OCEANS 2021: San Diego – Porto, 2021, Pages 1-10
Electronic ISBN:978-0-692-93559-0, SSN: 0197-7385
September 2021,
https://doi.org/10.23919/OCEANS44145.2021.9706039
https://archimer.ifremer.fr/doc/00759/87111/

An innovative sampling protocol for fish species identification methods in shallow waters: towed diver, towed video and stereoscopic camera system

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Abstract :

The European Marine Strategy Framework Directive (MSFD) requires the achievement of the good ecological state of all the component of the marine environment, including fish in coastal waters. It required surveying the coastal fish and cephalopods. The ACaPELA (ACoustic PELAgic) project aims to describe pelagic fish populations in shallow waters using active acoustic. One of the main issue of acoustic programs is to identify species associated with acoustic detection remains difficult, particularly in shallow waters with high species diversity. Innovative procedures for the specific allocation of echo trace are needed and tested in this study: one method based on "free divers" consist in divers searching for schools or aggregations and another based on "towed diver". Video was also deployed to create a ground truth for both methods. In addition, we used a stereoscopic video system that allows us to assess size and abundance measurements and compare them with the divers' estimations. The towed diving method shows an advantage in the implementation, the amount of acoustics ground truth acquired. The use of stereoscopic video shows that it can be used to overcome the diver and carry out precise measurements of individuals, but its use in a monitoring program should be based on automated video processing tools in order to limit processing time. However, with the today increasing advances in imaging analysis, our results suggest that autonomous system like a towed and remotely controlled submarine glider could be operational in the very near future.

Keywords : underwater video, stereoscopic video system, pelagic fish, Fisheries acoustics, MFSD, France

Introduction

Fisheries acoustics is the most efficient tool to describe pelagic fish populations at all scales (Benoit-Bird and Lawson, 2016). Nevertheless, species identification procedure associated to acoustic detection remains challenging (Horne, 2000). Many diving methods and underwater videos are used for the study of the marine environment (Mallet and Pelletier, 2014). Furthermore, the European Marine Strategy Framework Directive (MSFD) should cover the shallow part of the coast, seldom assessed and with high fish density (Brehmer et al., 2006). The objective of this paper is to compare ground truth construction methods for acoustic detection. In this way, we developed new fish species identification procedure for fisheries acoustics monitoring method. We took advantage of recent works underlining the limitation of visual observation and considering (i) scuba divers fish size estimation of pelagic fish are not calibrated, and that (ii) we have to foster harmless fish identification in marine protected area, park and reserve as all critical site. We thus tested the use of cameras or divers in optimized conditions (quiet weather, daytime and low water turbidity) in order to assess their efficiency.

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Material and Methods

Data have been recorded during a survey (ACaPELA Marseille August 2020) in the Calanques National Park of Marseille in the Mediterranean Sea during August 2020. Area was chosen for the good underwater visibility facilitating the work of divers and the use of video.

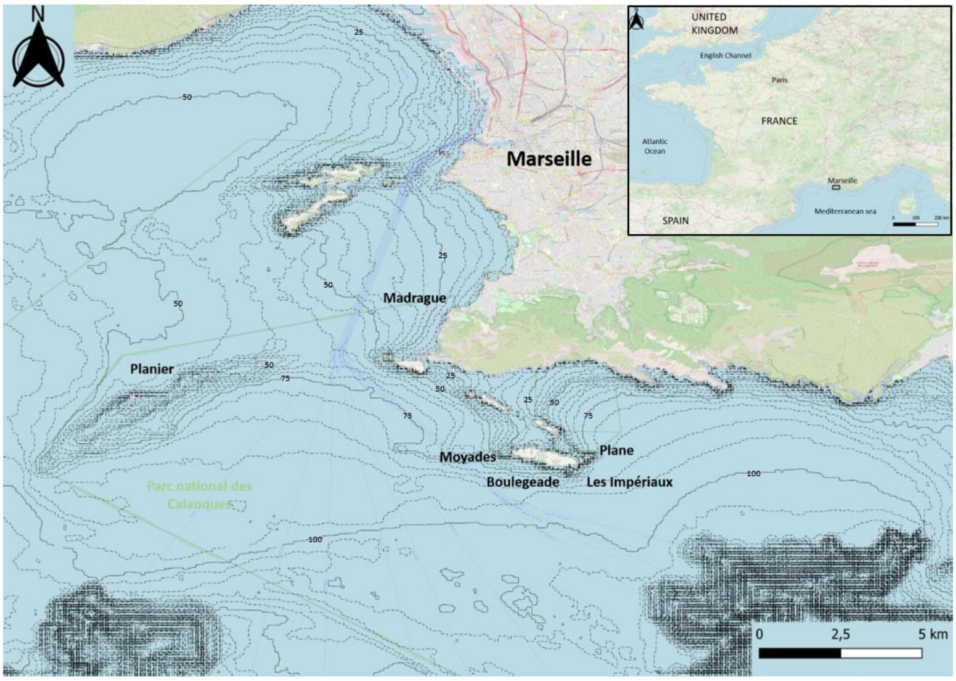

Figure 1: Map of sampling areas with isobaths curves. The dotted lines are the isobaths every 5 meters and the solid lines are those every 25 meters.

