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RESEARCH ARTICLE

Efficiency of automatic analyses of fish passages detected by an acoustic camera using Sonar5-Pro

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Abstract – The acoustic camera is a non-intrusive method increasingly used to monitor fish populations. Acoustic camera data are video-like, providing information on fish behaviour and morphology helpful to discriminate fish species. However, acoustic cameras used in long-term monitoring studies generate a large amount of data, making one of the technical limitations the time spent analysing data, especially for multi-species fish communities. The specific analysis software provided for DIDSON acoustic cameras is problematic to use for large datasets. Sonar5-Pro, a popular software in freshwater studies offers several advantages due to its automatic tracking tool that follows targets moving into the detection beam and distinguishes fish from other targets. This study aims to assess the effectiveness of Sonar5-Pro for detecting and describing fish passages in a high fish diversity river in low flow conditions. The tool's accuracy was assessed by comparing Sonar5-Pro outputs with a complete manual analysis using morphological and behavioural descriptors. Ninety-eight percent of the fish moving into the detection beam were successfully detected by the software. The fish swimming direction estimation was 90% efficient. Sonar5-Pro and its automatic tracking tool have great potential as a database pre-filtering process and decrease the overall time spent on data analysis but some limits were also identified. Multi-counting issues almost doubled the true fish abundance, requiring manual operator validation. Furthermore, fish length of each tracked fish needed to be manually measured with another software (SMC). In conclusion, a combination of Sonar5-Pro and SMC software can provide reliable results with a significant reduction of manpower needed for the analysis of a long-term monitoring DIDSON dataset.

Keywords: Acoustic camera / fish detection / automatic tracking / efficiency assessment / fish length calculation / behaviour description

1 Introduction

Hydroacoustics are increasingly used in aquatic ecological studies and for the monitoring of fish populations. This method provides reliable information about fish populations without interfering with their behaviour and is therefore considered non-intrusive (Becker and Suthers, 2014; Boulêtreau et al., 2020). Thus, hydroacoustics are able to record individual biological data when other methods are less effective or ineffective, notably in turbid or deep environments (Trenkel et al., 2011). Hydroacoustic technology uses the propagation capacity of acoustic waves in the water (MacLennan and Simmonds, 2013) and undergoes constant technical evolution (Martignac et al., 2015). The acoustic pulse emitted into the environment by echosounders spreads until it meets a target with a density different from that of the propagation environment (Simmonds and MacLennan, 2005). Over the last few decades, the sound frequency of the acoustic emissions has been increased to improve data resolution, with an increase of the opening angle (Colbo et al., 2014), giving rise to a new generation of sonars: so called acoustic cameras (Martignac et al., 2015). The DIDSON (Dual-frequency Identification Sonar) (Sound Metrics Corp, WA, USA) was the first sonar of this generation available for environmental studies (Belcher et al., 2001). In recent years, several other acoustic cameras have become available, such as the Sound Metrics Corp. ARIS Explorer (Sound Metrics Corp, WA, USA), which succeed to the DIDSON, the Teledyne BlueView (Teledyne Marine, Denmark) and the Blueprint Oculus

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(Blueprint, UK). However, the DIDSON camera is still one of the most commonly used to monitor fish populations (Bennett et al., 2020; Lenihan et al., 2019, 2020; van Keeken et al., 2020; Zhang et al., 2020). DIDSON data can be visualised similar to video files and provide direct information on fish morphology (length, volume) and behaviour (swimming direction, speed, activity such as feeding, hunting, searching, spawning, etc.), unlike the previous generation of echosounders. Although the main limitation of acoustic devices remains identifying fish species (Horne, 2000), the observation of morphology and behaviour provides reliable clues to identify species (Langkau et al., 2012; Lenihan et al., 2019). Consequently, acoustic cameras are frequently used in monitoring surveys of diadromous fish population migrations (Cronkite et al., 2006; Crossman et al., 2011; Grote et al., 2014; Maxwell et al., 2019; McCann et al., 2018; Pavlov et al., 2011). These surveys are performed for long-term monitoring, generating a large amount of data (up to 20 GB per day), and each file requires careful analysis by an operator. The most effective way to count the number of fish is that an operator visualises the entire dataset (Briand et al., 2016). However, this method is time-consuming (Burwen et al., 2007; Cronkite et al., 2006; Lenihan et al., 2019). Sound Metrics Corporation (SMC) software is an effective video reader but does not have effective automatic fish tracking capabilities (Pavlov et al., 2009; Rakowitz et al., 2012) and is therefore not very easy to use for long-term monitoring datasets (Cronkite et al., 2006; Davies and Griffith, 2011; Lilja et al., 2010). Sonar5-Pro (Balk and Lindem, 2012), which is one of the most commonly used software programs to analyse acoustic data in freshwater (Jones et al., 2008; Mouget et al., 2019; Poulain et al., 2010. p. 5), is an alternative solution because it includes an automatic fish tracking tool for DIDSON data. Nevertheless, few studies have used it to date to analyse DIDSON data (Rakowitz et al., 2012) and to the best of our knowledge, no comparison has been performed. Like SMC software, Sonar5-Pro provides behavioural information (swimming direction and speed) and morphological characteristics (length). Both types of information provide relevant clues for identifying fish species and the Sonar5-pro software. To assess the precision of Sonar5-pro, a DIDSON dataset was analysed using Sonar5-Pro's tracking tool and compared with the results obtained manually using SMC software.

