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INTERANNUAL FLUCTUATIONS IN ACOUSTIC BIOMASS ESTIMATES AND IN LANDINGS OF SMALL PELAGIC FISH POPULATIONS IN RELATION TO HYDROLOGY IN THE STRAIT OF SICILY

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The main results of research work carried out since 1998 with regard to the application of hydro-acoustic technologies for the evaluation of biomass and distribution of small pelagic fish species off the southern coast of Sicily are presented, taking into account information from hydrology and from ecology of the fish populations targeted. The biomass estimates and the population-density charts presented concern the two main species, *i.e.* sardine *Sardina pilchardus* (Walbaum, 1792) and anchovy *Engraulis encrasicolus* (Linnaeus, 1758). Both the sardine and anchovy populations experienced large inter-annual fluctuations, with biomass estimates ranging from 6000 to over 36,000 tonnes (t) (sardine) and from about 7000 to 23,000 t (anchovy). Acoustic estimates are largely consistent with landings recorded in Sciacca (the main fishing port for small pelagic species in the study area) during the year following the evaluation surveys. In addition, trends in sardine and anchovy biomass estimates appears to be negatively correlated with the mean sea surface temperature calculated over the time intervals January–September (sardine) and June–November (anchovy) of the preceding year, which correspond to larval and juvenile growth periods of target species. Observed patterns would suggest the importance of enrichment processes relevant to the survival of early stages, so determining recruitment success and finally higher population sizes.

Keywords: Small pelagic fish; Echointegration surveys; Biomass estimates trends; Spatial patterns; Sea surface temperature; Strait of Sicily

1 INTRODUCTION

European anchovy *Engraulis encrasicolus* (Linnaeus, 1758) and European sardine *Sardina pilchardus* (Walbaum, 1792), are the two most abundant small pelagic fish species landed

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in Sciacca, the main Italian port for this fishery in the Strait of Sicily (Mazzola *et al.*, 2002), jointly representing more than 90% of commercial small pelagic landings. Reported landings in Sciacca port have varied greatly over the last few years, from 126 t in 1999 to 2312 t in 2001 for anchovy and from 1233 t in 1999 to 2080 t in 2000 for sardine.

The bottom topography of the Strait of Sicily is characterized by a fairly narrow continental shelf, with a slope at about 15 nautical miles (nmi) from the coast from Mazara del Vallo to Cape Scaramia, though the shelf widens up over 50 nmi on the Adventure Bank and Malta shelf (Fig. 1). The surface circulation is controlled by the Modified Atlantic Water (MAW) motion, the so-called Atlantic-Ionian Stream (AIS), (Robinson *et al.*, 1991, 1999), a meandering surface current whose path is rather steady (Fig. 1). It enters the channel by its west boundary to describe a large cyclonic meander, which embraces the Adventure Bank. Then, it approaches the shore by the middle of the southern coast of Sicily and separates again when it encounters the shelf of Malta. In doing so, the AIS encircles two large cyclonic vortexes, that already mentioned and a second one around Malta shelf, off Cape Passero (the southernmost tip of Sicily). This kind of circulation favours the existence of "permanent" upwelling to the left of the Stream (looking downstream) at certain places, eventually reinforced by wind-induced upwelling events (Piccioni *et al.*, 1988), which are able to sharpen the density front due to the offshore Ekman transport. Coastal upwelling is believed to be the main source of nutrient pumping in the area (characterized by very low levels of rivers discharges). However, the AIS path is characterized by significant year-to-year variability (Lermusiaux, 1999; Lermusiaux and Robinson, 2001; Mazzola *et al.*, 2002), with possible consequences on

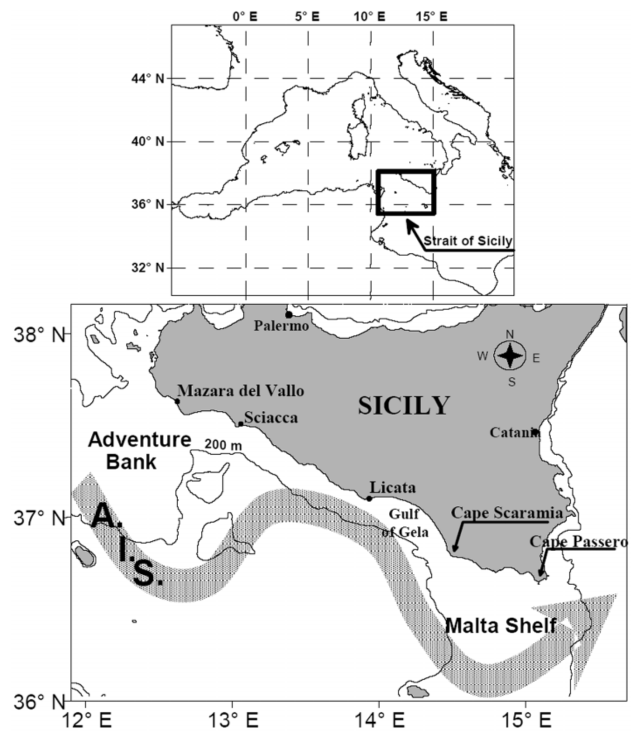

FIGURE 1 Western and Central Mediterranean, with the Strait of Sicily shown within the box (top panel), and a detailed map of the study area shown in the bottom panel with the average path of Atlantic Ionian Stream (AIS) superimposed.

the extension of upwelling and on the formation of frontal structures. This in turn may affect reproductive biology, spawning activity (Cuttitta *et al.*, 2003) and, in particular, recruitment success processes (e.g. survival/mortality rates in the early life stages) of fish populations, as already proposed by Garcìa Lafuente *et al.* (2002) for the Sicilian Channel anchovy stock. Ultimately, it determines future biomass levels of these short-lived fish species.

