# Size of mackerel in research vessel trawls and commercial purse-seine catches: implications for acoustic estimation of biomass

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In September after summer feeding has ceased, Northeast Atlantic mackerel (*Scomber scombrus*) tend to aggregate in ICES Area IVa before starting to migrate south towards the spawning grounds, between December and February. During this autumn period, the Norwegian purse-seine fleet catches mackerel in the southern part of the Norwegian Sea and the northern part of the North Sea. Between 1999 and 2005, Norway's Institute for Marine Research carried out annual acoustic surveys on a research vessel capable of trawling, to estimate the biomass concurrently with the fishery. During the surveys, mackerel were sampled with pelagic trawls (486 and 538 m circumference) at an average speed of 3.5–4 knots, and age, length, and weight was determined for use in biomass estimation. Mackerel age, length, weight, length-at-age, and weight-at-length (condition) in trawl catches were all significantly lower than observed in purse-seine catches from nearby commercial vessels, indicating that the research trawl selects younger, smaller, and perhaps weaker, fish. This finding has a significant influence on acoustic estimation of abundance of mackerel. Using data from purse-seine-caught mackerel instead of those caught in the trawl, the estimated total number of mackerel in the area of operation decreased by an average of 26.4%, and concurrent estimates of total biomass increased by an average of 32.2%. The results raise the importance of awareness of the differences in applying trawl samples to estimate year-class abundance and biomass and to study variations in growth and condition of fast-swimming species such as mackerel.

Keywords: acoustic biomass estimation, mackerel, purse-seine, trawl.

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## Introduction

The Northeast Atlantic (NEA) mackerel stock consists of three spawning components named after their spawning areas, the southern, the western, and North Sea component. The southern component spawns in Spanish and Portuguese waters, the western component in the Bay of Biscay and northwards along the Irish and UK coasts, and the North Sea component centrally in the North Sea and the Skagerrak. NEA mackerel are commercially important and the fisheries during the period 1992–2002 produced catches of the order of 565 000–821 000 t (ICES, 2006).

The southern and western spawning areas have been surveyed every third year, since 1977 (Lockwood *et al.*, 1981; ICES, 2002), to measure egg production, fecundity, and spawning–stock biomass (SSB). Surveys have been carried out in the North Sea since 1968. For many years, those surveys were carried out once per spawning season, but since 1980 (Iversen, 1981; ICES, 2003), the surveys have been extended to cover the spawning area several times per season to estimate egg production and SSB.

Egg estimates are the only SSB indices of mackerel that are fishery-independent and are therefore crucial when assessing the status of the NEA mackerel stock (ICES, 2003). However, the fact that mackerel, which do not have a swimbladder, can be distinguished from other fish species using echosounders operating synchronously at different frequencies (Korneliussen and Ona, 2003), suggests that the stock size can also be estimated acoustically. Therefore, Norway's Institute of Marine Research (IMR) has since 1999 utilized the research vessel (RV) "G. O. Sars" with multifrequency equipment yearly to estimate the distribution and abundance of mackerel in October/November as it aggregates in ICES Area IVa, before the stock migrates south to its spawning grounds (Iversen, 2002).

During both egg surveys and acoustic surveys, pelagic trawling is carried out to assess biological characteristics such as length and weight distributions, age, stage of maturity, and fecundity. The data on length and weight are necessary for both types of estimate and are based on the assumption that the samples are representative of the actual population. However, mackerel swim fast; schools tracked by sonar have been recorded at speeds up to $6 \text{ m s}^{-1}$ (Godø *et al.*, 2004). Hence, the present study examines the hypothesis that mackerel will, to some extent at least, tend to avoid the RV trawl, as demonstrated for other pelagic fish such as Cape horse mackerel (*Trachurus trachurus capensis*; Barange and Hampton, 1994), herring, and sprat (*Clupea harengus* and *Sprattus sprattus*, respectively;

Misund and Aglen, 1992), and sardinella (*Sardinella maderensis* and *Sardinella aurita*; Misund et al., 1999). In general, pelagic fish tend to dive under the net when the trawl approaches. Research trawls are smaller and towed more slowly than large commercial trawls towed at high speeds in the Irish and Scottish mackerel fisheries.