2 Materials and methods

2.1 Data collection

The Sélune River is a small coastal river (catchment area 1106 km^2, length 91 km, mean discharge 11 m^3 s^{-1}) located in Normandy (France). It flows into the English Channel in the Mont Saint-Michel Bay and is colonised by several diadromous fish species, such as Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*), European eel (*Anguilla anguilla*), sea lamprey (*Petromyzon marinus*), allis shad (*Alosa alosa*), and thinlip grey mullet (*Chelon ramada*) (Martignac 2016). The monitoring site, where a DIDSON 300 Standard Version was set, is located in the upper part of the estuary, upstream from the dynamic tide limit, on the right bank. At this location, the river is 18 m wide and has a maximum depth of almost 2 m during low-flow periods. During the study period, flow velocity recorded continuously on the monitoring site ranged from 0.2 to 0.4 m s^{-1} (Martignac, 2016). The site is not only a transit zone for diadromous fishes, but also a resting site for several freshwater fish species (Martignac, 2016) as well many cyprinid species such roach (*Rutilus rutilus*), common bream (*Abramis brama*), silver bream (*Blicca bjoerkna*), common carp (*Cyprinus carpio*), chub (*Squalius cephalus*) and carnivorous fishes such as European perch (*Perca fluviatilis*), zander (*Sander lucioperca*), pike (*Esox lucius*) and European catfish (*Silurus glanis*).

2.2 Dataset

For the comparison, sixteen 30-minute files were recorded in August 2013, including daytime and night-time activities and corresponding to the highest movement periods for all fish species (Martignac et al., 2013), thus maximising the number of tracked fish. Hydrologic conditions were constant during the collection period (recorded flow: 3.12 ± 0.03 m^3 s^{-1}). The operator noted individual behaviour and fish lengths. The DIDSON was set in High-Frequency Mode (1800 kHz) to record a 10-m window (range 6.5 to 16.5 m).

2.3 Analysis software

2.3.1 Sound Metrics Corporation® software (V5.25.40)

SMC software enables visualisation of DIDSON files. (Martignac, 2016) provided details on the settings used and the analysis parameters. SMC software is easy to use to perform basic analyses, such as measuring fish length, by drawing a line along the body. Nevertheless, its capacity for automatic tracking is limited (Rakowitz et al., 2012). The automatically tracked targets are unreliable because there are too few tracking settings, which are consequently not sufficiently selective. Previous analysis has shown that drifting objects, riverbed echoes and clusters of small fish are often considered a single individual fish (Martignac, 2016). Furthermore, the automatic process itself is time-consuming (5–6 minutes for a 30-minute file). Finally, the exported fish passage characteristics are limited to basic parameters, such as fish length (cm), swimming direction (upstream/downstream), position in the beam (in the X and Z dimensions), body angle (in degrees), cluster area (cm^2), and time.

2.3.2 Sonar5-Pro® software (V 6.0.2)

Sonar5-Pro (Balk and Lindem, 2012) is commonly used to analyse vertical echosounder data to quantify fish biomass in lakes (Guillard et al., 2006; Kubecka and Wittingerova, 1998) and from horizontal deployments in rivers to describe diadromous fish populations (Cronkite et al., 2007; Enzenhofer et al., 1998; Martignac et al., 2013; Romakkaniemi et al., 2000). Several parameters describe each fish passage, and users can customise module settings. Furthermore, the automatic tracking tool for DIDSON data provides the same morphological and behavioural data as the SMC software (fish length, swimming direction or position in the beam) as well as additional information, such as swimming speed. Sonar5 Pro also creates an output file that is easy to import into a database.

The Sonar5-Pro module is composed of several windows. Two are dedicated to visualisation: one to project DIDSON data in echogram mode and the other to play the videos. Two settings menus are available. The first one, the *Echogram Control Dialog*, is common to all acoustic data analysis in Sonar5-Pro and defines echogram visualisation thresholds and the section of the echogram analysed, i.e. the range of analyses. The second one, specific to DIDSON data, contains several tabs, such as visualisation settings (brightness and contrast thresholds, range selection, etc.), a manual tracking tool and the automatic tracking tool.

The automatic tracking tool can be configured using three settings: (i) pre-filtering of DIDSON videos; the algorithms smooth the data and remove all static echoes to focus only on moving objects; here default settings were used. (ii) The conditions under which targets are tracked: users can enter minimum and maximum values according to targeted species, such as the length or the area of the target, through the *Perimeter length* parameter. These values are expressed in samples, an expression of the video pixel, whose metric size depends on the window length during acquisition. In DIDSON High-Frequency mode, the number of samples is constant at 512 samples, from the bottom to the top of the window. Consequently, in a 10 m window, the sample size, or pixel height, represents 1.95 cm. The horizontal dimension of pixels depends on the number of beams and the distance of the sonar, ranging in our case from 34.3 mm (at 6.5 m) to 87 mm (at 16.5 m range). Other specific morphological criteria can be configured, such as the number of beams, the number of range bins cut by the target in a frame or the ratio of the number of beams to the number of range bins, which can express the length of the fish. Finally, fish detection can be restricted to only part of the DIDSON beam. For example, this option is very useful when macrophytes are present in part of the beam. (iii) Tracking parameter settings: users set the minimum number of consecutive frames (corresponding to pings) in which the target can be seen on the files and the maximum “gap” length, expressed as the number of frames between two detections of the same target.

Applying these three settings, the corresponding targets are then automatically tracked in one or in multiple files. Users can classify tracked targets according to their morphological (length) or behavioural characteristics (swimming direction, swimming speed, detection range and angle) and store them in temporary files (fish-baskets), easily exported into a database with the complete description of each detected target.

Applying image processing, the software creates a “backbone” along the fish body from the constituent contiguous pixels according to their level of brightness (Fig. 1) to estimate length. The backbone of the first frame is then tracked on subsequent frames to record the trajectory of the target in the detection beam. The exported fish length corresponds to the arithmetic mean across all frames in which the target was tracked. In the Sonar5-Pro version used here, it was not possible to export other fish length summaries. For instance, maximum length across frames might have been of interest.

