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Underwater tagging of the Atlantic Bluefin Tuna in the trap Fishery of Sardinia (W Mediterranean)

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Abstract:	Tagging bluefin tuna (BFT) has become an essential tool for fishery science that has improved the identification of growth parameters and age validation, population abundance estimates, movement and migration patterns and spatial and temporal population dynamics. Although innovative technologies and methodologies have been introduced, some unresolved issues regarding the possible alteration of fish behaviour and survival during post-tagging as consequence of capture and handling. Such issues have raised the question of whether underwater tagging might be less invasive and preferable to tagging fish on board. In the present study a framework to manage traditional trap gear "Tonnara" for underwater tagging and release purposes was developed for conventional tagging in the Sardinian traps. The general objective of the current study was to ameliorate the operational framework to determine best practices for the underwater tagging of BFT using pneumatic spearguns. Our specific objectives were: (1) to identify the proper size of pneumatic speargun and its operating pressure, (2) to identify the proper shooting distance for the aforementioned equipment, (3) to develop a tool for the indirect estimate of tuna size during tuna tagging operations and 4) to report the results of the tagging activities carried out with conventional tags in Sardinian traps during the 2014 season. The results of the penetration test showed that the shooting distance should be 1-3 m to be successful using a pneumatic speargun at 20 bars of pressure. The indirect length estimation of BFT size was more accurate when the lasers were exactly perpendicular to the animal. However, this method always underestimates the size of the fish, with an average relative error of about −30 cm. During tagging activities in the Sardinian trap in 2014, a total of 63 fish were tagged in 3.5 hours, and only one fish died directly from tagging injuries. The trap represents an optimal system for tagging large numbers of BFT in confined waters when the main goal is to release the fish in the best possible condition. The fish can be confined for several hours in the death chamber, allowing determination of the survival of tagged fish and tag retention.

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This work was carried out in accordance with The protocol and procedures are full in accordance with the European Directive 2010/63/EU for animal experiments.

Highlights

Tagging from the Mediterranean traps, the ancient fishery for bluefin tuna.

An operational framework to handle the trap and enable underwater tagging with speargun is described.

63 bluefin tunas were tagged underwater during their spawning migration in one day.

Length estimation by laser pointers underestimate the actual size of bluefin tunas.

Bluefin tuna confined for several hours allow to determine the survival of fish after the tagging.

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Abstract

Tagging bluefin tuna (BFT) has become an essential tool for fishery science that has improved the identification of growth parameters and age validation, population abundance estimates, movement and migration patterns and spatial and temporal population dynamics. Although innovative technologies and methodologies have been introduced, some unresolved issues remained regarding the possible alteration of fish behaviour and survival during post-tagging as consequence of capture and handling. Such issues have raised the question of whether underwater tagging might be less invasive and preferable to tagging fish on board. In the present study a framework to manage traditional trap gear "*Tonnara"* for underwater tagging and release purposes was developed for conventional tagging in the Sardinian traps. The general objective of the current study was to ameliorate the operational framework to determine best practices for the underwater tagging of BFT using pneumatic spearguns. Our specific objectives were: (1) to identify the proper size of pneumatic speargun and its operating pressure, (2) to identify the proper shooting distance for the aforementioned equipment, (3) to develop a tool for the indirect estimate of tuna size during tuna tagging operations and 4) to report the results of the tagging activities carried out with conventional tags in Sardinian traps during the 2014 season. The results of the penetration test showed that the shooting distance should be 1–3 m to be successful using a pneumatic speargun at 20 bars of pressure. The indirect length estimation of BFT size was more accurate when the lasers were exactly perpendicular to the animal. However, this method always underestimates the size of the fish, with an average relative error of about −30 cm. During tagging activities in the Sardinian trap in 2014, a total of 63 fish were tagged in 3.5 hours, and only one fish died directly from tagging injuries. The trap represents an optimal system for tagging large numbers of BFT in confined waters when the main goal is to release the fish in the best possible condition. The fish can be confined for several hours in the death chamber, allowing determination of the survival of tagged fish and tag retention.

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1. Introduction

The tagging of Atlantic bluefin tuna (BFT), *Thunnus thynnus* has long been recognised as a valuable means of studying key aspects of its biology, including its life history, migration, movements and population structure (Abascal et al., 2016; Block et al., 2005, 1998; Cermeño et al., 2015; Cort, 1990; Galuardi and Lutcavage, 2012; Sibert et al., 2006; Stokesbury et al., 2007; Teo et al., 2007a; Walli et al., 2009). Tagging programs were conducted in a systematic way in the Eastern Atlantic, Mediterranean Sea and Northwest Atlantic (Block, 1998; Block et al., 2005, 2001; Boustany et al., 2008; Kitagawa et al., 2007; Magnuson et al., 1994; Stokesbury et al., 2004, 2007). In the Eastern Atlantic and Mediterranean Sea, BFT tagging campaigns began in the early 1900s, and a significant increase in numbers of tagged fish was achieved in 1960–80 (Stokesbury et al., 2007; Tičina et al., 2007, 2004; Yamashita and Miyabe, 2001). In the last ten years, the International Commission for the Conservation of Atlantic Tunas (ICCAT), under the Atlantic-Wide Research Programme for Bluefin Tuna (GBYP), has sustained the collection of fisheries-independent data, as well as the improvement of information on stock structure and fish movements (ICCAT, 2013). Since 2010, the GBYP Programme has addressed the necessity of understanding key biological and ecological processes, assessment models and provision of scientific advice on stock status through conventional and electronic tagging. Such activities have been strongly stressed by the scientific community to improve information on the connectivity between Western–Eastern Atlantic stocks and vice versa, and with the Mediterranean Sea (Abascal et al., 2016; Cermeño et al., 2015; Fromentin and Lopuszanski, 2014; Rouyer et al., 2020).

The tagging of BFT involves three sequential phases: fish capture, tag insertion and release. Each phase may be achieved with different tools and techniques for handling the fish, a process that may cause physical injuries and stress or alter fish behaviour in tagged fish. Fish removed from their natural environment and from the school may gain injuries from hooking and is undergone to lower levels of oxygen. This can increase their disorientation and vulnerability to predation, thus nullifying the tagging (Hoyle et al., 2015; Skomal and Chase, 2002). One of the main concerns is the post-release phase, because if these impacts occur at that time, they are unrecognizable, particularly when fish are released after exhausting capture (Davenport et al., 2002).

In the Western Atlantic (Eastern North America), most of the tagging programs carried out on BFT have used the rod and reel technique, tagging hooked fish on board (Block, 1998; Brill et al., 2002; Lawson et al., 2010; Sibert et al., 2006; Stokesbury et al., 2011; Teo et al., 2007b; Walli et al., 2009). This technique has excellent results in terms of number of BFT tagged owing to the substantial abundance of BFT in this area during winter months (Block et al., 1998). A previous study reported the capture, tagging and release of 20–60 fish per day. However, the achievement of such numbers is unrealistic for the Mediterranean Sea. In fact, because of the spreading behaviour of BFT during the winter, the strike ratio of fishermen using a rod and reel is only 0–5 specimens per day (FIPSAS, 2019).

A promising technique for both successful tagging and animal welfare is to tag BFT directly underwater, preferably in confined waters where entrapped fish can be kept for scientific purposes. Information on the underwater tagging of BFT in the Eastern Atlantic and Mediterranean are scant and dated. Two studies focused on tagging of farmed tunas to investigate their growth performance in cages (Tičina et al., 2004, 2003), while the pioneering investigation of De Metrio et al. (2002) investigated the post-spawning behaviour of BFT tagged with pop-up satellite tags. More recently, underwater tagging has been advanced by purse seine or traditional traps for ICCAT programs (Abascal et al., 2016; Addis et al., 2014; Karakulak et al., 2015; Mariani et al., 2016).

Sardinia (Western Mediterranean), the second largest island in the Mediterranean Sea, is geographically located along the reproductive migration pathway of the Atlantic BFT (Addis et al., 2016a). From late April until mid-July, tuna schools migrate along the western coastline in a southward direction, swimming near the bathymetric contour of 40 m and lower, where they have for centuries been intercepted by the local trap fishery *tonnara* (Addis et al., 2012). This fishery is the only remaining commercially active trap fishery in the Mediterranean which, together with those on the Eastern Atlantic coasts of Spain, Morocco and Portugal, provides stationary scientific data about the status of the BFT population (ICCAT, 2012). These fisheries have implemented national and international scientific monitoring programs to study the biology and ecology of BFT, including conventional and electronic tagging activities (Di Natale et al., 2018).

The first conventional tagging in the Sardinian trap was carried out during the 2013 fishing season. This campaign resulted in the tagging and release of 250 BFT. Although this tagging program had satisfactory results in terms of number of fishes tagged, some methodological limitations occurred. These included tag applicator retention, speargun ballistics (size and air charge features), shooting distance, fish length estimation and effectiveness of the trap fishery for underwater tagging of BFT (Addis et al., 2014). These preliminary results have encouraged new experimental tagging methods to ameliorate the operational framework for the underwater tagging of BFT in traditional traps, which was the general objective of the current study.

