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RELIABILITY OF BLUEFIN TUNA SIZE ESTIMATES USING A STEREOSCOPIC CAMERA SYSTEM

I. Katavić[1], T. Šegvić-Bubić, L. Grubišić and I. Talijančić

SUMMARY

A Stereoscopic camera system was used to measure size of caged bluefin tuna at all Croatian farms, one to two weeks prior to the 2014/2015 harvesting season. Images were recorded in three replicates and stored directly onto a computer hard drive for further review. Precise bluefin size data were obtained at harvesting for comparison against the stereoscopic estimates. The obtained data were analysed for statistical differences using Analysis of Variance. The average 0.8% error in fork length and 2.8% error in weight provide a reliable recording-based estimate of relative fish biomass in the floating cage. There appears to be relationship between farm location and the Fulton condition factor, which could be due to variations in husbandry. The trial demonstrated that it is possible to utilize stereoscopic measurement as a rapid and non-invasive routine tool for obtaining accurate data on the size-frequency distribution of bluefin reared in a grow-out cage. This may benefit both the economic and environmental performance of tuna farming operations, and contribute to the improvement of wild bluefin tuna stock management.

RÉSUMÉ

Un système de caméra stéréoscopique a été utilisé pour mesurer la taille du thon rouge mis en cage dans toutes les fermes croates, une à deux semaines avant la saison de mise à mort de 2014/2015. Des images ont été enregistrées à trois reprises et stockées directement sur le disque dur d'un ordinateur aux fins d'un examen plus approfondi. Des données précises sur la taille du thon rouge ont été obtenues à la mise à mort afin d'être comparées avec les estimations stéréoscopiques. Les données obtenues ont été analysées pour rechercher les différences statistiques à l'aide de l'analyse de variance. L'erreur moyenne de 0,8 % dans la longueur à la fourche et de 2,8 % dans le poids fournit une estimation fiable fondée sur l'enregistrement de la biomasse relative des poissons dans la cage flottante. Il semble exister une relation entre l'emplacement de la ferme et le facteur de condition de Fulton, qui pourrait être due à des variations dans l'élevage. L'essai a démontré qu'il est possible d'utiliser une mesure stéréoscopique comme un outil quotidien rapide et non invasif permettant d'obtenir des données précises sur la distribution de fréquence des tailles du thon rouge élevé dans une cage d'embouche. Cela pourrait accroître les performances à la fois économiques et environnementales des opérations d'engraissement des thons, et contribuer à l'amélioration de la gestion des stocks de thons rouges sauvages.

RESUMEN

Se utilizó un sistema de cámaras estereoscópicas para medir la talla del atún rojo enjaulado en todas las granjas de Croacia, una o dos semanas antes de la temporada del sacrificio 2014/2015. Las imágenes se grabaron en tres réplicas y se almacenaron directamente en un disco duro para una posterior revisión. Se obtuvieron datos precisos de talla de atún rojo en el momento del sacrificio para compararlos con las estimaciones estereoscópicas. Los datos obtenidos se analizaron en busca de diferencias estadísticas utilizando un análisis de varianza. El error medio del 0,8% en la longitud a la horquilla y el error del 2,8% en el peso proporcionan una estimación fiable basada en las grabaciones de la biomasa relativa de peces en la jaula flotante. Parece existir una relación entre la ubicación de la granja y el factor de condición de Fulton, que podría deberse a variaciones en la cría. El ensayo demostró que es posible utilizar la medición estereoscópica como una herramienta rutinaria rápida y no invasiva para obtener datos precisos sobre la distribución de las frecuencias de tallas del atún rojo criado en una jaula de engorde. Esto podría beneficiar el rendimiento tanto económico como medioambiental de las operaciones de cría de túnidos y contribuir a la mejora de la ordenación del stock salvaje de atún rojo.

[1] *Institute of Oceanography and Fisheries, Split, Croatia* Corresponding author: katavic@izor.hr

KEYWORDS

*Atlantic bluefin tuna, Stereoscopic recordings data,
Harvest size measurement, Reliability of size estimates*

1. Introduction

In 1996, the first Atlantic bluefin tuna (BFT) caged production started in the Croatia, and in that year, 36 t was exported to Japan (Katavić *et al.*, 2003). Following intensive fattening operations in other Mediterranean countries, there were very strong impacts on BFT fisheries and its management. In the late 1990s, live juvenile BFT started to be used as stock for longer periods of time (Katavic *et al*., 2003b). There was a sudden increase in the demand for live juvenile BFT as stock in long-term farming that could last up to three years. This was followed by an increase in demands of many new entries and a rapid increase in the purse seine fishing catch (Miyake *et al*., 2001). In intensive farming, caught fish are not landed but are instead moved from the fishing net by a towing cage directly into the grow-out cage. Juvenile seed fish of ages 2-3 years are captured by purse seiners, kept alive, transferred to towing cages and again transferred to grow-out cages where they are raised for up to three years.

The initial method for estimating the biomass caught by purse seiners and transferred to the grow-out cage was the average of mort's multiplied with the estimated number of fish caught (assessed by divers) (Katavić *et al*., 2002). However, the lack of accuracy of overall weight estimates due to inadequate sample sizes prevented sufficiently precise estimates of the catch. Inaccurate weight estimates due to exclusion of larger or smaller fish usually caused the average estimated weight to be smaller or higher than if a representative sample would be secured. Estimates made by this method also question whether the purse seine catch might exceed the catch quota. In practice, the catch quantity of fish remaining underwater remained unknown. The only time in which fish can be seen above water and weighed is at the time of harvest for shipping to the market. However, there are issues with this practice due to the difficulties regarding catch statistics and the concurrence of catch data with trade data (Katavić *et al*., 2003).

