ICES Journal of Marine Science
April 2006; 63(3) : 444-451
http://dx.doi.org/10.1016/j.icesjms.2005.10.016

Evidence of a variable "unsampled" pelagic fish biomass in shallow water (<20 m): the case of the Gulf of Lion

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Abstract: Studies of small pelagic fish biomass are limited by the fact that research vessels and fishing boats are usually restricted to working areas with a bottom depth >20 m. Consequently, "unsampled" areas can represent a large proportion of the continental shelf, and the biomass in those areas can be important and must be taken into account in assessment methods in order to avoid misleading interpretations in population dynamics. A time-series ten years long has been compiled from acoustic-assessment surveys of small pelagic fish stocks, and the results show an overall increase in the acoustic fish density towards the coast, where values were the highest. Additional experiments on transects covering shallow-water areas (5–20 m) were conducted from 2001 to 2003 with small boats and a research vessel to evaluate the acoustic fish density in those areas. The results confirmed that the fish biomass in shallow water is significant, sometimes very large, and should be evaluated to avoid underestimation. Therefore, surveys should be conducted in shallow water, if at all possible, as well as at greater depths when carrying out surveys destined to support assessment exercises.

Keywords: assessment; hydroacoustic methods; shallow water; small pelagic fish; spatial distribution

Introduction

Most of the world fish tonnage landed comes from small pelagic fish, mainly belonging to the Clupeidae and Engraulidae (www.fao.org). The often critical current state of pelagic-fish fisheries (Troadec *et al.*, 2003) requires the use of stock-assessment methods that are either dependent on or independent of commercial fish landings. Regular scientific monitoring surveys of fish populations (Mesnil, 2003) are usually conducted by scientific trawling or hydroacoustic methods or a combination of both (Johannesson and Losse, 1977; MacLennan and Simmonds, 1992). The direct and indirect stock-assessment methods are carried out using oceanographic research vessels or commercial fishing boats (Hilborn and Walters, 1992; Fréon and Misund, 1999). Inshore coastal waters less than 20 m deep are inaccessible to these vessels for obvious navigational-safety reasons and also for the avoidance of conflict with artisanal fishers (Petursdottir *et al*., 2004). Therefore industrial fisheries are usually excluded from these waters by national regulations. On the other hand, small-scale fisheries are often very limited in their catches of small pelagic fish. Consequently very little is known about the fish populations of the shallow waters adjacent to coastlines. However, that part of the continental shelf with a depth of 0 to about 20 metres can account in some regions for a large proportion of the total shelf area. In our study the continental shelf along the French coastline in the 'Golfe du Lion' (Mediterranean Sea), where most of the small pelagic fish occur, accounts for about 8% of the total continental shelf. It is therefore necessary to determine whether the fact that these areas are not taken into account has any effect on direct fish-stock assessments. Indeed no official recommendation has been made in small pelagic-fish assessment methods regarding the biomass of shallow water areas, where research vessels usually do not go.

To determine the importance of the unsampled coastal waters in stock assessment, our study was focused on acoustic-assessment surveys of small pelagic fish (PELMED surveys conducted by IFREMER, ‘PELagiques MEDiterranée’) that took place every year from 1993 to 2003 in the ‘Golfe du Lion’ (Abad *et al.*, 1996; Guennégan *et al.*, 2000; Lleonart and Maynou, 2003). Surveys were completed by oceanographic research vessels at depths from 20 to 140 metres, the edge of the continental slope, where fish densities become very low (Whitehead, 1985). Complementary scientific surveys were carried out in the same area and at the same time but in shallow waters (5 to 40 m deep), for three consecutive years, at the end of the PELMED surveys, using a small boat fitted with an outboard and equipped with a scientific echo-sounder. Acoustic surveys in shallow waters have become more common in recent years (Duncan *et al.*, 1998; Thorne, 1998) and can be used to survey environments that until now have not been explored by this method (Mulligan, 2000; Trevorrow *et al*., 2000; Brehmer *et al*., 2003a). The goals of this paper are to show how to investigate shallow waters by hydroacoustic methods and demonstrate that an important part of the fish biomass distribution could occur in them.

