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SHORT-TERM CONTRACT FOR THE PILOT PROJECT TO TEST THE USE OF STEREOSCOPIC CAMERAS DURING THE FIRST TRANSFER AND THE AUTOMATION OF VIDEO FOOTAGE ANALYSIS

Deliverable #3: Final report

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Tests were conducted to evaluate the use of stereoscopic and conventional cameras during the first transfers of bluefin tuna from purse seine vessels to transport cages in the Mediterranean and Adriatic during the 2024 fishing campaigns. The technical feasibility of estimating weight at this early stage was confirmed. Length measurements were obtained from stereocamera recordings by marking the snout and fork tail points of individuals (32%, 21%, 45%, and 73% for four transfers in the Mediterranean, and 65% for one transfer in the Adriatic), while fish counts were determined from monocamera recordings. For two of the transfers in the Mediterranean, estimated weights could be compared to those from subsequent transfers to farm cages. Average fish lengths of 201.9 and 210.5 cm were obtained in first transfers, with 192.6 (-4.6%) and 207.4 (-1.5%) cm at caging. The disparity could be due to different sampling, operator variability and different software, but it should be further investigated. Average weights could be calculated applying the corresponding length-weight relationship. Regarding fish counting, it differed by 5% between first transfers and caging, likely due to operator variation and the difficulty of counting overlapping schools of fish. The time invested for counting varied between 1.5 and 4 hours per transfer, depending on the number of fish, amounting to a total of 10.5 hours across all the first transfers, whereas the time invested in fish length estimation varied between 1.3 and 9.5 hours, amounting to a total of 19 hours across all the first transfers. However, it should be borne in mind that there are some additional demands on the existing ones for first transfers that must be taken into account, in particular the use of a stereoscopic camera in addition to the conventional one currently in use, the training on stereoscopic camera usage and software of the personnel already used for bluefin tuna management and a longer time to carry out the transfer operation. The use of software and artificial intelligence to automatically determine the number of fish and their weight was also addressed, but its conclusions will be detailed in the reports of Objective 2 of the Pilot Project.

1. Description of the work carried out during the tests

The pilot project has two independent objectives: a) to test the use of stereoscopic cameras during the first transfers from purse seine vessels or traps to towing cages in order to be able to estimate at this stage the weight of the captured bluefin tuna (BFT). b) to test the use of available software and artificial intelligence to automatically determine the number of individuals and their weight. This report primarily focuses on the first objective, although results from the second are also included.

The primary mission during the tests was to:

- Test whether stereoscopic cameras in combination with conventional cameras allow successful recording of videos of first transfers in real conditions.
- Test the accuracy in determining the number of individuals and their average size at first transfer (from purse seiner or trap to transport cage) and compare it with that obtained by current means (from transport cage to farm cage).
- Analyze (determine the number of individuals from conventional camera video footage, and the number of individuals and their individual and average size from stereoscopic camera video footage), using the software for automatic analysis, the videos of first transfers.

The works initially proposed included testing the system in at least three transfers in the following scenarios:

- First transfer from a purse seiner to a transport cage in the Mediterranean.
- First transfer from a trap to a transport cage.
- First transfer from a purse seiner to a transport cage in the Adriatic.

However, the scenario involving a transfer from a trap to a transport cage was ultimately discarded. While Fuentes, a company based in Spain, expressed willingness to collaborate, their participation was not feasible due to the specific way their traps operate, which involves direct contact with a farm and does not utilize tugboats.

The specific work carried out in each scenario is detailed in the following subsections.

1.1. First transfers from purse seiners to transport cages in the Mediterranean

UPV coordinated with Balfegó Tuna, the company collaborating in the campaign, to organize the recordings. The agreements were as follows:

- UPV equipment (stereocameras and laptops for recording) will be placed on Nuevo Atxarre (a Balfegó Tuna auxiliar boat), from where the transfers will be recorded. UPV personnel will be transported to Nuevo Atxarre by the Spanish Army's Alborán patrol vessel, with a 2-hour margin before transfers begin.

- Divers will be in charge of recording the first transfers with three stereocameras and two monocameras. The setup mimics that used for transfers from transport cages to farm cages, using a monocamera for counting and a stereocamera for sizing. However, the lateral stereocameras are duplicated, and a ventral stereocamera is added to test the feasibility of that view. The positioning is depicted in Figure 1:

    - SC1 and SC2: Two stereocameras positioned 2-3 meters away on each side of the gate, capturing the fish from a lateral view (see Figure 2) at distances ranging from 2 to 12 meters.
    - SC3: One stereocamera positioned 2-3 meters below the gate, capturing the fish from a ventral view (see Figure 3).
    - MC: One monocamera, positioned 4-5 meters away from the gate, providing a lateral view and covering the entire gate.

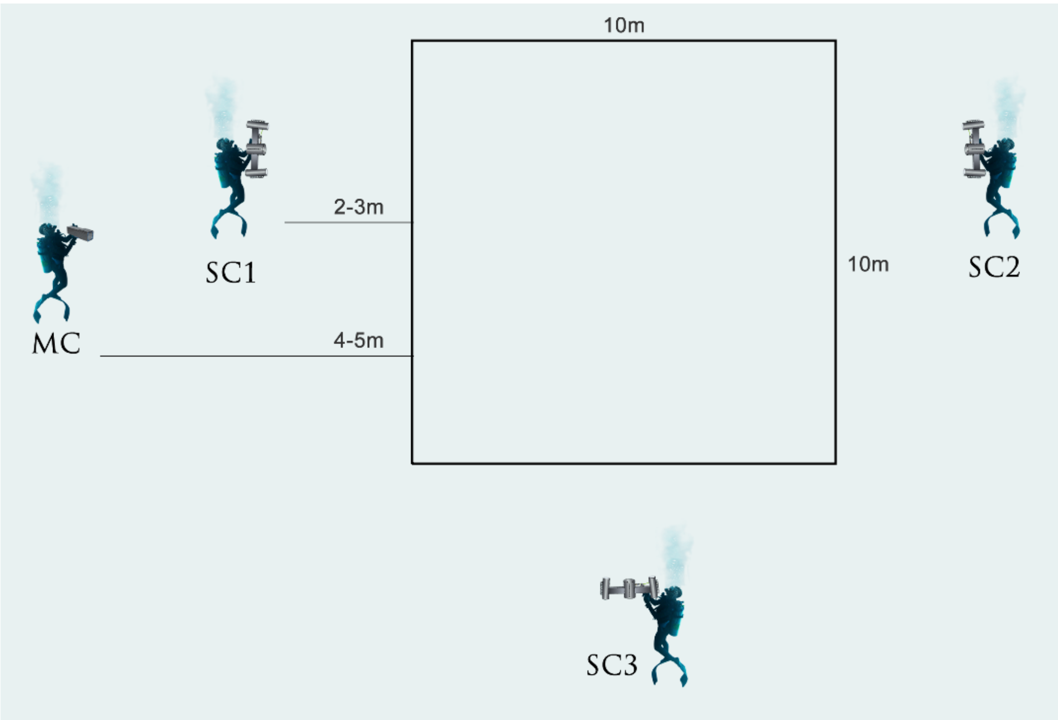

Figure 1. Positioning of monocamera (MC) and stereocameras (SC1, SC2, and SC3) during first transfers from purse seiners to transport cages in the Mediterranean.

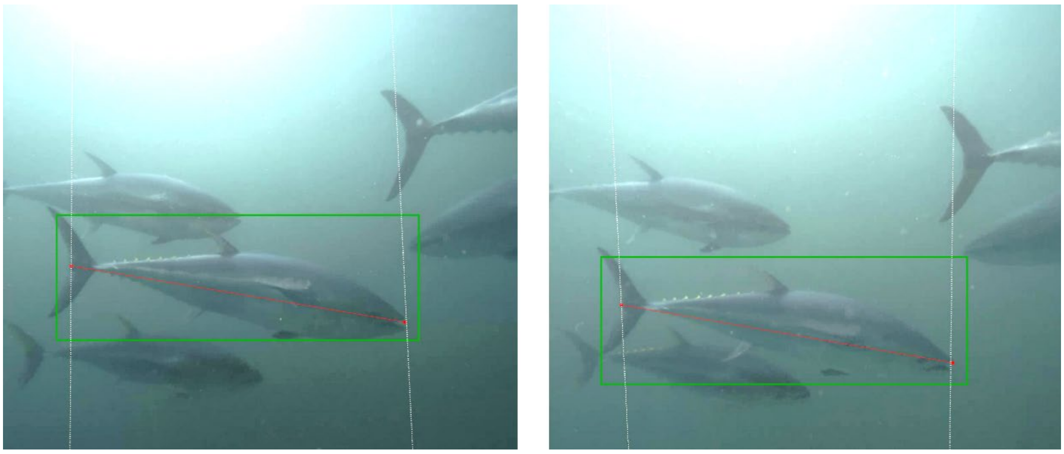

Figure 2. Stereoimage to be obtained from lateral views (SC1 and SC2 stereocameras).

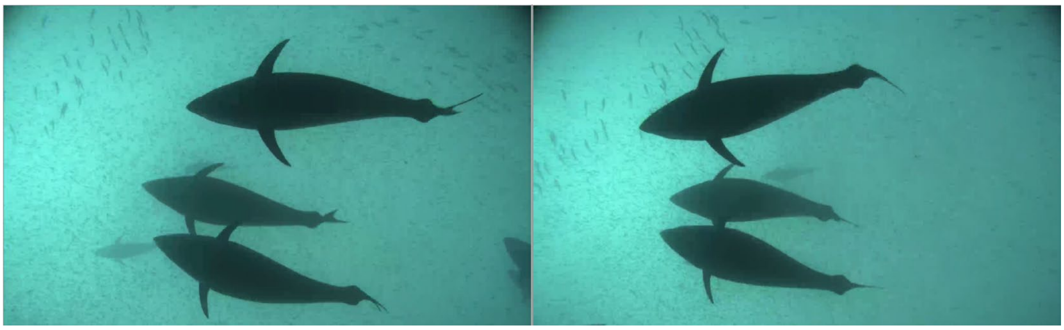

Figure 3. Stereoimage to be obtained from the ventral view (SC3 stereocamera).

