How much fish is hidden in the surface and bottom acoustic blind zones?

Carla Scalabrin, Christian Marfia, and Jean Boucher

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This paper presents results from the ALLEGRO-07 survey that was carried out from 1 to 15 September 2007 across the continental shelf in the Bay of Biscay by the RV “Thalassa”. The main objectives were to conduct experiments with a medium-sized, autonomous underwater vehicle (AUV) equipped with a fishery-acoustic scientific payload. This was needed to overcome the difficulties of sampling the surface and bottom blind zones, which are inaccessible to conventional, vessel-mounted transducers used for acoustic surveys in the Bay of Biscay. The AUV acoustic datasets from four dives were compared with those from the research vessel. The results were expressed for the nautical-area-scattering coefficient (s_A) and biomass estimates. The AUV provided higher s_A measurements than did the vessel. For particular environmental and fish-distribution patterns, the biomass estimated by the AUV was more than ten times that estimated by the vessel alone. The results presented indicate the magnitude of the error that may occur in acoustic surveys, if the biomass in the two blind zones is undetected.

Keywords: acoustic blind zone, anchovy, autonomous underwater vehicles, Bay of Biscay, hake.

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Introduction

Since the early 1990s, several research programmes have been carried out with autonomous underwater vehicles (AUVs) to explore different ocean features. Most of these were demonstration vehicles rather than operational platforms (Bellingham and Rajan, 2007). Until now, only two AUVs have been used as platforms for fishery-acoustic systems providing experimental data reported in the literature. These are the AUTOSUB (Fernandes *et al.*, 2000) and the HUGIN (Patel *et al.*, 2004). Both are rather large and heavy systems (>2 t) that carry sophisticated payloads, such as scientific echosounders. The AUTOSUB was equipped with a Simrad EK-500 operating with upward- or downward-looking transducers at 38 and 120 kHz and has been used to acquire acoustic data on schools of North Sea herring to study vessel-avoidance problems (Fernandes *et al.*, 2000, 2003) and to estimate the acoustic density and avoidance behaviour of krill under the Antarctic ice (Brierley *et al.*, 2002, 2003). The concept of exploring under-ice features with an AUV has also been considered for future space missions, such as the NEMO project, which aims to find life on Europa, a satellite of the planet Jupiter (Powell *et al.*, 2005). The HUGIN vehicle was equipped with a Simrad EK-60 echosounder and a 38-kHz, downward-looking transducer. It has been used to observe the behaviour of a large herring school in response to its own presence (Patel *et al.*, 2004).

Acoustic surveys have been used for several decades as a non-intrusive method to establish fishery-independent assessments of marine resources (MacLennan and Simmonds, 1992) and for ecosystem studies, including plankton (MacLennan and Holliday, 1996). However, hull-mounted acoustic sensors on research vessels cannot provide data on fish close to the sea surface, because of the limitations of the acoustic nearfield. In addition, the detection of fish close to the surface may be perturbed by avoidance behaviour resulting from water-flow disturbances generated by hull movements and by vessel-radiated noise (Mitson, 1995; Soria *et al.*, 1996). This upper layer is called the “surface blind zone”, and it can extend to $\sim$15 m below the surface, depending on the acoustic frequency, the draft of the vessel, and the sea state. The anchovy (*Engraulis encrasicolus*) is an important pelagic species in the Bay of Biscay (ICES, 2007). Its fishery collapsed in 2005 (Borja *et al.*, 2008; Ibaibarriaga *et al.*, 2008) and has been closed since 2006. Previous studies conducted in the Bay of Biscay provided evidence of high abundances of juvenile anchovy in the first 25 m below the surface (Carrera *et al.*, 2006), but it has not been possible to take full account of the upper 10 m in the abundance estimates, because of the problem of the surface blind zone.

Another constraint of hull-mounted transducers concerns the detection of demersal fish living close to the bottom or only a few metres above it. Over the continental shelf, useful detections of fish, such as hake or cod, may not be possible, if they are located within $\sim$2 m of the bottom. This region is known as the “bottom dead zone” (Ona and Mitson, 1996), but in this paper, it is called the “bottom acoustic blind zone”. Its volume depends on the beam pattern, pulse duration, and bottom slope, and it increases with depth. The vertical resolution between fish and bottom echoes depends on the pulse duration; the shorter the pulse the higher the capacity to discriminate fish close to the seabed. The minimum discrimination distance must be greater than the dorsal–ventral height of the fish, plus half of the pulse length (Ona and Mitson, 1996). For instance, considering a 0.1-m dorsal–ventral fish height and pulse durations of 1024 and 256 μs, the minimum distances between the fish and the seabed to resolve their echoes cannot be <0.86 and 0.30 m, respectively. Hake (*Merluccius merluccius*) is one of several demersal species in the Bay of Biscay that are assessed by ICES. The spawning-stock biomass has declined from the mid-1980s to the beginning of the 1990s, and has since remained low, despite a recovery plan implemented by the EU Commission in 2004 (De Pontual *et al.*, 2006). The European project CATEFA (Bez *et al.*, 2007) studied the relationship between simultaneous observations of fish with hull-mounted acoustics and bottom trawls. The conclusions of CATEFA were that both acoustic and trawl surveys are imperfect samplers of the true situation near the bottom. Problems of avoidance, herding, and escapement affect these tools in different ways. Essentially, both produce noisy results. An obvious remedy is to reduce the noise. This requires better understanding of the "whole-gear" selectivity and novel acoustic methods that would, for example, reduce the blind-zone detection problem. The overall negative tone of the CATEFA report emphasizes the difficulties encountered when using hull-mounted acoustics for detecting demersal fish.