The International Commission for the Conservation of Atlantic Tunas (ICCAT) has imposed the mandatory rule of the use of underwater video technology to improve the accuracy of the Atlantic BFT catch by purse seiners, and thus to better estimate the number of transferred BFT to farm cages (ICCAT, 2012). Contracting parties (CPCs) to the ICCAT were encouraged to continue to explore operationally viable Stereoscopic Camera (SC) technologies and methodologies for determining the length and biomass at caging (ICCAT, 2013). The implementation of these provisions in practice has shown good results (Ramfos *et al*., 2012; Espinosa *et al.*, 2012; Grubišić *et al.*, 2012; Yildirim *et al*. 2013; Deaguara *et al*. 2013; Deguara *et al.*, 2014). Following ICCAT Recommendation 14-04, CPCs were asked to cover 100% of rearing cages with SC systems in order to obtain the number and biomass of fish in caging operations. Recently, six countries have started submitting their size and weight data from catching operations obtained using SC systems (ICCAT, 2015).

As fish size is an important factor that influence the economics of an aquaculture enterprise, it needs to be consistently monitored throughout the farming period. Fork length (FL) enables the determine fish condition in offshore cage aquaculture, while size frequency and biomass of farmed fish can be used to adjust the feeding regime and other zootechnical measures in the course of the farming process. The aim of this study was to validate the reliability of a stereoscopic underwater camera system for the non-invasive estimation of fish size, and more specifically, to determine whether the BFT farming parameters such as growth rate and condition factor differ between farms in Croatia under specific environmental and zootechnical conditions.

2. Materials and methods

The fork length (FL) of 7,821 specimens was obtained from BFT filmed using the AM100 analysis software (AQ1 Systems Pty Ltd) developed in Australia for Southern BFT (Harvey *et al*., 2003). Actual size measurements were taken during the regular harvesting of caged BFT from 8 December 2014 to 12 February 2015. The time BFT spend in farms is from 18 to 32 months. Stocking density varied through the growing period, with a final density at harvesting from 1.5 to 4 kg/m^3. All four Croatian farms were recorded, with the inspection of two cages at each farm. In this study, BFT was filmed in net cages with a diameter from 40 to 60 m, and the depth of the bottom side of the cage varied from 20 to 25 m, thus providing a volume of 25,000 to 70,000 m^3. The SC system was lowered into rearing cages containing approximately from 750 to 2500 BFT, one to two weeks prior to harvesting. The camera mounting system included a 4.5 m long rectangular aluminium rod that was suspended into the water at a depth of 2 to 4 m, depending on light intensity and fish behaviour. Visibility during recording was estimated from 10 to 20 m.

Pursuant to paragraph 83 of the ICCAT Recommendation 14-04, the SC system was deployed for size data covering a 20% sample of fish caged. It was assumed that 30 minutes of recording would be enough to attract most fish to move around the underwater camera, and to obtain a representative sample of the caged BFT. To test this hypothesis, three replicates were conducted at each cage. This implies that each fish from the population in the grow-out cages has an equal probability of being included in the sample. Only readable images from the 30-minute recordings were used to measure fork length (FL, in cm). One session was not readable due to recording under unfavourable lighting conditions (Farm 1). To stimulate fish to pass through the camera's field of vision, bite was distributed over the surface of the cages. BFT in the grow-out cage did not appear to be disturbed by the presence of the camera. Fish regularly approached the camera, though only those fish at a distance of greater than 3 m from the camera were measured. When the margin of error between doubled cameras exceed 3.5%, these fish were not registered.

Recorded images were stored directly onto a computer hard drive. To avoid errors, filmed BFT were only measured when the bodies were straight or near straight. Conversion of FL obtained by underwater SC to round weight (RW) was made by means of the L-W relationship integrated into the camera software, as:

$$RW = (2.3139*10^{-5})*FL^{2.9840}$$

One to two weeks following recordings, real FL-RW data of 2,896 BFT were obtained for comparison against SC size data estimates. Fish were sampled at regular harvesting, killed and individually measured for FL with measuring callipers (MC) and subsequently weighted (±0.1 kg). RW was not adjusted for the blood-weight lost by killing.

The length of fish recorded by the camera in different replicates for each and among four farms was analysed for statistical differences. To test the difference between length data among individual farms, two-way nested ANOVA (StatSoft) was used. Cages and replicates served as factors. Two-way factorial ANOVA was applied on the data set to test the weight–length differences among locations and/or method of data collection (camera and/or sampled fish measurements).

3. Results

The mean length of the 7,821 Atlantic Bluefin Tuna (BFT) recorded and measured with SC was 144.0 cm (SD ±10.5 cm). The maximum length of fish was 169.9 cm while the minimum was 120.1 cm. Length frequency histograms (**Figure 1**) show an approximately normal distribution around the mean, with the majority of the fish lying between 140 and 150 cm. When converted to RW using the appropriate L-W equation, the average was 65.8 kg (SD ±14.15), with a minimum of 37.1 kg and a maximum of 116.0 kg. The overall results of this analysis demonstrate that there likely to be a difference in the mean lengths of BFT recorded by camera and those measured at harvesting **(Table 1)**. Length frequencies of BFT filmed with SC in the cage at each of four individual farms (Farm 1 to Farm 4) and in total, and subsequently harvested and individually measured fish were plotted as shown in **Figure 2**.

The FL data from the different SC recordings at four BFT farms were analysed for statistical difference using Analysis of Variance (ANOVA). A graphical summary shows mean SC FL and RW converted from FL using the appropriate L-W equation. The differences in the mean FL and estimated RW among replicates for eight cages at four locations are shown in **Figures 3 and 4**.

The cumulative data by farms (Farm 1 to Farm 4) were analysed (**Table 2)** and plotted **(Figure 5)** to determine whether the SC FL and estimated RW of BFT differed from the real data measurements between farms.