In this paper general results (abundance estimates, fish density distributions, etc.) from six hydro-acoustic echointegration surveys carried out from 1998 to 2002 are presented, taking into account information from hydrology, and from ecology and landings trends of the two target fish populations, *i.e.* anchovy and sardine. In addition, an attempt was made to correlate the recent trends in acoustic biomass estimates and landings from both species to sea surface temperature (SST) data. SST was used for its assumed ability to affect inter-annual fluctuations in fish abundance (Sissenwine, 1984; Southward and Boalch, 1994), essentially through the modulation of recruitment (e.g. Cape Anchovy stock; Richardson *et al.*, 1998). Though underlying processes are still largely unexplored, it is known that SST could have a direct effect on fish populations, especially trough the control of survival and growth rates of the early stages (Brett, 1970; Lo, 1985; Wood and McDonald, 1997); furthermore, SST may also be considered as representative of other oceanographic processes (e.g. current transport, turbulent mixing and upwelling events) able to affect food and larval retention processes (Demarcq and Faure, 2000; Faure *et al.*, 2000). The importance of those mechanisms in regulating the strength of recruitment has been stressed by various authors for different pelagic and demersal fish stocks (Bailey, 1981; Lasker, 1981; Parrish *et al.*, 1981; Peterman and Bradford, 1987; Bakun and Parrish, 1991; Bakun, 1996; Borja *et al.*, 1996; García and Palomera, 1996; Hutchings *et al.*, 1998; Daskalov, 1999; Sanchez and Gil, 2000; Levi *et al.*, 2003).

2 MATERIALS AND METHODS

The acoustic surveys were carried out on the continental shelf off the southern coast of Sicily, during June–July in 1998, 2000 and 2002 and during September–October in 1999, 2000 and 2001, taking into account the life cycles of both target populations. The summer surveys provide information on adult fraction of anchovy population, whereas biomass estimates from surveys carried out in the autumn may include the first signal of anchovy yearly recruitment.

Biomass estimates were carried out by applying a standardized methodology (Johannesson and Mitson, 1983, MacLennan and Simmonds, 1992). The equipment included:

- a calibrated SIMRAD EK 500 split beam echo sounder working at 38 kHz;
- pelagic trawl net for identification hauls with the following characteristics: horizontal opening 13–15 m, vertical opening 6–8 m, mesh size in the cod-end 10 mm;
- trawl monitoring system based on SCANMAR or SIMRAD ITI sensor.

The vessel's speed during echo-surveying was 6–10 knots, whereas during the fishing hauls, it was 3–4 knots.

The acoustic sampling design was originally planned as systematic parallel transects, sometimes discarded (in October 1999 and July 2000) in favour of a zigzag scheme, depending on sea weather conditions. Accordingly, the total length of the echosurvey track was shorter in October 1999 and July 2000 (345 nmi and 434 nmi, respectively) and varied from 580 to 650 nmi in the other surveys, whereas changes in area covered were less important (2800 nmi^2 in June 1998, 2000 nmi^2 in October 1999, 2300 nmi^2 in July 2000, and about 2500 nmi^2 for the remaining surveys).

For acoustic data acquisition, detailed echogram analysis and related calculations, the post-processing systems EP500 (Simrad, 1996), BI500 (Simrad, 1999) and EchoView (SonarData, 2002) were used. Data acquired by the 38 kHz transducer were used for extracting the s_A values (nautical acoustic scattering coefficient (NASC), m^2/nmi^2) (MacLennan *et al.*, 2002). The echointegration interval was constant, *i.e.* 1 nmi (=1852 m).

For each species a different target strength (TS) relationship was used. As no TS–length relationship has been established for the two species, for this study we adopted the TS–length relationships by Barange *et al.* (1996):

$$\mathrm{TS[db/kg]} = -14.90 * \log L[\mathrm{cm}] - 13.21 \text{ (for sardine)}$$
$$\mathrm{TS[db/kg]} = -12.15 * \log L[\mathrm{cm}] - 21.12 \text{ (for anchovy)}$$

For biomass estimates, the surveyed area was divided into different parts. For each part, the species composition in the identification hauls enabled sardine and anchovy s_A values to be estimated according to their proportion (in weight) in the catch.

Parameters for sardine and anchovy in each part of the area (lengths L_i for each size group (i), according to fish length classes $L_1, L_2, \ldots, L_n$, and related frequencies $f_1, f_2, \ldots, f_n$), as obtained by analysing information from the corresponding pelagic trawls, were used to estimate the appropriate values of target strength (TS_i) and consequently, applying the relationship $\mathrm{TS}_i = 10 * \log_{10}(\sigma_i/4\pi)$, the values of backscattering cross-section (σ_i, expressed in m^2).