Short pulses offer high-resolution data, but this raises the problem of the acoustic frequency that determines the useful range, i.e. the maximum distance at which targets can be distinguished from noise. Shorter pulses are possible at higher frequencies, but then the useful range becomes smaller. Therefore, the detection of fish resources on the continental slope, or in deeper water, by acoustic instruments on a vessel is conditioned to rather low frequencies, long pulse lengths, and poor vertical resolution, which limit the discrimination of fish and seabed echoes. Moreover, because of the large beam coverage and the irregular seabed topography in deep water, it might be impossible to provide useful acoustic estimates of fish abundance from these poorly understood ecosystems.

The increasing interest in using AUVs as acoustic platforms is motivated essentially by the possibilities for better sampling of the acoustic blind zones and hostile environments, as well as observations of fish behaviour or avoidance reactions at short target ranges. Increased use could also improve the sampling efficiency of acoustic surveys that have to cover larger areas, so improving the accuracy of fish-abundance estimates.

The Ifremer fishery-acoustics AUV project was established in 2002, within the framework of the "Défi Golfe de Gascogne" programme which, after the required technological developments had been made, became operational in 2004. The ALLEGRO survey was originally planned for 2004, but for reasons unrelated to the AUV development, it was delayed until 2007. The main objectives of ALLEGRO were to perform experiments using a medium-sized AUV equipped with a fishery-acoustics scientific payload aimed at better sampling of the surface and bottom blind zones in the continental-shelf waters of the Bay of Biscay.

Material and methods

The ALLEGRO experimental survey was carried out from 1 to 15 September 2007 by RV "Thalassa", which was equipped with five Simrad ER-60 echosounders operating at 18, 38, 70, 120, and 200 kHz, and the first version of the multibeam echosounder ME-70. The acoustic data from each hull-mounted transducer were continuously recorded throughout the survey. The AUV used during the survey, hereafter called the IdefX, was an EXPLORER 3000 developed by ISE (Canada) to an Ifremer specification based on its scientific requirements (Figure 1). It is a medium-sized vehicle (<1 t) that can operate down to 3000-m depth and has an autonomous range of 45 km, operating at a speed of 5 knots. IdefX was equipped with navigation, acoustic-positioning, and telemetry systems and was powered by lithium-ion batteries. Five "fins" allowed the control of heading, pitch, roll, depth, or altitude according to the mission programme. The depth of IdefX could be controlled by auto-altitude or auto-immersion programmes; therefore, the vehicle could either follow the bottom echo or maintain its depth at a predetermined distance. The fishery-acoustics payload comprised two calibrated Simrad ER-60 echosounders operating with a 70 kHz, a customized TRANSONICS transducer, and a 200-kHz Simrad deep-water transducer. These are circular split-beam transducers, with a beam width of 7°. Dedicated software specially developed for the purpose achieved the remote and autonomous control of the echosounders. Pulse transmissions were triggered in a synchronized manner to prevent interference with the ADCP. The position of the transducers and their orientation on the AUV were set according to the following alternative configurations as illustrated in Figure 2, with X: 200 kHz upward-looking towards the surface; and 70 kHz downward-looking towards the bottom; W: both transducers are upward-looking towards the surface; M: both transducers are downward-looking towards the bottom.

Figure 1. The AUV EXPLORER 3000 being recovered during the ALLEGRO survey; the windspeed is 22 knots.

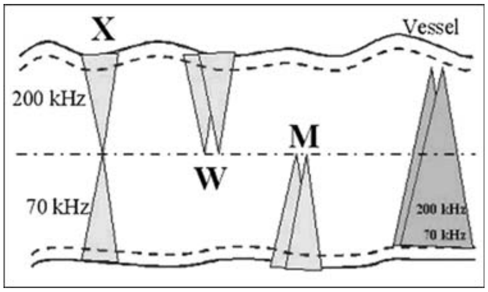


Figure 2. The position and orientation of the transducers on the AUV according to the X, W, and M configurations.

