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

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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.

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Introduction

Most of the world's fish catch is small pelagic fish, mainly belonging to the Clupeidae and Engraulidae (http://www.fao.org). The often-critical current state of pelagic fish stocks (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 of fish populations (Mesnil, 2003) is usually conducted by scientific trawling or hydroacoustic surveys, or a combination of both (Johannesson and Losse, 1977; MacLennan and Simmonds, 1992). Direct and indirect stock-assessment methods are carried out on research vessels or commercial fishing boats (Hilborn and Walters, 1992; Fréon and Misund, 1999). Inshore coastal waters shallower than 20 m are inaccessible to such vessels for safety reasons and also to avoid conflict with artisanal fishers (Petursdottir *et al.*, 2004). Therefore, industrial fisheries are usually excluded from such waters by national regulation. 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 shallow waters close to the coast. However, the part of the continental shelf up to about 20 m deep 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 Gulf of Lion (Mediterranean Sea), where most of the small pelagic fish of the area occur, accounts for about 8% of the total continental shelf. It is therefore necessary to determine whether the fact that the fish in these areas are not taken into account has any effect on direct fish stock assessments. Indeed, no official recommendation has been made for small pelagic fish assessment regarding the biomass in shallow water where research vessels cannot generally 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 Gulf of Lion (Abad *et al.*, 1996; Guennégan *et al.*, 2000; Lleonart and Maynou, 2003). Surveys were completed by research vessels at depths from 20 to 140 m, the edge of the continental slope, where pelagic fish densities drop (Whitehead, 1985). Complementary scientific surveys were carried out in the same area and at the same time but in shallow waters (5–40 m), 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 water 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 hydroacoustically, and to demonstrate that an important part of the fish biomass distribution could live there.

Material and methods

Annual PELMED surveys, 1993–2003

The 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 nine transects with a total length of 355 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 m, over the whole of the survey area. To avoid annual variations in total abundance and differences attributable to the change of boat and the analytical software used – successively (MacLennan *et al.*, 2002) the deviations (Q_p, mm) from 1993 to 1999, the energies (E, m^2 mV^{-2}) from 2000 to 2001, and finally the nautical area scattering coefficient (s_A, m^2 nautical mile^{-2}) 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 conducted onboard 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, then a Simrad EK500 with a constant pulse length of 1 ms. The threshold on the echo-sounder was −60 dB for echo-integration 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. 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 anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*).

In situ experimental observations in shallow water

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 coast (Figure 1a). In each of the three years these two vessels simultaneously conducted transects, the R/V "L'Europe" did not work shallower than 15 m in 2001 and 2002, or 20 m in 2003, whereas the "Chlamys", which was built for manoeuvring in very shallow waters, began at 30 m and systematically continued its transects towards the coast, to 5 m deep (Figure 1b). The R/V "L'Europe" was fitted with a Simrad EK500 echo-sounder and the "Chlamys" with a SIMRAD EY500 split-beam echo-sounder, 70 kHz frequency, pulse length 0.3 ms, and a pulse repetition rate of about eight

Table 1. The ten 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	Research 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+

