken (with a quantifiable error).

2. Materials and methods

The pilot study was carried out on 17th December 2011 using a 50m diameter tuna cage belonging to a registered farm in Malta (Fish & Fish Ltd) containing 91 BFT which were to be harvested and processed. A smaller enclosure was made inside the bigger cage using another piece of net such that fish could be transferred singly or in batches into the smaller enclosure from the main 50m holding cage.

The first part of the exercise consisted of divers transferring fish in ones, twos or threes into the smaller enclosure. When more than three fish passed into the smaller enclosure, the extra fish were let out back into the 50m cage or were harvested and removed to leave at maximum of three fish. The ideal situation occurred when only one fish was present in the smaller enclosure. If more than one fish were present, i.e. either two or three, it was confirmed by the experienced divers that the size of the fish remaining could be easily distinguished. If this was not the case, the extra fish were either passed out again into the 50m cage or harvested.

When one fish, or alternatively two or three fish of clearly different sizes, remained in the smaller enclosure the SC was lowered into the water and a diver filmed the fish for a period of time to ensure that sufficient footage of each fish, as the case may be, was obtained. At that point, the fish were then harvested individually, taken on board and measured using MC for FL (to the nearest mm) (**Figure 1**). The time the fish were taken on board was also recorded to enable the corresponding footage to be determined. When measuring FL at the tail end, it was ensured that the measurement was taken at the midpoint of the two ridges in the middle of the tail.

This process was carried out throughout the day and a total of 30 fish were measured both by SC in the water and by the use of the MC on board. In addition to the fish itself, a calibration rod (CR) of known length (0.897m) was also filmed by the SC (at various distances from the SC) in the cage.

The footage of the CR and of each fish or group (maximum of three fish) were analysed using the Analyser software of the AQ1 SC. After numerous measurement approaches involving repeated measurements of the CR and fish while varying the technique of measurements (zooming, varying brightness and contrast), a procedure was devised to increase the accuracy and precision of BFT fork length and calibration rod measurements.

3. Results

3.1 Establishing a measurement procedure

Following repeated measurements and changes in measurement technique, the following procedure was found to give the accuracy and precision indicated in the results presented further below.

1. Choose frame where fork ridges are clear in both images and at least very clear in one of the images (**Figure 2**). Select frames in which fish appear as perpendicular as possible to the SC. Use best judgement to tell if the fish appears straight and not turning or with tail clearly flexing.
2. Use ‘Enhance frames’ ‘Brightness’ and ‘Contrast’ to improve quality of image (**Figure 2**).
3. Zoom to 400% (**Figure 3**).
4. Choose best of the two frame images to make initial point marks, adjusting image quality as necessary with image enhance options.
5. Discard if range (distance from SC) is >6m away.
6. Discard if the line joining the two points on any one image is off-centre by more than + 25% on the midpoint of the caudal peduncle (**Figure 3**).
7. If you are measuring the CR, put points on the midpoint between the upper and lower part of the rod in both frames.
8. FL% error should be below 1.5% (**Figure 4**).
9. Use best judgement to move point marks of the nose and caudal fork in such a way that the nose and caudal fork errors are less than 0.2mm (maintaining condition 6 and using enhance options as necessary) (**Figure 4**). If unable to achieve, discard frame.
10. Repeat 5 times for each fish satisfying the above criteria; calculate average of FL and average of range (distance from SC).

3.2 SC estimate of length of calibration rod

Using the above procedure (where applicable), SC estimates of the length of the CR were obtained. The results obtained from these repeated measurements (9 to 12 times for each average distance) of the CR are presented in **Table 1**. **Figure 5a** presents the individual SC CR length estimates against distance from the SC, and **Figure 5b** presents the difference between the SC estimate and the CR length as percentages against distance from the SC, where

% Difference = 100 * ((SC length - CR length)/CR length).

In the majority of cases, the SC length estimate was greater than the actual length of the CR. In addition, there appeared to be a positive relationship between the percentage differences and distance from the SC and at the same time the variation of the estimates generally increased as distance increased. **Table 2** and **Figure 6** present the relationship between the average percentage differences and average distance from the SC.

The relationship between the average percentage error and the average distance of the rod from the SC can be represented by the equation:

$$E_{cal} = 0.1191D + 0.6134 \ (R^2 = 0.93)$$

where the calibration error, $E_{cal,}$ is the percentage difference between the SC estimate and the length of the CR (a +ve % indicates the SC estimate is longer than the CR length) and D is the distance (m) from the SC.

3.3 SC estimate of fish FL

After analysing the footage and applying the procedure indicated in Section 3.1 above, it was found that for 5 fish either the procedure could not be applied in its entirety or fish could not be adequately distinguished and identified from the footage. These fish were discarded from the rest of the analysis leaving 25 fish and associated data.

Following the procedure indicated above for 5 acceptable measurements for each of the 25 fish, the results seen in **Table 3** were obtained. **Table 4** presents the average value of the five SC FL estimates for each of the 25 fish as they compare to the MC length where

Absolute difference (mm) = SC FL – MC FL,
% Difference = 100 * ((SC FL – MC FL)/MC FL).