A diary of onboard experiences is presented in Annex 1, and Table 1 summarizes the recorded transfers. Two first transfers (ID 11 and 12) were recorded with the full setup but for the last two transfers (ID 20 and 21) the ventral view was discarded due to operational constraints. This view was previously used with success by our team for studying the evolution of the fattening progress in farm cages, but Balfegó Tuna explained that keeping the ventral stereocamera in position during transfers was difficult for the divers and caused significant delays. Note that the transfer ID was given by Balfegó Tuna based on its labelling of the transfers. Figure 4 shows the images recorded with monocamera (MC) and stereocameras (SC1, SC2 and SC3) with the proposed setup. The videos of all transfers can be downloaded from the provided links.

Transfer ID	11	12	20	21
Transport cage	ESP010R (with another transfer)		ESP014R	ESP008R
Date and time	20240604 17:23 – 18:34	20240605 10:46 – 11:52	20240611 10:07 – 10:57	20240613 07:05 – 08:16
Video duration (min)	71	66	50	71
Video duration transferring (min)	7	12	10	14
Number of cameras	2 lateral SC 1 ventral SC 1 MC	2 lateral SC 1 ventral SC 1 MC	2 lateral SC 1 MC	2 lateral SC 1 MC
Video links	Link	Link	Link	Link

Table 1. Transfers from purse seiners to transport cages recorded in the Mediterranean. SC: stereocamera; MC: monocamera.

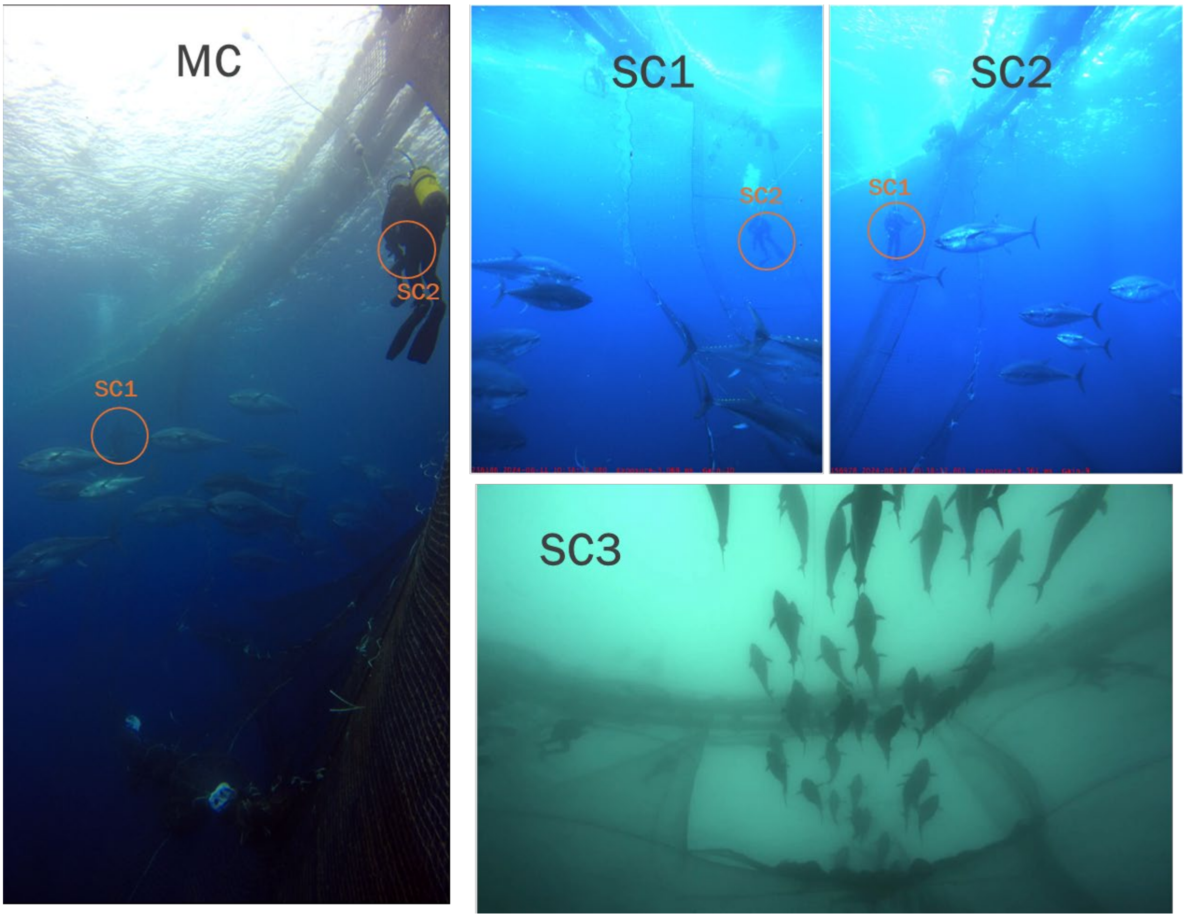

Figure 4. Images of transfers from a purse seiner to a transport cage recorded in the Mediterranean with one monocamera (MC), two stereocameras to record the lateral view of the fish (SC1 and SC2) and one stereocamera to record the ventral view of the fish (SC3). The position in the cage of the two divers holding the SC1 and SC2 stereocameras can be observed in the images of different cameras (highlighted in orange).

1.2. First transfer from purse seiners to transport cages in the Adriatic

UPV contacted the Croatian Ministry of Agriculture to coordinate the recordings. The agreements were as follows:

- Only stereocameras SC1 and SC2 will be used due to the size of the gate and the fish.
- Tests will occur late in the season when most of the quota would already be captured, as requested by operators.
- All first transfers from one purse seiner to transport cages will be recorded whenever possible.
- Only one operator, Jadran Tuna, will participate.
- Two patrol vessels equipped for diving and use of cameras will organize the transport of the project team. The transfers will be recorded from the patrol vessel.
- Fisheries inspection will provide two divers, which will hold the stereocameras for transfers recording.

The recording setup could not meet our initial idea of mimicking the setup at caging, as in the Mediterranean, since the gate sizes are very different. The size of the transfer gate during the first catch is determined by the opening of the purse seine net, which is typically 14x6 meters but can vary between 15x5 meters and 13x7 meters depending on weather and oceanographic conditions at the time of transfer. This contrasts with the smaller transfer gates (approximately 4x3.5 meters) used during caging operations, which are optimal for size estimation with stereocameras. However, the smaller gates are difficult to use for first transfers because they increase the likelihood of fish mortality, especially for smaller tuna, which are particularly sensitive to initial contact with the nets or other environmental disturbances. On the other hand, the desirable outcome of the project is to develop a technical solution and methodology to determine the number of individuals and biomass, preferably using a single video record. Given these conditions, two possibilities were agreed upon with the operators:

- Reduce the transfer gate to 7x6 meters and use one stereocamera to record smaller catches of up to 500 fish, with an average weight of 8-10 kg.
- For larger catches, record the transfers using two stereocameras, one on each side of the gate, with each stereocamera covering half of the gate (approximately 7x6 meters).

Conducting these two types of experiments would allow us to compare the results and provide recommendations. The first alternative would be ideal for the project's outcome and for future implementations, as it would only require one stereocamera. The second alternative, however, would involve higher costs.

Unfortunately, during our 17-day stay in Croatia, only one transfer was recorded, due to a lack of catches caused by unfavorable weather and sea conditions. Furthermore, the tests were conducted later in the season, when most of the quota had already been captured, as requested by the operators. UPV remained in Croatia until 15 July, the last authorized day of the fishing campaign.

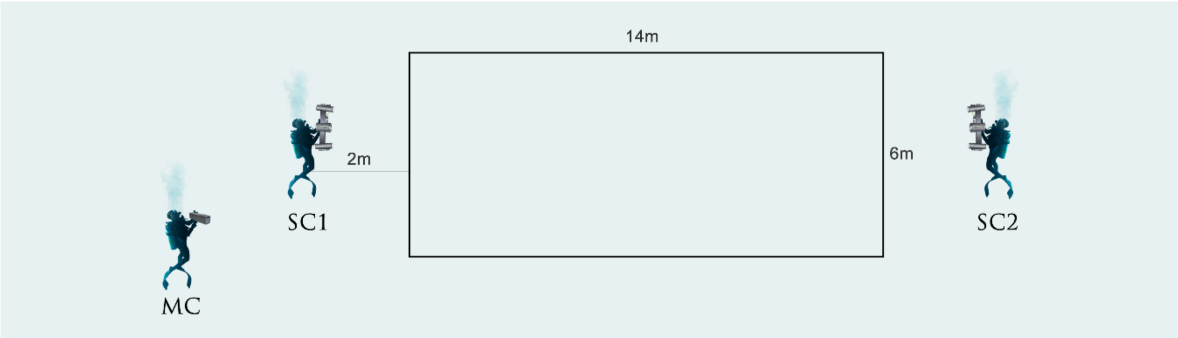

Figure 5. Positioning of monocamera (MC) and stereocameras (SC1, SC2, and SC3) during first transfers from purse seiners to transport cages in the Adriatic.

A diary of the on-board experiences is presented in Annex 1, and a summary of the recorded transfer is presented in Table 2. Figure 6 shows the images recorded using the proposed setup, with one monocamera and two stereocameras (SC1 and SC2).

