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Fishery and stock assessment of sardine *Sardina pilchardus* (WALB.) in the Adriatic Sea

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Sardine Sardina pilchardus *(WALB.) is - together with anchovy* Engraulis encrasicolus *(L.) - one of the most important commercial fish species in the Mediterranean Sea and, in particular, in the Adriatic Sea. The mean value of the annual catch of sardine in the Adriatic Sea is around 50.000 t, in the period 1975-1996.*

Since 1975, the IRPEM is involved in research on sardine and anchovy abundance in the northern and central Adriatic Sea, by means of population dynamics methods. In this paper, the sardine stock biomass values estimated for the time interval 1975-1996 are discussed. These estimates were obtained using three methods based on different data inputs: Length Cohort Analysis (LCA), Virtual Population Analysis (VPA) and an ad hoc *modified version of the DELURY model with recruitment index. A comparison between the biomass estimates derived from these methods was made. Values of biomass, as well as patterns over time, are consistent. In particular, strong fluctuations of biomass are evident. The possible effects of fishing effort on biomass were investigated and the stock-recruitment relationship analysed, in order to gain insight about the mechanisms underlying biomass fluctuations.*

Key words: sardine, Adriatic Sea, biomass fluctuations, population dynamics methods

INTRODUCTION

Sardine *Sardina pilchardus* (WALB.) is, together with anchovy *Engraulis encrasicolus* (*L.*), one of the most important commercial species of the Adriatic Sea. Fished sardine in the Adriatic Sea was around the 13 % of the Mediterranean sardine catch, and around 14 % of the total marine fishery catch in the Adriatic Sea, in 1992 (STAMATOPOULOS, 1995).

Our research on stock assessment of sardine and anchovy in the northern and central Adriatic Sea has been carried out since 1975 (CINGOLANI *et al.*, 1993; ARNERI, 1996; CINGOLANI *et al.*, 1996a,b, 1998a,b,c; SANTOJANNI *et al.*, 1999; SANTOJANNI *et al.*, in press). This paper deals with the estimate of the sardine stock biomass on the basis of data from 1975 up to 1996.

Analyses were performed to estimate the sardine stock biomass and point out the corresponding fluctuations over time. Biomass that was estimated by using three methods based on different data inputs: Length Cohort Analysis (LCA), Virtual Population Analysis (VPA) and a modified *ad hoc* version of the DELURY model with recruitment index.

Stock assessments of sardine in the Adriatic Sea were also performed on the basis of population dynamics methods used in papers by ALEGRÍA-HERNANDEZ (1983, 1984), LEVI *et al.*, (1984, 1985), SINOVČIĆ (1986, 1991). The same assessments were also performed using other methods, such as echo surveys (AZZALI *et al.*, 1990) and egg and larvae surveys (PICCINETTI *et al.*, 1981, 1984; REGNER *et al.*, 1983). Comparisons between our biomass estimates and the results obtained from these authors were made. The possible effects of fishing effort on stock biomass at sea were investigated and the stock-recruitment relationship analysed, in order to gain insight about the mechanisms underlying biomass fluctuations.

MATERIAL AND METHODS

Data

Data discussed in this paper are relative to the sardine stock in the northern and central Adriatic Sea and range from 1975 to 1996.

Monthly catches (i.e. landings) have been collected in the major fishing ports for pelagic fish along Italian coast (major ports in the text) as Trieste, Chioggia, Porto Garibaldi, Cesenatico, Cattolica, Ancona, San Benedetto del Tronto, Vieste, and also in other fishing ports as Grado, Marano Lagunare, Caorle, Goro, Rimini, Fano, Giulianova (minor ports in the text), where catch values are not high such as in the major ones (Fig. 1). Catch data for ex-

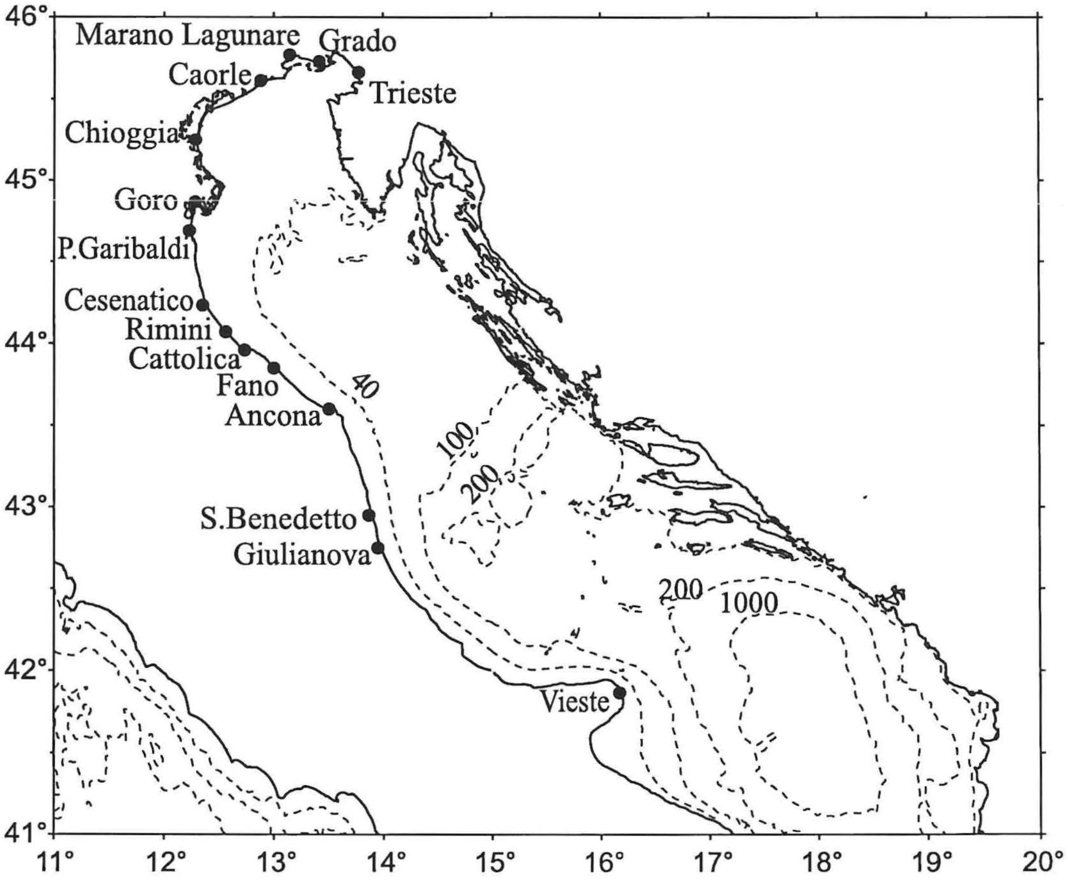

Fig.1. Geographic extent of the survey: the port of Vieste represents the southern limit (see text)

Yugoslavia - Croatia and Slovenia - have been derived from published sources (Morsko Ribarstvo, 1975-1994).

Fleet data have been collected for vessels employed in the fishery of anchovy and sardine in all the Italian ports, whereas fishing days in major ones only. The most used gear in the Italian Adriatic ports (north of San Benedetto del Tronto) for anchovy and sardine are mid-water pair trawls (*volante*). Another gear used in the Italian ports is given by purse seines (*lampara*), which are more diffuse than the previous ones south of Ancona (CINGOLANI *et al.*, 1998c).