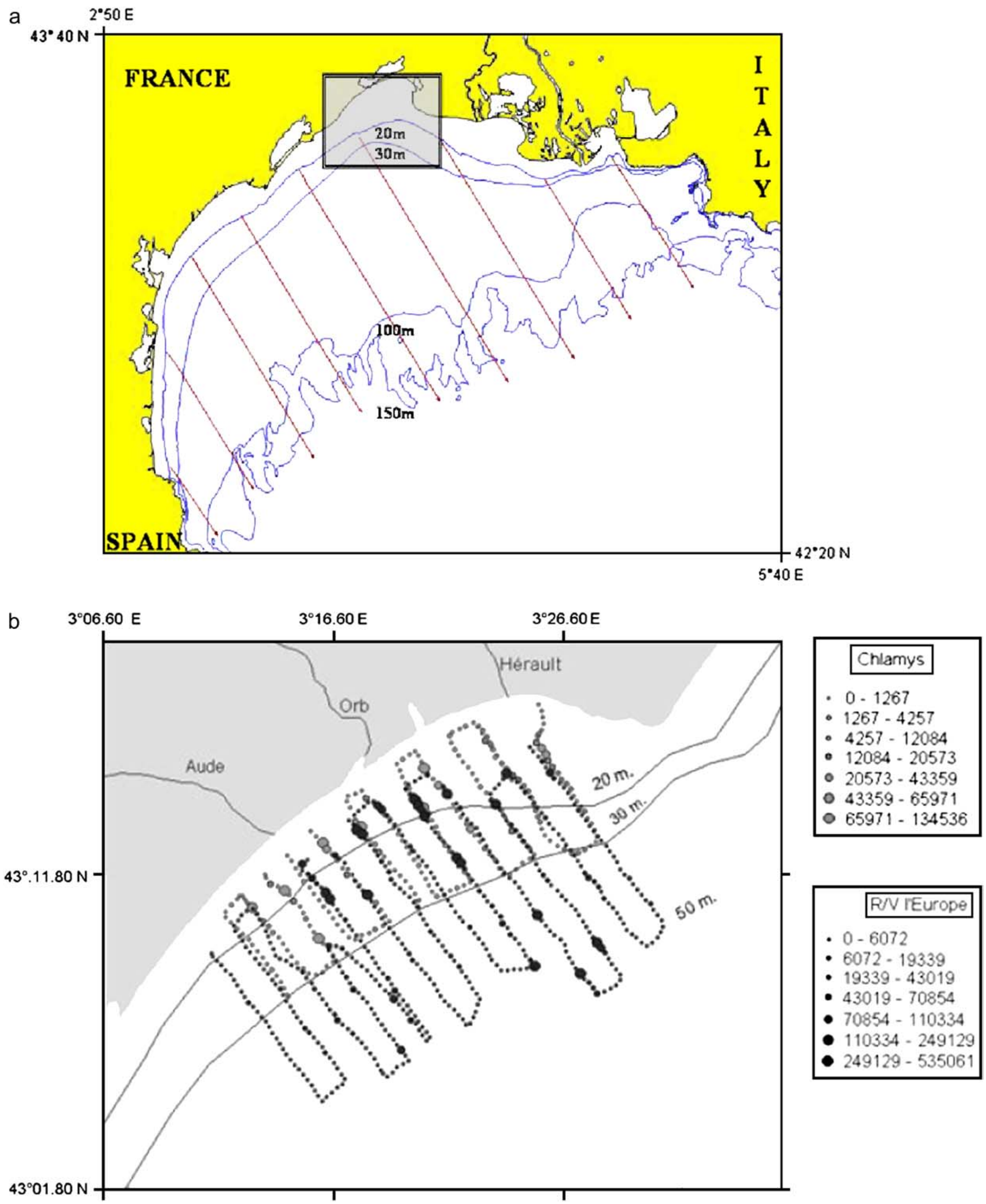

Figure 1. (a) The sampling scheme for each annual PELMED survey. The grey rectangle corresponds to the area where experimental observations were carried out in shallow water from 2001 to 2003; (b) example of the sampling scheme completed by the R/V "L'Europe" (black circle) and the "Chlamys" (grey circle)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

emissions per second. The transducer was fixed on a vertical pole alongside the outboard motor. All data collected by the "Chlamys" echo-sounder were processed using Movies+ software (Diner *et al.*, 2002) with the same threshold of −60 dB for echo-integration (in s_A). The arithmetic mean of the acoustic densities s_A observed by the R/V "L'Europe" and the "Chlamys" was calculated per depth class. For the "L'Europe" the bottom-depth classes were 15−20 m, 20−30 m, and 30−40 m, except in 2003 where depths <20 m were not sampled. For the "Chlamys", two depth classes were distinguished: <20 m (i.e. 5−20 m) and 20−30 m (Figure 1b).