Transfer ID	T_CRO
Transport cage	EUHRV013 (with other 4 transfers)
Date and time	20240713 08:59-9:30
Farm cage	HRV008004
Video duration (min)	31
Video duration transferring (min)	1
Number of cameras	2 lateral SC and 1 MC
Video link	Link

Table 2. Transfers from purse seiners to transport cages recorded in the Adriatic. SC: stereocamera; MC: monocameras.

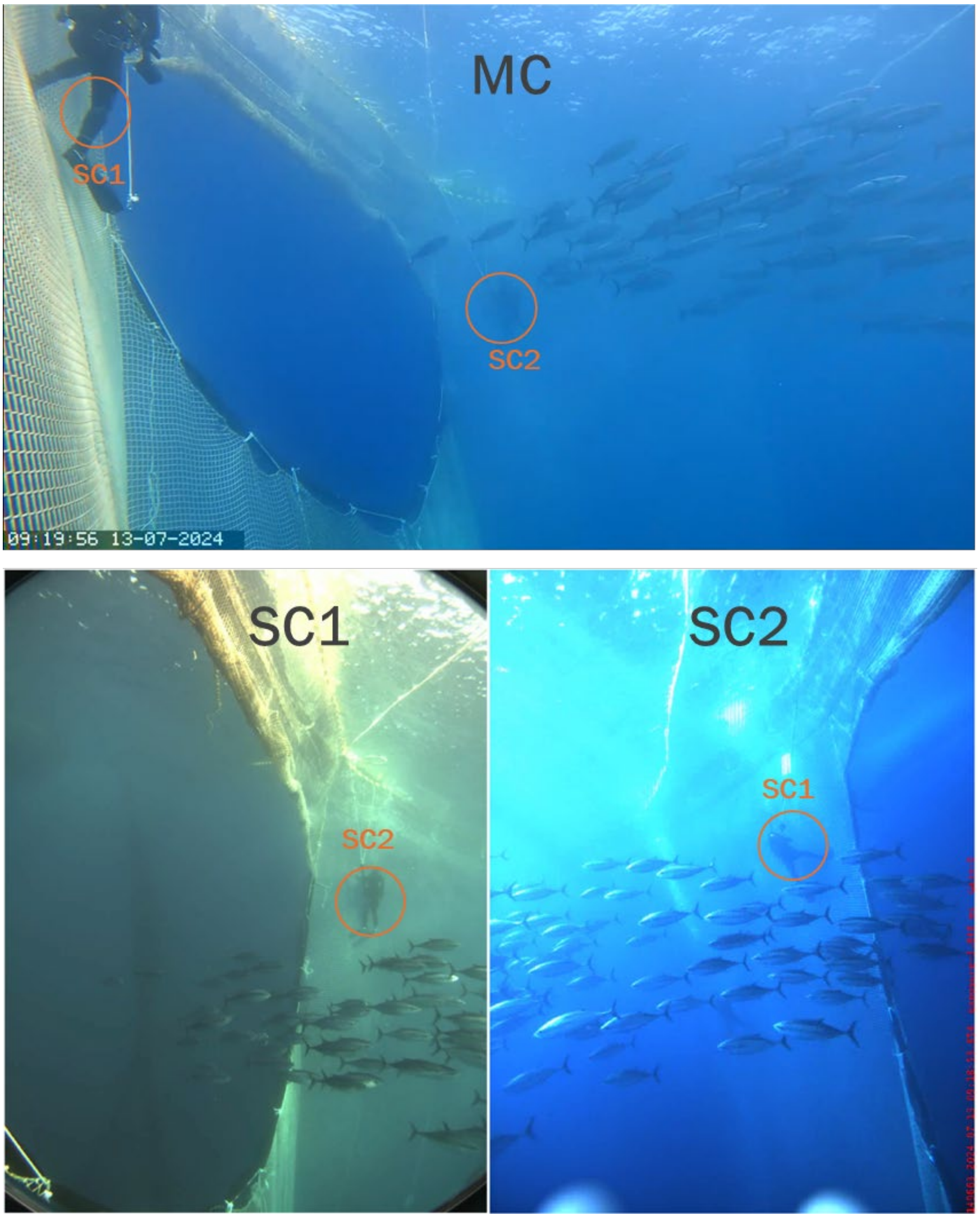

Figure 6. Images of a transfer from a purse seiner to a transport cage recorded in the Adriatic with one monocamera (MC) and two stereocameras (SC1 and SC2). The position in the cage of the two divers holding the stereocameras can be observed in the images of different cameras (highlighted in orange).

2. Materials and methods

2.1. Stereoscopic vision systems

Two types of stereocameras were employed during the recording of the transfers: AM100 stereocameras from AQ1 Systems and customized UPV stereocameras. The AM100 stereocamera, currently used by most operators, capture recordings a ta a resolution of 1.4 Megapixels (1360 x 1024), with a framerate ranging from 12 to 20 fps. The UPV stereocamera consists of two Gigabit Ethernet cameras, each with a resolution of 3.1 Megapixels (2048 × 1536) and a framerate of 33 fps. These cameras are mounted in an underwater housing with a baseline of 85 cm and 5° inward convergence. The system uses the IEEE 1588 Precision Time Protocol (PTP) synchronization and is rated to function at depths up to 40 meters. The system's power is supplied via ethernet umbilical cables, which also transfer images to a logging computer. The computer encodes the left and right videos using GPU encoding, and the system has been tested with cables extending up to 100 meters.

2.2. Stereocamera calibration

The principles of stereoscopic vision involve projective geometry and matrix algebra. Calibration of stereoscopic cameras requires recovering intrinsic parameters (such as the focal length, principal point, and lens distortion for each camera) and extrinsic parameters (the transformation between the two cameras). This calibration process is essential to correct image distortions and establish a relationship between the 2D image pixels and real-world 3D dimensions. The calibration typically involves capturing images of a checkerboard pattern from various angles, which are then processed to estimate the parameters via mathematical optimization. Accurate 3D measurements depend heavily on precise calibration of the cameras. Figure 7 illustrates a setup using the checkerboard method for calibration, which determines the rotation (R) and translation (T) between the two cameras, crucial for deriving length measurements from the images.

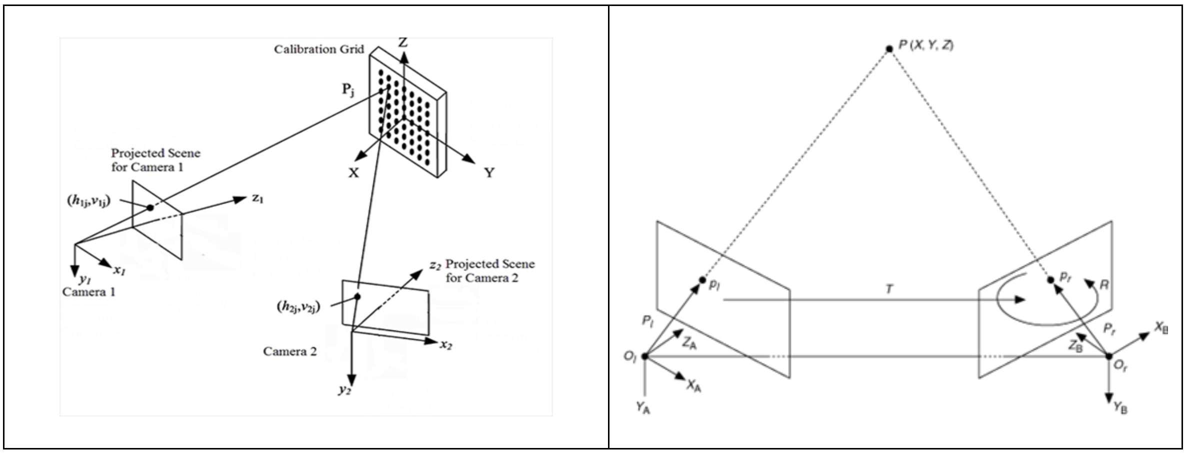

Figure 7. Description of a stereocamera calibration setup to find the rotation R and translation T between the two cameras.

In our projects, we use software such as Matlab and the OpenCV library to carry out the necessary geometric transformations and matrix calculations. presents a part of the calibration process using Matlab's Stereo Calibration Tool. This approach ensures compatibility across all stereocamera models and has been successfully demonstrated with the AM100 stereocamera in our research articles and enables us to operate commercial stereocameras in parallel with our custom stereocameras. Calibration parameters and images, necessary for the second objective of the Pilot Project, are provided together with the videos of each transfer.

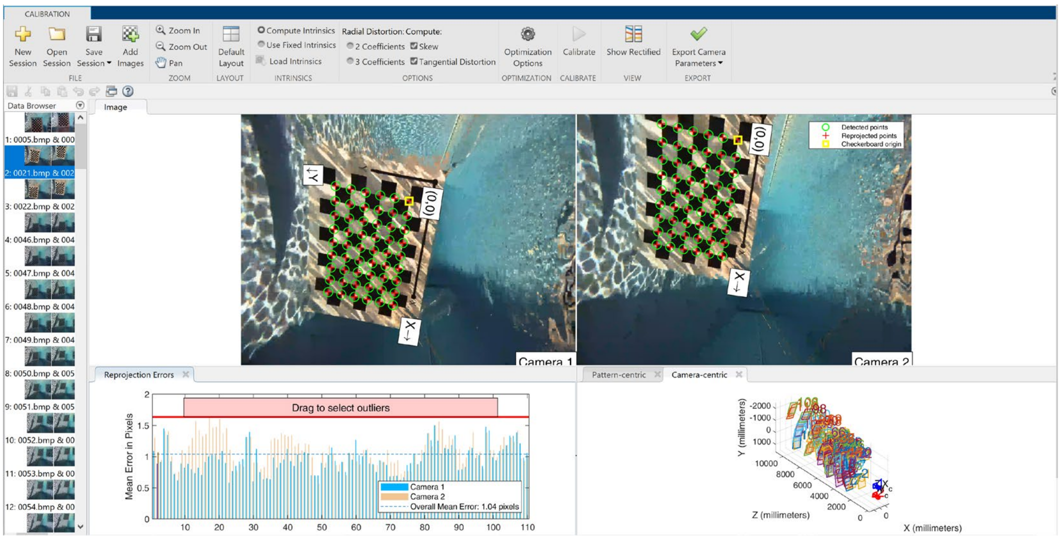

Figure 8. Snapshot of the stereocamera calibration process conducted using the Stereo Calibration Tool provided by Matlab.