Annual series of standardised effort data were calculated taking into account the number of vessels employed in the fishery of anchovy and sardine, fishing days spent from each vessel, potential fishing capability of single vessels, such as gear and engine power (CINGOLANI *et al.*, 1993, 1996a). Standardisation of effort was performed following a procedure defined by LEVI *et al.* (1985) and using the FPOW computer program (ABRAMSON, 1971).

Catch and effort data were utilised to calculate the time series of standardised catch-per-unit-effort (CPUE). The time series of CPUE calculated for Porto Garibaldi was used in this assessment because, in this port, the major amount of landed sardines (as well as anchovy) is recorded. In addition, a large part of the catch was used for meal reduction in the time period 1977-1985. That implies a high constant demand that could be associated to low discards.

This calculation of CPUE is based on effort involving both anchovy and sardine. Even if anchovy is more required from market than sardine, fishermen fish on schools indifferently formed of anchovies, sardines or both species. In addition, there are very few cases where only one species is caught during a month. In order to investigate possible effects due to the catch composition, CPUE series derived from different data collections that were constructed by using effort data with sardine monthly catches relatively high in respect of anchovy ones (higher than 50%, 75% or 90%). The trends in these CPUE series were similar (CINGOLANI *et al.*, 1993). Hence, effort can be thought as directed to sardine as well as anchovy.

Biological samples, required for length frequency, length-weight relationship, mean weight, recruitment index, have been collected in the major ports.

Length frequency data were obtained measuring fishes at the lower centimetre on the basis of 1 cm length classes. Catch weighted length frequencies for port and month were obtained multiplying corresponding length frequency distributions by "weights", which were ratios between catch for port and month and annual catch for all ports, calculated taking into account those ports and months for which length frequency data exist. These catch weighted length frequencies were then summed over ports and months, providing annual catch weighted length frequencies. In our calculation of catch weighted length frequency, all the major ports were taken into account.

Mean weight was calculated to transform the biomass value of landings into fish number. Two distinct series of annual mean weights were calculated to transform the number of fishes estimated by the DELURY *ad hoc* method into biomass, i.e. recruits and adults. The mean weight of recruits was calculated taking into account individuals whose length ranged between 13 and 14.9 cm, whereas the mean weight of adults was calculated taking into account individuals longer than 14.9.

The length-weight relationship obtained from raw data was fitted by the commonly used power function (CINGOLANI *et al.*, 1998c).

Methods

Length Cohort Analysis (LCA)

The LCA is a method based on the catch distribution in length classes (JONES, 1984; LLEONART, 1993; GALLUCCI *et al.*, 1996). It was previously utilised in stock assessments for sardine (PERTIERRA and PERROTTA, 1993) and anchovy (PERTIERRA and LLEONART,

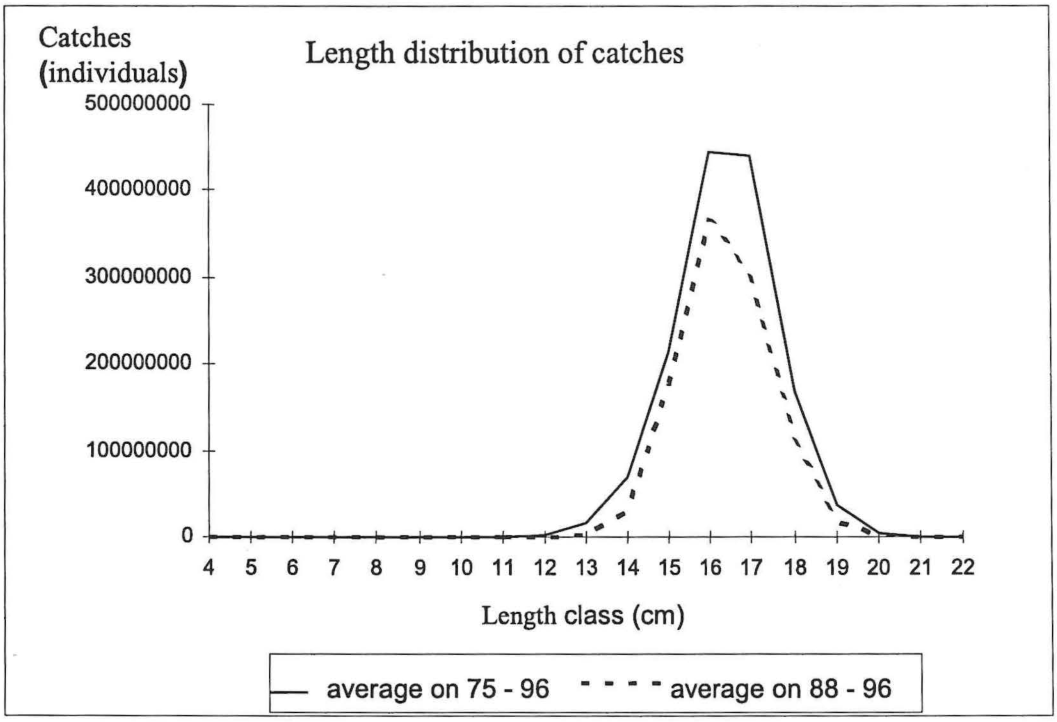

Fig.2. Average length distributions of the Adriatic sardine catch in the time intervals 1975-1996 and 1988-1996

1996; PERTIERRA *et al.*, 1997) in the Mediterranean Sea.

LCA is based on the steady state assumption, with the stock being thought to be constant over time. As a consequence, it provides a single estimate of fish number in the sea, for each length class. The number of fishes of a given length l+1 allows to estimate the individuals in the previous length class l, taking into account the individuals dead through the length interval l to l+1. At this aim, an estimate of the fishing mortality rate as a function of length (F_{length}), as well as the natural mortality rate, M, are required. The natural mortality rate is assumed constant as a function of length and time. Growth parameters are also required.

The fishing mortality F_{length} is calculated by LCA on the basis of the length distribution of the catch. In our case, two different approaches were taken into account. Firstly, LCA was performed using two length distributions of the catch calculated by averaging all the available data (i.e. since 1975 up to 1996) and more recent data only (i.e. since 1988 up to 1996). The difference between the two length distributions is shown in Fig. 2 : the mode of the latter distribution shifts from 16 to 15 cm. Moreover, on the whole, the average catch is higher in the former distribution.

Since steady state assumption may be not met and the two above mentioned distributions suggest that, LCA was repeated using average length distributions of the catch calculated for shorter time intervals: consecutive 3-year intervals were used, i.e. 1975-1977, 1978-1980,....., 1994-1996. The corresponding biomass estimates are the primary reference points in these assessments based on LCA.

Length classes ranged from 9 to 21 cm, by step of cm 1.0. The 19, 20 and 21 cm classes were joined in a plusgroup.

The value of F_{length} was assumed equal to 0.5 in the last length class (CINGOLANI *et al.*, 1998c).

In our assessment, M was assumed equal to 0.5 on the basis of the estimate reported by SINOVČIĆ (1984, 1986) for the Adriatic Sea. It is worth noting that, for the Adriatic Sea, the same author also reported $M = 0.3$ (SINOVČIĆ, 1991), whereas ALEGRÍA-HERNANDEZ (1984) obtained a relatively high value, $M = 0.74$; PICCINETTI *et al.* (1981) estimated $M = 0.55$, and LEVI *et al.* (1984; 1985) reported values of M ranging from 0.52 to 0.43 for the years since 1975 up to 1979, and $M = 0.32$ for 1980.

Two sets of growth parameters were used. They were derived from two distinct von BERTALANFFY curves, whose equation is

$$L(t) = L_\infty [1 - e^{-k(t-t_0)}] \qquad (1)$$

where $L(t)$ is the length at age t, L is the theoretical maximum value which $L(t)$ approaches asymptotically over time, k is sensitive to the overall speed (i.e. rate of growth) by which $L(t)$ approaches such a value and t_0 is a theoretical age at which length is zero.