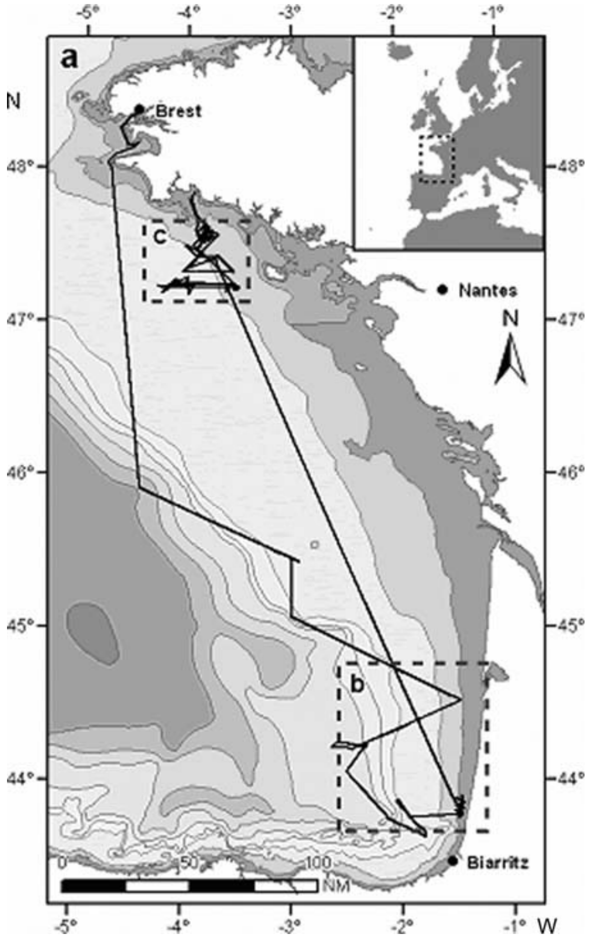


Figure 3. (a) A map of the area covered by the ALLEGRO survey identified in the small-scale inset; (b) the southeastern zone of the Bay of Biscay—location of dives 1 and 2; and (c) the Glénan and Belle-Île zones—location of dives 3 and 4.

The survey area was divided into three zones according to the expected fish distribution: (i) the southeastern zone of the Bay of Biscay, including the edge of the continental shelf, where juvenile anchovy schools are usually found at this time of year; (ii) the Glénan coastal zone in the north of the Bay of Biscay, where pelagic fish are often found; and (iii) the Belle-Île zone, an interesting area for demersal fish (Figure 3). Nine dives were completed with the fishery-acoustics payload, covering a total distance of 180 nautical miles. Only the results of the four most representative dives are presented here (Table 1). The experimental survey design was similar to that reported by Fernandes *et al.* (2003), where the AUV measured acoustic densities at a position 500 m ahead of the vessel on the same transect. For each dive, the transect length was 20 nautical miles covered at a speed of four knots, except for the dive on 11 September when the transect was 30 nautical miles at a speed of three knots. For the later data analysis, this dive was considered as two sections of similar length.

Ground-truthing data for echotrace identification and biological parameters (total length and mass of fish) were obtained from pelagic, surface-pelagic, and bottom trawls (Table 1). Fishing operations were carried out before or after each dive, along the same transect. Acoustic data from the hull-mounted and AUV echosounders were processed with MOVIES+ software (Weill *et al.*,

Table 1. Range of bottom depths during the dive, transducer orientation, and the position of the AUV in the water column (see text), as configured for the dive; pulse duration (τ), and ping interval for the AUV and vessel 70–200-kHz channels, and ground-truth results for each dive.

Dive	Bottom depths (m)	Dive configuration	AUV τ (μs)	Vessel τ (μs)	AUV ping interval (s)	Vessel ping interval (s)	Ground truth
Dive 1: 3 September, 13:43–18:43	140–89	X, auto-immersion 50 m	512	1 024	0.5	0.8	Hook fishing at the surface: *K. pelamis* Pelagic trawl close to the bottom: small hake and blue whiting
Dive 2: 4 September, 10:04–15:20	>200–130	W, auto-immersion 60 m	512	1 024	0.5	0.5	Surface pelagic trawl: krill
Dive 3: 9 September, 12:10–17:02	75–96	X, auto-altitude 40 m	512	1 024	0.5	0.5	Surface pelagic trawl: 90 kg 98% anchovy Pelagic trawl close to the bottom: 400 kg 94% *S. scombrus*
Dive 4: 11 September, 07:23–17:03	94–122	M, auto-altitude 30 m	256	1 024	0.3	0.5	Pelagic trawl close to the bottom: 10 kg 97% hake

1993; Berger *et al.*, 2007) adapted to take account of the transducer orientation for the X and W configurations. For comparison between AUV and vessel acoustics, only data at 70 and 200 kHz were considered. The four datasets were processed by the standard method of echo-integration within depth layers, using an elementary sampling unit (ESU) of 0.1 nautical miles. The surface offset for the vessel data was the vessel draft plus the transducer nearfield range; for the AUV data it was the depth of the wind-generated surface roughness determined from the echo-recordings. The bottom offsets were 1 and 0.5 m for the vessel and AUV data, respectively. However, no offset was required when the AUV was close to a flat bottom. The threshold on the volume-backscattering strength was set to −60 dB to eliminate plankton echoes.

To verify the vertical distribution of targets in the water column, nautical-area-scattering coefficients (NASC, s_A, m^2 nautical mile^{-2}) by depth bins were averaged over the whole dive for each dataset. The s_A-averaged profiles indicate the vertical-distribution patterns of targets and whether the AUV may provide helpful information concerning the surface and bottom blind zones. About the W and M configurations, the profiles also indicated whether the AUV had missed targets outside its detection volume. The horizontal alignment among datasets was not considered, because of the 500-m distance between the AUV and the vessel.

For statistical comparison, data were averaged by ESU over intervals of one nautical mile to ensure sample independence. This was confirmed by a "runs test" at a significance level of 0.05 (Bendat and Piersol, 1986) with data aggregated into equivalent vertical-sampling strata. Therefore, for the X-dive configuration (see above), the 200-kHz data from both platforms were aggregated from the AUV depth to the surface, whereas the 70-kHz data were aggregated from the AUV depth to the bottom. For the W and M dive configurations, the considered vertical strata extended, respectively, from the surface to the AUV position and from there to the bottom.

Results

As an overall trend (Table 2), the AUV provided higher s_A measurements than the vessel. The large standard deviations of the pelagic s_A distributions, compared with the 200-kHz channels of dives 1, 2, and 3, were generated by fish schools observed along the dive transects, reflecting the usual patchiness observed in such data. Conversely, the demersal data displayed less patchiness with lower standard deviations (dive 4).

