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Multibeam sonar detection of suspended mussel culture grounds in the open sea: Direct observation methods for management purposes

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Abstract: The exploitation of offshore mussel farms is becoming important throughout the world, but monitoring this activity remains a difficult task. Here, we propose a specific method for this purpose. A total of 140 long-lines were monitored on a mussel culture ground in the French Mediterranean Sea during four experimental surveys deploying multibeam sonar devices mounted on poles (Reson Seabat 6012, 455 kHz) on small boats. This allowed geo-referenced observations to be made of the submerged mussel long-lines, as well as three-dimensional (3D) drawings of the long-line structures and the sea bed shapes, using long-line longitudinal sonar sampling. Three sonar data-analysis methods were applied: (i) direct two-dimensional (2D) visual interpretation of raw sonar video images; (ii) indirect 2D long-line drawings; and (iii) 3D digital long-line reconstructions. The development of these acoustic methods in shallow water provides scientists, managers and local authorities with a tool for observing the 3D position (geographical position and depth) of mussel cultures, for counting each structure by the 'long-line echo-counting' method, for monitoring their shape in situ, and for classifying the mussel rope segments into three growth categories ('in growth', 'full' and 'empty'). The use of acoustic tools for monitoring underwater mussel culture grounds, for management purposes and for scientific studies, could be extended to other artificial structures in shallow water environments.

Keywords: Mussel; Long-line; Open sea; Sonar; Management

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Introduction

The French Mediterranean area accounts for 10% of the national shellfish production. Oysters (Crassostrea gigas) and mussels (Mytilus galloprovincialis) were traditionally developed on suspended structures inside lagoons (Gangnery et al., 2003). In order to increase mussel production, which was previously limited to along the coastline (Smaal, 2002), the potential of the open sea has been explored. The first culture trials began in around 1975 along the Sète coastline. However, after a series of experiments adapting the technology to the regional rough climatic conditions, production really began in 1985 with the subsurface long-line described by Bompais (1991). The offshore mussel production equipment was adapted to survive the winter tempests and new types of apparatus were proposed (Fig. 1 A). Economic studies and public subventions led to the development of four sites along the French part of the Lion Gulf (Vidal-Giraud, 1988) (Fig. 1 B). The management of these offshore areas is not easy due to their distance from the coastline (2 or 3 MN) and the subsurface position of the structures. The only management method used by the national administration in charge of the public marine space consists of visual observations (scuba diving) to evaluate the number of exploited structures. This method is time consuming, the results are inaccurate and it does not permit a synoptic view of the whole mussel culture ground.

In order to evaluate the actual number of concessions on the mussel culture ground, the number of long-lines per concession and the effects of storms on such structures, the managers and local authorities need to be able to count and monitor the mussel long-lines. Conventional acoustic methods cannot be used for these purposes. Open-sea aquaculture grounds are usually out of reach of acoustic tools (Brehmer et al., 2003) due to the large quantity of artefacts present in the water body (such as cages, lines and buoys), and because these objects cannot be discriminated from the mussel long-lines using acoustic vertical cross-sections (that is, by echo-sounding). Our methodology is the first to allow the rapid, cheap and efficient mapping of an open-sea mussel culture aquaculture ground and, thus, to facilitate the management of the area (Gerlotto et al., 1999; Mayers et al. 2002; Brehmer et al., 2003). This approach is designed for use by local authorities and managers. The technique was developed through a series of surveys during 2000 and 2001 off the Languedoc coastline.

Materials

The open-sea mussel-production unit

In the French Mediterranean Sea, the sub-surface structure that is used for mussel long-line culture — based on the Japanese experience with algae and gastropod cultures — is adapted to rough environmental conditions. The complete long-line is anchored by 1 to 2 tonne concrete ground-mooring blocks (Fig. 1 A) and the main hawser (a line with a length of 250 or 300 m) is maintained at 5 m below the water surface by buoys that are located every 50 m. The volume of these buoys varies from 300 to 800 l, depending on the charge. Between 400 and 500 ropes are suspended on the hawser's segments and buoys (300 to 800 l) are generally added to control the load line All the structures are installed within a 3 MN area between 20- and 30-m isobaths. They are positioned parallel to the coastline in a chequered distribution. Each square in this pattern represents one mussel concession, which constitutes three pairs of long-lines. Channels between the concessions allow both access by farmers and water circulation. One long-line is estimated to produce around 25–35 tonnes per year.