Results

The results are presented in two parts: first, the chronological series derived from the ten PELMED stock-assessment surveys (Figure 2); second, the results of the 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 a decreasing gradient in the estimated mean acoustic densities seaward from the coast. Gradients were more or less pronounced depending on 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 distance from shore, the years 2002 and 2003 being distinguished from the other years by a gentler slope. In all cases the acoustic densities were least on the margins of the continental slope, i.e. between 100 and 140 m.

Direct *in situ* observations of pelagic fish biomass in shallow water

The results for the years 2001 and 2002 for R/V "L'Europe" 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 mile^{-2}, some 9.4 times greater than in 2002 (Figure 3a). The densities in the 20−30-m and 30−40-m depth classes were of the same order. There was a pronounced gradient in density shorewards 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.

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

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

Discussion

A strongly decreasing gradient from the coast to offshore in fish biomass was recorded, irrespective of the year and variations in total acoustic density. This trend was consistent over all ten years in the French part of the Gulf of Lion, although in 2001 and 2002, the acoustic densities were not highest in the most inshore area sampled by the research vessel (20−40 m), but rather 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 would have implications for the sampling methods to be used in any one year, just as would classical fish spatio-temporal variability or migration phenomena (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 in coastal shallow waters of the whole Gulf of Lion because of the incomplete sampling to which we were restricted. However, the results showed that 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 greater than the next depth zone. In the following two years, this area did not have a higher density, but densities were similar to those found between 20 and 40-m depth. The observations made in 2002 and 2003 therefore show that the shallow inshore area is important in terms of acoustic fish biomass, i.e. it has a density higher than the mean density found on an entire PELMED transect from 20 m to >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, at least in terms of fish biomass.

Our study was limited to the Gulf of 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 isobath 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 coast and therefore escape acoustic sampling by standard survey vessels (Bertrand *et al.*, 2004). Similar events have been reported by Glantz (1996) during *El Niño* 1972/1973, in which pockets of cold waters close to the coast contained large numbers of anchovy. In other areas of the world, these shallow areas are very extensive, e.g. the Gabès Gulf off Tunisia or Gene in Italy, where the shallow-water part of

