Stock assessment of sardine (*Sardina pilchardus*, Walb.) in the Adriatic Sea, with an estimate of discards*

ALBERTO SANTOJANNI [1], NANDO CINGOLANI [1], ENRICO ARNERI [1], GEOFF KIRKWOOD [2], ANDREA BELARDINELLI [1], GIANFRANCO GIANNETTI [1], SABRINA COLELLA [1], FORTUNATA DONATO [1] and CATHERINE BARRY [3]

[1] ISMAR - CNR, Sezione Pesca Marittima, Largo Fiera della Pesca, 60125 Ancona, Italy. E-mail: a.santojanni@ismar.cnr.it
[2] Renewable Resources Assessment Group (RRAG), Department of Environmental Science and Technology, Imperial College, Prince Consort Road, London, UK.
[3] Marine Resources Assessment Group (MRAG), 27 Campden Street, London, UK.

SUMMARY:Analytical stock assessment of sardine (*Sardina pilchardus*, Walb.) in the Adriatic Sea from 1975 to 1999 was performed taking into account the occurrence of discarding at sea of sardine caught by the Italian fleet. We have attempted to model the fishermen's behaviour using data collected by an observer on board fishing vessels. This enabled us to estimate the amounts of discards, which were added to the catches landed, collected by ISMAR-CNR Ancona. Discards were calculated for the period 1987-1999, as their values were negligible before 1987. Stock assessment on the entire data series from 1975-1999 was carried out by means of Virtual Population Analysis (VPA). Discarding behaviour differs among ports due to different local customs and market conditions. The quantity added to the annual total catch ranged from 900 tonnes to 4000 tonnes, corresponding to between 2% and 15% of the total corrected catch. VPAs indicated that mid-year sardine stock biomass rose steadily from 400,000 tonnes in 1975 to a peak of 950,000 tonnes in 1984. Subsequently, biomass declined steadily to the more recent values, around 300,000 tonnes. Although discarded quantities were relatively high, their influence on stock assessment was not strong because of the high level of both catch and, in particular, estimated biomass at sea.

Keywords: sardine, Adriatic Sea, discards, observer data, regression tree models, stock assessment, population dynamics methods, Virtual Population Analysis (VPA).

RESUMEN: EVALUACIÓN DEL ESTOC DE SARDINA DEL MAR ADRIÁTICO (*SARDINA PILCHARDUS* WALB.), ESTIMANDO LOS DESCARTES. – Se realizó una evaluación analítica del estock de sardina (*Sardina pilchardus*, Walb.) del mar Adriático, desde 1975 a 1990, considerando los descartes de sardina realizados por la flota italiana. Se ha intentado modelar el comportamiento de los pescadores utilizando los datos recogidos por un observador a bordo de los barcos de pesca. Ello nos ha permitido estimar las cantidades descartadas y añadirlas posteriormente a los datos de desembarcos recogidos por ISMAR-CNR Ancona. Se calcularon los descartes para el período 1987-1999, ya que los valores eran insignificantes antes de 1987. Se realizó la evaluación del estock de sardina por medio del Análisis de Poblaciones Virtuales (VPA), aplicándolo a toda la serie de datos desde 1975 a 1999. El comportamiento en el descarte varía entre puertos debido a las diferentes costumbres locales y a las condiciones de mercado. La cantidad añadida a la captura total anual varía entre 900 y 4.000 toneladas, que corresponden al 2% y 15% respectivamente, del total de la captura corregida. Los VPAs indican que la biomasa del estock de sardina aumentó de manera constante de 400.000 toneladas en 1975 a un máximo de 950.000 toneladas en 1984. Posteriormente, la biomasa disminuyó de forma continuada hasta alcanzar valores aproximados de 300.000 toneladas en la actualidad. Aunque las cantidades descartadas fueron relativamente altas, su influencia en la evaluación del estock de sardina no parece ser importante, debido a los niveles altos de las capturas y, en particular, de las biomasas estimadas.

Palabras clave: sardina, mar Adriático, descartes, modelos de regresión en árbol, evaluación de estocks, métodos de dinámica de poblaciones, Análisis de Poblaciones Virtuales (VPA).

*Received July 12, 2004. Accepted April 29, 2005.

INTRODUCTION

Sardine (*Sardina pilchardus*, Walb.) is one of the most important commercial species of both the Mediterranean Sea and the Adriatic Sea. In 1992 the sardine catch in the Adriatic comprised over 14% of the total Adriatic marine fishery catch and over 13% of the Mediterranean sardine catch (Stamatopoulos, 1995). The fishery for small pelagics is particularly widespread in the northern and central Adriatic Sea and sardine is fished together with anchovy by the fleets from Italy, Slovenia, Croatia and previously by Yugoslavia. According to ISMAR-CNR Ancona's database, the mean annual quantity of sardine landed by these fleets was around 50,000 tonnes in the period 1975-1999. The Italian fleet in the northern and central Adriatic Sea comprises about 140 (70 couples) mid-water pelagic trawlers (*volante*) and about 40 purse seiners (*lampara*). *Lampare* operate south of Ancona and during the colder months their activity is suspended or replaced by *volante* gear as in the case of San Benedetto del Tronto (Cingolani *et al*., 1996a).

Since 1975 ISMAR has conducted research on the biology and stock assessment of sardine and anchovy in the northern and central Adriatic using population dynamics methods (Levi *et al*., 1984; Arneri, 1996; Cingolani *et al*., 1996a,b, 1998, 2000, 2002; Santojanni *et al*., 2001a,b, 2002, 2003). Assessments of Adriatic sardine based on population dynamics methods have also been carried out by Alegría-Hernandez (1984), and Sinovcić (1986, 1991), for the eastern Adriatic.

Information regarding discards at sea can be crucial in stock assessments based on population dynamics methods. Lack of discard data may lead to underestimated catches, inappropriate Catch Per Unit of fishing Effort (CPUE) and biased length frequency distributions of the catch (Saila, 1983; Hilborn and Walters, 1992; Alverson *et al*., 1994; Chopin *et al*., 1996; Allard and Chouinard, 1997; Chen and Gordon, 1997). Discarding by the Adriatic small pelagic fishery is a well-known practice, but no attempt has ever been made to quantify this phenomenon. Recently, an EU funded project (Cingolani *et al*., 2000), investigated this issue and some of the results were preliminarily reported in Cingolani *et al*. (2002). The present paper describes the application for the first time of an age-based analytical stock assessment of Adriatic sardine together with an attempt at estimating discards for this fishery. Discard investigations are usually very time consuming and expensive, requiring observers to be many days at sea. A possible solution proposed here is to model the discarding behaviour of fishermen using the observer data, in order to be able to predict and quantify the probability of discarding at sea. This also enabled us to attempt to reconstruct the discarding practice which occurred in the past. The effect of applying a discard correction to stock assessment data was examined for length frequencies, CPUE and in particular for both values and patterns over time of the biomass estimated by means of Virtual Population Analysis (VPA).

MATERIALS AND METHODS

Landing data

Monthly landings of sardine (and anchovy) have been collected, within the framework of the ongoing ISMAR programme on stock assessment of small pelagics in the Adriatic, in the major fishing ports for small pelagic fish along the Italian coast (major ports in the text) such as Trieste, Chioggia, Porto Garibaldi, Cesenatico, Cattolica, Ancona, San Benedetto del Tronto, Vieste, and also in other fishing ports such as Grado, Marano Lagunare, Caorle, Goro, Rimini, Fano, Giulianova (Fig. 1). Landing data for Croatia, Slovenia and the former Yugoslavia were derived from published sources up to 1994 (Anon., 1975-1993, 1994), whereas data for the years 1995-1999 were contributed by the Institute of Oceanography and Fisheries of Split (G. Sinovcić, pers. comm.).

Estimates of discards

Detailed data on sardine and anchovy catches and landings by haul, together with corresponding length frequency distributions, were collected by an observer on board the fishing vessels in the period 1996-1999. The fleets of four of the major ports (where approximately 60% of the total Italian sardine catches are landed) were sampled. A total of 12 daily observations for Chioggia, 17 for Porto Garibaldi, 15 for Ancona, 19 (13 *lampara* and 6 *volante*) for San Benedetto del Tronto were obtained and data referring to 198 hauls were collected (Fig. 1). All these ports are regularly sampled for landings and biological samples by ISMAR. In order to estimate discarded quantities, the factors potentially affecting sardine discarding were preliminarily identified as follows:

