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FEASIBILITY STUDY TO ASSESS THE UTILIZATION OF STEREO-VIDEO SYSTEMS DURING TRANSFER OF ATLANTIC BLUEFIN TUNAS (*THUNNUS THYNNUS*) TO EVALUATE THEIR NUMBER AND SIZE

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SUMMARY

The study reports the results of field trials carried out with the funding of the Italian Administration during 2011 in the bluefin tuna fish farm of Marina di Camerota (southern Italy). The study implemented the ICCAT request to initiate pilot studies on how to better estimate the number and weight of the bluefin tuna at the moment of capture and caging. During fields trials, the Australian methods used for southern bluefin tuna was tested to estimate its suitability in Mediterranean conditions. A lot of bluefin tunas of many different sizes were forced to pass through a gate between two cages, and filmed with a stereo camera. The fish were then fished and measured individually, while images were analysed through specific software. Results coming from measured sizes and assessed sizes were compared, showing an acceptable error between the two series. A series of practical suggestions have been made to adjust the system to Mediterranean conditions.

RÉSUMÉ

L'étude présente les résultats obtenus dans le cadre d'essais sur le terrain réalisés au moyen du financement de l'administration italienne en 2011 dans la ferme de thon rouge de Marina di Camerota (sud de l'Italie). L'étude répondait à la demande de l'ICCAT d'entamer des études pilotes sur la façon d'améliorer les estimations du nombre et du poids du thon rouge au moment de la capture et de la mise en cage. Pendant les essais menés sur le terrain, les méthodes australiennes utilisées pour le thon rouge du Sud ont été testées pour déterminer si celles-ci pouvaient s'appliquer aux conditions de la Méditerranée. De nombreux thons rouges de différentes tailles ont été contraints de passer par un portail entre deux cages et ont été filmés avec une caméra stéréoscopique. Les poissons ont ensuite été capturés et mesurés individuellement, et les images ont été analysées avec un programme spécifique. Les résultats des tailles mesurées et des tailles évaluées ont été comparés et ont fait apparaître une marge d'erreur acceptable entre les deux séries. Plusieurs suggestions pratiques ont été formulées afin d'adapter le système aux conditions de la Méditerranée.

RESUMEN

El estudio informa de los resultados de las pruebas de campo realizadas con la financiación de la administración italiana en 2011 en la granja de atún rojo Marina di Camerota (Italia meridional). El estudio respondía a la solicitud de ICCAT de iniciar estudios piloto sobre el mejor modo de estimar el número y peso del atún rojo en el momento de captura e introducción en jaula. Durante las pruebas de campo, se probaron los métodos australianos utilizados para el atún rojo del sur con el fin de estimar su idoneidad en las condiciones mediterráneas. Se hizo que muchos atunes rojos de tallas diferentes pasaran a través de una puerta entre dos jaulas, y se filmó con una cámara estereoscópica. Posteriormente, se pescó y midió cada ejemplar mientras que se analizaban las imágenes con un programa específico. Se compararon los resultados procedentes de las tallas medidas y las tallas estimadas y el margen de error entre las dos series fue aceptable. Se presentan una serie de sugerencias prácticas para ajustas el sistema a las condiciones del Mediterráneo.

KEYWORDS

Bluefin tuna, Tuna fisheries, Morphometry, Imaging techniques, Length-weight relationships, Accuracy, Size composition

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1. Background

The study follows the request of the ICCAT Commission for the CPCs to initiate pilot studies on how to better estimate the number and weight of Bluefin tuna at the point of capture and caging, including through the use of stereoscopical systems.

The pilot project proposal developed by EFCA (European Fisheries Control Agency) included two main components, namely:

1) Bluefin tuna transfer protocol - A definition of a protocol to be followed when transferring the Bluefin tunas.

2) Assessing accuracy and precision - Assess the accuracy and precision of stereo-video length measurements obtained under operational conditions, and assess the robustness and suitability of the stereo – video equipment under operational conditions.

An expert group has been set up to finalize the formulation of the “Feasibility study to assess the utilization of stereo-video systems in Atlantic Bluefin tuna (*Thunnus thynnus*) in a commercial setting”. Italy has implemented the feasibility study in an Italian farm and provided scientific support to the project. This document reports the results of field trials carried out in the Bluefin tuna fish farm of Marina di Camerota and of statistical analysis.

2. Introduction

The trials forecasted the use of the Australian software and stereo camera, with the objectives to test the suitability of such a system in Mediterranean conditions.

As stated in the pilot project proposal, the direct application of the Australian technology in the Atlantic Bluefin tuna fishery could entail some risks due to the differences in the species biology and farming management in Europe. Therefore, the setting up of the stereo camera, as well as its calibration, and the methodology for the transfer of tuna, had to be tested.

3. Material and methods

Equipment used:

- vessel: adequate sized vessel fitted with marine crane and capstan for net hauling purposes as well as floats needed to hold up the net up during the operation (**Figure 2**);
- cage: the cage have a diameter of 50 m and a depth of 30 m; to carry out the trials 2 cages were used (n° 1 and n°6of the farm) attached one to the other with the frame placed in one of the cage. In the cage n.1 a stock of around 150 tuna of mixed sizes were left (**Figure 3**);
- frame: the frame (**Figure 4**) was 6 x 4 m ; the bracket to fix the stereo camera was put on one of the 4 m vertical sides. There were no possibilities locally to prepare the frame in aluminium, therefore stainless steel was used;
- AQ1 AM10 stereo camera system
- power supply (UPS)
- measuring rod: a three meter long rod marked at 50 cm intervals.

3.1. Methodology

Trial was forecasted at the end of the farming period, right after the tuna harvest, between October and November 2011. The farm is approximately 3 Nm off the coast. During the trial 6 cages were available, but only 2 cages were used.

A first test was carried out from October 24 to 28. During this test some operational aspects were addressed, and a training course for local farmers was carried out by the Australian expert. Equipment (computer, software and stereo camera) was checked and explained.

Due to the delay in fishing operations because an unforeseen storm and a subsequent damage to some cages, only a test for the use of the stereo camera was performed. The filming was done during the passage of the tunas from the cage into an internal net “pocket” just before the killing of the fish (around 80 fishes). It was not possible to apply the methodological protocol, therefore no frame was put in place. The test was useful for a first approach to the use of the equipment in operational conditions (e.g. different conditions of water transparency).

A second test was carried out from November 3 to 5. This test was carried out between the end of fishing operations and a forecasted period of bad weather therefore all the activities were conditioned by the need to finish them before the bad weather. Because of this all the activities (equipment and gate preparation, stereo camera recording, fish harvest, individual measurements) had to be done only in one day.

Despite the above problems and with some forced adjustments the protocol was applied and tested.

Counting and sizing of the specimens was performed through AQ1 AM100 software.

4. Results

Cage positioning. To position the cages correctly, the anchor structures were left loose to be able to bring the cages together and then re-establish the safety measures. The anchor was secured to the vessel to be used in the winching operation and tensioned so that during the winching stage, the cage‘s shape would not be distorted by the force of the winching vessel. The vessel was positioned down tide of the two cages. When the cages were together they were secured, pontoon to pontoon with ropes. Cage walls were lifted in a way to reduce the amount of folds and maintain taut netting. This is a delicate point in the operation, because if there is a sudden weather change or a strong current, it could be dangerous for the structure and the fish, and so fishermen are very reluctant to do this operation.

Frame: transportation and setting up. The frame was then transported by the vessel and placed in the cage using the marine crane. A team of professional divers set up the frame in the right position in the same cage as the tuna because the strong current forced the vessel to anchor downstream of the cages. As well, another vessel was anchored next to the other cage ready for tuna harvesting.

Stereo camera setting up. Once the equipment was checked, the stereo camera was positioned to obtain an optimal visual of the transfer door (**Figure 5**). The stereo camera was connected to pc using the Ethernet cable from the AQ1 System. The stereo camera and pc were used in conjunction with an uninterrupted power supply (UPS). Recording began just before the opening of the door between the two cages to test image quality. The maximum frame rate was set at 15. No particular problems arose, even if a different frame structure would be better, as illustrated later on.

Transfer. The opening between the cages was created cutting the net by the lower and the lateral sides of the frame. Once cut, the net was raised to open the passage. The cut net was fixed at the upper side of the frame and used as drop down net, useful to provide a quick shut off in the event of an emergency. Just after the opening of the gate the volume in the first cage began to reduce due to the lifting of the floor using the floats and the marine crane. The fish were stressed and reluctant to pass into the other cage. At the beginning, only a few fish passed through and then large numbers followed. The transfer time was approximately 30 minutes. The gate was closed at the end of the transfer.