The parameter values used were: $L_\infty = 20.5$, $k = 0.46$, $t_0 = -0.50$ and $L = 21$, $k = 0.35$, $t_0 = -2.42$, reported by SINOVČIĆ (1984) and CGPM/GCFM (1980), respectively (SINOVČIĆ and CGPM growth curve in the text). The first growth curve was estimated for the eastern Adriatic Sea sardine stock, while the second one for sardine stock of the north western Mediterranean Sea.

LCA was performed using the software package VIT, developed by LLEONART and SALAT (1992).

Virtual Population Analysis (VPA)

Virtual Population Analysis (VPA) is a common method in fishery stock assessment, based on the catch distribution in age classes (GULLAND, 1983; HILBORN and WALTERS, 1992).

VPA provides estimates of annual fish number in the sea, for each age class. The number of fishes of a given age n+1 in the year t+1 allows to estimate the individuals aged n in the previous year t, taking into account the individuals dead through the time interval n to n+1. At this aim, an estimate of the fishing mortality rate as a function of age and time is required ($F_{age,\ year}$). The natural mortality rate, M, is also required. This parameter is assumed constant as a function of age and time. The fishing mortality $F_{age,\ year}$ is calculated by VPA on the basis of the age distribution of the annual catch. These distributions were obtained from the corresponding length distributions. At this aim, the von BERTALANFFY equation was used: the age of an individual of length $L(t)$ was established using the Equation 2. This was obtained changing the position of terms in the Equation 1, so that the age t is expressed as a function of the length $L(t)$:

$$t = t_0 - (1/k) \ln [(L_\infty - L(t)) / L_\infty] \qquad (2)$$

The parameter values were the same used for LCA. The oldest age class (a plusgroup) was 5 when the growth curve reported by CGPM was used, whereas it was 6 when using the SINOVČIĆ one. In fact, the individuals belonging to the age class 5 on the basis of the CGPM growth curve, were aged 6 when the other curve was used, and so on.

Individuals of the age class 0 have a length ranging from 12.0 up to 14.7 cm, on the basis of the CGPM growth curve, and from 4.2 to 10.2 cm when the SINOVČIĆ one is used. In the first case, the length range of the age 0 individuals is quite consistent with recruit one used in the DELURY *ad hoc* assessment.

The value of $F_{age,\ year}$ was assumed equal to 0.4 in the last age and in the last year (i.e. 1996). That allowed us to obtain F values in the last age - in all the other years - as close as possible to 0.5, i.e. the value in the last length class used in LCA assessments. These values of $F_{age,\ year}$ in the last age were calculated on the basis of a relationship between $F_{age,\ year}$ in the last age and in the last year and Porto Garibaldi effort, as follows:

$$F_{last\ age,\ year\ t} / E_t = F_{last\ age, 1996} / E_{1996} \qquad (3)$$

where E_t is the effort in the year t (CINGOLANI *et al.*, 1998c).

All the $F_{age,\ year}$ values were tuned by the LAUREC-SHEPHERD method (LAUREC and SHEPHERD, 1983; POPE and SHEPHERD, 1985). At this aim, CPUE values relative to each age class were used.

The natural mortality rate, M, was assumed equal to 0.5, such as for LCA.

VPA was performed using the software package MAFF-VPA, developed by DARBY and FLATMAN (1994).

DELURY *ad hoc* method

The DELURY *ad hoc* method is derived from the DELURY model with recruitment index, which is a depletion model (HILBORN and WALTERS, 1992; MRAG, 1992). The DELURY *ad hoc* method does not utilise recruitment index and for this reason was preferred to the common version. In fact, a not sufficiently reliable estimate of recruitment index was available in some years (CINGOLANI *et al.*, 1993,1998a,b,c). Anyway, a comparison with the assessments based on LCA and VPA is useful, because the DELURY *ad hoc* assessment is particularly sensitive to the CPUE trend.

The relationship between the individuals in the sea in the year t+1 and in the previous one, t, is the following:

$$N_{t+1} = [\, T_t \, e^{-M/2} - C_t \,] \, e^{-M/2} \qquad (4)$$

where N_{t+1} is the number of adults at the beginning of the year $t+1$; T_t is the total number of individuals at the beginning of the year t, formed by adults and recruits; C_t is the number of individuals caught during the year t; M is the natural mortality rate.

On the basis of the DELURY *ad hoc* method, T_t is obtained from the equation:

$$T_t = (\, CPUE_t / q + C_t / 2 \,) \, e^{M/2} \qquad (5)$$

where q is the catchability coefficient.

It is feasible to divide population structure in adults and recruits over years, except for the first year: recruits in the year t+1 can be calculated subtracting adults from the total number T_{t+1}.

The Equation 5 is derived from the basic equation of the DELURY model with recruitment index:

$$E(c_t) = q \, E_t \, [(N_t + \lambda R_t) \, e^{-M/2} - C_t / 2] \qquad (6)$$

where c_t is the catch taken with the effort E_t applied in the year t (in this case, C_t and c_t are not identical); R_t is the recruitment index during the year t; λ is the constant of proportionality between the recruitment index and the true annual recruitment. The DELURY model is fitted to data on the basis of the expected catch, $E(c_t)$, in the year t, according to this equation. The DELURY *ad hoc* method does not perform statistical fitting of empirical data distribution, such as the DELURY model.

When the DELURY *ad hoc* method is used C_t, CPUE$_t$, M, and q are input data, whereas the fitting of the DELURY model gives the estimates of the catchability coefficient, q . In order to obtain an estimate of this parameter, it was assumed that the catchability coefficient for sardine, associated to a specific CPUE series, is equal to the corresponding coefficient for anchovy (CINGOLANI *et al.*, 1993, 1998a,b,c). That means the catchability coefficient is mainly determined by fleet characteristics rather than animal behaviour. Different values of the catchability coefficient were employed in order to evaluate the sensitivity of biomass estimates to this parameter. These values were derived from the anchovy assessment based on the DELURY model with recruitment index and Porto Garibaldi CPUE, where it provided good results (CINGOLANI *et al.*, 1998a,b).

The primary reference point was the catchability coefficient estimated using anchovy data from 1975 to 1996, i.e. $q = 2.17E\text{-}5$.

Other values of q were estimated when the same assessment was repeated excluding data for some years, i.e. data up to 1995 or 94/ 93/ 92/ 91, and since 1976 or 77/ 78/ 79/ 80. The average of these values, $q = 3.51E\text{-}5$, was also used as a reference point. When data up to 1995 or 94/ 93/ 92/ 91, and since 1976 were used, q was estimated lower than the average and, in particular, slightly higher than $q = 2.17E\text{-}5$: the highest one was obtained with data up to 1994

(q = 2.38E-5). When data since 1977 or 78/ 79/ 80 were used, q was estimated higher than the average, and it ranged from 4.02E-5 to 6.64E-5. It is worth noting that these four estimates were associated with a quite diminished contrast in the trend of anchovy CPUE, due to the exclusion of the above mentioned years (data not reported).

Bootstrap simulations were performed on the anchovy assessment with data from 1975 to 1996, providing 90% and 70% confidence intervals for q. The average q = 3.51E-5 falls in the 90% confidence interval (0.30E-5 - 5.14E-5). Therefore, the two reference points used for q can be thought as belonging to the same distribution. The limit values of the 70% confidence interval (0.90E-5 - 3.55E-5) were also used in the sardine stock assessment.