The specific objective of the present study was to evaluate the effectiveness of underwater tagging, considering the effect of the following factors on the penetration and retention of the tag: 1) speargun size; 2) shooting distance; 3) tuna size; 4) shape of the tag applicator; and 5) diver skill in terms of good/bad shots. Moreover, the accuracy of indirect length estimation of tuna size by laser pointers was evaluated considering the effect of distance and angles.

Finally, we report here the results of tagging activities in a Sardinian trap fishery during the 2014 season to evaluate the suitability of traditional traps (*tonnara*) for underwater tagging of BFT.

2. Material and Methods

2.1. Study area and trap-gear adjustment for tagging

The study was conducted in southwestern Sardinia (Italy; 39°11′N, 08°18′E). Here the environmental features have made the area suitable for BFT occurrence and fisheries since the sixteenth century, when the first *tonnara* trap was documented (Addis et al., 2016a).

The trap is classified as a *tonnara di corsa* (arrival trap) because BFT are captured along their pre-spawning migration route with ripening gonads. The fishing gear consisted of five chambers settled at 42 m depth with a 1050 m long tail (Fig. 1). The chamber used for the experimental tagging corresponds to the death chamber (*camera della morte*), which has a moving net floor, the *corpus*. This is the chamber where the *mattanza* generally took place. The *corpus* is a net floor handled by fishermen (pull and cast net) that allows regulation of water volume and depth to maintain caged BFT. This feature permits users to keep tunas caged in a free-swimming state and to check their stress conditions, which can occur before and after tagging activities (Addis et al., 2013a). The trap crew is comprised of 25 fishermen. In mid-April, the trap fishery is fully operational, and the earliest entrapment of BFT occurs in late April. The gear reaches its maximum capture production in mid-May, after which the number of fishes entrapped decreases due to the progressive ending of the BFT reproductive migration (Addis et al., 2013b).

2.2. Test of tag penetration by pneumatic spearguns

The applicators for conventional tagging designed by ICCAT utilize three different systems: single barb spaghetti (FT), double barb (FIM) and large billfish double barb (BFIM) tag applicators. These applicators have been specifically designed for the insertion of tags by hand, so control of pressure when inserting the applicator into the BFT body is the responsibility of the tagger. Previous tests have shown that FT and FIM applicators are not suitable for speargun tagging because of breakage of the nylon tag with FT applicators and breakage of the thin steel tip with FIM applicators (Addis et al., 2014).

For this reason, BFIM applicators were used for the penetration test. The trial was conducted using different pneumatic spearguns (Mares, mod. Cyrano HTM Sport GmbH, Austria) of 85, 97 and 110 cm total length with an operating air pressure of 20 bars. All spearguns were equipped with a 7 mm ∅ shaft modified for a BFIM applicator. Tag penetration into the BFT body was evaluated considering the tag applicator with a stopper (Y) and without a stopper (I). Three shooting distances (1, 3 and 5 m) were tested.

The penetration test was carried out on a sample of six dead BFT belonging to two size classes: small (S) (127–150 cm fork length; n = 3 fish) and giant (G) (212–235 cm fork length n = 3). Experiments were carried out with tunas placed on the sea bottom at 5 m depth. The placement point for tagging was at the base of the second dorsal fin of the BFT (Fig. 2), which corresponds to the conventional point for tagging tunas (Cort et al., 2010). Specimens of BFT used for the penetration test were supplied by the trap company and consisted of fish killed by entanglement in the trap nets.

The penetration capacity of the BFIM applicator in the tuna body was categorized as follows: Too Deep (TD), Deep (DP), Correct Position (CP), Not Penetrate (NP) and Not Reach the target (NR). The tag was in the TD position when the tag was not visible and was completely embedded into the muscle of the fish. The tag was in the DP position when the tag was partially embedded into the muscle of the fish and the tag code was not visible. The tag was in the CP position when the anchor was completely embedded into the muscle of the fish and the tag code was entirely visible. The tag was considered NP as a result of unsuccessful anchoring on the tuna body. When the shaft did not reach the fish, it was categorized as NR.

A pairwise Fisher's exact test ($\alpha = 0.05$) was used to compare the penetration levels among shooting distances (1 m vs. 3 m, 1 m vs. 5 m, 3 m vs. 5 m), speargun length (85 cm vs. 97 cm, 97 cm vs. 110 cm, 85 cm vs. 110 cm), applicators (I vs. Y) and BFT size (S vs. G).

2.3. Length validation by laser measurements

The laser device used for the length estimation employs the same principle described in other studies (Deakos, 2010; Rohner et al., 2011; Rowe and Dawson, 2008). Those authors used two parallel lasers (horizontally mounted) at a known distance apart on a fixed camera-speargun base. In the present study, we used two green laser pointers for SCUBA diving (Apinex model BALP-LG05-B150, Montreal, Canada; waterproof up to 300 feet; wavelength 532 nm). The laser pointers were assembled using a Lexan™ holder with an inter-distance of 9 cm. The holder had calibration screws to adjust and maintain the laser beams at a constant inter-distance. To avoid a parallax error, the lasers' inter-distance was calibrated from the water projecting laser beams on a wall at 1, 3 and 5 m, respectively. The development of the laser device and camera mounting apparatus evolved through diverse stages to produce a robust, precise, accurate and fully adjustable setup.

Validation of length estimates obtained by the lasers was performed by comparing the real size of fish to the indirect size estimates. The experiment was conducted on a sample of three dead BFT of different sizes (fork length = 127, 150 and 233 cm). A set of video frames was collected, considering two explorative variables: (a) angle of laser beam (0°, i.e. perpendicular to fish body, 20° and 60°) and (b) distance from the specimen (1 m, 3 m or 5 m).

Three video frames for each size, angle and shooting distance were collected as replicates for the image analysis (Fig. 3). The fork length (FL) of each target fish was estimated using laser dots spotted on the tuna body (dot inter-distance = 9 cm) as reference scale. Frames were captured in full HD resolution (1080 pixels; 60 frame per second; GoPro Hero3 Black). Post processing of video frames was performed using Tpsdig2 (Rohlf, 2009).

The relative error of FL was calculated by subtracting the estimated length from the actual fish length. Negative values represented underestimates, and positive numbers represented overestimates. The coefficient of variation (CV) was calculated by dividing the standard deviation of the estimate by the mean value and was expressed as a percentage (Thresher and Gunn, 1986). CV is a useful measure of precision that is widely used in field research (Thresher and Gunn, 1986). The standard error (SE) of the measurements was also calculated.

2.4 . Tagging operation by traditional 'tonnara' traps

During the 2014 fishing season, a tagging campaign was planned based on the framework described above. Tagging operations were planned based on BFT remaining in the trap after the tuna quota was achieved by the fishery (165 metric tonnes for the Sardinian trap).

Tagging operations consisted of moving and separating the school of tunas from the *camera* to the *camera della morte*. This was achieved by a sequence of opening/closing of the doors/chambers operated by the fishing team on-board and the SCUBA divers. The net-floor 'corpus' was progressively raised to ~7 m from the sea surface, permitting the fish to swim freely and divers to operate in safe conditions. Tagging was carried out by two free divers using a pneumatic speargun with the equipment described above. To prevent possible post-release infection, each applicator was treated with a waterproof disinfectant spray. Tagging was recorded at all phases by the camera mounted on the speargun (Fig. 4). Length estimation was performed by image analysis, as described above.

In order to evaluate the effect of the tagger (the free diver responsible for tagging) on the Correct (C) or Wrong (W) deployment of the tag in the target area (Fig. 2), we analysed video recordings for each tagged BFT. The tag was considered to be in the C when it was inserted in the target area (Cort et al., 2010), whereas all of the other positions were considered Wrong. The effect of the tagger (A or B) on tag position (C or W) was evaluated by a χ^2 test ($\alpha = 0.05$) using the contingency tables for small numbers (Yates, 1934).

Fish mortality was also evaluated during tagging operations in the trap. It was evaluated by counting tuna dead over time (minutes) and categorizing them as follows: post-tagging mortality (Post), number of deaths caused by injuries from tag insertion; entanglement mortality (Ent), the number of fish entangled in the trap nets due to swimming exhaustion; and total mortality (Tot), the cumulative mortality of Post and Ent. Once the tagging activities were concluded, the entrapped fish were monitored for 2 h and then released.

3. Results

3.1. Penetration test by pneumatic spearguns

A total of 36 shots were performed for the explorative variables: shooting distance, speargun length, applicator and BFT size. The shooting distance level of 5 metres was not considered in the statistical analysis because for all shots, the tag did not reach the tuna (NR = 100%). Regardless of applicator type (I vs. Y) and speargun size (85, 97 and 110 cm), statistical analysis showed no significant differences ($P = 0.64$). Significant differences were recorded between shooting distances of 1 m and 3 m ($P = 0.0042$). Statistical differences were found between BFT size ($P = 0.0006$) when most of the shots were placed in CP for the small fish (Table 1).