We used the visual information of divers and videos as ground truthing for specific pelagic fish identification and fish size estimation. All sampling were made during daytime. We used two complementary acoustic systems. A wide-band scientific echo sounders (Simrad EK 80: 70, 120 and 200 KHz) and a multibeam sonar (Simard M3, 500 KHz) in vertical beaming crossing the sampling volume of the echo sounders. Acoustics transceivers were placed in a specific support at the end of a pole fixed to the edge of the vessel.

Two methods were tested for the divers. The first protocol, called “free divers”, consisted in a team of three biologist divers equipped with closed circuit rebreather (CCR). CCR is used to avoid bubbles which disturb good acoustic acquisitions. Divers use underwater scooter to move faster between areas of interest. Their goal was to locate shoals of coastal pelagic fish. To coordinate the vessel instrumented by acoustics system and the divers’ team, one diver launch an underwater parachute to signal their global position to the vessel (Diver 1, Figure 2.A and B). This diver is able to communicate in wireframe with the pneumatic boat crew that can stay in place above (Diver 1, Figure 2.A and B). It allows him to precisely guide the boat equipped with the acoustics system toward the observed high fish density area position (Diver 1, Figure 2.A and B). The vessel speed was set to 5 knots. The goal of the second diver was to identify, count and estimate the size of individuals (total length) to constitute ground truth (Diver 2, Figure 2.A). The last one filmed the shoals with the stereo camera system (Diver 3, Figure 2.A) to confront divers’ length estimation to stereoscopic measurements.

The second protocol called “towed diver” consisted in towing a diver behind the vessel equipped with sounders. The line is 20 meters long (20 to 30 seconds separated the acoustic observations from those of the diver) and the diver has a board to control his depth (Figure 2.C and D). The goal of the diver was to estimate the size of individuals as well as the depth of each aggregation or school. He also identified them to constitute ground truth. He transmitted directly to the board of the vessel by wireframe communication. Thus, the diver directly observed each sounded aggregation or school. The diver's mask was equipped with a camera (Paralenz) for video acquisition. The speed of the vessel has been reduced to 2 knots to ensure the safety of the diver.

In both protocols, a logbook was fill on-board the vessel to associate diver observation with acoustic data. Divers estimate their error on fish length to be around 10%.

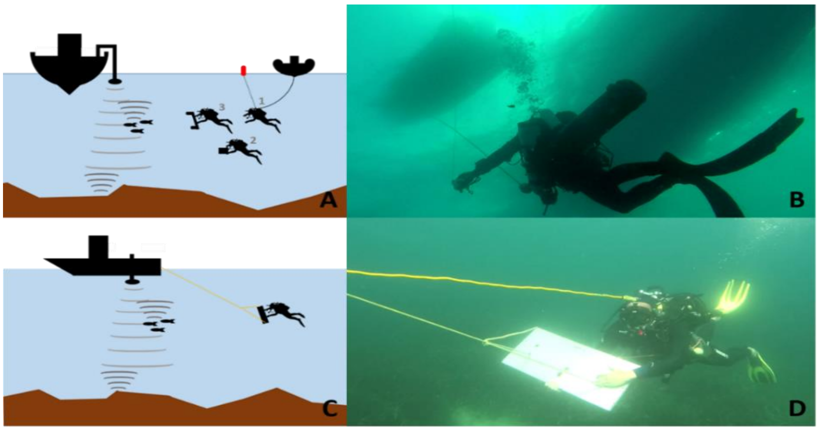

Figure 2: A) Schema explaining the "free divers" protocol B) Coordination diver during an echo-sounding operation C) Schema explaining the "towed divers" protocol D) Towed diver during the sampling

For the video observations, an expert scuba divers team was equipped with either a stereoscopic camera system (SeaGis, swimmable stereo camera system) using Gopro (Hero 5, 1080p Wide) in the protocol "free divers" or an underwater camera with pressure sensor (Paralenz) in the protocol "towed diver" (Table 1). Consequently, the data obtained, are underwater videos and pictures as well expert estimation of fish length and species.

Table 1: Compilation of the data available obtain during the sea survey ACaPELA Marseille August 2020.

Site	Date	Number	Protocol	Stereoscopic camera system	Single camera
Moyades_17/08_n°1	17/08/20	1	Free divers	✓	
Moyades_17/08_n°2	17/08/20	2	Free divers	✓	
Impériaux_18/08_n°1	18/08/20	1	Free divers	✓	
Plane_18/08_n°2	18/08/20	2	Free divers	✓	
Boulegeade_19/08_n°1	19/08/20	1	Free divers	✓	
Planier_20/08_n°1	20/08/20	1	Towed diver		✓
Madrague_20/08_n°2	20/08/20	2	Towed diver		✓
Madrague_21/08_n°1	21/08/20	1	Towed diver		✓
Madrague_21/08_n°2	21/08/20	2	Towed diver		✓

Videos were analysed to spotted aggregations and schools and identify species. Aggregations and schools spot on videos are precisely time-stamped to the second to synchronise them with acoustics data. Fish formations were described as aggregations or schools. Grouping for extrinsic reasons defines aggregations (Pitcher, 1983). Schools defines coordinated swimming groups of fish (Pitcher, 1983). Aggregations and schools were considered as monospecific if more than 95% of the fish forming it are from the same species. For the "free divers" method, the time between spots on video and an echo-sounding manoeuver was evaluate to assess the certainty of video and acoustic coupling. In addition, knowing the stereo camera system characteristics that allows to measure objects that are at a maximum distance of 8 to 10 meters according to SeaGis developer (Langlois et al., 2020), aggregations and schools are caracterised as measurable or not. The same analysis was made for the single camera used in the « towed diver » method to assess the efficiency of this method to obtain usable stereoscopic videos. Divers' information written on the logbook were synchronized with the videos.