The natural mortality rate, M, was assumed equal to 0.5, such as for LCA and VPA.

RESULTS AND DISCUSSION

Total catches, as well as catches of the minor, major and ex-Yugoslav ports, are displayed as a function of time in Fig. 3. The prevalent contribution of the major and ex-Yugoslav ports is evident.

Catches recorded for the major ports over years are displayed in Fig. 4. On the whole, the highest values are recorded in the first half of 1980s, as seen for groups of ports (i.e. total, major, etc.). It is evident that Porto Garibaldi catches are higher than in other ports. The ratio between total and Porto Garibaldi catches over time can be derived from Fig. 5: in the period 1975-1996, the average ratio is estimated equal to 0.20. The fraction of sardine landed in Porto Garibaldi increases over time, since the total catch value decreases more rapidly than the Porto Garibaldi time series does; nevertheless, trends are quite similar.

The values of biomass estimated by LCA are reported in Fig. 6. When the CGPM growth

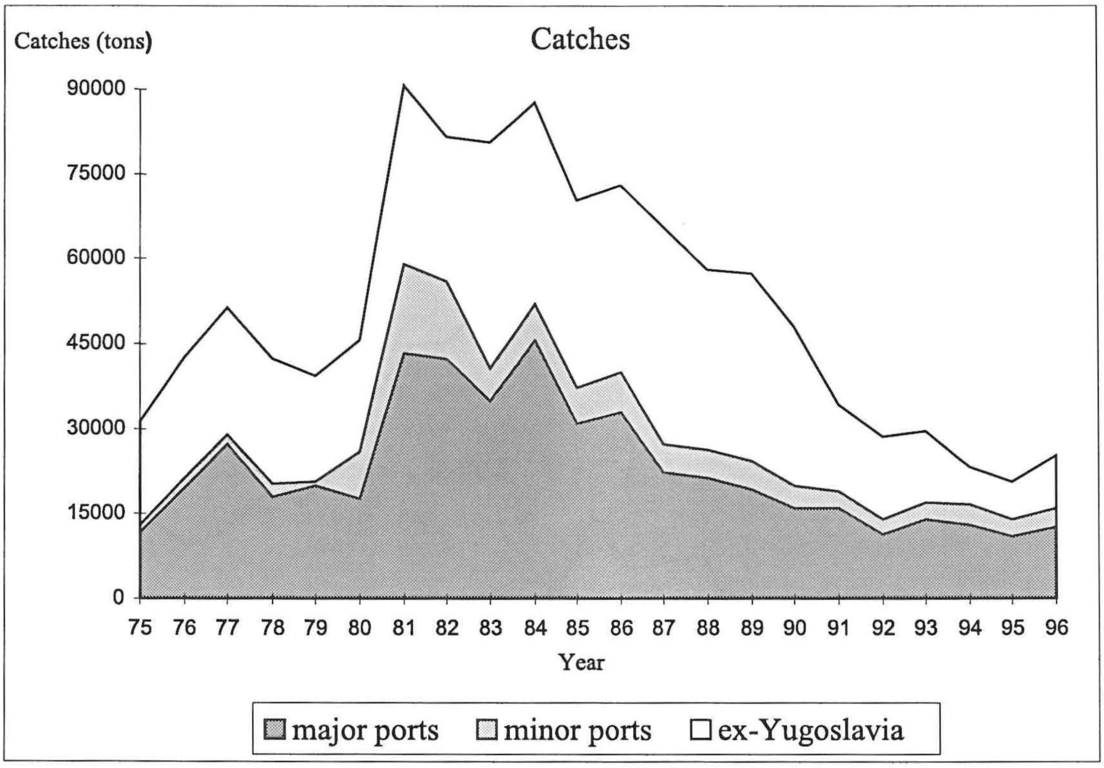

Fig.3. Sardine catches in the Italian major and minor fishing ports for pelagic fish and in ex-*Yugoslavia - Croatia and Slovenia - as a function of time (year)*

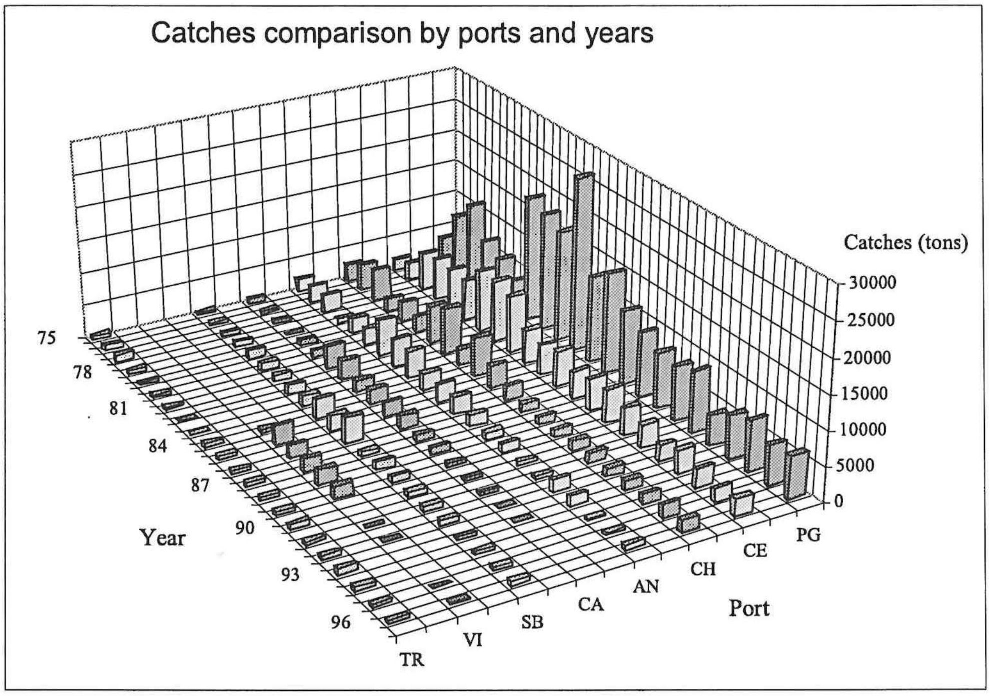

Fig.4. Sardine catches in the Italian major fishing ports for pelagic fish, as a function of time (year). TR = Trieste, VI = Vieste, SB = San Benedetto del Tronto, CA = Cattolica, AN = Ancona, CH = Chioggia, CE = Cesenatico, PG = Porto Garibaldi