2.3. Fish sizing and counting software

A custom software was developed for manual sizing and counting of the fish, featuring a user-friendly interface. Users can navigate through video recordings, zoom in on specific regions, and mark the snout and fork tail points of selected fish in both the left and right video frames. This allows the extraction of Straight Fork Length (SFL), and the software can also infer fish weight based on established length-weight relationships. Figure 9 and Figure 10 showcase the software's interface and a length-frequency histogram from a first transfer in the Mediterranean. In addition to manual processing, the software is equipped for automatic processing of the recordings.

For automatic fish sizing, we use Deep Learning (DL) and Convolutional Neural Networks (CNN) to extract fish features from the video frames, ensuring robust detection despite 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. Additionally, a tracking algorithm has been developed that uses temporal and spatial information to provide reliable and more accurate size measurements by repeating several measurements of the same fish. Since each fish is measured multiple times, the software computes the fish length as the median of all lengths.

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 designed to be intuitive and requires no knowledge of the underlying algorithms. It has already been applied in situ on first transfers in multiple campaigns by Balfegó Tuna and in Southern BFT transfers in Australia. The algorithm's details and performance are set to be published soon in a research article, while previous versions of these procedures have been documented in various of our studies (Muñoz-Benavent et al. 2018a, 2018b, 2024 and Puig-Pons et al., 2019).

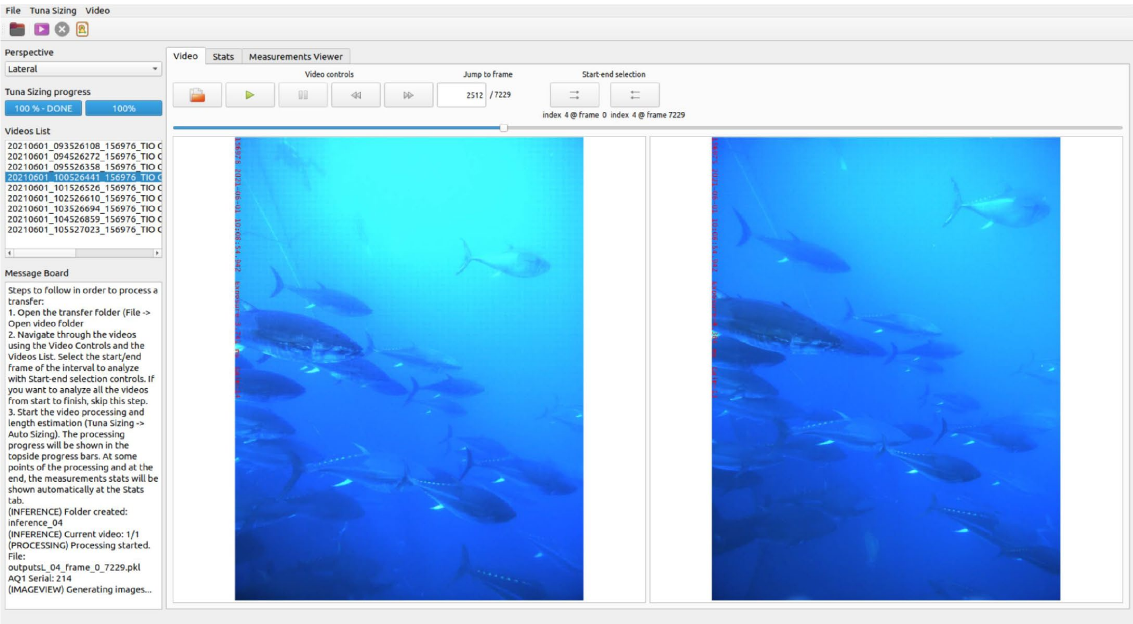

Figure 9. Snapshot of the software's user interface for fish sizing and counting from stereocamera recordings.

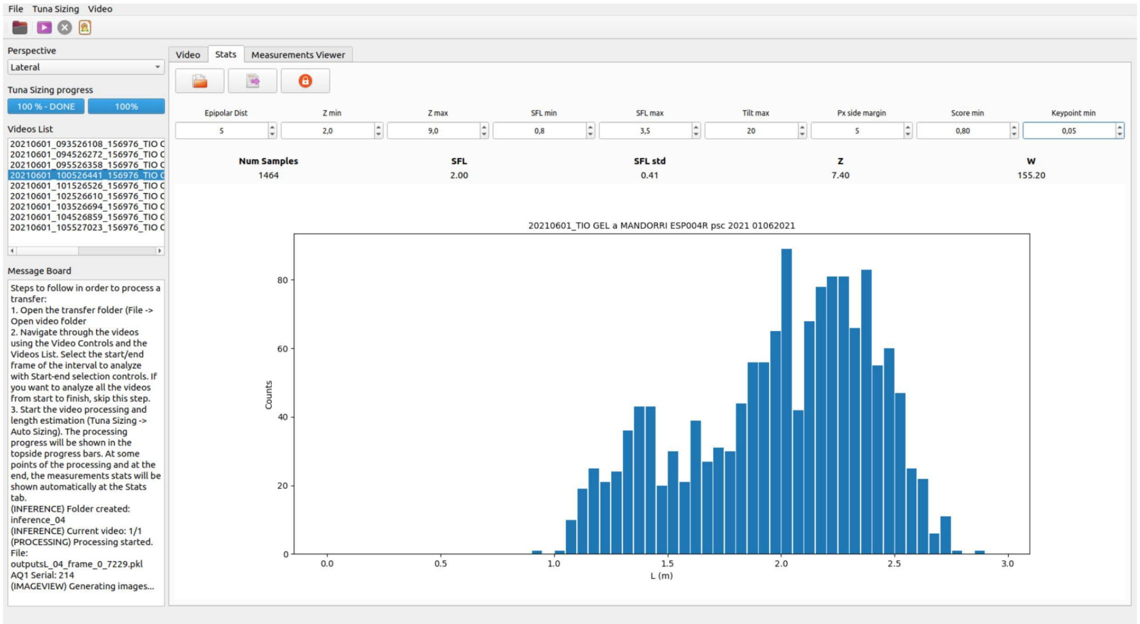

Figure 10. Snapshot of the length-frequency histogram resulting from fish sizing using the UPV software.

3. Results

This section presents an analysis of the procedures for counting and sizing fish during both first transfers and at caging. Fish counting is conducted manually by visually inspecting recordings from a monocamera and a stereocamera, as well as automatically with the software. For fish sizing, stereocamera recordings of first transfers are processed using both manual and automatic methods to examine the average length, number of samples, and time invested. Where available, comparisons are made with caging results provided by the authorities. In at least one transfer from each scenario, the manual measurements aim to cover as close to 100% of the transferred individuals as possible.

3.1. First transfers from a purse seiner to a transport cage in the Mediterranean

Table 3 presents the results for manual fish counting with the monocamera during first transfers and at caging. Our team performed the fish counts twice for each first transfer, while fish counts at caging were performed by fishing inspectors. The disparity in transfer 11 is due to the bad visibility in the monocamera recording. In transfers 20 and 21, where no additional fish were transferred to the transport cage, the counts using the monocamera differed by 5%. Since all fish fit within the camera's field of view, this disparity can be attributed to variations in water turbidity, differences between operators, and the inherent difficulty of counting fish in overlapping schools. Studying the feasibility of using acoustic echosounders for counting—capable of detecting occluded fish even in turbid waters and potentially automatable—may be beneficial. The time invested in counting ranged from 1.5 to 4 hours per transfer, with a cumulative total of 10.5 hours for all transfers.

First transfers ID	**11**	**12**	**20**	**21**
Number of fish	308/430	280/285	1379/1391	687/689
Time (min)	120 (2h)	90 (1.5h)	240 (4h)	180 (3h)
Transport cages	**ESP010R (with another transfer)**		**ESP014R**	**ESP008R**
Number of fish	1129		1315 (-5%)	653 (-5%)

Table 3. Manual fish counting with the monocamera during first transfers and at caging in the Mediterranean.

Table 4 summarizes the results for manual and automatic counting with stereocamera during first transfers. Due to the narrower field of view of the stereocamera compared to the monocamera, fewer fish are counted. Automatic counting software yielded fish counts between 74% and 116% of the manual stereocamera counts, while drastically reducing the time required from 10.5 hours to 26 minutes. Note that the automatic software algorithms are still in development, and further improvements are expected, capable of being applied to monocamera recordings as well.

First transfers ID		11	12	20	21
Manual	Number of fish	313	272	1138	559
	Time (min)	120 (2h)	90 (1.5h)	240 (4h)	180 (3h)
Automatic software	Number of fish	231 (74%)	288 (106%)	1274 (116%)	463 (83%)
	Time (min)	5	4	12	5

Table 4. Manual and automatic fish counting with one stereocamera during first transfers in the Mediterranean.