Another hypothesis is that avoidance will increase as the fish grow, as a consequence of the ability to swim faster as a fish gets larger (Ware, 1975, 1978). However, avoidance ability may decrease if body condition is reduced (i.e. weaker fish). A purse-seine, in contrast, is assumed to be a non-selective gear because it catches whole schools of up to several hundreds of tonnes, although the schools themselves may also manage to avoid the purse-seines (Misund, 1993).

The objective of this study was to test whether the mackerel caught in RV trawls are smaller and in worse condition than the mackerel being taken synchronously by neighbouring purse-seiners, and if so the extent to which this might affect estimation of biomass.

## Methods

The biological data used to test for possible size selectivity in RV trawls for mackerel were the 1999–2005 catch data from the "G. O. Sars" in ICES Area IVa in October and November, and data from commercial purse-seine catches from the same area and season (Figure 1, Table 1). The Norwegian purse-seine fishery starts in September. Hence, the fishery data were analysed from both September and October to look for "within season" differences in mackerel size. An "Åkra" trawl with a circumference of 486 m (Valdemarsen and Misund, 1995) was used throughout. However, the trawl opening was changed to a circumference of 538 m before the 2005 survey. Also, from 2003, the new "G. O. Sars" was used rather than its predecessor, but trawling continued with the same trawl net and at the same speed, i.e. the speed was limited by the trawl construction, not the vessel power.

Many of the mackerel samples from the commercial fishery were measured for length only (Table 1). However, the total weight of these samples was noted, so the mean weight could be calculated. In the present study, the mean length and the mean weight of all samples (where the number of fish $n > 9$) were used as input data in statistical tests when comparing mackerel length and weight between catch months and gears. In a small number of samples, at least 50 fish (if available) and sometimes up to 100 fish were assessed for other biological parameters such as weight, sex, stage of maturity, and age (from otoliths). Data on individual mackerel from these samples were used in statistical tests when comparing length-at-age and weight-at-length (condition) between catch months and gears. In some samples, as many as 50 sets of otoliths were taken for age determination; length and weight data were generally collected from more mackerel.

As demonstrated by the mean catch size and mean number of fish in a sample (Table 1), the goal of at least 50 fish was difficult to achieve from trawls. The tendency of the mackerel to avoid the trawl was so great that in some cases "G. O. Sars" caught none or very few fish. However, the mean catch size and number of individuals sampled increased after the new "G. O. Sars" entered service in 2003, perhaps indicating more efficient trawling. The trawl samples were still small, the biggest catch being 0.660 t in 2003. However, by comparison, the sampled purse-seine catches were always large, varying from 137 to 230 t, and increased from September to October.