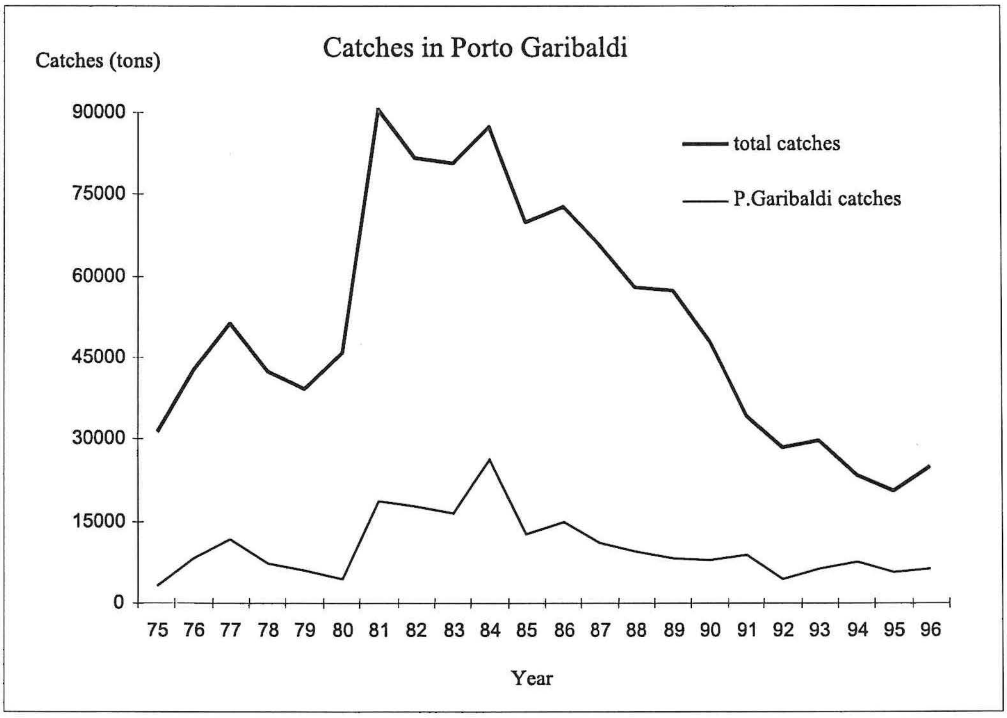

Fig.5. Total and Porto Garibaldi catches of sardine as a function of time (year)

curve is used, biomass increases from 1975 (185.000 t) up to 1982 (348.000 t, the maximum value). Such an increase is particularly sharp since 1980. Then, there is a small decline up to 1988 (303.000 t), whereas decline is strong in the time interval 1988-1991: biomass falls at 149.000 t. Decline is slower in the subsequent years and biomass reaches the minimum value in 1996 (85.000 t). In the same figure, this trend is compared with the single value obtained using the average length distribution of the catch in the time interval 1975-1996, i.e. 246.000 t : the values of the biomass trend fluctuate around it. When the average length distribution is relative to the period 1988-1996, biomass is estimated equal to 152.000 t.

When the SINOVČIĆ growth curve is used, biomass shows lower values in respect to the CGPM one (Fig. 6). The corresponding values estimated under the steady state hypothesis are equal to 182.000 t and 113.000 t, on the basis of the length distributions calculated for the time intervals 1975-1996 (Fig. 6) and 1988-1996, respectively.

Table 1. The parameters of the von BERTALANFFY growth curve estimated for sardine by different authors, are reported along with the corresponding values of biomass (tons), obtained by means of LCA using the average length distributions of the catch for the time period 1975-1996 (1) and 1988-1996 (2)

Author	L_∞	k	t_0	(1) Biomass	(2) Biomass
SINOVČIĆ	20.50	0.46	-0.50	182,000	113,000
CGPM	21.00	0.35	-2.42	246,000	152,000

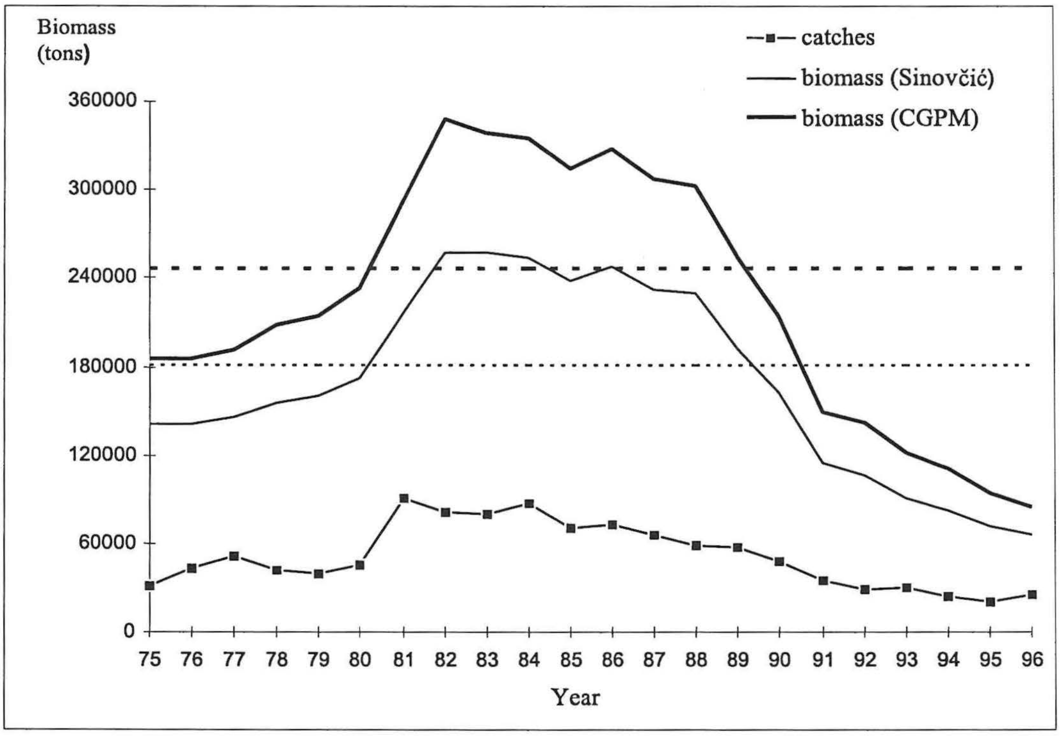

Fig.6. Annual mean biomass of sardine estimated by LCA as well as total catches are reported. Biomass estimates were obtained using average length distributions of the catch calculated for consecutive 3-year intervals and the von BERTALANFFY curves reported by SINOVČIĆ (1984) and CGPM (1980). Dotted lines represent corresponding LCA biomass estimates obtained using the average length distribution of the catch for the time period 1975-1996, with the bold type being referred to the von BERTALANFFY curve reported by CGPM (1980)

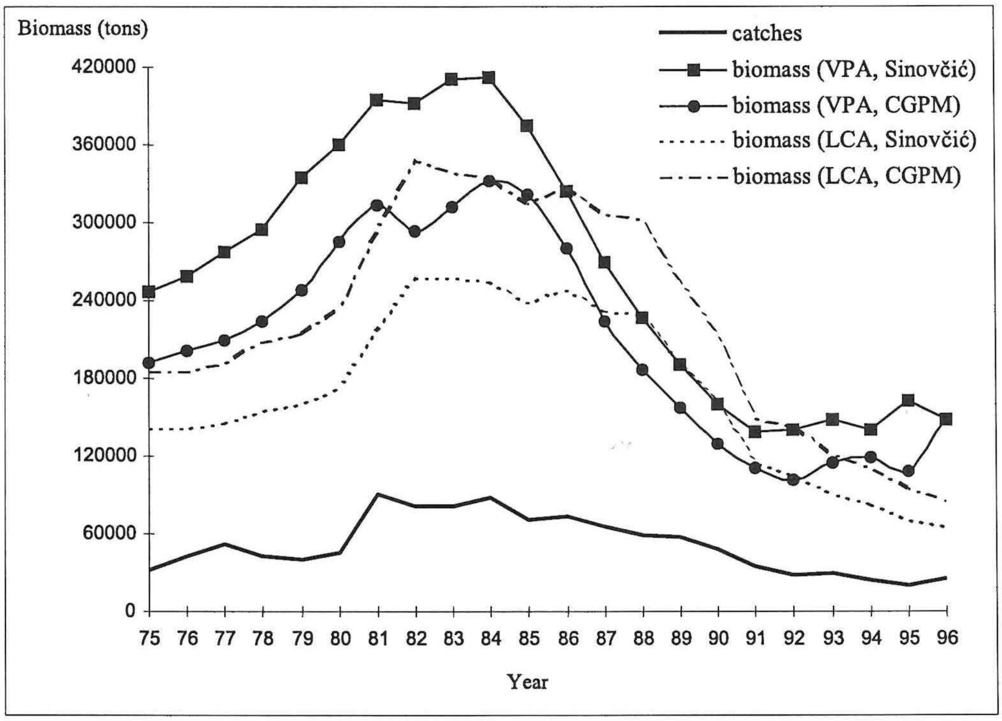

Fig.7. *Biomass values of sardine estimated by VPA and LCA are compared over years. Total catches are also reported. Mid-year values of biomass derived from VPA - as well as annual mean values derived from LCA - were obtained using the von BERTALANFFY curves reported by SINOVČIĆ (1984) and CGPM (1980)*