Material and methods

The annual ‘PELMED’ surveys, 1993 - 2003

These stock-assessment surveys were conducted each year during summer (Table 1) using the same sampling strategy of transects perpendicular to the coast. The distance between each transect was 12 nautical miles and each survey consisted of 9 transects with a total length of 355 nautical miles (Figure 1). An Elementary Sampling Distance Unit, ESDU, was defined for each mile covered and the acoustic energies reflected by the fish were measured for each ESDU. The mean acoustic energies, i.e. the sum of the deviations or energies divided by the number of ESDUs, were calculated for each year and each isobath interval, in increments of 20 metres depth, over the whole of the survey. To avoid annual variations in total abundance and differences due to the change of boat and the analysis software used - successively the deviations (‘Q_p’ in mm) from 1993 to 1999, the energies (‘E’ in m².mV²) from 2000 to 2001 and finally the ‘nautical area scattering coefficient’ (s_A, m². nmi^{-2}) (Mac Lennan *et al.*, 2002) in 2002 and 2003 - we standardized the data by using the total acoustic energy percentage for each year. Except for the first survey (1993) which was made from the R/V Thalassa (73.6 m, Ifremer) the work was carried out from the R/V L'Europe (29.6 m, Ifremer). The 38 kHz echo-sounders used were an Ossian 1500, and then a Simrad EK500 with a constant pulse length of 1 ms. The threshold on the echo-sounder was -60 dB for echointegration analysis, to ensure that only pelagic fish were detected. The data-processing software was Ines-Movies at first (Weill *et al*., 1993) then Movies+ (Diner *et al*., 2002), following technological developments in this field. This change had no effect on the stock-estimation process. The ten years of acoustic survey and trawl-sampling data collected (Table 1) provided the estimated biomass of a fish stock that was mainly anchovies (*Engraulis encrasicolus*) and sardines (*Sardina pilchardus*).

In situ experimental observations in shallow waters

At the end of the PELMED surveys in the period 2001-2003, specific investigations were conducted in shallow waters from the ‘Chlamys’ (aft draught: 0.50 m), which was powered by an outboard motor, and from R/V L'Europe (aft draught: 3.40 m) to determine the importance of the acoustic fish density in the inshore area situated between the 20 m isobath and the coastline (Figure 1 A). In each of the three years these two vessels simultaneously conducted transects, the R/V L’Europe stopping at a depth of 15 m in 2001 and 2002, and 20 m in 2003, whereas the Chlamys, which was built for manoeuvring in very shallow waters, began at 30 m depth and systematically continued its transects toward the coast up to 5 m bottom depth (Figure 1 B). The R/V L’Europe was fitted with a Simrad EK500 echo-sounder while the Chlamys was equipped with a SIMRAD EY500 split-beam echo-sounder, 70 kHz frequency, pulse length 0.3 ms and a pulse repetition rate of about 8 emissions per second. The transducer was fixed on a vertical pole alongside the outboard motor. All the data collected by the Chlamys echo-sounder were processed using *Movies+* software (Diner *et al.*, 2002) with the same threshold of -60 dB for echointegration (in s_A). The arithmetic mean of the acoustic densities s_A observed by the R/V L'Europe and the Chlamys were calculated per depth class. For the R/V L'Europe the bottom-depth classes were defined as follows: 15-20 m, 20-30 m and 30-40 m; except in 2003 where depths of less than 20 m were not sampled. For the Chlamys, two depth classes were distinguished: less than 20 m (i.e. 5-20 m), and 20-30 m (Figure 1 B).

Results

The results are presented in two parts. First, the chronological series derived from the ten PELMED stock-assessment surveys (Figure 2) and second, the specific experiments in shallow water (Figure 3).

All the data derived from the PELMED stock-assessment surveys (Table 1) can be represented graphically from the coast to offshore by plotting the mean acoustic densities for each increasing depth class and by year (Figure 2). These graphs show that there is a decreasing gradient in the estimated mean acoustic densities seaward from the coast. Gradients were more or less pronounced depending on the year, but always followed the same trend. The linear regressions (Figure 2) calculated for the ten years of surveys showed the same characteristic trend (Table 2). The slopes of the fitted regressions were always negative, reflecting the decreasing acoustic densities the greater the distances from the shore; the years 2002 and 2003 being distinguished from the other years by a gentler slope. In all cases the lowest acoustic densities occurred on the margins of the continental slope, i.e. at depths between 100 and 140 m.

Direct *in situ* observations of the pelagic-fish biomass present in shallow water

Observations from the R/V L'Europe

The results for the years 2001 and 2002 in the area shallower than 20 m differed greatly from one another; the arithmetic mean of observed s_A in 2001 was 5437 $m^2.nmi^{-2}$, some 9.4 times greater than that found in 2002 (Figure 3 A). The density for the 20-30 m and 30-40 m depth class was of the same order. There was a pronounced gradient in density from the seaward in 2001. In 2002, the 20-30 m depth class had a higher density (factor 2.6) than the 5-20 m class and 1.8 times greater than the 30-40 m class. In 2003, the acoustics densities (s_A) in the 20-30 m and 30-40 m depth classes were similar.

The ‘Chlamys’ observations

In 2001, the acoustic density (s_A) for depths of less than 20 metres was some five times greater than that measured in 2002 and 2003. For the 20-30 m depth class, the densities were very similar for the three consecutive years (Figure 3 B). In 2001 the highest density were found close to the coast and was three times that found in the next depth class, 20-30 m.