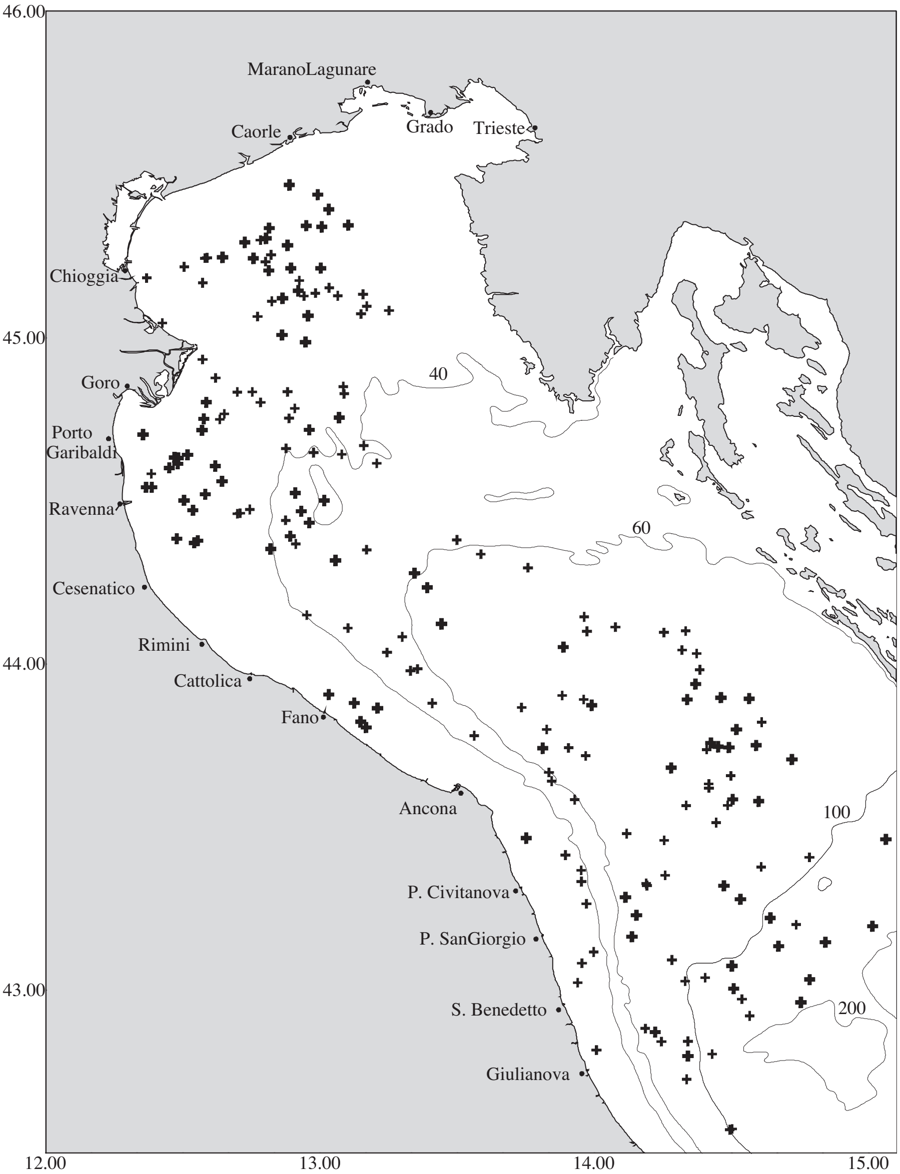

FIG. 1. – Northern and central Adriatic: landing ports for small pelagic fish together with hauls sampled by the observer on board fishing vessels, both *volanti* and *lampare* (see text).

(1) Unmarketable, small and/or damaged sardine are always discarded.

(2) Sardine are more likely to be discarded on days when large quantities of high-quality big-sized anchovy are caught. The potential reasons for this are related to the greater economic value of anchovy.

(3) Similarly, when the catch comprises large quantities of small (but marketable) anchovy, sardine tend to be discarded. Furthermore, smaller anchovy caught in mixed schools are easily damaged, so top priority is assigned to boxing them first, often leaving the sardine to be discarded.

Given these factors, the proportions of sardine discarded were examined as a function of the following variables: the number of boxes of sardine landed or caught (1 box = 7-10 kg of fish, depending on the sampled port), the mean length of sardine, the number of boxes of anchovy landed (≈ caught), the mean length of anchovy. Discarding decisions are taken based on the results of the entire fishing day rather than on a haul by haul basis. Therefore, each data point corresponded to one fishing day (= one observer trip) of a single vessel pair (*volante*) or vessel (*lampara*).

Firstly, the observer data were analysed by plotting the proportions of sardine discarded as a function of each variable mentioned above. Then, the influence of each of these variables and the interactions between them were quantitatively assessed by means of regression tree models, using the S-Plus software package (Venables and Ripley, 1994).

Additional information that is at least potentially useful for estimating discards was represented by sardine and anchovy landings and corresponding (sardine) catch-weighted length frequencies. In particular, daily landings per vessel pair were available for Porto Garibaldi (1975-1999) and Ancona (1997-1999). An index of sardine abundance at sea was given by the CPUE calculated for Porto Garibaldi. Finally, trends in prices and biomass for anchovy and sardine together with changes in management policies in this fishery were also used to make reasonable assumptions on the discarding behaviour of the fleets in the past.

Fishing effort standardisation and CPUE data

Catch (landings) and fishing effort data were utilised to calculate a time series of standardised CPUE, which is useful for estimates of discards and VPA calculations (tuning). In this CPUE, effort was thought to be directed at both sardine and anchovy. In fact, the two species are often mixed in the catch. Missing data in the data set did not allow us to obtain an effort series for all ports and all years. Porto Garibaldi is the port offering the best series of effort data and generating the highest quantities of sardine and anchovy landed, thus the CPUE calculated for this port was used in the assessment. The effort series was obtained by using fishing days and fishing power values of those vessel pairs fishing both species. For each vessel pair *h*, fishing days were known for each year *i* and month *j*: they were multiplied by the corresponding fishing power value, which is related to the fishing capability. Fishing power indicated how much the fishing capability of the vessel pair *h* was higher or lower with respect to the vessel pair used as a reference point. This implied standardisation of fishing days and as a consequence fishing effort. The values of fishing power were estimated by means of Generalized Linear Models (GLMs), as suggested by Hilborn and Walters (1992), using the S-Plus software. The model employed was the following:

$$\text{Ln Landing rate}_{ijh} = \text{Year}_i + \text{Month}_j + \text{Vessel pair}_h$$

where the landing rate was the average amount of kg of sardine and anchovy landed per fishing day over the month *j* of the year *i*, by each vessel pair *h* (for anchovy landed ≈ caught). The variability of landing rates was explained on the basis of variables thought to be related to abundance, year *i* and month *j*, and fishing capability, vessel pair *h* (Cingolani *et al*., 2000; Santojanni *et al*., 2002). Log transformation allowed the basic model (catch = catchability × fishing effort × abundance) to be converted from multiplicative into additive. If the statistical error is also thought to be multiplicative, which is likely, the log transformation will convert it into an additive error as well. Thus, the error distribution would be lognormal for the original landing rates and normal for the log transformed ones.

These (sardine + anchovy) landing rate data were not corrected for sardine discards. In fact, there was no reason to believe discards differed between vessel pairs in Porto Garibaldi, and an annual amount proportionally distributed among them would not have strong effects on fishing power estimates. In addition, most vessel pairs fished over long time intervals: these intervals could include both years with discarding (i.e. after 1987, see results) and years without discarding (before 1987), thus smoothing the effects on fishing power estimates of correcting average daily landing rates after 1987. Finally, a preliminary analysis by GLMs showed that vessel pair Gross Registered Tonnage (GRT), when taken as the variable related to fishing capability, explained a very high portion of the variability in the landing rate data, highlighting how fishing powers were strongly influenced by this fleet characteristic. The discard-corrected value of annual CPUE was thus obtained by dividing the discard-corrected landings by the effort calculated using non-corrected landing rates.

Biological data

Monthly biological samples were collected in the major ports over the years. Annual catch-weighted length frequency distributions of catches were obtained for these ports, measuring fish according to 0.5 cm length classes (1 cm before 1984). Age was estimated by reading sardine otoliths. About 8,000 otoliths were read from the ports of Chioggia, Porto Garibaldi, Ancona and San Benedetto del Tronto, for the years 1984, 1988, 1994 and 1998. The four years mentioned were selected as representative of the key periods in the history of the sardine fishery: 1984 was well before the anchovy crash, during a time when sardine landings were subsidised; 1988 was just after the anchovy crash; 1994 and 1998 span the subsequent years up to the present. Annual catch-weighted length frequency distributions were converted to estimated annual catches at age in the following way: the age-length key for 1984 was used for the period 1975-1987, the 1988 key for 1988-1991, the 1994 key for 1992-1996 and the 1998 key for 1997-1999. The age classes ranged from 0 to 6+, with the last class including individuals older than 6 years, i.e. a plus-group.