Measuring rod. In the empty cage, a diver with the measuring rod was filmed as a recorded reference of the measurements was needed.

Fish measuring. The fish were then harvested and transferred to the refrigeration ship to be individually measured: every fish was measured for total weight and fork length.

The recordings were then examined, and the fish were counted and measured using the software AQ1 AM100 analyzer developed by Australian experts.

Software AM100 Analyzer: counting measurement. The counting was done using the software counting. Each frame of the video was viewed to identify the single fish as they pass through the gate. Each fish was “marked” to avoid the risk of recounting the same fish (**Figure 7**). 164 individuals were counted.

Software AM100 Analyzer: sizing measurement. The fork length was measured for approx. 40% of individuals, locating a suitable subject (relatively close to the camera, visible in both frames), reading the Analyzer status bar at the bottom of the window to see which point is the next one required and marking the required point on the subject. As you click to mark the Analyzer status bar updates, prompting you to mark up the next point. As you mark-up points on one image, lines will be drawn on the adjacent image (call epipolar lines, designed to guide the placement of points on conjugate images). After all required points are entered, the measurement list is updated (**Figure 8**). The software estimated the round weight using length-weight relationships adopted by the ICCAT - SCRS for Mediterranean Bluefin tuna. Also a measurement of the measuring rod was done. In **Figure 9** and **Figure 10** the fork length distribution and the weight distribution respectively are reported.

5. Assessing accuracy and precision

During the data elaboration the two sets of measurements (assessed and observed) were compared.

5.1. Methodological notes and results

Evaluating the accuracy of fish size estimates obtained from a dual-camera system is - in theory - a very straightforward task. Obviously, it requires the comparison of measured and assessed fish size, which in turn requires that each specimen is individually recognized and that both its measured size and its assessed size are known. Needless to say, such a procedure implies that each specimen has been tagged before video recording and that is still tagged at the moment of the direct biometric measurements.

Unfortunately, tagging a large number of specimens is a very complex task, while tagging a small subset of specimens does not provide enough information. Moreover, tagging can be harmful and is certainly time consuming.

An alternate solution is the comparison of the assessed size frequency distribution with the measured size frequency distribution. If the two are similar enough to each other, size estimates based on a dual-camera system can be considered as a good proxy for directly measured data.

A first attempt allowed to assess only the size of 66 out of 168 specimens (39.3%) that were clearly separated from others in the available video frames, thus making it possible to detect and mark both their tip of nose and tip of tail. This was regarded as a random sample extracted from a larger set of specimens and some preliminary estimates about the accuracy of the dual-camera system were obtained.

The information obtained from the subset of specimens that were not recognized individually allowed testing differences between sample and overall mean, median, size distribution, etc., but unfortunately this was not our main objective, as a sample-based approach did not allow obtaining a direct estimate of the error in size assessment for the tested dual-camera system.

However, an indirect estimate of the error, with special reference to fish weight, was obtained by comparing the empirical frequency distributions of measured and assessed fish size after normalization. In particular, size at each percentile of the assessed frequency distribution was compared to size at the corresponding percentile of the measured frequency distribution. This approach was far from perfect, as it could not separate the error component related to fish image sampling from the one related to the actual assessment of fish size, but - given the available data - it was the only viable solution. On this basis, the overall error in dual-camera estimates was larger than 10% of the overall fish weight.

A second attempt at acquiring the coordinates of tip of nose and tip of tail in video frames for each specimen was then performed, accepting the best guess in all the cases in which one of the two landmarks was not clearly detectable. The size of 164 specimens out of 168 was assessed this way, making the comparison with measured size much easier. Nevertheless, four specimens were actually caught and measured, but not spotted in the video frames, thus requiring a procedure that once again was based on an indirect comparison, i.e. on the analysis of deviations at each percentile of the assessed and measured size distributions.

With respect to the first attempt, estimating the size at each percentile of the assessed size distribution is much less affected by error, given the much larger number of specimens spotted in the video frames. However, specimens that were not considered at first because the tips of nose and tail were not clearly shown introduced another source of error – which is impossible to exactly quantify. Unfortunately, this kind of error, in addition to the uncertainty in the exact number of specimens that passed through the field of the dual-camera system, is inherent to any video-based method.

Length and weight data, both assessed from video (in italics) and measured, are shown in **Table 1** and **Table 2** respectively, while some basic statistical parameters are shown in **Table 3** and **Table 4**.

Figure 12 shows a histogram of the fish length distributions, while the one for fish weight is shown in **Figure 13** (observed in blue, assessed in red). Two thin solid lines show the combination of two normal distributions that best fit the data sets.

Although the number of specimens was not exactly the same in the two data sets (168 measured values, 164 assessed ones), we applied the Kolmogorov-Smirnov test to check whether the two frequency distributions were equal or not. The results showed that the null hypothesis of equal frequency distributions could not be rejected in the case of length ($D=0.12079$, $p=0.1653$), whereas it could be rejected for weight ($D=0.16986$, $p=0.01447$).

As for length, the lack of significant differences between the measured and assessed frequency distribution certainly testified a good agreement between them, although it did not prove that the errors were small enough to be neglected in practical applications. The difference in weight distributions, on the other hand, was significant, but the value of the Kolmogorov-Smirnov's D statistics was not much larger than in the case of length. Moreover, as weight was obtained as a power function of length, the two results were certainly not independent of each other.

While a certain degree of similarity between the length frequency distributions for assessed and observed data was implicit in this result, it provided no information about the accuracy of size assessment based on video images. In fact, to obtain estimates of the error in size assessment, frequency distributions needed to be somehow normalized (both for length and weight, and for measured and assessed size). As previously explained, we opted for computing length and weight at each percentile of their frequency distributions, as shown in **Figure 14** and **Figure 15**.

This plots are equivalent to cumulated frequency distributions mirrored and 90° clockwise rotated and therefore the maximum horizontal (i.e. along the x axis) distance between the two curves corresponds to the Kolmogorov-Smirnov D statistics. The vertical (i.e. along the y axis) distance between the two curves, on the other hand, can be regarded as an estimate of the overall error associated to each percentile of the size distribution, i.e. an estimate of the combination of sampling (availability of images that are suitable for processing) and measurement (assessment of fish size) errors.

The error estimates at each percentile of the length frequency distribution are shown in **Figure 16**, while their absolute value is shown in **Figure 17**. Errors are mostly negative (i.e. the assessed length is shorter than the observed length) for smaller specimens ($L<130$ cm), while they are mostly positive (i.e. the assessed length is larger than the observed length) for larger specimens ($L>220$ cm). In terms of absolute value, however, the errors exceed 5% of the assessed length only in the case of the smallest specimens (see the solid blue line above the red dashed on the left side in **Figure 17**).

As for weight, error estimates at each percentile of the frequency distribution are shown in **Figure 18**, while their absolute value is shown in **Figure 19**. Errors are negative (i.e. the assessed weight is smaller than the observed one) for the very smallest specimens, while they are positive (i.e. assessed values are overestimated) for fishes which exceed 210 kg in assessed weight. As for the absolute value of the error, it is larger than 5% for all specimens below 50 kg and for several other size ranges, showing a lesser overall accuracy than length. This result is obviously related to the same sources of error that accounted for the significant difference between the measured and assessed size distributions that was highlighted by the Kolmogorov-Smirnov test.

In order to obtain an overall estimate of the error in weight assessment, the number of specimens in each discrete weight class (class range 10 kg) was multiplied by the corresponding average error obtained from the error distribution at each percentile. The overall estimate for the assessed weight error was -637.2 kg (769.1 kg in absolute value), which had to be divided by 164 (specimens in the image-processed sample) and multiplied by 168 (overall number of specimens) to obtain -652.7 kg (787.9 kg in absolute value) as the best estimate for the overall weight error.

As the overall measured weight of the 168 specimens was 17541.0 kg, the error associated to weight assessment based on video processing is -3.72% (4.49% in absolute value) of the overall measured fish weight.