Comparison between the R/V L'Europe and Chlamys results

The same trends in terms of variations in acoustic density according to the bottom depth were observed irrespective of the type of boat used, but the values measured from the research vessel (38 kHz) were always higher than those of the small boat (70 kHz) (Figure 3).

Discussion

A strongly decreasing gradient from the coast to offshore in fish-biomass estimation was observed, irrespective of the year and the variations in total acoustic density. This trend was consistent over all the ten years in the French part of the ‘Golfe du Lion’ though in 2001 and 2002, the highest acoustic densities were not in the most inshore area sampled by the research vessel (20-40 m), but just inside the next zone (40-60 m). This could have been related to different meteorological or trophic conditions in those years which in turn has implications for the sampling methods to be used in any one year just as classical fish spatio-temporal variability or migration phenomenon have (Godø, 1989; McAllister, 1998).

The surveys conducted in waters shallower than 20 m, to a depth of 15 m by the R/V L’Europe, did not provide a good overall view of the biomass distribution occurring in coastal shallow waters of the whole ‘Golfe du Lion’ because of the incomplete sampling to which we were restricted. However, the results obtained showed the acoustic fish density in the shallowest zone was of the same order as that in the adjacent zone (20-40 m), which according to the ‘PELMED’ time series was the zone with the highest values. In 2001, the coastal zone (5-20 m deep) had densities three times higher than the next depth zone. In the following two years, this area did not have a higher density but was similar to that found at between 20 and 40 m. The observations made in 2002 and 2003 therefore show that the shallow inshore area is important in terms of acoustic fish biomass, i.e. that it has an important higher density than the mean density found on an entire ‘PELMED’ transect from 20 to more than 140 m. Hence the ten-year series of surveys and direct observations in shallow waters combine to indicate the importance of the usually unsampled inshore area, in terms of fish biomass.

Our study was limited to the ‘Golfe du Lion’, but in many regions the areas that are inaccessible to research vessels are less extensive, as in the case of Peru where the 20 m depth contour is usually close to the coast. However, during specific climatic conditions such as El Niño events, part of the considerable anchovy biomass can concentrate very close to the coastline and therefore escape acoustic sampling by standard survey vessels (Bertrand *et al.*, 2005). Similar event have been reported by Glantz (1996) during ‘El Niño 1972/1973’ where pockets of cold waters close to the coastline contained large numbers of anchovies. In other regions, these shallow areas are very extensive, e.g. the Gabès Gulf off Tunisia or Gene in Italy, where the shallow-water part of the continental shelf is bigger than in the 'Golfe du Lion'. In such a case it is quite possible that leaving the zone unsampled could lead to significant errors in stock assessment by underestimating stocks.

It seems likely that this 'methodological' sampling error does not only effect the values provided by scientific fishing or echo-integration analysis produced by data collection from oceanographic vessels, but that other factors may be involved. In fact historically in many countries national fisheries regulations rarely allow trawling in shallow inshore waters, only small-scale fishing (Petursdottir *et al.*, 2004) being authorized there. Therefore an overabundance of small pelagic fish near the coast can quickly lead to the small-scale fisheries outlets becoming saturated. This was the case, for example, during the acoustic survey conducted off the southern shelf coast of Senegal 'Petite Côte' in 1999 by IRD personnel on board R/V Antéa (Brehmer, 2004). Almost no *Sardinella aurita* was detected in the areas sampled (> 20 m) by the R/V Antéa (unpublished data), whereas the landings by local small-scale fishermen quickly flooded the markets, overcoming the capacities of the local fish wholesaler. Surveys conducted in areas shallower than 15 m in the same Senegalese region (Guillard and Lebourges, 1998) showed the importance of this zone, which is not usually sampled, in terms of quantitative and qualitative biomass, with the occurrence mostly of juvenile fish.

In some case, a concentration of the biomass near the coast, can lead to an increase in the catch (Glantz, 1996). Consequently catch data that already suffer from catchability variation (Arreguin-Sanchez, 1996; Brehmer and Gerlotto, 2001), are difficult to interpret and cannot reflect the real population biomass, but only the available biomass (i.e. fish stock). Obviously even in the short term, if the environmental characteristics are more attractive or less repulsive according the specific intrinsic fish behaviour, a similar process can occur in the case of the offshore distribution of the fish stock as that found in the shallow waters of the continental shelf. In this case the targeted fish are out of the fishing areas. So the assumption that the production of biomass can be described by a function of exploited biomass may be false in this instance of inaccessible biomass (Laloë, 1988).