3.2. Length validation by laser measurements

The image analysis always underestimated the actual fish length (Fig. 5). At 1 m distance, the mean error (± SE) was −30.8 ± 26.4 cm (CV = 149.8%), −49 ± 18.4 cm (CV = 65.7) and 73.7 ± 19.6 cm (CV = 46.4) at 0°, 20° and 60°, respectively. At 3 m distance, the mean error was −34.3 ± 23.2 cm (CV=118.3), −46.7 ± 16.0cm (CV=60.1) and −57.7 ± 15.4 cm (CV = 46.7) at 0°, 20° and 60°, respectively. At 5 m, the mean error was −39.3 ± 27.9 cm (CV = 124.5) when the lasers were perpendicular to the fish (0°), whereas the mean error was not estimated for 20° and 60° because the lasers were not visible at these offset angles.

3.3. Tagging activities

During the 2014 fishing season, a total of 163 BFT were entrapped in the *camera della morte* (the 'death chamber') and 63 (39% of the total fish) fish were tagged. The size distribution of the tagged fish is reported in Fig. 6. A total of 41 tags (65% of the total) were inserted in C (Table 2). A significant effect of diver skill was observed in the comparison of Wrong and Correct tag positions ($\chi^2 = 6.10$, df = 1; $P < 0.05$).

A total of four tagged BFT (3.1%) died during the tagging operation (Fig. 7). One tagged BFT died instantly from spinal cord injuries (Post = 1.6%), a symptom that could be directly attributed to the tagging process. At the end of tagging operations, four additional individuals without tags died from entanglement causes (Ent = 2.5%). The entanglement mortality rate (Ent) increased with tagging operational time starting from the fourth hour, with only one BFT dead until three fish were entrapped in the sixth hour (Fig. 7).

Among the tagged fish, only one was recaptured (BYP072413) in the Gulf of Lion after 431 d at liberty. The fish was 140 cm in length at the date of tagging and 201 cm at the date of recapture.

4. Discussion

Experience with conventional tagging conducted in the Sardinian trap during the 2013 fishing season (Addis et al., 2014) was the practical basis of the current trial. Our aim was to address the main limitations regarding the use of spearguns for tagging and length estimation. During the tagging activities conducted in 2013, we developed a framework to manage the trap gear for tagging and release purposes. The challenge consisted of adapting the processes and the trap equipment to entrap the tunas to be tagged in the *camera della morte* (death chamber) for convenient and stress-free tagging and release of the fish. Based on the expertise of the trap chief (*Rais*) and considering the technical features of the trap chambers, we excluded an *a priori* tagging operation in the 'Grande' and 'Bordonaro' chambers. Due to the large size and depth of these enclosures, tagging operations in the above chambers were unsuitable because BFT become too scattered and scared after the first shots and are thus difficult to approach. In order to simplify the tagging operations, the net floor (*corpus*) of the death chamber was raised to 5–7 meters to minimize the swimming volume and bring the fish close to the surface for tagging. Tagging in the death chamber ensured that the fish experienced minimal physiological stress, far less than they would have with typical on-board tagging.

4.1. Penetration test by pneumatic spearguns

The results of the penetration test showed that shooting distance and fish size were the main parameters affecting the correct insertion of the tag. The statistical analysis showed that at 1 m it was preferable to use a stopper immediately after the BFIM applicator to avoid deep penetration of the tags. On the other hand, between 1 and 3 m it was possible to shoot the tag without a stopper, which was confirmed by the taggers during the tagging operations. Considering the size of the BFT, spearguns with a length over of 1 m were needed for the correct insertion of the tag. With spearguns over 3 m, tag insertion was ineffective. The major disadvantage of underwater tagging by speargun is the risk of deficient insertion of the anchoring system, which shortens the tag retention time. Many teams prefer to tag the fish onboard: this ensures that the tag has the highest probability of long retention times (Abascal et al., 2016; Aranda et al., 2013; Block et al., 2005; Cort et al., 2010). The main reason is that it offers a more accurate way to put the tag in the appropriate spot, within the pterygiophores of the fish (Cort et al. 2010). However, Aranda et al. (2013) suggested that for electronic tag there were no difference between tagging animals on deck rather than in the water. The maximum and medium retention times achieved in this study were low (151 days and about 38 days, respectively) and do not give strong support to a general statement on tag retention times depending on the technique. Indeed, tag retention is particularly important for electronic tags due to their cost and the fact that a double anchorage is generally preferred and is impossible to achieve with a speargun. This is not as important matter for conventional tagging compared to e-tags as their cost is minimal but could be one of the explanations why only a little amount of tags has been recovered. It would be interesting to discard tag retention as an issue to compare the retention times achieved with conventional and electronic tags deployed underwater or on deck with an appropriate trial in the traps. This will give quantitative information on this issue and the fish does not need to be recaptured to know whether the tag stayed on the fish.

4.2. Length validation by laser measurements

The length validation was carried out using two-paired-laser photogrammetry with equipment mounted onto a single camera to project points of light onto the dead BFT, which involved taking measurements of body dimensions from photographs. The photogrammetry method is not new and has been used to measure morphometrics on large terrestrial and marine mammals (Barrickman et al., 2015), the dorsal fins of killer whale *Orcinus orca* (Durban and Parsons, 2006), bottlenose dolphin *Tursiops truncates* (Rowe and Dawson, 2008), small fish at close range (Mueller et al., 2006; Yoshihara, 1997) and the largest ocean fish (Deakos, 2010; Heppell et al., 2012; Rohner et al., 2011). The main advantage of the technique is that it is relatively simple and compact and can be implemented by a single photographer or operator. In contrast, the estimates of fish length were limited due to high error rates and originated from the variable distance between the fish and the reference scale included in the scene (Trobbiani and Venerus, 2015). The machine learning approach along with static and mobile devices have been developed for more accurate and precise estimates of fish with mean relative errors <1% (Harvey et al., 2002, 2001; Harvey and Shortis, 1995; Karakulak et al., 2015). However, the reduction of measurement errors comes with increased equipment costs, as it requires two cameras with housings and specialized stereo-photo software (Bouguet, 2008; Deguara et al., 2014).

In the present study, length validation was carried out with the aim of finding the relative error and applying a correction factor to the estimates of fish tagged. The results showed that the length estimation of BFT size was more accurate when the lasers were exactly perpendicular to the animal, and that this method always underestimates BFT size. Although the laser beams were maintained in a perpendicular direction and projected onto the target, a relative error of about −30 cm was detected for all distances and sizes of fish considered. This error measurement was probably due to the image distortion caused by light refraction in the camera housing and the wide angle of the camera lens (Deakos, 2010; Swaminathan and Nayar, 1999). Another possible cause of error is non-parallel alignment of the lasers, but that was not the case in this study, because the laser device had calibration screws to adjust and maintain the laser beams at a constant inter-distance. Moreover, the calibration was carried out before the length validation test and the subsequent tagging activities. The observed increasing error, varying the beam angles, was probably caused by parallax error during the tagging activities, which has been detected as a problematic source of error with paired laser photogrammetry. This occurs when laser projections are not perpendicular to the surface of the target to be measured (Durban and Parsons, 2006). In our study, this type of error could exceed 60 cm of error in estimation at a shooting angle of 60°. However, this high angle was not common during the tagging activities, and the video recordings of BFT at other times allowed us to choose the best frames for image analysis.

4.3. 2014 Tagging activities and recapture

During the 2014 tagging activities in the Sardinian trap, a total of 63 fish were tagged by a crew composed of two free diver taggers and two on-board assistants. The full operations lasted 3.5 h. The numbers of fish tagged per day was comparable to the number of fish tagged in the Western Atlantic, where BFT schools are abundant (Block, 1998). Analysis of the position of the tag showed that most of the fish (65%) were correctly tagged near the second dorsal fin, with significant statistical differences between the two taggers. These differences were caused both by the different levels of expertise of the taggers and the high mobility of the subjects, which was the main source of error. Several shots did not reach the fish, and schools of large numbers of fishes can create confusion in choosing targets for the tagger.

Regarding mortality, only one fish died directly as consequence of tagging injuries; it was the first tagged fish of the day and its death was caused by a lethal shot. The entangling mortality occurred after 2 h of tagging activities. At this time, the fish became stressed and changed their behaviour, becoming more scattered and increasing the number of entangling events. After the tagging operations, the fish were left to calm down for 2 h and then released. Tagging directly underwater could avoid or reduce fish stress as opposed to capturing and tagging on board, which has been found to cause some degree of stress and metabolic disruption (Hoyle et al., 2015; Skomal and Chase, 2002).

Only one fish (BYP072413) was recaptured in the Gulf of Lion, after 431 d at liberty. The size of the fish estimated by photogrammetry was 140 cm, whereas the FL at the date of recapture was 201 cm. The increase in size perfectly matched the age growth curve for the species (Cort et al., 2014). Tags returned from commercial or recreational fisheries in conjunction with tag-recovery and capture-recapture models are the basis for determining many life history parameters (Rooker et al., 2007). Overall recapture rate, pooled across programs and years, rarely exceeds 10% (Rooker et al., 2007). Most of the tagging programs in the Mediterranean Sea, including our tagging activity from traps, were carried out before the spawning season. These programs were very interesting as it will allow to cover the spawning period and identify the spawning areas for the species. However, such period is also just before the purse seine fishing season (end of May, end of June), during which a very large proportion of the total allowable catch is caught (Di Natale et al., 2018). This probably increases drastically the probability of recapture after a short amount of time or after several months, if the fish were kept in cages (the harvesting season starts generally in October). This could be a second explanation why only a little amount of tags has been recovered. In this case, the traps give the opportunity to explore the possibility to tag the fish later by keeping the fish for some time in the trap and released them after the spawning season in order to be caught the next year.