Figure 7 compares the averages of the five SC FL estimated measurements against the corresponding MC FL of the 25 fish. The average overall difference between SC FL estimate and the MC FL was 1.71%.

To determine whether the size of the fish being measured had any impact on the absolute or percentage difference between SC FL estimates and the MC FL, these were plotted against MC FL (**Figures 8a and 8b)**. No clear relationship with fish size was found (R^2 = 0.01 and 0.14 respectively). **Figure 9** was plotted in order to determine if distance from the SC had any bearing on the percentage difference between SC FL estimates and the MC FL measurements; no clear relationship was found (R^2 = 0.19).

Due to the strong relationship between the % E_{cal} and distance from the SC, the E_{cal}, was calculated for each of the SC FL estimates for each of the 25 fish and a new adjusted SC FL estimate was determined (**Table 5**) and plotted against the MC FL (**Figure 10**). By including E_{cal}, the average overall difference between SC FL estimate and the MC FL was reduced to 0.66%. There was no clear relationship between adjusted percentage difference and MC FL (R^2 =0.14).

To check if applying the E_{cal} resulted in any change in the relationship between the adjusted percentage difference between the SC FL estimate and the MC FL and distance from SC, this was plotted as shown in **Figure 11**. There was still no clear relationship with distance (R^2 = 0.24).

4. Discussion

The origin of the requirement by ICCAT to improve the determination of FL of ABFT at the point of catch (by purse seiners) and at caging is the necessity to control the amount, or rather RWT, of ABFT caught by the fleet to ensure that vessels do not catch more than is scientifically deemed to be sustainable for the Eastern Atlantic and Mediterranean ABFT stock. In addition to this control measure, is the requirement by the scientists of the SCRS to utilise the FL data itself which can then be converted with the appropriate length-weight (L-W) relationship for the purpose of determining the catch-at-size for the fishery in a particular year.

So far various applications have been tested to determine the FL or RWT of a particular group of ABFT at the point of caging. These have involved various techniques, such as the use of SC systems either singly or in combination with other technologies such as acoustic systems or by using various combinations of standard single lens cameras.

The SC system from AQ1 was developed with the southern bluefin tuna in mind and has found to be easily put into use in the Mediterranean. However, a number of important practical differences are apparent which may or may not affect the precision and accuracy of the measurements coming from the use of this equipment. The first practical difference is related to the size of the fish itself where in the Mediterranean, fish varying in size up to anything like 2.5m may be encountered in contrast to the smaller normal sizes seen in the southern bluefin tuna. Secondly, as a consequence of the size of the fish, when carrying out transfers, bigger (height and width) doors are used on the nets in order to reduce the risk of mortality of fish during the actual transfers and cagings.

Once footage is taken either of the fish passing through a door or from inside the cage, the next requirement is the correct FL measurement of the fish. When analysing the footage using the Analyser software available with the AQ1 SC system, it was clear that very wide variations in FLs would be recorded unless a rigorous procedure was put into place so that all measurements are carried out in the same standardised way. Some of the variables encountered which affect the accuracy of the measurements were the degree of flexing of the tail, clarity definition of the two images and the positioning of the two points (head, tail) on both images. To add to these, variations in the various Analyser defined errors (FL% error, nose and caudal fork error) were also found to have an impact on the resulting FL estimate.

The importance of establishing a consistent and accurate procedure (as much as possible) lies in the fact that the FL measurements made by the SC will then be used to convert to RWT using the appropriate L-W equation. Even a small error in the measurement could be of great significance when converted from FL to RWT. Thus, for example, using the following equation L-W relationship (Rodriguez *et al*., 2013):

$$RWT = (2.8009*10^{-5}) * FL^{2.912}$$

for a fish with a real FL of 200cm, RWT would be 140.6kg. With an error of only 3%, i.e. an SC measurement of 194cm or 206cm, the RWT would be 128.6kg or 153.2kg respectively, i.e. between 8 and 9% smaller or bigger. Worked out for a population of fish being caged, this could be a significant difference.

The results obtained here are indicative that it is possible to achieve measurements having good precision. This was seen both in the case of the calibration rod and the individual fish. The accuracy, in the case of the calibration rod was fairly good, with an overall difference between SC estimate and rod length of around 1% over the 41 measurements taken. However, it was found that both precision and accuracy deteriorated as the distance from the SC increased. These observations were an important factor that led to the adoption of the final procedure indicated in Section 3.1. When the calibration error (E_{cal}) was deducted from the average SC FL estimate for each fish, there was a deduction in the overall error between SC FL estimates and MC FL measurement of the whole group of 25 fish from 1.71% to 0.66%.

On the other hand, there was no clear relationship between % differences between SC FL estimate and MC FL either in relation to the size of the fish being measured or the distance from the SC. This should be analysed further by studying the footage for individual fish in more detail.