The effect of using purse-seine samples rather than trawl samples in biomass estimation was investigated. Conversion of the area echo-abundance-area, i.e. the nautical-area backscattering coefficient (NASC), $s_A$ (MacLennan et al., 2002), to numerical fish quantities and biomass was achieved using the adopted mean target strength, TS, to length ($L$) relationships for mackerel, as used in the standard assessment surveys (Foote, 1987):
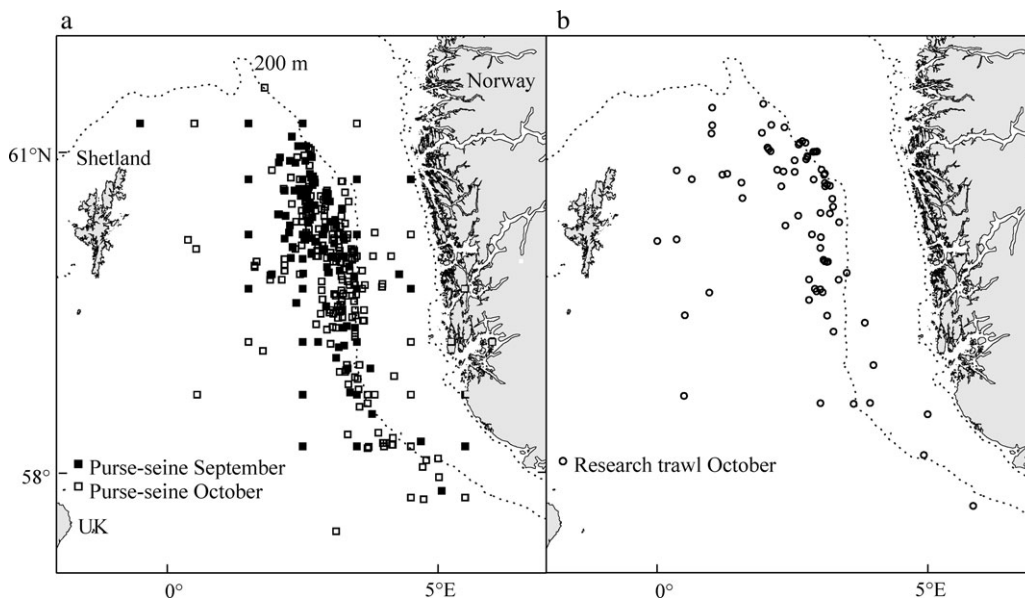
$$TS = 20\log_{10} L - 84.9. \qquad (1)$$



**Figure 1.** Maps of (a) the geographical distribution of mackerel samples derived from commercial purse-seine catches in September and October of the years 1999–2005, and (b) pelagic-trawl catches taken by RV "G. O. Sars" during October of the same years. Positions are only given for catches where $n > 9$.

**Table 1.** Overview of the data used in analyses by catch gear, month, and year.

| Gear | Month (weeks) | Year | $C_T$ (t) | $C_M$ (t) | $C_{NL}$ | $L_{MN}$ | $L_{TN}$ | $C_{NI}$ | $I_{MN}$ | $I_{TN}$ | $A_{TN}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RT | 10 (3) | 1999 | 0.412 | 0.034 | 12 | 51.3 | 616 | 11 | 38.8 | 427 | 421 |
| RT | 10 (3–4) | 2000 | 0.301 | 0.012 | 25 | 34.4 | 860 | 24 | 35.0 | 840 | 244 |
| RT | 10 (3–4) | 2001 | 0.059 | 0.005 | 13 | 23.2 | 302 | 13 | 22.5 | 293 | 256 |
| RT | 10 (3–4) | 2002 | 0.940 | 0.034 | 27 | 21.8 | 589 | 27 | 21.8 | 589 | 325 |
| RT | 10 (3–4)–11 (1) | 2003 | 8.645 | 0.288 | 29 | 48.8 | 1 415 | 29 | 48.8 | 1 415 | 611 |
| RT | 10 (3–4)–11 (1) | 2004 | 13.887 | 0.661 | 21 | 65.3 | 1 371 | 21 | 65.3 | 1 371 | 698 |
| RT | 11 (1–3) | 2005 | 3.959 | 0.264 | 18 | 56.2 | 1 012 | 18 | 56.2 | 1 012 | 455 |
| PS | 9 | 1999 | 11 497.424 | 161.936 | 71 | 114.3 | 8 118 | 27 | 80.3 | 2 167 | 794 |
| PS | 9 | 2000 | 5 546.575 | 149.907 | 37 | 138.7 | 5 133 | 9 | 55.2 | 497 | 483 |
| PS | 9 | 2001 | 19 291.781 | 137.798 | 140 | 124.8 | 17 475 | 49 | 85.1 | 4 172 | 1 051 |
| PS | 9 | 2002 | 28 304.194 | 161.738 | 175 | 118.4 | 20 726 | 62 | 65.1 | 4 039 | 1 502 |
| PS | 9 | 2003 | 24 097.445 | 161.728 | 149 | 124.4 | 18 531 | 45 | 61.3 | 2 758 | 1 255 |
| PS | 9 | 2004 | 40 461.143 | 175.156 | 231 | 79.5 | 18 365 | 23 | 53.0 | 1 220 | 930 |
| PS | 9 | 2005 | 25 939.900 | 146.553 | 177 | 75.2 | 13 307 | 32 | 62.9 | 2 012 | 726 |
| PS | 10 | 1999 | 12 816.000 | 166.442 | 77 | 109.5 | 8 429 | 23 | 87.9 | 2 021 | 496 |
| PS | 10 | 2000 | 12 386.427 | 196.610 | 63 | 101.8 | 6 416 | 22 | 65.0 | 1 430 | 1 334 |
| PS | 10 | 2001 | 15 804.613 | 213.576 | 74 | 122.2 | 9 042 | 10 | 73.4 | 734 | 324 |
| PS | 10 | 2002 | 6 883.007 | 176.487 | 39 | 102.9 | 4 014 | 15 | 78.1 | 1 172 | 458 |
| PS | 10 | 2003 | 27 673.395 | 190.851 | 145 | 121.0 | 17 552 | 36 | 76.2 | 2 743 | 513 |
| PS | 10 | 2004 | 21 477.159 | 230.937 | 93 | 93.8 | 8 719 | 6 | 90.5 | 543 | 175 |
| PS | 10 | 2005 | 16 025.900 | 195.438 | 82 | 90.0 | 7 382 | 3 | 49.0 | 147 | 146 |