5. Conclusions

In conclusion, underwater tagging of BFT using the traditional trap had some advantages and disadvantages. The trap represents an optimal system for tagging large numbers of BFT with conventional tags in confined waters and could be also useful for implanting electronic tags (Addis et al., 2016b), temperature loggers (Addis et al., 2013b) and direct visual estimation of abundances (Addis et al., 2013c). The proposed method could be beneficial when the goal is to release the fish in healthy or stress-free conditions. It allowed us to determine the fraction of tagged fish that survive after the initial stress of capture, handling, tagging and release by keeping the fish confined for several hours in the death chambers. Tagging in confined water is extremely useful for the observation of fish health, and in the case of electronic tagging, allowed the recovery of the devices (extremely expensive) when a fish died, or a quick pop-up occurred. Tagging fish underwater requires low turbidity (better clear waters), and the success of the tagging can be affected by the expertise of the tagger and the high mobility of BFT. Length estimation by laser pointers (accuracy) is the main issue with the method and could be avoided when a study is focused on fish size or growth. Indeed, according to Cort's growth curve for Bluefin Tuna (Cort et al., 2014), an error of 30 cm would correspond to a year-class difference, which would make the use of the data difficult for a growth analysis although it is possible to estimate the error and to apply a correction factor to the estimated size.

References

Abascal, F.J., Medina, A., De La Serna, J.M., Godoy, D., Aranda, G., 2016. Tracking bluefin tuna reproductive migration into the Mediterranean Sea with electronic pop-up satellite archival tags using two tagging procedures. Fish. Oceanogr. 25, 54–66. https://doi.org/10.1111/fog.12134

Addis, P., Corrias, S., Garau, C., Secci, M., 2013a. Physiologic responses to stress and changes in Atlantic bluefin tuna (*T. thynnus*) meat color during trap fisheries capture and processing in sardinia (W. Mediterranean). J. Aquat. Food Prod. Technol. 22, 298–309. https://doi.org/10.1080/10498850.2011.647596

Addis, P., Secci, M., Biancacci, C., Loddo, D., Cuccu, D., Palmas, F., Sabatini, A., 2016a. Reproductive status of Atlantic bluefin tuna, *Thunnus thynnus,* during migration off the coast of Sardinia (western Mediterranean). Fish. Res. 181. https://doi.org/10.1016/j.fishres.2016.04.009

Addis, P., Secci, M., Cau, A., 2013b. The effect of mistral (a strong NW wind) episodes on the occurrence and abundance of Atlantic bluefin tuna (*Thunnus thynnus*) in the trap fishery of sardinia (W mediterranean). Sci. Mar. 77. https://doi.org/10.3989/scimar.03830.26B

Addis, P., Secci, M., Locci, I., Cau, A., Sabatini, A., 2012. Analysis of Atlantic bluefin tuna catches from the last Tonnara in the Mediterranean Sea: 1993-2010. Fish. Res. 127–128. https://doi.org/10.1016/j.fishres.2012.05.010

Addis, P., Secci, M., Sabatini, A., Palmas, F., 2016b. Electronic tagging of Bluefin tuna in the trap fishery of Sardinia (W-Mediterranean). ICCAT Collect. Vol. Sci. Pap. 72, 1835–1841.

Addis, P., Secci, M., Sabatini, A., Palmas, F., Culurgioni, J., 2014. Conventional Tagging of Bluefin Tunas in the Trap Fishery of Sardinia (W-Mediterranean): a Critical Review. Collect. Vol. Sci. Pap. - ICCAT 70, 585–591.

Aranda, G., Abascal, F.J., Varela, J.L., Medina, A., 2013. Spawning behaviour and post-spawning migration patterns of Atlantic Bluefin Tuna (*Thunnus thynnus*) ascertained from satellite archival tags. PLoS One 8, 1–14. https://doi.org/10.1371/journal.pone.0076445

Barrickman, N.L., Schreier, A.L., Glander, K.E., 2015. Testing parallel laser image scaling for remotely measuring body dimensions on mantled howling monkeys (*Alouatta palliata*). Am. J. Primatol. 77, 823–832. https://doi.org/10.1002/ajp.22416

Block, B.A., 1998. Archival tagging of Atlantic bluefin tuna (*Thunnus thynnus*). Mar. Technol. Soc. J. 32, 37–46.

Block, B.A., Dewar, H., Blackwell, S.B., Williams, T.D., Prince, E.D., Farwell, C.J., Boustany, A., Teo, S.L.H., Steitz, A., Walli, A., Fudge, D., 2001. Migratory Movements, depth preferences, and thermal biology of Atlantic Bluefin Tuna. Science (80-.). 293, 1310–1314.

https://doi.org/10.1126/science.1061197

Block, B.A., Dewar, H., Farwell, C., Prince, E.D., 1998. A new satellite technology for tracking the movements of Atlantic bluefin tuna. Proc. Natl. Acad. Sci. U. S. A. 95, 9384–9389. https://doi.org/10.1073/pnas.95.16.9384

Block, B.A., Teo, S.L.H., Walli, A., Boustany, A., Stokesbury, M.J.W., Farwell, C.J., Weng, K.C., Dewar, H., Williams, T.D., 2005. Electronic tagging and population structure of Atlantic bluefin tuna. Nature 434, 1121–1127. https://doi.org/10.1029/2002PA000862

Bouguet, 2008. Camera calibration for Matlab.

Boustany, A.M., Reeb, C.A., Block, B.A., 2008. Mitochondrial DNA and electronic tracking reveal population structure of Atlantic bluefin tuna (*Thunnus thynnus*). Mar. Biol. 156, 13–24. https://doi.org/10.1007/s00227-008-1058-0

Brill, R., Lutcavage, M., Metzger, G., Bushnell, P., Arendt, M., Lucy, J., Watson, C., Foley, D., 2002. Horizontal and vertical movements of juvenile bluefin tuna (*Thunnus thynnus*), in relation to oceanographic conditions of the western North Atlantic, determined with ultrasonic telemetry. Fish. Bull. 100, 155–167.

Cermeño, P., Quílez-Badia, G., Ospina-Alvarez, A., Sainz-Trápaga, S., Boustany, A.M., Seitz, A.C., Tudela, S., Block, B.A., 2015. Electronic tagging of Atlantic bluefin tuna (*Thunnus thynnus*, L.) reveals habitat use and behaviors in the Mediterranean Sea. PLoS One 10, 2–34. https://doi.org/10.1371/journal.pone.0116638

Cort, J.L., 1990. Biologia y pesca del Atun rojo, *Thunnus Thynnus* (L.), del Mar Cantabrico, Numero 4. ed. Publicaciones Especiales Instituto Español de Oceanografia, Madrid.

Cort, J.L., Abascal, F.J., Belda, E., Bello, G., Deflorio, M., De La Serna, J.M., Estruch, V.D., Godoy, D., Velasco, M., 2010. Tagging manual fo the Atlantic-wide research programme for bluefin tuna (GBYP). The International commission for the Conservation of Atlantic Tunas (ICCAT), Madrid.

Cort, J.L., Arregui, I., Estruch, V.D., Deguara, S., 2014. Validation of the growth equation applicable to the Eastern Atlantic Bluefin Tuna, *Thunnus thynnus* (L.), using Lmax, tag-recapture, and first dorsal spine analysis. Rev. Fish. Sci. Aquac. 22, 239–255. https://doi.org/10.1080/23308249.2014.931173

Davenport, J., Baras, E., Fabi, G., Jonsson, G., 2002. Fish welfare and health in relation to tagging, in: Thorsteinsson, V. (Ed.), Tagging Methods for Stock Assessment and Research in Fisheries, Report of Concerted Action FAIR CT.96.1394 (CATAG). Marine Research Institute Technical Report 79. Reykjavik, p. 179. https://doi.org/PDF 15 & 132

De Metrio, G., Arnold, G.P., Block, B. a, Deflorio, M., Cataldo, M., Megalofonou, P., Beemer, S., Farwell, C., Seitz, a, 2002. Behaviour of post-spawning Atlantic bluefin tuna tagged with pop-up satellite tags in the Mediterranean and eastern Atlantic. Collect. Vol. Sci. Pap. ICCAT 54, 415–424.

Deakos, M.H., 2010. Paired-laser photogrammetry as a simple and accurate system for measuring the body size of free-ranging manta rays *Manta alfredi*. Aquat. Biol. 10, 1–10. https://doi.org/10.3354/ab00258

Deguara, S., Caruana, S., Gatt, M., 2014. Towards developing a procedure for the accurate and precise measurement of fork length of Atlantic bluefin tuna (*Thunnus thynnus* l.) using stereocamera technology. ICCAT Collect. Vol. Sci. Pap. 70, 592–605.

Di Natale, A., Tensek, S., Pagà Garcìa, A., 2018. ICCAT Atlantic-wide Research Programme for Bluefin Tuna (GBYP) activity report for 2013 (extension of Phase 3 and first part of Phase 4). ICCAT Collect. Vol. Sci. Pap. 74, 3100–3171.