The surface densities of each size group for the two species and for each echointegration interval were derived from Simrad (1996) formulation as:

$$\rho_i = \frac{s_A \cdot f_i \cdot 10^{-3}}{\sum_i f_i \cdot \sigma_i},$$

where ρ_i is expressed in t/nmi^2.

The fish surface densities by species for each echointegration interval were calculated as:

$$\rho = \sum_i \rho_i.$$

Distributions of fish surface density were obtained by interpolating single echointegration values using the geostatistical Kriging method (Cressie, 1991; Goovaerts, 1997) as implemented by SURFER© (Golden Software, Golden, CO). The biomass for each species was computed as the integral of surface density on the investigation area.

The acoustic biomass estimates thus obtained were compared with small pelagic landings data collected in Sciacca, the main port for this fishery along the southern coast of Sicily (Mazzola *et al.*, 2002), to identify possible consistency patterns in trends of the two series.

Further investigations concerned the correlation patterns between landings, biomass estimates and SST data. To this aim, monthly $1^\circ \times 1^\circ$ (spatial resolution) global SST analyses, available from November 1981 to the present day, were obtained from a collection of SST analyses prepared at the National Center for Environmental Prediction (formerly NMC) by D. Reynolds, D. Stokes and T. Smith. These analyses are determined by blending marine surface observations and satellite AVHRR data using an optimum interpolation (OI) method. A description of the OI analysis can be found in Reynolds and Smith (1994).

SST data were provided by the Data Support Section of the University Corporation for Atmospheric Research (UCAR), Boulder, CO, from their website at http://dss.ucar.edu/. From the whole data set, we extracted one SST time series relating to the site off the southern coast of Sicily (geographical coordinates: 37° 30′ N, 12° 30′ E).

3 RESULTS

A total of 102 identification hauls were carried out during the surveys (1998–2002), 74.5% (76 out of 102) of which contained sardine and 73.5% (75 out of 102) of which contained anchovy (Tab. I).

The sardine biomass appears to be fairly uniformly distributed along the southern coast of Sicily, though large differences occur in the extent of area occupied and biomass estimates between surveys (Figs. 2 and 3). The anchovy population exhibits a more patchy distribution compared with the sardine. During the peak spawning period for anchovy (Cuttitta *et al.*, 1999, 2000) (echo integration surveys in July 1998 and 2000), the main concentrations were observed from Sciacca to Licata, in the central part of the study area, while in the surveys conducted in the autumn, two main concentrations were detected north of Sciacca and in the Gulf of Gela (south of Licata). In addition, during July 2002, the sardine and anchovy populations appeared segregated, with sardines in the northern region and anchovy in the southern part of study area.

The estimated biomasses by year and species are listed in Table II. During the period 1998–2002, both sardine and anchovy populations experienced large inter-annual fluctuations. With regard to sardine, biomass estimates range from 6000 t in July 2002 to over 36,000 t in July 2000; anchovy evaluations range from about 7100 t in June 1998 to 23,000 t in October 2001. The sardine population showed a steadily decreasing trend during the last few years, from 36,000 t in 2000 to just 6000 t in 2002, so that from 2001, anchovy biomass began to exceed the sardine biomass.

Figure 4 shows how biomass estimates for sardine and anchovy populations appear to be correlated to corresponding landings in Sciacca port during the year following the evaluation surveys. Reported landings have varied from 126 t in 1999 to 2312 t in 2001 for anchovy and from 1233 t in 1999 to 2080 t in 2000 for sardine (Mazzola *et al.*, 2002).

Finally, Figures 5 and 6 show SST and biomass estimates trends (notice that in both figures, the SST axis is reversed). Both anchovy and sardine biomass appears to be negatively correlated with the mean SST calculated over January–September (sardine) and June–November (anchovy) of the preceding year.

TABLE I Number of fishing hauls by survey, with correspondent percentage of hauls with sardine and anchovy presence (in parantheses).

Survey dates	*Total fishing hauls*	*Fishing hauls with sardine presence*	*Fishing hauls with anchovy presence*
19–22 June 1998	12	10 (83.3%)	6 (50.0%)
14–29 October 1999	11	10 (90.9%)	11 (100.0%)
6–16 July 2000	18	15 (83.3%)	12 (66.7%)
11–16 September 2000	18	11 (61.1%)	12 (66.7%)
4–17 October 2001	22	15 (68.2%)	20 (90.9%)
4–15 July 2002	21	15 (71.4%)	14 (66.7%)
Total	102	76 (74.5%)	75 (73.5%)