Characteristics of the acoustic device used for underwater detection

The acoustic device used was a high-resolution multi-beam side-scan sonar RESON 'Seabat 6012' (frequency 455 kHz), which is referred to as 'MBS' in this paper. The MBS allows three-dimensional (3D) monitoring of pelagic and bottom targets. It has 60 beams of 1.5°*15°, covering a 90° total sector. The MBS range was set at 50 or 100 m, the pulse length was 0.06 ms and the time-varied gain (TVG) function was adjusted in 20 log R (with R being the distance between the transducer and the target). The MBS is a portable device, which was mounted on a small boat like those used by mussel farmers (Julie's, 20 m) and on a speedboat

(Chlamys, 9 m) during ours surveys. Observations of mussel long-lines by MBS data were made from 2000 to 2001 during four acoustic surveys.

Mussel long-line detection and analysis

The MBS orientation plane axis was set at 90° below the boat and 45° starboard (Fig. 2 A). The transducer was pole-mounted on the side of the boat. Sonar echoes displayed on the monitor were recorded on S-Vhs videotape and then digitized through a video card (Fig. 2 B) in order to extract the long-line characteristics: vertical depth in the water column, length and geographical position (GPS). Local depth was also recorded. The long-line and mussel rope dimensions were calculated by direct measurement of the video-monitor image: the along-beam dimension 'Lw' was calculated by applying a sonar image scale factor 's' ($m.pixel^{-1}$), equal to the sonar range 'R' (m) divided by the display sonar range 'R_d' (pixel). Using this scale factor, the Lw could be converted into meters. Then, the corrected dimension was calculated using the Misund (1991) formula:

$Lw_{corrected} = Lw \cos T - R_r$

Here, 'T' the beam tilt angle (°) and 'R_r' the range resolution (m) equal the sound celerity in water ($m.s^{-1}$) multiplied by the 'ι' pulse length (ms) divided by two.

MBS data were also recorded in a specific digital format, in order to allow them to be exploited by adapted software (Fig. 2 B) developed in previous studies for the analysis of fish schools (Lecornu et al., 1998; Gerlotto et al., 1999). This allowed the analysis of the MBS data and provided 3D morphology, spatial position and energetic descriptors of the mussel long-lines. The MBS digital data stored for each ping allowed the whole long-line architecture to be reconstructed in a 3D representation and gave its basic morphological parameters: surface, volume, height, width and length (m). The echo energy of each single element (volumetric pixel or voxel) inside the 3D volume was available in a relative scale of 256 levels with classical statistical descriptors (standard deviation, skewness and kurtosis).

Results

Our objective was to show the effectiveness and feasibility of a 'mussel long-line echo-counting' method inside a mussel culture ground along with its monitoring capabilities according to the results obtained in a sample of the concessions.

Detection and positioning method: 'long-line echo-counting'

The MBS raw two-dimensional (2D) detections (Fig. 3) showed all the elements of the long-lines. The mussel culture systems are below the surface at the top corner of the MBS image ('boat position', Fig. 3 A), the sea bed is easily detectable (continuous straight lower line), and the other visible parts of the long-line structure are the ground-mooring concrete blocks (Fig. 3 B), the mussel ropes, the main hawser and the buoys (Fig. 3 C, D, E, F). The mussel long-lines were positioned (longitude and latitude) with the help of a GPS (Global Positioning System) associated to the MBS. Their vertical position in the water column (altitude over the sea bed and depth below the surface) could also be monitored and estimated directly on the MBS images. This information allowed the location and characterization of each mussel long-line inside a concession (three pairs of long-lines). Using this method, we counted 140 mussel long-lines during the experimental surveys. On average, it took less than 10 minutes to exhaustively record a long-line. Clandestine (or lost) long-lines were also observed in the main access channel.

Shape and dimensions of long-lines and mussel ropes: global monitoring

The MBS allowed us to observe instantaneously the global shape of the long-line (Fig. 3 G and H). During rough weather, the mussel production units were strongly affected structurally by the swell effect (Fig. 3 I). Contact of the mussel ropes with the sea bed was observed in several long-lines, even during quieter weather (Fig. 3 F).