Dive 1 (3 September) was carried out in the southeastern zone of the Bay of Biscay, from the edge of the continental shelf towards the coast using the X configuration. The AUV surveyed at a constant depth of 50 m over bottoms ranging from 90 to 140 m. A pelagic trawl fishing close to the bottom caught small quantities of young hake (*M. merluccius*) and blue whiting (*Micromesistius poutassou*). Along the dive transect, many dolphins and birds were observed from the vessel, as well as tuna schools at the surface. The tuna species *Katsuwonus pelamis* was identified by hook fishing from the vessel. These schools were in the surface blind zone of the vessel, but they were successfully detected by the AUV, which explains the difference between the s_A profiles at 200 kHz (Figure 4). Figure 5 shows the composite echogram of both AUV channels, separated by the AUV immersion line, and an expanded view of one tuna school detected during the dive. This school was close to the surface, and the dimensions of the acoustic image were ~100-m long × 5-m high. Since the AUV was far from the bottom, the differences between the downward-looking 70-kHz channels were less significant (Table 2).

Dive 2 (4 September) was carried out in the same area, but it progressed from offshore towards the middle part of the continental shelf, using the W configuration. The AUV surveyed at a constant depth of 60 m over bottoms varying from 130 to 1000 m. The surface echo detected by the AUV was very wide, because of the surface roughness generated by the wind (Figures 1 and 6). In addition to an offset of 6 m, the surface echo was scrutinized to remove false surface detections. Juvenile anchovy schools had been expected in this area, but a near-surface pelagic trawl caught only a small amount of krill. Both AUV channels presented higher acoustic densities than those of the vessel (Figure 7), although the Kolmogorov–Smirnov *p*-value of the 200-kHz channels was high (Table 2). The vertical profiles of the AUV channels were quite different. At 70 kHz, there was a smooth decrease of acoustic density from the surface to 60-m depth, whereas at 200 kHz, there were maxima at the surface and ~30-m depth. The schools located at 30-m depth were indeed hardly detected on the 70-kHz channel (Figure 6). Because of the use of the W configuration, frequency differences could be observed between 200 and 70 kHz, as would be expected for krill backscattering (Table 2).

Dive 3 (9 September) was carried out near the Glénan archipelago in the northeastern sector of the Bay of Biscay using the X configuration. The dive was a round trip of 20 nautical miles starting and ending at the same position with the AUV at a constant altitude of 40 m over bottom depths ranging from 75 to 96 m. Two trawls were made for the ground-truthing of fish close to the surface and the bottom. They caught anchovy (*E. encrasicolus*) at the surface and Atlantic mackerel (*Scomber scombrus*) near the bottom. The fish located beyond 70 m were similarly detected by the vessel and the AUV at 70 kHz (Table 2). However, considering only the data from the near-surface layer sampled by both 200-kHz

Table 2. Statistics of the s_A measured by the AUV and vessel 70- and 200-kHz channels.

		Vertical strata 200 kHz			Vertical strata 70 kHz		
Dive	***n***	**AUV**	**Vessel**	***p*-value**	**AUV**	**Vessel**	***p*-value**
Dive 1: X auto-immersion 50 m	19	105 ± 178, *25*	8 ± 4, *6*	<0.001	161 ± 242, *35*	99 ± 268, *22*	0.40
Dive 2: W auto-immersion 60 m	20	178 ± 320, *21*	65 ± 118, *10*	0.59	44 ± 27, *31*	12 ± 21, *2*	<0.001
Dive 3: X auto-altitude 40 m	18	100 ± 101, *85*	7 ± 7, *5*	<0.001	174 ± 226, *111*	159 ± 175, *129*	0.71
Dive 4: M auto-altitude 30 m	12	36 ± 7, *35*	5 ± 3, *4*	<0.001	9 ± 2, *9*	4 ± 3, *3*	<0.001

s_A values (m^2 nautical mile^{-2}) provided by using an elementary sampling unit (ESU) of one nautical mile along the dive (n = number of ESUs).
Vertical-strata statistics (mean ± standard deviation, *median*) correspond to data aggregated into equivalent vertical-sampling strata for the AUV and vessel channels according to the dive configuration (see text); *p*-values from the two-sample Kolmogorov–Smirnov test performed at a significance level of 0.01.

echosounders, there was a significant difference between the s_A profiles (Figure 8). In this case, the AUV profile had a maximum s_A at 10-m depth, which was the lower limit of the surface blind zone of the vessel. In addition, down to 30-m depth, the s_A values from the AUV were higher than those of the vessel were.

To estimate how much fish was hidden or undetected in the surface blind zone of the vessel, biomass estimates were computed using data from both 200-kHz channels assuming that the fish is anchovy (Figure 9). The considered depth stratum extended from the surface down to the depth of the AUV; the corresponding mean s_A of the AUV and the vessel were 99 and 7 m^2 nautical mile^{-2}, respectively (Table 2). The biomass was estimated using the target-strength relationship $TS = 20 \log L - 71.9$ dB, with L the fish length in centimetres (Foote, 1987). The mean length (18 cm) and mass (41 g) of anchovy were obtained from the trawl catches. Over the whole dive distance, anchovy densities indicated by the AUV and the vessel were 16 630 and 1193 kg nautical mile^{-2}, respectively. This large difference was attributed to anchovy schools in the surface blind zone of the vessel, with some contribution from other schools down to 30-m depth. Therefore, the surface blind zone alone cannot explain why the AUV biomass was 14 times higher than the vessel biomass, suggesting that fish avoidance of the vessel must also have been an important factor.