We used the software SeaGIS for the analysis of stereoscopic data. A calibration was done before the survey, following builder recommendations (Boutros, 2015). Then, the operator manually points individuals to measure them. We measure the fork length. The RMS is the difference in position taken from the measurement on the right image and on the left image. We only keep length with a RMS <20 mm as recommending by the SeaGis developer.

All graphics and analyses were made with R software version 4.0.4 (2021-02-15).

Results

Each part of the videos were species identification were feasible were selected. As well, the type of fish formation (schools or aggregation) were characterized and the species identified (e.g. *Sphyraena viridensis* monospecific school or *Chromis chromis* monospecific aggregation) (Figure 3).

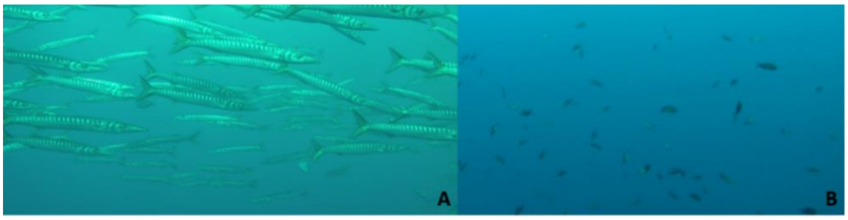

Figure 3: A) Sphyraena viridensis monospecific school B) Chromis chromis monospecific aggregation selected for further analysis

Comparison of the accuracy of protocols for species identification for ground truth constitution.

For the "free divers", the divers transmitted 60 shoals whereas 345 were spotted on the videos. Species richness were 16 and 14 for the divers and the videos respectively. For species allocation, we only keep monospecific shoals filmed or transmitted by the divers at less than 30 seconds from an echo-sounding manoeuvre. Therefore, there are 93 shoals spotted on the videos against 9 transmitted by divers (Figure 4.A and B). This protocol was deployed for 465 minutes, thus divers transmitted 1 aggregation or school per hour while videos spots 12 shoals per hour.

For the "Towed diver" protocol, 99 transmitted shoals were transmitted by the divers whereas 64 were spotted on the videos. Species richness seen by the divers were 8 and were 6 on the videos. We only keep monospecific shoals filmed or transmitted by the divers. Therefore, there are 47 shoals filmed against 74 transmitted (Figure 4.C and D). This protocol was deployed for 256 minutes, thus diver transmitted 17 shoals per hour while videos spots 11 shoals per hour.