Durban, J.W., Parsons, K.M., 2006. Laser-metrics of free-ranging killer whales. Mar. Mammal Sci. 22, 735–743. https://doi.org/10.1111/j.1748-7692.2006.00068.x

FIPSAS, 2019. BIG GAME FISHING [WWW Document]. URL http://www.fipsas.it/attivita-agonistiche/pesca-di-superficie/discipline-pesca-di-superficie/big-game/gare-big-game (accessed 5.22.19).

Fromentin, J., Lopuszanski, D., 2014. Migration, residency, and homing of bluefin tuna in the western Mediterranean Sea. ICES J. Mar. Sci. 71, 510–518. https://doi.org/10.1093/icesjms/fss041

Galuardi, B., Lutcavage, M., 2012. Dispersal routes and habitat utilization of juvenile atlantic bluefin tuna, *Thunnus thynnus*, tracked with mini PSAT and archival tags. PLoS One 7, e37829. https://doi.org/10.1371/journal.pone.0037829

Harvey, E., Shortis, M., 1995. A system for stereo-video measurement of sub-tidal organisms. Mar. Technol. Soc. J. 29, 10–22. https://doi.org/10.1007/s00227-010-1404-x

Harvey, E., Shortis, M., Stadler, M., Cappo, M., 2002. A comparison of the accuracy and precision of measurements from single and stereo-video systems. Mar. Technol. Soc. J. 36, 38–49. https://doi.org/10.4031/002533202787914106

Harvey, E.S., Fletcher, D., Shortis, M.R., 2001. A comparison of the precision and accuracy of estimates of reef-fish lengths made by divers and a stereo-video system. Fish. Bull. 99, 63–71.

Heppell, S.A., Semmens, B.X., Archer, S.K., Pattengill-Semmens, C. V., Bush, P.G., McCoy, C.M., Heppell, S.S., Johnson, B.C., 2012. Documenting recovery of a spawning aggregation through size frequency analysis from underwater laser calipers measurements. Biol. Conserv. 155, 119–127. https://doi.org/10.1016/j.biocon.2012.06.002

Hoyle, S.D., Leroy, B.M., Nicol, S.J., Hampton, W.J., 2015. Covariates of release mortality and tag loss in large-scale tuna tagging experiments. Fish. Res. 163, 106–118. https://doi.org/10.1016/j.fishres.2014.02.023

ICCAT, 2013. Report of the 2013 bluefin meeting on biological parameters review. Tenerife, Spain - May 7 to 13, 2013.

ICCAT, 2012. ICCAT-GBYP Symposium on trap fisheries for bluefin tuna, in: GBYP Symposium on BFT Trap Fisheries. ICCAT, Tangiers, Morocco – May 23 to 25, 2011, pp. 1–13.

Karakulak, S., Yildiz, T., Mariani, A., Valastro, M., Dell'Aquila, M., 2015. Electronic tagging of adult bluefin tunas by purse-seiners in the Eastern Mediterranean.

Kitagawa, T., Boustany, A.M., Farwell, C.J., Williams, T.D., Castleton, M.R., Block, B.A., 2007. Horizontal and vertical movements of juvenile bluefin tuna (*Thunnus orientalis*) in relation to seasons and oceanographic conditions in the eastern Pacific Ocean. Fish. Oceanogr. 16, 409–421. https://doi.org/10.1111/j.1365-2419.2007.00441.x

Lawson, G.L., Castleton, M.R., Block, B.A., 2010. Movements and diving behavior of Atlantic bluefin tuna *Thunnus thynnus* in relation to water column structure in the northwestern Atlantic. Mar. Ecol. Prog. Ser. 400, 245–265. https://doi.org/10.3354/meps08394

Magnuson, J.J., Block, B.A., Deriso, B., Gold, J.R., Grant, W.S., Quinn, T.J., Saila, S.B., Shapiro, L., Stevens, E.D., 1994. An assessment of Atlantic bluefin tuna. National Academy Press, Washington D.C.

Mariani, A., Dell'Aquila, M., Scardi, M., Valastro, M., 2016. Electronic tagging of adult bluefin tunas (*Thunnus thynnus*) in the Eastern Mediterranean and Sardinian Sea; improving the precision of tuna size estimates. Collect. Vol. Sci. Pap. - ICCAT 72, 1808–1814.

Mueller, R., Brown, R., Hop, H., Moulton, L., 2006. Video and acoustic camera techniques for studying fish under ice: a review and comparison. Rev Fish Biol Fish 16:213–226. Rev. Fish Biol. Fish. 16, 213–226.

Rohlf, F.J., 2009. TpsDig Version 2.14.

Rohner, C.A., Richardson, A.J., Marshall, A.D., Weeks, S.J., Pierce, S.J., 2011. How large is the world's largest fish? Measuring whale sharks *Rhincodon typus* with laser photogrammetry. J. Fish Biol. 78, 378–385. https://doi.org/10.1111/j.1095-8649.2010.02861.x

Rooker, J.R., Alvarado Bremer, J.R., Block, B.A., Dewar, H., De Metrio, G., Corriero, A., Kraus, R.T., Prince, E.D., Rod, E., In, I.-M., Secor, D.H., 2007. Life history and stock structure of Atlantic Bluefin Tuna (*Thunnus thynnus*), Reviews in Fisheries Science. https://doi.org/10.1080/10641260701484135

Rouyer, T., Bonhommeau, S., Giordano, N., Giordano, F., Ellul, S., Ellul, G., Deguara, S., Wendling, B., Bernard, S., Kerzerho, V., 2020. Tagging Atlantic bluefin tuna from a Mediterranean spawning ground using a purse seiner. Fish. Res. 226, 105522.

Rowe, E.L., Dawson, S.M., 2008. Laser photogrammetry to determine dorsal fin size in a population of bottlenose dolphins from Doubtful Sound, New Zealand. Aust. J. Zool. 25, 19–34.

Sibert, J.R., Lutcavage, M.E., Nielsen, A., Brill, R.W., Wilson, S.G., 2006. Interannual variation in large-scale movement of Atlantic bluefin tuna (*Thunnus thynnus*) determined from pop-up satellite archival tags. Can. J. Fish. Aquat. Sci. 63, 2154–2166. https://doi.org/10.1139/f06-114

Skomal, G.B., Chase, B.C., 2002. The physiological effects of angling on post-release survivorship in tunas, sharks, and marlin. Am. Fish. Soc. Symp. 30, 135–138.

Stokesbury, M.J., Teo, S.L., Seitz, A., O'Dor, R.K., Block, B. a, 2004. Movement of Atlantic bluefin tuna (*Thunnus thynnus*) as determined by satellite tagging experiments initiated off New England. Can. J. Fish. Aquat. Sci. 61, 1976–1987. https://doi.org/10.1139/f04-130

Stokesbury, M.J.W., Cosgrove, R., Boustany, A., Browne, D., Teo, S.L.H., O'Dor, R.K., Block, B.A., 2007. Results of satellite tagging of Atlantic bluefin tuna, *Thunnus thynnus*, off the coast of Ireland. Hydrobiologia 582, 91–97. https://doi.org/10.1007/s10750-006-0552-y

Stokesbury, M.J.W., Neilson, J.D., Susko, E., Cooke, S.J., 2011. Estimating mortality of Atlantic bluefin tuna (*Thunnus thynnus*) in an experimental recreational catch-and-release fishery. Biol. Conserv. 144, 2684–2691. https://doi.org/10.1016/j.biocon.2011.07.029

Swaminathan, R., Nayar, S., 1999. Polycameras: camera clusters for wide angle imaging (No. CUCS-013-99). New York.

Teo, S.L.H., Boustany, A., Dewar, H., Stokesbury, M.J.W., Weng, K.C., Beemer, S., Seitz, A.C., Farwell, C.J., Prince, E.D., Block, B.A., 2007a. Annual migrations, diving behavior, and thermal biology of Atlantic bluefin tuna, *Thunnus thynnus*, on their Gulf of Mexico breeding grounds. Mar. Biol. 151, 1–18. https://doi.org/10.1007/s00227-006-0447-5

Teo, S.L.H., Boustany, A.M., Block, B.A., 2007b. Oceanographic preferences of Atlantic bluefin tuna, *Thunnus thynnus*, on their Gulf of Mexico breeding grounds. Mar. Biol. 152, 1105–1119. https://doi.org/10.1007/s00227-007-0758-1

Thresher, R.E., Gunn, J.S., 1986. Comparative analysis of visual census techniques for highly mobile, reef associated piscivores (Carangidae). Environ. Biol. Fishes 17, 93–116.