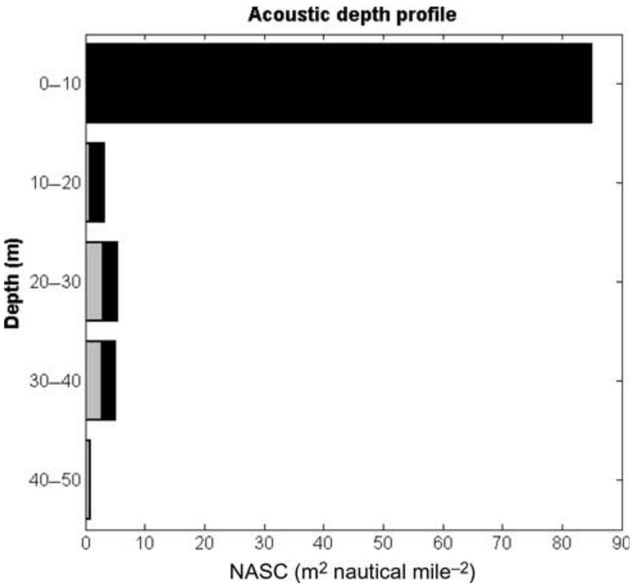


Figure 4. Average NASC (s_A) depth profiles of the AUV (black) and vessel (grey) 200-kHz channels from dive 1 (X configuration, 10-m depth bins).

Dive 4 (11 September) was completed over the continental shelf in the northeastern area of the Bay of Biscay, from Belle-Île island towards the open sea. This dive was dedicated to the survey of the bottom blind zone; consequently, the M configuration was used with the AUV positioned at an altitude of 30 m. This transect was a straight line stretching over 30 nautical miles. Ground-truthing was done with two pelagic trawls, which sampled fish before the beginning and after the end of the dive. The first trawl caught Atlantic mackerel (*S. scombrus*) and horse mackerel (*Trachurus trachurus*). The second caught hake (*M. merluccius*). The dive transect was divided into two sections, each 15 nautical miles long, to assign the echotraces more accurately to the trawl catches; only the results relating to the objective of surveying demersal fish are reported here.

The second section of dive 4 occurred in the area where hake were caught. There were significant differences among the profiles in the bottom blind zone (Figure 10), which are explained by the near-seabed echograms of the AUV (Figure 11a) and the vessel (Figure 11b). The AUV detected several fish echoes within 2 m of the bottom, whereas the vessel operating in the same area detected practically nothing.

To estimate how much fish was hidden in the bottom blind zone of the vessel, the same approach as followed for dive 3 was

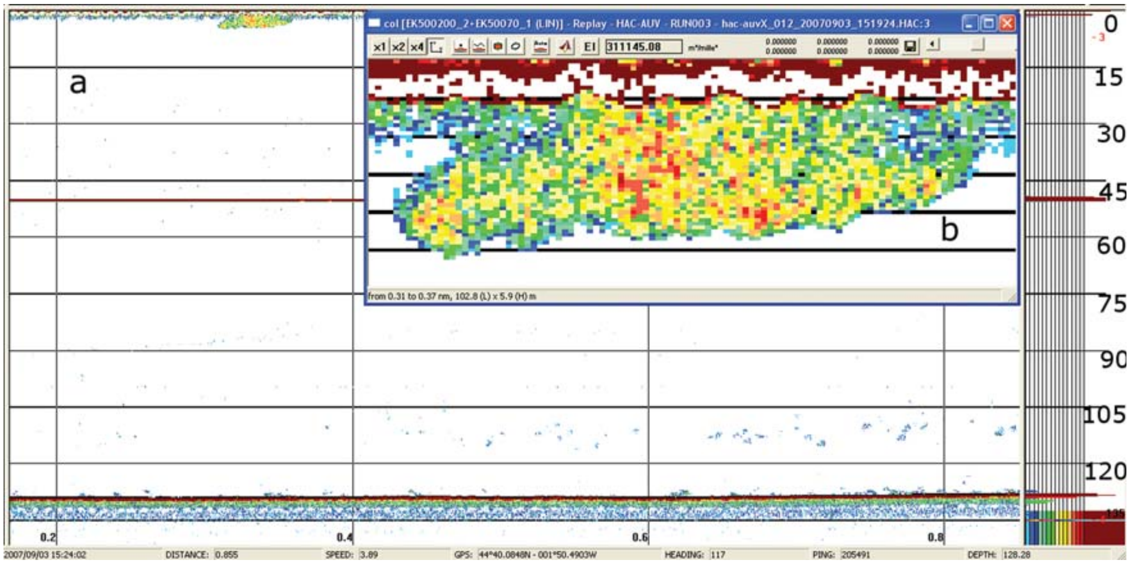
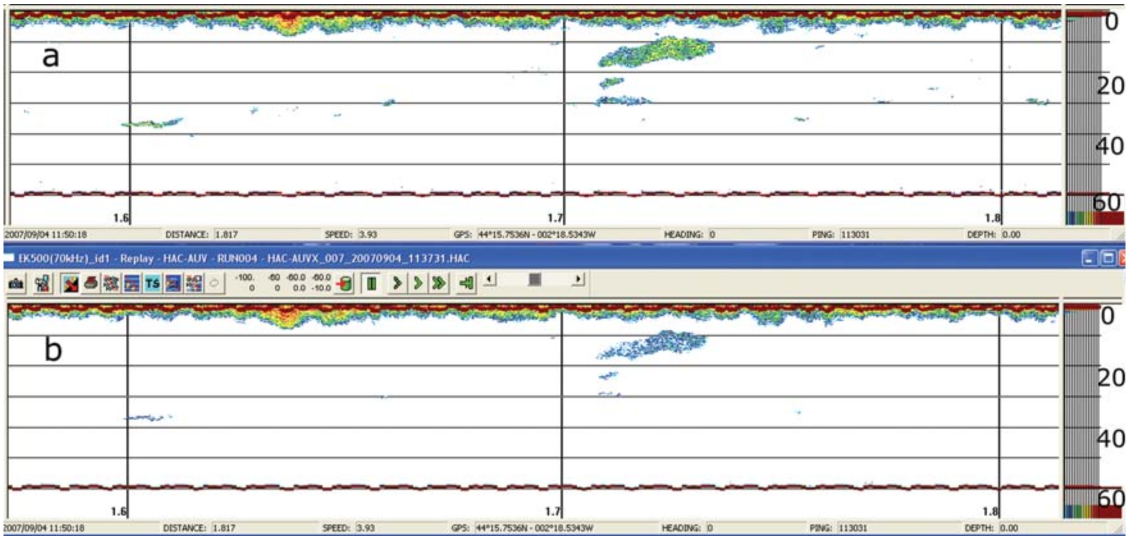