Assessment method

Virtual Population Analysis (VPA) is based on analysing the annual age frequency distributions of the total catch (Hilborn and Walters, 1992). It was performed by means of Laurec-Shepherd tuning (Laurec and Shepherd, 1983; Pope and Shepherd, 1985). This method attempts to estimate the values of the age specific fishing mortality rates, F, in the final year by fitting CPUE at age data, under the assumption of constant annual selectivity at age. There are good reasons to believe that the selectivity on younger sardine was most probably considerably higher prior to the 1987 anchovy crash, when the prices of both sardine and anchovy were quite similar and there was an effective incentive to catch and land small sardine (see AIMA phenomenon below). Hence, tuning was carried out for the period 1987-1999. A vector of annual values of F at the last true age (age 5 in our case, the same value was applied to the plus-group 6+) was also utilised as input data. In the last year, 1999, this fishing mortality rate was assumed to be equal to the total fishing mortality rate in the most recent years, 0.3 (yr^{-1}). This value was obtained by subtracting M, the natural mortality rate, from Z, the total mortality rate, which was calculated by means of catch curve analysis (Hilborn and Walters, 1992). To do this we employed the mean total catch at age data for the period 1997-1999, in which the age distribution of the stock was assumed to be in equilibrium. The values of $F_{5,\ year}$ in all the other years were calculated on the basis of a relationship between $F_{5,\ 1999}$ and Porto Garibaldi fishing effort, E_{year}, as follows:

$$F_{5,\ year} / E_{year} = F_{5,\ 1999} / E_{1999}$$

The natural mortality rate, M, was assumed to be equal to 0.5 (yr^{-1}) on the basis of the observed age composition of the total catch. In fact, the age-length keys of the ISMAR database suggested a longevity of Adriatic sardine of around 10 years (with some specimens being recorded as up to 12 years old) which was thought to be consistent with M = 0.5; in particular, higher values of M could not explain the occurrence of the old individuals mentioned. Moreover, for the Adriatic sardine, M = 0.5 was reported by Sinovcić (1986), and Piccinetti *et al.* (1981), estimated a very similar value: M = 0.55. Anyway, VPA based on different values was also carried out. For this purpose, alternative values were extracted from the literature: for the Adriatic sardine, Sinovcić (1991) also reported M = 0.3, whereas Alegría-Hernandez (1984) obtained a relatively high value, M = 0.74; the estimates provided by Levi *et al.* (1984; 1985), ranged from 0.43 to 0.52 in the period 1975-1979, while in 1980 M was equal to 0.32. Finally, it is of some interest that for the sardine stock in the Catalan Sea the values of M estimated by Pertierra and Perrotta (1993), ranged from 0.29 to 0.62.

VPA calculations were performed using the MAFF-VPA software package (Ministry of Agriculture, Fishery and Food, UK), developed by Darby and Flatman (1994).

RESULTS

Fishing effort

The analysis by GLMs provided a value of R^2 equal to 0.71, with variability being explained mainly by the independent variables $Year_i$ and $Vessel\ pair_h$. The distribution of residuals (observed - expected Ln Landing $rate_{ijh}$) showed a deviation from the normal distribution in the tails, but there was no skewness.

The standardised annual fishing effort values relative to the Porto Garibaldi fleet are shown in Figure 2. The quantities of sardine and anchovy landed by this fleet are also shown along with the corresponding catches withdrawn thanks to European Community subsidies (the so-called AIMA phenomenon). The highest values of fishing effort were estimated for the period 1978-1985 and high values of landings were recorded in these years at Porto Garibaldi, as well as in other Italian Adriatic ports. The AIMA withdrawals occurred from the mid 1970s to the mid 1980s and in many years represented rather high fractions of the landings: these well subsidised withdrawals were a strong incentive to fish as much as possible and to land all sardine caught (Cingolani *et al.*, 2000).

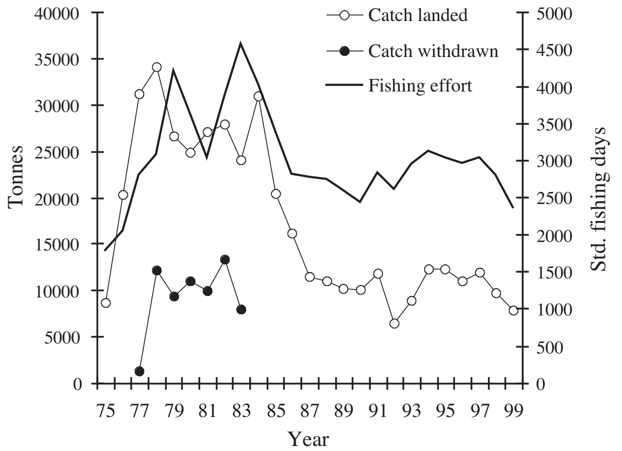

FIG. 2. – Standardised fishing effort directed at both sardine and anchovy, calculated for the fleet of Porto Garibaldi, over years. The trend of this series is compared with that of two quantities of sardine and anchovy relative to the same fleet: catch landed and catch withdrawn by the Italian governmental agency responsible for interventions in the agricultural market (AIMA), with subsidies from European Community. No discard correction was employed for any of these data.

Discarding behaviour over time

Given that observations on discards were carried out over a limited time interval, it was also necessary to establish the time span (years) over which discarding could be reasonably assumed to have occurred. It is thought that there was no incentive to discard sardine before 1987 and consequently discard corrections were made for the years following 1987 only, mainly for two reasons:

A) This date corresponds to a strong crisis in the anchovy fishery and consequent increase in the anchovy price (Cingolani *et al.*, 1996a). Before 1987, the market prices of the two species were quite similar. The increase in anchovy price after 1987 is evident in Figure 3, in which prices, adjusted to inflation, are displayed for both sardine and anchovy sold at the fish market of Chioggia from 1947 to 1998. This increase was also observed in all the other Adriatic fishing ports (ISTAT, 1975-1999). The ratio between sardine and anchovy prices, also shown in Figure 3, reaches the lowest levels after 1980 with absolute minima in 1986 and 1987.

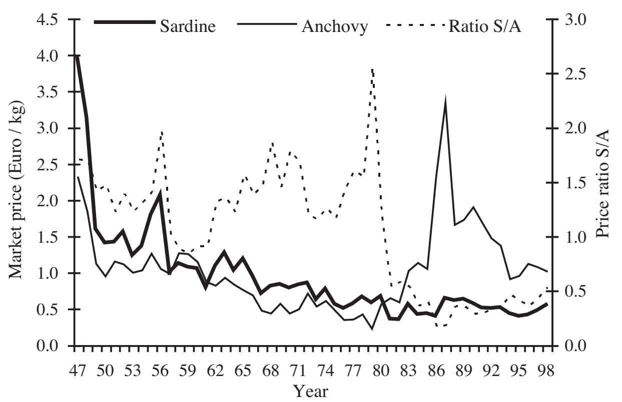

FIG. 3. – Anchovy and sardine prices at the fish market in Chioggia from 1947 to 1998. Data were collected by the Chamber of Commerce of Venice and adjusted to inflation with February 1999 as the reference value; the ratio between sardine and anchovy prices is also shown.

B) Before 1987, subsidies were paid to fishermen by the European Community (the AIMA phenomenon) for all small pelagic fish landed and unsold. As mentioned previously, this is believed to have represented a strong incentive to land every fish caught.

Chioggia fleet

Observer data revealed very low levels of discarding for the Chioggia fleet: on a total of 12 daily observations, sardine were caught and discarded in two cases only. In the first case, a negligible amount of boxes (20 of a total of 1,250, 1 box = 7 kg) was discarded; in the second, 130 boxes of sardine (of a total of 500, i.e. 26%) and 55 boxes of anchovy (of a total of 182) were discarded. On this fishing day, the catch composition of the vessel pair was mainly composed of other pelagic species (*Trachurus* spp., *Scomber* spp., *Sprattus sprattus*), of which 276 boxes were caught and 256 boxes landed. Fishing for other pelagics and also “white fish” (Sparidae, Mugilidae, *Merlangius merlangus*, etc.) by *volante* occurs occasionally and opportunistically at Chioggia and is considered sufficiently rare as to be safely ignored as a potential factor when estimating sardine discarding.

Furthermore, in the port of Chioggia there was (and is) an important market for fresh sardine. There are usually agreements or contracts with processing industries and there is the possibility of storing frozen sardine. These facts make the demand for sardine rather constant, of a certain importance and in any case not particularly influenced by the anchovy fishery. Hence, for assessment purposes, discarding was assumed not to occur in relevant quantities at this port. Similar assumptions were made for Cesenatico, another major port not included in the observer sampling programme, but geographically close and with a very similar small pelagic fleet (Cingolani *et al.*, 1996a).

San Benedetto del Tronto fleet

Very little discarding resulted from the observer data collected for San Benedetto del Tronto, where

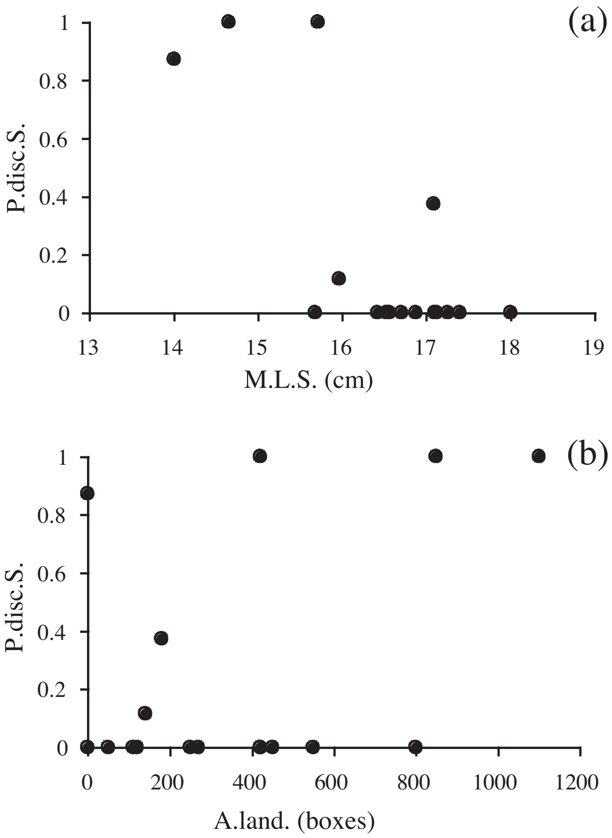

FIG. 4. – Daily proportion of sardine discarded at sea per vessel pair (P.disc.S.) as a function of **(a)** the mean length (cm) of sardine (M.L.S.) and **(b)** the number of boxes (1 box = 7 kg) of anchovy landed (A.land.), using observer data for the fleet of Porto Garibaldi.