Tičina, V., Grubišić, L., Katavić, I., 2004. Sampling and tagging of live bluefin tuna in growth-out floating cages. Aquac. Res. 35, 307–310. https://doi.org/10.1111/j.1365-2109.2004.01011.x

Tičina, V., Katavić, I., Grubišić, L., 2007. Growth indices of small northern bluefin tuna (*Thunnus thynnus*, L.) in growth-out rearing cages. Aquaculture 269, 538–543. https://doi.org/10.1016/j.aquaculture.2007.05.029

Tičina, V., Katavic, I., Jeftimijades, I., Franicevic, V., 2003. Tagging of small Bluefin tuna in the

growth-out floating cage - report of the research activities on tuna farming in the Adriatic sea during 2002. Collect. Vol. Sci. Pap. ICCAT 55, 1278–1281.
Trobbiani, G.A., Venerus, L.A., 2015. A novel method to obtain accurate length estimates of carnivorous reef fishes from a single video camera. Neotrop. Ichthyol. 13, 93–102. https://doi.org/10.1590/1982-0224-20140101
Walli, A., Teo, S.L.H., Boustany, A., Farwell, C.J., Williams, T., Dewar, H., Prince, E., Block, B.A., 2009. Seasonal movements, aggregations and diving behavior of Atlantic bluefin tuna (*Thunnus thynnus*) revealed with archival tags. PLoS One 4. https://doi.org/10.1371/journal.pone.0006151
Yamashita, H., Miyabe, N., 2001. Report of bluefin tuna archival tagging conducted by Japan in 1999 in the Adriatic Sea. Collect. Vol. Sci. Pap. ICCAT 52, 809–823.
Yates, F., 1934. Contingency Tables Involving Small Numbers and the $\chi 2$ Test. Suppl. to J. R. Stat. Soc. 1, 217–235.
Yoshihara, K., 1997. A fish body length measuring method using an underwater video camera in combination with laser discharge equipment. Fish. Sci. 63, 676–680.

List of tables

Table 1

Ballistic tests with three different size of speargun (85, 97, 110), two applicator (I, Y), two size of BFT (Small, Giant) and three shooting distances (1, 3, 5 m). TD = too deep; DP = deep; CP = correct position; NP = not penetrate; NR = not reach (arrive). In bracket: shooting number.

Distance		1 m			3 m			5 m		
Spear gun size		85	97	110	85	97	110	85	97	110
BFT size	Applicator Type									
S	I	TD (n=3)	TD (n=3)	TD (n=3)	**CP (n=3)**	**CP (n=3)**	**CP (n=3)**	NR (n=3)	NR (n=3)	NR (n=3)
G	I	DP (n=3)	DP (n=3)	DP (n=3)	NP (n=3)	**CP (n=1)** NP (n=2)	**CP (n=3)**	NR (n=3)	NR (n=3)	NR (n=3)
S	Y	**CP (n=3)**	**CP (n=3)**	**CP (n=3)**	**CP (n=1)** NP (n=2)	**CP (n=3)**	**CP (n=3)**	NR (n=3)	NR (n=3)	NR (n=3)
G	Y	**CP (n=3)**	**CP (n=3)**	**CP (n=3)**	NP (n=3)	NP (n=3)	**CP (n=1)** NP (n=2)	NR (n=3)	NR (n=3)	NR (n=3)

Table 2

Results of the trial testing the effect of two divers (A, B) on the position of the tag (Correct, Wrong).

Diver	Wrong	Correct	Total
A	16	15	31
B	6	26	32
TOTAL	22	41	63

Figure Captions

Fig. 1. The trap array in Sardinia (Cort, permission) consists of nylon nets arranged in a tail and five chambers (from east to west): the “Grande” (120 m x 45 m), the “Bordonaro” (50 m x 45 m), the “Bastardo” (45 m x 40 m), the “Camera di ponente” (45 m x 40 m) and the “Camera della morte” (the “death chamber”) (45 m x 30 m). Only the death chamber has a vertical moving net ‘floor’ (corpus) used to pull up bluefin tuna during the “mattanza”. Once entrapped in the first chamber (the “Grande), tunas swim naturally from east to west chambers crossing the doors (a system of vertical nets with a large mesh size). Bluefin tuna unlikely swim in the reverse path, therefore specimens tend to concentrate into western chambers.

Fig. 2. Target area for the conventional tagging of BFT (Cort et al., 2010) and projections of the fixed-distance laser dots.

Fig. 3. Setup of the experimental design for length validation using laser measurements. First row: BFT of three different size. Second row: angle of laser beam. Third row: distance (m) from the target. Fourth: replicates of video frames collected for each angle and distance.

Fig. 4. The tagging phases followed during the 2014 activities: 1) start the video recording; 2) record the number of the tag; 3) Point the fish with the laser 4) tag the fish; 5) ascertain the correct insertion of the tag in the fish, which is the dorsal musculature at the base of the second dorsal fin, and the health of the fish; 6) Release of the fishes.

Fig. 5. The effect of increasing angle of shooting on the accuracy of laser point device in length estimation (Mean error ± SE and coefficient of variation).

Fig. 6. Bar plot reporting fish tagged for small, medium and giant sizes in the traditional trap of Sardinia in 2014.

Fig. 7. Cumulative number of BFT tagged, cumulative post tagging mortality and cumulative mortality by entanglement during the tagging-time operation in 2014.