The variations in biomass between years in the coastal area can be caused by either fish behavioural changes or resource exploitation or environmental changes (Binet *et al.*, 2001) or a combination of all three factors. The comparison between the spatial structures of that occur with shoal clustering should be done in two and three dimensions (Petitgas *et al*., 2001) using echo-sounder data and also long-range sonar data (Petitgas *et al.*, 1996) to properly describe the spatial characteristics of the fish biomass. The extent of small-scale spatial and temporal migrations of small pelagic fish is not well known because of the absence of direct field observations of shoal movements (Misund and Aglen, 1992; Brehmer *et al.*, 2005). Another point where the fish behaviour can have an important impact in biomass estimation is the avoidance reaction in front of a boat, the fishing gear or the echo-sounder beam (Olsen *et al.*, 1983; Misund and Aglen, 1992; Fréon *et al.*, 1993; Brehmer, 2004). It may be thought likely that the avoidance behaviour of shoals of small pelagic fish would differ greatly depending on the very different characteristics of the two types of boats used (Mitson, 1995) in this instance but this was not entirely the case. The same number of shoals was observed with both boats but the vertical avoidance movements were different, the shoals observed by the R/V L'Europe being significantly deeper than those observed by the Chlamys (Brehmer *et al.*, 2003b). Gauthier and Rose (2002) have shown a significant increase in the target-strength values (Love, 1977) on the same fish (*Sebastes* spp.) between the targets detected below 50 m depth compared with more shallow ones. They attribute this phenomenon to fish-avoidance reaction. This vertical diving phenomenon could explain the differences in the backscattered energies observed between the two boats. The noise generated in the water column is higher for the R/V L'Europe than for the outboard (Brehmer *et al.*, 2003b). The difference of a factor

3 to 4 in acoustic fish density (Figure 3) between the two frequencies can be caused by the noise generated by the type of vessel used (i.e. R/V vs. small craft) or to an acoustic effect of the echo-sounder frequency used (38 kHz *vs* 70 kHz).

Nowadays the technologies available for direct hydroacoustic observation in shallow waters include both traditional split-beam echo-sounders and also multi-beam sonars (Gerlotto *et al*., 2000; Mayers *et al.,* 2002; Brehmer *et al*., 2003a), on mobile or fixed stations (Fabi and Sala, 2002). Platforms like the Autonomous Under-water Vehicle (Fernandes *et al.,* 2003) should allow these shallow areas to be surveyed. Aerial or Lidar observations, which are also suitable for shallow environments and gregarious populations, can also be envisaged (Churnside *et al*., 2003).

Conclusion

In the case of 'Golfe du Lion' a significant underestimate may occur in the assessment of the small pelagic fish stock if the coastal zone is not taken into account because of the spatial and temporal distribution of the population. Whatever the methodology used, it seems to be essential to assess the importance of the coastal strip that is not sampled by conventional research vessels. The results can then be taken into consideration in the fisheries management and ecological studies based on the variations of small pelagic fish stocks biomass. The assessment underestimation variability depends on characteristics of the continental shelf (available area under 20 m and water temperature/salinity) and the natural habitat of the small pelagic fish, but mainly on their displacement strategies, which could lead to an unsampled biomass of part of the resources targeted. Although the factors determining the behavioural aspects of spatial distribution of small pelagic fish are not yet well understood, methods exist for taking into consideration the biomass occurring in the coastal zone. It is necessary to use them to confirm or refute the importance of the biomass present in those areas that are inaccessible to normal sampling vessels and that are often not sampled in commercial landings data. We suggest carrying out traditional acoustic-assessment surveys over the deeper continental shelf part by the research vessel, simultaneously with shallow-water surveys from a small craft equipped with a portable echo-sounder. Similarly adapted pelagic trawl (Guillard and Gerdeaux, 1993) should be used to sample the fish population in these areas and complete the trawling carried out in the deeper continental shelf part by the research vessel.

Acknowledgements

We appreciate the interest of Francois Gerlotto in our Mediterranean shallow-waters programme. We thank the crews of the R/V L'Europe and the Chlamys for their help. We also thank Bruno Voituriez, Arnaud Bertrand and two anonymous referees for their helpful comments on earlier drafts of this paper.

References

Abad R., Miquel J., and Iglesias M. 1996. Campanas de evaluación por métodos acústicos se sardina, boquerón y ochavo en el Mediterráneo Occidental. FAO Fisheries Report 537: 191-193.

Arreguin-Sanchez, F. 1996. Catchability: a key parameter for fish stock assessment. Review in Fish Biology and Fisheries, 6: 221-242.

Bertrand, A., Segura, M., Gutiérrez, M., and Vásquez, L. 2004. From small-scale habitat loopholes to decadal cycles: a habitat-based hypothesis explaining fluctuation in pelagic fish populations off Peru. Fish and Fisheries, 5(4): 296-316.

Binet, D., Gobert, B., and Maloueki, L. 2001. El Niño-like warm events in the eastern Atlantic (6 degree N, 20 degree S) and fish availability from Congo to Angola (1964-1999). Aquatic Living Resources, 14(2): 99-113.

Brehmer, P., and Gerlotto, F. 2001. Comparative analysis of swimming behaviour in different populations of *Sardinella aurita*: influence of environment and exploitation; effect on catchability. ICES, CM 2001/Q:00.