Figure 5. (a) A composite AUV echogram of the whole water column from dive 1, which illustrates the detection of a tuna school close to the surface. The red line at 50 m indicates the depth of the AUV. (b) Expanded view of the tuna school surrounded by a red rectangle in the composite echogram; the inset is 103-m long and 6-m high.



2007/09/04 11:50:18 DISTANCE: 1.817 SPEED: 3.93 GPS: 44°15.7536N - 002°18.5343W HEADING: 0 PING: 113031 DEPTH: 0.00

EK500(70kHz)_id1 - Replay - HAC-AUV - RUN004 - HAC-AUVX_007_20070904_113731.HAC

2007/09/04 11:50:18 DISTANCE: 1.817 SPEED: 3.93 GPS: 44°15.7536N - 002°18.5343W HEADING: 0 PING: 113031 DEPTH: 0.00

Figure 6. AUV echograms of krill schools from dive 2: (a) 200 and (b) 70 kHz.

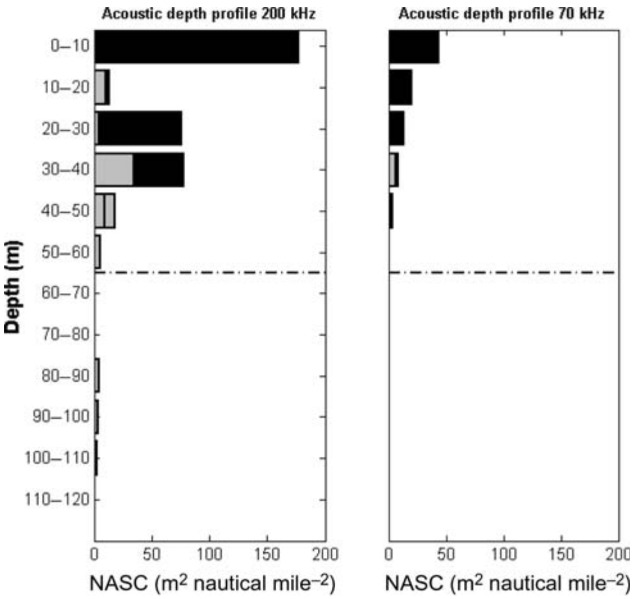


Figure 7. Average NASC (s_A) depth profiles of the AUV and vessel 200 kHz (left) and 70 kHz (right) channels from dive 2 (W configuration, 10-m depth bins). The dashed line indicates the operating depth of the AUV. The bars illustrate the superimposed s_A of the AUV (black) and the vessel (grey).