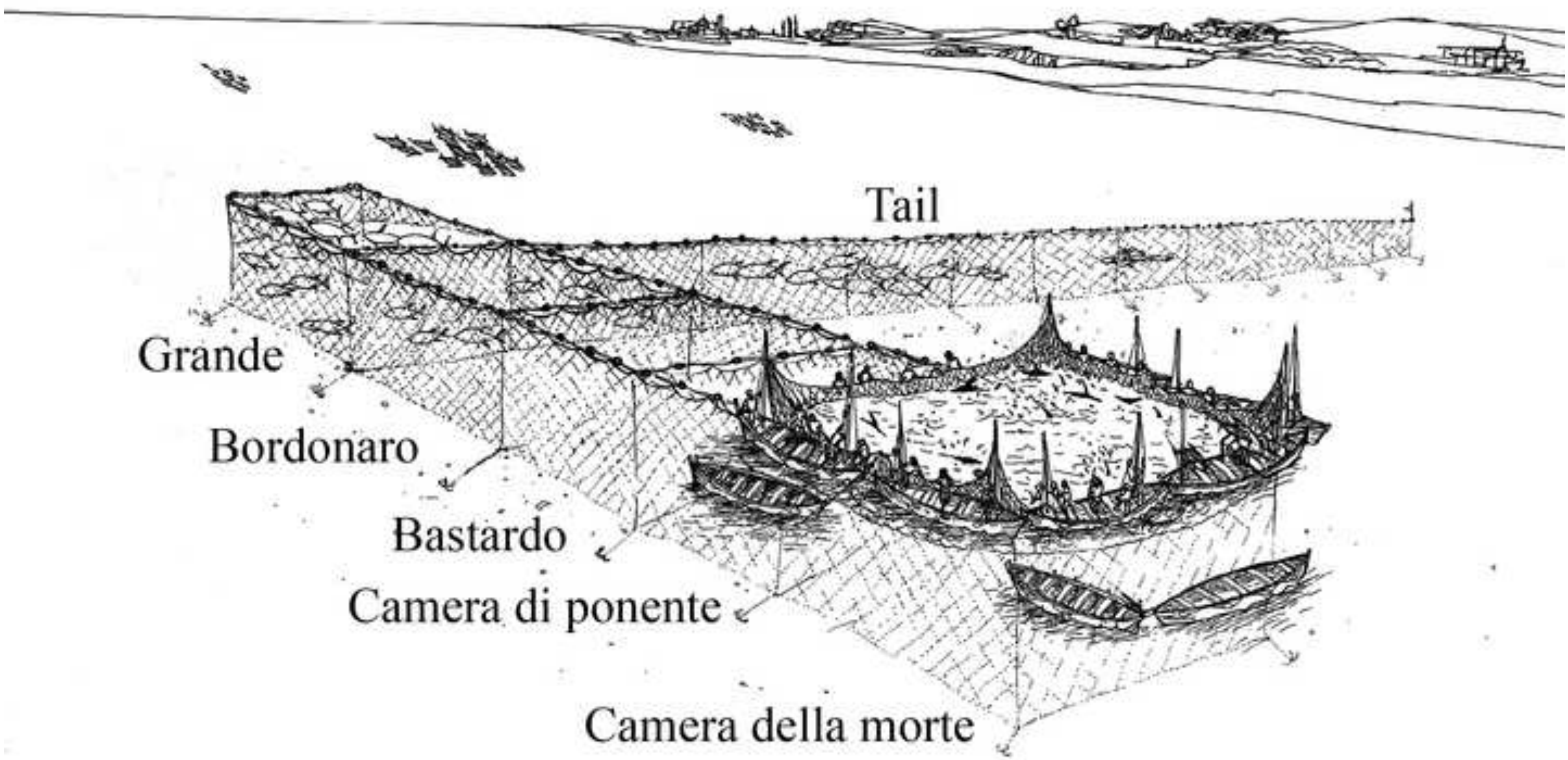

Tail
Grande
Bordonaro
Bastardo
Camera di ponente
Camera della morte

Figure 2

Click here to access/download;Figure;Figure 2.tif

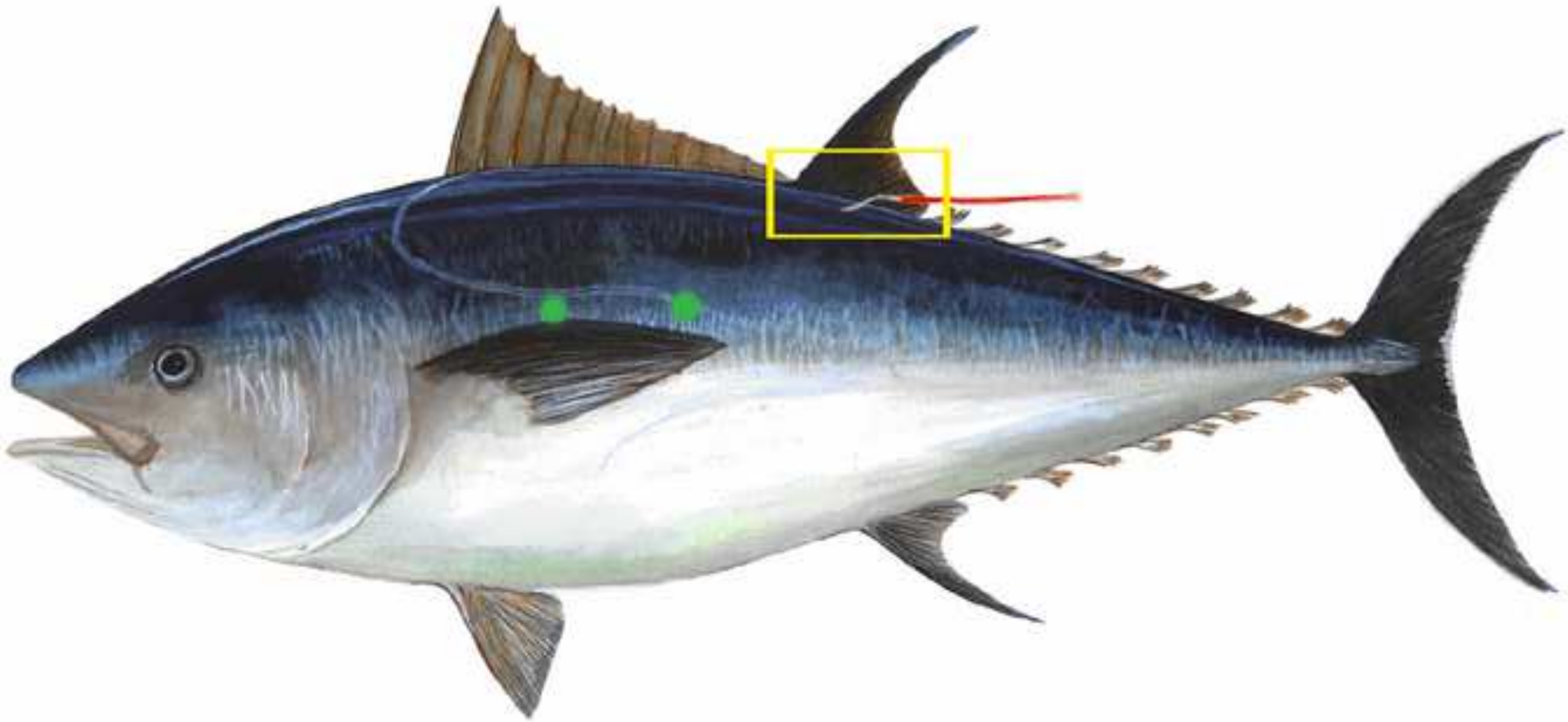


Figure 3

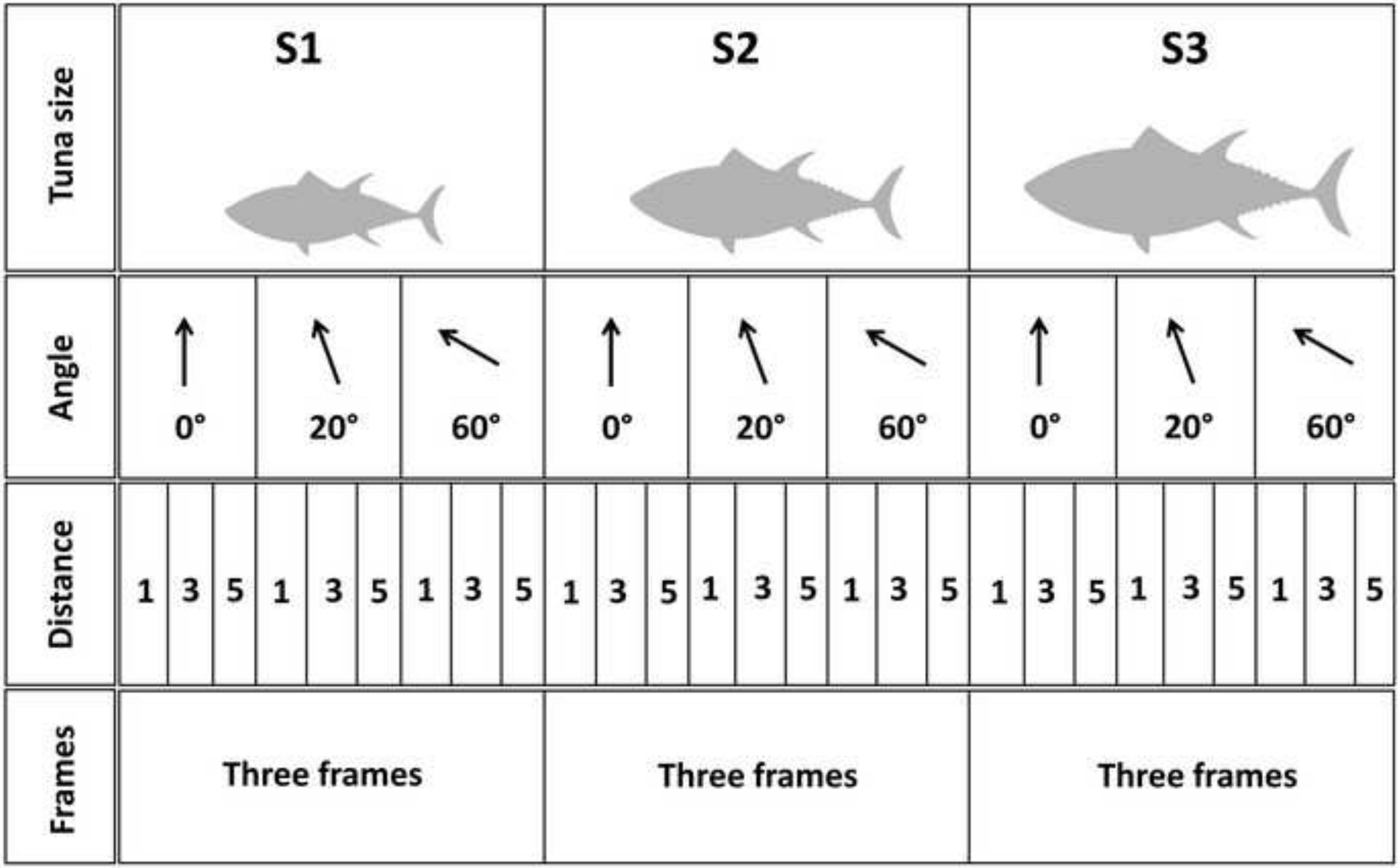

Tuna size
S1
S2
S3
Angle
0°
20°
60°
0°
20°
60°
0°
20°
60°
Distance
1 3 5 1 3 5 1 3 5 1 3 5 1 3 5 1 3 5 1 3 5 1 3 5 1 3 5
Frames
Three frames
Three frames
Three frames

