Trialling Stereo Video in Australia's Southern Bluefin Tuna Farms

CCSBT31

1. The trial

In October 2020 Australia advised CCSBT 27 that it would trial the cost effectiveness and accuracy of fully automated stereo video systems in situ in Australia's tuna farms. Australia advised it would test the market to see what systems were available and the likelihood that they will meet its preconditions for implementation of fully automated and cost effective.

Following a tender process in 2021, Australia engaged Universitat Politecnica de Valencia (UPV) to undertake the trial in Port Lincoln, South Australia over two phases:

- Accuracy and length trials: As outlined by Australia in Circular 2023/11, phase 1 tested the accuracy of stereo video monitoring on SBT. This phase took place in February and March of 2023.
- Transfer trials: The second and final phase, which tested stereo video technology in a commercially operational environment, took place 8-27 February 2024. The report of phase 2 is attached.

The full stereo video trial final report is being finalised and will be provided to CCSBT when it is available.

2. Phase 2

During phase 2, stereo video was trialled on all transfers from three tow pens of two different companies. There were 10 separate transfers from tow pens to holding pens although the first tow pen was found to produce unreliable estimates and was excluded from the trial.

The trial has demonstrated that fully automated stereo video technology can be used in Australian conditions. Stereo video integrated well with normal farm operations, however, phase 2 also identified a number of issues including:

- identifying and costing software to implement. UPV has advised that its system is not commercially available. The pathway for software and licensing to be developed and made commercially available is highly uncertain, with development and licensing costs difficult to determine
- the requirement and cost for additional time to manually review footage to avoid identified occurrences of:
  - stereo video counting the same fish more than once. The tracking algorithm software produced double measurements of some individual fish during the onsite analysis, resulting in an overestimation of the true fish count
  - stereo video counting the tail of one fish and the head of another as one fish
  - stereo video counting species other than SBT as SBT
- agreeing and accounting for the cost of back up systems as an alternative method if technical difficulties arise when operating the stereo video system, such as power failure or in turbid water conditions where automated detection is not possible

- confirmation of the appropriate length to weight conversion factor to be used for deducting quota: the length weight conversion factor applied in the accuracy and length trials underestimated the true fish weight
- determine an appropriate calibration process to ensure continued accuracy: during the transfer trial the stereo video camera's calibration was compromised due to transport and handling which produced inaccurate fish measurements. This required in water calibration and off site correction.

3. Summary

In October 2022, Australia provided CCSBT 29 with *Stereo video implementation: trial and implementation steps in Australia's farm sector* (Workplan) as a basis for measuring progress in implementing the technology.

Australia has met all milestones in the Workplan to date. However, the issues identified in phase 2 of the trial and outlined above mean that the cost of the stereo video system in delivering a reliable and representative length measurement of fish during operational transfers is uncertain.

Ensuring stereo video is capable of accurately capturing lengths with a high level of confidence, and being able to convert those lengths to accurate weight, is vital for quota deduction. Based on the insights gained during the trial and as indicated in the reports, the issues identified above would need to be addressed in a cost-effective way before stereo video can be implemented in Australia's farm sector.

Australia will provide CCSBT the final trial report when it is available along with any updates in relation to the issues identified above.

Report: Findings of the Transfer Trial

Universitat Politècnica de València (UPV)

This report describes the activities and tests conducted by the UPV team during the Transfer Trial held in Port Lincoln from February 8th to 27th, 2024, along with its subsequent analysis. The report is structured as follows:

1. Trial visit program: Detailed scheduling of the activities conducted during the trial visit.
2. Approach and methodology: Introduction to prior agreements and a comprehensive overview of the efforts made, including the redesign of the stereocamera and its positioning in the frame to align with the operational practices of the industry during transfers.
3. Materials and Methods: Detailed description of the stereoscopic vision system, the stereocamera calibration procedure, and the key characteristics of the automatic Southern Bluefin Tuna (fish/SBT) sizing software.
4. Results: Recapitulation of the data delivered on-site and the off-site revision of the results. The on-site results (section 4.1) are presented as they were during the trial, with no modifications. In contrast, the off-site revision (section 4.2) presents the definitive results, after analysing and correcting the issues identified.
5. Conclusions

1. Trial visit program

The UPV team visited Port Lincoln from February 6th to 28th for the Transfer Trial. Three transfers from tow pens (T1, T2 and T3) to holding pens were carried out in collaboration with two different fishing companies: Australian Fisheries Enterprises (AFE) and Blaslov Fishing Group.
The schedule was as follows:

- February 6th
  - 19:55: arrival to Port Lincoln

- February 7th
  - 8:30: Meeting at Profab facilities with Jeremy Smith (AFMA) and Selina Stoute (AFMA) to inspect the frame delivered by AFMA and Seatec to Profab for necessary modifications to install stereocameras for recording transfers from a lateral perspective.
  - In the afternoon, John Isle (AFE) and Daniel Casement (ASBTIA) visited Profab to verify that the changes made to the frame would be suitable for the working environment of a real transfer.

- February 8th → T1 transfer with AFE company
  - 06:00-20:00: The transfer from the first tow pen (T1) with AFE company was completed, with the fish being transferred to three different holding pens.

- February 9th → Presentation of results
  - 9:30-12:00 Meeting held at AFE's premises with representatives from AFMA, ASBTIA, and the Australian Government to present the preliminary results of T1 transfers.

- February 16th → New stereocamera calibration
  - A new calibration process is carried out by the UPV team at the Port Lincoln pool. This has required the manufacture of a calibration board at Port Lincoln.

- February 20th
  - 17:00: The cameras and other necessary materials were transported to the Blaslov boat in preparation for the next day's transfer operation.

- February 21-22nd → T2 transfer with Blaslov company
  - The transfer from the second tow pen (T2) with Blaslov company was completed in two days, with the fish being transferred to three different holding pens.

- February 26-27th → T3 transfer with AFE company
  - The transfer from the third tow pen (T3) with AFE company was completed in two days, with the fish being transferred to four different holding pens.

2. Approach and methodology

Initially, two trials were considered: estimating the average weight in the tow pen before transfer (Tow Pen Trial) and during transfers (Transfer Trial). However, it was decided to prioritize the Transfer Trial over the Tow Pen Trial for future use due to the following reasons:

- It is impossible to know the number of fish in the tow pen until they are transferred to holding pens. As long as transfers need to be recorded to count fish, the same operation can be used to record and measure fish with stereovision.
- Whereas in transfers fish can only cross the camera's field of view once and are measured accordingly, fish in the tow pens are in constant motion, repeatedly passing in front of the camera. This repeated exposure could introduce bias in the estimation due to multiple measurements of the same fish.

Regarding the Transfer Trial, we proposed an operational approach to accommodate the way companies have operated during transfers up to now, with as little disruption to the operation as possible.

Firstly, attaching the stereocamera to the frame that is currently used to record the transfers with a monocamera for fish counting, with as few modifications as possible. The construction of the frame was completed at Profab installations, and the final configuration is depicted in Figure 1, while the detailed dimensions can be found in Figure 2. The stereocamera was affixed to the frame to maintain a perpendicular orientation to the water surface, facilitating the recording of the lateral view of the fish. Additionally, it was positioned away from the gate using a 1.2m high post. Our proposal to either remove the lateral white panel or extend it to double its size was not able to be adopted for the trial because of concerns about operational disruption. Figure 3 presents a sample of images obtained during the Transfer Trial using this finalized configuration.

Secondly, the stereocamera was redesigned to have longer cable (90 meters) and much lower weight (2.5 kg) to make it lighter and easier for divers to handle during transfers (see Figure 4). The same procedure used for the monocamera, which records transfers for fish counting, was followed with the stereocamera. It's worth noting that the stereocamera could potentially replace the monocamera for fish counting, as its footages can also be used to manually count the number of transferred fish.

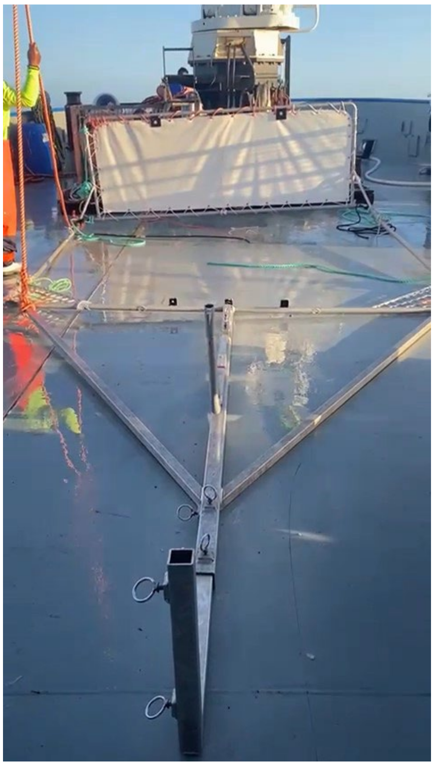

Figure 1. Frame used to record the transfers with a mono-camera for fish counting and the stereocamera for fish sizing.