Error in the SC measurement of FL when compared with real values was relatively small, and did not greatly differ among farms (+0.6%, -0.4%, +1.4 and +0.2% respectively). When SC FL wa converted to RW using the appropriate L-W equation, the average difference by farms was within ±4%. Overall, the SC recorded and measured FL and RW estimates did not differ greatly from the real measured FL and RW data at harvesting **(Table 3).**

The plotted length frequency of all BFT measured by stereoscopic measurements and sampled at harvesting shows that RW was either underestimated or overestimated. It appears that smaller fish <130 cm FL are underestimated by SC recordings, while larger fish >160 cm FL are overestimated in RW **(Figure 6).** The difference in FL-RW relationships by farm estimated by SC recordings and real measurement of killed fish at harvesting was plotted as shown in **Figure 7.** There appears to be relationship between location and the Fulton condition factor (CF) by farm, ranging from 2.07 to 2.35. Heavier fish were 12% higher in CF compared to the most weight-inferior farmed fish of a similar size **(Table 4).**

4. Discussion

The length-frequency histogram shows an approximately normal distribution around the mean with the majority of fish lying between 140 and 150 cm, and 50 to 70 kg in weight (**Figure 1**). In general, there are two main trends in farming operations in Croatia: a longer farming term of juvenile bluefin tuna that are held for at least 30 months, and a shorter term in which fish are kept around 18 months. The time spent at farms logically has a positive impact on the increase in both length and weight of the fish. However, variations in size of fish among farms (**Table 2**) could be additionally related to the density of fish in the cage, feeding protocol, forage, environmental temperature and oxygen saturation, size/age at harvest, and many other factors (Ortiz, 2015).

Recent management regulations with the newly introduced ICCAT observer system and improved catch document (ICCAT, 2011) prohibits the mixing of fish from different sources or fishing seasons in one cage, though the complete implementation of this measure is still difficult to apply. However, mixing of fish from different cohorts may overlap and thus disrupt traceability, making back calculation unfeasible. A further difficulty is that fish from the same harvesting season may be age-mixed and through an optimization of densities may be distributed differently by size or age. As is well known, in the course of feeding, small fish cannot compete with big fish, and therefore their growth might be slowed.

Some differences in the mean length of fish recorded by SC at different 30-minutes time intervals (**Figure 3**) could be explained by the relatively high variability of size frequencies in cages (**Table 2**) and the SC reader which aims to catch up to 20% of the fish reared in the cage.

Weight gain in farming operations differed among farms (**Figure 5**), supporting previous reports from different farming locations (Katavic *et al.,* 2002; Tzoumas *et al.,* 2010).

There were no substantial differences in camera recorded FL converted to RW using the appropriate L-W equation compared to the real measured fish at harvesting. The average 0.8% error in FL and 2.8% error in weight provide a reliable estimate of the relative biomass in the floating cage. Previous studies have also confirmed the reliability of such technology in conducting size monitoring of BFT in cages, i.e. for southern bluefin tuna (*Thunnus maccoyii*) (Harvey *et al*., 2003) and for giant Atlantic BFT (>100 kg) (Yildirim *et al*., 2013). The use of new generation SC technology was previously reported by Grubišić *et al.* (2012), who tested the accuracy of SC recordings and measured L-W data during the transfer and caging of newly caught bluefin juveniles. Different L-W relations were compared among estimated and real measured fish; . The relative error in weight was from 2.8% to 7.1%.

The precision of measurement appears to be greatly affected by fish size. SC estimates of smaller BFT (<130 cm FL) tended to underestimate actual weight. On the contrary, larger fish (>160 cm FL) showed overestimated biomass (**Figure 6**). This is likely the consequence of the applied algorithm for fish of varying Fulton's condition factor (CF). In other words, another algorithm might better approximate the length–weight relations of these fish size categories. There appears to be a relationship between location and CF by farm ranging from 2.07 to 2.35 that could primarily be due to the applied husbandry methods (**Table 4**). Katavić *et al*. (2003) found that caged BFT juveniles above 25 kg in weight resulted in a gradual increase of CF, suggesting that BFT biomass gained more by fish fattening than by the length increment. Table 4 shows that heavier fish had a 12% greater CF than most weight-inferior farmed fish of a similar size. Significantly higher CF-values were recorded in large fattened bluefin tuna as compared to wild ones of the same length. Thomas *et al*. (2010) found average CF-values of about 1.7 for wild and about 2.2 for fattened BFT, which corresponds to our findings. The higher CF-values are consistent with higher muscle fat content. Orban *et al.* (2006) reported that adult bluefin tuna fattened for 5–6 months can increase muscle fat from 5% at stocking to 30% at harvesting.

CF is an important factor in BFT farming practices, as it is the basis by which farmed BFT are graded. BFT with higher CF-values obtain a higher price on the specialized Japanese *sushi* and *sashimi* markets (Ikeda, 2003). Tičina *et al*. (2007) found a significant increase in CF-values of BFT harvested after a certain farming period, as compared to the CF-values of wild BFT of similar size. Farmed southern bluefin tuna (SBT) juveniles showed an increase in CF from 1.94 to 2.38 when fed on pilchard after a 133-day rearing period (Carter *et al*. 1998).

In summary, SC has proven to be an acceptable, non-invasive tool for the accurate length measurement of caged, live bluefin tuna that can be converted by an L-W equation into relatively accurate fish biomass. Moreover, underwater video recordings can be easily used on a routine basis to obtain reliable data on the size frequency distribution of BFT reared in grow-out cages, and for the adjustment of the feeding regime or other zootechnical measures at the farm accordingly. This may benefit both the economic and environmental performance of tuna farming operations, while also contributing to the improvement of wild bluefin tuna stock management.

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Table 1. Stereoscopic measurements and measurements at harvesting of BFT fork length (FL in cm) and round weight (RW in kg). No statistically significant differences were found in weight and length (P<0.05) among camera recorded and real measured BFT at harvest.

		Average ±SD	*Min–Max*
Camera recorded and measured (n=7821)	FL (cm)	144.0* ± 10.5	120.1 – 169.9
	RW (kg)	66.1* ± 14.1	37.0 – 104.6
Real measurement at harvesting (n=2896)	FL (cm)	142.8 ± 9.8	111.0 – 174.4
	RW (kg)	67.8 ± 13.7	30.1 – 116.0

Table 2. Differences in the mean length (FL) and converted mean weight (RW) of BFT stereoscopic camera (SC) recorded and real measured (RM) BFT at harvesting from four Croatian farms (Farms 1–4). * denotes a statistically significant difference (P<0.05).