vessels switch from *volante* in winter to *lampara* in summer. Of the 6 daily observations on *volante*, discarding of sardine occurred in one case only and in a negligible amount: 4 out of 10 boxes (1 box = 10 kg) of sardine caught were discarded (because damaged), compared to 130 boxes of anchovy caught and landed, together with 960 boxes of "white fish", which were exclusively composed of Mugilidae. Of the 13 daily observations on *lampara*, discarding occurred in two cases, when the amount of sardine caught was minimal (from 2 to 5 boxes). In a third case, the fishery was exceptionally successful, with a catch comprising 550 boxes of anchovy, 700 boxes of sardine and 350 boxes of other fish, and it would have been virtually impossible to box all these fish before arriving back at the port, meaning 300 boxes of sardine were discarded, despite being large (mean length = 17.8 cm). *Lampare* operating from San Benedetto del Tronto are frequently only able to catch anchovy; on more than half of the observations no sardine were caught. When caught, sardine generally tend to be large and thus highly marketable. The above mentioned *lampara* catch of 1,600 boxes (about 16 tonnes) of fish can be considered a rather rare event. Since the only other instances of sardine discarding were observed to occur when the catch was low, it was concluded that no relevant discarding of sardine occurs at San Benedetto del Tronto.

Porto Garibaldi fleet

Moderate discarding was identified for the fleet of Porto Garibaldi on the basis of observer data. The proportion of sardine discarded (1 box = 7 kg) as a function of the mean length of sardine is shown in Figure 4a. This graph clearly suggests that smaller sardine were discarded and larger ones were kept. This is reinforced by the fact that the one apparent counter example - in which sardine were discarded when their mean length was 17.09 cm (i.e. quite high value) - corresponded to a sardine catch of 640 boxes of which 240 were discarded. It is very likely that 400 boxes landed per day by a vessel pair constituted the maximum the market could bear for that day.

No clear relationship emerged when the proportion of sardine discarded was examined as a function of the other explanatory variables, sardine landings and anchovy landings; as an example, the case of anchovy landings is shown in Figure 4b. Again, a record in this figure is thought to be unusual: the first point from the upper left corner, which corresponds to a catch of 150 boxes of very small (mean = 9.23 cm) anchovy that were all discarded, and of 580 boxes of small sardine (mean = 14.01 cm), 87% of which were discarded.

As shown in Figure 5a, when tree models are applied, only the mean length of sardine and the anchovy landings enter into the tree model fitted. The first split is in the mean length of sardine, and it is by far the most significant, as indicated by the longer arms of the forks. This split matches the impression derived from the plots mentioned above (Fig. 4a,b), where the clearest relationship is shown with this explanatory variable. If sardine caught are less than 16.2 cm in length, this model predicts that approximately 60% of the catch will be discarded. The second split - with smaller fork arm lengths - is in anchovy landings, and it somewhat oddly suggests that a small proportion (0.08) of sardine is discarded when the number of boxes of anchovy landed is relatively low (< 260), but none when it is high (> 260). This results directly from the inclusion of the two unusual records mentioned above. When

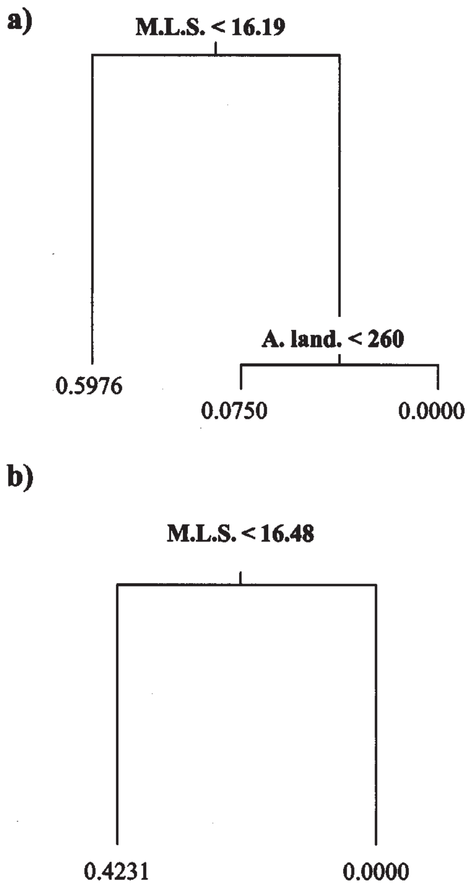

FIG. 5. – **(a)** Regression tree model relating the daily proportion of sardine discarded at sea per vessel pair to the mean length (cm) of sardine (M.L.S.) and the number of boxes (1 box = 7 kg) of anchovy landed (A.land.), using observer data for the fleet of Porto Garibaldi. At each node if the inequality shown is true the left fork is taken. The proportions discarded expected from the model are shown at the bottom of the tree. **(b)** Analysis (a) was repeated with two unusual records being omitted (see text for more details).

these records are omitted, the tree model includes the mean length of sardine only, suggesting that no sardine are discarded if their mean length exceeds 16.5 cm, while 42.3% are discarded if they are smaller than 16.48 cm (Fig. 5b). It seems therefore reasonable to base the estimates of annual proportions of sardine discarded by the fleet of Porto Garibaldi on the length of sardine only. It also seems reasonable to conclude from the two tree models (Fig. 5a,b) that fishermen discard approximately 50% of the sardine smaller than 16 cm length. The percentage discarded and the threshold of 16 cm were assumed not to vary from 1987 to 1999. Such a correction implies an increased annual catch for the length classes under 16 cm and therefore a change in the catch-weighted length frequencies for Porto Garibaldi from 1987 to 1999, and consequently a change in the catch at age data used as VPA input (both total catch at age and Porto Garibaldi CPUE at age for tuning, see Stock assessment below). Estimated discards and catches together with recorded landings are shown in Table 1. The estimates of annual proportions discarded range between 4% and 24%.

Ancona fleet

Substantial discarding was identified for the fleet of Ancona. The proportion of sardine discarded as a function of their mean length is shown in Figure 6a. Discarding does not occur when mean length is higher than 17.2 cm, but for smaller sardine there is no clear relationship between the two variables. The plot of the proportion of sardine discarded against the boxes (1 box = 8 kg) of sardine caught (Fig. 6b) does not show a clear relationship: in most cases the proportion is either zero or one. This means that in most cases when no sardine are landed, they are caught and discarded. This is clearly shown in Figure 6c as well, where the proportions of sardine discarded are plotted against sardine landings: there are no observations with zero boxes landed and zero boxes discarded, i.e. it never happens that no sardine are caught at all. Moreover, there is a clear tendency for a greater proportion of sardine to be discarded when the anchovy landings are higher than 300 boxes (Fig. 6d). As shown in Figure 7a, the first tree model used relates the proportion of sardine discarded to sardine catch, anchovy landings and the mean length of sardine and anchovy: only the mean length of sardine and sardine catch enter into the fitted model. This model, through the first split, picks up the fact that all large (> 17.2 cm) sardine are

TABLE 1. – Estimates of quantities (tonnes) and proportions of sardine discarded by the fleet of Porto Garibaldi, in the period 1987-1999. Corresponding catch with discard correction is also reported along with non-corrected catch (=Recorded landings).

Year	Recorded landings	Estimated discards	Estimated catch	Proportion discarded
1987	10981	1373	12354	0.11
1988	9477	1750	11227	0.16
1989	8219	2543	10762	0.24
1990	7987	1551	9538	0.16
1991	8988	823	9811	0.08
1992	4486	198	4684	0.04
1993	6344	582	6926	0.08
1994	7507	1091	8598	0.13
1995	5851	229	6080	0.04
1996	6275	623	6898	0.09
1997	6433	653	7086	0.09
1998	5799	907	6706	0.14
1999	3754	895	4649	0.19