Brehmer, P., Gerlotto, F., Guillard, J., Sanguinède, F., Guennégan, Y., and Buestel, D. 2003a. Monitoring anthropized aquatic ecosystems using acoustics: the case of fisheries and marine-culture grounds along the French Mediterranean coastline. Aquatic Living Resources, 16: 333-339.

Brehmer, P., Guennégan, Y., Arzelies, P., Guillard, J., Chéret, Y., Dufromentelle, P., and Colon, M. 2003b. *In situ* radiated noise of a platform in a shallow-water area on echo-sounder data in fisheries science. Hydroacoustic, 6: 31-40.

Brehmer, P. 2004. Analyse comparée des caractéristiques dynamiques et spatiales de diverses populations de Sardinella aurita: adaptation comportementale face à son environnement et son exploitation, effet sur sa capturabilité. PhD thesis ENSA Rennes, France, 386 pp.

Brehmer P., Gerlotto F. and Anchury A. 2005. Comportamiento dinámico y reacción de evitamiento en agregaciones de peces pelágicos ante el estímulo del buque de prospección acústica. Memoria de la Fundacion La Salle de Ciencias Naturales, (161-162), 201-214.

Churnside, J.H., Demer, D.A., and Mahmoudi, B. 2003. Comparison of lidar and echosounder measurements of fish schools in the Gulf of Mexico. ICES Journal of Marine Science, 60: 147-154.

Diner, N., Marchalot, C., and Berger, L. 2002. Echo integration by shoal using Movies+ software. April 2002, Version 3.4, DTI/DSI/DTI/98-243, Ifremer, France.

Duncan, A., Butterworth, A.J., Gerlotto, F. and Kubecka, J. 1998. Editorial. Fisheries Research, 35: 1-3.

Fabi, G., and Sala, A. 2002. An assessment of biomass and diel activity of fish at an artificial reef (Adriatic Sea) using a stationary hydroacoustic technique. ICES Journal of Marine Science, 59: 411-420.

Fernandes, P.G., Stevenson, P., Brierley, A.S., Armstrong, F., and Simmonds, E.J. 2003. Autonomous underwater vehicles: future platforms for fisheries acoustics. ICES Journal of Marine Science, 60: 684-691.

Fréon P., Gerlotto F., and Soria M. 1993. Variability of *Harengula* spp. school reactions to boats or predators in shallow water. ICES marine Science Symposium, 196: 30-35.

Fréon, P., and Misund, O. A. 1999. Dynamics of pelagic fish distribution and behaviour: effects on fisheries and stock assessment, Blackwell, London. 348 pp.

Gauthier, S., and Rose, G.A. 2002. *In situ* target-strength studies on Atlantic redfish (*Sebastes spp.).* ICES Journal of Marine Science, 59: 805-815.

Gerlotto, F., Georgakarakos, S., and Eriksen, P., 2000. The application of multi-beam sonar technology for quantitative estimates of fish density in shallow-water acoustic surveys. Aquatic Living Resources, 13: 1-10.

Glantz, M.H. 1996. Currents of change: El Niño's impact on climate and society. Cambridge University Press, Cambridge.

Godø, O.R. 1989. The use of tagging studies to determine the optimal time for estimating acoustic abundance. Fisheries Research, 8**:** 129-140.

Guennégan, Y., Liorzou, B., and Bigot, J.L. 2000. Exploitation des petits pélagiques dans le golfe du Lion et suivi de l’évolution des stocks par écho-intégration de 1995 à 1999. Food and Agriculture Organization-CGPM, paper presentation in WG small pelagic fish. Fuengirola, Espagne 1-3 March. 27 p.

Guillard, J., and Gerdeaux, D. 1993. *In situ* determinations of the target strength of roach (Rutilus rutilus L.) in Lake Bourget with a single-beam sounder. Aquatic Living Resources, 6: 285-289.

Guillard, J., and Lebourges-Dhaussy, A. 1998. Preliminary results of fish population distribution in a Senegalese coastal area with depths less than 15 m, using acoustic methods. Aquating Living Resources, 11: 13-20.

Hilborn, R., and Walters, C.J. 1992. Quantitative fisheries stock assessment.Chapman and Hall, London.

Johannesson, K.A., and Losse, G.F. 1977. Methodology of acoustic estimations of fish abundance in some UNDP/FAO resource-survey projects. Rapport et Procès verbaux des Réunions du Conseil International pour l’Exploration des Mers: 296-318.

Laloë, F. 1988. A surplus production model with inaccessible quantity of biomass depending on environmental conditions. Application to data from *Sardinella aurita* fishery in Ivory Coast and Ghana. Aquatic Living Resources, 4: 289-298.

Lleonart, J., and Maynou, F. 2003. Fish-stock assessments in the Mediterranean: state of the art. Scientia Marina, 67(1): 37-49.