Table 5 provides an overview of fish length estimation. In each transfer, fish were measured both manually and using automatic software. Manual measurements were carried out by using custom software and stereocamera recordings, based on marking snout and fork-tail points of at least 20% of the number of fish being caged. In first transfers, 32%, 21%, 45%, and 73% of fish recorded by the stereocamera were manually measured, corresponding to 23%, 20%, 37%, and 59% of the fish recorded by the monocamera. Note that the percentage of samples depends on whether the counting is based on the monocamera or the stereocamera recordings, due to the fish missing due to stereocamera's narrower field of view. The time invested for fish length estimation varied between 1.3 and 9.5 hours per transfer, amounting to a total of 16.3 hours across all first transfers.

In transfers 20 and 21, there were no additional transfers after the first, so the results could be compared with those obtained by fishing authorities from caging transfer videos. Average lengths were 201.9 and 210.5 cm in the first transfers, compared to 192.6 (-4.6%) and 207.4 (-1.5%) cm in the caging transfers. This disparity could stem from differences in sampling, operator variability, and software (with caging transfer measurements provided by fishing authorities using AM100 software), but this needs further investigation.

Automatic sizing achieved measurements for 73%, 90%, 75%, and 73% of the fish counted with the stereocamera for transfers 11, 12, 20, and 21, respectively, which corresponds to 63%, 87%, 62%, and 59% of the fish counted with the monocamera. However, further development of the tracking algorithm is needed to provide a reliable sample size, since the same fish are sometimes mistakenly identified as different individuals and measured multiple times. This can result in an inflated percentage of fish measured, suggesting a higher figure than the actual number of unique fish recorded. The average length obtained from manual and automatic measurements is very similar (-1.7%, -2.0%, -2.0% and +1.5%, respectively) and the time invested is reduced from 16 hours to 2 hours, considering the addition of the time invested for each transfer. Length-frequency histograms that provide information about the size distribution within the sample population are presented in Figure 11. Note that the shape of the distributions for manual and automatic measurements are very similar, and the manual measurements, which are lower in number, fit within the histogram of automatic measurements. For transfer 20 and 21, where the number of manual samples is higher (45% and 73% of the fish), the similarity between histograms is even greater.

The difference in average length between manual and automatic measurements is attributable to the difference in sampling (probably not the same fish are measured and not at the same time instant) and the inherent error in estimating length from stereovision, as a disparity of a few pixels in the image can result in several centimeters of length. In addition, manual measurements are operator- and time-dependent, and such variability can affect the accuracy of each measurement and the average length. The average distances from the measured fish to the cameras are very similar for all transfers. The distance-frequency histograms in Figure 12 show that the fish are measured in similar ranges (from 3 to 9 meters), but no influence of distance on length estimates can be inferred.

First transfers ID		11	12	20	21
Manual counting with monocamera		308/430	280/285	1379	687/689
Manual counting with stereocamera		313	272	1138	559
Manual	Number of samples (%SC - %MC)	97 (31% - 23%)	56 (21% - 20%)	507 (45% - 37%)	406 (73% - 59%)
	Average length (cm)	207.3	212.7	201.9	210.5
	Average distance (m)	5.6	5.6	5.8	5.4
	Time (min)	150 (2.5h)	80 (1.3h)	570 (9.5 h)	180 (3h)
Auto	Number of samples* (%SC - %MC)	230 (73% - 63%)	244 (90% - 87%)	859 (75% - 62%)	409 (73% - 59%)
	Average length (cm)	203.8 (-1.7%)	208.5 (-2.0%)	197.8 (-2.0%)	213.7 (+1.5%)
	Average distance (m)	6.3	6.0	6.0	5.5
	Time (min)	14	33	35	42
Caging: transport cage ID		**ESP010R (with another transfer)**		**ESP014R**	**ESP008R**
Manual counting with monocamera		not provided		1315	not provided
Manual counting with stereocamera		1140		1119	642
Manual	Number of samples (%SC - %MC)	242		270 (24% - 21%)	130
	Average length (cm)	212.0		192.6	207.4
	Average distance (m)	6.2		6.1	6.3

Table 5. Manual and automatic fish length estimation with one stereocamera during first transfers in the Mediterranean. %SC: Percentage of samples with respect to manual counting with stereocamera; %MC: Percentage of samples with respect to manual counting with monocamera. *The tracking algorithm needs revision to verify the actual number of samples, as these results may be inflated.

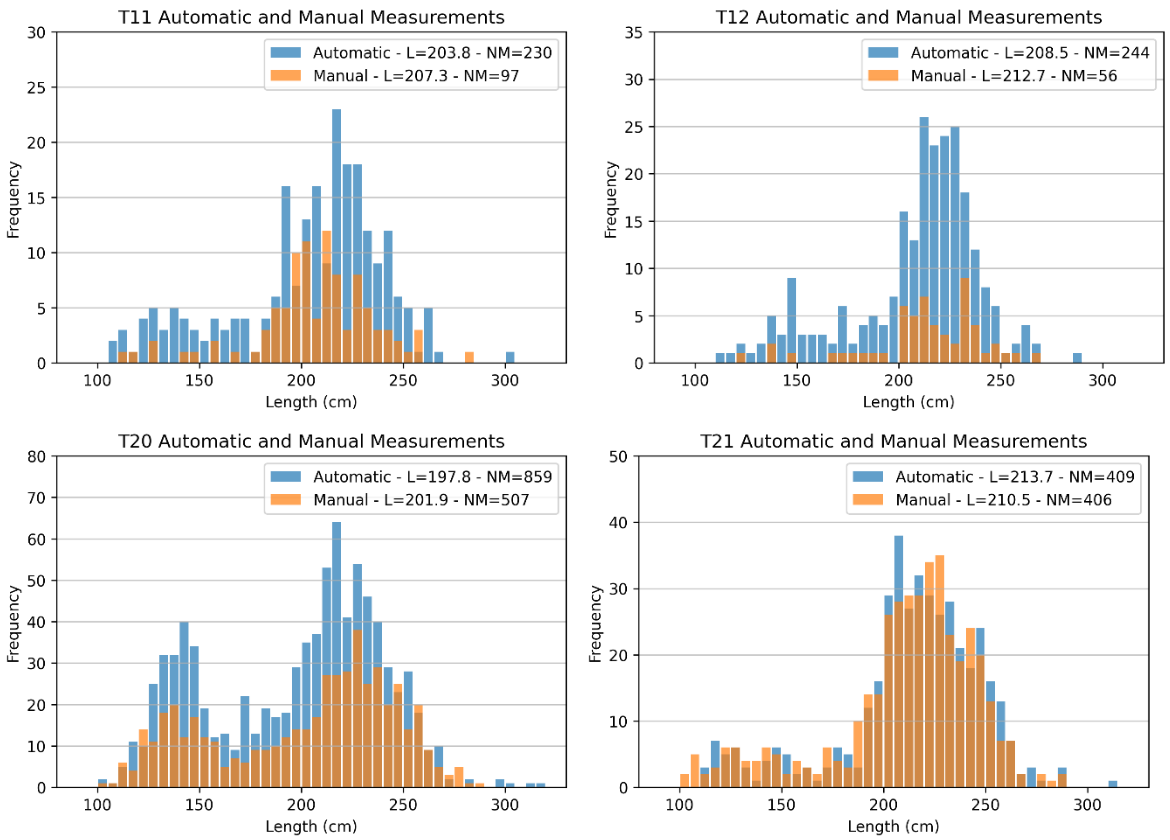

Figure 11. Length-frequency histograms of the four first transfers in the Mediterranean. L: average length in centimeters; NM: number of measurements.

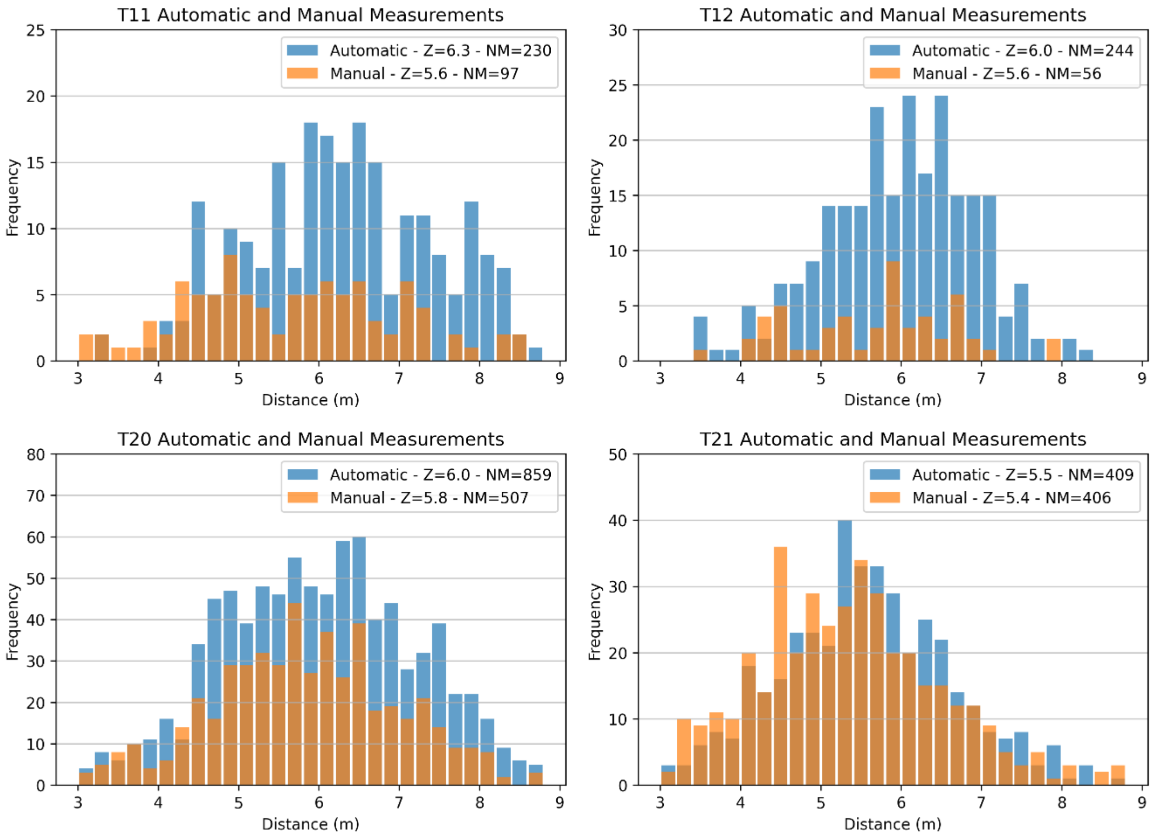

Figure 12. Distance-frequency histograms of the four first transfers in the Mediterranean. Z: average distance in meters; NM: number of measurements.