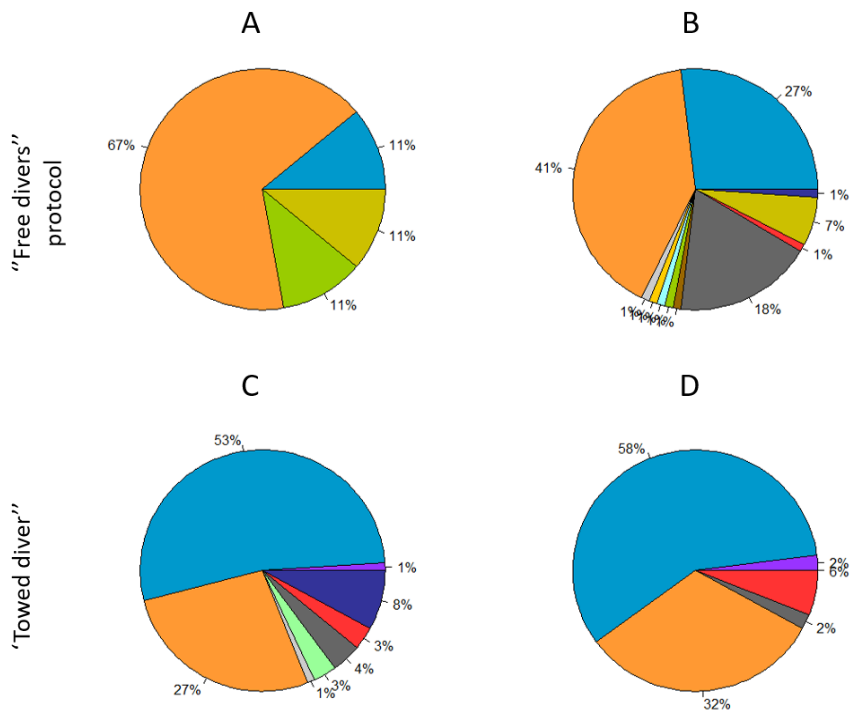

Figure 4: Proportion (in %) of shoals per species A) transmitted by the divers (N=9) B) spotted on the videos (N=93) with the "free divers" method. : Proportion (in %) of shoals per species C) transmitted by the divers (N=74) D) spotted on the videos (N=47) with the "towed diver" method. Purple is for Anthias anthias, Blue is for Boops boops, Orange is for Chromis chromis, Light grey is for Dentex dentex, Yellow is for Dicentrachus labrax, Ligth blue is for Diplodus sargus, Light green is for Diplodus sp, Green is for Diplodus vulgaris, Brown is for Epinephelus marginatus, Grey is for Oblada melanura, Red is for Sarpa salpa, Geen khaki is for Sphyraena viridensis, Dark blue is for Spicara spp

Comparison of the ability of the two video methods to obtain images usable for stereoscopic measurements.

Respectively 75% of free divers' camera and 83% of towed diver' camera were usable spotted schools or aggregations on the videos (Figure 5).

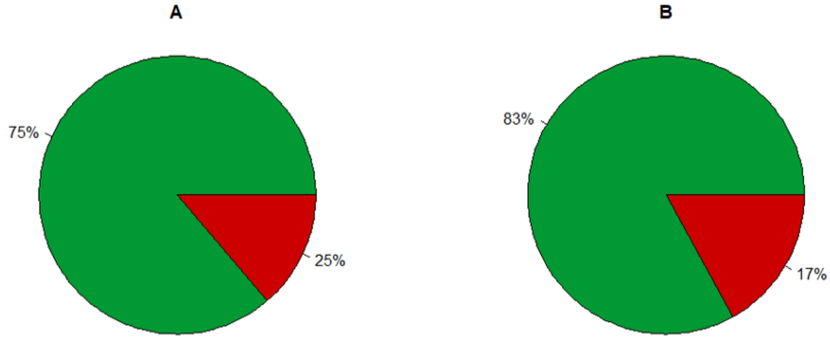

Figure 5: Percentage of measurable (Green) and non-measurable (Red) of shoals A) with the "free divers" method and B) with the "towed diver" method

Other filters were added because it was necessary that the aggregations and schools were extracted. Consequently, the echo-sounding database is constituted by 25 shoals from the "free divers" protocol and 14 from the "towed diver" protocol. It respectively represents 27 and 30% of the monospecific shoals spotted on videos, which are exploitable for acoustics analysis. In addition, 20 of the shoals used for acoustics analysis were spotted on videos but not transmitted by divers.

Results on the stereoscopic measurements

The stereoscopic measurements were compared with the estimated sizes of our divers. The length acquired concerning a *Boops boops* school whose estimated size is between 8 and 12 centimetres. With 10% error estimation for the divers, the length of the fish should be between 7 and 13 centimetres.

363 fishes were measured on 10 freeze frames. 36.9% of the measurements are over the upper limit of the divers estimation (Figure 6).

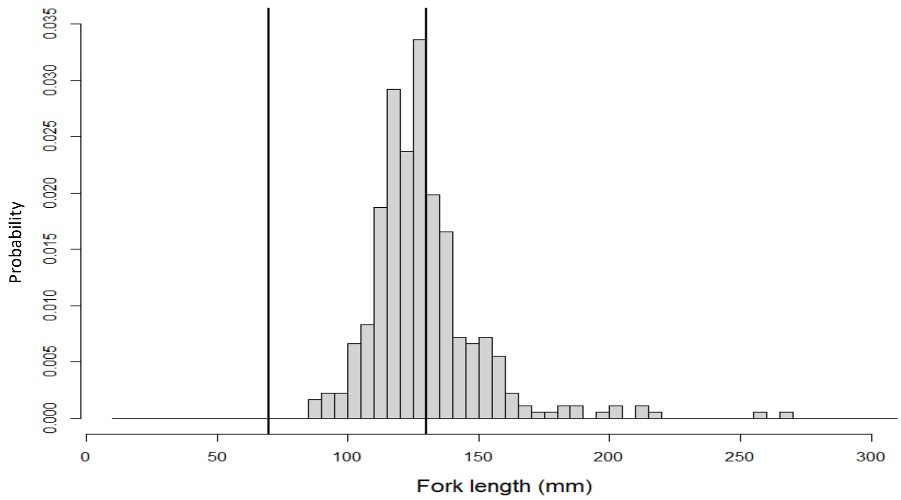

Figure 6: Histogram of fork length of Boops boops (N=363), vertical lines indicate estimated length by divers

The difference was also observed with the others measured shoals. There are between 37 and 100% of the lengths measured above the upper limit of the intervals and there is between 0 and 17% of the lengths measured under the lower limit if the intervals.

The lengths measured also significantly increase with the range (Distance between individuals and the centre of the stereoscopic system) (Figure 7).

As the measurements drifted with the increase in the range, a filter was applied to keep the data with a range under six meters (fixed bellow the stereoscopic system ability) to ensure its quality. The SeaGis parameter called “precision” (Mathematical derivative of the position of the measure in space compared to the stereoscopic system) also significantly increase with the range (Figure 8), which translates a decrease in the quality of the measurements.