Comparing the fish size at each percentile of the frequency distribution allowed estimating the error notwithstanding a different number of specimens in the assessed and measured sets. However, specimens that were not spotted in the available video frames obviously contributed to the actual overall error. As 164 out of 168 specimens were counted in video frames, an additional (1-164/168)*100=2.38% error should be taken into account and added to the above-mentioned estimate. Therefore, the final estimate for the error associated to the tested dual-camera system is -6.1% (6.9% in absolute value). According to this percent error, the overall weight assessed by means of video processing is 1070 kg (1205 kg in absolute value) smaller than the actual overall weight. Unfortunately the latter component of the error (fish missing from video frames or – in other cases – fish counted twice) is much more variable than the one directly related to the dual-camera system and it is strictly related to the way the fish transfer is managed.

6. Notes and focus points

6.1. First component: Bluefin tuna transfer protocol

Despite the problem of urgency and the impossibility to repeat the transfer (as it would have been advisable), the trial was extremely useful to test the whole system. Some of the main findings are:

- *Frame.* The size used was not easy to manage, and needed quite a big vessel for transportation. Moreover, the frame 6 x 4 m used seems inadequate for Atlantic bluefin tuna sizes, and a 6 x 6 m frame, at least, would be better. The school tended to wait, and entered all together reducing the light at the gate and increasing the risk of the fish scraping against the structure (in normal conditions the fish numbers would be much higher). This can result in an increase in fish mortality after a few days. It must be underlined that damages and eventual mortalities cannot be calculated at the moment of transfer. Note according to fishermen, a size of 8 x 8 m would be advisable.

- *Screen.* The screen was made of plexiglass, but this material and its size created many difficulties:

    - the positioning because it is cumbersome to set up; a lighter material could be better (e.g. a softer and lighter net);
    - the creation of an interference factor for the fish at the moment of transfer;

- *Water transparency*. Water transparency must be judged case by case, but in general it seems that it is much better in Mediterranean waters, as shown in the film. In **Figure 6** two pictures, from Australian and Mediterranean environments, can be seen. The difference in water transparency is very evident, around 20 m in the Italian farm and 6 m in the Australian one (according to the Australian expert). Due to the better water transparency in the Italian farm, eliminating the screen could be considered. In this case, the structure would be much easier to manage, and the frame could be made of a series of plastic tubes that could be assembled directly in the water, with the stereo camera bracket placed on one of the side tubes.

- *Camera gate positioning.* Due to the very different fish sizes, the distance between the two cameras could be increased, but in this case, also the camera focus must be adjusted. If possible, it would also be necessary to increase the distance of the cameras from the gate to frame the whole gate area (otherwise some areas of the gate will be covered by only one camera), or to study the possibility of placing more than two camera in different positions on the frame. In any case a solution must be studied. Stereo-camera is foreseen to record through a gate of 3 x 3 m, therefore with a maximum distance (including the bracket) of around 4 m. In a project about the implementation and validation of a stereo-video system for measuring the length of Southern Bluefin Tuna during transfers (Harvey *et al.*, 2003), the accuracy of the system decreased with increasing distance (**Figure 11**), as expected according to error propagation. At distances greater than 5 metres large errors were recorded. When the system is mounted on the Protec Marine transfer gate fish will be recorded at distances between 1.5 and 4.5 metres, most commonly in a window between 2 and 4 metres. If data recorded from distances 5 metres and greater is disregarded the system had a mean error of -2.31 mm. During this trial the stereo camera was put on a bracket at around 2.3 m from the gate of 6 x 4 m, therefore at a maximum distance of 8.3 m; this could entail an increased error of the measurements through the video.

- *Recorder.* Recording of the transfer must be done with a number of frames per second higher than 15 because the tuna pass through the gate quickly and many at a time, therefore in some case it is difficult to distinguish the single fish.

- The fish were particularly stressed, due to the "speed" of the operations and/or because they were the last group after many days of harvesting operations. The school in the cage numbered 150 tuna and was highly representative of the Atlantic species, with sizes ranging from approximately 30 to more than 400 kg (see later exact references).

- *Size of individuals.* The sizes examined were very different, as mentioned before. As a consequence a bigger fish passing between the camera and other smaller fishes could completely hide the smaller ones. This is a problem that must be taken into account.

6.2 Second component; assessing accuracy and precision

The estimated error we reported (about 6%) is probably not too large relative to other approaches, but the way it was obtained is far from perfect. In particular, we could not discriminate between sampling error (that cannot be avoided due to the practical impossibility of collecting suitable images for all the specimens to be measured) and measurement errors due to video processing. Moreover, we assumed that directly measured fish weight and length were not affected at all by error (which most probably was not the case).

Obviously, better estimates of the error associated to video processing can only be obtained by acquiring new (and more abundant) data. The first step toward a better assessment of the error in fish size estimates is certainly the acquisition of suitable images for all the specimens. This goal is far from trivial, but a solution can be probably found if more cameras (and possibly cheaper ones) are deployed, e.g. pointing to the opening between the cages from different depths. An alternate solution is to carefully manage the fish transfer operations, allowing only a few fish (and possibly only a single specimen) to pass through the camera field at a time. Once the assessed and measured size is obtained for all the specimens, the error component due to missing or double-counted specimens can be completely removed.

An indirect improvement in size assessment can be also obtained by defining suitable post-processing routines (Annex 1) that transform the size assessment based on video processing in a way that minimizes the error. This is obviously simpler in the best scenario (paired assessed and measured size), but some degree of optimization could be also reached by analyzing paired size distributions. In the worst-case scenario (no further data) a post-processing procedure will be developed by means of resampling techniques based on the available data.

Finally, it is important to underline the big difficulty of working harmonizing the very different needs of fishermen and researchers. Due to the high commercial value of the fishes, it is very difficult to conduct these tests both during and at the end of farming period. During the farming it is difficult because there is always the possibility of damages or loss the fish during the trials, and this loss could not be refunded; during the harvesting because of the urgency to finish the operations, either because there is always the possibility of a sudden change of the weather; moreover must be considered the timing of the buyers, always present in loco for the direct transformation of the fishes for the reference market. Apparently the only real possibility to mitigate these problems would be to secure a scientific quota from ICCAT, if further studies on this field are to be implemented.

7. Annex: Post-processing of size estimates obtained from a dual-camera system

Fish size estimates obtained from any dual-camera system are based on the different aspect, size and positioning of the image of the same fish in the two frames captured by the stereo-mounted cameras.

In theory, extracting size estimates from this information can be done by means of simple relationships that are well known in optical geometry, but in practice there are several sources of error and distortion, which are partly unknown and in many cases depend on the physical setup of the dual-camera system. Moreover, uncertainty in size assessment depends on the position of the target relative to the centre of the common field of view of the two cameras (best results are obtained with targets close to this point), on the aspect of the target, on its distance, etc.

If a suitable set of assessed and measured sizes is available, it is certainly possible to post-process the assessed size data in order to reduce their deviations from the actual measurements and then to apply the same transformation to all the other the data acquired by the same dual-camera system. The optimal transformation can be found by means of a simple relationship (e.g. a linear regressive model) or by means of more advanced methods, which are able to optimize complex non-linear transformations. Among the latter, some types of Artificial Neural Networks are particularly effective, with the additional advantage that they do not require that type of transformation is to be specified in advance by the modeller.

A data post-processing strategy, however, requires a complete set of known data to be really effective, i.e. a data set that includes information about observed and assessed size of each specimen. Unfortunately, such data are not available at present, because measured size is available for all the specimens (n=168), while assessed size is only available for those that were spotted in the video frames (n=164), which – in spite of the lack of tags - we assume were not measured more than once. Moreover, there is no biunivocal correspondence between the two sets, and therefore each measured size is not associated with an assessed size and vice versa.

In this scenario, post processing the assessed size data is still possible, but much less effective. However, we already experimented the most straightforward solution, i.e. we "trained" a neural network (a 3-layer error back-propagation perception) to transform the assessed sizes at each percentile to match the measured one as closely as possible. Of course, this is not the very best solution, but it is the only feasible without a biunivocal correspondence between assessed and measured data.

The results are outlined in figure and look very promising. The two curves (measured: solid blue line; assessed and then post-processed: red dashed line) are much closer after post-processing the assessed sizes (length in this case). The mean square error (relative to sizes at percentile) was reduced by more than 50% and the largest share of residual error (more than 50%, i.e. more than 25% of the overall uncorrected error) is accounted for by the largest specimen alone. Unfortunately, improving the correction for the extreme sizes (smallest and largest) would require measures in that size range from a larger number of specimen, which are not available.

This approach will be optimized as far as possible and compared to other methods, with special reference to those based on conventional regressive techniques. The lack of information about very small and especially very large specimens will be taken carefully into account and the optimal post-processing strategy will be selected among those that are less sensitive to the lack of extreme sizes.