To quantify swimming direction, the software calculates the “velocity in the x-direction between the first and last echo” (*Velocity*). The camera having been installed horizontally on the right riverbank, the x-axis extends in flow direction. A negative value of *Velocity* thus corresponds to a fish moving upstream (Fig. 2).

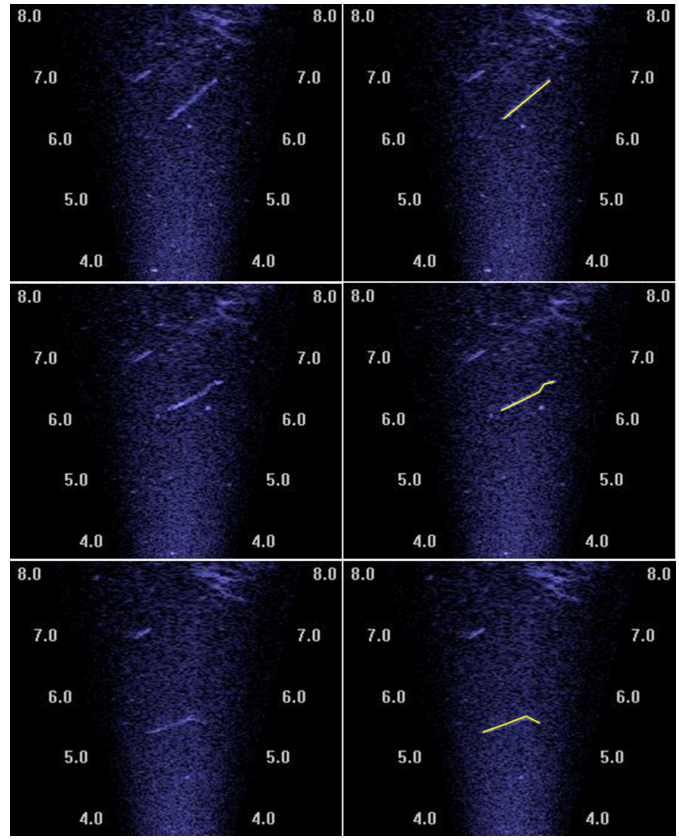

Fig. 1. Left: echoes of the same large fish in successive frames from the DIDSON (from top to bottom: frames 66, 73, 115); right: automatic tracking of the fish and “backbone” drawing with the Sonar5-Pro tool.

2.4 Software settings and validation protocol

This study focused on fish larger than 35 cm (total length). Hence the only parameter set in the “*Evaluator*” menu was *perimeter length*, which was configured to a minimum value of 17 samples corresponding to a minimum target of around 33 cm. This step was also carried out as least restrictive as possible: minimum track length was set to three consecutive frames, and maximum gap was set to two frames. These automatic tracking tool settings aimed to maximise the tracking rate of the fish larger than 35 cm. All tracked targets were exported into a database. An experienced operator manually checked all of them with SMC software to validate whether the targets were true fish according to their morphology and swimming behaviour. Fish were manually described using the selected parameters (length, behaviour, swimming direction) and other parameters automatically calculated from the line manually drawn along the fish body during fish measurement on the frame the operator considered the most representative for the given fish passage (frame number, angular position on the x-axis, fish body angle in the beam, time, and hour). Swimming direction was defined as

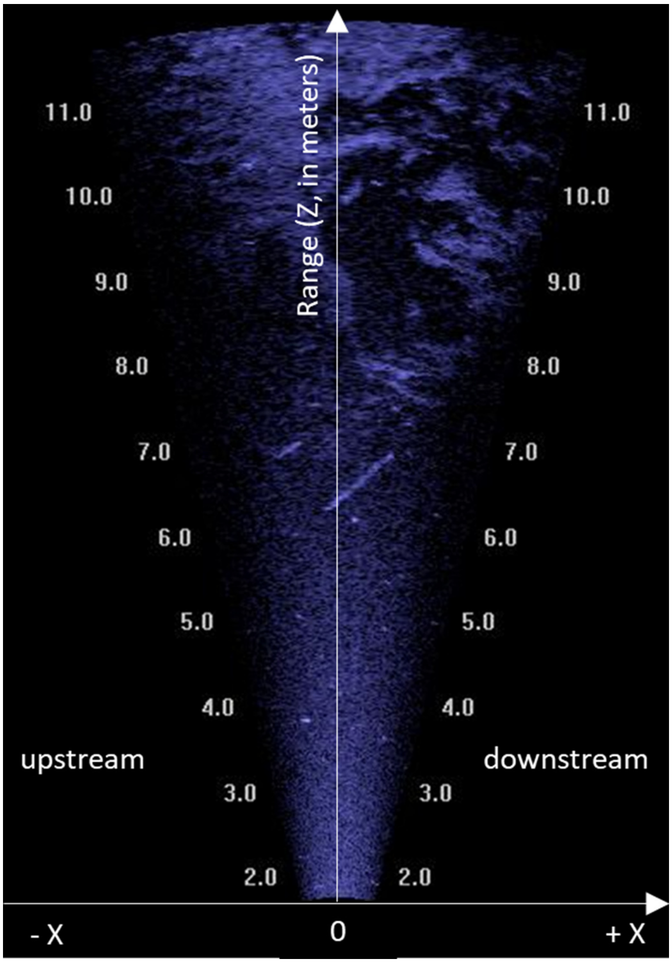

Fig. 2. Exported frame recorded by the DIDSON on the Sélune River monitoring site. The camera been set on the right riverbank; the river flow goes from left to right.

upstream, downstream or erratic, which included turning around. The manually measured length was then compared to the length automatically estimated by Sonar5-Pro. The *Velocity* parameter and information about the position of the fish in the beam were also compared to the swimming direction of each fish on the DIDSON videos. Sonar5-Pro tracking efficiency was evaluated as the number of fish tracked by Sonar5-Pro compared to the number of observed fish using SMC software.