Other authors investigating the accuracy and precision of the SC systems have also found similar variability in accuracy and precision. Harvey *et al*. (2003) and Phillips *et al*. (2008), both working with the application of SCs in the southern bluefin tuna (*Thunnus maccoyii*), also found that there were variations in the accuracy and precision of SC FL estimates for measured southern bluefin tuna. These authors found that SC estimates of FL varied depending on which frame was chosen for the measurement and in some cases accuracy could be greatly affected by this choice.

Whilst the procedure presented in Section 3.1 is clearly suitable for making accurate and precise BFT measurements from video footage it is quite time consuming. The question therefore arises as to the effect on both accuracy and precision if the procedure is not followed as presented. For example, if there are time restrictions and/or fish behaviour does not allow point 10 of procedure to be followed, with only one measurement being taken instead of five, accuracy of the measurements carried out will still be expected to be high. However, the percentage errors associated with deviations from other steps in the procedure have not yet been quantified and further analysis to determine these should be carried out.

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Table 1. Repeated estimates of the calibration rod (CR) length by the stereocamera (SC) showing distance from the SC, the corresponding error values taken from the Analyser software of the SC (in line with the measurement procedure established in Section 3.1), and the % difference between each SC estimate and the rod length.

Distance of CR from SC (m)	*SC estimated CR length (m)*	*FL error (%)*	*Nose error (mm)*	*Caudal Fork error (mm)*	*% diff between SC estimate and CR length*
2.0966	0.902	0.3507	0.0643	0.0969	0.57
2.1012	0.908	0.3534	0.0419	0.0967	1.19
2.1328	0.908	0.3584	0.0403	0.0344	1.26
2.1334	0.901	0.3582	0.0990	0.0887	0.45
2.1518	0.904	0.3715	0.0991	0.0040	0.77
2.1543	0.902	0.3663	0.0651	0.0218	0.56
2.1724	0.903	0.5107	0.0866	0.0978	0.71
2.1790	0.901	0.3716	0.0407	0.0876	0.49
2.1870	0.904	0.3784	0.0874	0.0251	0.77
2.1883	0.909	0.3746	0.0943	0.0141	1.28
2.1917	0.908	0.3746	0.0802	0.0391	1.25
2.2001	0.903	0.3752	0.0648	0.0948	0.71
2.8984	0.903	0.4922	0.0725	0.0989	0.61
2.9338	0.908	0.4929	0.0209	0.0395	1.27
2.9401	0.906	0.5064	0.0907	0.0609	1.05
2.9456	0.904	0.5073	0.0903	0.0987	0.81
2.9593	0.905	0.5326	0.0622	0.0668	0.89
2.9927	0.908	0.5048	0.0856	0.0796	1.22
3.0015	0.907	0.5204	0.0751	0.0418	1.13
3.0217	0.906	0.5335	0.0993	0.0983	0.98
3.0390	0.908	0.5138	0.0828	0.0878	1.23
3.0438	0.907	0.5439	0.0912	0.0301	1.11
4.0553	0.903	0.7130	0.0663	0.0830	0.61
4.0633	0.909	0.7046	0.0454	0.0310	1.28
4.0739	0.904	0.7865	0.0979	0.0864	0.74
4.0747	0.908	0.7314	0.0046	0.0913	1.23
4.1048	0.909	0.8886	0.0847	0.0482	1.37
4.1072	0.909	0.6997	0.0063	0.0431	1.28
4.1291	0.901	0.7448	0.0944	0.0924	0.42
4.1344	0.908	0.8397	0.0864	0.0921	1.24
4.1625	0.912	0.7451	0.0804	0.0069	1.62
5.1027	0.895	0.9952	0.0720	0.0921	-0.20
5.1141	0.903	0.9007	0.0181	0.0682	0.61
5.1202	0.910	1.0532	0.0772	0.0819	1.46
5.1244	0.910	0.9085	0.0790	0.0400	1.39
5.1697	0.909	0.9103	0.0642	0.0353	1.35
5.1727	0.915	1.3363	0.0987	0.0776	1.95
5.1886	0.902	1.0569	0.0950	0.0915	0.57
5.2139	0.915	1.1240	0.0929	0.0817	1.95
5.2195	0.910	0.9378	0.0863	0.0877	1.47
5.2714	0.912	1.0592	0.0317	0.0127	1.68

Table 2. Percentage differences between average values of SC estimates for the calibration rod and the actual calibration rod length based on average distances of the calibration rod from the SC. Values in brackets indicate 1 SD.

Average distance of CR from SC (m)	Average SC estimated CR length (m) for each average distance from SC	% Difference between SC estimate and CR length (0.897m)
2.1574	0.905	0.83
(0.0352)	(0.003)	(0.32)
2.9776	0.906	1.03
(0.0493)	(0.002)	(0.21)
4.1006	0.907	1.09
(0.0365)	(0.004)	(0.40)
5.1697	0.908	1.22
(0.0550)	(0.006)	(0.69)

Table 3. Individual stereocamera (SC) fork length (FL) estimates for 5 frames for each of the 25 fish analysed according to the measurement procedure established in Section 3.1.