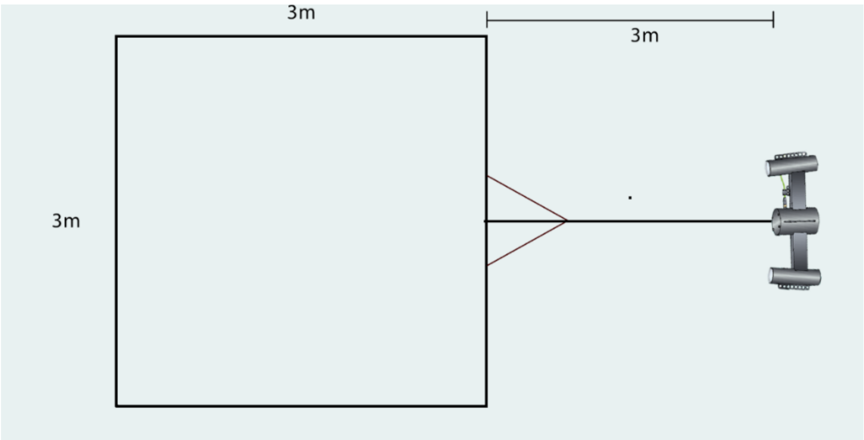

Figure 2. Dimensions of the frame used during the Transfer Trial.

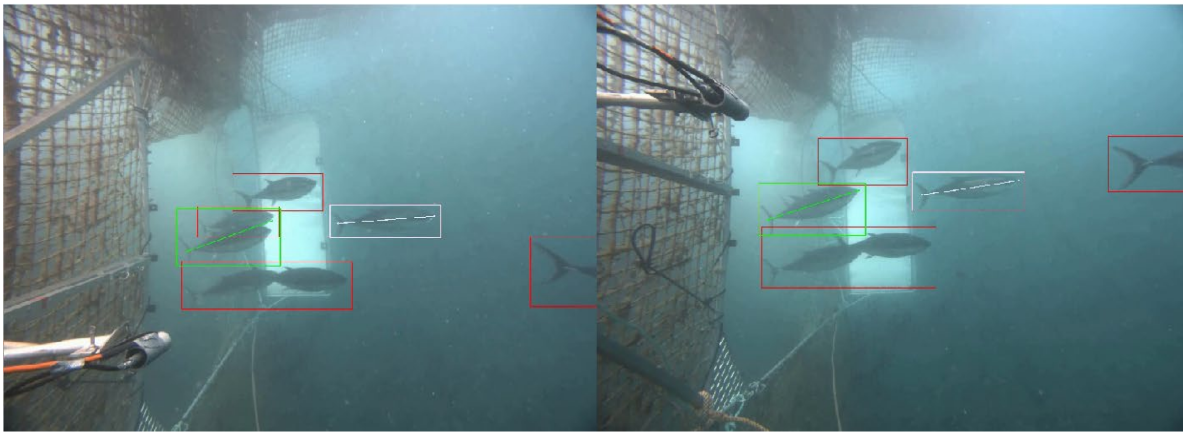

Figure 3. Sample of a pair of images from the stereocamera during the Transfer Trial. In the left image, can be observed the monocamera used for counting.

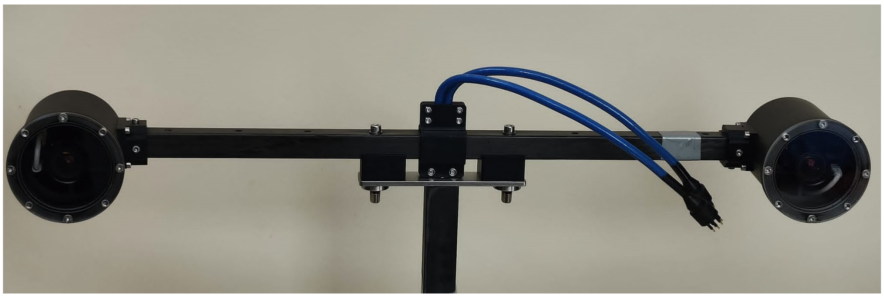

Figure 4. Image of the new lighter stereocamera.

3. Materials and methods

3.1. Stereoscopic vision system

The stereocamera used in the Transfer Trial consists of two Gigabit Ethernet cameras, with a 3.1 Megapixels resolution (2048x1536) and framerate of 33 fps. The cameras are mounted in an underwater housing, with a baseline of 85 cm and inward convergence of 5°. Camera synchronization is achieved using the IEEE 1588 Precision Time Protocol (PTP). The system is designed to operate at depths of up to 40 meters and is equipped with two umbilical Gigabit Ethernet cables, each extending 90 meters in length. These cables supply power over ethernet to the cameras and transfers images to a logging computer, which encodes left and right videos using GPU encoding.

Two laptops, each equipped with powerful graphics cards (Nvidia RTX), were employed during the transfers. One laptop was dedicated to video recording, while the other handled the automatic processing of the video to extract fish measurements. This parallel setup enabled us to analyse the videos simultaneously with recording, providing an estimate within minutes after the transfer's conclusion. However, it's worth noting that if only one laptop had been used, video processing would have commenced after the transfer's completion.

The system was powered using the boat’s power supply, although it would have been advisable to use an Uninterruptible Power Supply (UPS) to safeguard against interruptions in recording. During the trial, 10 minutes of recording were lost due to a failure in the boat’s power supply. Additionally, there is a need for improvement in the recording software, which is currently underway, as it experiences brief interruptions during video splitting, approximately 10 seconds per split. A total of 469 minutes were recorded, and 12 minutes of footage were missed as a result of video splitting.

3.2. Stereocamera calibration

It's worth noting that the mathematics behind stereo vision primarily involves projective geometry and matrix algebra. In our computer vision and artificial intelligence projects, we typically employ Matlab software or OpenCV library functions to carry out geometric transformations and conduct matrix calculations. Figure 5 illustrates a segment of the calibration process conducted using Matlab.

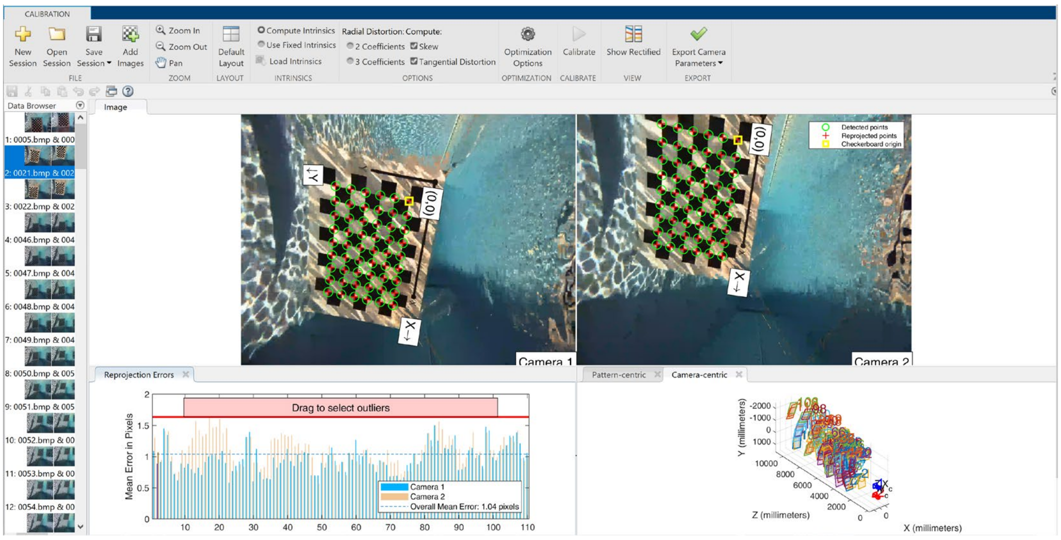

Figure 5. Snapshot of the stereocamera calibration process conducted using Matlab.

The calibration procedure of a stereo camera generally involves the recovery of intrinsic parameters (i.e. the principal point, the focal length and the lens distortions of both cameras) and extrinsic parameters (i.e. the rigid transformation between the two cameras). The major purpose of camera calibration is to remove the distortions in the image and thereby establish a relation between image pixels (projection 2D of the world) and real-world dimensions (3D world). Calibration typically involves capturing images of a calibration pattern from multiple viewpoints and using these images to estimate the parameters through mathematical optimization techniques. High-accuracy 3D measurement based on binocular vision system is heavily dependent on the accurate calibration of two rigidly fixed cameras.

The two images of Figure 6 describe a stereocamera setup using the checkerboard method for calibration. The calibration essentially finds out the rotation R and translation T between both cameras that will allow the computation of length measurements from image coordinates.