RT, research trawl; PS, purse-seine; $C_T$, total biomass of the catch analysed; $C_M$, mean catch size; $C_{NL}$, number of catches sampled for length composition; $L_{MN}$, mean number of fish measured for length per catch; $L_{TN}$, total number of fish measured for length; $C_{NI}$, number of catches sampled for additional biological parameters such as weight, sex, maturity, and age; $I_{MN}$, mean number of individuals per catch for which additional biological measurements were made; $I_{TN}$, total number of individuals for which additional biological measurements were taken; $A_{TN}$, total number of fish aged. Note that the weeks sampled (1–4) within a month is given for the RT data, whereas in the PS data, all weeks were sampled in all years.

The number of fish, $N$, within a particular area ($A$) was computed in the standard manner:

$$N = \langle s_A \rangle A (4\pi \langle \sigma_{bs} \rangle)^{-1}, \qquad (2)$$

where $s_A$ is the mean NASC within the area, $A$ the area in square nautical miles, and $\sigma_{bs}$ is the mean backscattering cross section of the fish species, as estimated from the target-strength equation (MacLennan *et al.*, 2002).

The possible effect of gear selectivity on estimates of abundance was investigated using the mean $L$ by gear and year of all samples in the study area, based on the assumption that both gears sampled the same schools (Figure 1). Hence, the acoustic data were not stratified in any way, i.e. abundance was estimated using the same set of NASC values and areas $A$ for all years. Based on the applied length–weight relationships, the appropriate mean weight of mackerel of mean $L$ by gear and year was estimated to determine biomass. Finally, the relative difference (%) between the estimate based on trawl and purse-seine samples was calculated.

## Results

A comparison of the length and age distributions between RV trawl- and purse-seine-sampled mackerel in ICES Area IVa during autumn of the years 1999–2005 showed clearly the tendency of the trawl to catch smaller (Figure 2a), younger (Figure 2b) mackerel.

Statistical tests showed that the length (Figure 3a) and weight (Figure 3b) of mackerel in October was influenced by both sampling gear and year (ANOVA, $p < 0.001$), i.e. mackerel length and weight were significantly lower in the trawl samples than in the purse-seine samples in all years, with a tendency to decrease over the study period. Further, the length and the weight of purse-seine-caught mackerel were significantly lower in October than in September (ANOVA, $p < 0.001$).

An ANOVA run with year as covariate further demonstrated that both length-at-age (Figure 4a) and weight-at-length (condition) (Figure 4b) were significantly lower for the trawled mackerel than for purse-seined mackerel ($p < 0.001$). ANOVA also showed that mackerel condition in the purse-seine fishery decreased significantly between September and October ($p < 0.001$), although there was no difference in age-at-length between catches made in these months.