Fish No.	SC FL estimate 1 (m)	SC FL estimate 2 (m)	SC FL estimate 3 (m)	SC FL estimate 4 (m)	SC FL estimate 5 (m)	Average of 5 SC FL estimates (m)	SD 5 fish (m)
1	2.020	2.046	2.048	2.049	2.051	2.043	0.013
2	1.477	1.486	1.486	1.488	1.489	1.485	0.005
3	1.766	1.766	1.767	1.781	1.783	1.773	0.009
4	1.402	1.403	1.404	1.408	1.408	1.405	0.003
5	2.240	2.252	2.246	2.245	2.261	2.249	0.008
6	1.523	1.528	1.532	1.546	1.553	1.536	0.013
7	1.984	1.997	2.003	2.004	2.005	1.999	0.009
8	2.195	2.207	2.228	2.232	2.245	2.221	0.020
9	1.565	1.58	1.586	1.591	1.596	1.584	0.012
10	1.365	1.382	1.371	1.358	1.363	1.368	0.009
11	1.952	1.956	1.959	1.962	1.973	1.960	0.008
12	2.080	2.093	2.097	2.104	2.105	2.096	0.010
13	1.968	1.978	1.978	1.982	1.986	1.978	0.007
14	1.421	1.428	1.428	1.43	1.456	1.433	0.014
15	1.893	1.921	1.937	1.953	1.959	1.933	0.027
16	1.303	1.298	1.283	1.302	1.304	1.298	0.009
17	1.464	1.470	1.477	1.486	1.470	1.473	0.008
18	1.774	1.782	1.791	1.786	1.792	1.785	0.007
19	2.188	2.206	2.221	2.223	2.244	2.216	0.021
20	1.225	1.232	1.233	1.233	1.240	1.233	0.005
21	1.697	1.722	1.724	1.725	1.726	1.719	0.012
22	1.556	1.547	1.549	1.553	1.564	1.554	0.007
23	1.418	1.431	1.435	1.440	1.424	1.430	0.009
24	1.437	1.455	1.468	1.473	1.485	1.464	0.018
25	1.326	1.356	1.361	1.374	1.375	1.358	0.020

Table 4. Absolute difference and percentage difference between the average stereocamera (SC) fork length (FL) estimates (estimated in line with the measurement procedure established in Section 3.1) and the measuring calliper (MC) fork length.

Fish No.	*Average of 5 SC FL estimates (m)*	*MC FL (m)*	*Absolute difference(mm)*	*% difference between av. SC FL and MC FL*
1	2.043	1.982	0.061	3.07
2	1.485	1.448	0.037	2.57
3	1.773	1.726	0.047	2.70
4	1.405	1.369	0.036	2.63
5	2.249	2.226	0.023	1.02
6	1.536	1.561	-0.025	-1.58
7	1.999	1.98	0.019	0.94
8	2.221	2.188	0.033	1.53
9	1.584	1.554	0.030	1.90
10	1.368	1.361	0.007	0.50
11	1.960	1.956	0.004	0.22
12	2.096	2.051	0.045	2.18
13	1.978	1.939	0.039	2.03
14	1.433	1.408	0.025	1.75
15	1.933	1.93	0.003	0.13
16	1.298	1.258	0.040	3.18
17	1.473	1.43	0.043	3.03
18	1.785	1.747	0.038	2.18
19	2.216	2.208	0.008	0.38
20	1.233	1.186	0.047	3.93
21	1.719	1.704	0.015	0.87
22	1.554	1.527	0.027	1.76
23	1.430	1.386	0.044	3.15
24	1.464	1.458	0.006	0.38
25	1.358	1.328	0.030	2.29

Table 5. Percentage difference between the average stereocamera (SC) fork length (FL) estimates (estimated in line with the measurement procedure established in Section 3.1) and the measuring calliper (MC) fork length after adjustment of fork length with the % calibration error based on the average distance from the stereocamera.

Fish No.	*Av. of 5 SC FL est. (m)*	*MC FL (m)*	*% difference (av. SC FL/ MC FL)*	*Average distance from SC (m)*	*% calibration error based on distance from SC*	*Adjusted % difference (av. SC FL/MC FL)*
1	2.043	1.982	3.07	3.723	1.06	2.01
2	1.485	1.448	2.57	2.804	0.95	1.62
3	1.773	1.726	2.70	3.595	1.04	1.66
4	1.405	1.369	2.63	2.653	0.93	1.70
5	2.249	2.226	1.02	4.237	1.12	-0.09
6	1.536	1.561	-1.58	4.065	1.10	-2.67
7	1.999	1.98	0.94	3.355	1.01	-0.07
8	2.221	2.188	1.53	2.66	0.93	0.60
9	1.584	1.554	1.90	3.061	0.98	0.93
10	1.368	1.361	0.50	3.573	1.04	-0.54
11	1.960	1.956	0.22	4.701	1.17	-0.95
12	2.096	2.051	2.18	3.21	1.00	1.19
13	1.978	1.939	2.03	3.319	1.01	1.02
14	1.433	1.408	1.75	3.189	0.99	0.75
15	1.933	1.93	0.13	5.048	1.21	-1.08
16	1.298	1.258	3.18	4.016	1.09	2.09
17	1.473	1.43	3.03	4.154	1.11	1.93
18	1.785	1.747	2.18	3.649	1.05	1.13
19	2.216	2.208	0.38	5.065	1.22	-0.84
20	1.233	1.186	3.93	2.714	0.94	2.99
21	1.719	1.704	0.87	4.244	1.12	-0.25
22	1.554	1.527	1.76	3.464	1.03	0.73
23	1.430	1.386	3.15	4.396	1.14	2.01
24	1.464	1.458	0.38	3.497	1.03	-0.65
25	1.358	1.328	2.29	2.921	0.96	1.33