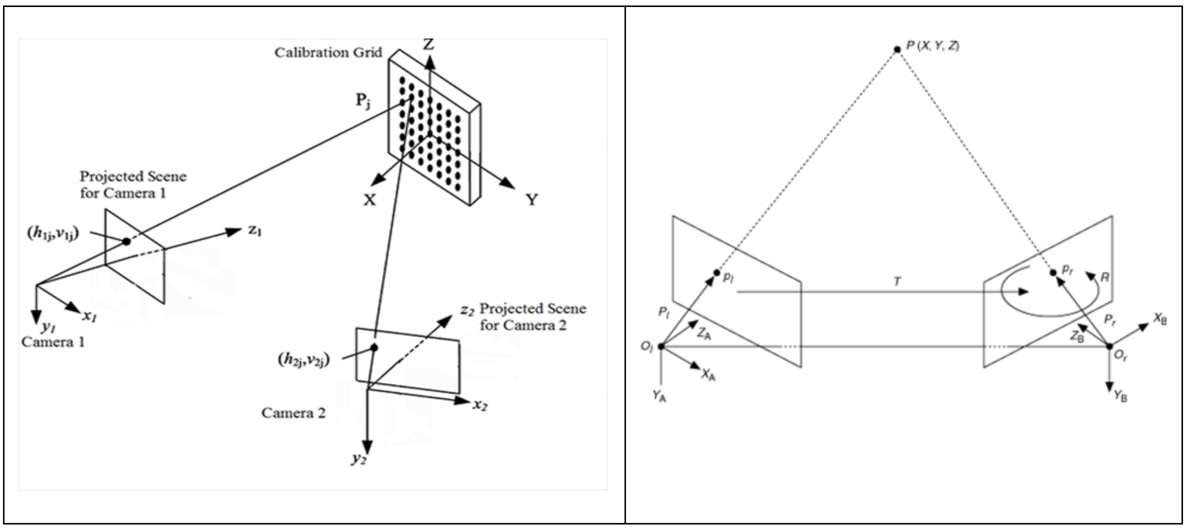

Figure 6. Description of a stereocamera calibration setup.

3.3. Automatic fish sizing software

Our automatic fish sizing algorithms employ a fusion of Deep Learning (DL) and Convolutional Neural Networks (CNN) techniques. These advanced methodologies enable the extraction of defining features from fish shapes, ensuring robust detection that remains unaffected by variations in image attributes. DL techniques have revolutionized various fields, surpassing the state of the art in areas such as speech recognition, face recognition, character recognition, and particularly in image analysis. Nonetheless, the efficacy of such systems hinges on extensive datasets (images in our case) and prolonged neural network training periods to achieve optimal performance. Furthermore, we have designed a tracking algorithm based on temporal and spatial information, providing reliable and more accurate size measurements by repeating several measurements of the same fish. Noting that a fish is measured multiple times, the recorded fish length is computed as the median of all individual lengths. The median is a measure of central tendency that is less sensitive to outliers compared to the mean. This means that extreme values have less impact on the median than they do on the mean. By using the median, influence of extreme outliers is discarded, making it a useful measure for datasets with potential high-deviated measurements.

The software is operated through a user-friendly graphical interface that does not require any knowledge of the underlying algorithms. Although two software experts were required to operate the system during the trial, no specific technical expertise is needed to operate the software. It's important to note that while the system had been previously tested with ABT in the Mediterranean and Norwegian Sea, this was its first application with SBT in the Indian Ocean, requiring technical adjustments to be made.

Two different modes were utilised during the Transfer Trial, termed Performance and Quality Mode. The distinction between them lies in the video resolution and frame rate, as outlined in Table 1. The Performance Mode operates with lower resolution and frame rate, resulting in faster processing speed but potentially reduced accuracy and measurement capabilities. Comparatively, Quality Mode is more effective in sizing capabilities and requires additional time to render footage due to the higher resolution. The functionality of these modes will be analysed in the results section.

Mode	Video resolution	Frame rate
Quality Mode	2048x1536 pixels	33 frames per second
Performance Mode	1024x768 pixels	16.5 frames per second

Table 1. Characteristics of the two modes of the automatic fish sizing software used in the Transfer Trial.

The evaluation of essential metrics for each transfer is crucial for gaining a comprehensive understanding of the system's performance and effectiveness. These metrics include:

- The number of automatic measurements and their respective percentage relative to the total number of fish counted. This metric provides valuable insights into the system's efficiency in capturing fish data, offering a comprehensive overview of its performance in accurately detecting and measuring fish.
- The average length of the fish measured, together with length-frequency histograms to provide essential information about the size distribution within the sample population.
- Computation time, which denotes the time it takes for the automatic system to deliver estimations. This metric is essential for evaluating the system's processing speed and efficiency, allowing us to assess its real-time performance in providing timely and reliable data. This metric is calculated from the moment automatic video processing begins. In on-site practice, the starting point would be five minutes after the start of the transfer, just after the first video split.

By evaluating these metrics for each transfer, we can gain a thorough understanding of the system's performance and effectiveness under various operational conditions.

4. Results

A total of 10 transfers were conducted from 3 tow pens, as detailed in Table 2. Each transfer is uniquely identified by the tow pen number and the sequential transfer number. For instance, T1.2 denotes the second transfer from the first tow pen.

Tow pen	Date	Transfers	Company
T1	8/02/2024	T1.1, T1.2, T1.3	AFE
T2	21/02/2024 and 22/02/2024	T2.1, T2.2, T2.3	Blaslov Fishing Group
T3	26/02/2024 and 27/02/2024	T3.1, T3.2, T3.3, T3.4	AFE

Table 2. Transfers made in the Transfer Trial

4.1. On-site results

4.1.1. Transfers from first tow pen T1

The on-site results for the first tow pen T1 are shown in Table 3, while the length-frequency histogram is depicted in Figure 7. It is noteworthy that the Performance Mode was employed for these assessments.

	T1.1	T1.2	T1.3	T1
Fish count[1]	1956	3700	2344	8000
Video duration	25′	30'	22′	77′
Number of automatic measurements	769 (39%)	512 (14%)	443 (19%)	1724 (22%)
Average length (cm)	94,1	97,2	94,3	94,7
Computing time	35′	38′	29′	34′

Table 3. On-site results for transfers from first tow pen T1

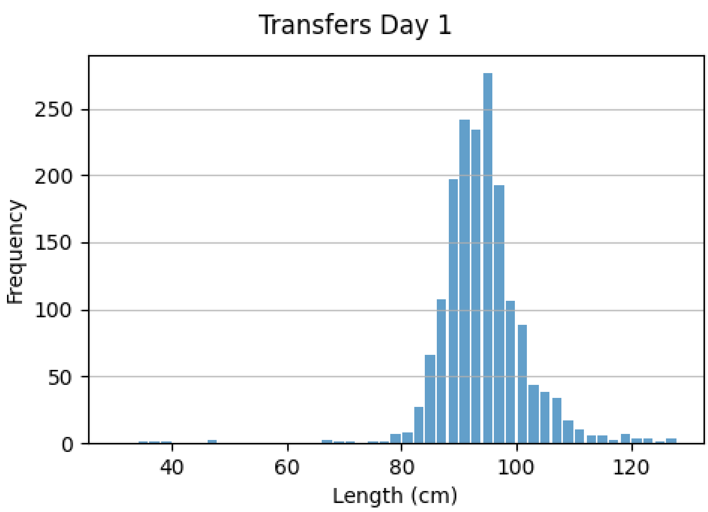

Figure 7. Length-frequency histogram of on-site results for transfers from first tow pen T1.

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[1] the fish count is an independently verified count conducted by the Australian Government contractor and is a census of fish transferred, reviewed using the mono-camera deployed during the transfers

These results were presented to the Stereo Video Working Group (SVWG) at AFE's facilities on February 9th. Feedback from industry representatives highlighted two key points: firstly, the average length of 93-94 cm exceeded that of manually sampled fish previously and the stereo video length frequency histogram included very few / no fish in the length frequency histogram determined by the hook weight sample, raising concerns. Secondly, the presence of fish exceeding 110 cm was deemed unusual and drew attention.

Subsequent analysis revealed that the camera configuration had become uncalibrated prior to sampling from tow pen T1, likely impacting the accuracy of the length measurements. It was concluded that a review of the system was necessary to identify and address potential sources of error leading to overestimation of fish length.

In response, the UPV team and collaborators worked together to investigate possible sources of error. It was determined that the calibration of the stereocamera had been compromised during transport and manipulation. To rectify this issue, a calibration checkerboard was constructed, and a new calibration procedure was conducted at the Port Lincoln pool. Furthermore, improvements were made to the video quality, as it was found to be suboptimal under the prevailing environmental conditions.

After this initial experience, we adopted a new procedure in the setup: before commencing each individual transfer, and after attaching the stereocamera to the transfer gate frame, a diver is required to present the calibration checkerboard to the stereocamera, following the instructions outlined in Figure 8. This allows for on-site calibration mitigating the potential impact of camera transport and manipulation on length measurements. Example images illustrating this process are provided in Figure 9.

Furthermore, measures were taken to ensure the visibility of marks on the white panel (refer to Figure 10) during transfers. These marks are spaced 120 cm apart and serve as a reference for verifying the calibration.