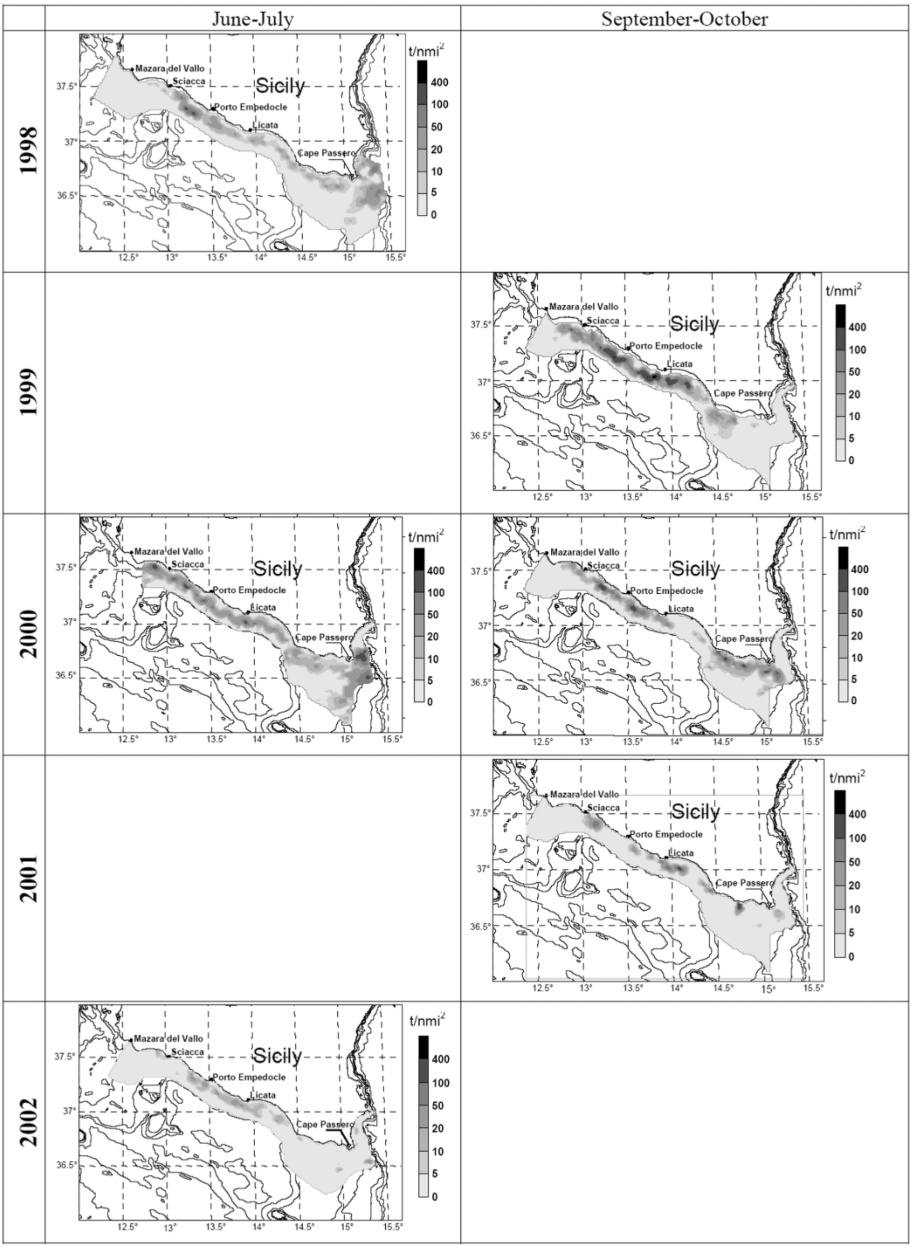

FIGURE 2 Sardine density distributions inferred from echo surveys on the continental shelf off the southern coast of Sicily from 1998 to 2002.

4 DISCUSSION

Cuttitta *et al.* (2003) related anchovy egg distribution patterns obtained from summer ichthyoplanktonic and oceanographic surveys carried out along the southern coast of Sicily, to the temperature regime of surface waters induced by the AIS trajectory. Specifically, the AIS path has been shown to be able to produce changes in the temperature and extent of the upwelling in the northern part of the area. This in turn may reflect the