2.5 Statistical analysis

Automatic (Sonar5-Pro) and manual (SMC) fish descriptors were compared using a Wilcoxon signed-rank test (Wilcoxon, 1945) and a Student's t-test depending upon the presence or absence of a normal distribution. Linear regressions were used to evaluate the relationship between certain (continuous) descriptors, such as fish position and orientation in the beam, the number of echoes during fish tracking, manually measured fish length, and the difference between Sonar5-Pro's automatic fish-length estimates and manual estimates with SMC (dependent variable). The best fitting model with one explanatory variable was selected using the Akaike Information Criteria (AIC) (Akaike, 1987). To evaluate the significance of each explanatory variable, an analysis of variance (ANOVA) between the null model and each single variable linear regression was used.

Table 1. Visual checking of targets automatically tracked by Sonar5-Pro by use of SMC software.

True type of target	Number	Percentage
Individual fish passage	120	48%
Fish already tracked (multiple counting)	59	24%
Aggregation of small fish	54	22%
Drifting objects	12	5%
Artefact	3	1%
Automatically tracked targets	248	100%

3 Results

3.1 Automatic fish tracking efficiency

Overall, 248 targets were automatically tracked. Using SMC software to manually check the nature of the targets, 52% of those targets were considered to represent several individuals (Tab. 1). The four types of errors Sonar5-Pro made were: confusing fish and other targets, multiple counting of the same fish (24%), aggregation of 2–3 small fish of a school into one single target (22%), tracking of drifting objects (5%), and tracking of the fish acoustic shadow (1%). The main part corresponded to individual fish echoes, but 24% were counted twice in different frames. Full manual analysis of all files by the operator identified 123 fish >35 cm in the detection beam, while 120 were detected in the database exported from the Sonar5-Pro automatic tracking tool (97.6% agreement). The first three fish not tracked by Sonar5-Pro moved downstream at a range of 15 m, leading to non-continuous visible movement into the detection beam. The second (52 cm) and the third (48 cm) untracked fish had similar behaviour: they swam downstream, but turned back in the left part of the detection beam without crossing the central beam.

3.2 Accuracy of descriptors

3.2.1 Behavioural characteristics

Descriptors for the 179 fish tracked by the Sonar5-Pro tool were compared to the information extracted with the SMC software. The 179 fish represented 120 individual fish targets and 59 multiple-counted fish targets seen at different times. Comparing the *Velocity* parameter to visual behavioural observation showed good agreement between these quantitative and qualitative variables (Fig. 3). As expected, the *Velocity* values were mainly positive (89%) when the fish moved downstream (mean velocity 0.25 $m\,s^{-1}$) and were negative or null (91%) when they moved upstream (mean velocity $-0.12\,m\,s^{-1}$). Erratic behaviour was defined by a zero *Velocity* value (mean velocity 0.00 $m\,s^{-1}$). Distributions of *Velocity* were significantly different according to the true

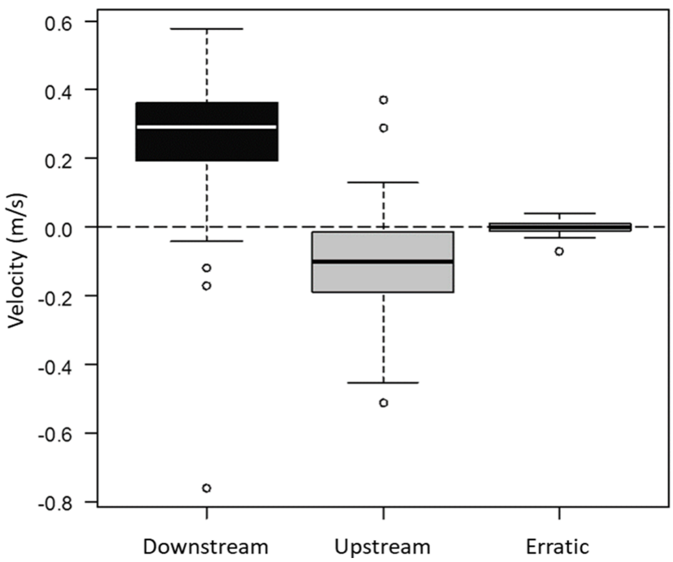

Fig. 3. Boxplot of the *Velocity* ($m\,s^{-1}$) as a function of the visual description of the swimming direction of the 179 automatically tracked fish (downstream: $n = 75$; upstream: $n = 95$; erratic behaviour: $n = 9$).

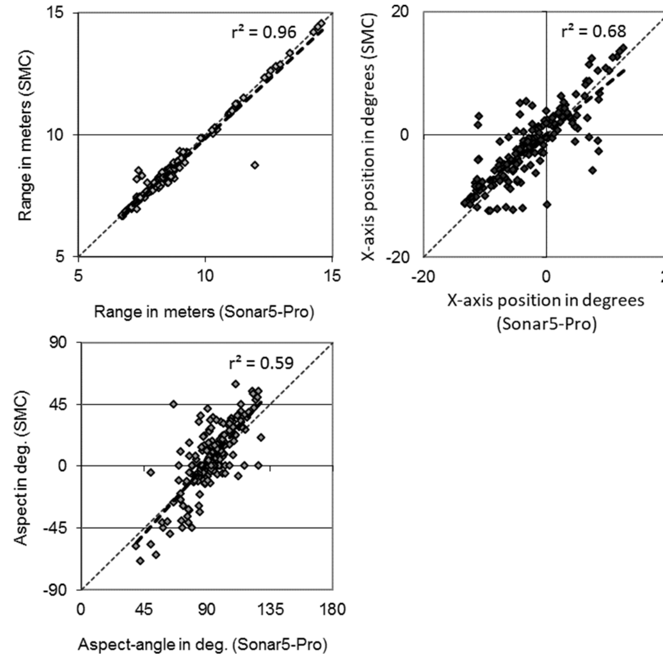

Fig. 4. Correlation between parameters exported from SMC software and those exported by Sonar5-Pro software for the same fish ($n = 179$). From left to right: detection range (m); angular X-axis position (degrees); fish body angle in the beam (degrees); 90° aspect angle means that the fish body was perpendicular to the central DIDSON beam.