	Farm 1		***Farm 2***		***Farm 3***		***Farm 4***	
	SC *N=1286*	***RM*** *N=666*	***SC*** *N=1121*	***RM*** *N=289*	***SC*** *N=2389*	***RM*** *N=803*	***SC*** *N=3025*	***RM*** *N=1138*
FL(cm) ± SD	**144.4** ±9.5	**143.5** ±8.2	**152.8** ±6.7	**153.5** ±5.6	**142.5*** ±8.6	**140.5** ±8.7	**141.5** ±11.6	**141.2** ±10.3
RW(kg) ± SD	**64.9** ±12.8	**67.3** ±13.07	**77.2** ±9.9	**80.1** ±9.8	**61.9** ±11.5	**61.6** ±11.6	**60.6** ±15.5	**58.8** ±12.1
FL Min	120.6	117.0	124.9	135.0	121.3	111.0	120.0	120.6
FL Max	169.9	169.0	169.9	167.0	169.9	168.0	169.9	174.4
Wt Min	37.6	31.1	41.7	53.0	38.3	30.2	37.0	34.1
Wt Max	104.6	116.0	104.5	110.1	104.5	95.0	104.6	103.1

Table 3. Grouped data differences (Δ) in mean fork length (FL) and mean round weight (RW) of stereoscopic camera (SC) recorded and real measurement (RM) BFT at harvesting from four Croatian farms expressed as a percentage (%).

Diff.(Δ) SC/RM	*Farm 1*	*Farm 2*	*Farm 3*	*Farm 4*	$\sum F1 - F4$
ΔFL (%)	+0.6%	-0.4%	+1.4%	+0.2%	+0.8%
ΔRW (%)	-3.7 %	-3.8%	+0.5%	+3.0%	-2.6%

Table 4. Fulton's condition factor (CF) based on data collected from Croatian BFT farms at harvesting with standard deviation (±SD).

Farms (1–4)	*No samples*	*Fulton's CF*	*±SD*
Farm 1	666	2.35	±0.18
Farm 2	289	2.21	±0.15
Farm 3	803	2.13	±0.19
Farm 4	1138	2.07	±0.16

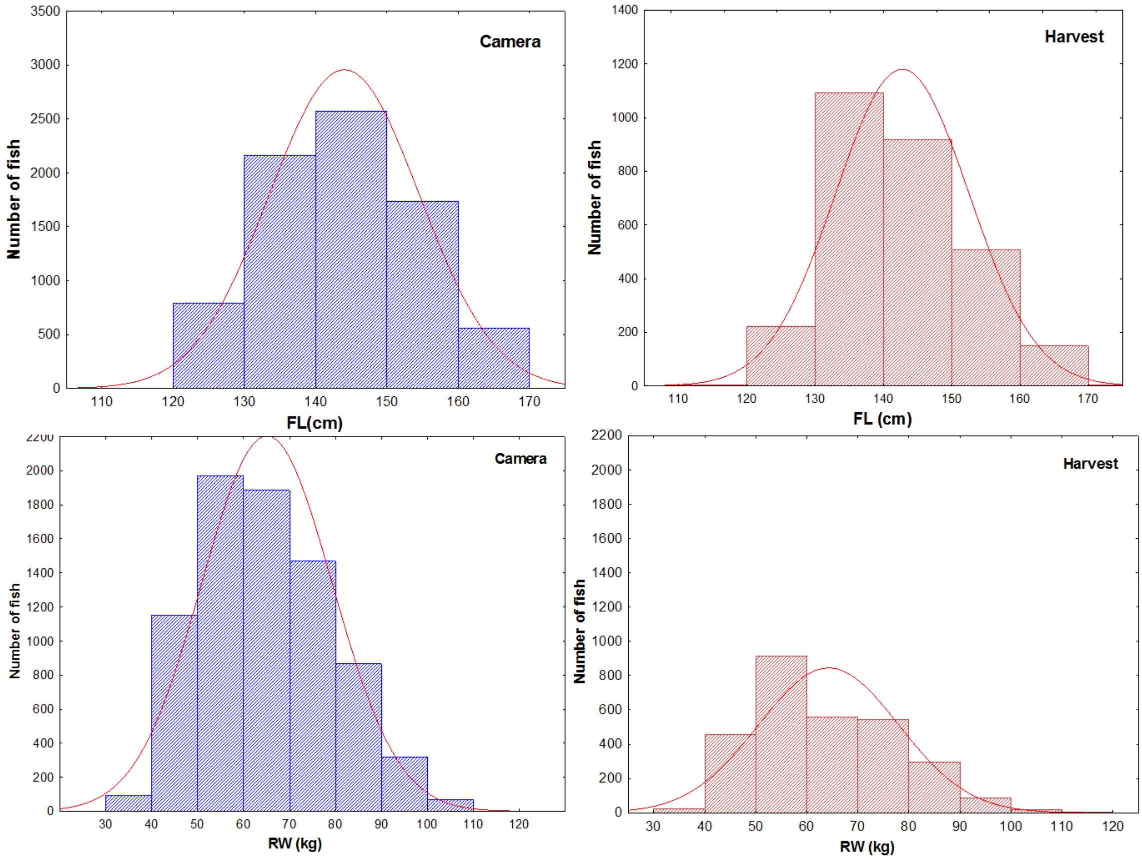


Figure 1. Number of fish (three replicates grouped) recorded and measured by stereoscopic cameras (blue) and real measurements at harvesting (red) for different BFT weight and length (FL-RW) categories.