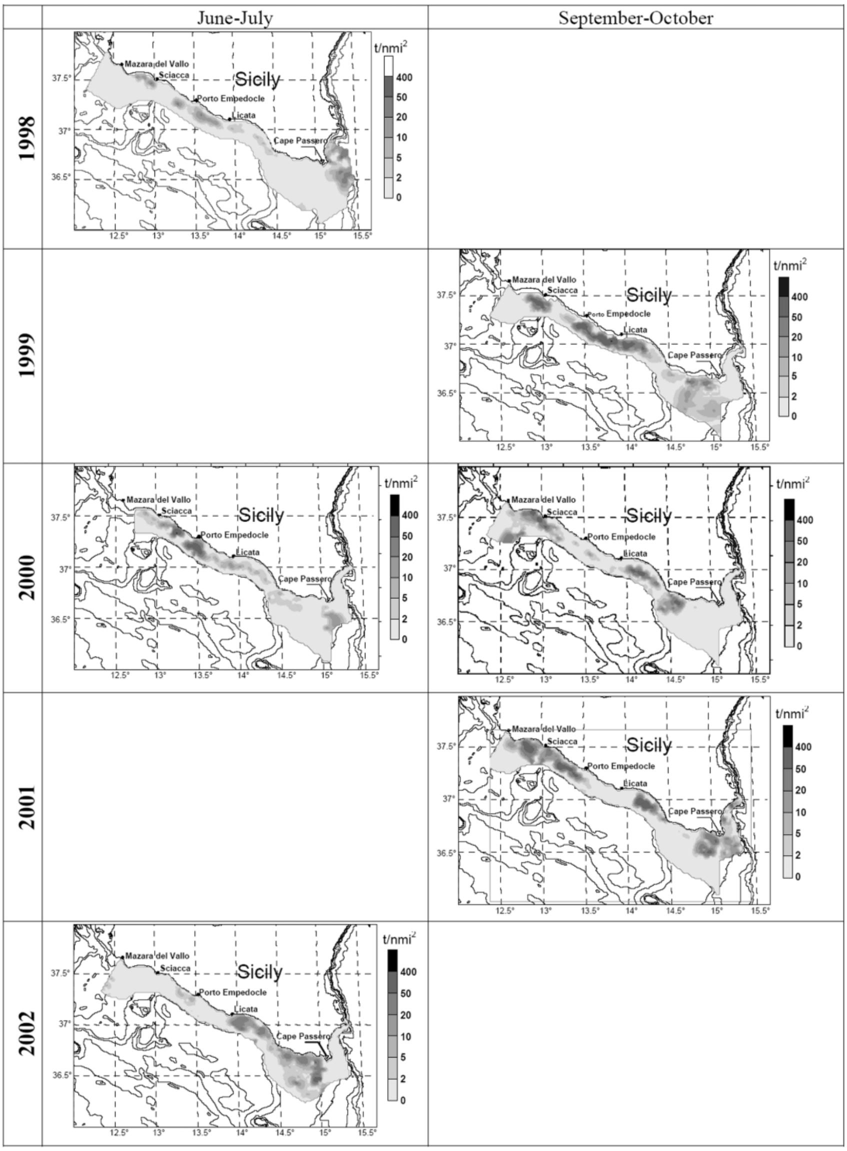

FIGURE 3 Anchovy fish density distributions inferred from echo surveys on the continental shelf off the southern coast of Sicily from 1998 to 2002.

TABLE II Biomass estimates (t) for sardine and anchovy populations off the southern coast of Sicily by survey (investigated area: 2000–2800 nmi^2).

Echo-survey	*Sardine*	*Anchovy*	*Total*
June 1998	20,000	7,100	27,100
October 1999	33,700	20,200	53,900
July 2000	36,370	11,000	47,370
September 2000	24,800	11,050	35,850
October 2001	10,054	22,950	33,004
July 2002	6,000	11,500	17,500

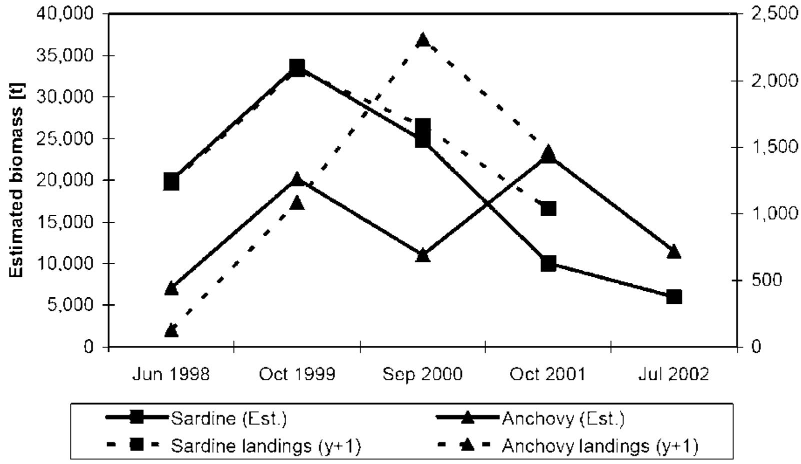

FIGURE 4 Biomass estimates for sardine and anchovy populations off the southern coast of Sicily and landings in Sciacca during the year following the evaluation surveys (landings data updated to August 2002).

distribution pattern of anchovy spawning grounds, as low-temperature regimes appeared to be able to inhibit the spawning process (Mazzola *et al.*, 2002). In this context, it is worth noting that the distribution patterns of anchovy fish density observed during the summer echo surveys (1998, 2000 and 2002) are consistent with the hypothesis of a link between temperature and anchovy spawning activity. In fact, in 2002, when anchovy aggregations were found only in the southern part of the study area (unlike in 1998 and 2000), the northern coastal areas were characterized by a low-temperature regime (unfavourable for spawning).