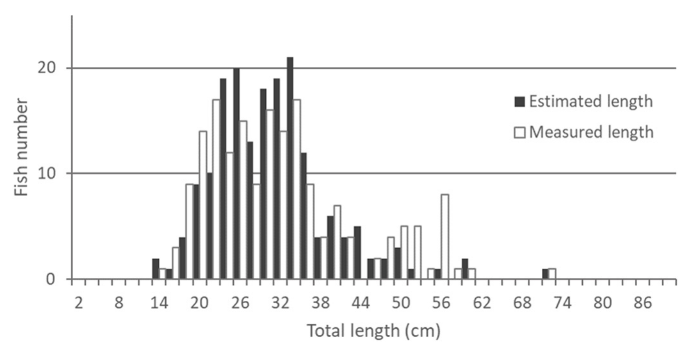

Fig. 5. Mean length distribution estimated by the Sonar5-Pro software and measured manually with SMC software for the 179 individual fish tracked by the Sonar5-Pro DIDSON tool.

swimming direction of fish ($p < 0.05$). Most fish moving downstream had a speed of 0.2 to $0.4\,m\,s^{-1}$, which corresponded to the flow velocity recorded at the site during at the time. Most of these fish drifted with the flow through the detection beam. For 91% of fish moving upstream, the *Velocity* range values included zero, while for 76% of fish values were strictly negative.

Significant correlations were found between fish range ($r^2 = 0.96$) *x*-axis position ($r^2 = 0.68$) and aspect angle ($r^2 = 0.59$) measured with Sonar5-Pro and the same descriptors calculated from the manually drawn line along the fish body using SMC software, demonstrating the reliability of the Sonar5-Pro software tool (Fig. 4). SMC software calculated these descriptors from only one annotated frame. Conversely, fish position using Sonar5-Pro tracking was measured during the entire trajectory in the beam and then averaged. These methodological differences influenced estimates, particularly for fish that did not have a constant and linear trajectory in the beam.

3.2.2 Morphological descriptors

No significant difference was observed between the overall estimated length distribution exported from Sonar5-Pro (arithmetic means of all detections for the same individual), and the manually measured length distribution using SMC (Wilcoxon test, $p = 0.90$). Both distributions showed a mode between 25 cm and 35 cm (Fig. 5). Even when the tool configuration focused analysis on fish larger than 35 cm with the 17-sample length limitation, 80% of the tracked fish were smaller than this threshold.

In contrast, the linear regressions revealed the significant influence of two descriptors on the difference between individual Sonar5-Pro automatic fish length estimates and manual SMC length estimates. The most important explanatory variable was fish length itself (Fig. 6A): the larger the fish, the more its length was underestimated by Sonar5-Pro ($r^2 = 0.47$; $p < 0.05$). The second descriptor was the angular deviation of a fish's perpendicular passage relative to the central axis of the detection beam ($r^2 = 0.29$; $p < 0.05$). Individuals for which length was most underestimated were those tracked during oblique movement (angle >20°) into the beam (Fig. 6B). Other descriptors such as swimming speed, the number of echoes or the detection range of the fish were not significant ($p > 0.05$).

The absolute bias in Sonar5-Pro fish length estimates became much larger for fish above around 45 cm (Fig. 7). The smaller fish (15 to 45 cm, $n = 152$) estimated length was significantly correlated with measured length ($r^2 = 0.53$). For