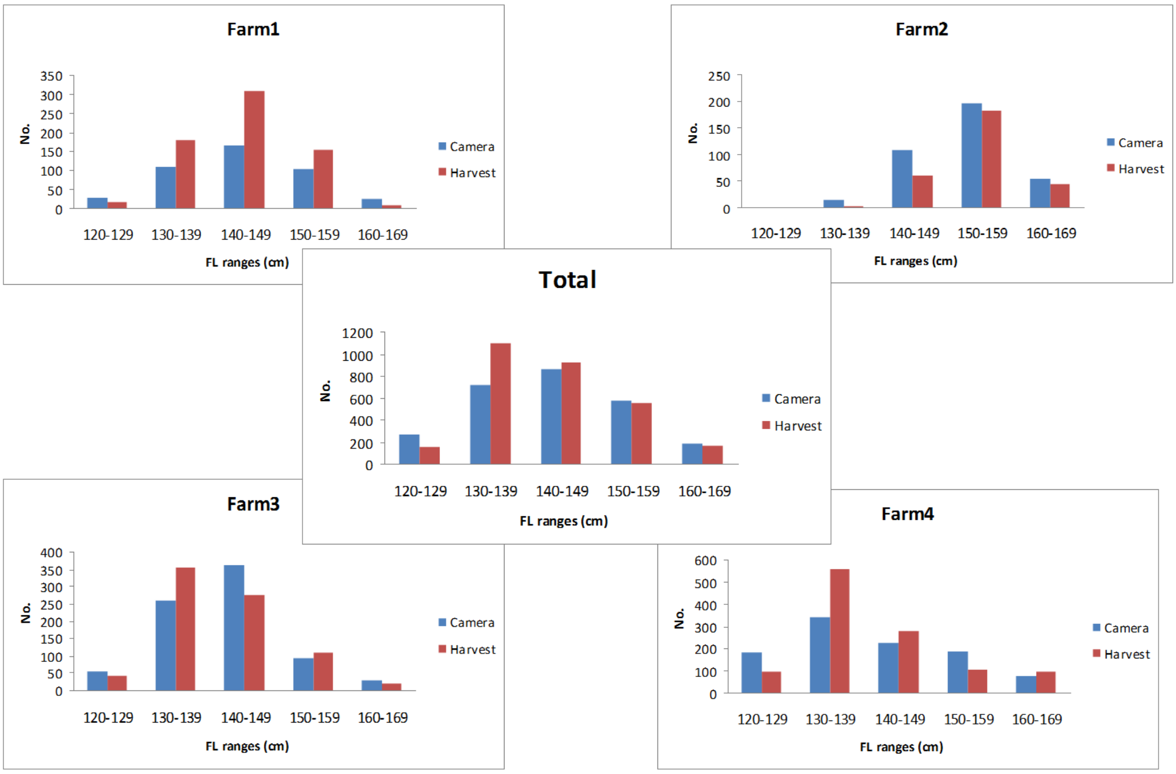


Figure 2. Number of fish (No.) by length frequencies directly measured at harvest (red) and by SC* (blue) in the total and at each individual farm (F1-F4). *represents the average of three replicates.

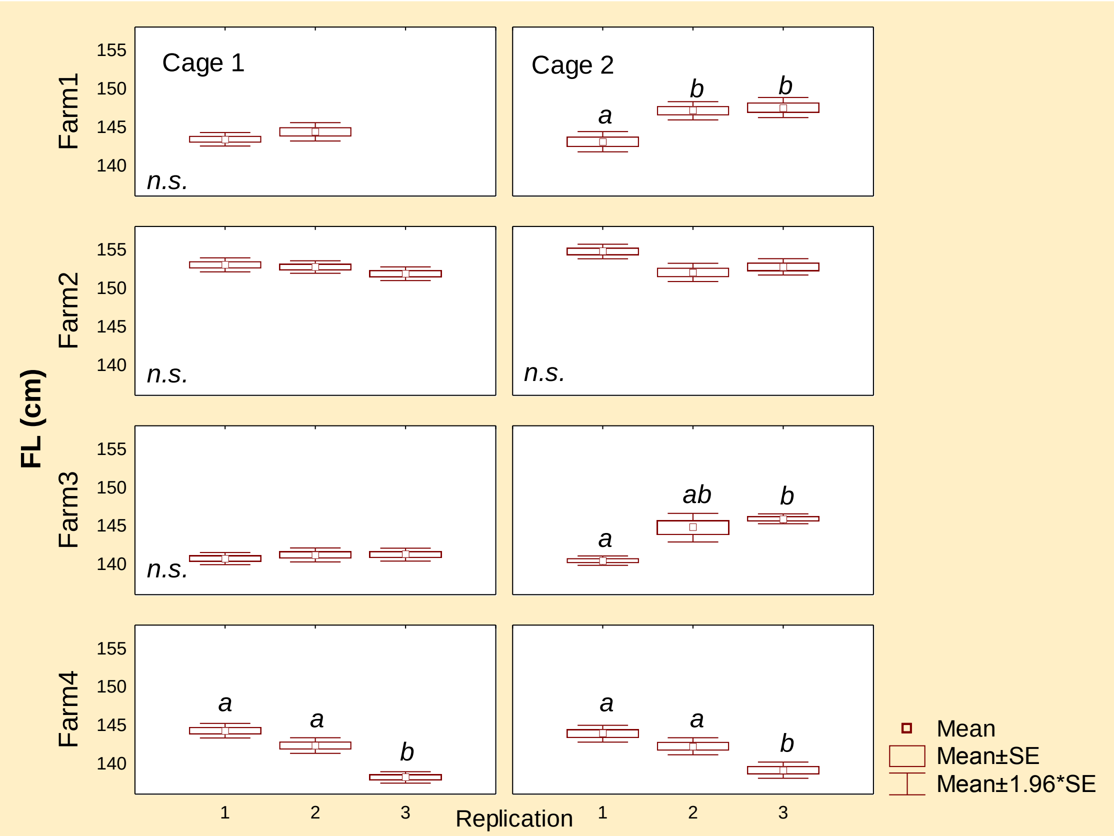


Figure 3. Stereoscopic camera system (SC) sampling design that includes three replicates for two cages at four farms for fork length (FL, in cm). Differences among replicates were tested using the nested ANOVA. n.s. indicates no significant difference; different letters (a, b, ab) indicate a significant difference among replicates.