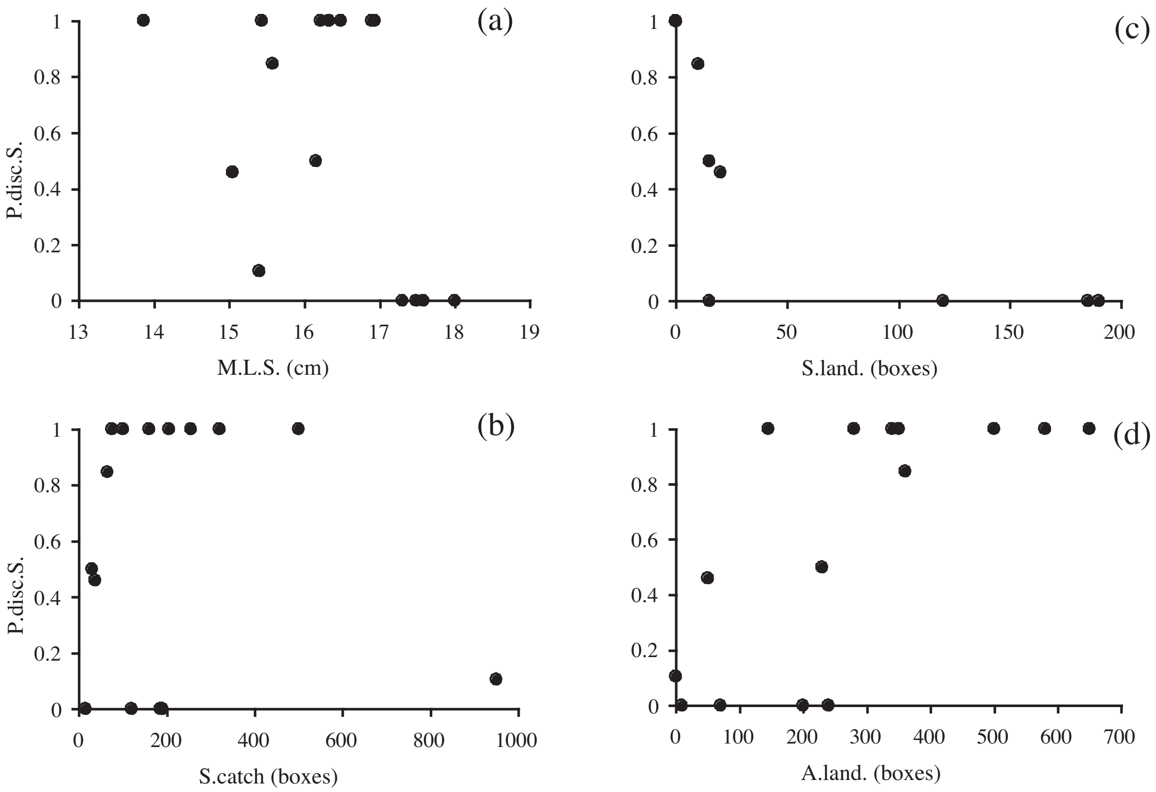

FIG. 6. – Daily proportion of sardine discarded at sea per vessel pair (P.disc.S.) as a function of **(a)** the mean length (cm) of sardine (M.L.S.), **(b)** the number of boxes (1 box = 8 kg) of sardine caught (S.catch), **(c)** the number of boxes (1 box = 8 kg) of sardine landed (S.land.) and **(d)** the number of boxes (1 box = 8 kg) of anchovy landed (A.land.), using observer data for the fleet of Ancona. In plot (c) P.disc.S. is equal to 1 in more than one case, i.e. 7 data points.

landed. Then, through the second split, it suggests that when substantial numbers (> 70) of boxes of smaller (< 17.2 cm) sardine are caught, the entire catch is discarded, while an intermediate proportion (0.60) of catch is discarded when a small number (< 70) of boxes of sardine is caught. The model summarises well the plots mentioned and can be considered an acceptable description of the Ancona fleet discarding behaviour, but it is not useful for estimating discards since the true sardine catch is not available except for the observer trips. Using the landed boxes of sardine instead of those caught (Fig. 6c), the tree model (Fig. 7b) shows that when sardine landings are very small (less than 13 boxes) 98% of

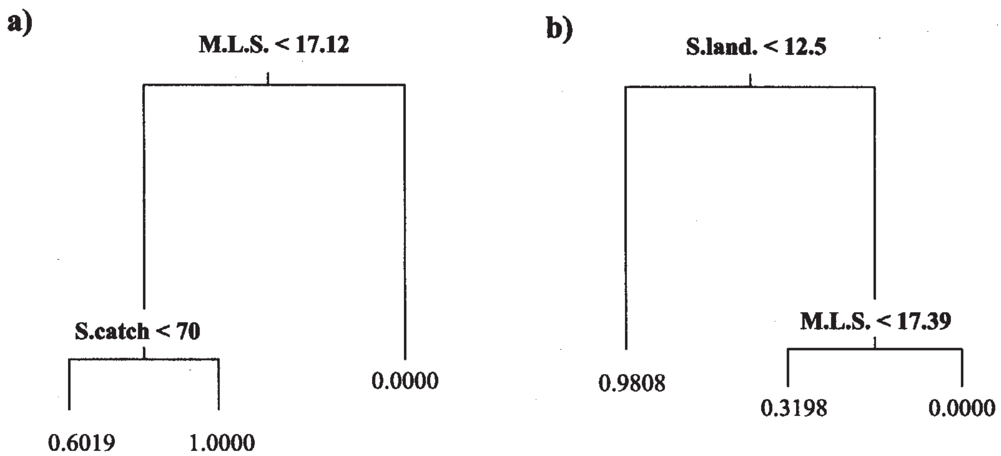

FIG. 7. – Regression tree model relating the daily proportion of sardine discarded at sea per vessel pair to the mean length (cm) of sardine (M.L.S.) and the number of boxes (1 box = 8 kg) of sardine **(a)** caught (S.catch) or **(b)** landed (S.land.), using observer data for the fleet of Ancona. At each node if the inequality shown is true the left fork is taken. The proportions discarded expected from the model are shown at the bottom of the tree.

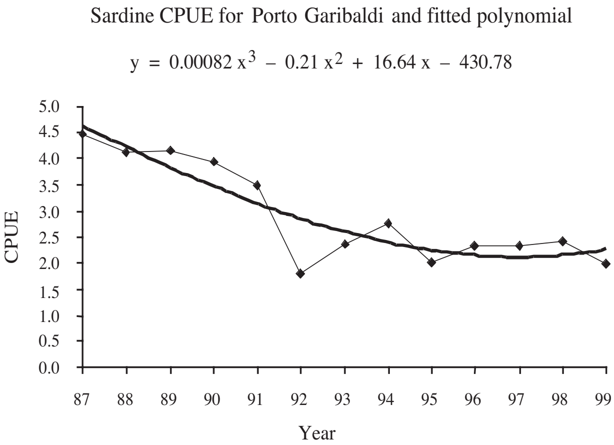

FIG. 8. – Sardine CPUE (tonnes per day per vessel pair) calculated for the fleet of Porto Garibaldi, using discard-corrected catch data. Data from 1987 to 1999 (line with indicators) are reported and fitted by a third degree polynomial (solid line). The smoothed CPUE obtained in this way was used to estimate sardine discarded by the fleet of Ancona (see text for details of calculations).

the sardine caught (of unknown quantity) are discarded; when landings are more than 13 boxes, sardine are discarded if their mean length is less than 17.4 cm. Discards are zero when sardine are large (> 17.4 cm length).

Additional information, which should be treated with caution, comes from logbooks compiled by the fishermen of the Ancona fleet (Cingolani *et al.*, 2000), as well as from informal interviews with skippers, and confirms the observer data, i.e. that sardine are caught every day but landed only in some cases.

The case of the fleet of Ancona is more problematic compared to that of Porto Garibaldi and a discard correction based on an increase in small-sized sardine catch only, as done for Porto Garibaldi, would not be sensible. The case of zero (or very small) sardine landings is the best predictor of discarding of the species. This suggests that it is possible to obtain an estimate of the sardine caught by multiplying an average daily sardine catch of a vessel pair for 1999, derived from the observer data, by the number of fishing days of the fleet for that year. The quantity of sardine caught by a vessel pair of Ancona in 1999 was thus assumed to be, on average, 160 boxes per day (i.e. the mean value in the observer data). The catch per day should be closely related to the abundance at sea, so for other years the catch was calculated as proportionally higher or lower than that in 1999, in accordance with the smoothed values of Porto Garibaldi CPUE corrected for discarding and used as an index of abundance. These smoothed CPUE values were obtained by fitting a third degree polynomial to the original data, as shown in Figure 8. For example, the daily catch in 1998 resulted to be 0.95 (= 2.16 / 2.27) times the daily catch in 1999 (Tab. 2). On average, the Ancona fleet fishes 130 days each year and the number of vessel pairs operating is known for each year. It was therefore possible to calculate the probable quantity of sardine caught by this fleet from 1987 onwards and thus obtain estimates of discards by subtracting landings from catches. The estimated values of annual sardine catch and the corresponding quantities and proportions of discards are also shown in Table 2. The proportions discarded are quite variable and often high. They range from 0.11 (in 1987) to 0.90 (in 1994), with the value for 1999 being around the average of the whole period (0.53).

TABLE 2. – Estimates of quantities (tonnes) and proportions of discarded sardine by the fleet of Ancona in the period 1987-1999. Corresponding catch with and without discard correction is also reported. Corrected daily catch (boxes, 1 box = 8 kg) per vessel pair and number of fishing vessel pairs are reported for the same fleet, along with raw and smoothed discard-corrected CPUE (tonnes per day per vessel pair) calculated for the fleet of Porto Garibaldi.