3.2. First transfers from purse seiners to transport cages in the Adriatic

Table 6 presents the results for manual counting with the monocamera and one stereocamera during the first transfer and at caging. Our team counted each recording of the first transfer twice and the count with the stereocamera resulted in 16.7% fewer fish than count with the monocamera. However, since all fish fit within the field of view of both the monocamera and the stereocamera, the disparity is attributable to occlusions, the different perspective, and the wider field of view of the monocamera. Fishing inspection counted the fish during the transfer at caging, but no comparison can be made, as fish from four additional transfers were placed in the transport cage prior to caging.

Transfer ID	T_CRO
Date and time	20240713 08:59-09:30
Transport cage	EUHRV013 (with other 4 transfers)
Farm cage	HRV008004
Video duration (min)	31
Video duration transferring (min)	1
Counting in First Transfers	
Manual with monocamera	290/300
Manual with stereocamera	243/250 (-16.7%)
Counting at caging	
Manual with stereocamera	2668 (with other 4 transfers)

Table 6. Manual fish counting with monocamera and stereocamera during first transfers and at caging in the Adriatic.

Table 7 presents the results for fish length estimation during first transfers and at caging in the Adriatic. Manual measurements covered 65% of fish counted with the stereocamera, which corresponds to 54% of fish counted with the monocamera. The rest could not be measured due to occlusion. The comparison between manual sizing in first transfers and at caging cannot be made as fish from other four first transfers were placed in the transport cage prior to caging.

The first transfer was analyzed automatically with the software, delivering a small sample size (12%) of the fish counted with stereocamera, which corresponds to 10% of the fish counted with monocamera. The average lengths obtained manually and automatically are very similar, with only a -1.6% difference, and the time invested was reduced from 3 hours to 3 minutes. The length-frequency histogram presented in Figure 13 shows that the distribution of the automatic measurements fit within the histogram of manual measurements, whereas the distance-frequency histogram shows that the fish are measured in similar ranges (from 4 to 9 meters).

Transfer ID		T_CRO
Date and time		20240713 08:59-09:30
Transport cage		EUHRV013 (with other 4 transfers)
Farm cage		HRV008004
Video duration (min)		31
Video duration transferring (min)		1
Length estimation in First Transfers		
Number of fish with monocamera		290/300
Number of fish with stereocamera		243/250
Manual with stereocamera	Number of samples	160 (SC: 65% - MC: 54%)
	Average length (cm)	80.6
	Time (min)	180 (3h)
Auto with stereocamera	Number of samples	30 (SC: 12% - MC: 10%)
	Average length (cm)	79.3 (-1.6%)
	Time (min)	3
Length estimation at caging		
Manual with stereocamera	Number of fish	2668
	Number of samples	917 (34%)
	Average length (cm)	79.1

Table 7. Manual and automatic fish length estimation during first transfers and at caging in the Adriatic. %SC: Percentage of samples with respect to manual counting with stereocamera; %MC: Percentage of samples with respect to manual counting with monocamera.

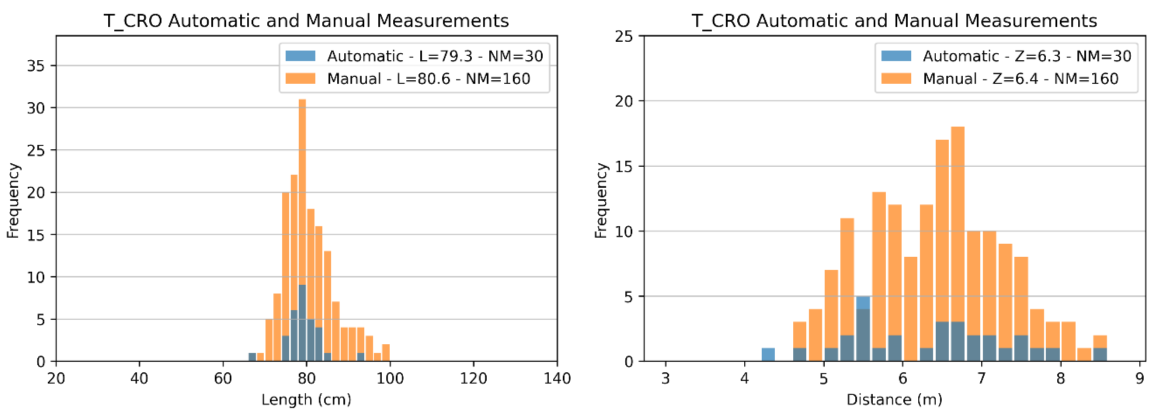

Figure 13. Length-frequency and distance-frequency histograms of the first transfer in the Adriatic. L: average length in centimeters; Z: average distance in meters; NM: number of measurements.

The explanation to the small sample size is related to the difficulty of detecting fish individuals swimming in highly dense schools, in comparison with the more isolated swimming in the Mediterranean, and the training of our software. First of all, it is necessary to extend the training dataset of the neural model from images similar to those that can be found in the recordings of these fishing campaigns. This allows to better adapt the neural network for the detection of the tuna and its keypoints. Secondly, the recordings must have favorable visibility conditions. The better the tuna can be distinguished, the easier it is to detect them. Situations such as poor lighting, turbidity in the image, tuna passing too far away from the cameras or occlusions can cause tuna detection and tracking failures. Changes in the recording setup should also be studied, as proposed in Section 1.2, by reducing the transfer gate and making its dimensions as similar as possible to the setup used during caging operations, where gates approximately 4x3.5m in size are used, since it represents the optimal configuration for estimating sizes with stereocameras.

3.3. Measurement Reliability

In previous projects involving Southern Bluefin Tuna caging transfers, incorrect measurements were found to range from 1% to 4%. However, removing these errors resulted in a minimal impact, reducing the average length by less than 1 cm. In the present study, a similar analysis was conducted using two-minute videos from transfers 20 and 21 in the Mediterranean, as well as the entire transfer in the Adriatic. The results, presented in Table 8, show that incorrect measurements accounted for less than 1.5% of the correct measurements. Most of these were caused by the snout point being placed on one fish and the fork point on another (see Figure 14, Figure 15, Figure 16 and Figure 17 for representative examples of each type of incorrect measurement). As future work, the software will be trained with images of these incorrect detections to reduce the likelihood of such errors.

It is important to note that the number of correct measurements refers to the total number of times fish were measured, rather than the number of individual fish measured. The system employs a tracking algorithm to measure each fish multiple times throughout the video, calculating the median of all length measurements to determine the final length. This process increases measurement accuracy and helps filter out errors. On average, each fish was measured between 5.5 and 12.4 times in the Mediterranean transfers (averaging 5.5, 12.4, 9.1, and 7.4 for transfers 11, 12, 20, and 21, respectively) and 2.3 times in the Adriatic transfer. The primary factors influencing these differences are the density of the fish school and the duration that each fish remains within the camera's field of view, which is related to the distance of the fish from the camera. For an incorrect measurement to be considered as the final fish length, several conditions must be met: the snout and fork points must be incorrectly placed in both images of the stereocamera pair, and this incorrect measurement must be repeated in the majority of instances that the fish is measured.

		T20	T21	T_CRO	Example image
Type of incorrect measurement	Keypoints in different near fish	13	1	1	Figure 14 and Figure 17
	Keypoints in different overlapped fish	14	2	-	Figure 15
	Keypoints in points different from snout and fork	3	-	-	Figure 16
Number of incorrect measurements		30 (0.9%)	3 (0.5%)	1 (1.5%)	
Number of correct measurements		3459	608	67	

Table 8. Quantification and classification of incorrect measurements identified in two-minutes video clips from transfers 20 and 21 in the Mediterranean and the entire transfer in the Adriatic.

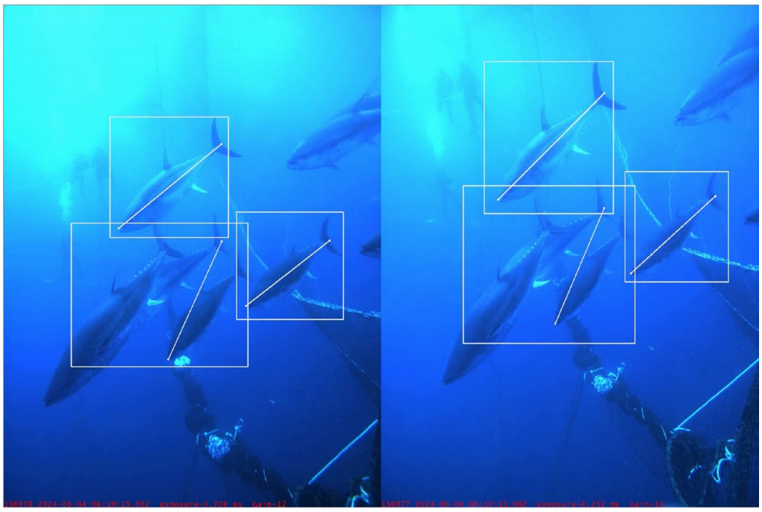

Figure 14. Example of incorrect measurement by the automatic software during first transfers in the Mediterranean, where the snout point is placed on one fish and the fork point on a nearby fish.