Observed trends in biomass estimates suggest that possible compensation processes permitted the total (sardine + anchovy) estimated biomass to vary moderately in the study

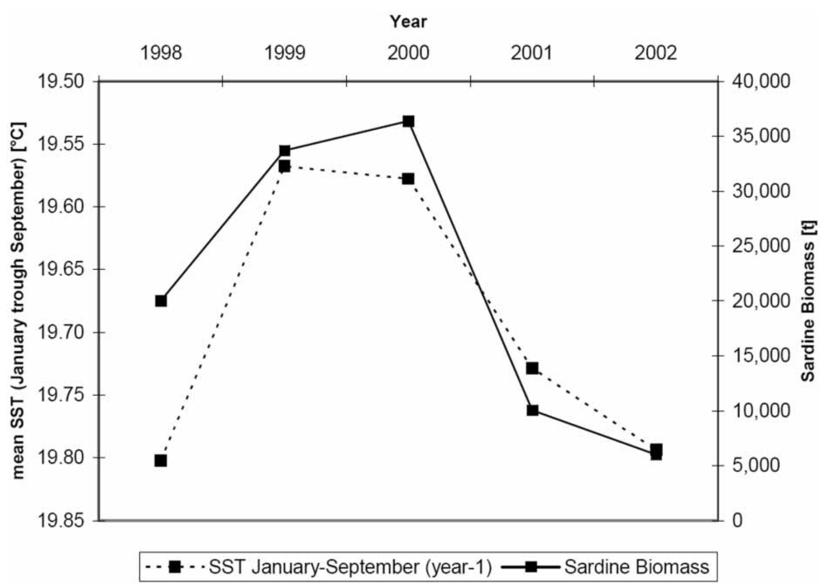

FIGURE 5 Sardine biomass estimates (right axis) from 1998 to 2002 and corresponding mean SST calculated over January–September of the preceding year (left axis, reversed orientation; from 1997 to 2001).

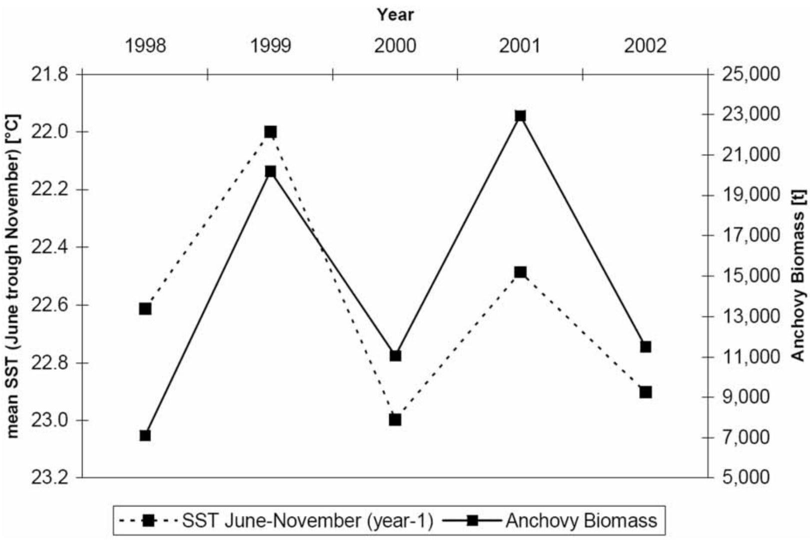

FIGURE 6 Anchovy biomass estimates (right axis) from 1998 to 2002 and corresponding mean SST calculated over June–November of the preceding year (left axis, reversed orientation; from 1997 to 2001).

area, at least up to 2001. For instance, in one year, from September 2000 to October 2001, the sardine biomass dropped by 60%, and the anchovy biomass increased by 108%, but the total biomass declined by only 8%. Because of the lack of information on total catches along the southern coast of Sicily, it is not possible to calculate an exact exploitation ratio for the targeted fish populations. However, landings in Sciacca are assumed to represent not less than 50% of total yield of the small pelagic fishery vessels in the study area. As the amount of landings in Sciacca is one order of magnitude lower than the biomass estimates, much of the observed fluctuations in biomass is believed to be related to the effects of environmental factor variability on the early stages of the populations, which could affect yearly recruitment success and, ultimately, fishing yields during the following year, when recruitment size is reached (incidentally, the anchovy age structure of anchovy commercial catches during 2000–2001 was found to be dominated by 1–2 year classes) (Basilone *et al.*, 2003).

These present results show that acoustic estimates obtained at recruitment time are largely consistent with catch levels recorded in Sciacca port during the year following the evaluation surveys (Fig. 4). The main exception is the anchovy biomass estimate in September 2000, which was quite low compared with anchovy landings during 2001. However, September is probably too early to include a significant effect from recruitment success for a population whose spawning peak occurs in July. This seems to be confirmed by the inspection of length frequency distributions of anchovy specimens collected during the identification hauls. In fact, the proportion of juveniles (total length smaller than 11 cm) was 76.6% and 70.0% in October 1999 and October 2001, but only 56.6% in September 2000.

The negative correlations between anchovy and sardine biomass and mean SST over January–September (sardine) and June–November (anchovy) of the preceding year need to be explained. Since relatively lower SST temperature values in the study area are linked to the upwelling of deep waters pumping nutrients along the coastal region, where recruitment of both sardine and anchovy occurs, the patterns observed here would suggest the importance of enrichment processes relevant to the survival of early stages, thus determining recruitment success and finally higher population sizes for the investigated species (Lasker, 1975). However, because of the limited length of the time series on which the present study is based, these encouraging but preliminary results need to be confirmed by future research work.