Divers estimate their error on size estimates to be around 10% so a filter was applied to keep the data with a precision under 10%.

The range’s filter permitted to keep measurements coherent with the ground truth. 65% of them are in the estimation interval against 63% without this filter (Figure 9). 78% of the measurements are in the estimation interval thanks to the Precision filter or the precision and range filter (Figure 9). These filters allow correcting the shift between the estimations and the measurements.

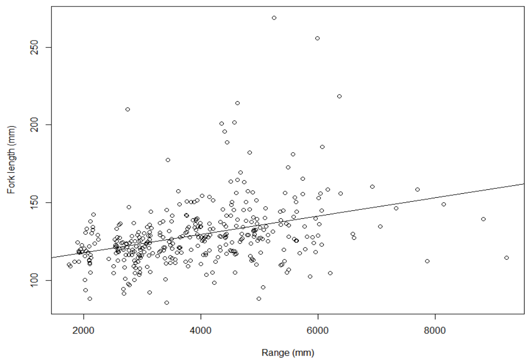

Figure 7: Relation between fork length estimated by divers and range from the camera. The curves were fitted by y = ax + b (N= 363, r²ajusted = 0.1278, P < 0.05)

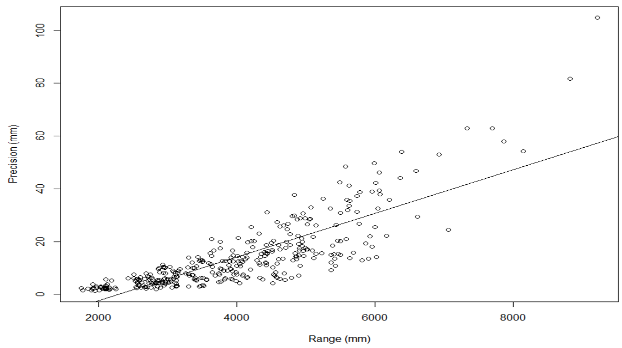

Figure 8: Relation between precision and range from the camera. The curves were fitted by y = ax + b (N=363, r²ajusted = 0.69, P < 0.05)

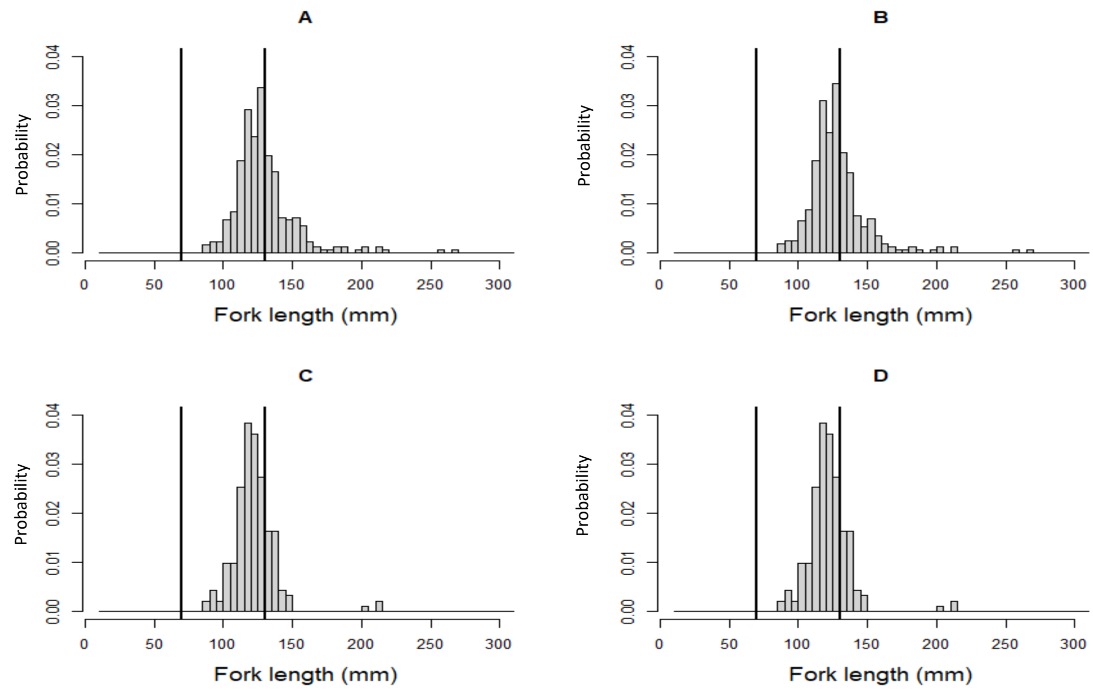

Figure 9: Histogram of fork length A: with no filter (N= 363); B: with a Range less than 6 meters (N=343); C: with a Precision less than 10% (N=182); D: with a Range less than 6 meters and a Precision less than 10% (N=182).