The final post-processing method will be implemented in software as a very simple tool that will be able to read the output of the dual-camera system, correct the assessed sizes and write back the results in the same format as the original one.

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Table 1. Length data assessed from video and measured.

Assessed length (cm, n=164)					**Measured length (cm, n=168)**					
85	124	131	144	212	113	128	131	140	211	250
100	125	131	144	213	113	128	132	140	215	252
106	125	131	145	214	115	128	132	142	215	278
109	125	131	146	215	115	129	132	142	217	
111	125	131	147	216	116	129	132	143	217	
111	125	132	148	219	116	129	132	143	217	
111	125	132	148	219	117	129	132	143	218	
114	126	132	149	220	118	129	132	143	219	
114	126	132	150	220	119	129	132	146	220	
115	126	133	151	221	120	129	132	149	220	
116	127	133	153	224	120	129	132	151	221	
116	127	133	155	228	121	129	133	152	221	
116	127	133	155	228	122	129	133	152	225	
117	127	133	160	229	122	129	133	153	226	
118	127	133	161	230	123	129	133	154	226	
118	127	134	175	232	123	130	134	156	226	
118	128	135	180	234	123	130	134	165	228	
119	128	135	180	236	124	130	135	167	228	
119	128	137	182	238	125	130	135	173	229	
120	128	138	186	239	125	130	136	177	230	
120	129	138	194	239	125	130	137	182	230	
120	129	138	194	240	125	130	137	188	232	
121	129	138	196	241	125	130	137	188	233	
122	129	139	197	242	126	130	137	190	233	
122	129	139	197	242	126	130	137	190	233	
122	130	140	198	245	126	130	137	193	235	
122	130	140	201	246	126	131	138	193	236	
122	130	140	201	247	126	131	138	197	236	
123	130	141	207	254	126	131	138	202	238	
124	130	141	207	254	126	131	139	203	240	
124	130	142	207	259	127	131	139	204	243	
124	131	143	208	273	128	131	140	208	243	
124	131	144	210		128	131	140	210	245	

Table 2. Weight data assessed from video and measured.

Assessed weight (kg, n=66)					**Measured weight (kg, n=168)**					
11	39	46	61	195	30	44	49	59	205	329
18	40	46	62	198	30	44	49	62	208	367
24	40	46	63	202	30	44	49	62	210	415
27	40	46	64	204	31	45	50	62	212	
28	40	47	65	207	31	45	50	63	212	
28	40	47	66	216	33	45	50	64	217	
28	40	47	67	217	34	45	51	64	220	
30	41	47	68	219	34	45	51	64	221	
30	41	48	69	220	35	45	51	68	222	
31	41	48	70	222	36	45	51	69	223	
32	42	48	74	230	37	45	52	72	225	
32	42	48	76	243	37	45	52	74	229	
32	42	49	77	243	38	46	52	74	229	
33	42	49	85	246	39	46	52	77	235	
33	42	49	85	252	39	47	52	77	236	
34	42	49	109	256	39	47	52	87	244	
34	43	50	119	265	39	47	52	100	245	
34	43	51	119	270	40	47	53	107	245	
35	43	52	124	278	40	47	54	109	246	
36	43	54	132	280	40	47	54	126	247	
36	44	54	150	282	40	47	54	139	260	
36	44	54	151	286	41	48	54	142	263	
36	44	54	154	289	41	48	54	149	269	
37	44	55	156	290	41	48	55	150	275	
37	44	56	157	292	42	48	55	150	287	
37	44	56	159	301	42	48	56	154	287	
37	45	56	166	305	42	48	56	157	287	
37	45	56	168	310	42	49	56	158	295	
38	45	57	183	336	42	49	56	159	296	
39	45	57	183	336	43	49	57	164	298	
39	45	58	183	359	43	49	58	185	303	
39	46	60	185	421	43	49	58	185	303	
39	46	61	189		44	49	58	188	305	

Table 3. Length: basic statistical parameters.

Length (cm)	**Measured (blue)**	***Assessed (red)***
N	168	*164*
Min	113	*84.5*
Max	278	*273.4*
Sum	26621.4	*25782.6*
Mean	158.461	*157.211*
Std. error	3.29158	*3.47727*
Variance	1820.2	*1983.0*
Stand. dev.	42.6638	*44.5308*
Median	135.072	*134.411*
25 percentile	129.0	*126.1*
75 percentile	196.0	*196.8*
Skewness	0.97741	*0.93130*
Kurtosis	-0.6067	*-0.5540*
Geom. mean	153.456	*151.669*

Table 4. Weight: basic statistical parameters.

Weight (kg)	**Measured (blue)**	***Assessed (red)***
N	168	*164*
Min	30	*11.4*
Max	415	*421.4*
Sum	17541	*16495.5*
Mean	104.411	*100.582*
Std. error	6.96512	*7.16134*
Variance	8150.17	*8410.71*
Stand. dev.	90.2783	*91.7099*
Median	53.5	*49.7*
25 percentile	45.0	*41.1*
75 percentile	157.8	*156.6*
Skewness	1.30931	*1.37282*
Kurtosis	0.47769	*0.73091*
Geom. mean	77.0048	*71.4673*

Figure 1. Farm of Marina di Camerota.

Figure 2. The vessel used in the test.

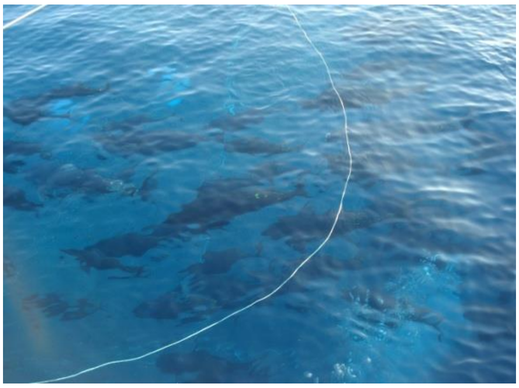

Figure 3. Fish into the cage during the transfer.

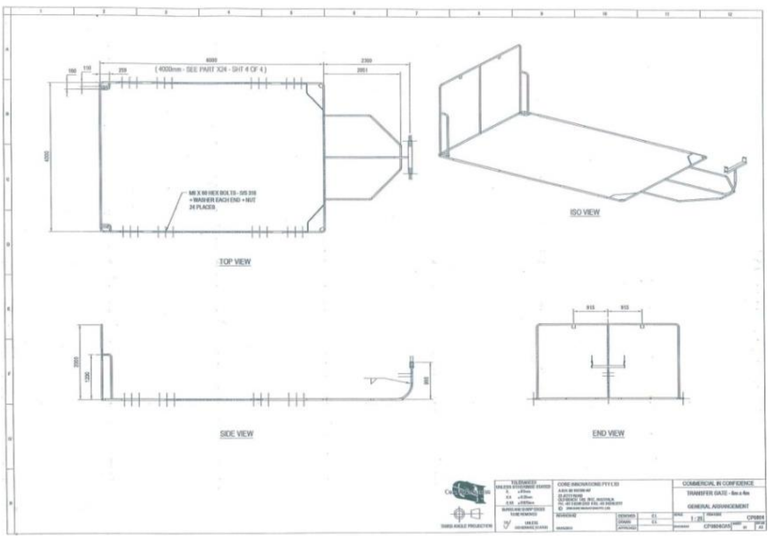

Figure 4. The structure of the frame.

Figure 5. The gate in between the two cages of the farm of Marina di Camerota.

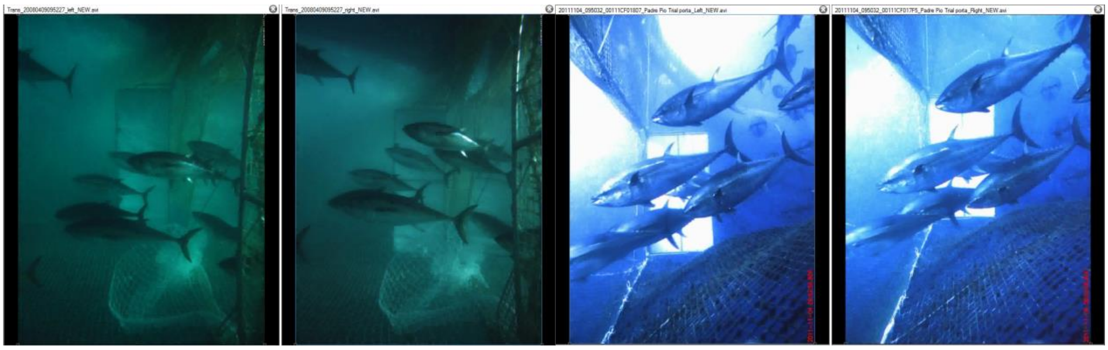

Figure 6. The transfer in the Australian (left) and Mediterranean (right) farms.