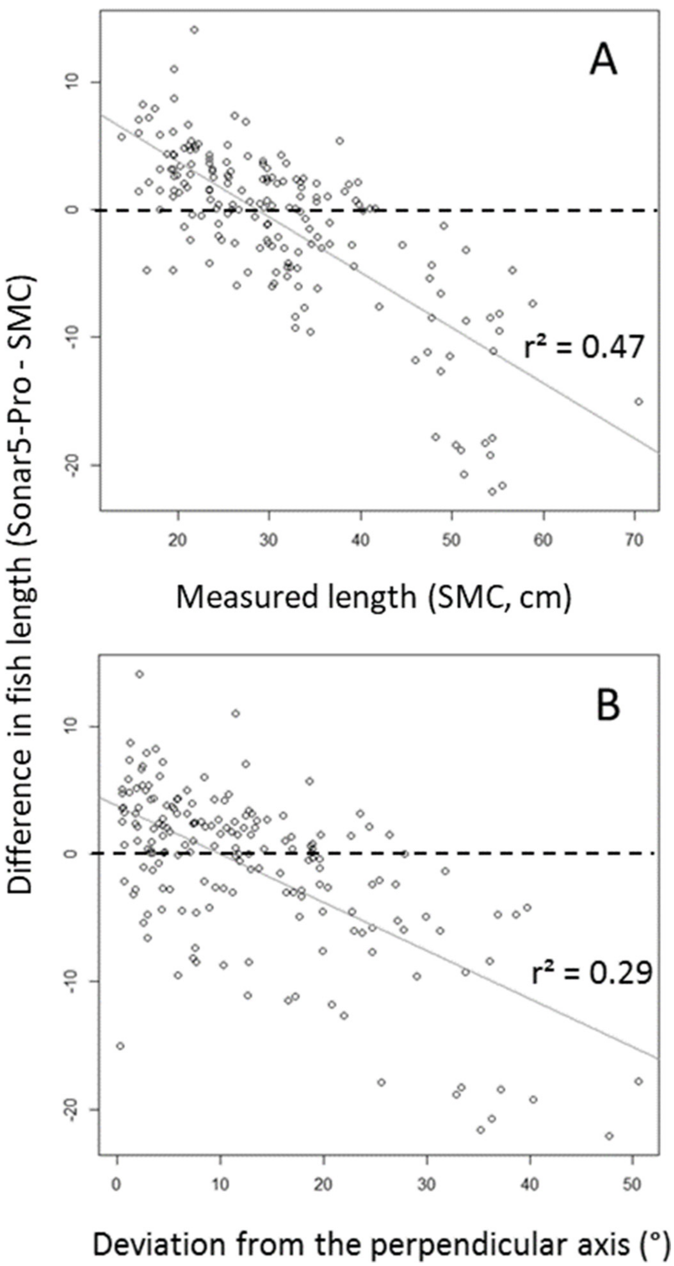

Fig. 6. Evaluation of the accuracy of the Sonar5-Pro exported length as a function of (A) measured fish length (cm), and (B) fish body angle (degrees) ($n = 179$). Line represents linear regression.

80% among these fish, the difference between measured and estimated length for these fish was less than 10 cm, with the mean absolute value of 3.9 cm not being significantly different from zero ($p = 0.20$) with a mean relative difference of 15.7%. Conversely, the length of fish larger than 45 cm ($n = 27$) was significantly underestimated by Sonar5-Pro (mean relative difference = 26.4%; mean absolute difference = 13.7 cm, $p < 0.05$). For this length category, the correlation between the estimated and measured length was not significant ($r^2 = 0.11$). A linear regression for fish larger than 45 cm provided insights into the reasons (Fig. 8A), confirming that fish body orientation was the main cause of underestimation by the Sonar5-Pro automatic tracking tool ($p < 0.05$). No significant relationship was identified in a linear regression focused on fish smaller than 45 cm (Fig. 8B).

These results showed that absolute accuracy in estimated fish length was higher for smaller fish as well as for larger fish moving perpendicularly to the central axis of the detection beam. The more a large fish followed an oblique trajectory, the more underestimated its length was by Sonar5-Pro.

4 Discussion

In long-term monitoring and in fisheries management studies, the time spent analysing data is an important parameter to consider. Long-term studies generate a large amount of data, thus time spent to analyse them should be efficient and fisheries managers often need rapid responses to implement adequate management measures, notably for diadromous species, which are often threatened. However, while acoustic cameras are useful for monitoring fish populations, they produce very large amounts of data. Different analysis protocols are available for DIDSON users, such as data sub-sampling (Davies and Griffith, 2011) or pairing with another estimation method, such as visual counting (Holmes et al., 2006) or optical cameras (Moursund, 2003). In contrast, automatic tracking processes allow file reading, data pre-processing (e.g. for fish detection) and database creation to remain independent from other methods.

This study demonstrated the potential of the Sonar5-Pro software for analysis of DIDSON data. The availability of many settings offers possibilities for users to adapt this tool to particular study conditions, such as the site configuration, the studied species or the information to extract from the data. The large number of descriptors allows the user to extract nearly all quantitative information contained in DIDSON files. Incorporating tracking results into a database is easy and effective. After two levels of settings, the automatic tracking tool starts to read the dataset and records all tracked targets that correspond to the chosen filters.

Our results showed that fish larger than 35 cm are generally well detected and tracked by the Sonar5-Pro tool, allowing reliable counting of fish. In the study, only 3% of fish passing into the beam were not identified because fish detection was limited for individuals not crossing the central beam. However, it appears that more than half of the tracked targets were not individual fish when compared to the reading of the DIDSON files by an operator. This mismatch was due to three factors: multiple counting, aggregations, and artefacts. Firstly, some fish that do not have constant movement in the beam, or whose detection is cut by an artefact or an acoustic shadow, may be tracked multiple times. Changes in swimming speed or direction, as well as missing a fish in one or more consecutive beams, are other causes for multiple counting by the Sonar5-Pro software. In all, 24% of the targets from our database were counted several times. Then, when two fish are so close in the beam that their pixel clusters are contiguous, Sonar5-Pro detects only one fish. In our dataset, 22% of the tracked targets resulted from such aggregations. Lastly, other false-positive targets, such as drifting objects (5% of the database) or acoustic shadows (1%), were observed. This factor was