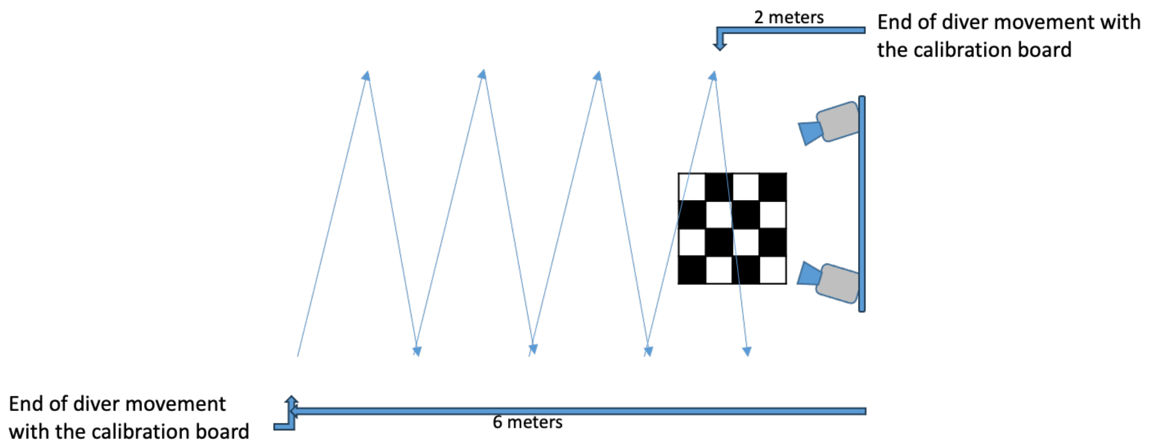

Figure 8. Instructions for divers for moving the calibration checkboard in front of the camera prior to starting each new transfer to allow on-site calibration.

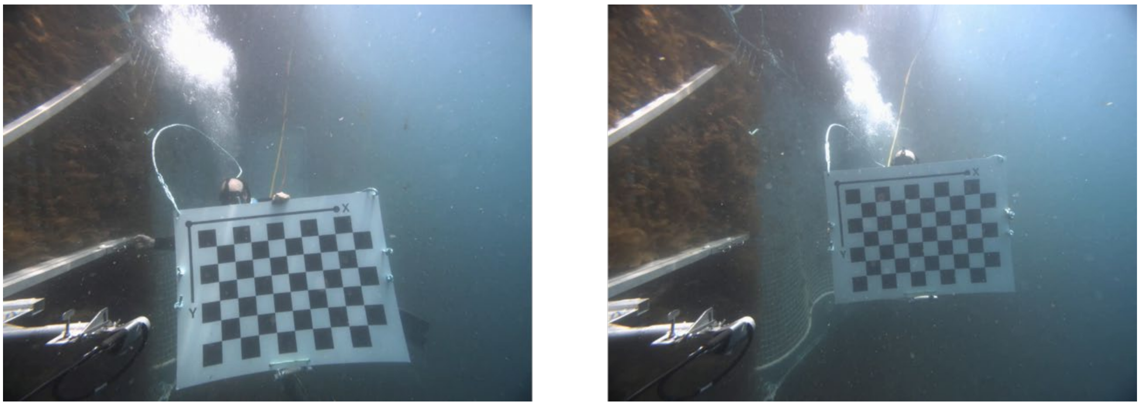

Figure 9. Example of images taken before commencing each new transfer in T2 and T3 to allow on-site calibration.

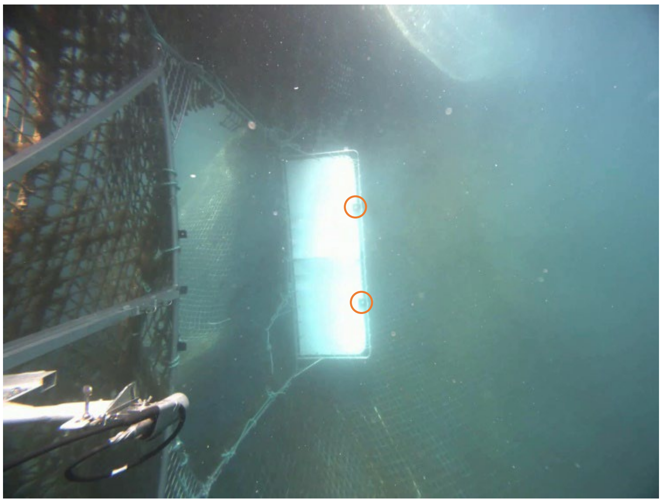

Figure 10. Marks on the white panel, spaced 120 cm apart, serve as a reference for verifying the calibration.

4.1.2. Transfers from second (T2) and third (T3) tow pens

The results of the T2 and T3 transfers were presented to the SVWG on-site during the trial and are summarized in Table 4 and Table 5, respectively. The average total length for T2 transfers are 89,1 cm and 88,6 cm in Performance and Quality Mode, respectively, with automatic measurements accounting for 17% and 84% of the total fish count, respectively. Similarly, for T3 transfers, the average total lengths are 91,3 cm and 90,3 cm in Performance and Quality Mode, respectively, with automatic measurements comprising 25% and 75% of the total fish count, respectively.

It's important to note that the number of automatic measurements in T2.3 (higher than the fish counted) suggests that a same fish is identified by the tracking algorithm as a different fish and measured more than once (what we coin duplicate measurements), potentially biasing the results in all transfers. The causes and their impact on the statistics are investigated later in the off-site revision of the results section (4.2).

T2 Transfers		T2.1	T2.2	T2.3	Total
Fish count		3214	5027	3182	11423
Performance Mode	Number of automatic measurements	663 (21%)	738 (15%)	539 (17%)	1940 (17%)
	Average length (cm)	86,1	89,2	92,7	89,1
Quality Mode	Number of automatic measurements	1567 (50%)	4429 (87%)	3567 (112%)	9563 (84%)
	Average length (cm)	86,7	87,0	91,3	88,6

Table 4. On-site results for transfers from T2

T3 Transfers		T3.1	T3.2	T3.3	T3.4	Total
Fish count		4122	3943	4088	3587	15740
Performance Mode	Number of automatic measurements	1530 (36%)	608 (15%)	782 (19%)	999 (28%)	3919 (25%)
	Average length (cm)	92,1	89,4	92,8	90,1	91,3
Quality Mode	Number of automatic measurements	2811 (68%)	2740 (69%)	3104 (76%)	3257 (91%)	11912 (75%)
	Average length (cm)	91,8	87,4	92,1	89,9	90,3

Table 5. On-site results for transfers from T3

4.1.3. Conclusions from on-site results

The results of transfers from T1 were significantly affected by loss of stereocamera calibration prior to sampling, resulting in an overestimation of the average length. As a result, these results should be excluded from comparative analysis. Nonetheless, the experience gained during this period enabled us to validate the feasibility of our operation and refine our methodology for future transfers. This involved introducing a calibration board before commencing transfers and ensuring clear visibility of panel marks to verify camera calibration.

In the case of T2 and T3 transfers, the average lengths measured were 89,1 cm and 91,3 cm in Performance Mode, and 88,6 cm and 90,3 cm in Quality Mode, respectively. In Performance Mode, automatic measurements constituted 17% and 25% of the total fish count, while in Quality Mode, they accounted for 84% and 75%.

It's imperative to highlight the need for a comprehensive review of both camera calibration and the tracking algorithm. Any adjustments made as a result of this review may have implications for the recorded average lengths and the percentage of automatic measurements during subsequent off-site analyses.

Some of the issues to be reviewed during the off-site revision process are the following:

1. Verify the validity of camera calibration for transfers from T2 and T3. Assess whether the calibration conducted in the pool remains accurate when measuring fish in T2 and T3 transfers following days of stereocamera transport and handling. This will be addressed in section 4.2.1.
2. Conduct a thorough review of tracking algorithm parameters to mitigate the occurrence of duplicate measurements of individual fish during the transfer trial. This will be addressed in section 4.2.2.
3. Determine and quantify the impact of incorrect and duplicate measurements and their influence on the overall data accuracy. This will be addressed in section 4.2.4.
4. Determine the extent of potential bias introduced into estimates given the characteristics of unmeasured fish (e.g. are the unmeasured fish smaller or larger than measured fish). This will be addressed in the Final Report.

4.2. Off-site revision of the results

4.2.1. Validation of the camera calibration

The primary issue addressed during the revision of the results was on validating the camera calibration. The distance between marks on the white panel, shown in Figure 10 and spaced 120 cm apart, served as a reference for ensuring the continued accuracy of the calibration performed in the pool at the facility in Port Lincoln. Any deviation from the expected 120 cm measurement would indicate loss of calibration due to transport and handling. In such instances, the images of the calibration checkerboard captured before initiating each transfer could be utilized to conduct an on-site calibration procedure.

The distance between marks was manually measured using our software. For each transfer, three measurements of the distance were taken, utilizing both the calibration performed in the pool and the on-site calibration. The average distance for each case is presented in Table 6.

Analysis of the results indicates that the distance estimated with the calibration performed in the pool aligns closely with the expected 120 cm for T2.1 and T2.2, but deviates between 6,3 cm (5,3%) and 11,7 cm (11,5%) starting from T2.3. Conversely, the on-site calibration consistently yields measurements around the expected 120 cm, with a maximum deviation of 0,6 cm (0,5%), which is within the error margin of manual measurements with stereoscopic systems[2]. Please note that the panel mark is at approximately 6 meters, and the variability intrinsic to manual measurements is magnified with the distance. This finding has substantial implications for the preceding section's results, as it demonstrates that the stereocamera was out of calibration when the results were given on-site. In the present section, the on-site calibration is used to estimate fish sizes.