As expected, the mussel long-line descriptors could be extracted from the MBS data. We obtained the following parameters: rope diameter 'R_d', long-line length 'L_{length}' and height 'R_{height}' by segment; vertical position of the mussel rope (minimum distance to the sea bed 'R_{bottom}' and to the surface '$R_{surface}$'); vertical position of the main hawser 'R_{hawser}'; vertical position of the buoy 'R_{buoy}'; and local depth 'D' (according to the GPS position). These parameters allowed us not only to monitor the culture but also to control the 'status' of the structure (that is, good or bad condition).

From these direct video data measurements, we reconstructed a mussel long-line (Fig. 4). The diameter, which represents the volume of the mussels present on the ropes, allowed the discrimination of three modalities: 'empty', 'in growth' or 'full' (Fig. 4). The long-line illustrated in Fig. 4 showed all three stages of mussel culture. All parts of the mussel long-line structure could be measured and positioned vertically in the water column. The ropes of the same segment had a similar vertical height (8, 15 and 16 m), but several different mussel segment characteristics were observed on the same long-line (Fig. 4).

The 3D reconstruction was carried out for one mussel production unit (that is, along an entire long-line). This gave a volume of 1868 m^3 for a surface of 6765 m^2 including a hole of 184 m^2 and 10.5 m^3 (free space between the rope) with a length of 130.9 m, a width of 5.08 m and a height of 13.83 m (Fig. 5). The mean acoustic density was 189 for the whole long-line structures, but was highly variable (standard deviation = 51.7, skewness = -0.13, kurtosis = -1.40).

Discussion

At a range of 100 m, the MBS resolution and sea bed interference made the image analysis of each mussel rope difficult; thus, a 50-m range is recommended. The longitudinal views allowed the direct detection of mussel long-lines, but prevented any 3D digital rebuilding. No fish schools are encountered during night-time observations (Brehmer et al., 2003), which makes mussel rope detection easier. The use of MBS 2D raw sonar images permits real-time long-line counting and geographical positioning, but the measurements need visual post-processing. By contrast, the software Sbiviewer 5.01 gives an accurate view of the mussel long-lines, in terms of their morphological and acoustic parameters (ASCII file), but does not permit real-time long-line echo-counting. The MBS observations could provide exhaustive mapping of the mussel long-line culture within a few days. The only alternative method is using visual or video monitoring. However, these methods would take months to obtain the same exhaustive observations (scuba diver team), principally because of the ranges of these tools (effective range of around 10 m). Besides, the delay between the beginning and the end of the video survey does not allow the results to be considered as a synoptic overview. In addition, visual or video monitoring is often impossible to apply in turbid water in contrast to sonar monitoring, which can be operated even at night.

The methodologies for mussel long-line monitoring presented in this paper are operational and suitable for routine use, and can thus be applied by coastline managers for various objectives. The number of long-lines per mussel concession can be measured (normal conditions = 6 per concession). Lateral views of mussel long-lines allow the consecutive observation of each mussel rope. These methods, at a 50-m MBS range, give a ‘growth stage’ classification into three categories (‘full’, ‘in growth’ or ‘empty’) for each segment of the mussel long-line. The methodology can also be applied to continuous mussel growth-rate monitoring (Sims, 1994; Gangnery et al., 2004) in the open sea (Sarà et al., 1998). Since 1997, these culture areas have been attacked by predatory fish (Sparidae). This problem is responsible for the decline in offshore mussel production. Predation by these fish in the French Mediterranean mussel culture grounds can be explored by our methodology through real-time observations of the segments attacked by predators (empty segments). The MBS information could also allow cleaning operations in the area, and the removal of objects, such as mussel long-lines that have been destroyed by tempests, or clandestine (or lost) long-lines.

Although the scientific echo-sounder output is more accurate in terms of the energy descriptors, its use is limited by its small sampling volume. Nevertheless, future research should combine multifrequency split-beam echo-sounders (MacLennan and Simmonds, 1992) with multibeam high-resolution sonar. A combination of direct biometric measurements (dimension and weight) from scuba diving and mussel rope sampling at different growth stages (from spat to commercial size) could be used in the future for biomass assessment purposes.