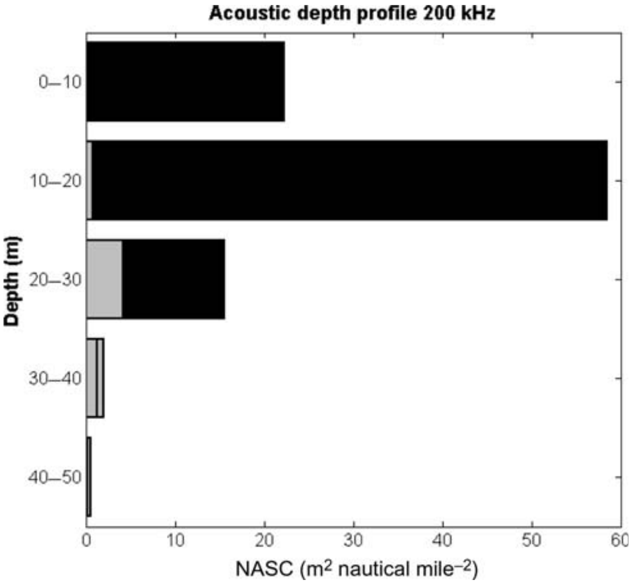
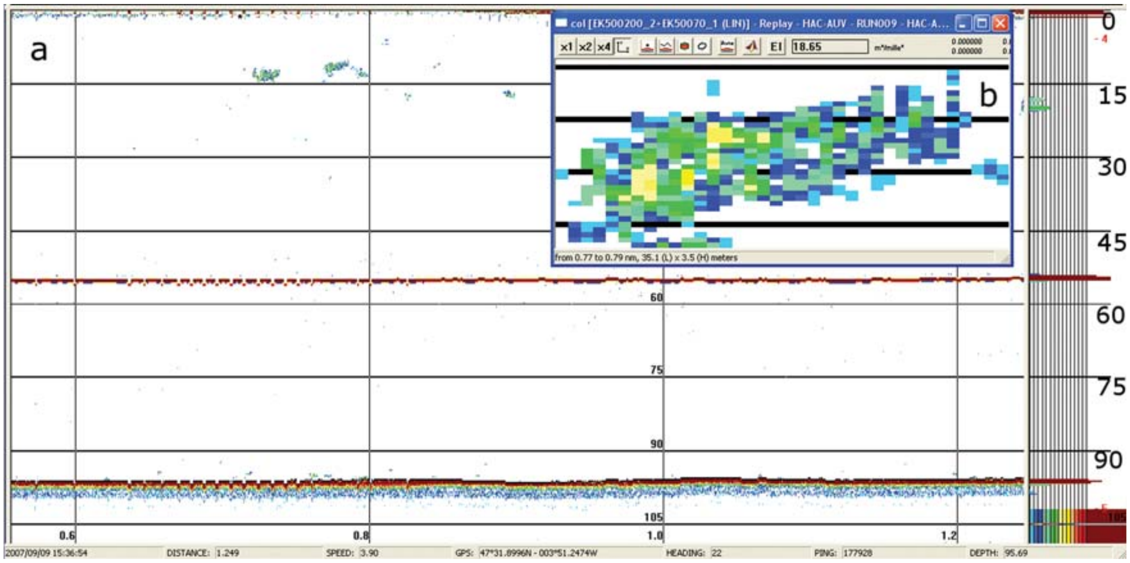


Figure 8. Average NASC (s_A) depth profiles of the AUV and vessel 200-kHz channels from dive 3 (X configuration, 10-m depth bins). The bars illustrate the superimposed s_A of the AUV (black) and the vessel (grey).

applied to the 200-kHz data from dive 4. For the layer within 2 m of the bottom, the mean s_A of the AUV and the vessel were 26 and 3 m^2 nautical mile^{-2}, respectively, based on the target-strength relationship $TS = 20 \log L - 68$ (Agostini *et al.*, 2006). Average hake length (22 cm) and weight (90 g) were determined from the trawl catches. Over the whole dive transect, the average hake abundances were 2470 (AUV) and 285 (vessel) kg nautical mile^{-2}, respectively. The difference might be attributable to hake that were located in the bottom blind zone of the vessel. The estimated AUV density of 0.008 fish m^{-2} implies an average occupancy of one fish per 125 m^2. The high resolution of the AUV data stems from the reduced target-to-sensor distance, with less noise, which allowed the use of a shorter pulse length (Table 1).

Discussion

The biomass differences observed in the surface and bottom blind zones could be attributed to the better performance of the AUV as a platform for collecting acoustic data on targets near these boundaries. However, these preliminary results should be confirmed by other experiments and should not be generalized. The results for anchovy and hake came from geographical areas where these species were abundant, and the dives all took place during daylight. Different results might be expected for dives made at



col [EK500200_2+EK50070_1 (LIN)] - Replay - HAC-AUV - RUN009 - HAC-A...

EI 18.65 m²/mille²

from 0.77 to 0.79 nm, 35.1 (L) x 3.5 (H) meters

2007/09/09 15:36:54 DISTANCE: 1.249 SPEED: 3.90 GPS: 47°31.8996N - 003°51.2474W HEADING: 22 PING: 177928 DEPTH: 95.69

Figure 9. (a) Composite AUV echogram of the whole water column from dive 3 illustrating the detection of anchovy schools close to the surface. The red line at 55 m indicates the depth of the AUV. (b) Expanded view of one anchovy school surrounded by a red rectangle in the composite echogram; the inset is 35-m long and 3.5-m high.

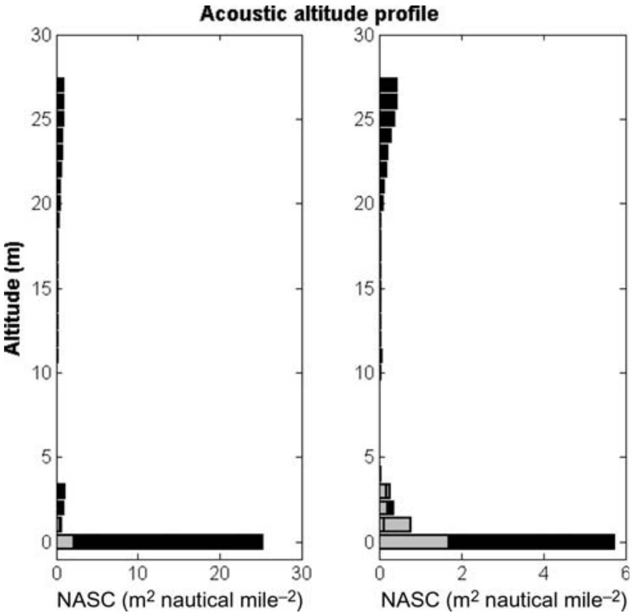


Figure 10. Average NASC (s_A) profiles of the AUV and vessel 200 kHz (left) and 70 kHz (right) channels from dive 4 (M configuration, 1-m depth bins). The bars illustrate the superimposed s_A of the AUV (black) and the vessel (grey).