Transfer	T2.1	T2.2	T2.3	T3.1	T3.2	T3.3	T3.4
Measured distance (cm) between panel marks using the calibration in the pool	120,6 (+0,5%)	120,1 (+0,1%)	129,3 (+7,8%)	131,7 (9,7%)	126,3 (+5,3%)	133,8 (+11,5%)	130,8 (+9,0%)
Measured distance (cm) between panel marks using the on-site calibration	120,3 (+0,2%)	120,2 (+0,2%)	119,9 (-0,1%)	119,8 (-0,2%)	120,3 (+0,2%)	120,6 (+0,5%)	120,5 (+0,4%)

Table 6. Distance (cm) between panel marks measured manually with the software, comparing the calibration in the pool with the calibration performed using on-site images recorded prior to each new transfer (on-site calibration). The actual distance between marks is 120 cm.

4.2.2. *Revision of the tracking algorithm parameters*

The second issue reviewed was the high number of measurements, which was solved by adjusting the parameters of the tracking algorithm. Videos with the detections were visually inspected to fine-tune the parameters and prevent duplicate measurements of individual fish. These parameters take into account the video framerate and swimming speed of the fish, aspects that had not been previously tested in this species and environment.

4.2.3. *Results with on-site calibration and updated tracking algorithm*

Table 7 presents the results for T2 and T3 transfers, respectively, using the on-site calibration and updated tracking algorithm. They indicate that Performance Mode delivers between 22% (T2.1) and 63% (T2.3) of measured fish (averaging 41% for T2 and 40% for T3) and Quality Mode delivers between 38% (T2.1) and 82% (T2.2) of measured fish (averaging 62% for both T2 and T3). The total average lengths in Performance Mode are 87,3 (T2) and 86,3 cm (T3), respectively, whereas in Quality Mode they are 86,9 (T2) and 86,0 cm (T3). The length-frequency histograms of each transfer and the whole tow pens are attached in Annex A for clarity. Comparatively, the results indicate that the average lengths in Performance Mode are higher than in Quality Mode. This discrepancy is primarily attributed to two factors: video resolution and the number of times the same individual is measured. The video resolution directly impacts measurement accuracy; thus, higher resolution leads to greater accuracy. Similarly, multiple measurements of the same individual increase confidence in accuracy.

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[2] Refer for example to the Annex 9, point 1.vi of Recommendation by ICCAT amending the Recommendation 21-08 establishing a multi-annual management plan for bluefin tuna in the eastern Atlantic and the Mediterranean (Rec. 22-08): “the margin of error for determining weight, inherent to the technical specifications of the stereoscopic camera system, shall not exceed a range of +/- 5 percent”, which would imply approximately a +/- 1.5 percent in length for SBT between 65 and 85 cm.

Nevertheless, the average length in both modes differ by less than 1 cm in all transfers, being 0,4 cm and 0,3 cm for the whole T2 and T3 tow pens, respectively.

Regarding computing time, with videos spanning 165 and 227 minutes for T2 and T3, respectively, the Performance Mode lasts 117 and 172 minutes, while the Quality Mode lasts 297 and 392 minutes, respectively. This indicates that the current Performance Mode can be implemented onboard vessels to provide a real-time estimation of approximately 40% of the population, whereas the Quality Mode offers an estimation of approximately 60% of the population but requires more time. Nevertheless, considering the optimization of a commercial version of the software and the rapid advancement of technology, particularly in graphic cards, which consume most of the computing time in our algorithms, we anticipate the development of faster versions in the near future. These advancements will enable real-time estimation of a higher percentage of sampled fish.

The spreadsheet reports containing results for all transfers, including averages and number of measured fish, are available for download from the following link[3]. Additionally, the link includes a sample video of each transfer recorded during the transfer trial to illustrate the software's capabilities and to provide transparency on the results in this report. Each fish measurement is highlighted in the videos with a bounding box, along with the snout and fork points. Additionally, a line connecting these two points is drawn. The first measurement is indicated in green, while subsequent measurements are denoted in pink to illustrate the functioning of the tracking algorithm.

Transfer		T2.1	T2.2	T2.3	T2
Number of fish		3214	5027	3182	11423
Video duration (min)		57	54	54	165
Time of day the video starts		11:54	15:44	11:07	-
Performance Mode	Number of automatic measurements	721 (22%)	3172 (63%)	802 (25%)	4695 (41%)
	Average length (cm)	86,6	87,1	88,0	87,3
	Computing time (min)	45	35	37	117
Quality Mode	Number of automatic measurements	1234 (38%)	4144 (82%)	1757 (55%)	7135 (62%)
	Average length (cm)	86,5	86,8	87,6	86,9
	Computing time (min)	102	110	85	297

Table 7. Off-site results for transfers from second tow pen T2

Transfer		T3.1	T3.2	T3.3	T3.4	T3
Number of fish		4122	3943	4088	3587	15803
Video duration (min)		72	56	58	41	227
Time of day the video starts		17:35	10:53	15:05	13:13	-
Performance Mode	Number of automatic measurements	1595 (39%)	1376 (35%)	2088 (51%)	1261 (35%)	6320 (40%)
	Average length (cm)	85,7	88,1	85,6	86,3	86,3
	Computing time (min)	43	41	52	36	172
Quality Mode	Number of automatic measurements	1914 (46%)	2204 (56%)	3000 (73%)	2618 (73%)	9736 (62%)
	Average length (cm)	85,5	87,8	85,6	85,4	86,0
	Computing time (min)	91	96	122	83	392

Table 8. Off-site results for transfers from third tow pen T3.

[3] https://upvedues-my.sharepoint.com/:f:/g/personal/pamuobe_upv_edu_es/Et2FvvoqV75GndXd7Piu8toB9ZOW5_QPkXY3i7Pv-dNmGw?e=KFNEPE

4.2.4. *Influence of incorrect and duplicate measurements*

After automatic processing, the fish detections of all transfers were thoroughly reviewed to identify incorrect and duplicate measurements. Given the laborious and time-consuming nature of reviewing and annotating all transfers, our focus was on Quality Mode, which provides the most accurate measurements. Duplicate measurements occur when the same fish is mistakenly identified as a different fish and measured more than once (see Figure 15). Incorrect measurements refer to the misplacement of the snout or fork points. The following cases of incorrect measurements have been identified:

- The snout point is placed on one fish and fork point on another fish (see Figure 11 for an example)
- The snout or fork points are placed on a wrong place due to suspended particles (see Figure 12 for an example) or confusion introduced by parts of other fish (see Figure 13 for an example).
- The fork point is placed on the gate frame (see Figure 14 for an example)
- Different fish species are measured as SBT.

The impact of incorrect and duplicate measurements on the statistics is presented in Table 9. The number of incorrect measurements ranges from 1,0% to 3,8% for all transfers (averaging 1,3% for T2 and 2,6% for T3), whereas the number of duplicate measurements ranges from 0% to 1,1% (averaging 0,2% for T2 and 0,1% for T3). The average length, when incorrect and duplicate measurements, are removed decreases between 0,2 and 0,4 cm, modifying the average length of T2 from 86,9 to 86,7 and T3 from 85,7 to 85,3. Notably, 90% of the incorrect measurements are due to the snout point being placed on one fish and the fork point on another.

As future work, the software will be trained with images of incorrect detections to reduce this kind of errors. The more SBT images from different transfers and weather conditions is trained on, the better the results it can deliver.

It is worth noting that the high number of detections, high framerate cameras, and tracking algorithms help filter out incorrect measurements. According to the results, a fish is measured an average number of times between 6,5 and 14,0 (averaging 9,1 both for T2 and T3), and the system delivers the median of all length measurements as the fish length. For an incorrect measurement to be delivered, several conditions must be met: the snout and fork points must be wrongly placed in both images of the stereocamera pair, and the incorrect measurement must be repeated in the majority of the times the fish is measured.

Transfer		**T2.1**	**T2.2**	**T2.3**	**TOTAL**
Fish count		3214	5027	3182	11423
Video duration		57	54	54	165
Quality Mode	Number of automatic measurements	1234 (38%)	4144 (82%)	1757 (55%)	7135 (62%)
	Number of incorrect measurements	16 (1,3%)	95 (1,9%)	33 (1,0%)	144 (1,3%)
	Number of duplicate measurements	14 (1,1%)	9 (0,2%)	4 (0,1%)	27 (0,2%)
	Average length (cm)	86,5	86,8	87,6	86,9
	Average length excluding incorrect and duplicate measurements (cm)	86,4	86,4	87,5	86,7
	Average number of measurements per fish	6,5	12,1	6,9	9,1

Table 9. Number of incorrect and duplicate measurements and their influence on the statistics for transfers from second tow pen T2.

Transfer		T3.1	T3.2	T3.3	T3.4	TOTAL
Fish count		4122	3943	4088	3587	15803
Video duration		72	56	58	41	227
Quality Mode	Number of automatic measurements	1914 (46%)	2204 (56%)	3000 (73%)	2618 (73%)	9736 (62%)
	Number of incorrect measurements	73 (3,8%)	61 (2,8%)	56 (1,9%)	62 (2,4%)	252 (2,6%)
	Number of duplicate measurements	6 (0,3%)	-	-	6 (0,2%)	12 (0,1%)
	Average length (cm)	85,5	87,8	85,6	85,4	85,7
	Average length excluding incorrect and duplicate measurements (cm)	85,3	87,5	84,9	84,9	85,3
	Average number of measurements per fish	14,0	8,5	7,9	5,8	9,1

Table 10. Number of incorrect and duplicate measurements and their influence on the statistics for transfers from third tow pen T3.