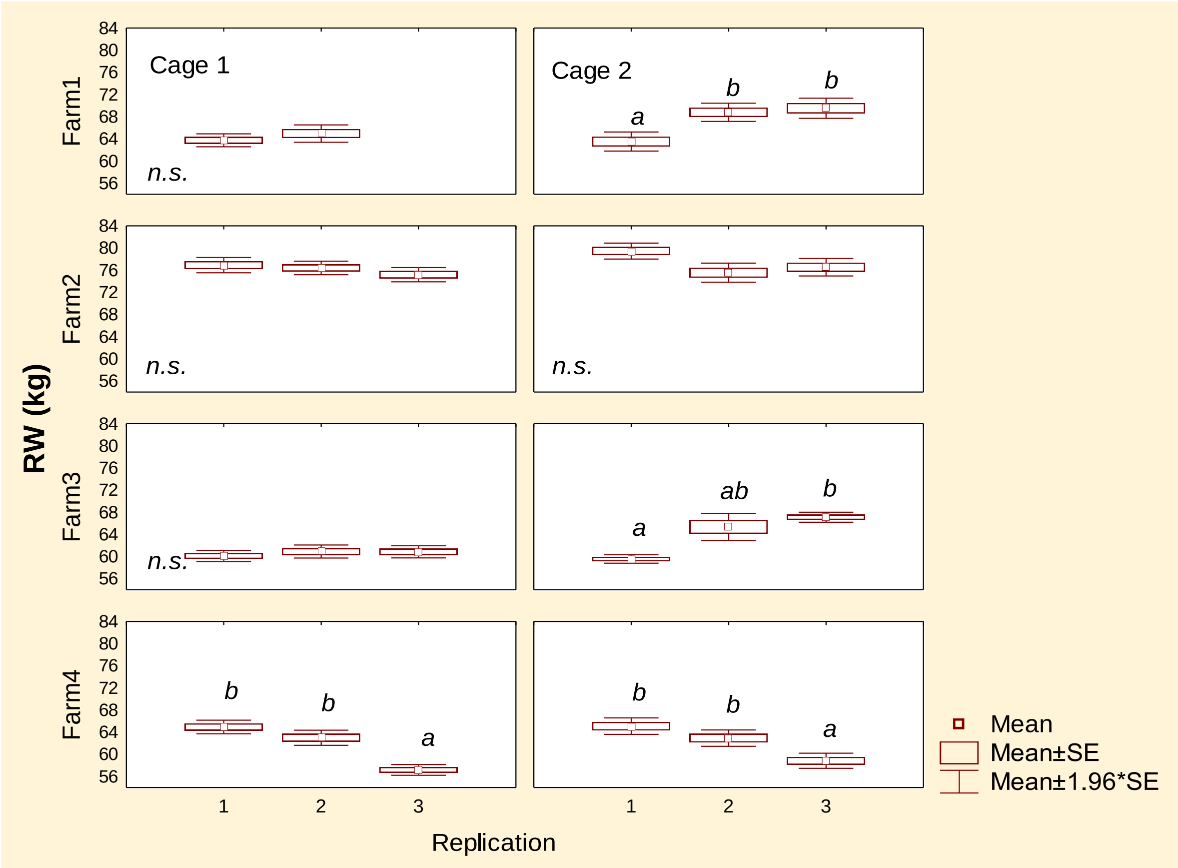
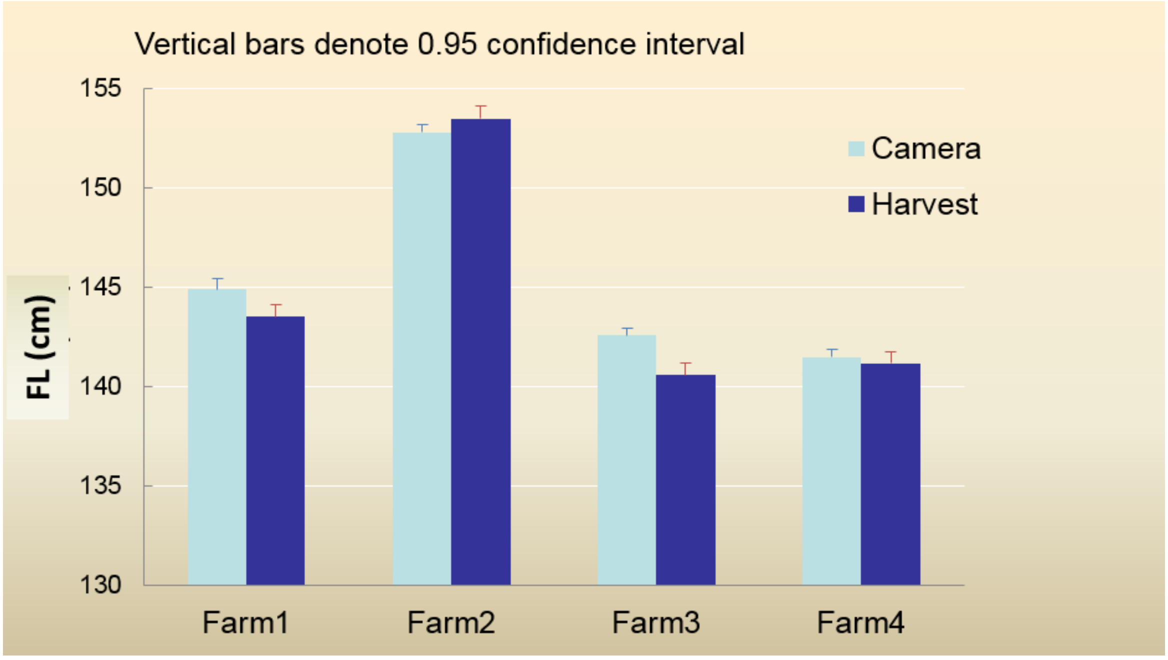