VPA results are reported in Fig. 7. When the CGPM growth curve is used, biomass increases from 1975 (192.000 t) up to 1981 (313.000 t), and reaches the maximum value (332.000 t) in 1984. Then, it declines at 321.000 t in 1985 and 186.000 t in 1988 and reaches the minimum value (102.000 t) in 1992. Biomass is constant in the period 1992-1995 and increases in 1996 (148.000 t).

When the SINOVČIĆ growth curve is used, biomass shows higher values in respect to the CGPM one (Fig. 7). This pattern is due to the higher number of age classes in the catch obtained on the basis of the SINOVČIĆ growth curve.

The mid-year biomass values estimated by VPA are compared with the annual mean biomass values derived from LCA, in Fig. 7. On the whole, biomass values estimated by LCA are quite consistent with the estimates derived from the VPA based on the CGPM growth curve, whereas the agree is lower if the VPA based on the SINOVČIĆ growth curve is taken into account. The fluctuations of biomass on the basis of LCA and VPA are quite similar, except for the strong decrease after 1988 yielded by LCA, observed after 1984 when VPA is used.

The Porto Garibaldi CPUE is displayed as a function of time in Fig. 8. This abundance index shows evident fluctuations and the corresponding biomass trend estimated on the basis of the DELURY *ad hoc* method is similar (Fig. 9a,b). When q = 2.17*E-5* is used (Fig. 9a), biomass increases from 1975 (95.000 t, the minimum value) up to 1977 (237.000 t) and falls at 104.000 t in 1980. Then, there is a strong increases in 1981: biomass is around 400.000 t, such as in the 1982 (i.e. the maximum values). After 1982, biomass decreases and is at 243.000 t in 1986 and 152.000 t in 1992. In the time interval 1992-1996, biomass ranges from 131.000 t to 158.000 t. Obviously, when q = 3.51*E-5* is used, estimated biomass is lower in respect to q = 2.17*E-5* (Fig. 9a).

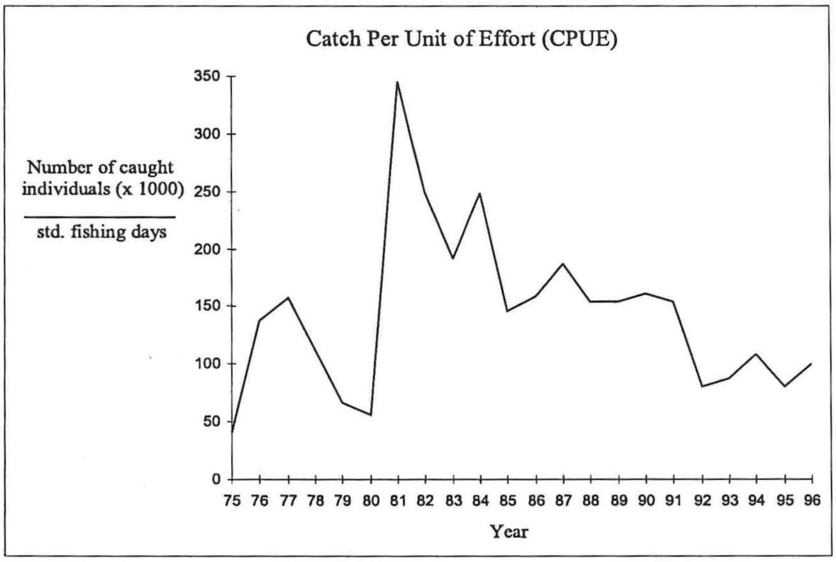

Fig.8. Porto Garibaldi CPUE of sardine as a function of time (year)

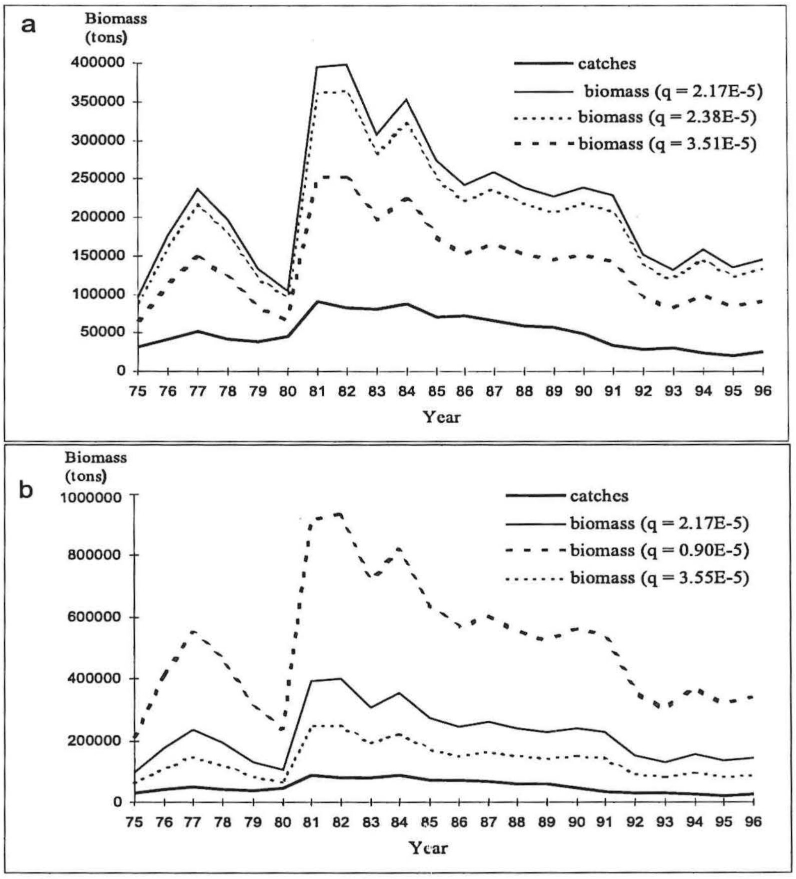

Fig.9. Mid-year biomass of sardine estimated by the DELURY ad hoc method as well as total catches are reported. Biomass estimates were obtained using the CPUE of Porto Garibaldi and different values of the catchability coefficient, q. (a): the values of q were estimated for anchovy by the DELURY model, with data up to 1994 (q = 2.38E-5) and 1996 (q = 2.17E-5), or by calculating the average of different estimates of q obtained excluding data for some years (q = 3.51E-5). (b): the values of q were the lower and upper limits of the 70% confidence interval, derived from bootstrap simulations on anchovy data up to 1996