Figure 4

Figure 5

Click here to access/download;Figure;Figure 5.tif

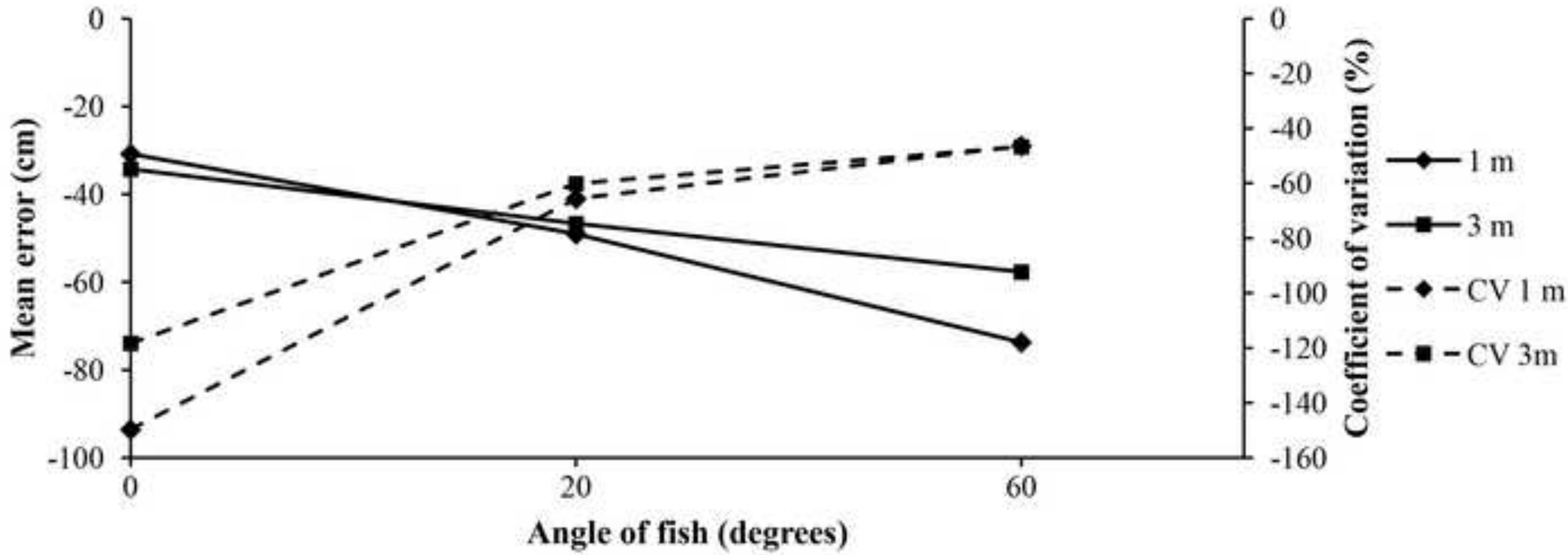
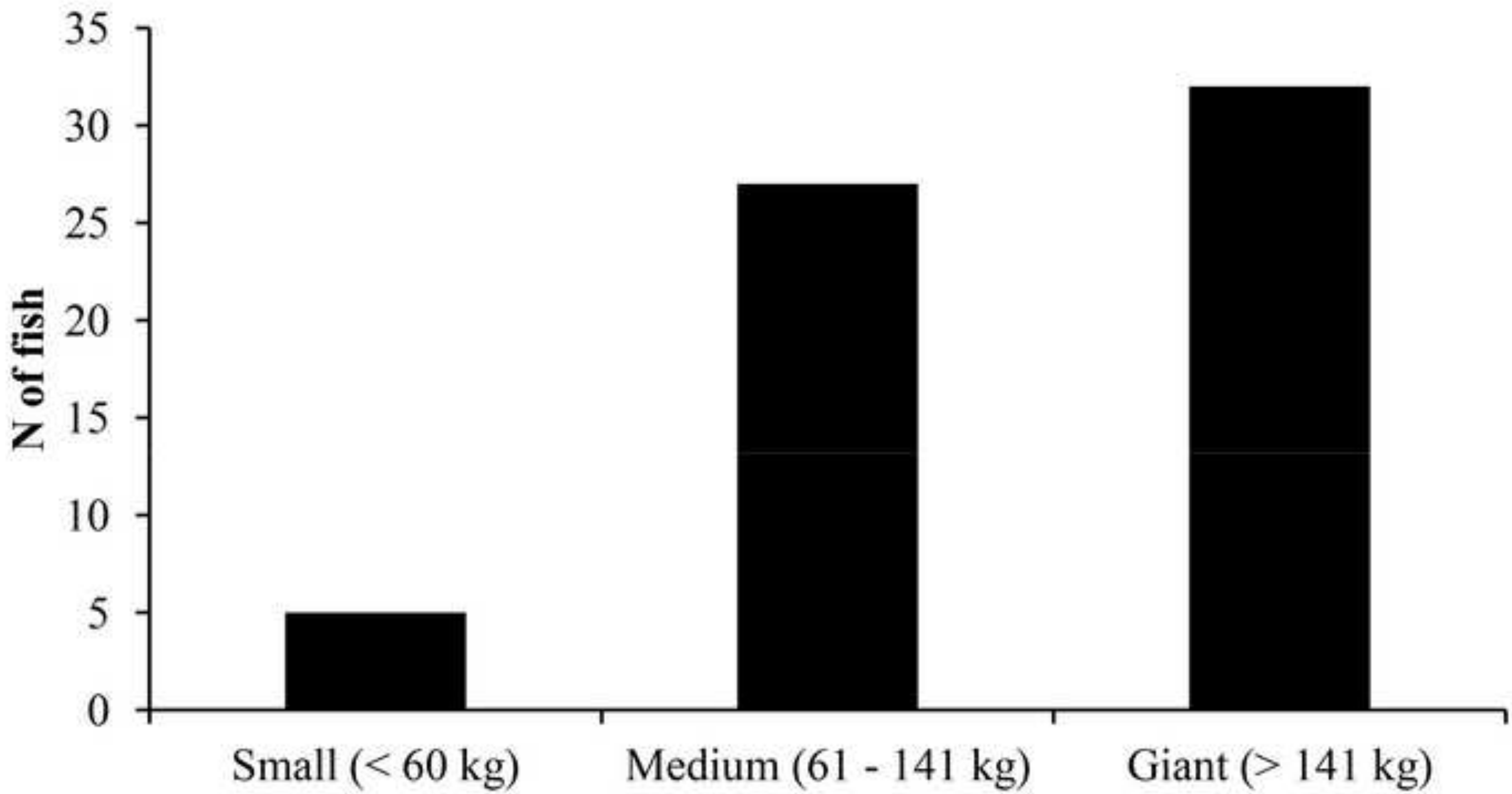
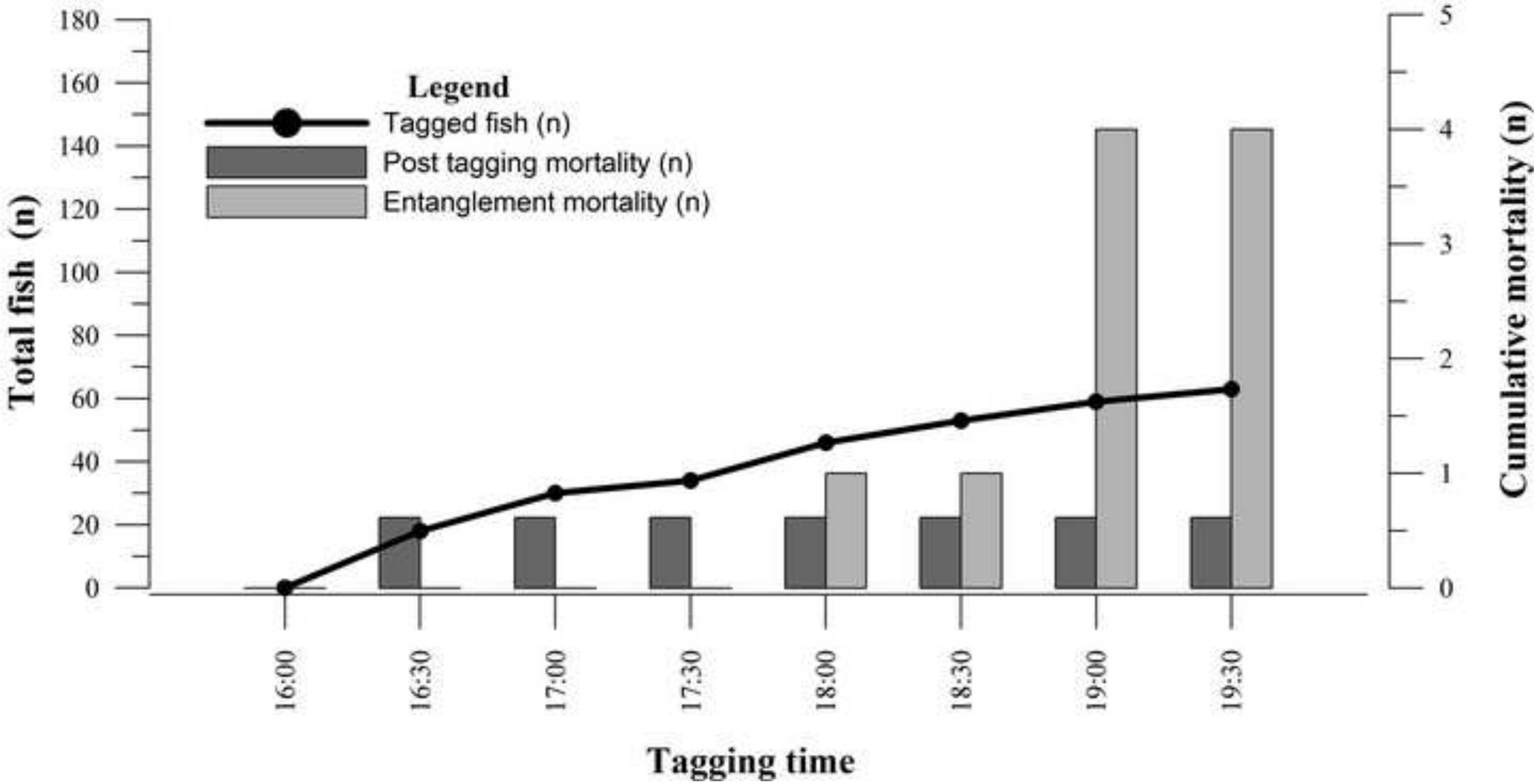


Figure 6



N of fish
35
30
25
20
15
10
5
0
Small (< 60 kg)
Medium (61 - 141 kg)
Giant (> 141 kg)

Figure 7


Legend
Tagged fish (n)
Post tagging mortality (n)
Entanglement mortality (n)
Total fish (n)
Cumulative mortality (n)
Tagging time
0
20
40
60
80
100
120
140
160
180
0
1
2
3
4
5
16:00
16:30
17:00
17:30
18:00
18:30
19:00
19:30