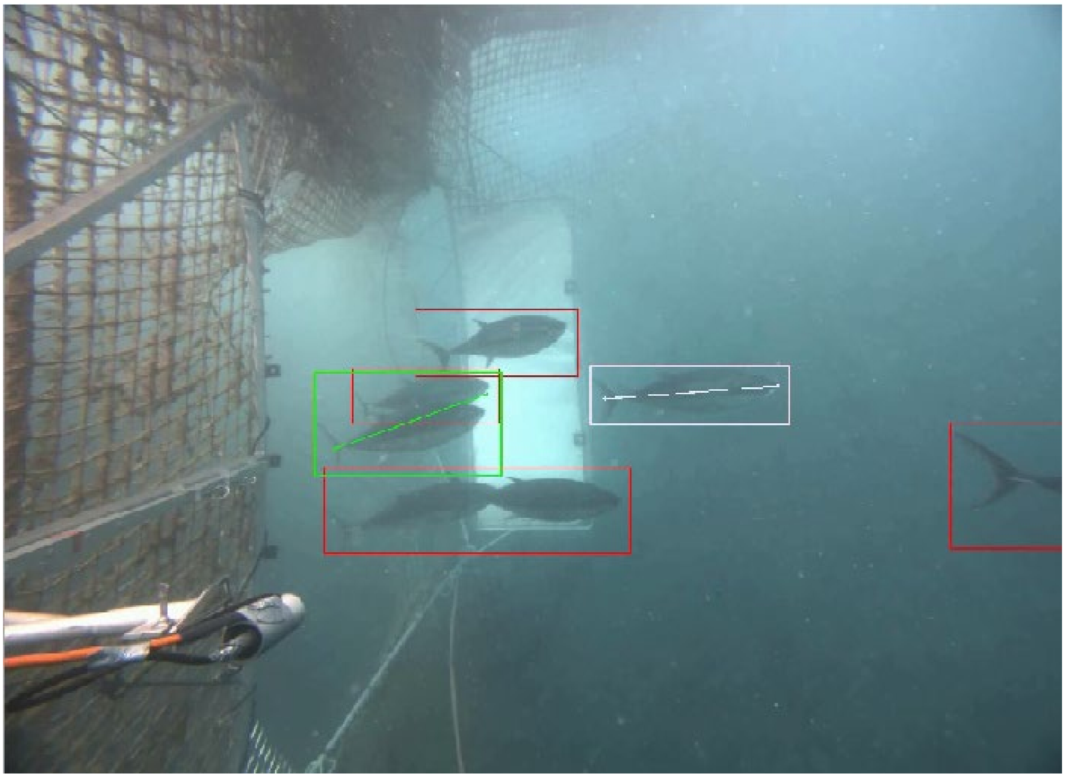


Figure 11. Examples of incorrect measurements. The snout point is placed on one fish and fork point on another fish (green box)

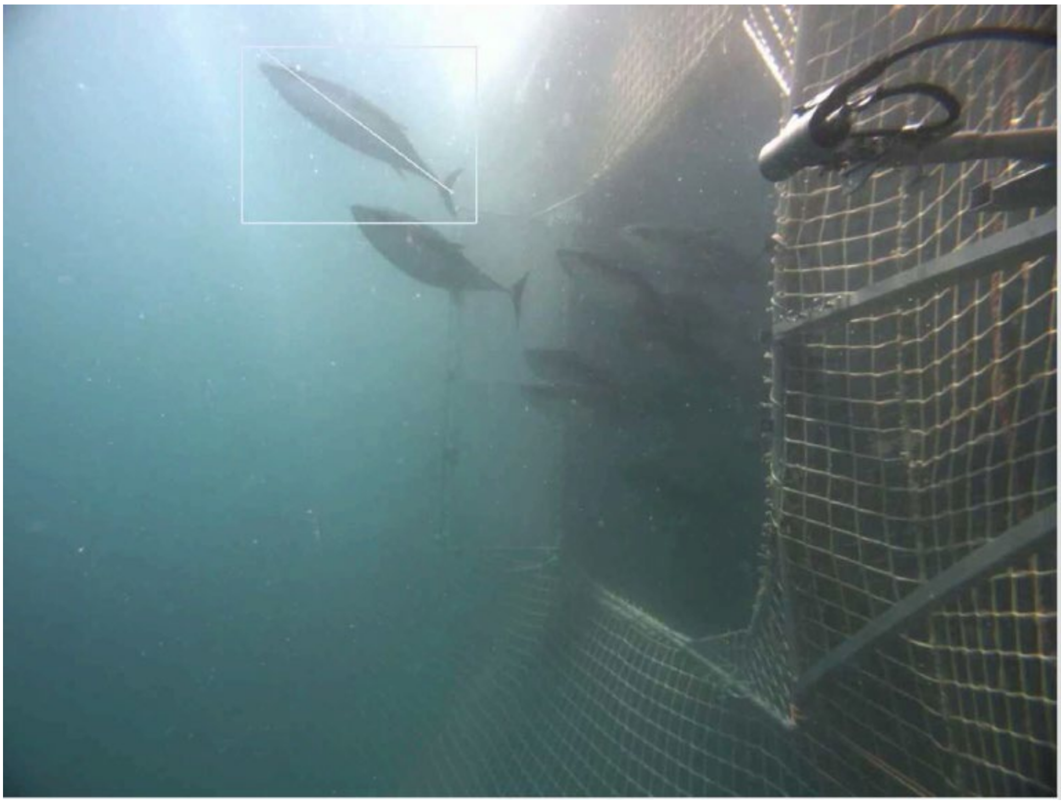


Figure 12. Examples of incorrect measurements. The snout or fork points are placed on a wrong place due to suspended particles

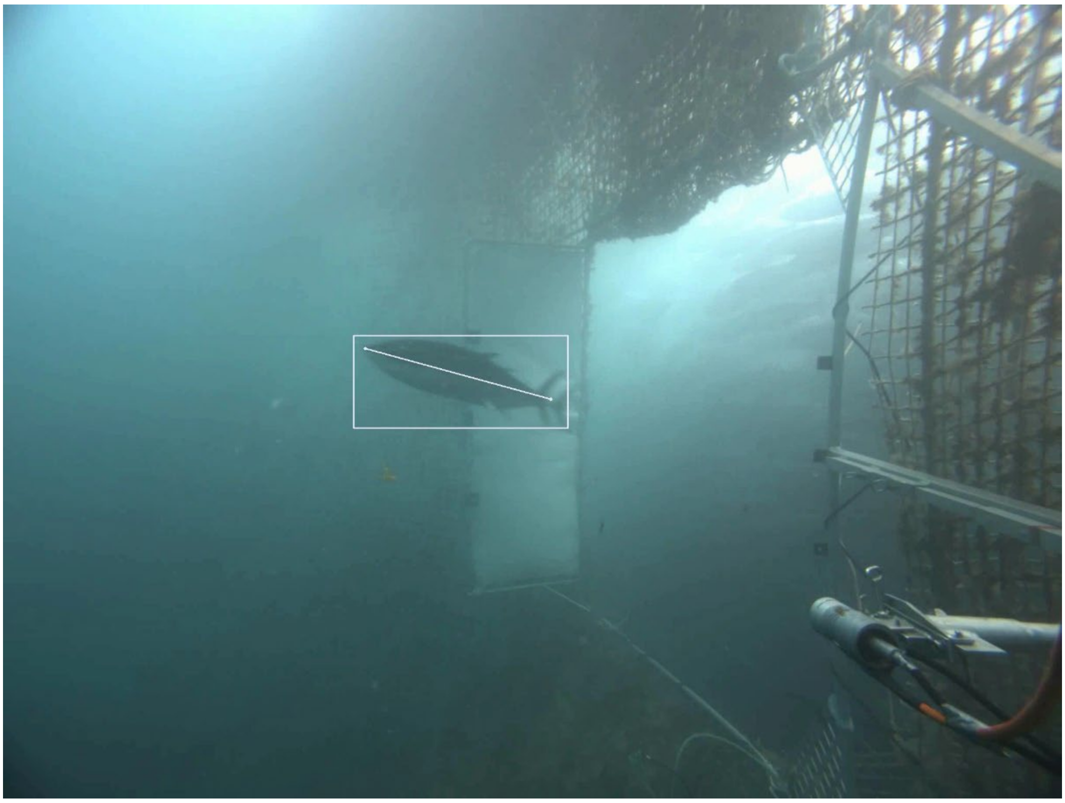


Figure 13. Examples of incorrect measurements. The snout or fork points are placed on a wrong place due to confusion introduced by parts of other fish.