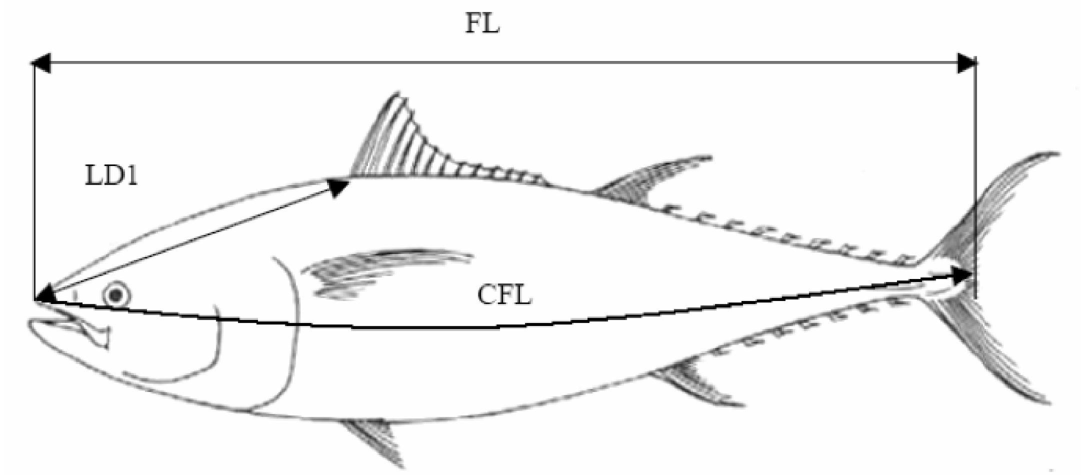


Figure 1. Typical measurements taken from Atlantic bluefin tuna (FL = fork length, CFL = curved fork length, LD1 = first dorsal fin length).

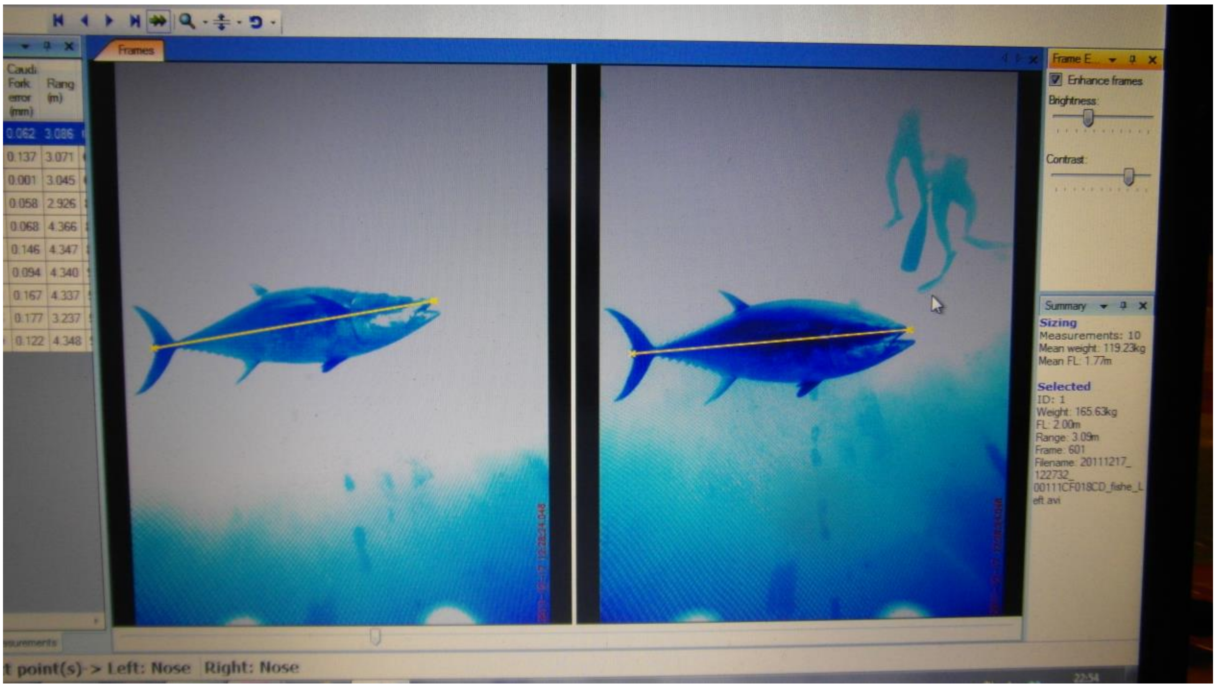


Figure 2. Screen shot of AQ1 stereocamera Analyser software showing images of BFT and highlighting frame enhancement options which may need to be adjusted for each of the images on the left or right frame to improve quality.