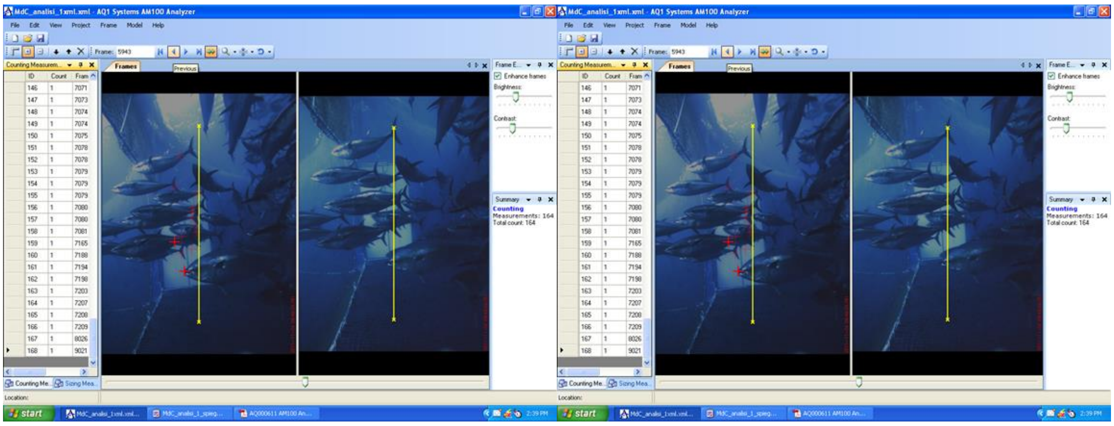

Figure 7. Images of the counting measurement.

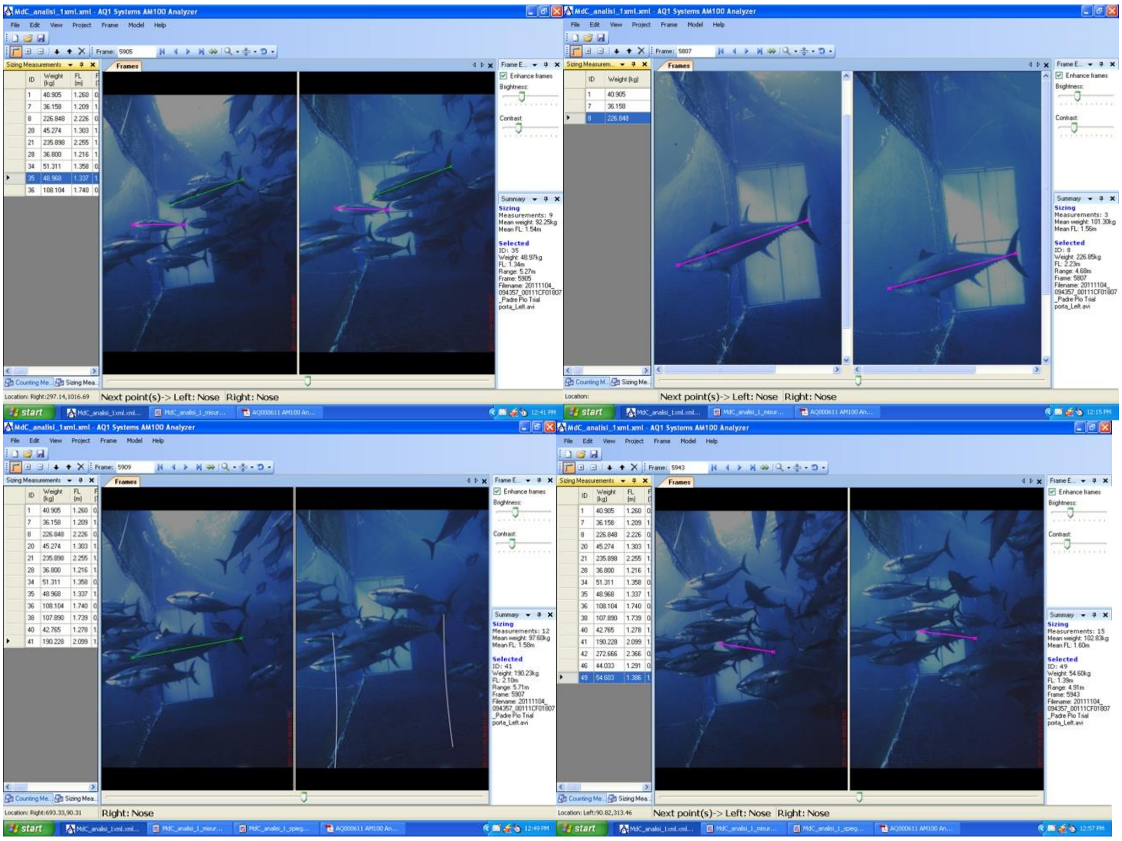

Figure 8. Image of the sizing measurement.

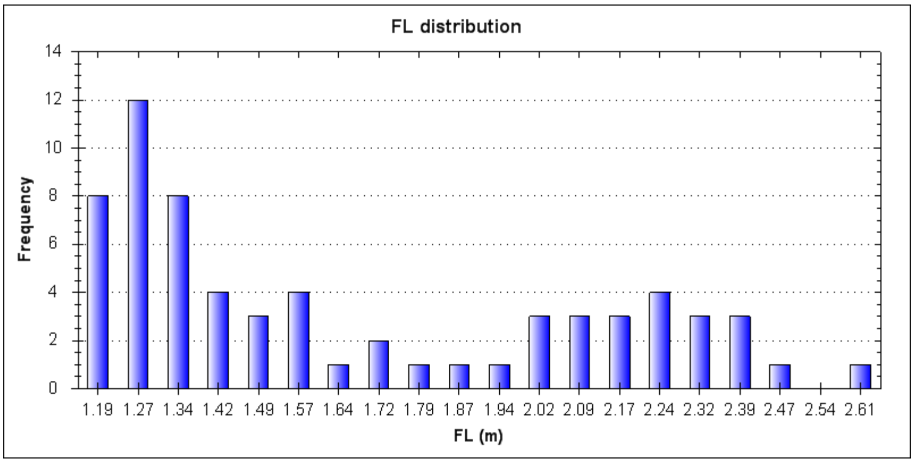

Figure 9. Fork length distribution.

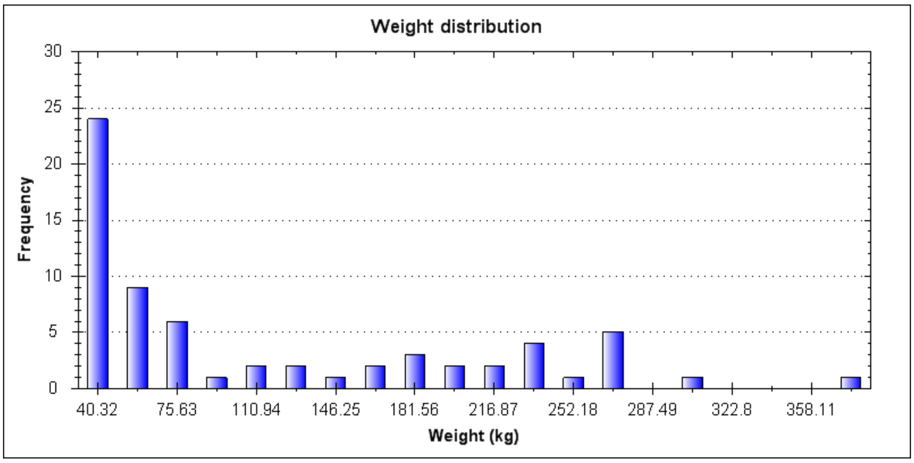

Figure 10. Weight distribution.