Discussion

The two diving methods made it possible to identify echo-sounded shoals. 25 aggregations were finally selected from the "free divers" method and 14 from "towed diver" one. However, "free divers" method has shown some limitations. Indeed, part of the acoustic data turned out to be unusable because of the bubbles of the divers, despite the air rebreathers, which prevent the correct acquisition of the acoustic data. This is particular true for the M3 multibeam echo-sounder whose beam width is wide (120°). In addition, implementing such method requires quiet a lot of materials and manpower. Indeed 3 divers minimum are required, including at least one experienced biologist to perform identifications and estimations, equipped with air rebreathers and underwater scooters. In addition, wired communication was not directly done with the boat equipped with sounders but with the intermediary of the pneumatic boat. The time required for the boat with the sounders to perform the maneuvers requested by the divers can create an uncertainty between the visual and acoustic observations. Moreover, the time needed for the boat with the sounders to perform the maneuvers requested by the divers can create a significant delay between the *in situ* observations of the divers and the effective acoustic data acquisition. Such delay may allow the departure or arrival of fish species and may bring uncertainties between the ground truth and the acoustic observations.

Concerning the "towed diver" method, as the diver is towed behind the vessel, he does not need to be fitted with an air rebreather, as his bubbles cannot been seen by echo. This method requires functional wired communication, as well as an experienced biologist diver to identify and estimate abundances and sizes while in movement. For this survey, areas with the highest density of fish were targeted and the manipulations stopped when there were not enough fish. The vessel speed for sampling was nevertheless limited to 2-2.5 knots maximum for the diver safety. Despite that, the diver has been continuously behind the vessel, hence, there is no sampling downtime as it was the case with "free divers" method. So, with towed method, the sampled area is larger and the sampling more efficient with 17 aggregations per hour of "towed diver" method versus just 1 per hour of "free divers" method. Finally, 30% of the information usable for the analysis of acoustic data against 27% in the "free divers" protocol. Consequently, we found that the "towed diver" method was a more relevant method over the "free divers" one to obtain fish species identifications for acoustic allocations.

However, diving and therefore "towed diver" had some disadvantages such as the safety of divers, the limit of diving time and the costs that the divers represent. Moreover, in other areas, environmental conditions (e.g. low temperatures) may limit the deployment of divers. The "Towed diver" method tires out more quickly the diver. Therefore, it is impossible to make very long transects without a consequent number of divers. Nevertheless, changing diver introduces a bias in the estimates of the length of individuals. In comparison to diving, the use of video as an identification technique to produce ground truth also shows that 49% of the shoals retained for the acoustic analysis had been identified by the divers and on the videos and 51% came exclusively from the videos. Consequently, the use of the videos could overcome these limitations as found to be a promising alternative method.

In addition, the analysis of the fish length measured with the stereoscopic system for *Boops boops* and the other species tested were coherent with common and maximal length of this species (Fischer et al., 1987 ; Crec'hriou et al., 2013). Hence, this technique was found to be a relevant method to implement *in situ* fish measurements. However, the stereoscopic measurement and the counting carried out manually by an operator are very time-consuming. It takes several tens of minutes to measure individuals on a single image. The processing time of videos for identifying, counting and measuring individuals could be greatly reduced through automation. Indeed, the use of underwater cameras and video processing tools is booming because they are non-intrusive sampling methods (Shortis et al., 2013). Indeed, researchers are developing tools for automatic identification of species based on the shape and patterns characteristic of the species (Shortis et al., 2013 ; Rova et al., 2007). Many automatic detection methods on videos are also being developed in order to carry out the counts and measurements of fish in the marine environment (Shortis et al., 2013) by adaptation to the methods widely used in aquaculture, in particular based on pattern recognition (Tillet et al., 2000 ; Spampinato et al., 2008 ; Shafait et al., 2017).

The analysis of the data of the stereoscopic system showed that the position of the fish in relation to the cameras strongly limits the number of measurable individuals. In fact, the individuals must be as parallel as possible to the system to be measured precisely. In addition, comparison of the measurements with the divers' estimates showed a shift with 63% of the measurements in the interval given by the divers. This shift can be reduced to 22% of measurements outside the estimate by limiting the range to 6 meters and the precision to 10% of the estimate's class center. Hence, the recommendations on the distance of individuals to the cameras for this type of system were optimistic in the conditions encountered during the mission. In fact, the indications given by SeaGis, software developer, the stereoscopic system was supposed to measure individuals up to 8 or 10 meters from the cameras (Langlois et al., 2020) while our measurements have shown their limits beyond 6 meters. Finally, the cameras must also be well fixed to the support and not manipulated during the experiment to avoid bias in the measurements and optimize the fact of obtaining the RMS < 20 mm. With these recommendations, the stereoscopic system therefore allows accurate and repeatable measurements of fish length (Harvey and Shortis, 1995 ; Harvey et al., 2010). In addition, the video is a permanent record which can be reviewed and re-analyzed for future studies (Cappo et al., 2003 ; Mallet and Pelletier, 2014).