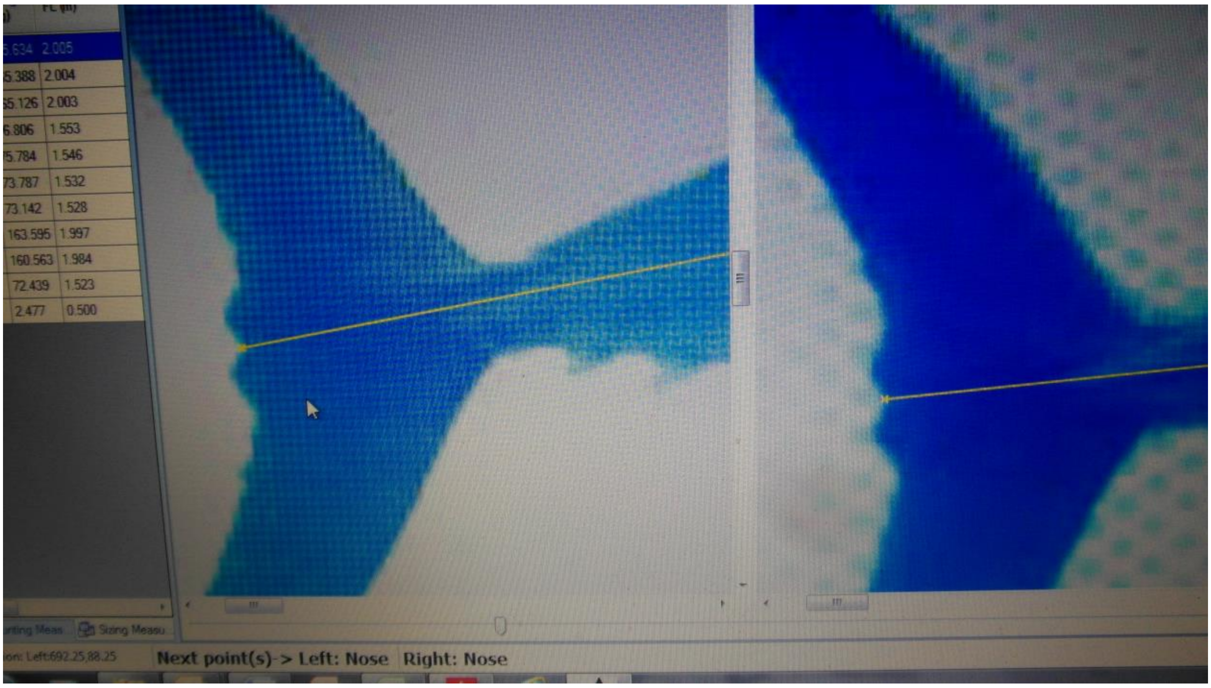
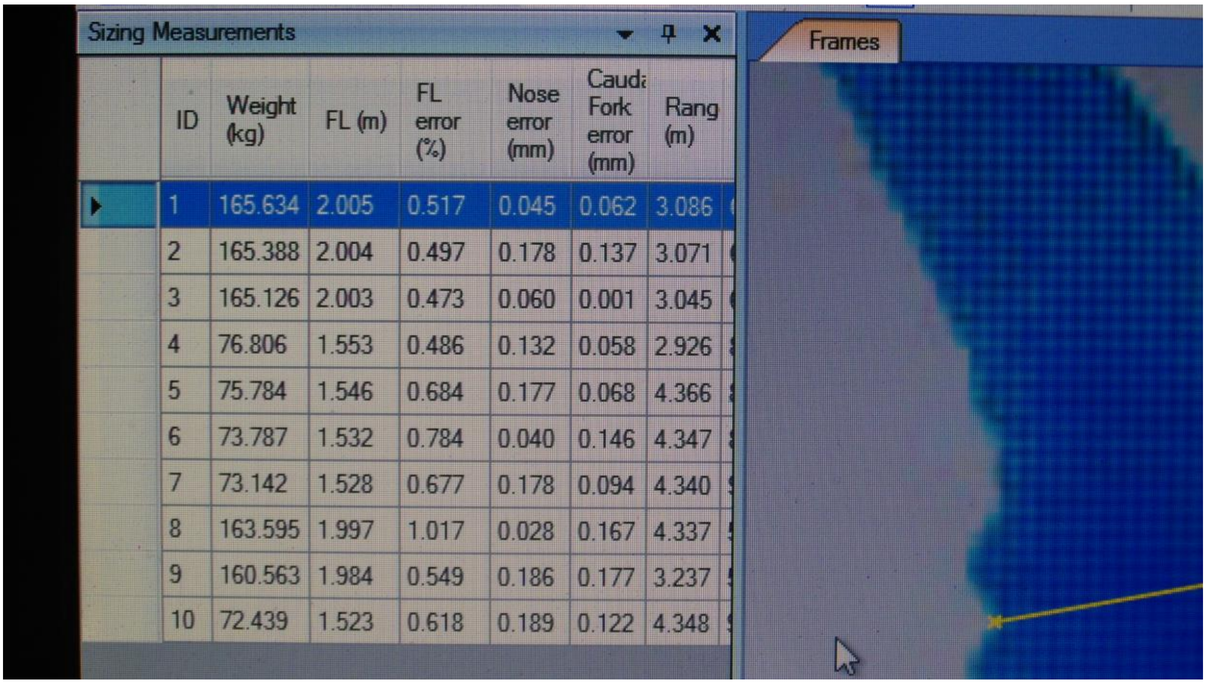