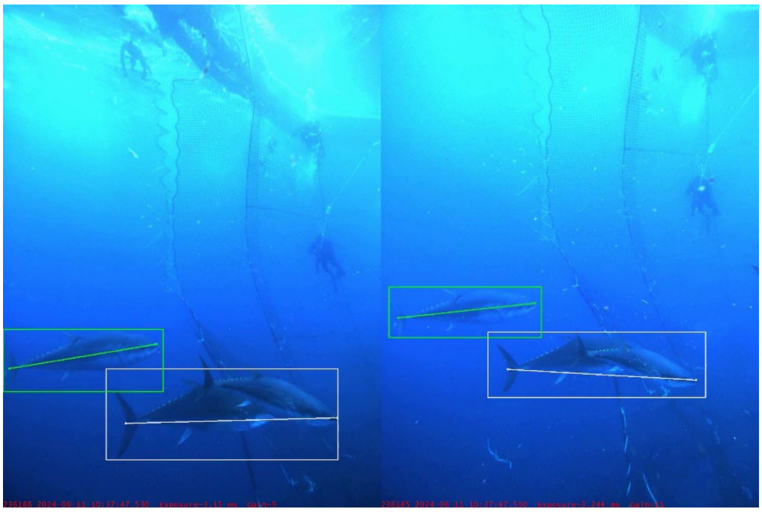

Figure 15. Example of incorrect measurement by the automatic software during first transfers in the Mediterranean, where the snout point is placed on one fish and the fork point on a nearby fish due to overlap.

Figure 16. Example of incorrect measurement by the automatic software during first transfers in the Mediterranean, where the fork point is placed on the dorsal fin instead of the tail fork.

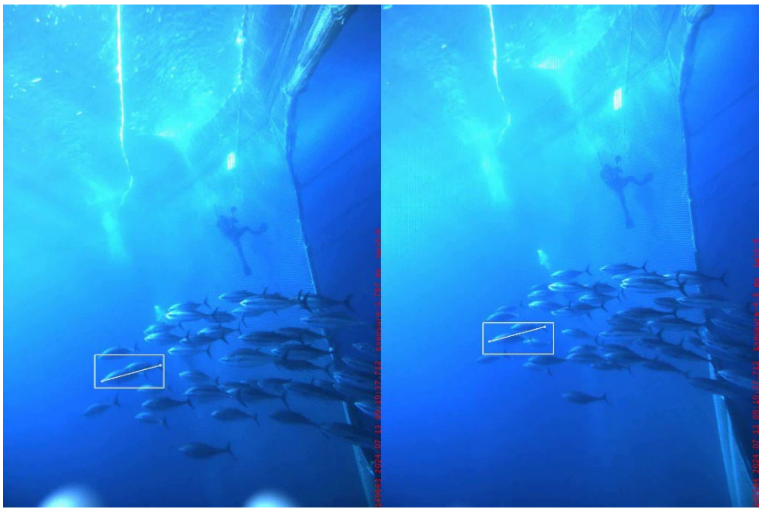

Figure 17. Example of incorrect measurement by the automatic software during first transfers in the Adriatic, where the snout point is placed on one fish and the fork point on a nearby fish.

4. Conclusions

The tests proved that estimating the weight of the captured bluefin tuna during first transfers from purse seine vessels to towing cages is technically feasible. In the Mediterranean, four first transfers were recorded, mimicking the setup normally used at caging (transfer from the transport cage to the farm cage), with the fish being recorded from a lateral view using a monocamera for counting and a stereocamera for sizing. In two of the four transfers, where no additional fish were transferred to the transport cage, the fish counts obtained via monocamera differed by 5% between first transfers and caging. Since all fish fit within the camera's field of view, the disparity is attributed to variations in water turbidity, differences between operators, and the inherent difficulty of counting fish in overlapping schools

Samples from the stereocamera recordings were manually measured by marking the snout and fork points (32%, 21%, 45%, and 73% of individuals, respectively, for each transfer). However, a comparison with sizing at caging could not be made, as the data from authorities were not yet available.

In conclusion, estimating the weight of captured bluefin tuna during first transfers from purse seine vessels to towing cages proved technically feasible in the Mediterranean, using a procedure similar to that employed in caging transfers. This approach involves a monocamera for fish counting and a stereocamera for fish length estimation, as outlined in Annexes 8 and 9 of the ICCAT Recommendation amending Recommendation 21-08, which establishes a multi-annual management plan for bluefin tuna in the eastern Atlantic and the Mediterranean (Rec. 22-08). However, it should be borne in mind that there are some additional demands on the existing ones for first transfers that must be taken into account, in particular the use of a stereoscopic camera in addition to the conventional one currently in use, the training on stereoscopic camera usage and software of the personnel already used for bluefin tuna management and a longer time to carry out the transfer operation.

In the Adriatic, two different recording setups, involving varying gate sizes and stereocamera configurations, were planned. However, only one first transfer was recorded due to the lack of catches during the study period, primarily because of unfavorable weather and sea conditions. Additionally, the tests were conducted late in the season when most of the quota had already been captured, as requested by the operators. In this case, comparisons between first transfer and caging for fish counting and sizing were not possible, as fish from four other transfers were placed in the transport cage. Nevertheless, manual counting and sizing during first transfers were successful, with fish counted using the monocamera and 65% of fish sized using the stereocamera. The Adriatic Sea fishery presents particular conditions, as bluefin tuna farming is based on catching small schools of juveniles. The fact that only one test could be carried out and the differences between this fishery and the Mediterranean fishery do not allow a clear conclusion on the suitability of the use of stereoscopic cameras in the Adriatic, and further testing would be desirable.

Our software proved to be capable of automatically measuring a large sample size of fish during first transfers in the Mediterranean, though further training is required to improve performance in the Adriatic. All first transfers were processed automatically using the software. In the Mediterranean, the software delivered high sample sizes (73%, 90%, 75%, and 73%), with average lengths closely matching manual measurements (-1.7%, -2.0%, -2.0%, +1.5%). However, further development of the tracking algorithm is needed to provide a reliable sample size, since the same fish are sometimes mistakenly identified as different individuals and measured multiple times. This can result in an inflated percentage of fish measured, suggesting a higher figure than the actual number of unique fish recorded. The time required for the measurements of the four transfers was reduced from 16 hours to 2 hours. In the Adriatic, although the sample size was lower (12%), the average length was comparable to manual measurements (-1.6%), and the time required decreased from 3 hours to just 3 minutes.

The software can be implemented onboard vessels in a laptop without internet connection to provide a real-time estimation of a high percentage of the population. The software features a user-friendly graphical interface that does not require technical expertise or any knowledge of the underlying algorithms. Furthermore, 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 expect faster versions of the software to be developed soon.

Spreadsheets containing detailed results for all transfers, including average lengths and number of measured fish, are available for download via the following link[1]. The link also includes sample videos for each transfer, demonstrating the software's capabilities and providing transparency for the report’s findings. Each fish measurement is highlighted in the videos with a bounding box, snout, and fork points. The first measurement is shown in green, and subsequent measurements of the same fish are marked in pink, illustrating the tracking algorithm's functionality.

Acknowledgements

This work has been carried out within the scope of the project REM-BFT (project acronym), and co-funded by the European Union through the EU Grant Agreement No. 101103829, and a voluntary contribution by the United States.

The UPV team acknowledges the assistance provided by Balfegó Tuna and the Patrullero de Altura Alborán P-62 of the Spanish Navy in supplying boats and divers to record the transfers in the Mediterranean. Likewise, we acknowledge the assistance provided by Jadran Tuna and the Croatian Ministry of Agriculture in supplying boats and divers to record the transfers in the Adriatic.

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[1] https://upvedues-my.sharepoint.com/:f:/g/personal/pamuobe_upv_edu_es/EmBbujDyRMVAumwubK3X7KEB_zxNufx-wtOoqgMIeKA1bg?e=aIDPRG

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Annex 1: Diaries of the fishing campaigns.

In the present section the logbooks of the two fishing campaigns are presented. The first one, in the Mediterranean (Balearic Sea, Spain), and the second one in the Adriatic (Croatia). Both transferring from purse seine to transport cages.

Diary in the Mediterranean (Balearic Sea, Spain)

25/05/2024
Two technicians from the Universitat Politècnica de València embarked at the Real Club Náutico de Dénia aboard the Spanish Navy's patrol vessel Patrullero de Altura Alborán P-62. We set course for the Ibiza-Mallorca waterway. Upon boarding, we were informed that there was no satellite internet, so we lost connection as soon as we moved away from the coast.

26/05/2024
We woke up off the northeast coast of Ibiza and met with the fisheries inspectors. It was suggested that the objectives of the inspectors and the UPV might not align, as there are many other vessels from various companies that could be inspected. Around 10:30, we received instructions to proceed to the position of Tio Gel II (a collaborating vessel) to record a possible transfer. However, we were unable to reach the transfer due to a breakdown in the vessel’s black water system, which forced us to return to Cartagena. A delay of at least 1 or 2 days is expected.

27/05/2024
We arrived at the port of Cartagena in the morning and waited for further information. Around 17:30, we were informed that the repairs had been completed and that we could be back in the fishing area by 29 May 2024, around 8:00.

28/05/2024
At around 11:30, the Navy and fisheries inspectors conducted simulated exercises to practice the inspection and seizure of a fishing boat. We then set course for the Balearic Islands again.

29/05/2024
We arrived in the area where most of the boats were located. We spent the day near La Frau (a collaborating vessel) and Tio Gel II, but we received no communication throughout the day.