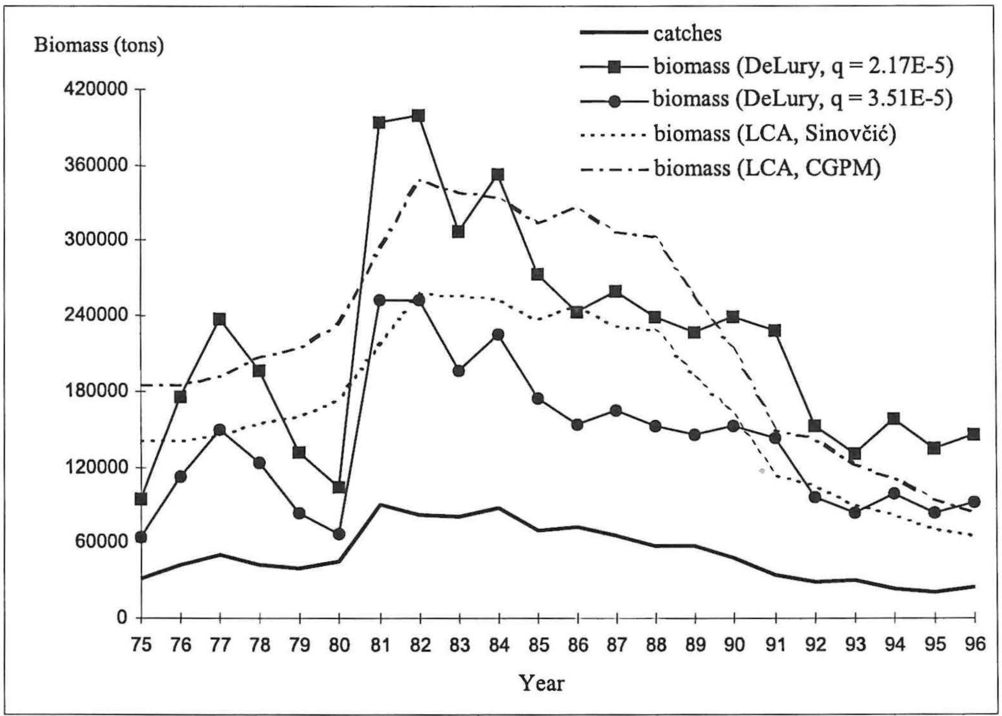

Fig. 10. Sardine biomass values estimated by the DELURY ad hoc method and LCA are compared over years. *Total catches are also reported. Mid-year values of biomass derived from the DELURY ad hoc method were obtained using different values of the catchability coefficient estimated for anchovy (q = 2.17E-5 and q = 3.51E-5). Annual mean values of biomass derived from LCA were obtained using length distributions of the catch calculated for consecutive 3-year intervals and the von BERTALANFFY curves reported by SINOVČIĆ (1984) and CGPM (1980)*

The mid-year biomass values estimated by the DELURY *ad hoc* method using both catchability coefficients $q = 2.17E\text{-}5$ and $q = 3.51E\text{-}5$, are compared with the annual mean biomass values derived from LCA, in Fig. 10. When $q = 2.17E\text{-}5$ is used, biomass values are closer to those obtained from LCA by the CGPM growth curve; when $q = 3.51E\text{-}5$ is used, they are closer to those obtained by the SINOVČIĆ one. The fluctuations of biomass on the basis of these two methods are quite similar, except for the time interval 1975-1980. In this period, the DELURY *ad hoc* method yields fluctuations of biomass not observed using either LCA or VPA.

These three methods allowed us to obtain a range within the value of the Adriatic sardine stock biomass may fall, in the time interval 1975-1996 (Fig. 7, 10). In this period, the average ratio between catch and biomass is estimated equal to 0.24.

Previous assessments based on population dynamics methods gave lower values for a less wide area in the Adriatic Sea. ALEGRÍA-HERNANDEZ (1984) estimated 54.000 t in 1967, 126.000 t in 1979 and 90.000 t in 1982, for the eastern Adriatic, by using production models. SINOVČIĆ (1986) estimated around 90,000 t in the time interval 1979-1981, for the central part of the eastern Adriatic, by using the BARANOV's catch equation. The same value was estimated to be around 70.000 t when VPA was performed (SINOVČIĆ, 1991). It is worth noting that SINOVČIĆ used $M = 0.5$ for the estimate obtained from BARANOV's catch equation and $M = 0.3$ for the estimate by VPA: the last method would have given higher values of biomass, with $M = 0.5$.

Biomass levels yielded by echo-surveys (AZZALI *et al.*, 1990) are quite consistent with our estimates, even if they are relatively high in the first half of 1980s (i.e. ranging from 400.000

to 600.000 tons). We obtained such high values only when the DELURY *ad hoc* assessment was performed by using $q = 0.90E\text{-}5$, i.e. the lower limit of the 70% confidence interval.

Fluctuations of biomass over time are always evident on the basis of our assessments. VPA and LCA biomass patterns over time are quite similar and show evident fluctuations on a relatively small time scale (3-4-5 years). For example, biomass obtained from LCA by the CGPM growth curve decreases from 303.000 t to 149.000 t in the time interval 1988-1991. These two biomass trends are also quite consistent with DELURY *ad hoc* ones, but in the latter case fluctuations happen also on a smaller time scale (1-2 years). An example is the increases in 1981: around 400.000 t against 104.000 t in 1980, when $q = 2.17E\text{-}5$ is used.

Evident fluctuations of biomass estimated by population dynamics methods were also reported by ALEGRÍA-HERNANDEZ (*ibid.*). Echo-survey assessments (AZZALI *et al.*, 1990) yielded fluctuations of the Adriatic sardine stock biomass quite consistent with those discussed in this paper. In particular, the strong biomass increase around 1981, outlined by our assessments, is also evident on the basis of echo-surveys. In addition, in the 1980s, echo-survey estimates of biomass show more pronounced fluctuations.

The fluctuations derived from our assessments do not seem to be strongly influenced by fishery. In Fig. 11, the biomass estimated by the VPA performed using the CGPM growth curve, is displayed together with Porto Garibaldi effort: a relationship between these two variables is not evident. It is worth noting that, since 1981 up to 1984, fishing effort increases (76%) and reaches the highest value, as well as bio-