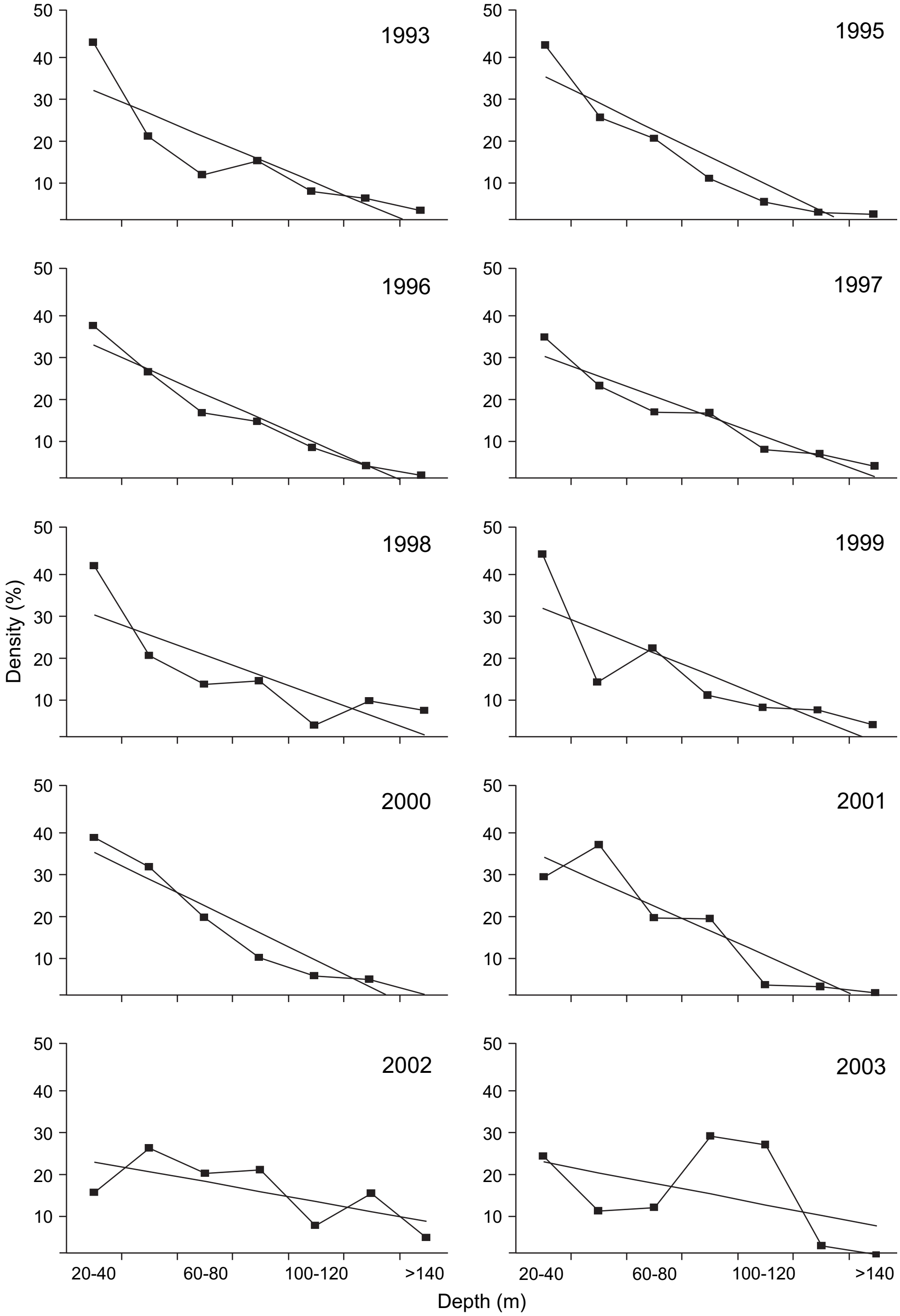

Figure 2. The detected acoustic-density percentage in each 20-m depth class compared with the total density obtained during the whole survey for the ten PELMED surveys. For each year, a trend curve has been calculated by fitting a linear regression.

the continental shelf is more extensive than in the Gulf of 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 not only affects the values provided by scientific fishing or echo-integration analysis produced by data collection from research vessels, but that other factors may be

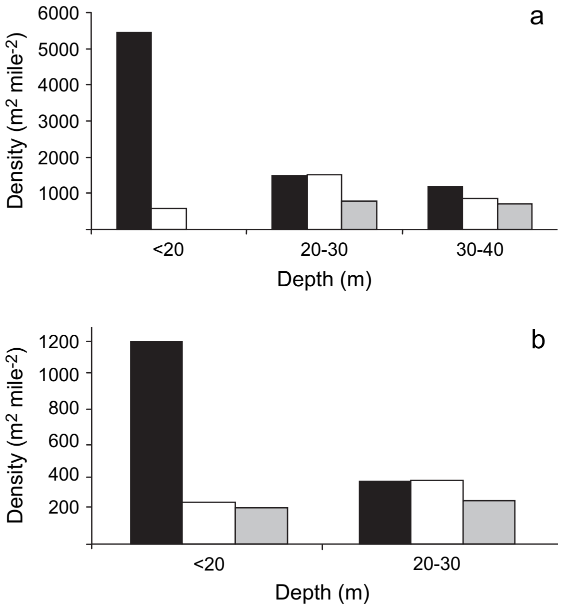

Figure 3. (a) Acoustic densities (s_A, m^2 mile^{-2}) from 2001 to 2003, respectively, in black, white, and grey, recorded by the R/V "L'Europe" for the depth zones 15–20 m, 20–30 m, and 30–40 m, respectively; (b) acoustic densities (s_A) from 2001 to 2003, respectively, in black, white, and grey, recorded by "Chlamys" for sampling in the 5–20 m and 20–30 m depth zones.