Figure 3. Screen shot of AQ1 stereocamera Analyser software showing images of BFT after zooming to 400% to enhance image of fork ridges.



Sizing Measurements

ID	Weight (kg)	FL (m)	FL error (%)	Nose error (mm)	Cauda Fork error (mm)	Rang (m)
1	165.634	2.005	0.517	0.045	0.062	3.086
2	165.388	2.004	0.497	0.178	0.137	3.071
3	165.126	2.003	0.473	0.060	0.001	3.045
4	76.806	1.553	0.486	0.132	0.058	2.926
5	75.784	1.546	0.684	0.177	0.068	4.366
6	73.787	1.532	0.784	0.040	0.146	4.347
7	73.142	1.528	0.677	0.178	0.094	4.340
8	163.595	1.997	1.017	0.028	0.167	4.337
9	160.563	1.984	0.549	0.186	0.177	3.237
10	72.439	1.523	0.618	0.189	0.122	4.348

Figure 4. Screen shot of AQ1 stereocamera Analyser software showing sizing information obtained with each measurement, including fork length (FL) error, nose error, caudal fork error and range (i.e. distance from stereocamera).

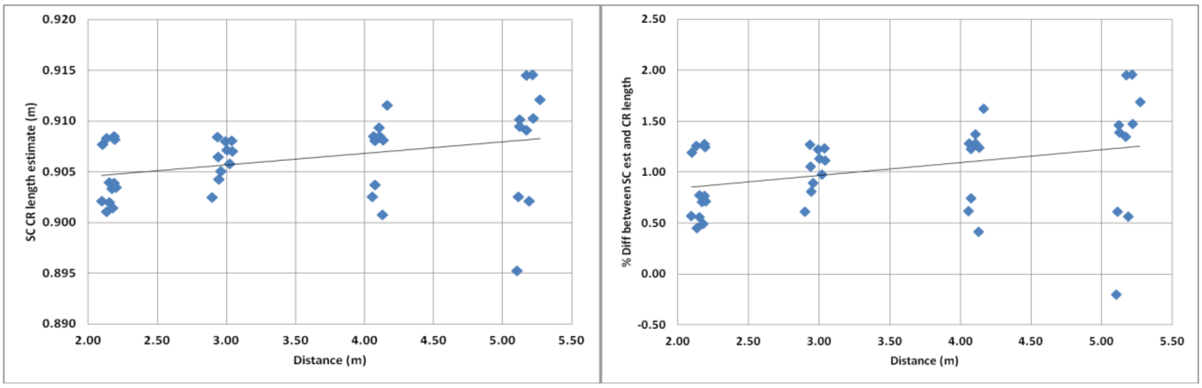


Figure 5. Stereocamera (SC) estimates of the length of the calibration rod (CR) plotted against distance from the stereocamera. Data presented as (a) absolute estimate and (b) as a percentage difference between the stereocamera estimate and the actual length of the calibration rod

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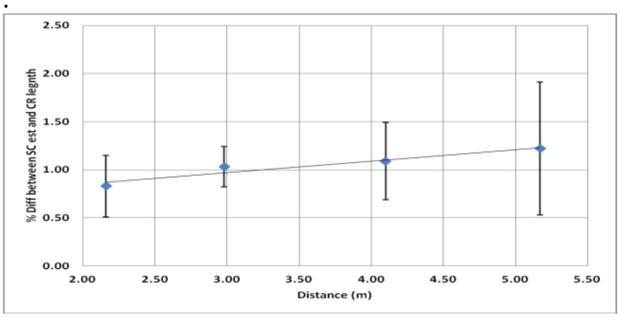

Figure 6. Relationship between the average percentage differences between stereocamera (SC) estimated length and calibration rod (CR) length and average distance from the stereocamera. Bars indicate $\pm$ 1 SD.

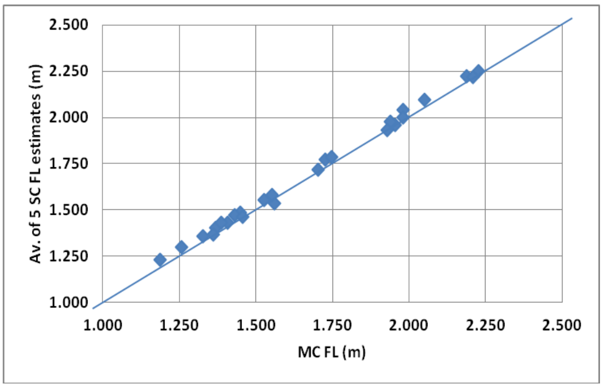

Figure 7. Averages of the five stereocamera fork length (SC FL) estimated measurements against the corresponding measuring calliper (MC) fork length of the 25 fish analysed according to the measurement procedure established in Section 3.1.