night, when fish behaviour might change according to the light intensity and their feeding activity. Moreover, the same dorsal-aspect, target-strength relationship was used to estimate the anchovy biomass detected by both the AUV and the vessel, although the AUV observed these surface-shoaling fish in the ventral aspect. This is a reasonable assumption in the present state of knowledge (Love, 1977), although it is not obvious that the ventral- and dorsal-aspect target strengths should be the same. Another source of error was the calibration of the echosounders. The vessel echosounders were calibrated several times per year, and they exhibited no performance changes over time. The AUV echosounders were calibrated only twice in the pool facilities at Ifremer in Brest. These calibrations were in good agreement, but they were done at near-surface pressure, whereas the AUV transducers were specially designed for deep-water use. It has been suggested that a variation of 2 dB could occur in the calibration results between the transducer at the surface and 200-m depth (E. Ona, pers. comm.).

Nonetheless, the biomass differences between the AUV and the vessel (almost 11 dB) were high enough to demonstrate the relative utility of these platforms. The biomass of near-surface pelagic fish could have been underestimated by vessel echosounders, because of the vessel draft and fish-avoidance reactions. For the surface blind zone, AUVs could prove to be an effective solution, as demonstrated by our results. An alternative method would be to use a vessel fitted with horizontally directed sonar to observe the near-surface schools. However, this approach would depend on the availability of satisfactory calibration methods for such instruments, and knowledge of the side-aspect target strengths required for accurate biomass results. For demersal fish, a single-target echo close to the bottom might easily be lost in the strong background of the bottom echo. A non-intrusive platform, allowing fish detections at closer range with shorter pulse durations, might offer interesting information about their behaviour and density. Towed bodies operated at depth from a vessel might provide data as good as that from an AUV, but their deployment from a vessel moving at speed remains problematic.

The question remains whether continuing advances in AUV technology can cope with the constraints imposed by standard survey procedures in fishery acoustics, considering that the autonomy of the AUV, and consequently its speed and size, are major limitations of the technique. The development of effective power sources and decreasing technology costs should soon make it possible to deploy AUVs as complementary observation

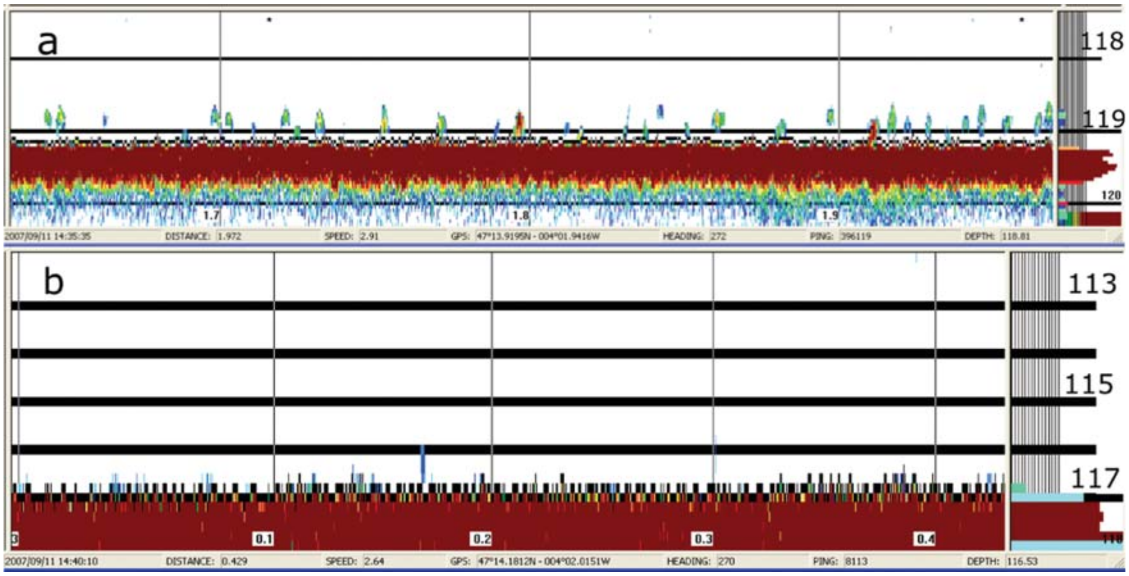


Figure 11. (a) AUV 200-kHz echogram of hake echotraces close to the bottom from dive 4. (b) A vessel 200-kHz echogram of the same area.

and monitoring platforms to standard acoustic-assessment techniques.

Conclusions

Results from the ALLEGRO 2007 survey have been presented and analysed to examine whether or not an AUV can be a useful acoustic platform for sampling the surface and bottom blind zones in the continental shelf of the Bay of Biscay.

Although the medium-sized AUV is not yet suitable for conducting standard acoustic-assessment surveys of fish resources under current protocols, the results presented here indicate how much fish could be hidden in the surface and bottom acoustic blind zones. In some cases, the biomass estimated by an AUV could be greater than ten times that indicated by vessel-based echosounders.

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