Love, R.H. 1977. Target strength of an individual fish at any aspect. Journal of the Acoustical Society of Amercica, 72: 1397-1402.

McAllister, M. K. 1998. Modelling the effects of fish migration on bias and variance in area-swept estimates of biomass: a vector-based approach. Canadian Journal of Fisheries and Aquatic Science, 55: 2622-2641.

MacLennan, D.N., and Simmonds, E.J. 1992. Fisheries acoustics. Fish and Fisheries series 5 Chapman and Hall, London. 325 pp.

MacLennan, D., Fernandes, P.G., and Dalen, J. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES Journal of Marine Science, 59: 365-369.

Mayer, L., Li, Y., and Melvin, G. 2002. 3D visualization for pelagic fisheries research and assessment. ICES Journal of Marine Science, 59: 216-225.

Mesnil, B. 2003. Dynamique des populations exploitées et principaux modèles démographiques appliqués à la gestion des pêches. In Exploitation et surexploitation des ressources marines vivantes. Académies des sciences, Rapport sur la science et la technologie 17, Edition Tec & Doc., Paris. pp 123-155.

Misund, O.A., and Aglen, A. 1992. Swimming behaviour of fish schools in the North Sea during acoustic surveying and pelagic-trawl sampling. ICES Journal of Marine Science, 49: 325-334.

Mitson, R.B. 1995. Underwater noise of research vessels, Review and recommendations. ICES Cooperative Research Report, 209, Copenhagen. 209 pp.

Mulligan, T. 2000. Shallow-water fisheries sonar: a personal view. Aquatic Living Resources, 13: 269-273.

Olsen, K., Angell, J., Pettersen, F., and Lovik, A. 1983. Observed fish reactions to a surveying vessel with special reference to herring, cod, capelin and polar cod. FAO Fisheries Report, 300: 131-138.

Petitgas, P., Monimeau, L., Brehmer P., and Gerlotto F., 1996. Characterizing the spatial distribution of fish schools with a point-process approach: a first application on sonar recordings. ICES CM96/B :31.

Petitgas, P., Reid, D., Carrera, P., Iglesias, M., Georgakarakos, G., Liorzou, B., and Massé, J., 2001. On the relation between schools, clusters of schools, and abundance in pelagic fish stocks. ICES Journal of Marine Science, 58, 1150-1160.

Petursdottir, G., Hannibalsson, O., and Turner, J.M.M. 2004. La sécurité en mer, élément essentiel de la gestion des pêches. FAO, Rome circulaire sur les pêches, n:966, FIIT/C966.

Thorne, D. 1998. Review: experiences with shallow-water acoustics. Fisheries Research, 35: 137-142.

Trevorrow, M., Burczynski, J., and Kubecka, J. 2000. Editorial. Aquatic Living Resources, 13: 267.

Troadec, J.P., Boncœur, J., and Boucher, J. 2003. Le constat. *In* Exploitation et surexploitation des ressources marines vivantes. Académies des sciences, Rapport sur la science et la technologie 17, Edition Tec & Doc., Paris. pp 16-56.

Weill, A.C., Scalabrin, C., and Diner, N. 1993. MOVIES-B: acoustic-detection description software. Application to shoal species classification. Aquatic Living Resources, 6: 255-267.

Whitehead, P.J.P. 1985. FAO species catalogue. Clupeid fishes of the world. An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings. Part 1 - Chirocentridae, Clupeid and Pristigasteridae. FAO Fisheries Synopsis, 125, Vol. 7.

Table 1: The nine PELMED acoustics surveys with the research-vessel name and the echo-sounder model used (frequency: 38 kHz). The data have been processed using Ines-Movies software then with Movies+.

Year	Month	Vessel	Echo-sounder 38 kHz	Software
1993	July	Thalassa	Ossian 1500	Movies-B
1995	August	L'Europe	Ossian 1500	Movies-B
1996	July	L'Europe	Ossian 1500	Movies-B
1997	July	L'Europe	Ossian 1500	Movies-B
1998	July	L'Europe	Ossian 1500	Movies-B
1999	July	L'Europe	Ossian 1500	Movies-B
2000	July	L'Europe	Simrad Ek500	Movies+
2001	July	L'Europe	Simrad Ek500	Movies+
2002	July	L'Europe	Simrad Ek500	Movies+
2003	July	L'Europe	Simrad Ek500	Movies+

Table 2: Results of the linear regression (slope and R² linear coefficient), between the acoustic density of fish and bottom-depth layer for each year of the Pelmed surveys in the ‘Golfe du Lion’. For all nine years the slope was negative.