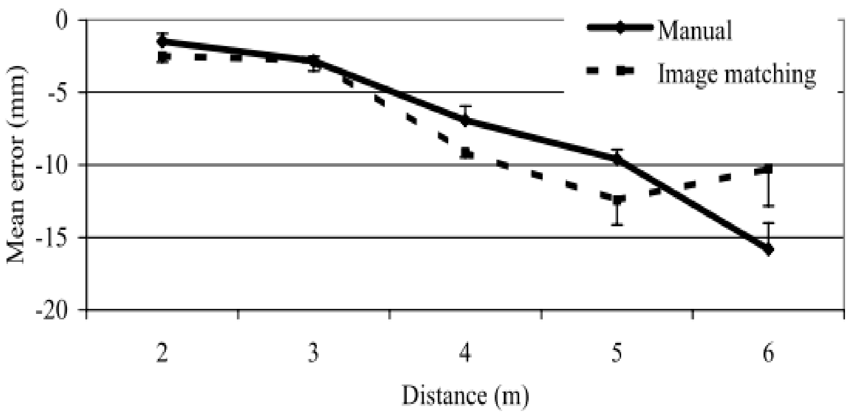

Figure 11. Measurement accuracy and precision of the PC based stereo-video system.

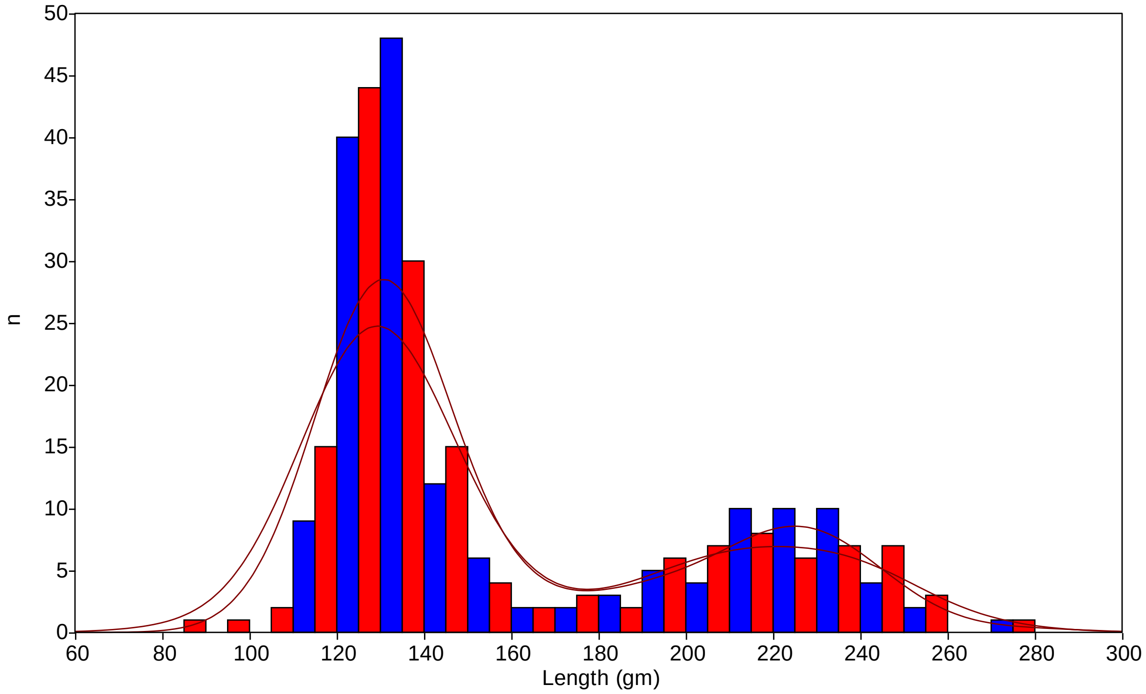

Figure 12. Measured (blue) and assessed (red) length distribution.

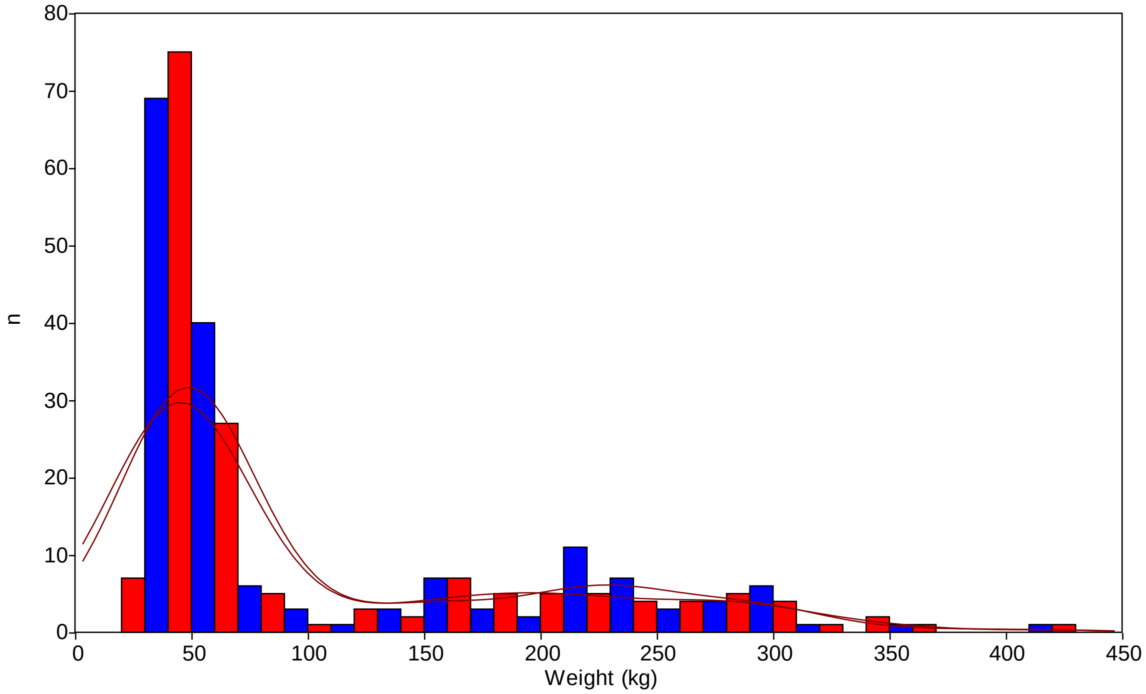

Figure 13. Measured (blue) and assessed (red) weight distribution.

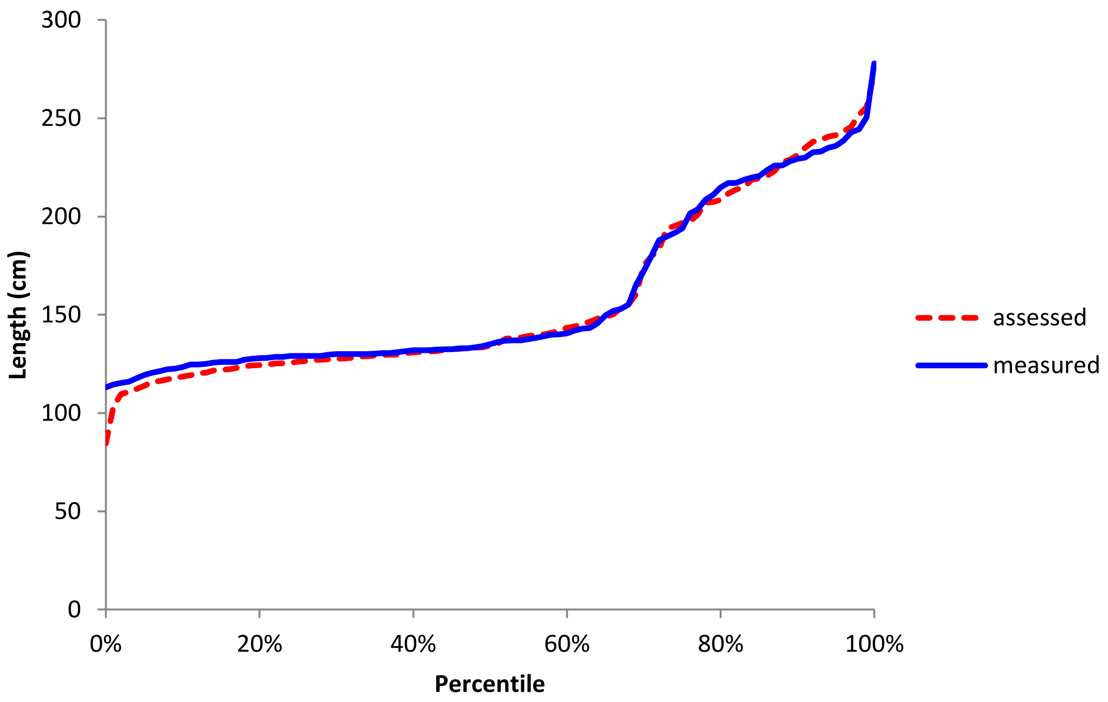

Figure 14. Cumulated frequency distributions of measured (blue) and assessed (red) length.