Using length and weight data from purse-seined mackerel rather than trawled mackerel with the acoustic data led to an average reduction in total fish numbers of 26.4% on average (range 17–50%) (Figure 5a), whereas the concurrent estimates of total biomass increased by 30.6% on average (range 19.6–58.5%) (Figure 5b). Of course, the parameter SSB is used commonly in assessments, and the trawl samples certainly include more small and hence immature fish than the purse-seine catch. Hence, the enhanced SSB calculated using purse-seine samples rather than trawl samples will be even higher than the increase in total biomass.
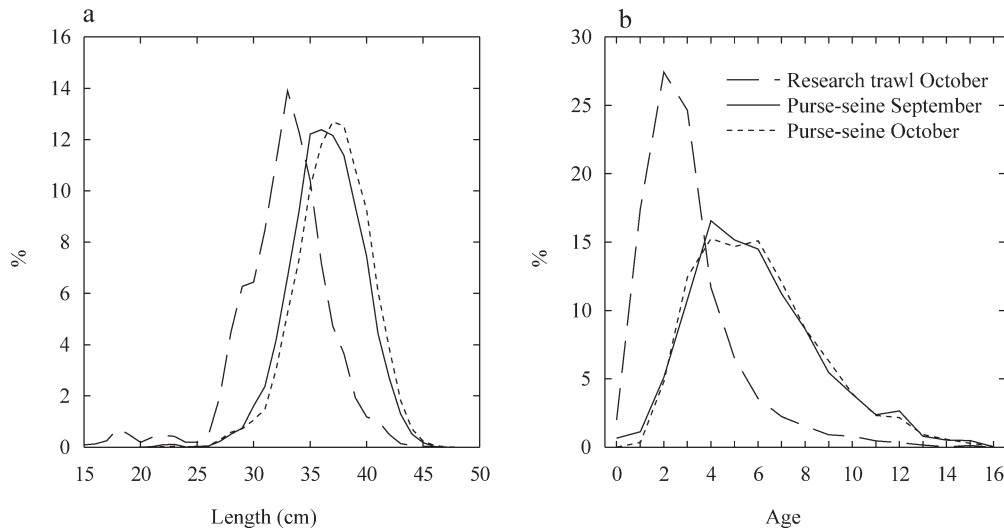
**Figure 2.** Comparison of mackerel sampled from commercial purse-seine catches in September and October with fish from pelagic-trawl catches of the RV "G. O. Sars" during October of 1999–2005. (a) Length distribution, and (b) age distribution of mackerel caught in ICES Area IVa.

## Discussion

We have demonstrated that the age, length, length-at-age, and weight-at-length (condition) of mackerel caught in RV trawls is significantly lower than that observed in the purse-seine catches from nearby commercial vessels. A potential problem with RV catches is also evident simply from their small volume.

One explanation of the results is that the fast-swimming mackerel schools (Godø *et al.*, 2004) simply avoid the small research trawl, and that this tendency increases as the fish grow older and larger and can swim faster (Ware, 1975, 1978). Herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) schools in the North Sea have been shown to have length-dependent swimming speeds and increasing ability to avoid trawl nets, i.e they can also swim faster and avoid nets more easily as they grow (Misund and Aglen, 1992). Vessel avoidance has a significant influence on

estimates of abundance of fish and pelagic fish, whereas the effect of gear avoidance in general is considered to be a serious problem only in estimating groundfish abundance (Fréon *et al.*, 1993). However, our results clearly indicate that size-dependent trawl avoidance may have a significant influence on the estimated year-class abundance of mackerel, a pelagic fish, overestimating young fish and total abundance, and underestimating total biomass.