Year	Vessel pairs	CPUE	Smoothed CPUE	Daily catch with correction	Catch with correction	Catch without correction	Quantity discarded	Proportion discarded
1987	6	4.45	4.64	327	2039	1808	231	0.11
1988	5	4.11	4.22	298	1548	1041	507	0.33
1989	5	4.15	3.83	270	1405	1181	224	0.16
1990	8	3.93	3.47	245	2036	595	1441	0.71
1991	12	3.48	3.14	222	2764	427	2337	0.85
1992	12	1.80	2.85	201	2507	1779	728	0.29
1993	16	2.36	2.60	183	3050	1459	1591	0.52
1994	18	2.76	2.40	169	3164	324	2840	0.90
1995	16	2.01	2.25	159	2637	460	2177	0.83
1996	14	2.33	2.16	152	2212	803	1409	0.64
1997	14	2.34	2.12	150	2181	536	1645	0.75
1998	16	2.39	2.16	152	2535	1795	740	0.29
1999	10	1.97	2.27	160	1664	825	839	0.50

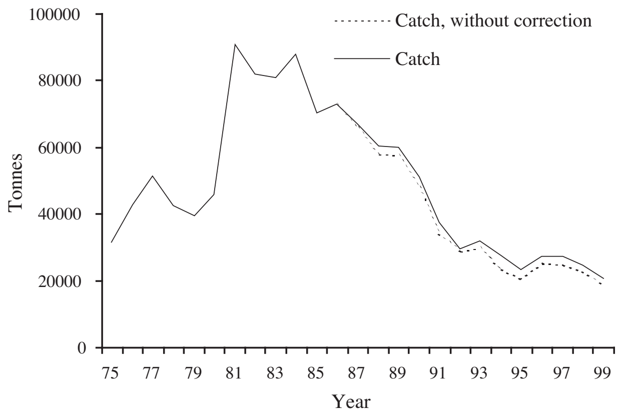

FIG. 9. – Annual total catch of sardine with and without discard correction, over years.

Stock assessment

An estimate of corrected total catches of sardine was obtained by pooling the effects of historical discard estimates for Porto Garibaldi and Ancona catches. The proportion of sardine discarded increased from low levels in 1987 to generally high levels between 1991 and 1995, followed by a decreasing trend. The annual values of total catch with and without discard correction (i.e. recorded landings) are compared over time in Figure 9. The increase in annual total catch due to the discard correction is relatively small: it ranges from around 900 tonnes to 4,000 tonnes, i.e. 2-15% of the corrected total catch. The discard correction also yields changes in the catch-weighted length frequency of Porto Garibaldi catches and, as a consequence, in the age frequency distributions of Porto Garibaldi (used in the tuning of VPA) and of the whole Adriatic catch (Fig. 10). This is related to the fact that Porto Garibaldi accounts for about 20% of the annual sardine landings in the Adriatic (Santojanni *et al.*, 2001a). The greatest changes in the catch at age numbers are for ages 0 and 1. In most years, these age classes did not comprise high proportions of the total age distribution. However, in the most recent years, the proportions of these two classes in Porto Garibaldi catches are higher: in 1998 and 1999, the age classes 0 and 1 account for 15% and 25% of the total respectively before discard correction, and 25% and 38% after discard correction (Fig. 10). Again this is reflected in the overall age frequency distributions.

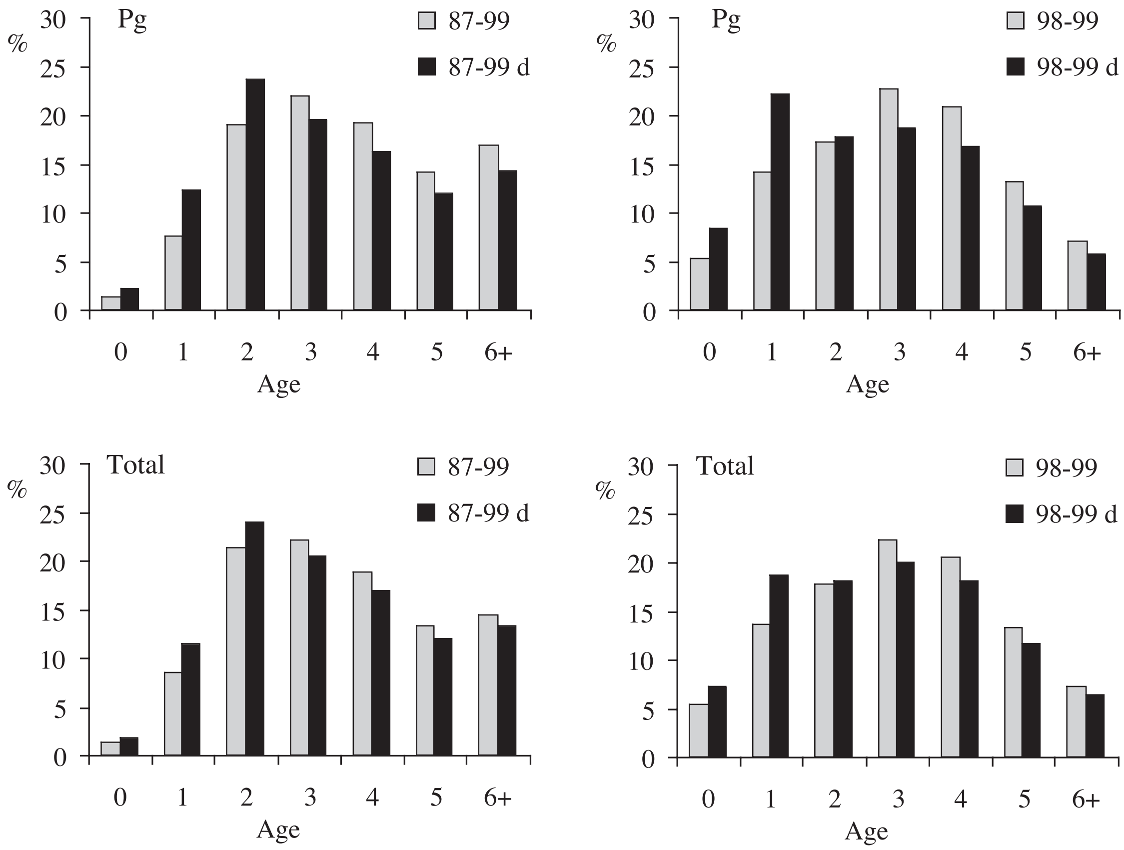

FIG. 10. – Age frequency distribution of Porto Garibaldi (Pg) and total catch of sardine, calculated for numbers of individuals. Four average distributions are shown: for the periods 1987-1999 and 1998-1999, both with (indicated by d) and without discard correction.

Both VPAs with and without discard correction, yielded sensible results. In Figure 11 the diagnostic plot for the Laurec-Shepherd tuning, in which the residuals from the fitted log catchabilities are plotted for each age as a function of time, is shown. No relevant monotonic trends are observed in these residuals over time, but large fluctuations are seen in the residuals for ages 0 and 1. This suggests that the selectivity on fish of these ages varies over time, but not with any relevant trend. The residuals for the older ages are more consistent. Thus, the assumption of constant selectivity in the period 1987-1999 can be considered as respected.

The annual fishing mortality rate at age estimated by VPAs shows a pattern over age groups which is characterised by an increase, and this is thought to be realistic for sardine (Fig. 12).

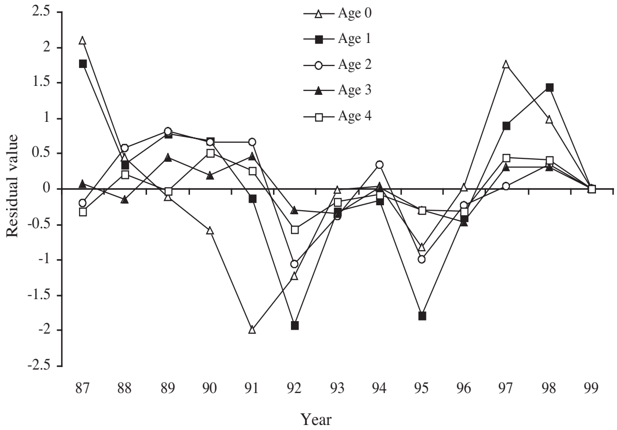

FIG. 11. – Residuals (i.e. observed - expected values) of log catchability at age over years, estimated by means of VPA. Data with discard correction.