Another perspective for long-line echo-counting will be to use omnidirectional long range sonar (Simrad SR240, 23.75 kHz). This will permit observations in a 2D horizontal view (in km^2) of the mussel culture grounds. Omnidirectional sonar offers a quick simultaneous overview of the mussel long-line positions in several concessions. The fixed long-line echoes can be discriminated from the mobile biological ones (for example, fish schools) (Brehmer et al. 2003). This kind of analysis provides information about the horizontal position of mussel long-lines over a large area but with a low size accuracy (range = 800 m, pulse length = 8 ms, R_r >6 m). This potential long-range low-resolution method is complementary to the short-range high-resolution information delivered by MBS.

Conclusion

In a complex exploitation system in the open sea, the information provided by acoustic tools helps to improve our knowledge of mussel culture grounds. Our results show the power of detection of acoustic multibeam sonar over mussel culture grounds in shallow water. This method is independent from the environment (water turbidity and day/night). Moreover, precise 3D positioning of the mussel long-lines is made possible. Measurements of their shapes and sizes are given by *in situ* observations. Post-processing the MBS data allows the reconstruction of the mussel long-lines in 2D or 3D. Acoustic tools in aquaculture fields can also be valuable for management purposes. The methodology of mussel culture ground monitoring will allow the application of the long-line echo-counting method, along with studies of the *in situ* mussel growth rate, mussel predation events and weather effects (long-line shape deformation). This multibeam sonar monitoring methodology could also be applied in off-shore pelagic aquaculture structures and open-sea fish farms.

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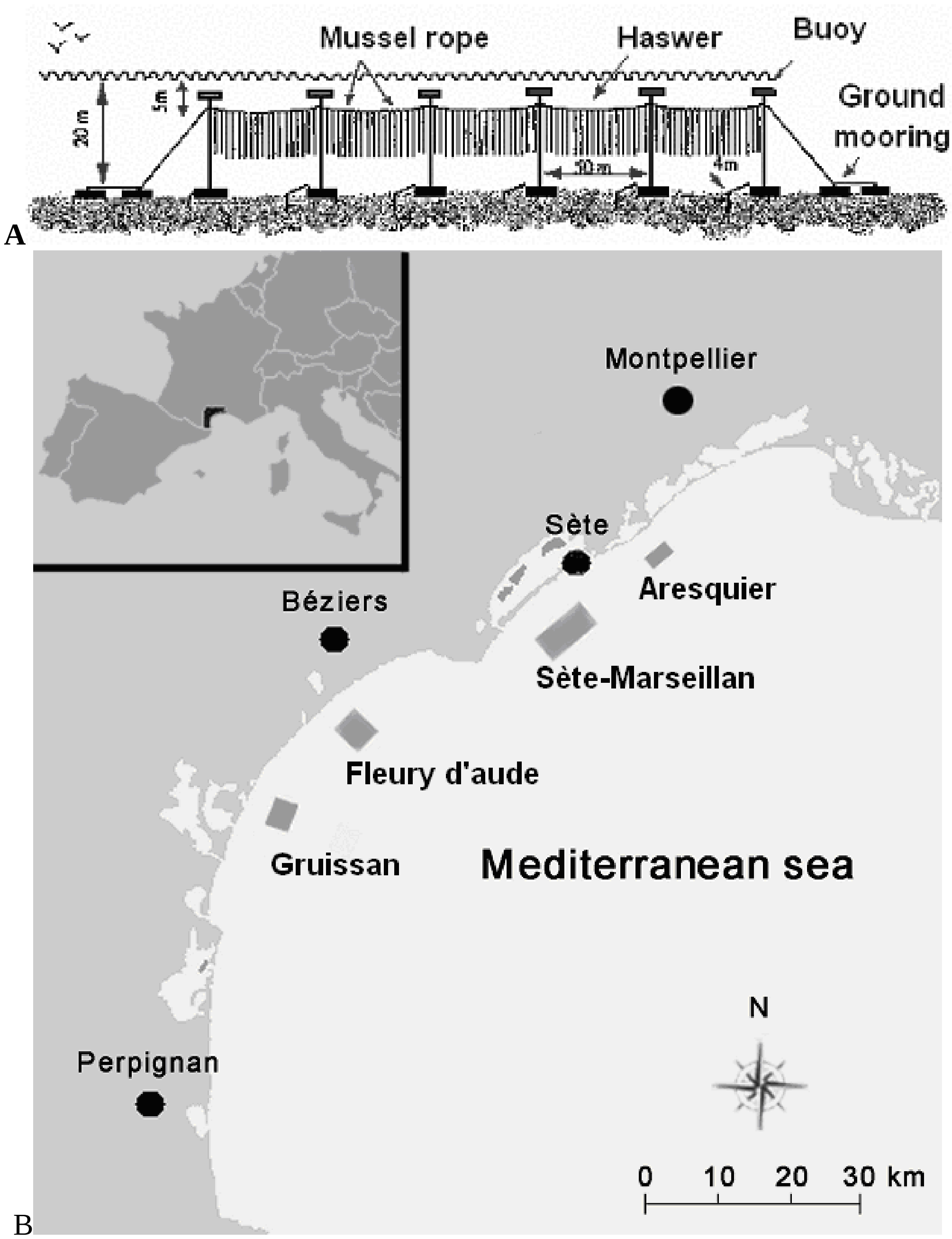
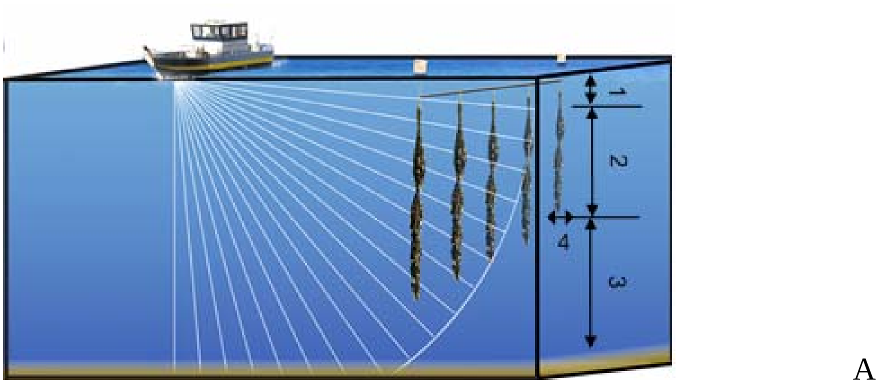