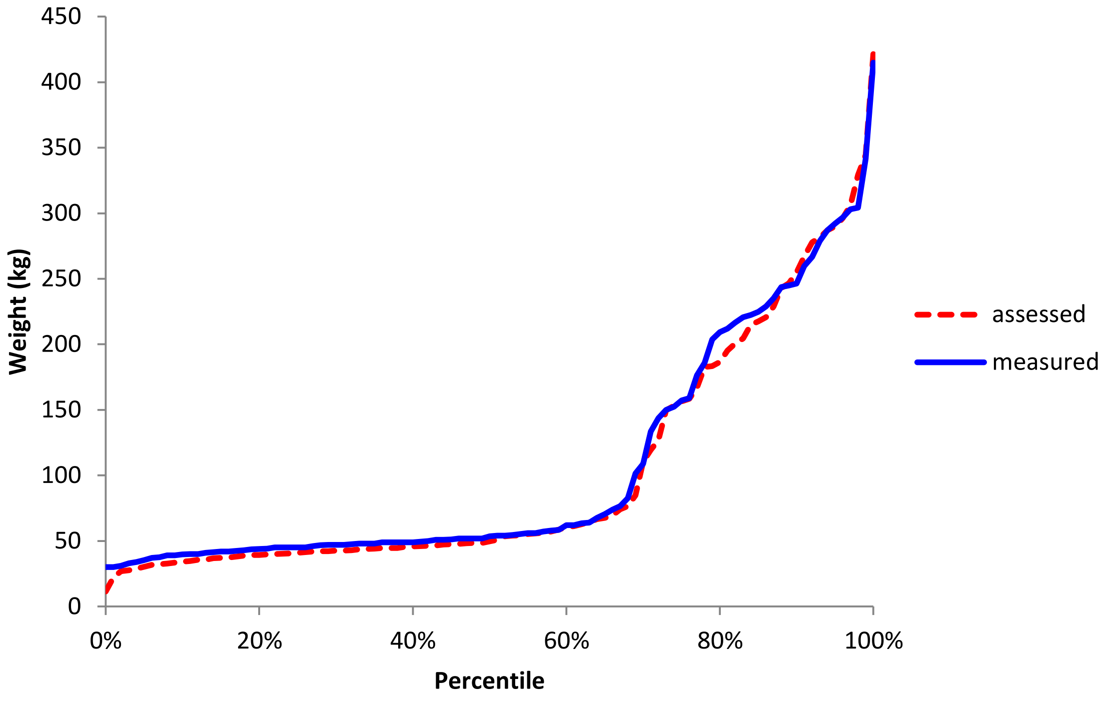

Figure 15. Cumulated frequency distributions of measured (blue) and assessed (red) weight.

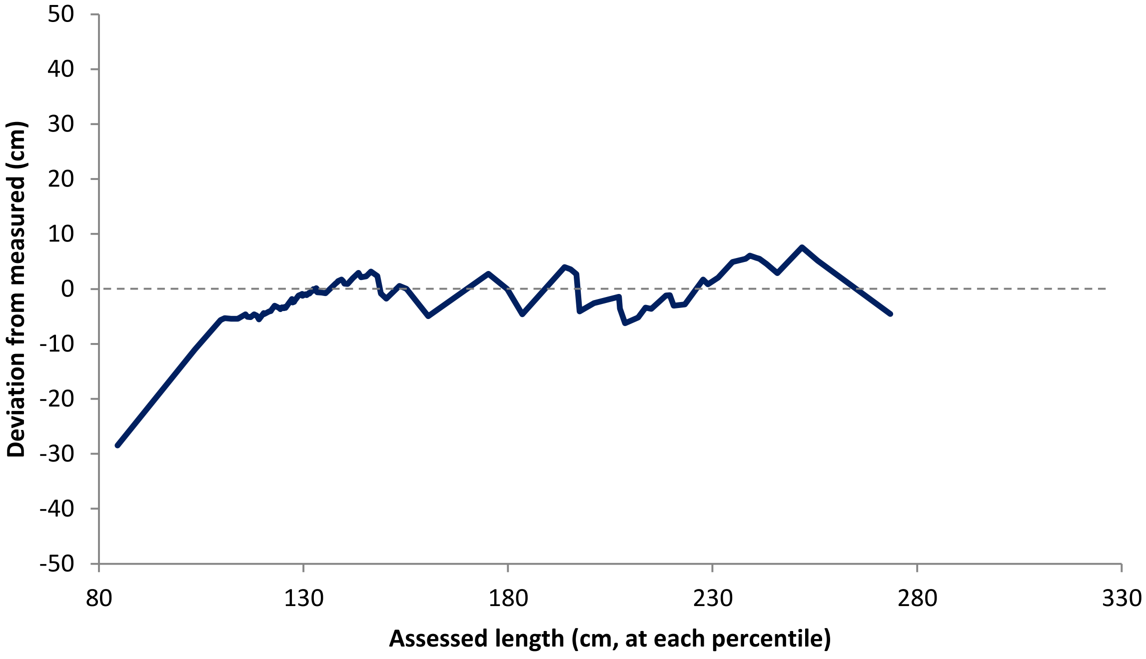

Figure 16. Deviation from measured length at each percentile of the assessed length distribution.

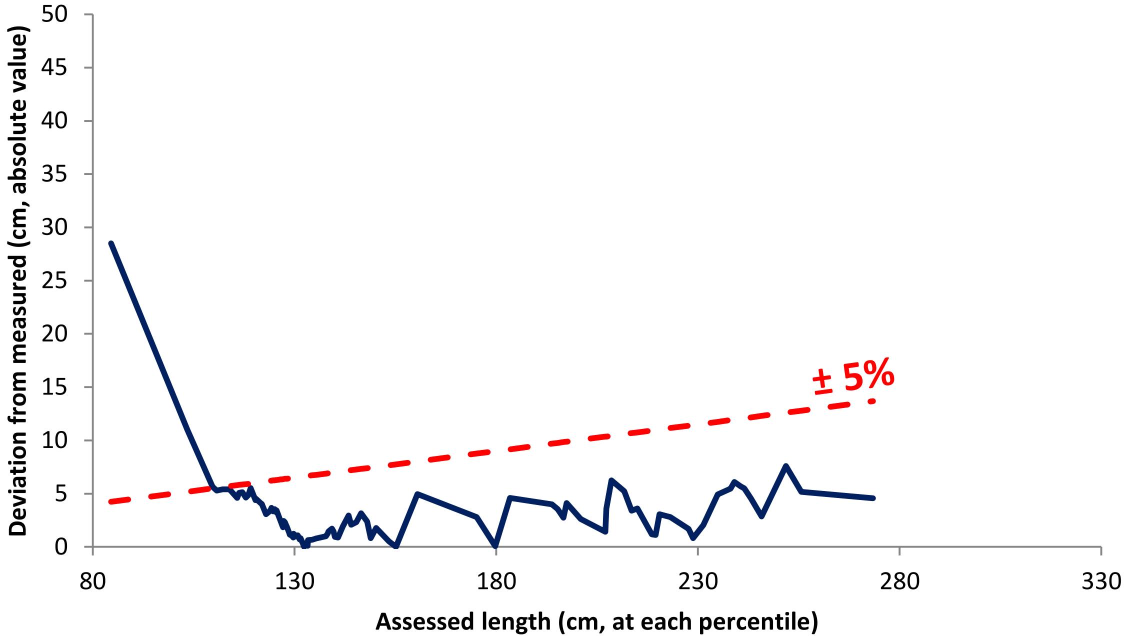

Figure 17. Absolute value of the deviation from measured length at each percentile of the assessed length distribution. The area under the dashed red line corresponds to deviations in the ±5% range.