Year	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003
Slope	-5.46	-6.44	-5.66	-4.71	-4.72	-5.19	-6.26	-5.73	-2.29	-2.46
R^2_{linear}	0.756	0.888	0.942	0.919	0.673	0.681	0.918	0.849	0.459	0.23

Figure 1: (A) The sampling scheme for each annual PELMED survey. The grey rectangle corresponds to the area of experimental observations carried out in shallow waters from 2001 to 2003; (B) Example of the sampling scheme completed by the R/V L'Europe (black circle) and the Chlamys (grey circle) extending into shallow waters (5 m); circles are proportional to fish acoustic density in s_A ($m^2 . nmi^{-2}$).

Figure 2: The detected acoustic-density percentage in each 20 m depth class compared to the total density obtained during the whole survey for the ten PELMED surveys. For each year a trend curve has been calculated by fitting a linear regression.

Figure 3: (A) The acoustic densities (s_A in $m^2 . nmi^{-2}$) from 2001 to 2003, respectively in black, white and grey, recorded by the R/V L'Europe for the depth zones 15-20 m, 20-30 m, and 30-40 m respectively; (B) the acoustic densities (s_A) from 2001 to 2003, respectively in black, white and grey, recorded by Chlamys, for sampling in the 5-20 m and 20-30 m depth zones.

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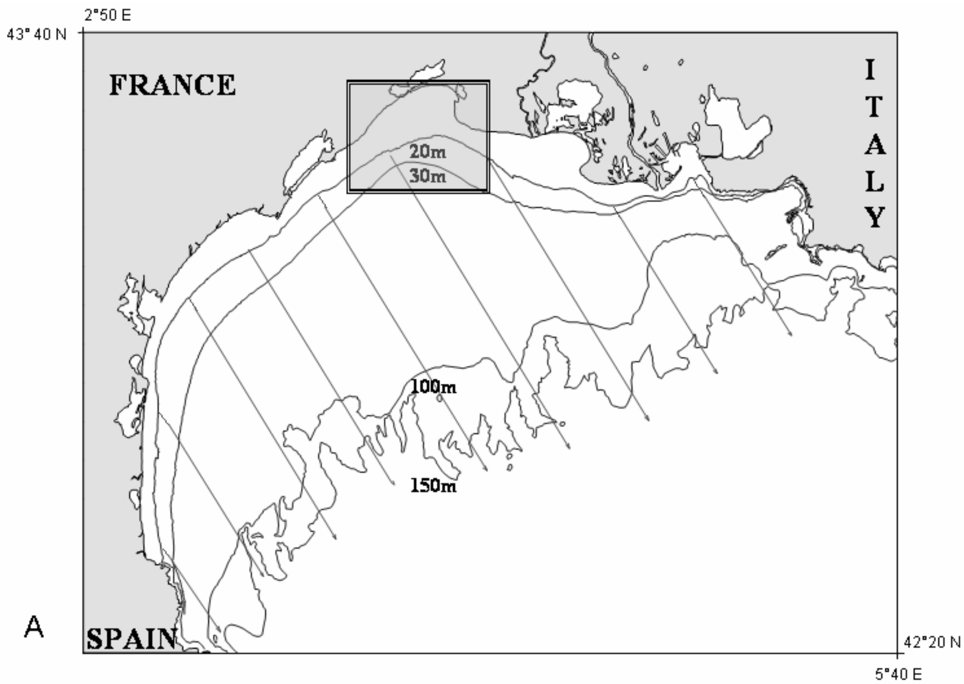

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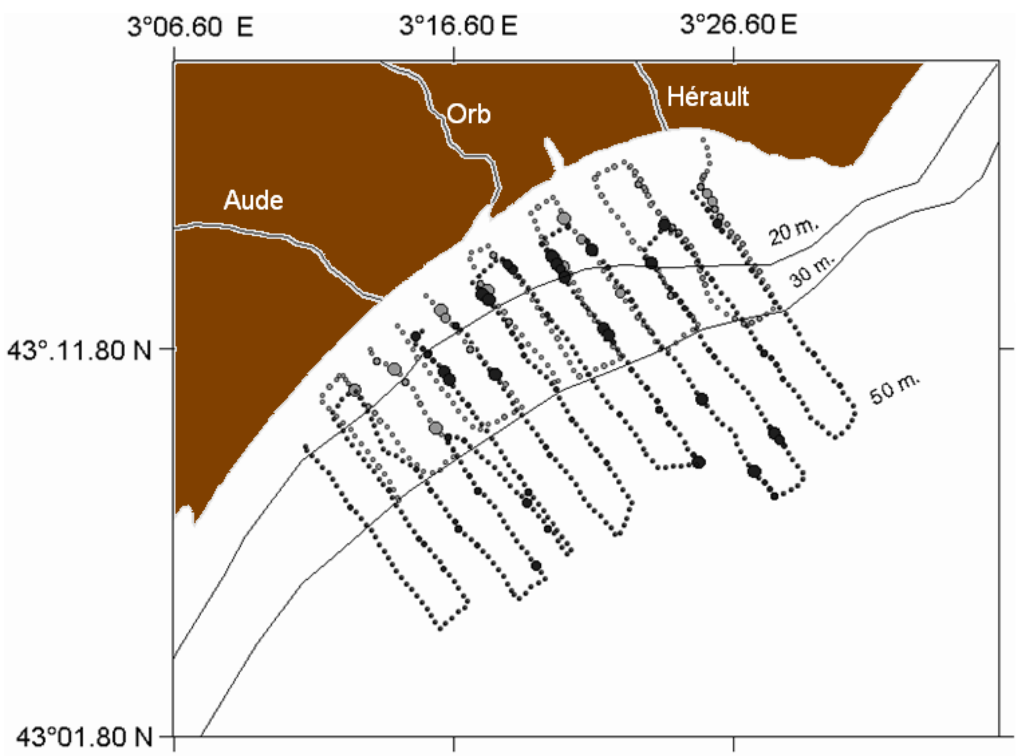