Fig. 1. (A) Map of mussel culture grounds (grey squares) along the Mediterranean French coast. The main study area was Sète-Marseillan (situated in a quadrilateral: 43°20.7N; 3°38.2E/43°19.6N; 3°39.7E/43°15.7N; 3°34.3E/43°16.7N; 3°32.8E). (B) Schematic diagram of a standard mussel long-line in the open sea. The whole structure is submerged at 5 m depth.



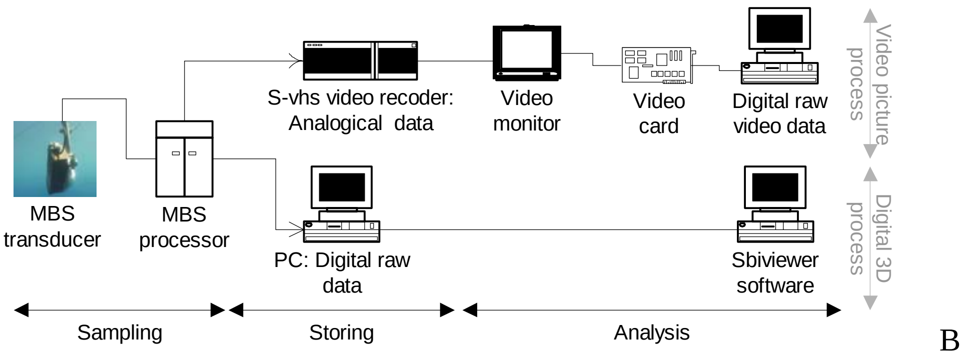


Fig. 2. (A) Sampling volume of the multibeam sonar used for mussel long-line monitoring. The dimensions derived from fish-school extraction are as follows: '1' = depth of the mussel rope from the surface; '2' = vertical mussel rope dimension; '3' = altitude from the sea bed; and '4' = mussel rope diameter. (B) Scheme of the two distinct methods for MBS data recording and analysis. The first approach (the video image process) is to store the MBS image on videotape and then digitalize it with a video card for 2D image analysis. The second approach (the digital 3D process) is to sample in a digital format the MBS data in order to process them with dedicated software in a direct 3D format.