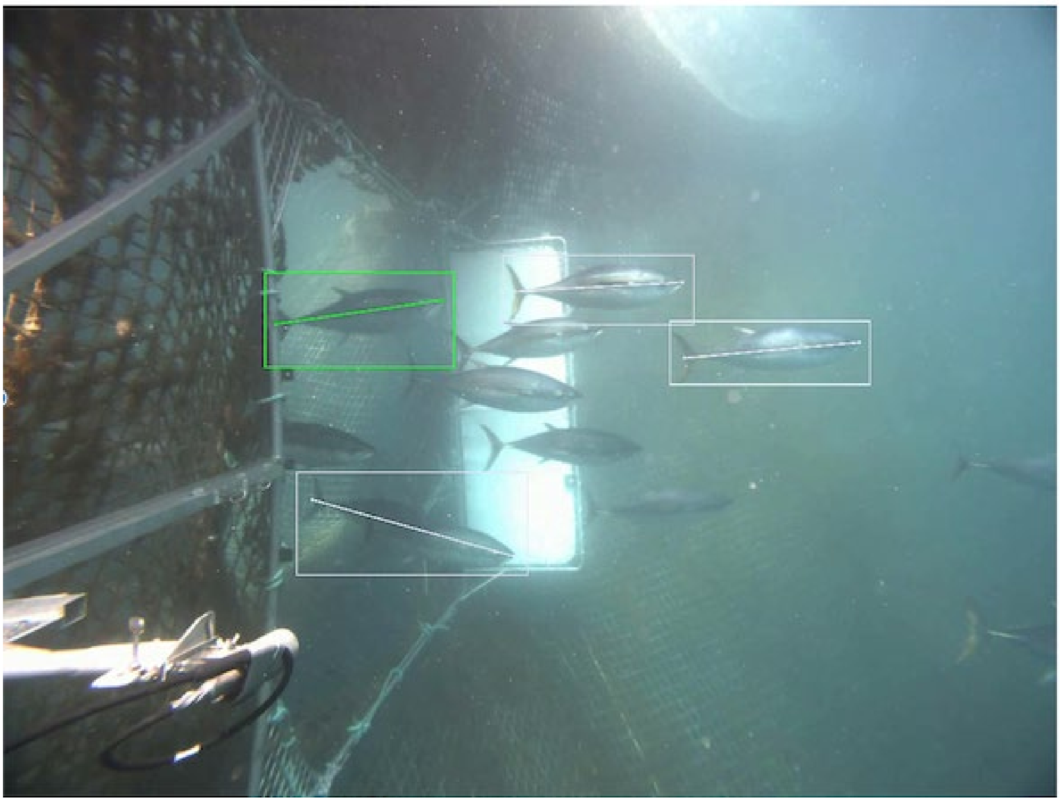


Figure 14. Examples of incorrect measurements. The fork point is placed on the gate frame (green box).

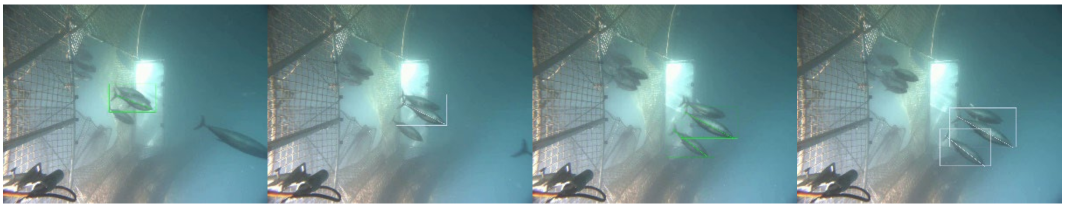


Figure 15. Example of duplicate measurements. A fish is highlighted with a green bounding box more than once in a sequence of images.

4.2.5. Influence of different fish species

Regarding how different fish species and suspended particles can introduce incorrect measurements, no one was found during the revision of the transfers The software includes parameters to discard automatically non SBT species, such as the following:

- The length of the recognised fish must be in a range according to the specie under study. In the SBT case, measurements under 40 cm and above 140 cm are discarded.
- The recognition of snout and tail must have a high similarity with the images used to train the software. Since the images used to train are ABT and SBT individuals, only fish with high similarities can be confused with SBT. Perhaps, Australian salmon and kingfish, which aren't that different to SBT, may have been measured, but from our position of non-experts we were not able to identify any of them. Nevertheless, the videos with the automatic measurements can be accessed in the following link[4].

Additionally, the software allows for checking of measurements by displaying images of each measurement taken (see Figure 12 above).

[4] https://upvedues-my.sharepoint.com/:f:/g/personal/pamuobe_upv_edu_es/Et2FvvoqV75GndXd7Piu8toB9ZOW5_QPkXY3i7Pv-dNmGw?e=KFNEPE

5. Conclusions

The Transfer Trial demonstrated the operation of our fully automated stereo video system's ability to obtain an average length estimate of SBT in situ during the transfer from tow pens to holding pens.

Our operational approach was carefully designed to harmonize with established industry practices, ensuring minimal disruption to ongoing operations. Firstly, we integrated the stereocamera into the existing frame used for recording transfers, originally designed for fish counting with a monocamera. This integration involved making as few modifications as possible to maintain compatibility. Secondly, we designed a stereocamera with a long cable (90 meters) and low weight (2.5 kg) to ensure the ease of handling for divers during the transfer process. The success of this approach was demonstrated as the stereocamera system was incorporated without causing any disruptions.

Ten transfers to holding pens from three different tow pens (T1, T2 and T3) were conducted in collaboration with two different fishing companies: Australian Fisheries Enterprises (AFE) and Blaslov Fishing Group. Analysis of the first transfer, carried out in Port Lincoln in the days following, revealed that the camera configuration had become uncalibrated prior to sampling due to transport and handling, likely impacting the accuracy of the length measurements and resulting in an overestimation of the average length.

Nevertheless, the experience gained during the initial T1 transfers enabled us to refine our methodology for subsequent T2 and T3 transfers. A new procedure was introduced in the trial setup: before commencing each individual transfer, a commercial diver presented the calibration checkerboard to the stereocamera. The pre-transfer images were later utilized during the off-site revision of the results to calibrate the stereocamera before each transfer, ensuring that the measurements were not affected by a loss of calibration.

These calibration difficulties arose as a result of the pursuit of a very lightweight stereocamera, which was redesigned for the occasion. It's crucial to ensure a perfectly rigid union between the pair of cameras constituting the stereocamera to prevent it from becoming uncalibrated. As detailed in Section 3.2, maintaining the distance and angle between the pair of cameras from the calibration process to their use is essential for accurate measurements. This condition is typically met in commercial stereocameras and was also true for our stereocamera used during the Accuracy Trial in 2023. If this condition is guaranteed, there is no need to present the calibration checkerboard to the stereocamera before each transfer.

Regarding the results, three key metrics have been analysed for each transfer: the number of automatic measurements and their respective percentage relative to the total number of fish counted, the average length and length-frequency histograms of the measured fish, and the computation time. All transfers have been analysed in two different modes, termed Performance and Quality Mode. The distinction between them lies in the video resolution and frame rate. The Performance Mode operates with lower resolution and frame rate, resulting in faster processing speed but potentially reduced accuracy and measurement capabilities.

The results indicate that Performance Mode delivers between 22% and 63% measured fish (averaging 41% for T2 and 40% for T3) and Quality Mode delivers between 38% and 85% of measured fish (averaging 62% for both T2 and T3). The average lengths in Performance Mode are 87,3 and 86,3 cm for T2 and T3, respectively, whereas in Quality Mode they are 86,9 and 86,0 cm. Generally, average lengths in Performance Mode are higher than in Quality Mode. Nevertheless, the average length in both modes differ by less than 1 cm in all transfers, being 0,4 cm and 0,3 cm for the whole T2 and T3 tow pens, respectively. Despite varying luminosity conditions resulting from different times of day and weather conditions, the system consistently delivers accurate measurements. Specifically, it achieves at least 22% and 35% of measured fish in Performance and Quality Mode, respectively.

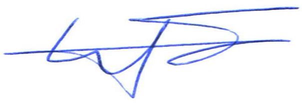
The results indicate that the number of incorrect measurements (mostly due to the snout point being placed on one fish and the fork point on another) ranges from 1,0% to 3,8% for all transfers (averaging 1,3% for T2 and 2,6% for T3), whereas the number of duplicate measurements (the same fish is mistakenly identified as a different fish and measured more than once) ranges from 0% to 1,1% (averaging 0,2% for T2 and 0,1% for T3). The average length, when incorrect and duplicate measurements, are removed decreases between 0,2 and 0,4 cm, modifying the average length of T2 from 86,9 to 86,7 and T3 from 85,7 to 85,3. It is worth noting that the high number of detections, high framerate cameras, and tracking algorithms help filter out incorrect measurements. According to the results, a fish is measured an average number of times between 6,5 and 14,0 (averaging 9,1 both for T2 and T3), and the system delivers the median of all length measurements as the fish length. Bias quantification will be addressed in next report by manually measuring fish that were not measured automatically.