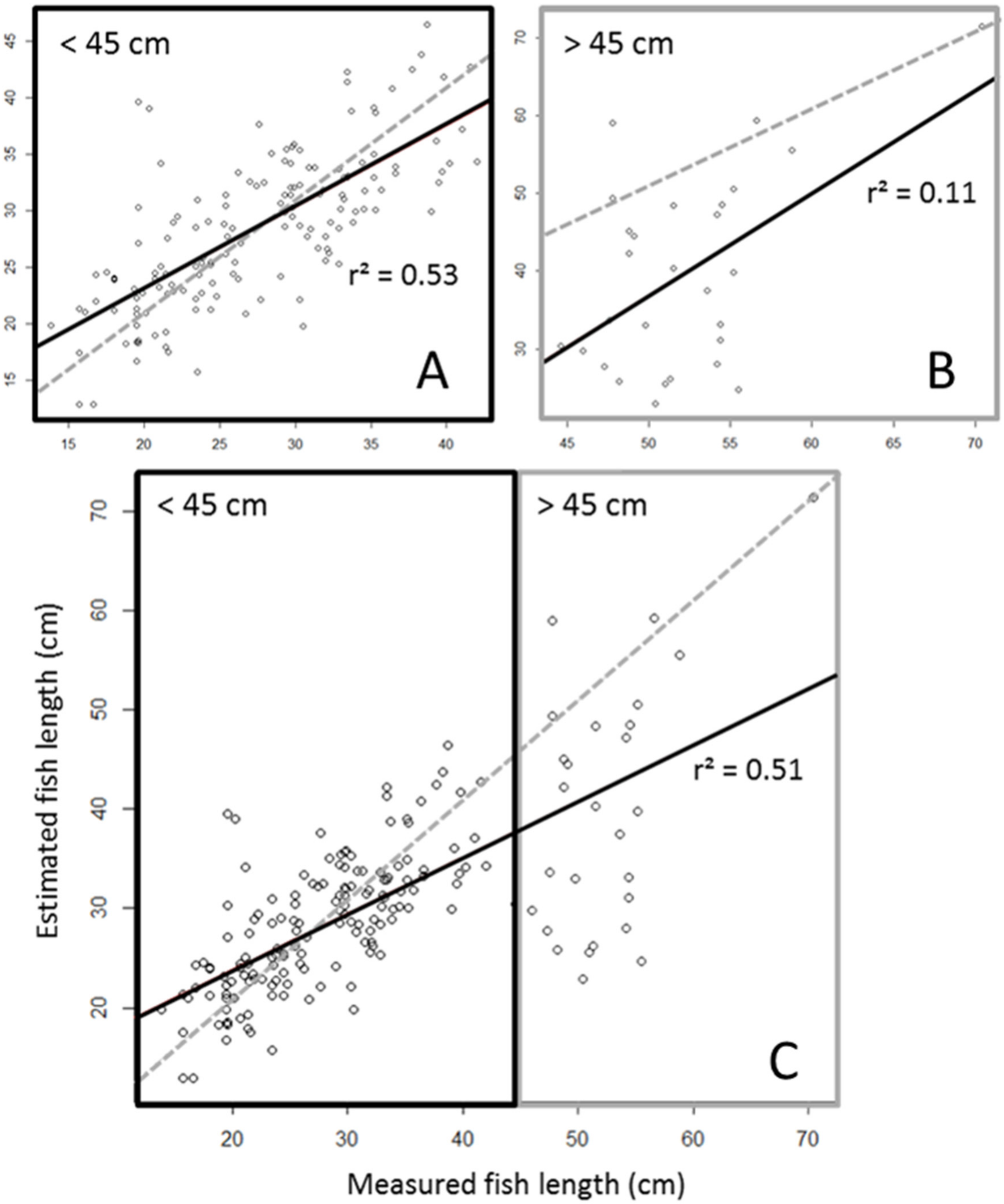

Fig. 7. Correlation between fish length estimated by the Sonar5-Pro tool and fish length measured manually using SMC software for (A) fish < 45 cm ($n = 152$); (B) fish > 45 cm ($n = 27$); (C) all the fish ($n = 179$). Grey dashed lines represent 1:1 line.

negligible because the study was carried in a low flow period. Conversely, Martignac (2016) showed that during high-flow conditions, overestimation of fish abundance is much higher: of more than 2100 targets exported using the Sonar5-Pro software, only three were actual fish that moved into the beam (Martignac, 2016). In these particular conditions, during which biological activity is greatly reduced (Cunjak, 1996), the drifting of fine sediment clouds represents most of the identified targets. Although the fish-detection rate of the tracking tool is high, target abundance differs greatly from true fish abundance as counted manually.

Both behavioural and morphological characteristics can be measured using Sonar5-Pro. Fish swimming behaviour is derived from consecutive positions by collecting information about fish swimming speed, its trajectory through the beam, the angle of the fish in the beam, and its direction. The comparison of calculated and observed swimming directions showed the high reliability of this parameter, which is essential in monitoring studies of diadromous fish during their migration. SMC software uses observations from one single frame, while Sonar5-Pro provides behavioural descriptors based on all frames of each fish detected in the DIDSON beam.