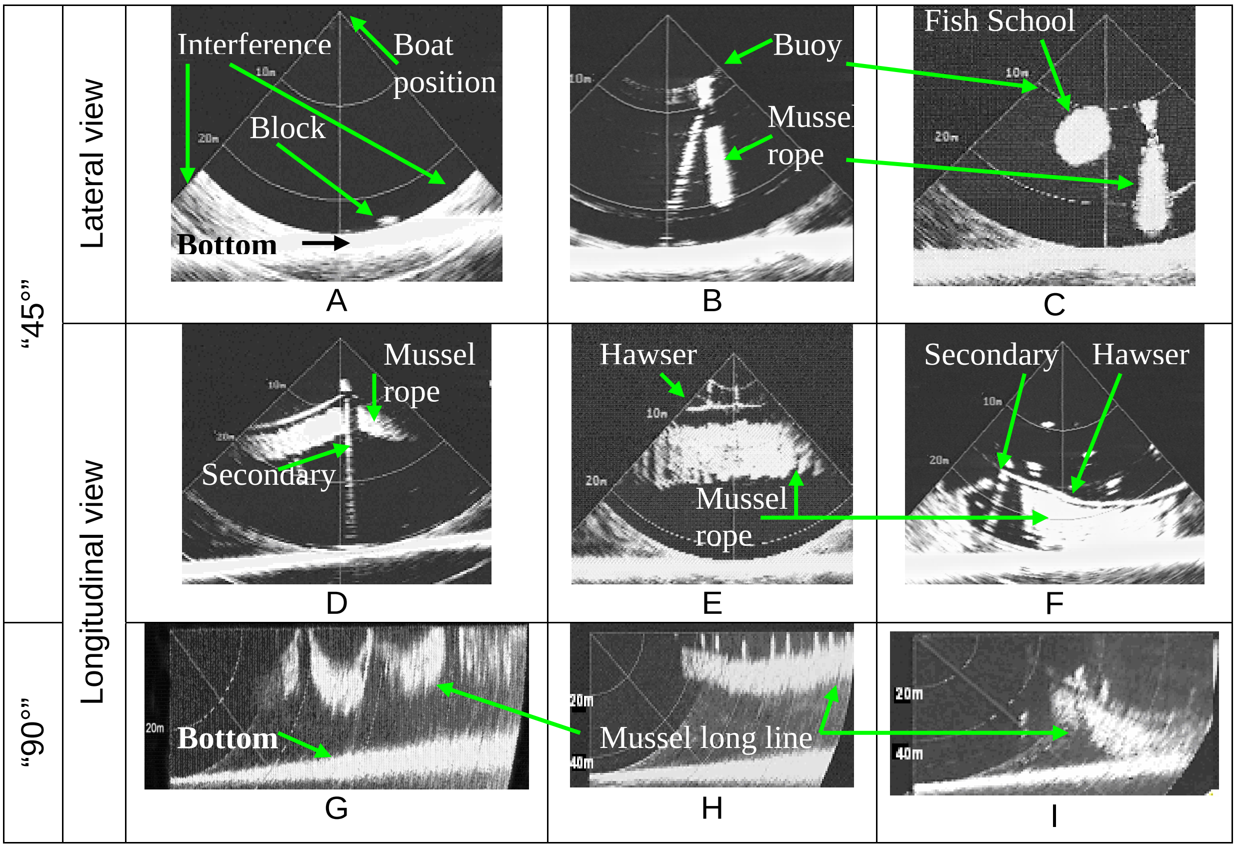


Fig. 3. Side-scan sonar image of the mussel-production unit in longitudinal and lateral views (A, B, C, E and F, range = 50 m; D, range = 100 m). The angle of the transducer is '45°' at the surface (G to I) or parallel to the surface at '90°' (A to F). The shape of the mussel long-line is monitored, and the mussel rope (B to I), hawser (D, E and F), secondary rope (B, D and F), buoy (D and F) and ground-mooring concrete block (A, B and D) can be discriminated.