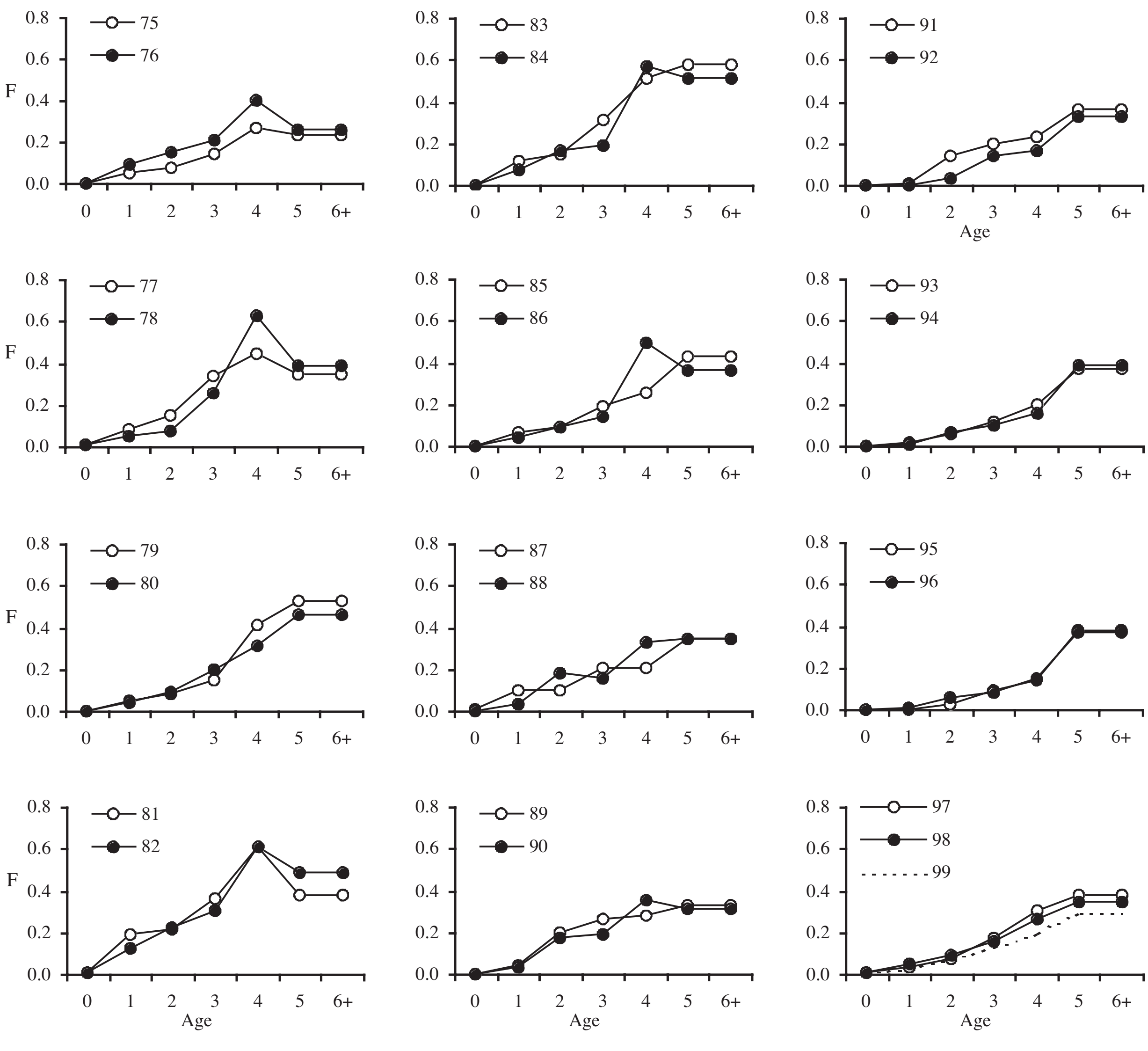

FIG. 12. – Sardine fishing mortality rate (F) as a function of age from 1975 to 1999, estimated by means of VPA. Data with discard correction.

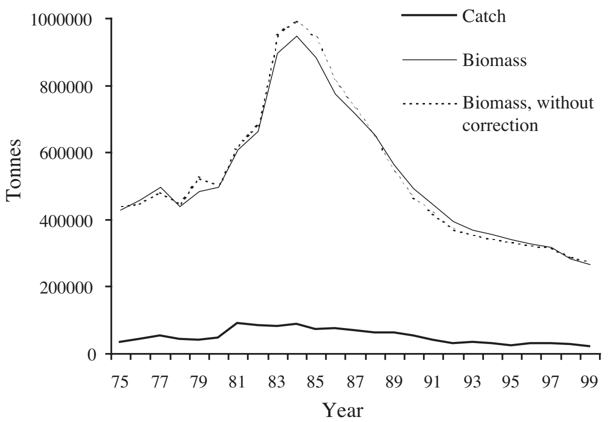

FIG. 13. – Sardine total catch and mid-year stock biomass at sea estimated by means of VPA, both with discard correction, are compared over years. The values of biomass obtained without discard correction are also shown.

The annual values of sardine mid-year stock biomass at sea, estimated by the VPA performed using total catch data with discard correction, are shown in Figure 13 along with the biomass estimated without correction for discards and the total corrected catch. The biomass increased between 1975 and 1984 from 400,000 tonnes in 1975 to a peak of 950,000 tonnes in 1984 and then declined reaching 300,000 tonnes in 1999, although after 1992 the rate of decline was slower. The smallest value of biomass was obtained in 1999. The influence of discard correction on the VPA results was very small because of the relatively high level of biomass with respect to the discarded quantity. The differences between the two trends of biomass obtained with and without discard correction - ranging from -9% to + 6% of the biomass with discard correction - can be explained by taking into account the structure of the catch at age data employed. The higher proportion of the youngest individuals due to the discard correction resulted in a higher estimate of the number of the youngest individuals at sea, as well as higher corresponding biomass, from 1987 onwards. Using corrected catch at age data also yielded a lower number of the oldest individuals at sea in the years close to 1987, which in turn implied a lower number of young individuals and a lower biomass before 1987.

DISCUSSION

The estimates of sardine catches presented here rely heavily on the major assumption that the discarding behaviour described for 1996-1999 did not change from 1987 onwards, irrespective of changes in abundance at sea. For instance, higher abundances in the past could have spurred the Porto Garibaldi fleet to discard percentages higher than 50% of < 16 cm length sardine estimated here. The no discarding situation assumed for Chioggia and San Benedetto del Tronto could also have been different in the late 1980s, when sardine biomass was higher. No data are available on discarding from former Yugoslavian and now Croatian and Slovenian fleets, but the fact that these fleets were fishing to supply canning industries allows us to believe that discarding (which is market driven) was negligible. Moreover, in the recent years lack of sardine supply for Croatian canning factories (S. Jukić, pers. comm.) rules out the possibility that discarding of sardine is taking place. The original research project (Cingolani *et al.*, 2000), included using a logbook scheme to be compiled by skippers, but the results obtained were of little use for scientific purposes. The logbooks were not returned compiled or they were compiled without the necessary accuracy. Therefore, the only reliable data were those obtained by the observer on board. This is a rather common situation, at least in Mediterranean fisheries, and makes investigating discards particularly expensive to conduct; it is not a case that, often, information on discards is not available for this area (Alverson *et al.*, 1994; Carbonell *et al.*, 1998). The importance of budget in determining the accuracy of estimated discards in sampling programmes involving observers on board was recently stressed by Borges *et al.* (2004). In particular, an increase in the target precision by half could be obtained by means of a high increase in sampling and associated cost. Nevertheless, surveys based on observers on board of vessels should represent the main way of estimating discards in the present and future. Obviously, quantifying past discards is more complicated. In our case, this task was "facilitated" by the collapse of anchovy stock in 1987, after which anchovy price increased compared to sardine, as well as by the occurrence of subsidies for sardine withdrawals in the previous years. These features allowed us to assume that no discards occurred before 1987. This choice was reasonable also because this fishery has essentially two target species, whereas a more complicated situation would be found in the presence of many more target species, as in the case of Mediterranean bottom trawlers. Furthermore, the withdrawals were well paid making it realistic to believe that in those years all the sardine caught were landed.

The correction for discards did not change the stock assessment results substantially. This is because the change in catch, although considerable for one fleet (up to 90% of discarding in some years for the Ancona fleet), was relatively small (2-15%) when compared to the total catches (with a mean around 35,000 tonnes in the period 1987-1999) for the Adriatic and tiny when compared to biomass estimates, which were in the range of hundreds of thousands of tonnes.

The estimates of biomass provided by VPA are lower if a lower value of natural mortality rate is employed. In the present assessment the main value used was M = 0.5, which is not one of the highest values reported for this species in this area. However, a lower value, M = 0.3, has been reported in literature. When M = 0.3 was used in our assessment, the biomass estimated for the most recent years - representing the minimum level of the series - decreased from over 300,000 to around 200,000 tonnes. This change was obtained if the value of F at the last true age in the last year (1999) was maintained as fixed (F = 0.3). Instead, these estimates of biomass decreased to around 150,000 tonnes when the same F was recalculated as equal to the difference between Z, estimated by catch curve analysis, and M = 0.3 , i.e. F was increased from 0.3 to 0.5. As a consequence, the value of F at the last true age was also calculated as higher in all the other years and thus the estimated biomass further decreased. These biomass estimates again resulted to be well over the total catches, whose average in the period 1995-1999 was below 25,000 tonnes. Not surprisingly, both the mentioned decreases in biomass were not essentially influenced by the discard correction. With a higher M, such as 0.74, reported by Alegría-Hernandez (1984), the difference between the two series of biomass obtained, including or not the discard correction, would have become further negligible in comparison with the high level of abundance.

On the whole, the range of biomass estimates was consistent with those reported by Azzali *et al.* (2002), using acoustic surveys (a fishery independent method), as well as with those reported by Santojanni *et al.* (2001a), using Length Cohort Analysis.

The mean ratio between catch and spawning biomass estimated by VPA (with M = 0.5) was around 0.20, and the current ratio was just around this value. The VPA estimates of the annual fishing mortality rate for age classes 0-5 were lower or equal to 0.20 in most cases (70%), with the average over the whole period being equal to 0.18. The highest values were estimated in the period 1981-1984 (around 0.28), because of higher catches recorded for all age classes in these years, including classes 1 and 2. This implied higher fishing mortality in a large portion of the stock in the sea. Due to the relatively low natural mortality rate value used, the exploitation rate of the sardine stock, F/(F+M), was equal to 0.26 over the whole period and around 0.36 in the interval 1981-1984. This means exploitation may not be negligible despite relatively low catches with respect to high biomass in the sea, since the effects yielded by the fishery on different age classes may change over time, e.g. the exploitation of age class 1 could increase again as in 1981-1984. Exploitation rate values are still below the reference point of 0.4 suggested by Patterson (1992), for small pelagic fish stocks, nevertheless the trend in biomass (Fig. 13) clearly indicates a constant decline of the stock since 1984. A recent study (Grbec *et al.*, 2002), suggested that increase and decline of the sardine stock in the Adriatic might be correlated with climatic fluctuations influencing the advection of Levantine Intermediate Waters (Buljan and Zore-Armanda, 1976). Years with low advection (from the mid 1980s onwards) may be unfavourable for the recruitment of sardine. The biological mechanism by which Levantine Intermediate Waters (LIW) could influence recruitment can only be postulated (LIW conveying nutrients to offshore areas of the Adriatic where sardine spawns, increasing primary production and thus food for larvae) and no clear conclusion can be drawn at present.