involved. Historically in many countries, national fisheries regulations rarely allow trawling in shallow inshore water, only small-scale fishing (Petursdottir *et al.*, 2004) being authorized there. Therefore, an abundance of small pelagic fish near the coast can quickly lead to small-scale fisheries outlets becoming saturated. This was the case, for example, during the acoustic survey conducted off the southern shelf coast of Senegal's Petite Côte in 1999 by IRD personnel on board R/V "Antéa" (Brehmer, 2004). Almost no *Sardinella aurita* were detected in the areas sampled (>20 m) by the R/V "Antéa" (unpublished data), but landings by local small-scale fishers quickly flooded the markets, overcoming the capacities of the local fish wholesaler. Surveys conducted shallower than 15 m in the same Senegalese region by Guillard and Lebourges-Dhaussy (1998) showed the importance of this zone, which usually goes unsampled in terms of quantitative and qualitative biomass, with the occurrence there mostly of juvenile fish.

In some cases, 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 can reflect only the available biomass, not the real population biomass. Obviously, even in the short term, if the environmental conditions are more attractive or less repulsive to 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. Again, targeted fish can be found outside the fishing areas, so the assumption that biomass can be described by a function of exploited biomass may be false just because of its inaccessibility (Laloë, 1988).

The variations in biomass between years in the coastal area can be caused by fish behavioural changes, resource exploitation, or environmental changes (Binet *et al.*, 2001), or a combination of all three. Any comparison between spatial structures and shoal clustering should be done in two and three dimensions (Petitgas *et al.*, 2001) using echo-sounder data and long-range sonar data (Petitgas *et al.*, 1996) to 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 fish behaviour can have an important impact on biomass estimation is 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 that the avoidance behaviour of shoals of small pelagic fish would differ greatly depending on the very different characteristics of the two types of boat used (Mitson, 1995) in this instance, but this was not entirely the case. The same number of shoals was observed with both boats, but vertical avoidance was 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) showed a significant increase in target strength (Love, 1977) of the same fish (*Sebastes* spp.) between targets detected below 50 m and shallower ones. They attribute this phenomenon to fish avoidance. Vertical diving could explain the differences in backscattered energy observed here between the two boats. The noise generated in the water column is

Table 2. Results of the linear regression (slope and r^2 linear coefficient) between the acoustic density of fish and bottom depth for each year of the PELMED surveys in the Gulf of Lion. For all ten 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

higher for the R/V "L'Europe" than for the "Chlamys" (Brehmer *et al.*, 2003b). A difference of a factor of 3 or 4 in acoustic fish density (Figure 3) between the two frequencies can be attributed to the noise generated by the type of vessel used (i.e. research vessel 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 water include both traditional split-beam echo-sounders and 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 Underwater Vehicle (Fernandes *et al.*, 2003) could allow 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 the Gulf of Lion, there may be a significant underestimate of the size of the small pelagic fish stock if shallower water than surveyed by the research vessel is not taken into account because of the spatial and temporal distribution of the population. Whatever the methodology used, it would seem crucial to assess the importance of the coastal strip not sampled by the conventional research vessel. 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. Variation in assessment underestimation depends on characteristics of the continental shelf (available area shallower than 20 m and water temperature/salinity) and the natural habitat of small pelagic fish, but mainly on their displacement strategies, which could lead to an unsampled biomass of part of the target resource. 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 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. We suggest carrying out traditional acoustic-assessment surveys over the deeper continental shelf part by research vessel, and simultaneously to survey shallow water from a small craft equipped with a portable echo-sounder. Similarly adapted pelagic trawls (Guillard and Gerdeaux, 1993) should be used to sample the fish population in the same areas and to complete the sampling carried out in deeper water by the research vessel.

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