In addition, the stereoscopic system makes it possible to obtain the size distribution (e.g. Langlois et al., 2012) while the divers can only provide size intervals. It also avoids the observer effect of the visual estimations. From size data acquired with stereovision systems, the estimation of biomass is possible (e.g. Chan et al., 1998 ; Harvey et al., 2001 ; Dios et al., 2003). It is an important step towards quantifying biomass for monitoring the ecological state of marine water bodies. The system could be improved for example by multiplying the number of simple cameras to cover a greater viewing angle by placing systems pointing forward, to the sides or to the back to maximize the number of measurable individuals. Cameras can also be added to the stereoscopic system to obtain a system with more than two cameras to create different measurement properties. Indeed, cameras that are more distant will make it possible to measure more distant individuals (Boutros et al., 2015). Finally, with a view to reducing the size and weight of the system to facilitate its use (Shortis et al., 2000), for example, the use of Paralenz cameras, specially designed for underwater use, make it possible to do without camera housings which are voluminous. Consequently, the use of cameras and stereoscopic systems could then help to have good measurements of fish length and abundances and thus help to better quantify biomass of fish populations in shallow waters in order to assess their ecological status.

Finally, the coordinated use of two sounding technologies, the wideband vertical sounder and the multibeam sounder, and the identification of the species by the divers or the cameras for the construction of a ground truth has therefore made it possible to apprehend the effectiveness, to compare and detect the limits of these different methods. In addition, this made it possible to produce a small but strong certainty database that is not always acquired with the usual identification trawling techniques. This is because identification trawling is subject to gear selectivity and the avoidance of certain species (Brabant and Nedelec, 1988) and suffer from correlation issues between the real fish abundance and the acoustic observations (Gunderson, 1993 ; Fernö and Olsen , 1994). In addition, detection trawling remains an intrusive method that is not ethically consistent with the preservation of biodiversity targeted by scientists. The use of non-intrusive method bases on divers and cameras, especially with a towed protocol, appeared to be promising alternative methods of constructing ground truths in shallow waters. In contrast, the use of cameras or divers is restricted to data collected during quiet weather, daytime and low water turbidity.

Conclusion

We found that the acquisition of non-intrusive ground truth in coastal pelagic environments by using innovative diving methods was possible. "Towed diver" appear to be more efficient at combining visual and acoustic data and limit noise on acoustic data due to divers' bubbles. Obviously "towed diver" method request *ad hoc* safety material and procedures as a high level of diving expertise. The "towed diver" method was thus a relevant method to observe pelagic fish populations in shallow waters. However, it could not be deployed in routine survey as requested by the MSFD to survey fish and cephalopods in coastal pelagic environments. To do that, the use of underwater videos have shown their ability to overcome divers. In addition, the use of a stereoscopic system could allow having successfully *in situ* measurements of pelagic fish. Future development in artificial intelligence will greatly help to reduce the processing time. The towed diver or video methods should facilitate the monitoring of populations in shallow waters to enhance the management and protect biodiversity. However, the use of the video may be limited to area with low water turbidity.

Acknowledgments

This project was funded by the measure 80 of the FEAMP agreement (PFEA800219DM0530003). The authors wish to thank all people who contributed to the surveys including the crew members of the Cro-Magnon (Septentrion association). Thanks to James Seager, the developer of the software SeaGis for all his advice. We also thank Jérémie Habasque for the loan of the SeaGis operating license and for his advice on its use as well as the SHOM for their Digital Terrain Model data.

References

(1) Benoit-Bird, K. J.; Lawson, G. L. Ecological Insights from Pelagic Habitats Acquired Using Active Acoustic Techniques. *Annual Review of Marine Science* **2016**, *8* (1), 463–490. https://doi.org/10.1146/annurev-marine-122414-034001.

(2) Boutros, N.; Shortis, M. R.; Harvey, E. S. A Comparison of Calibration Methods and System Configurations of Underwater Stereo-Video Systems for Applications in Marine Ecology. *Limnology and Oceanography: Methods* **2015**, *13* (5), 224–236. https://doi.org/10.1002/lom3.10020.

(3) Brabant, J.-C.; Nedelec, C. Les chaluts. Conception, construction, mise en oeuvre. **1988**.

(4) Brehmer, P.; Guillard, J.; Guennégan, Y.; Bigot, J. L.; Liorzou, B. Evidence of a Variable "Unsampled" Pelagic Fish Biomass in Shallow Water (<20 m): The Case of the Gulf of Lion. *ICES Journal of Marine Science* **2006**, *63* (3), 444–451. https://doi.org/10.1016/j.icesjms.2005.10.016.

(5) Cappo, M.; Harvey, E.; Malcolm, H.; Speare, P. Advantages and Applications of Novel "Video-Fishing" Techniques to Design and Monitor Marine Protected Areas. *Aquatic Protected Areas-What works best and how do we know* **2003**, 455–464.

(6) Chan, D.; Mcfarlane, N.; Hockaday, S.; Tillett, R. D.; Ross, G. *Image Processing for Underwater Measurement of Salmon Biomass*; **1998**; p 12/6. https://doi.org/10.1049/ic:19980129.

(7) Crec'hriou, R.; Neveu, R.; Lenfant, P. Length-Weight Relationship of Main Commercial Fishes from the French Catalan Coast. *Journal of Applied Ichthyology* **2013**, *29* (5), 1191–1192. https://doi.org/10.1111/jai.12320.

(8) Fernö, A.; Olsen, S. *Marine Fish Behaviour in Capture and Abundance Estimation*; Fishing News Books: Oxford, **1994**.