Regarding computing time, with videos spanning 165 and 227 minutes for T2 and T3, respectively, the Performance Mode lasts 117 and 172 minutes, while the Quality Mode lasts 297 and 392 minutes, respectively. Computing time denotes the time it takes for the automatic system to deliver estimations from the moment automatic video processing begins. In on-site practice, the starting point would be five minutes after the start of the transfer, just after the first video split. This indicates that the current Performance Mode can be implemented onboard vessels to provide a real-time estimation of approximately 40% of the population, whereas the Quality Mode offers an estimation of approximately 60% of the population but requires more computing time. Nevertheless, considering the optimization of a commercial version of the software and the rapid advancement of technology, particularly in graphic cards, which consume most of the computing time in our algorithms, we anticipate the development of faster versions in the near future. These advancements will enable real-time estimation of a higher percentage of sampled fish.

The software features a user-friendly graphical interface that does not require technical expertise or any knowledge of the underlying algorithms. Two software experts were required to operate the system during the trial because, while the system had previously undergone testing with ABT in the Mediterranean and Norwegian Sea, this trial marked its inaugural application with dense schools of SBT, prompting necessary technical adjustments.

The spreadsheet reports containing results for all transfers, including averages and number of measured fish, are available for download from the following link[5], together with videos of the automatic detections of all transfer to illustrate the software's capabilities and to provide transparency on the delivered results.

Gandia. June 19th of 2024



Signed: Víctor Espinosa Roselló

[5] https://upvedues-my.sharepoint.com/:f:/g/personal/pamuobe_upv_edu_es/Et2FvvoqV75GndXd7Piu8toB9ZOW5_QPkXY3i7Pv-dNmGw?e=KFNEPE

Annex A

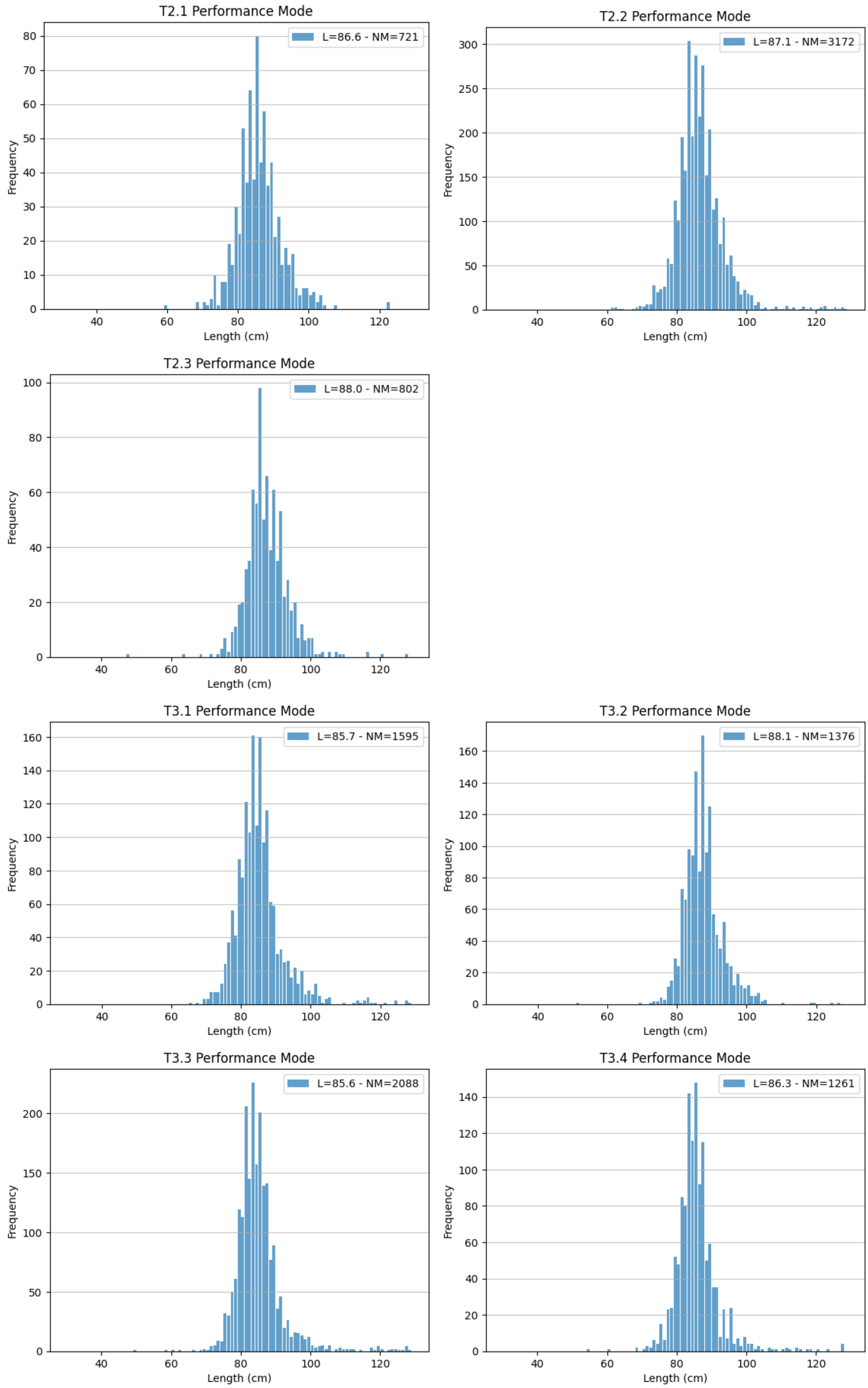


Figure 16. Length-frequency histogram of all transfers in Performance Mode.

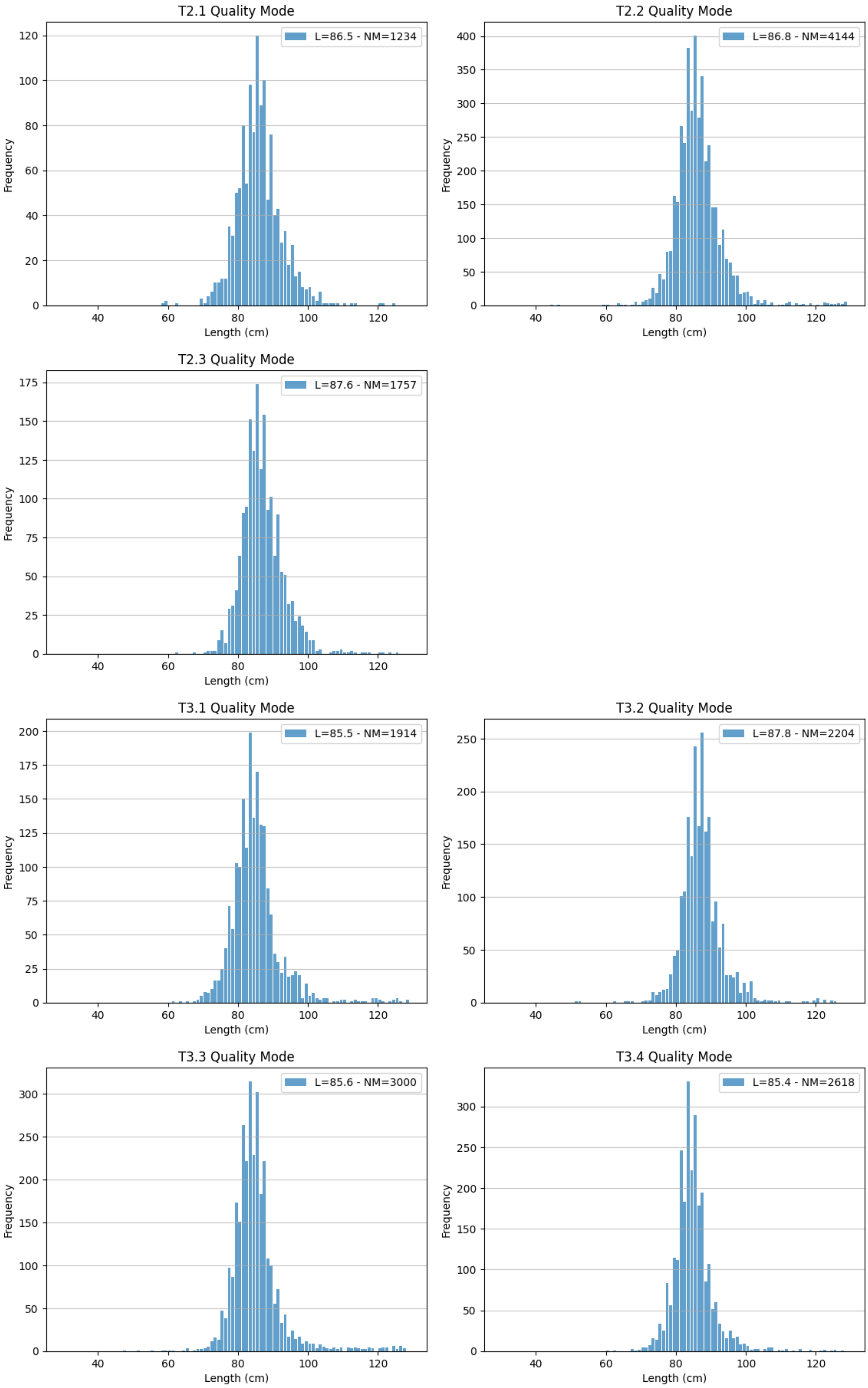


Figure 17. Length-frequency histogram of all transfers in Quality Mode.