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References

Bailey, K. M. (1981). Larval transport and recruitment of Pacific hake *Merluccius productus*. *Marine Ecology Progress Series*, **6**, 1–9.

Bakun, A. (1996). *Patterns in the Ocean: Ocean Processes and Marine Population Dynamics*. Centro de Investigaciones biologicas del Nordeste, La Paz, Mexico and University of California (Sea Grant Program), La Jolla, CA.

Bakun, A. and Parrish, R. H. (1991). Comparative studies of coastal pelagic fish reproductive habitat: the anchovy (*Engraulis anchoita*) of the southwestern Atlantic. *ICES Journal of Marine Science*, **48**, 343–361.

Barange, M., Hampton, I. and Soule, M. (1996). Empirical determination of *in situ* target strengths of three loosely aggregated pelagic fish species. *ICES Journal of Marine Science*, **53**, 225–232.

Basilone, G., Guisande, C., Patti, B., Mazzola, S., Cuttitta, A., Bonanno, A., Vitale, S. and Kallianiotis, A. (2003). Age and growth of the European anchovy (*Engraulis encrasicolus*) in the Strait of Sicily. Scientific Advisory Committee – FAO/GFCM. Sub-Committee on Stock Assessment. Working Group on Small Pelagics, Tangier, Morocco, 12–14 March 2003.

Borja, A., Uriarte, A., Valencia, V., Motos, L. and Uriarte, A. (1996). Relationships between anchovy (*Engraulis encrasicolus*) recruitment and the environment in the Bay of Biscay. *Scientia Marina*, **60**, 179–192.

Brett, J. R. (1970). Temperature – fishes. In: Kinne, O. (ed.), *Marine Ecology. Volume 1. Environmental Factors. Part 1*. Wiley Interscience, Glasglow, UK, pp. 514–616.

Cressie, N. A. (1991). *Statistics for Spatial Data*. Wiley, New York.

Cuttitta, A., Basilone, G., Patti, B., Bonanno, A., Mazzola, S. and Giusto, B. (1999). Trends of anchovy (*Engraulis encrasicolus*) condition factor and gonadosomatic index in the Sicilian Channel (in Italian). *Biologia Marina Mediterranea*, **6**(1), 566–568.

Cuttitta, A., Carini, V., Patti, B., Bonanno, A., Basilone, G., Mazzola, S., Garcìa Lafuente, J., Garcìa, A., Buscaino, G., Aguzzi, L., Rollandi, L., Morizzo, G. and Cavalcante, C. (2003). Anchovy egg and larval distribution in relation to biological and physical oceanography in the Strait of Sicily. *Hydrobiologia*, **503**, 117–120.

Cuttitta, A., Patti, B., Bonanno, A., Basilone, G., Garcia La fluente, J., Quintanilla, L., Carpena, A., Carrasco, N., Godoy, L. and Mazzola, S. (2000). First data on the spawning of (*Engraulis encrasicolus*) in the Sicilian Channel (in Italian). *Biologia Marina Mediterranea*, **7**(1), 865–867.

Daskalov, G. (1999). Relating fish recruitment to stock biomass and physical environment in the Black Sea using generalized additive models. *Fisheries Research*, **41**, 1–23.

Demarcq, H. and Faure, V. (2000). Coastal upwelling and associated retention indices derived from satellite SST. Application to *Octopus vulgaris* recruitment. *Oceanologica Acta*, **23**(4), 391–408.

Faure, V., Inejih, C. A., Demarcq, H. and Cury, P. (2000). The importance of retention processes in upwelling areas for recruitment of *Octopus vulgaris*: the example of the Arguin Bank (Mauritania). *Fisheries Oceanography*, **9**(4), 343–355.

García, A. and Palomera, I. (1996). Anchovy early life history and its relation to its surrounding environment in the Western Mediterranean basin. *Scientia Marina*, **60**(2), 155–166.

Garcìa Lafuente, J., García, A., Mazzola, S., Quintanilla, L., Delgado, J., Cuttitta, A. and Patti, B. (2002). Hydrographic phenomena influencing early life stages of the Sicilian Channel anchovy. *Fisheries Oceanography*, **11**(1), 31–44.

Goovaerts, P. (1997). *Geostatistics for Natural Resources Evaluation*. Oxford University Press, New York.

Hutchings, L., Barange, M., Bloomer, S. F., Boyd, A. J., Crawford, R. J. M., Huggett, J. A., Kerstan, M., Korrubel, J. I., De Oliveira, J. A. A., Painting, S. J., Richardson, A. J., Shannon, L. J., Schüelein, F. H., Van Der Lingen, C. D. and Verheye, H. M. (1998). Multiple factors affecting South African anchovy recruitment in the spawning, transport and nursery areas. In: Pillar, S. C., Moloney, C. L., Payne, A. L. I. and Shillington, F. A. (eds.), Benguela dynamics. Impacts of variability on shelf-sea environments and their living resources. *South African Journal of Marine Science*, **19**, 211–225.

Johannesson, K. A., and Mitson, R. B. (1983). *Fisheries Acoustics – A Practical Manual for Aquatic Biomass Estimation*. FAO Fisheries Technical Paper 240–FIRM/T240.