Figure 4. Stereoscopic camera system (SC) sampling design that includes three replicates for two cages at four farms for round weight (RW, in kg). Differences among replicates were tested using the nested ANOVA. n.s. indicates no significant difference; different letters (a, b, ab) indicates a significant difference among replicates.

a)



b)

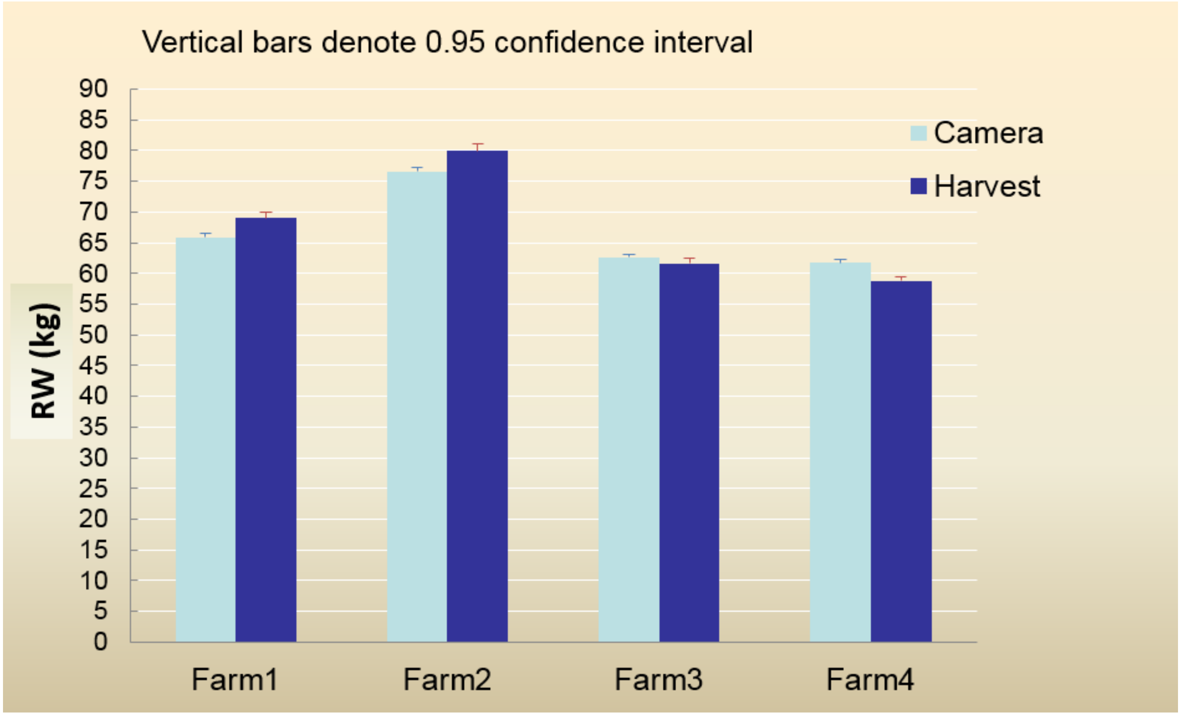
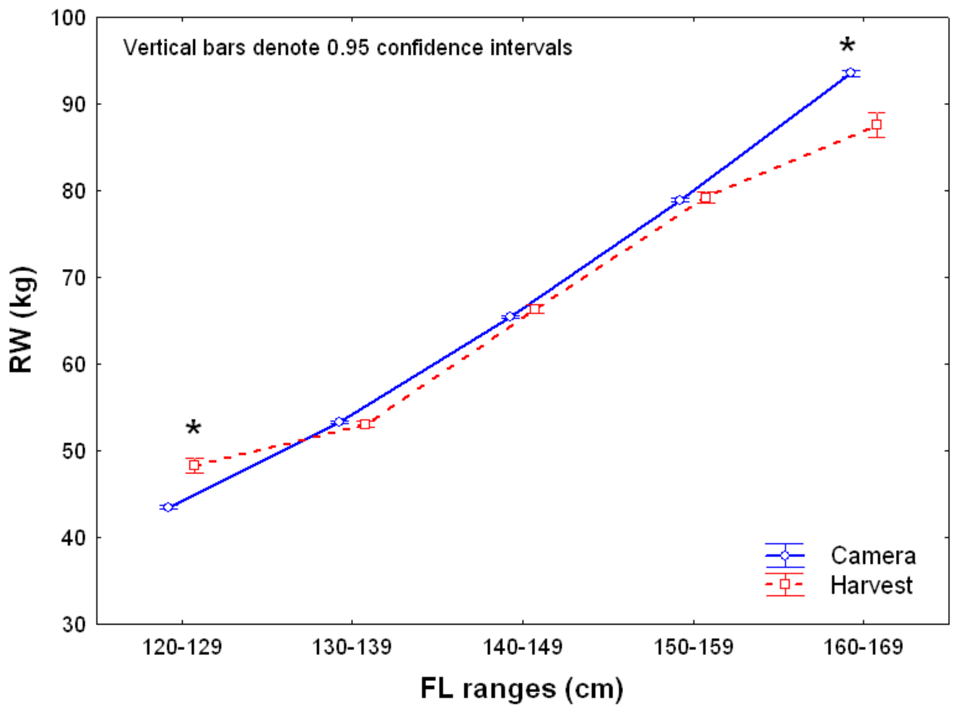


Figure 5. (a) Fork length (FL in cm) estimates obtained by SC and direct measurements at harvesting, and (b) round weight (RW in kg) estimated by SC and direct measurements at harvesting, by farm.

a)



b)