30/05/2024
We remained close to the Balfegó vessels all day but received no further notice. No fishing took place today. Bad weather is expected in the coming hours. We met with the Navy Commander to request divers. They are willing to provide divers, provided it does not interfere with inspection work and meets safety protocols.

31/05/2024
We stayed sheltered from the storm. No fishing activity was reported all day.

01/06/2024
At 12:30, we received notice from Balfegó staff. We successfully completed the first recording, although we have concerns about the quality of the ventral perspective. Later, we were informed that the catch was released due to the presence of too many small fish.

03/06/2024
The Balfegó staff informed us that Cap Horizon (a collaborating vessel) was going to make a transfer. They were located north of Ibiza, but we were 3 hours away and unable to reach them because the inspectors were conducting an inspection between Denia and Ibiza. Tio Gel II was in this area.

04/06/2024
We recorded the second transfer. It was challenging due to rough sea conditions. The Navy divers were occasionally operating outside their safety limits. The ventral perspective was difficult to capture because they could not hold their position, but the other two perspectives were successful.

05/06/2024
We were unable to record today. Tio Gel II deployed a fishing gear around a tuna school, but the fish escaped.

06/06/2024
We were ready to record a transfer from La Frau, but ultimately, the Balfegó staff informed us that recording was not possible because it was a double transfer, and longer cables would be needed.

07/06/2024
At around 17:00, we docked at the port of Maó (Menorca), concluding our stay after 13 days onboard. Due the complexity of managing fish inspection needs and UPV needs in the patrol vessel, and coordinating with Balfegó Tuna's fishing boats, it was agreed between Balfegó Tuna and UPV that, in case some more transfers could be done during the following days, at least one more first transfer will be recorded with two lateral stereocameras. Thanks to this symbiosis, two more first transfers were finally recorded and apported to the project.

Diary in the Adriatic (Croatia)

30/06/2024
Two technicians from the Universitat Politècnica de València traveled to Sibenik (Croatia). We arrived at Sibenik - Amadria Park at approximately 22:00.

01/07/2024
We met with the fishing inspectors, divers, and collaborating fishermen. The details for making the recordings were finalized. The remaining quota percentage was small (about 5%). The weather forecast for the next two or three days is unfavorable, with bad seas expected.

02/07/2024 and 03/07/2024

The boats remained in port due to bad weather. We stayed at the hotel in Amadria Park, which is 10 minutes from the pier, ready for the inspectors' call.

04/07/2024
The inspectors advised us that the fishing boats went out to sea early in the morning. However, they returned to port in the afternoon with no catch due to bad weather.

05/07/2024
The fishing boats left the port in the morning, and the inspectors informed us that we would depart with the patrol boat tomorrow. A transfer was made, but the inspectors reported that we did not meet the recording requirements. The exact reason is unknown. We extended our stay in Croatia.

06/07/2024
We went out to sea and waited all day. Bad weather in the afternoon forced us to return to port. Upon arrival, the inspectors informed us that a catch had been made, but no communication was sent until after we had left.

07/07/2024

No news all day. In the evening, we contacted the inspectors, who told us they would provide a forecast the following morning.

08/07/2024

We went out to sea but made no recordings, and there was no catch. Bad weather in the afternoon forced us to return.

09/07/2024

In the afternoon, the inspectors informed us that they could only provide divers for two more days; beyond that, they could not guarantee anything.

10/07/2024

We went out to sea without recording. In the afternoon, we were informed that the surveyors had other obligations the next day and could not take us out to sea. We picked up a third team member from the airport to take over.

11/07/2024

A team member left Sibenik. We did not go out to sea all day and remained at Amadria Park, awaiting news from the inspectors. Late in the evening, we were informed that we would go to sea the following morning at 6:00 a.m.

12/07/2024

We went out to sea, but there was no notification of a catch. In the afternoon, we were informed that, due to health reasons, the divers they were providing would not be available until Sunday or Monday. We made arrangements to contract two new local divers for the next day.

13/07/2024

We set sail early and successfully recorded the first transfer.

14/07/2024

We went out to sea but did not receive any notice of a catch. Divers were provided again by Croatian authorities.

15/07/2024

We went out to sea but did not receive any notice of a catch.

16/07/2024

Return trip to Spain after a 17-day extended stay, up until the final day of the campaign.

Executive Summary

Tests for the use of stereoscopic cameras during the first transfers from purse seine vessels to towing cages in order to be able to estimate at this stage the weight of the captured bluefin tuna (BFT) were conducted during the fishing campaigns of 2024 in the Mediterranean and the Adriatic.

In the Mediterranean, four first transfers were recorded in collaboration with Balfegó Tuna after a 13-day extended stay on board a patrol vessel, simulating the typical setup used during caging transfers from transport cages to farm cages —fish recorded laterally with a monocamera for counting and a stereocamera for length estimation. Fish length estimations were carried out by using custom software and stereocamera recordings, based on marking snout and fork-tail points of at least 20% of the number of fish being caged. In first transfers, 32%, 21%, 45%, and 73% of fish recorded by the stereocamera were manually measured, corresponding to 23%, 20%, 37%, and 59% of the fish recorded by the monocamera. Note that the percentage of samples depends on whether the counting is based on the monocamera or the stereocamera recordings, due to the fish missing due to stereocamera's narrower field of view. The time invested for fish counting varied between 1.5 and 4 hours per transfer, depending on the number of fish, amounting to a total of 10.5 hours across all the first transfers, whereas the time invested for fish length estimation varied between 1.3 and 9.5 hours per transfer, amounting to a total of 16.3 hours across all first transfers.

In two transfers, there were no additional transfers after the first, so the results could be compared with those obtained by fishing authorities from caging transfer videos. Average lengths were 201.9 and 210.5 cm in the first transfers, compared to 192.6 (-4.6%) and 207.4 (-1.5%) cm in the caging transfers. This disparity could stem from differences in sampling, operator variability, and software (with caging transfer measurements provided by fishing authorities using AM100 software), but this needs further investigation. Average weights could be derived by applying the corresponding length-weight relationship. Fish counts differed by 5%, likely due to operator differences and the difficulty of counting schools in video footage. Studying the feasibility of using acoustic echosounders for counting—capable of detecting occluded fish and potentially automatable—may be beneficial.

In conclusion, estimating the weight of captured bluefin tuna during first transfers from purse seine vessels to towing cages proved technically feasible in the Mediterranean, using a procedure similar to that employed in caging transfers. This approach involves a monocamera for fish counting and a stereocamera for fish length estimation, as outlined in Annexes 8 and 9 of the ICCAT Recommendation amending Recommendation 21-08, which establishes a multi-annual management plan for bluefin tuna in the eastern Atlantic and the Mediterranean (Rec. 22-08). However, it should be borne in mind that there are some additional demands on the existing ones for first transfers that must be taken into account, in particular the use of a stereoscopic camera in addition to the conventional one currently in use, the training on stereoscopic camera usage and software of the personnel already used for bluefin tuna management and a longer time to carry out the transfer operation.

Two alternative recording setups were proposed for the Adriatic: 1) Use a 7x6 meter gate and record with one stereocamera for small catches, up to 500 fish averaging 8-10 kg. 2) Use the common 14x6 meters gate and record with two stereocameras, positioned on either side of the gate, to accommodate larger catches. These setups were intended to allow for comparisons and recommendations. Unfortunately, after a 17-day extended stay in Croatia, only one transfer was recorded using a setup with two stereocameras and 10x6 meter gate. The lack of additional recordings was due to a scarcity of catches during our stay, primarily caused by unfavorable weather and sea conditions. Additionally, the tests were conducted late in the season, by which time most of the quota had already been captured as per the operators' request. A comparison of fish counting and sizing between first transfers and caging could not be performed, as fish from four other first transfers were placed into the transport cage.

Fish length estimation covered 65% of fish counted with the stereocamera, which corresponds to 54% of fish counted with the monocamera. The rest could not be measured due to occlusion. Fish counts using the monocamera and the stereocamera differed by 16.7%. Given that all fish were within the field of view of both cameras, the discrepancy is likely due to occlusions and the different perspective and wider field of view of the monocamera. The comparison between first transfers and caging transfers could not be made as fish from other four first transfers were placed in the transport cage prior to caging, although average lengths (80.6 and 79.1 cm) and average distances (6.4 and 5.4 meters) are similar.

In conclusion, estimating the weight of captured bluefin tuna during the first transfers from purse seine vessels to towing cages was technically feasible in the Adriatic. The transferred fish could be counted with one monocamera and measured with one stereocamera using a gate size of 10x6 meters, as the fish passed at a distance between 4 and 9 meters from the camera (most between 5 and 8 meters). However, since only one experiment was conducted, further experiments are likely needed to properly determine the optimal gate size and number of stereocameras required. With the current 14x6 meter gate, two stereocameras should be used to adequately sample the transferred fish. If the transfer gate size could be reduced to 7x6 meters, one stereocamera would be sufficient. Additionally, the possibility of implementing the optimal setup used for stereocamera sizing at caging—where smaller gates of approximately 4x3.5 meters are employed together with a frame attached to the transfer gate to hold the cameras—should also be explored. The Adriatic Sea fishery presents particular conditions, as bluefin tuna farming is based on catching small schools of juveniles. The fact that only one test could be carried out and the differences between this fishery and the Mediterranean fishery do not allow a clear conclusion on the suitability of the use of stereoscopic cameras in the Adriatic, and further testing would be desirable.

Spreadsheets containing detailed results for all transfers are available for download via the following link[2] to provide transparency for the report's findings.

València, on the date of electronic signature

Signed: Pau Muñoz Benavent

[2] https://upvedues-my.sharepoint.com/:f:/g/personal/pamuobe_upv_edu_es/EmBbujDyRMVAumwubK3X7KEB_zxNufx-wtOoqgMIeKA1bg?e=aIDPRG