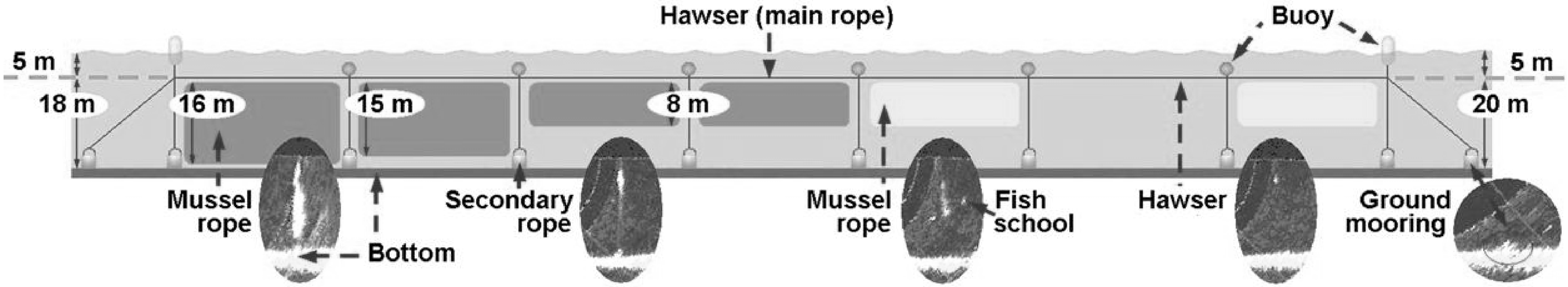


Fig. 4. Monitoring a mussel long-line through MBS recordings allows the reconstruction of the structure according to raw video sonar detection. Three stages of mussel segments are recognised from their mussel rope size and can be classified as ‘full’ (grey segment), ‘in growth’ (clear grey segment) or ‘empty’ (no mussel rope). The vertical dimensions of the mussel ropes vary and can also be measured.

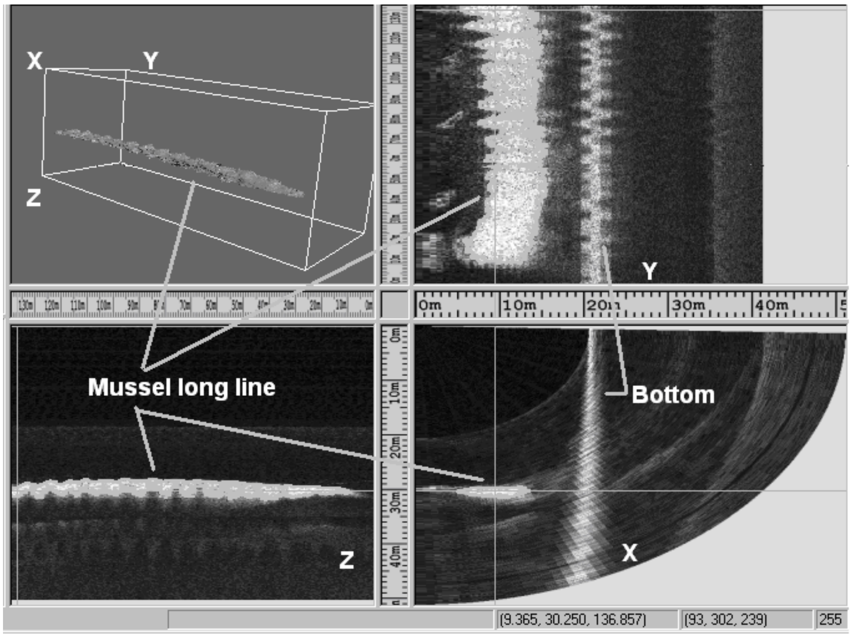


Fig. 5. Sbiviewers 5.01 digital data-processing allows the whole mussel long-line and the sea bed to be displayed by 3D positioning (X = vertical plane perpendicular to the vessel route; Y = vertical plane parallel to the vessel route; and Z = horizontal plane) and in the 3D view by video animation.