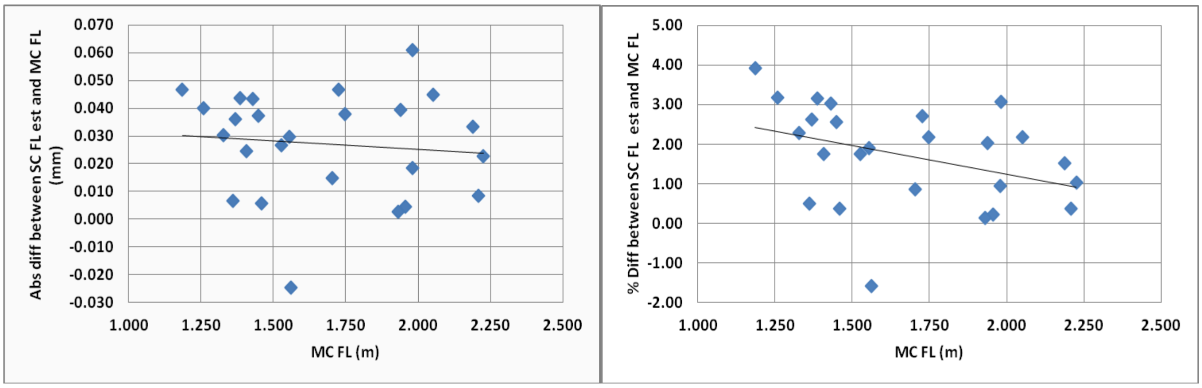

Figure 8. Difference between the average stereocamera (SC) estimates of the fork length (FL) of the 25 fish plotted against measuring callipers (MC) fork length. Data presented as (a) absolute difference and (b) as a percentage difference between the stereocamera estimate and the measuring calliper fork length of the individual fish.

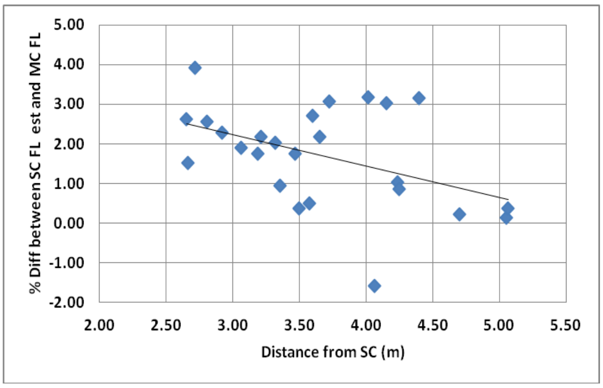

Figure 9. Percentage difference between stereocamera (SC) estimates of the fork length (FL) and measuring calliper (MC) fork length of the fish as a function of distance from the stereocamera.

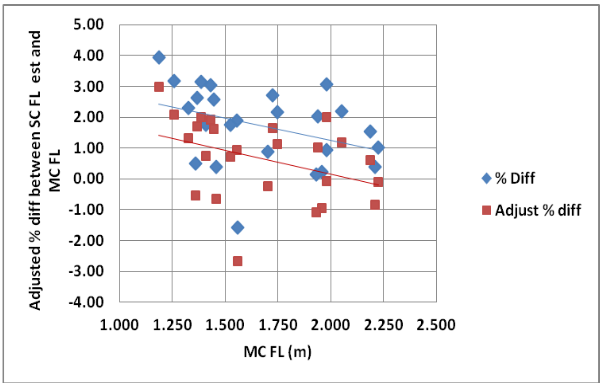

Figure 10. Unadjusted and adjusted percentage differences between stereocamera (SC) estimates of the fork length (FL) of the 25 fish plotted against the measuring calliper (MC) fork length.

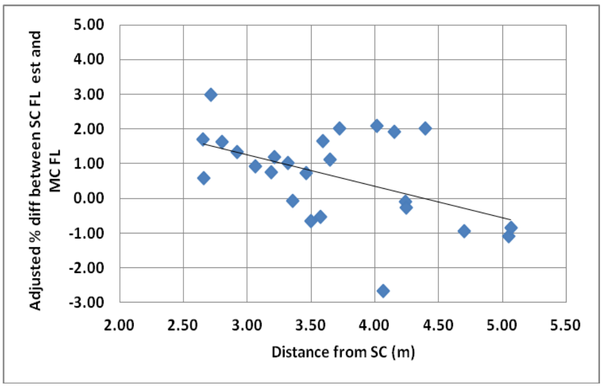

Figure 11. Adjdusted percentage difference between stereocamera (SC) estimates of the fork length (FL) and measuring calliper (MC) fork length of the fish as a function of distance from the stereocamera.