Another plausible explanation for the differences in mackerel size in trawl and purse-seine catches could be the fishers tending to focus their effort in areas with the largest and most valuable mackerel. Such selective fishing has been observed in Norwegian spring-spawning herring during the spawning season (Slotte and Johannessen, 1997). However, in the data used in the present analysis, the RV and the commercial vessels operated side by
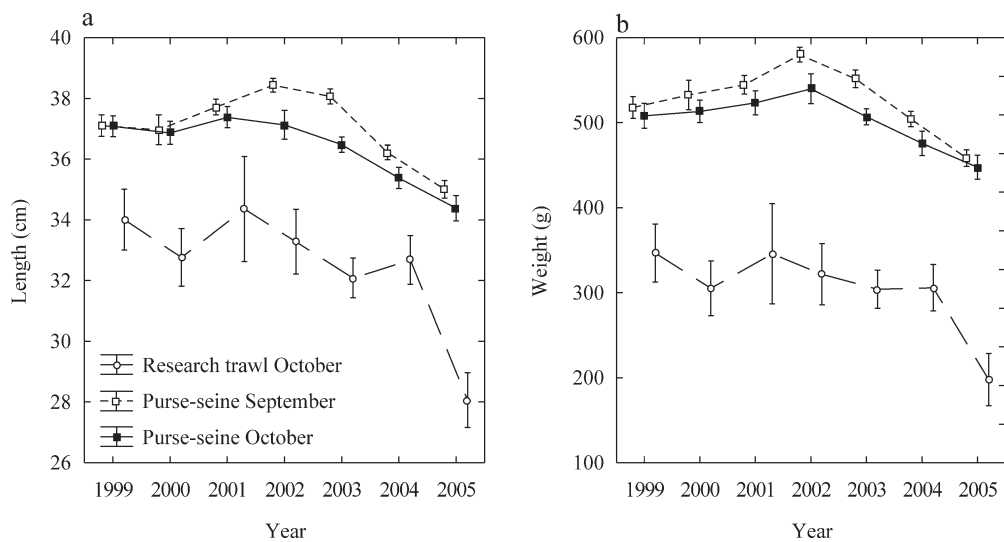


**Figure 3.** Commercial purse-seine catches made in September and October and pelagic-trawl catches taken by the RV "G. O. Sars" in October. (a) Length, and (b) weight of mackerel in ICES Area IVa by year and catching gear. Mean values ± 95% confidence intervals.
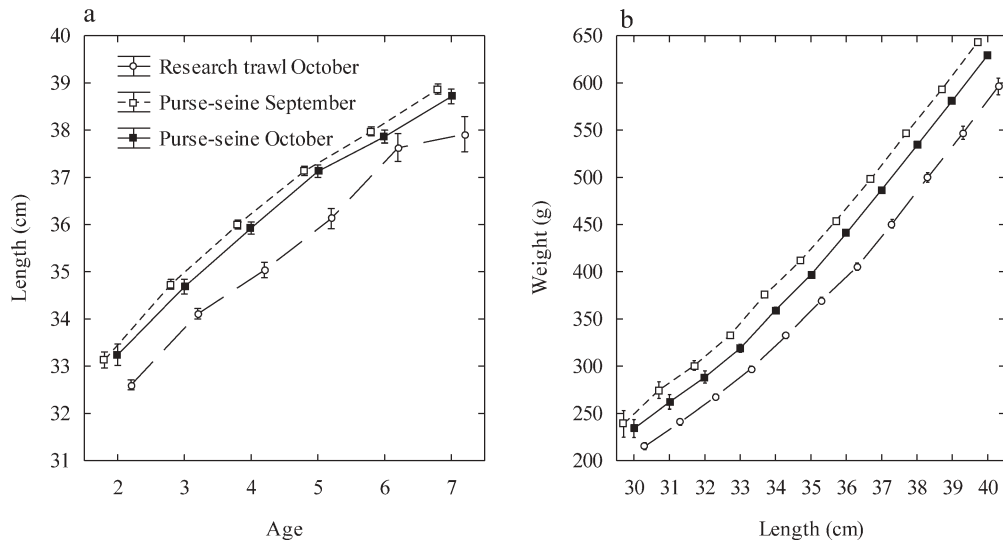
**Figure 4.** Commercial purse-seine catches in September and October and pelagic-trawl catches taken by the RV "G. O. Sars" in October. (a) Length-at-age, and (b) weight-at-length of mackerel in ICES Area IVa related to year and catching gear. Mean values ± 95% confidence intervals.

side on the same aggregations of mackerel, at least insofar as visual acoustics are concerned. Therefore, in theory at least, they should be trying to catch the same fish.