(9) Fischer, W.; Schiender, M.; Bauchot, M. L. Fiches FAO d'identification des especes pour les besoins de la pêche. Méditerranée et Mer Noire (Zone De Pêche 37),Révision 1, Volume 2 http://www.fao.org/3/x0170f/x0170f00.htm (accessed 2021 -05 -31).

(10) Gunderson, D. R. *Surveys of Fisheries Resources*; John Wiley & Sons, 1993.

(11) Harvey, E.; Fletcher, D.; Shortis, M.; others. A Comparison of the Precision and Accuracy of Estimates of Reef-Fish Lengths Determined Visually by Divers with Estimates Produced by a Stereo-Video System. *FISHERY BULLETIN-NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION* **2001**, *99*, 63–71.

(12) Harvey, E.; Goetze, J.; McLaren, B.; Langlois, T.; Shortis, M. Influence of Range, Angle of View, Image Resolution and Image Compression on Underwater Stereo-Video Measurements: High-Definition and Broadcast-Resolution Video Cameras Compared. *Marine Technology Society Journal* **2010**, *44*, 75–85. https://doi.org/10.4031/MTSJ.44.1.3.

(13) Harvey, E.; Shortis, M. A System for Stereo-Video Measurement of Sub-Tidal Organisms. *Marine Technology Society Journal* **1995**, *29*, 10–22.

(14) Horne, J. K. Acoustic Approaches to Remote Species Identification: A Review. *Fisheries Oceanography* **2000**, *9* (4), 356–371.

(15) Langlois, T.; Goetze, J.; Bond, T.; Monk, J.; Abesamis, R.; Asher, J.; Barrett, N.; Bernard, A.; Bouchet, P.; Birt, M.; Cappo, M.; Currey-Randall, L.; Fairclough, D.; Fullwood, L.; Gibbons, B.; Harasti, D.; Heupel, M.; Hicks, J.; Holmes, T.; Harvey, E. A Field and Video-annotation Guide for Baited Remote Underwater Stereo-video Surveys of Demersal Fish Assemblages. *Methods in Ecology and Evolution* **2020**, *11*. https://doi.org/10.1111/2041-210X.13470.

(16) Langlois, T.; Harvey, E.; Meeuwig, J. Strong Direct and Inconsistent Indirect Effects of Fishing Found Using Stereo-Video: Testing Indicators from Fisheries Closures. *Ecological Indicators* **2012**, *23*, 524–534. https://doi.org/10.1016/j.ecolind.2012.04.030.

(17) Mallet, D.; Pelletier, D. Underwater Video Techniques for Observing Coastal Marine Biodiversity: A Review of Sixty Years of Publications (1952–2012). *Fisheries Research* **2014**, *154*, 44–62. https://doi.org/10.1016/j.fishres.2014.01.019.

(18) Martinez-de Dios, J. R.; Serna, C.; Ollero, A. Computer Vision and Robotics Techniques in Fish Farms. Robotica. *Robotica* **2003**, *21*, 233–243. https://doi.org/10.1017/S0263574702004733.

(19) Pitcher, T. J. Heuristic Definitions of Fish Shoaling Behaviour. *Animal Behaviour* **1983**, *31* (2), 611–613. https://doi.org/10.1016/S0003-3472(83)80087-6.

(20) Rova, A.; Mori, G.; Dill, L. M. One Fish, Two Fish, Butterfish, Trumpeter: Recognizing Fish in Underwater Video; **2007**.

(21) Shafait, F.; Harvey, E. S.; Shortis, M. R.; Mian, A.; Ravanbakhsh, M.; Seager, J. W.; Culverhouse, P. F.; Cline, D. E.; Edgington, D. R. Towards Automating Underwater Measurement of Fish Length: A Comparison of Semi-Automatic and Manual Stereo–Video Measurements. *ICES Journal of Marine Science* **2017**, *74* (6), 1690–1701. https://doi.org/10.1093/icesjms/fsx007.

(22) Shortis, M.; Harvey, E.; Miller, S.; Robson, S. An Analysis of the Calibration Stability and Measurement Accuracy of an Underwater Stereo-Video System Used for Shellfish Surveys. *undefined* **2000**.

(23) Shortis, M. R.; Ravanbakskh, M.; Shaifat, F.; Harvey, E. S.; Mian, A.; Seager, J. W.; Culverhouse, P. F.; Cline, D. E.; Edgington, D. R. A Review of Techniques for the Identification and Measurement of Fish in Underwater Stereo-Video Image Sequences. **2013**, *8791*, 87910G. https://doi.org/10.1117/12.2020941.

(24) Spampinato, C.; Chen-Burger, Y.-H.; Nadarajan, G.; Fisher, R. Detecting, Tracking and Counting Fish in Low Quality Unconstrained Underwater Videos. *Proc. 3rd Int. Conf. on Computer Vision Theory and Applications (VISAPP)* **2008**, 514–519.

(25) Tillett, R.; McFarlane, N.; Lines, J. Estimating Dimensions of Free-Swimming Fish Using 3D Point Distribution Models. *Computer Vision and Image Understanding* **2000**, *79* (1), 123–141. https://doi.org/10.1006/cviu.2000.0847.