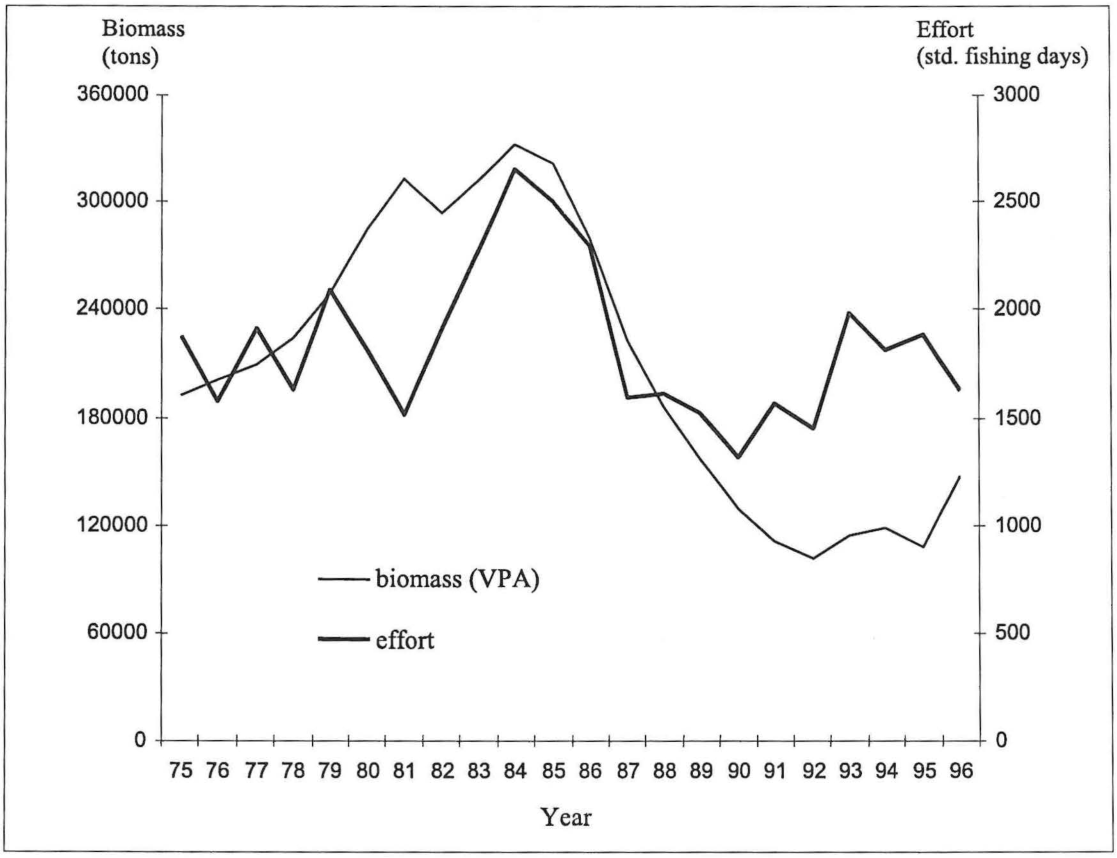

Fig.11. Fishing effort and mid-year biomass of sardine estimated by the VPA performed using the growth curve reported by CGPM (1980), are compared over years

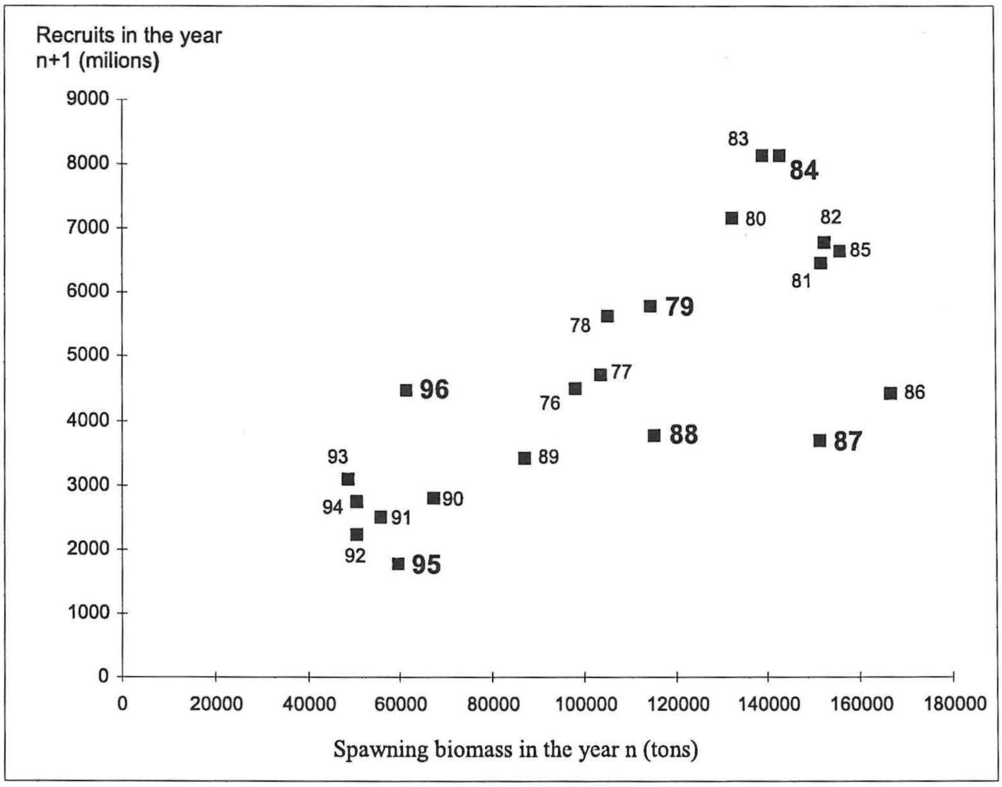

Fig.12. Stock-recruitment relationship for sardine derived from the VPA performed using the growth curve reported by CGPM (1980). Recruits are individuals belonging to the age class 0. Years are reported for each data point and some of them in evidence by higher characters (see text)

mass. However, the biomass decrease begins after 1984.

The stock dynamics of many fish species - in particular pelagic ones such as anchovy, sardines, herrings, etc. - is thought to be strongly influenced by environmental factors, which determine food availability both in time and space for larvae and juveniles (SHEPHERD *et al.*, 1984; BOMBACE, 1992; HEATH, 1992; MANN, 1993; CSIRKE, 1995; CUSHING, 1996).

The relationship between spawning stock biomass in the year *n* and recruits in the consecutive year, *n*+1, could outline inter-annual fluctuations of mortality in young individuals not yet belonging to the stock. The relationship was derived from the VPA performed using the CGPM growth curve, with recruits being the age class 0, and reported in Fig. 12.

Even if there is a trend in the distribution, data points show a strong dispersion. That means a spawning biomass value may be associated to very different recruitment values. The most important case is represented by 1984 and 1987 data points, since the decreasing recruitment has a corresponding decrease in total biomass in the time interval 1984-1987 (see also Fig. 11).

We observed a similar and more pronounced picture in the stock-recruitment relationship of the Adriatic anchovy, on the basis of VPA and DELURY model with recruitment index (CINGOLANI *et al.*, 1993; SANTOJANNI *et al.*, *in press*). Fluctuations of biomass were observed for another Adriatic small pelagic species, sprat (*Sprattus sprattus*), on the basis of echo-survey assessments (AZZALI *et al.*, 1990). It is worth noting that this species is largely unexploited by the Adriatic fishery (BOMBACE, 1992).

BOMBACE (1992) suggested that the fluctuations of small pelagic stocks in the Adriatic Sea may be due to modifications of the production level in the ecosystem, determined by changing river inputs of nutrients. In conclusion, further investigations taking into account the food web structure of the Adriatic Sea ecosystem, may allow to gain insight about factors which determine the stock dynamics of sardine and other small pelagics.

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Ribolov i procjena veličine populacije srdele, *Sardina pilchardus* (WALB.) u Jadranu

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SAŽETAK

Srdela, *Sardina pilchardus* (WALB.) je uz inćuna, *Encraulis encrasicolus* (L.) jedna od najvažnijih komercijalnih vrsta riba Mediterana, te naročito Jadrana. Prosječni godišnji ulov srdele u razdoblju 1975-1976 u Jadranu iznosi oko 50.000 t.

Od 1975. godine dalje je u istraživanja abundancije srdele i inćuna u sjevernom i srednjem Jadranu uključen IRPEM s metodama dinamike populacija.

U ovom radu su diskutirani iznosi biomase populacije srdele u razdoblju 1975 - 1996. Procjene su učinjene na temelju triju metoda: Cohort analize dužine (LCA), populacijske analize (VPA) i modificiranog DELURY-jevog modela s indeksom obnavljanja. Uspoređene su procjene biomase dobivene tim metodama. Očevidno je da su fluktuacije biomase značajne. Istraživane su moguće posljedice iskorištavanja ribolovom na biomasu, te je analiziran odnos štok - obnavljanje kako bi se dobio uvid u mehanizme fluktuacije biomase.