Certainly the data presented could be influenced both by the behaviour of the mackerel that increase in size and by differences through the catching season. Perhaps, the trawl may catch more of the mackerel not visible acoustically but scattered throughout the water column and that young fish may tend to be more scattered than old fish. The smaller size of mackerel in the purse-seine fishery from September to October is probably due to larger fish leaving the area before smaller ones, heading south towards the spawning grounds (Walsh *et al.*, 1995). Alternatively, the issue may be that more young fish arrive in the area as the season progresses. However, the drop in condition (weight-at-length) over

the same period is the result of normal weight loss in a period with little feeding activity. The larger purse-seine catches in October than in September could be explained by a change in behaviour of the schools, which according to fishers tend to be deeper by day during October. Hence, the catch process would be shifted towards the night when the schools move closer to the surface, but at the same time, estimation of school size would be more difficult, resulting in larger catches than anticipated.

To conclude, our results emphasize the importance of interpreting with caution the results of RV trawl samples of the fast-swimming mackerel in acoustic estimates of abundance. The size and the age structure utilized in acoustic estimates may be skewed towards younger fish and fish in worse condition than the average individual in the school, which would increase the
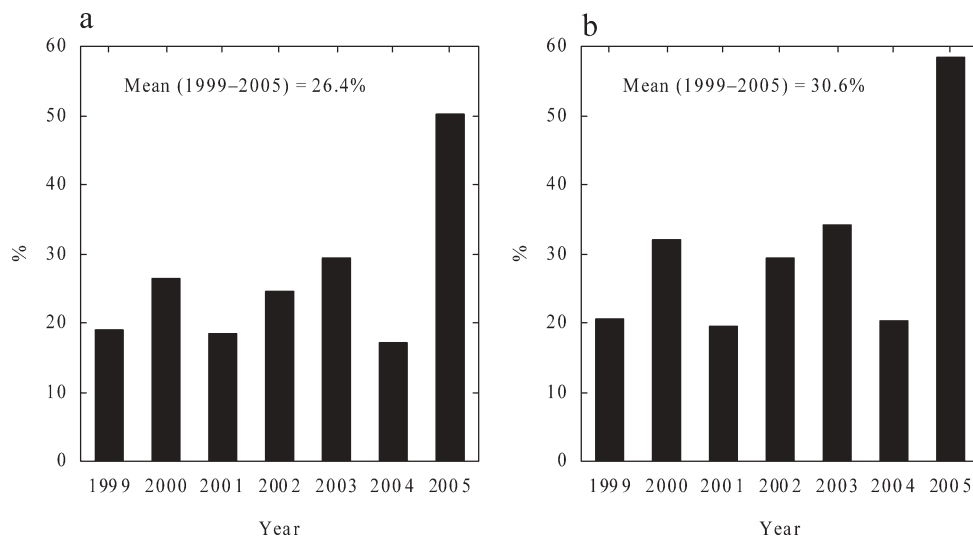


**Figure 5.** Annual. (a) Percentage decrease in acoustic abundance, and (b) concurrent increase in biomass of mackerel in ICES Area IVa in October, using data on length and weight from commercial purse-seine catches instead of pelagic-trawl samples taken by the RV "G. O. Sars".

total abundance estimates and reduce the SSB estimates significantly. Moreover, use of trawl samples is not recommended for any studies on mackerel growth, given the lower length-at-age and weight-at-length (condition) values calculated in comparison with the purse-seine-caught fish. Finally, because of over-representation of fish in poor condition in the trawl samples, trawl-caught samples may have a significant influence of on the results of studies of maturation and egg production, both of which are essential to the assessment of this stock (Lockwood *et al.*, 1981).

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