Lasker, R. (1975). Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. *U.S. Fishery Bulletin*, **78**, 811–816.

Lasker, R. (1981). Factors contributing to variable recruitment of the northern anchovy (*Engraulis mordax*) in the California Current: contrasting years 1975 through 1978. *ICES Rapports et Proces-Verbaux*, **178**, 375–388.

Lermusiaux, P. F. J. (1999). Estimation and study of mesoscale variability in the Strait of Sicily. *Dynamics of Atmospheres and Oceans*, **29**, 255–303.

Lermusiaux, P. F. J. and Robinson, A. R. (2001). Features of dominant mesoscale variability, circulation patterns and dynmics in the Strait of Sicily. *Deep Sea Research I*, **48**, 1953–1997.

Levi, D., Andreoli, M. G., Bonanno, A., Fiorentino, F., Garofano, G., Mazzola, S., Norrito, G., Patti, B., Pernice, G., Ragonese, S., Giusto, G. B. and Rizzo, P. (2003). The influence of hydrological features on the recruitment of red mullet (*Mullus barbatus* L. 1758) in the Strait of Sicily. *Scientia Marina*, **67**(Suppl. 1), 259–268.

Lo, N. C. H. (1985). A model for temperature-dependent northern anchovy egg development and an automated procedure for the assignment of age to staged eggs. In: Lasker, R. (ed.). An Egg Production Method for Estimating Spawning Biomass of Pelagic Fish: Application to the Northern Anchovy, *Engraulis Mordax*. *NOAA Technical Report NMFS*, **36**, 4350.

MacLennan, D. and Simmonds, E. (1992). *Fisheries Acoustics*. Chapman & Hall, London.

MacLennan, D. N., 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.

Mazzola, S., García, A. and García Lafuente, J. (2002). The Sicilian channel anchovy fishery and the underlying oceanographic and biological processes conditioning their inter-annual fluctuations. DG XIV, MED 98-070 *Final Report*.

Parrish, R. H., Nelson, C. S. and Bakun, A. (1981). Transport mechanisms and reproductive success of fishes in the California current. *Biological Oceanography*, **1**(2), 175–203.

Peterman, R. M. and Bradford, M. J. (1987). Wind speed and mortality rate of a marine fish, the northern anchovy (*Engraulis mordax*). *Science*, **235**, 354–356.

Piccioni, A., Gabriele, M., Salusti, E. and Zambianchi, E. (1988). Wind-induced upwellings off the southern coast of Sicily. *Oceanologica Acta*, **11**(4), 309–314.

Reynolds, R. W. and Smith, T. M. (1994). Improved global sea surface temperature analyses. *Journal of Climate*, **7**, 929–948.

Richardson, A. J., Mitchell-Innes, B. A., Fowler, J. L., Bloomer, S. F., Verheye, H. M., Field, J. G., Hutchings, L. and Painting, S. J. (1998). The effects of sea temperature and food availability on the spawning success of the Cape anchovy *Engraulis capensis* in the Southern Benguela. In: Pillar, S. C., Moloney, C. L., Payne, A. L. I. and Shillington, F. A. (eds.), Benguela dynamics. Impacts of variability on shelf-sea environments and their living resources. *South African Journal of Marine Science*, **19**, 275–290.

Robinson, A. R., Golnaraghi, M., Leslie, W. G., Artegiani, A., Hecht, A., Lazzoni, E., Michelato, A., Sansone, E., Theocharis, A. and Unluata, U. (1991). The Eastern Mediterranean general circulation: Features, structure and variability. *Dynamics of Atmospheres and Oceans*, **15**(3–5), 215–240.

Robinson, A. R., Sellschopp, J., Warn-Varnas, A., Leslie, W. G., Lozano, C. J., Haley, P. J., Anderson, L. A. and Lermusiaux, P. F. J. (1999). The Atlantic Ionian Stream. *Journal of Marine Systems*, **20**, 113–128.

Sanchez, F. and Gil, J. (2000). Hydrographic mesoscale structures and poleward current as determinant of hake (*Merluccius merluccius*) recruitment in southern Bay of Biscay. *ICES Journal of Marine Science*, **57**, 152–170.

Simrad (1996). *Simrad EP500: Instruction Manual, Echo Processing System, P259E*. Horten, Norway.

Simrad (1999). *Simrad BI500 Post-Processing System Manual*. Simrad AS Horten, Norway.

Sissenwine, M. P. (1984). Why do fish populations vary? In: May, R. M. (ed.), *Exploitation of Marine Communities, Dahlem Konferenzen*. Springer, Berlin, pp. 59–94.

SonarData (2002). *Echoview Tutorial ver. 2.25*. SonarData, Hobart, Australia.

Southward, A. J. and Boalch, G. T. (1994). The effect of changing climate on marine life: past events and future predictions. In: Fisher, S. (ed.), Man and the maritime environment. *Exeter Maritime Studies*, **9**, 101–143.

Wood, C. M. and McDonald, D. G. (eds.) (1997). *Global Warming: Implications for Freshwater and Marine Fish*. Society for Experimental Biology. Seminar Series, 61. Cambridge University Press, Cambridge.