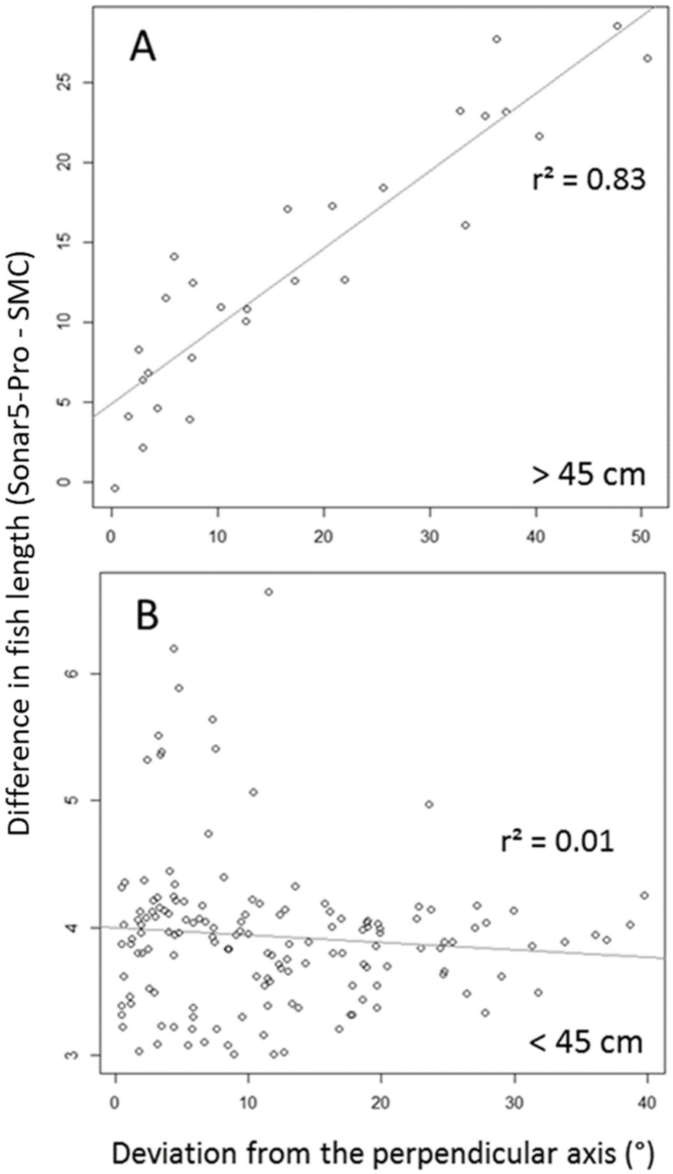

Fig. 8. Evaluation of the influence of fish body orientation deviating from the perpendicular beam axis (degrees) on the accuracy of estimated length by Sonar5-Pro, as a function of manually measured fish length. (A) fish < 45 cm (n = 152); (B) fish > 45 cm (n = 27).

Fish length is important for identifying or distinguishing species. With SMC software, fish length is directly measured on the DIDSON video. Some studies showed that these measured lengths are close to true lengths (Burwen et al., 2010; Hightower et al., 2013; Holmes et al., 2006), although high intra- and inter-user variability can require repeating manual measurements to increase accuracy (Daroux et al., 2019). Sonar5-Pro uses an algorithm to detect each fish and to create a backbone along its body according to the brightness of contiguous video pixels. The fish are then tracked on consecutive frames. Length estimation is based on all fish backbone lengths during the entire track. Our results revealed that fish lengths are accurate for the smallest fish (smaller than 0.45 m) with a mean relative difference of 15.7% (i.e., from 2.3 cm for a 15-cm fish to 7 cm for a 45-cm fish), but can be largely underestimated for larger fish under certain conditions (e.g., up to 30 cm difference for a 55 cm fish, i.e. 55% difference). Neither detection range, swimming speed, nor the number of consecutive frames in which the fish was tracked explained the bias in length estimates for fish larger than 45 cm. In contrast, a clear relationship was found between fish body angle in the beam and the underestimation of its length. This result is due to the fact when a fish moves perpendicular (90°) to the beam's central axis, its entire body is clearly visible and consequently, Sonar5-Pro's length estimate is accurate, while it was biased for fish swimming at other angles. The larger the deviation from 90°, the less the edges of a fish's body can be observed. Sonar5-Pro software suffers from this loss in image intensity, which decreases the physical connectivity between the fish body and its caudal fin in DIDSON pictures. Importantly, in DIDSON videos, the extremities of fish moving transversally are darker than the rest of its body. This phenomenon causes Sonar5-Pro to underestimate fish length. This result is consistent with results from other studies showing that, with Sonar5-Pro software, fish body deviation from a perpendicular orientation decreases length measurement accuracy for acoustic camera data (Burwen et al., 2010; Cook et al., 2019; Tušer et al., 2014). Conversely, for SMC software, the high accuracy of manual length measurements in DIDSON files is due to operator skill, compensating for the decrease in caudal-fin pixel brightness by observing fish body undulation in consecutive frames. Moreover, with SMC software, the operator is able to choose the most representative frame for each fish. The ability to export a maximum calculated length might be a relevant solution to improve the accuracy of fish measurements by Sonar5-Pro, this value being most likely calculated for a position of the fish close to perpendicular to the sonar central beam axis.

Other methods have been developed for automatic analysis of acoustic camera data, e.g. using Echoview (Boswell et al., 2008; Eggleston et al., 2020; Helminen and Linnansaari, 2021; Kang, 2011) or custom code in Matlab (Kupilik and Petersen, 2014). The efficiency of Sonar5-Pro to evaluate swimming direction is similar to the procedure developed by Helminen and Linnansaari, 2021, while multiple counting appears to be a shared limitation between the different methods (Helminen and Linnansaari, 2021; Petreman et al., 2014). However, to efficiently compare different approaches, their contributions and their limitations, they have to be applied to a common acoustic camera dataset. A collaborative work should be the next key step to identify or to design the most optimised method to automatically analyse large datasets recorded by acoustic cameras, in order to correctly estimate fish abundances and to accurately calculate their morphological and behavioural characteristics.

The Sonar5-Pro® automatic tracking tool for DIDSON data can be considered a useful approach for the analysis of DIDSON long-term datasets. Our study showed that the automatic tracking tool of Sonar5-Pro software can analyse the same DIDSON files in about a third of the time that it takes an operator. Image conversion and automatic tracking analysis are automated processes, with the user monitoring the software to identify unexpected issues. Exporting the tracked-target data from Sonar5-Pro is quick and easy. The last step, validating each target in the raw files using SMC software, is the most time-consuming. Unfortunately, Sonar5-Pro does not contain a video reader as easy to use as SMC software. The visualisation of each identified target directly on the same software would speed up the validation process.

At this step, users can adapt the selectivity threshold to the purpose of the study and conditions of the monitoring site. Thus, in the Sélune River case study used here, it was important to be able to identify salmon at low abundance among the multi-species fish community. Previously available tools, such as the CSOT tool in SMC software, are not efficient enough to compress the dataset to only frames with fauna activity, and thus to decrease the time spent by the operator during reading. Sonar5-Pro offers an alternative that acts as a pre-filter of the raw files and identifies several periods of high activity of the study species. An operator can then correct most of the identified issues, such as overestimated fish abundance or high uncertainty in estimated fish length.

In conclusion, this study demonstrated the potential of Sonar5-Pro, although additional studies and tools are required to increase its efficiency in describing fish populations. Counting fish with non-intrusive tools is an effective way to monitor threatened fish populations and will help to preserve and manage these species. The development of advanced automatic protocols will greatly improve their future use.

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