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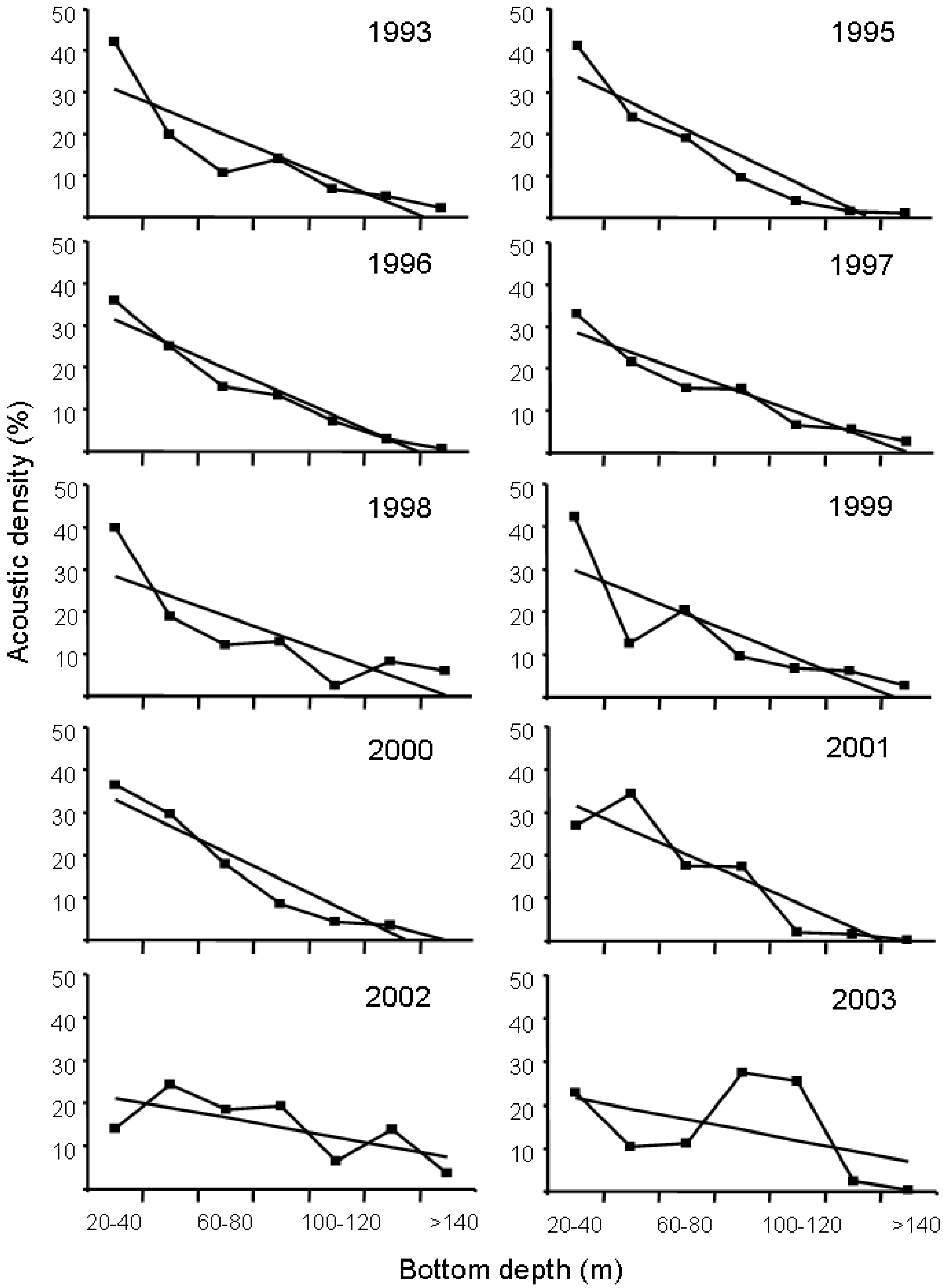

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