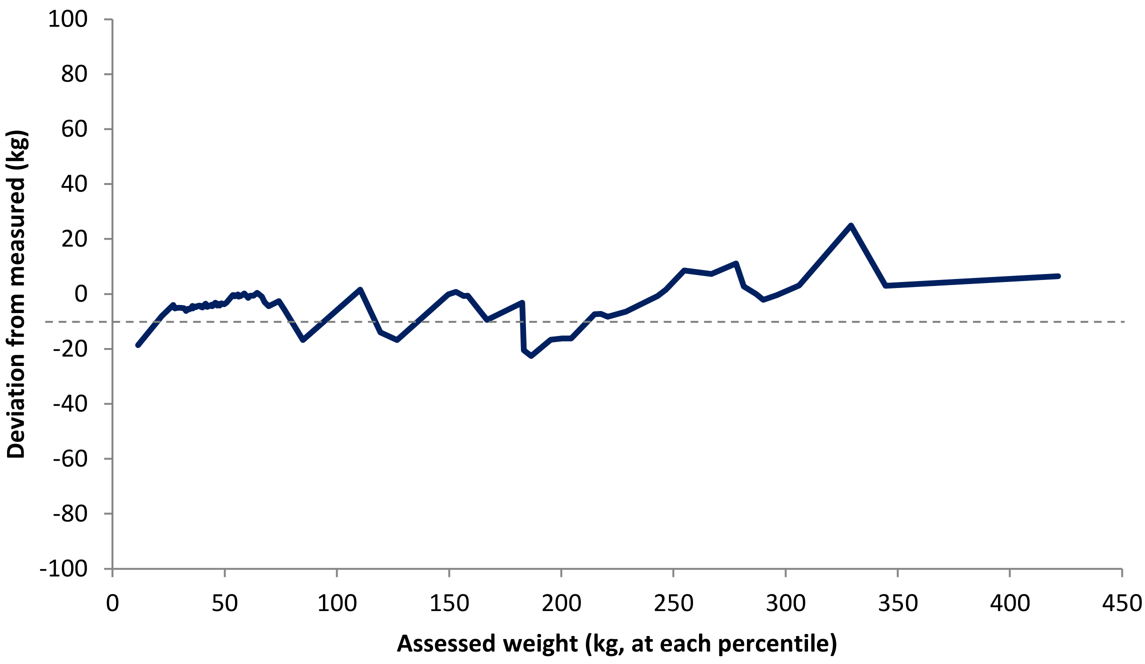

Figure 18. Deviation from measured weight at each percentile of the assessed weight distribution.

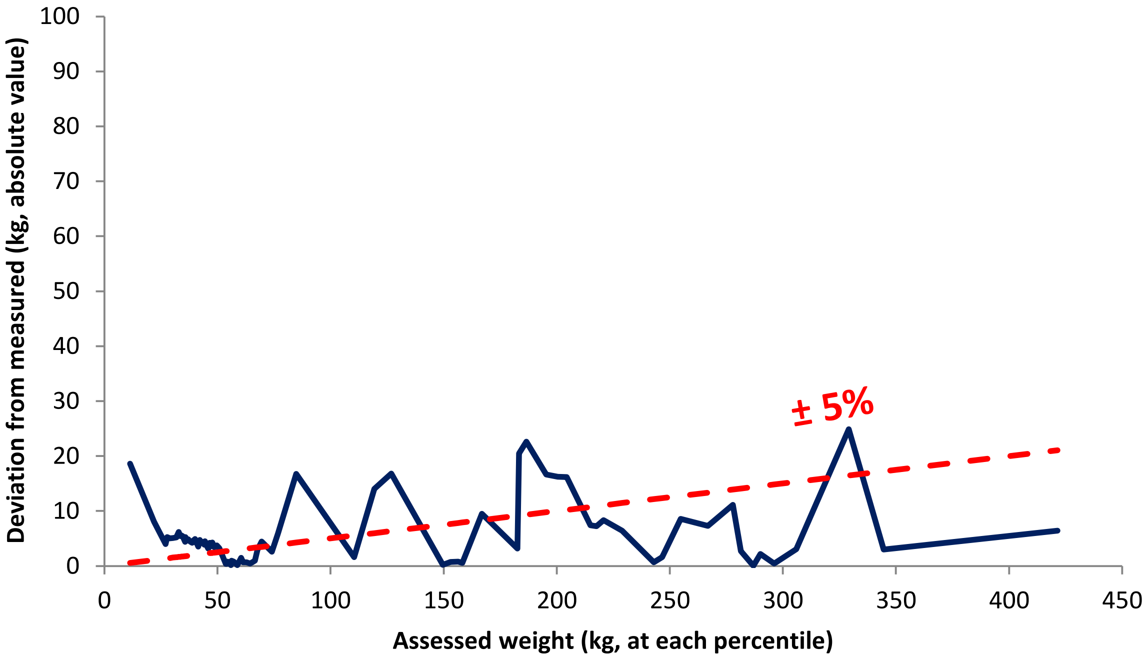

Figure 19. Absolute value of the deviation from measured weight at each percentile of the assessed weight distribution. The area under the dashed red line corresponds to deviations in the ±5% range.

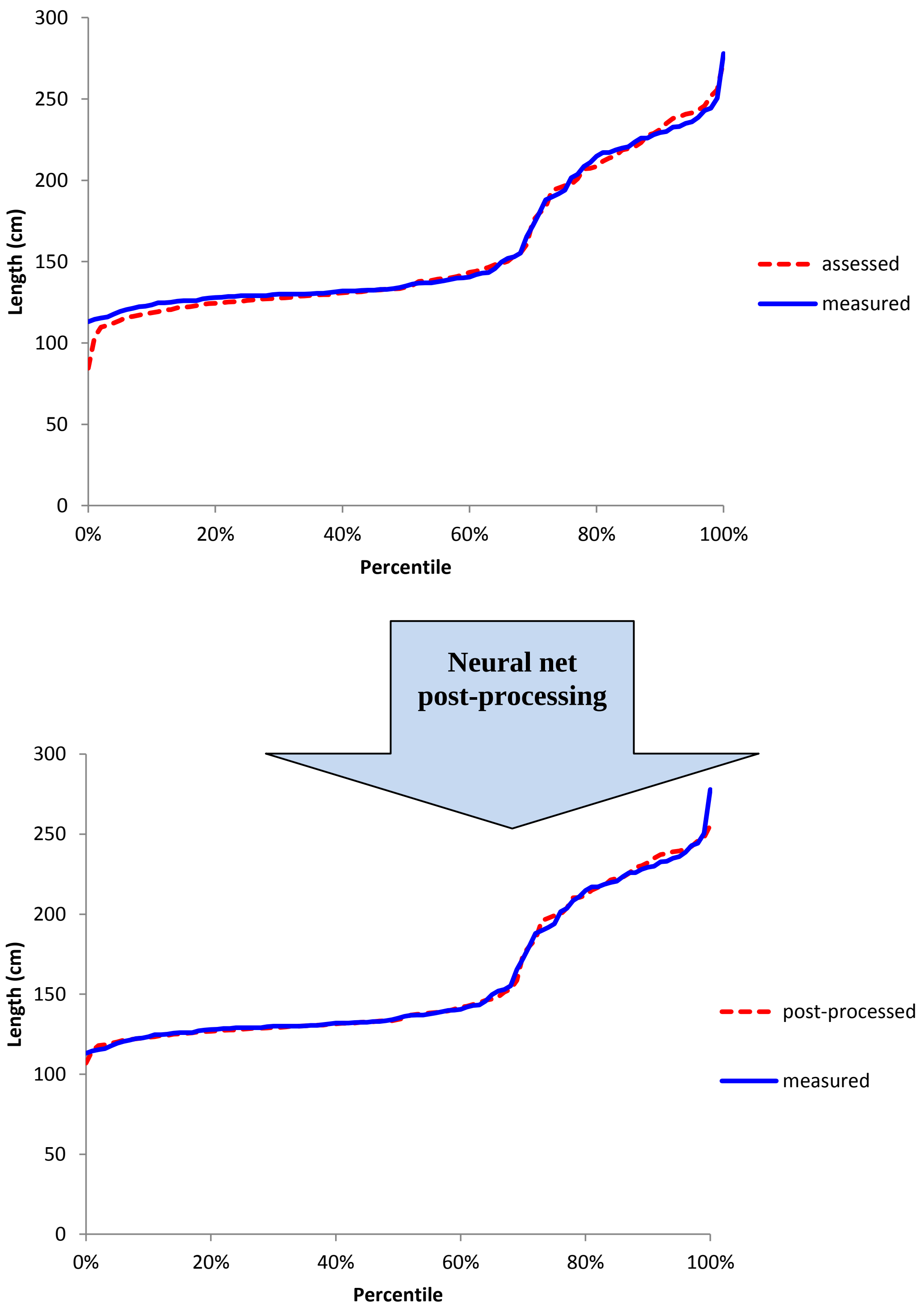

Figure 20. Cumulated frequency distributions after neural network post-processing.