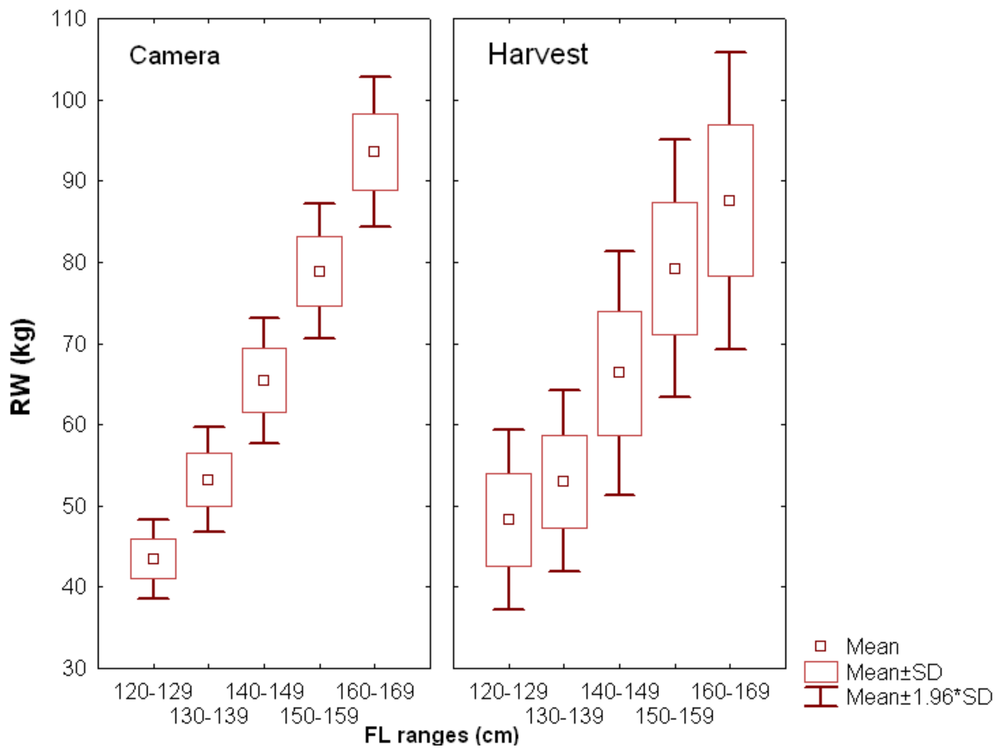


Figure 6. (a) Overall fork length–round weight (FL-RW) relationship of bluefin tuna estimated by stereoscopic cameras compared with empirical data measured at harvesting. * denotes a statistically significant difference in RW among cameras and real size data for specific FL categories resulting in the underestimation of smaller fish, and overestimation of larger fish. (b) RW dispersion in relation to FL categories (cm) with standard deviation (± SD), and 95% confidence interval indicated.

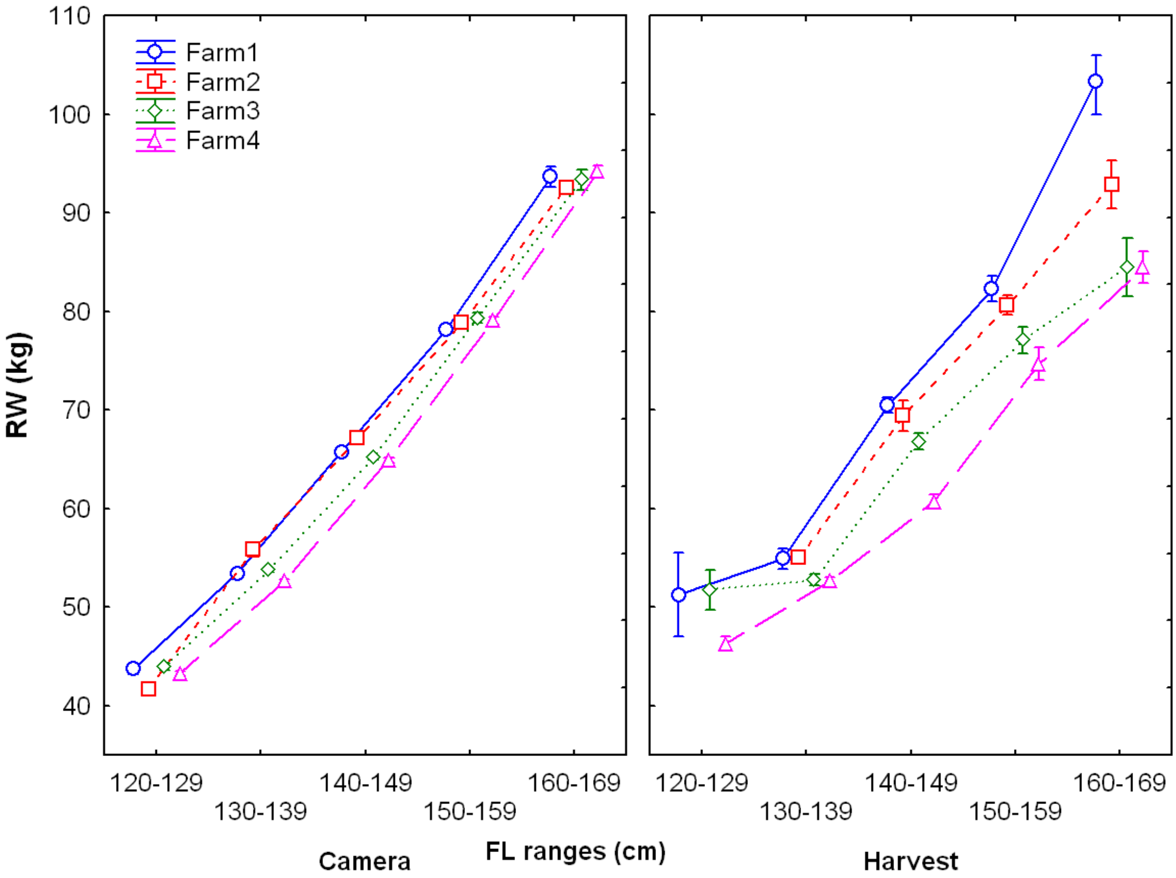


Figure 7. Differences in the fork length–round weight (FL-RW) relationship among farms (Farms 1–4) estimated by stereoscopic cameras and direct measurements at harvesting.