ACKNOWLEDGEMENTS

We wish to thank the Directorate General for Fisheries of the European Commission and Direzione Generale della Pesca Marittima of the Italian Ministry for Agriculture which partially funded this research. The Chambers of Commerce of Venice and Ancona, skippers and crews of the commercial vessels which collaborated in this research and Dr. E. Morello, who reviewed the English language of the manuscript, are greatly acknowledged.

REFERENCES

Alegría-Hernandez, V. – 1984. Application of production model to the eastern Adriatic sardine (*Sardina pilchardus*, Walb.) population. *FAO Fish. Rep.*, 290: 191-194.

Allard, J. and G.A. Chouinard. – 1997. A strategy to detect fish discarding by combining onboard and onshore sampling. *Can. J. Fish. Aquat. Sci.*, 54: 2955-2963.
Alverson, D.L., M.H. Freeberg, J.G. Pope and S.A. Murawski. – 1994. A global assessment of fisheries bycatch and discards. *FAO Fish. Tech. Pap.*, 339: 233 pp.
Anon. – 1975-1993. Morska lovina SFRJ po područjima i glavnim vrstama. *Morsko Ribarstvo,* 27-45.
Anon. – 1994. Morski ulov Republike Hrvatske po područjima i glavnim vrstama. *Morsko Ribarstvo,* 46.
Arneri, E. – 1996. Fisheries resources assessment and management in the Adriatic and Ionian Seas. FAO-GFCM 3rd Technical Consultation on Stock Assessment in the Central Mediterranean, Tunis, 8-12 November 1994. *FAO Fish. Rep.*, 553(suppl.): 7-20.
Azzali, M., A. De Felice, M. Luna, G. Cosimi and F. Parmiggiani. – 2002. The state of the Adriatic Sea centered on the small pelagic fish populations. *P.S.Z.N. Mar. Ecol.*, 23 (suppl. 1): 78-91.
Borges, L., A.F. Zuur, E. Rogan and R. Officer. – 2004. Optimum sampling levels in discard sampling programmes. *Can. J. Fish. Aquat. Sci.*, 61: 1918-1928.
Buljan, M. and M. Zore-Armanda. – 1976. Oceanographical properties of the Adriatic Sea. *Oceanogr. Mar. Biol. Annu. Rev.*, 14: 11-98.
Carbonell, A., P. Martín and S. de Ranieri. – 1998. Discards of the western Mediterranean trawl fleets. *Rapp. Comm. int. Mer Médit.*, 35(2): 392-393.
Chen, Y. and G.N.G. Gordon. – 1997. Assessing discarding at sea using a length-structured yield-per-recruit model. *Fish. Res.*, 30: 43-55.
Chopin, F., Y. Inoue and T. Arimoto. – 1996. Development of a catch mortality model. *Fish. Res.*, 25: 377-383.
Cingolani, N., G. Giannetti and E. Arneri. – 1996a. Anchovy fisheries in the Adriatic Sea. *Sci. Mar.*, 60 (Suppl. 2): 269-277.
Cingolani, N., G. Kirkwood, G. Giannetti, E. Arneri and D. Levi. – 1996b. Note on the stock assessment of *Engraulis encrasicolus* (L.) and *Sardina pilchardus* (Walb.) of the northern and central Adriatic Sea. FAO-GFCM 3rd Technical Consultation on Stock Assessment in the Central Mediterranean, Tunis, 8-12 November 1994. *FAO Fish. Rep.*, 553 (suppl.): 1-5.
Cingolani, N., G. Kirkwood, E. Arneri, J. Rousseau, A. Belardinelli, G. Giannetti, A. Santojanni and C. Barry. – 1998. *Optimal allocation of effort in sampling for age and length from commercial fisheries*. Final report on European Community funded project, EC XIV/95/33, 185 pp.
Cingolani, N., G. Kirkwood, E. Arneri, A. Santojanni, A. Belardinelli, G. Giannetti, S. Colella, F. Donato and C. Barry. – 2000. *Discards from the Adriatic small pelagic fishery*. Final report on European Community funded project, EU 97/065, 284 pp.
Cingolani, N., E. Arneri, A. Santojanni, A. Belardinelli, G. Giannetti, S. Colella and F. Donato. – 2002. Stock Assessment of sardine (*Sardina pilchardus*, Walb.) in the Adriatic sea. *Biol. Mar. Medit.*, 9(1): 82-88.
Darby, C.D. and S. Flatman. – 1994. *Virtual Population Analysis: version 3.1 (Windows/Dos) user guide*. Info. Tech. Ser. MAFF Direct. Fish. Res., Lowestoft, 1, 85 pp.
Grbec, B., J. Dulcic and M. Morovic. – 2002. Long-term changes in landings of small pelagic fish in the eastern Adriatic-possible influence of climate oscillations over the Northern Hemisphere. *Clim. Res.*, 20: 241-252.
Hilborn, R. and C.J. Walters. – 1992. *Quantitative fisheries stock assessment: choice, dynamics and uncertainty*. Chapman and Hall, New York.
ISTAT, Istituto Nazionale di Statistica. Statistiche della caccia e della pesca, Roma, 1975-1999.
Laurec, A. and J.G. Shepherd. – 1983. On the analysis of catch and effort data. *J. Cons. Int. Explor. Mer*, 41: 81-84.
Levi, D., N. Cingolani, G.F. Giannetti, R. Scorcelletti, E. Peloni and N. Frontini. – 1984. Preliminary results on the assessment of two stocks of small pelagic fish in the north-central Adriatic Sea (*Sardina pilchardus*, Walb. and *Engraulis encrasicolus*, L.). *FAO Fish. Rep.*, 290: 195-198.
Levi, D., N. Cingolani, G.F. Giannetti, R. Scorcelletti, E. Peloni and N. Frontini. – 1985. Stock assessment of *Sardina pilchardus* (Walb.) and *Engraulis encrasicolus* (L.) of the north Adriatic Sea: some preliminary results. *Quad. Ist. Ric. Pesca Marittima*, 4(1): 64 pp.
Patterson, K. – 1992. Fisheries for small pelagic species: an empirical approach to managements targets. *Rev. Fish Biol. Fish.*, 2: 321-338.
Pertierra, J.P. and R.G. Perrotta. – 1993. On the population dynamics of sardine, *Sardina pilchardus* Walbaum, 1792, from the Catalan Sea (northwestern Mediterranean). *Sci. Mar.*, 57: 235-241.
Piccinetti, C., S. Regner and M. Specchi. – 1981. Estimation préliminaire de la production maximale d'anchois et de sardine en Adriatique. *FAO Fish. Rep.*, 253: 155-158.
Saila, S.B. – 1983. Importance and assessment of discards in commercial fisheries. *FAO Fish. Circ.*, 765, 62 pp.
Santojanni, A., E. Arneri, A. Belardinelli, N. Cingolani and G. Giannetti. – 2001a. Fishery and stock assessment of sardine *Sardina pilchardus* (Walb.) in the Adriatic Sea. *Acta Adriat.*, 42(1): 151-168.
Santojanni, A., E. Arneri, A. Belardinelli, N. Cingolani and G. Giannetti. – 2001b. Small pelagic fish in the Adriatic: stocks fluctuations and environmental factors. In: M. Astraldi, A. Navarra, N. Pinardi, M. Ribera d'Alcalà and F. Trincardi (eds). *Conference proceedings of first SINAPSI workshop, Roma, 6-7 April 1998. Archo Oceanog. Limnol.*, 22: 133-138.
Santojanni, A., N. Cingolani, E. Arneri, G. Giannetti, A. Belardinelli, F. Donato and S. Colella. – 2002. Calculation of small pelagic catch per unit of fishing effort in the Adriatic Sea. *Biol. Mar. Medit.*, 9(1): 89-95.
Santojanni, A., E. Arneri, C. Barry, A. Belardinelli, N. Cingolani, G. Giannetti and G. Kirkwood. – 2003. Trends of anchovy (*Engraulis encrasicolus*, L.) biomass in the northern and central Adriatic Sea. *Sci. Mar.*, 67(3): 327-340.
Sinovcić, G. – 1986. Estimation of growth, mortality, production and stock size of sardine, *Sardina pilchardus* (Walb.), from the middle Adriatic. *Acta Adriat.*, 27: 67-74.
Sinovcić, G. – 1991. Stock size assessment of sardine, *Sardina pilchardus* (Walb.) population from the central eastern Adriatic on the basis of VPA method. *Acta Adriat.*, 32: 869-884.
Stamatopoulos, C. – 1995. Trends in catches and landings, Mediterranean and Black Sea fisheries: 1972-1992. *FAO Fish. Circ.*, 855.4(Suppl.), 55 pp.
Venables, W.N. and B.D. Ripley. – 1994. *Modern applied statistics with S-Plus*. Springer-Verlag, Berlin.

Scient. ed.: I. Palomera